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Physico-chemical characteristics and microbial status with special reference to zooplankton diversity of Sasthamkotta Ramsar Site, Kerala, India

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ABSTRACT

Aquatic ecosystems are the most complex and unpredictable ecosystems and zooplankton assemblages in these systems serve as excellent bio-indicators of ecosystem quality, which also influence pelagic fishery potentials. The present study was designed to assess the hydrogeochemical characteristics and microbial status with special reference to zooplankton diversity of the Sasthamkotta Ramsar Site, Kerala, India. Sample collections were carried out for premonsoon during February 2020 from four selected sites of the wetland. Physico-chemical parameters of surface water such as temperature, pH, salinity, turbidity, conductivity, total dissolved solids, dissolved oxygen, biological oxygen demand, carbon dioxide, inorganic nutrients such as nitrate-nitrogen, phosphate-phosphorous and silicate-silicon and sedimentological parameters like temperature, pH and organic carbon were analysed using standard methods. Zooplankton assemblages, total coliform and faecal coliform count samples were collected and identified using standard keys. CCA analysis, mean-standard deviation and diversity indices were computed using PAST, SPSS Vs 20 and Primer Vs 6 softwares respectively. In the present study, zooplankton composition included four groups - Rotifers, Cladocerans, Copepods and Cheatognathans belonging to seven species viz; *Daphnia pulicaria, Thermocyclops crassus, Acartia southwelli, Cypridopsis vidua, Parasagitta elegans, Asplanchna priodonta* and *Mesocyclops leukarti.* Among this, *Mesocyclops leukarti* showed greater abundance whereas *Daphnia pulicaria* and *Asplanchna priodonta* were least abundant. Highest values of both total coliform (1600/100 mL) and faecal count (260/100 mL) were recorded at site III which showed low dissolved oxygen and high BOD with greater abundance of *Mesocyclops leukarti. Mesocyclops leukarti* showed a wide range of tolerance and thrived well in all the sites with greater abundance. Species richness and diversity recorded high values at site IV, whereas evenness was high at site II. Species dominance indicated high value at site III. The water and sediment samples from the four sites indicated slight deterioration in quality due to pilgrim influx and various other anthropogenic interventions.

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1. Introduction

Aquatic ecosystems, the most indispensable natural resources, are critically needed for all the living organisms to survive on Earth (Mishra and Kumar, 2020). Their conservation, through quality assessments, especially that of Ramsar wetlands, is considered one of the critical issues in recent years at national and international perspectives. Freshwater ecosystems are essential for several human needs such as drinking, sanitation, irrigation, navigation, aquaculture, recreation, industrial uses etc. (Sharifina *et al*., 2019), and any alteration of their environmental quality and water renewal rates has wide-ranging ecological and social implications. The overall condition or health of the aquatic ecosystem is determined by the interaction of all its physical, chemical and biological components, which make up its ecosystem (Divya and Kani, 2018). Freshwater ecosystems also provide important ecosystem services. They act as natural regulators of river flow by trapping sediments and nutrients from rivers and streams that flow into them. Lakes have long been the center of human attention due to their various socio-economic benefits and also anthropogenic threats. The management of natural surface water resources needs an understanding of water quality (Sharma and Tiwari, 2018). The quality of surface water is unpredictable because the water quality is dynamic, and pollutants can be introduced at any time. In recent years, water quality evaluation is considered as one of the pivotal issues, especially when freshwater is becoming a scarce resource with great variability (Gleick and Cooley, 2021).

Surface water resources like fresh water lakes are the most preferred sources of drinking water in developing countries like India (Peter and Sreedevi, 2013). Pathogenic bacteria may enter in to surface water sources from anthropogenic discharges which has become a serious threat to water quality (Pandy *et al*., 2014). Various anthropogenic interventions including the disposal of domestic sewage from the densely populated areas can create bacteriological contamination of the fresh water system making it unsuitable for human consumption. The faecal bacteria can also settle down and accumulate in benthic environment (Murali *et al*., 2019).

Zooplanktons are the myriads of diverse floating and drifting animals with the limited power of locomotion and are involved in the conservation of energy from phytoplankton to higher trophic levels thereby influencing the pelagic fishery potentials and serve as excellent bio-indicators of ecosystem quality (Vincy *et al*., 2018). Plankton production in water bodies is determined by the physical and chemical parameters like temperature, light availability and nutrients (Geng *et al*., 2022). Any alteration in their quality will adversely affect the survival, reproduction, and growth of biotic communities, which will deteriorate the quality of the entire ecosystem. All aquatic animals depend directly or indirectly on the planktonic assemblages, and a healthy zooplankton community in an aquatic ecosystem is necessary for a productive aquatic ecosystem (Archana and Gupta, 2021).

The fresh water resources of southern Kerala, due to various anthropogenic interventions, are at the brink of destruction in multiple ways (Das *et al*., 2021). Sasthamkotta Ramsar Site, which serves as fresh water drinking source, is the major wetland located in Kollam district, Kerala, India. Various research works have been carried out regarding water quality status (Prakasam, 1991; Prakasam and Joseph, 2000; George and Koshy, 2008; Sujayakumari and Lisy, 2017; Peter and Sreedevi, 2013; Salin *et al.,* 2013; Irshad, 2015; Divya and Kani, 2018), sediment-water interactions (Sreejith, 1998), Phytoplankton diversity (Revathy and Krishnakumar, 2018; Pournami *et al*., 2022), Ichthyofaunal diversity (Girijakumari *et al*., 2011), trophic web structure and ecological network analysis (Regi *et al.,* 2020) and microbial pollution status (Girijakumari *et al*., 2006; Murali *et al.,*2019) in this wetland. Eventhough considerable research have been carried out in this wetland, there is a paucity of information regarding the combined evaluation of hydrogeochemical variables along with zooplankton assemblages and microbial status. To fill the existing lacuna, an attempt has been made to assess the physico-chemical parameters along with microbial status and zooplanktonic abundance from the four selected sites of Sasthamkotta wetland of Southern Kerala.

2. Materials and Methods

2.1 Study Area and Sampling Sites

Sasthamkotta Ramsar Site 9^0 1′ 35″ N to 9^0 3′ 17″ N and 76^0 36′-42″ E to 76^0 38′ 48 ″ E called ”Queen of lakes” located in Kunnathur taluk, Kollam, Kerala, India, is the largest freshwater wetland of the state and a major source of drinking water in Kollam city and adjoining panchayats. This ‘F’ shaped spring fed fresh water wetland is one of the major tourist destinations in Kerala. Inland navigation and fishing are the major economic activities taking place in this Ramsar Site.

Sample collections for the present study were carried out during premonsoon from the four selected sites of Sasthamkotta wetland viz; Site I (Vilanthara Region), Site II (Pipe House Junction Region), Site III (Ambalakkadavu Region) and Site IV (Pattakadavu Region) during February 2020. A map of selected sampling stations is presented in figure 1.

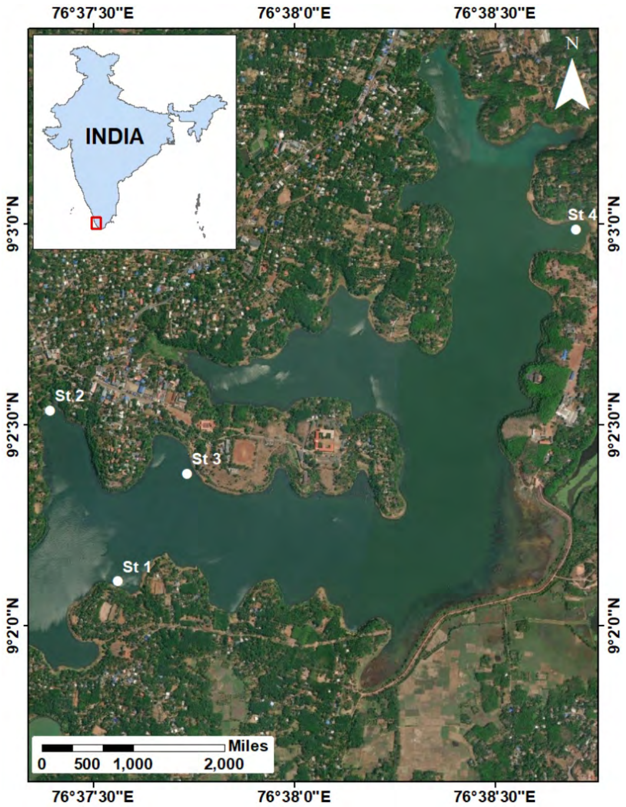

Fig. 1. Map showing the study area

2.2 Sampling Methods and Laboratory Analysis

Water, sediment, microbial and zooplankton sample collections were carried out during premonsoon in 2020. The surface water samples were collected using a clean plastic bucket, while the sediment samples for analyses were collected by using a corer. Temperature of both water and sediment were analyzed using a thermometer with an accuracy of 0.5^0 C. pH was determined by a digital p^H pen, salinity by Mohr-Knudsen method (Grasshoff *et al.,* 1983), TDS and conductivity were analysed by using a water analyser (systronics model 371), turbidity was determined by nephelometer, dissolved oxygen by Winkler’s method (Winkler, 1888), carbon dioxide by titrimetric method (APHA, 1992) and biological oxygen demand was determined by 5-day incubation by Winkler’s method (APHA, 1992). Inorganic nutrients such as nitrate-nitrogen, phosphate-phosphorous and silicate-silicates were analyzed spectrophotometrically (APHA, 1992). Sediment organic carbon was estimated by Wet Oxidation Method (El Wakeel and Riley, 1956). Samples for zooplankton analyses were collected using a conical shaped plankton net (mesh size - 300 µm). The collected samples were preserved in 4 % neutral formaldehyde solution and were identified using standard keys (Raymont, 1963; Smith, 1997; Harris *et al*., 2000**).** Surface water bacteriological characteristics such as standard total coliform count and faecal coliform count were also analysed (APHA, 2012).

2.3 Statistical Analysis

Primer Vs 6 was used to analyze biological indices such as Margalef’s index (d), Shannon Weiner index (H’), Pielous Evenness (J’) and Simpson’s dominance index (ʎ). SPSS Vs 20.0 was used to analyze the mean-standard deviation and PAST software was used to compute CCA analysis

3. Results and Discussion

The various hydrogeochemical, zooplankton and bacteriological parameters studied from Sasthamkotta wetland revealed significant variations between sites.

3.1 Hydrogeochemical Parameters

The present study on the water and sediment quality assessment of Sasthamkotta Ramsar Site has provided valuable data regarding the physico-chemical characteristics of the wetland. The characteristic variation of hydrogeochemical parameters from the four sites is given in figures 2-11.

In the present study, atmospheric, surface water and sediment temperatures recorded maximum values at site III. Water temperature in an aquatic ecosystem may depend on the geographic location, seasons and sampling time (Ancy and shaji, 2016). The atmospheric temperature recorded its maximum value of 29^{0}C at site III and minimum value of 27^{0}C at site I with a mean ± standard deviation of 28 ± 0.81. The surface water temperature showed a maximum value of 30^{0}C at site III and exhibited minimum value of 27 ^{0}C at site IV with a mean ± standard deviation of 28.5 ± 1.29. The sediment temperature ranged from 31^{0}C at site III to 28^{0}C at site I with a mean ± standard deviation of 29.5 ± 1.29. High premonsoon water temperature can be attributed to higher atmospheric temperature which prevailed at that time (Smina *et al*., 2019). pH of the fresh water wetlands determines the suitability of water for various purposes (Pandey and Verma, 2008). In the present study, surface water pH value ranged between 6.76 at site III and 7.88 at site IV with a mean ± standard deviation of 7.41 ±0.47. There are various factors that bring about changes in the pH of water and the distribution of aquatic flora and fauna in rivers, lakes and wetlands (APHA, 2017). However, surface water pH values of all the four sites were within the acceptable range of Bureau of Indian Standards (BIS) .ie, 6.5 to 8.5. The sediment pH also recorded similar pattern as that of surface water pH with its maximum value of 4.88 at site IV and minimum value of 4.28 at site III with a mean ± standard deviation of 4.48 ± 0.27. The higher pH values observed, suggested that carbon dioxide, carbonate-bicarbonate equilibrium was affected, due to the changes in physico-chemical conditions (Bhateria and Jain, 2016).

The surface water turbidity recorded its maximum value of 17 NTU at site III and all other sites recorded same value of 16 NTU with a mean ± standard deviation of 16.25 ± 0.5. Higher turbidity might be due to the presence of higher number of microscopic organisms. Turbid waters also can increase surface water temperatures above normal level due to the absorption of heat from sunlight by the suspended particles near the water surface (Divya and Murthy, 2013). The extent of turbidity in an aquatic system is generally taken as a measure of pollution intensity (Prasad and Kani, 2017). The surface water conductivity (S/m) indicated its maximum value of 0.99 S/m at site IV and minimum value of 0.3 S/m at site III with a mean ± standard deviation of 0.79 ± 0.33. Low conductivity could be attributed to the release of organic contaminants, such as pesticides from agricultural fields into the wetland from adjoining areas (Mishra *et al.,* 2023). This could impact the growth and survival of certain species and limit the productivity of the ecosystem (Whigham and Jordan, 2003). Higher conductivity was observed due to human interference in this region and such a high value of conductivity was also recorded from Pamba River in Pathanamthitta district due to bathing of pilgrims (Koshy and Nair, 2000). The surface water TDS (ppt) ranged from 0.066 ppt at sites II and IV to 0.067 ppt at sites I and III with a mean ± standard deviation of 0.07 ± 0.001. The highest value of TDS was due to the

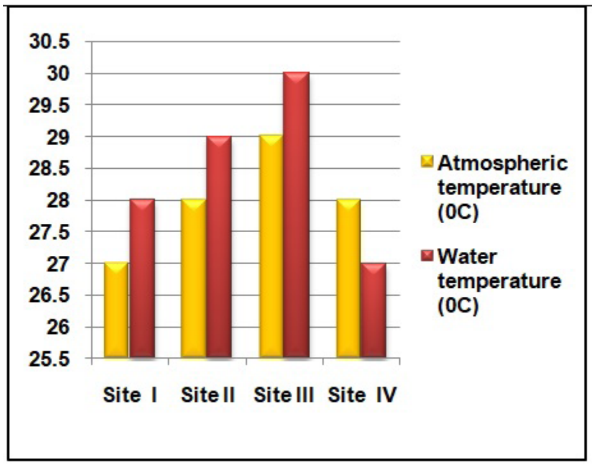

Fig. 2. Variation in the atmospheric and surface water temperature (^{0}C)

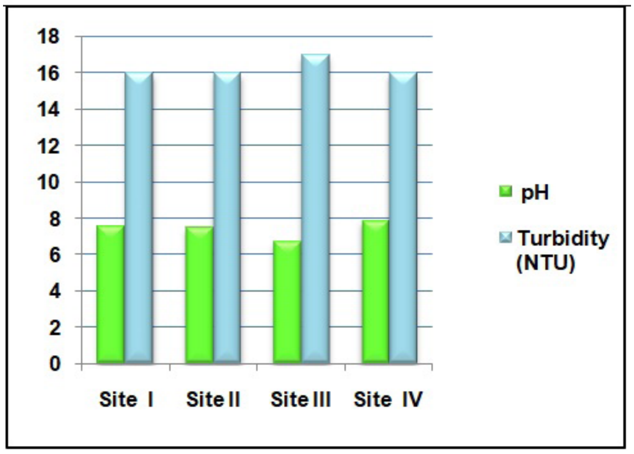

Fig. 3. Variation in surface water pH and turbidity (NTU)

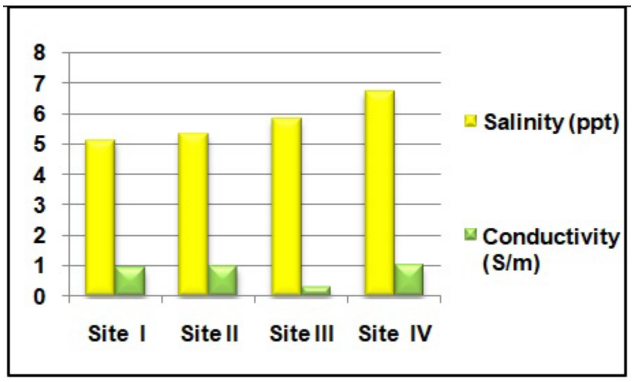

Fig. 4. Variation in the surface water salinity (ppt) and conductivity (S/m).

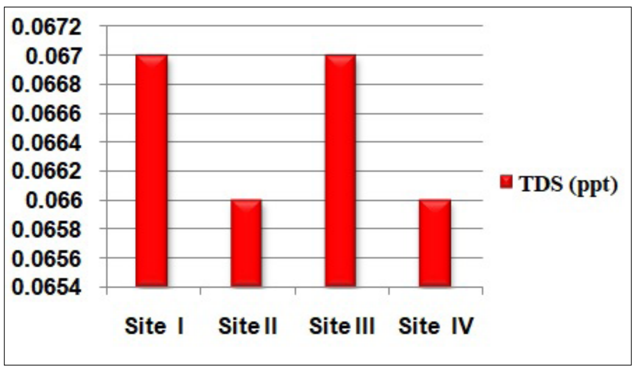

Fig. 5. Variation in the surface water TDS (ppt)

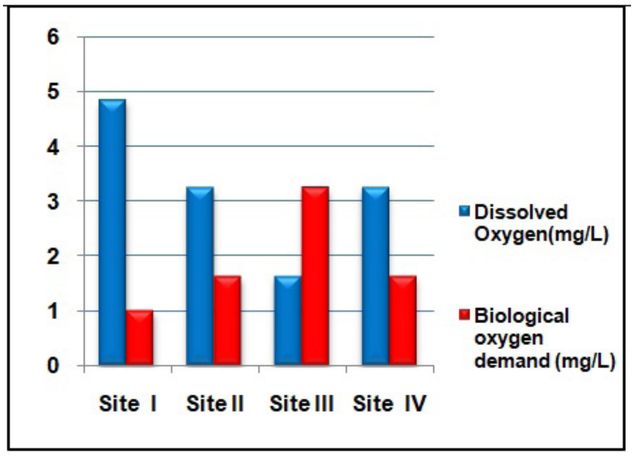

Fig. 6. Variation in surface water dissolved oxygen (mg /L) and BOD (mg /L)

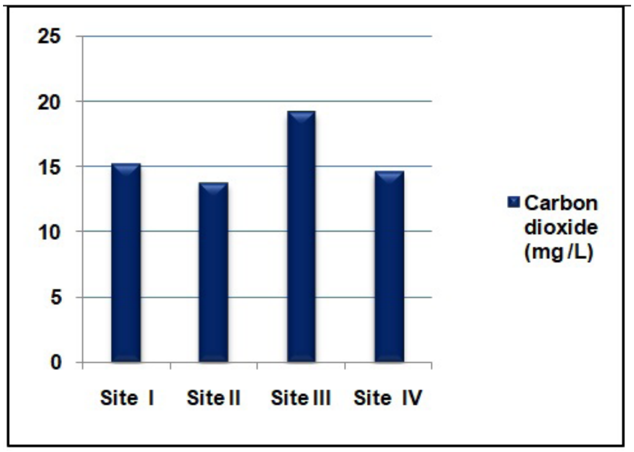

Fig. 7. Variation in surface water carbon dioxide (mg /L)

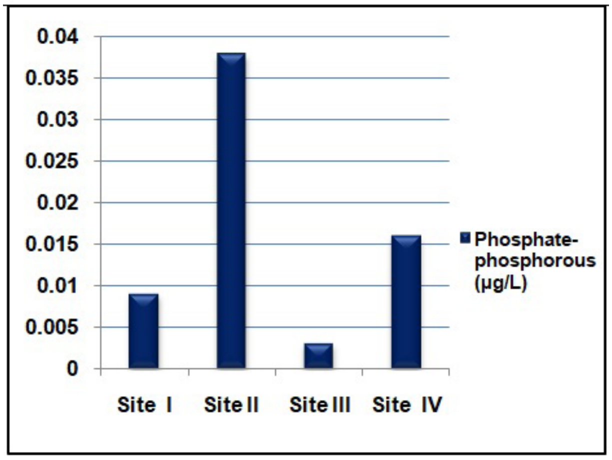

Fig. 8. Variation in the surface phosphate- phosphorous (µg/L)

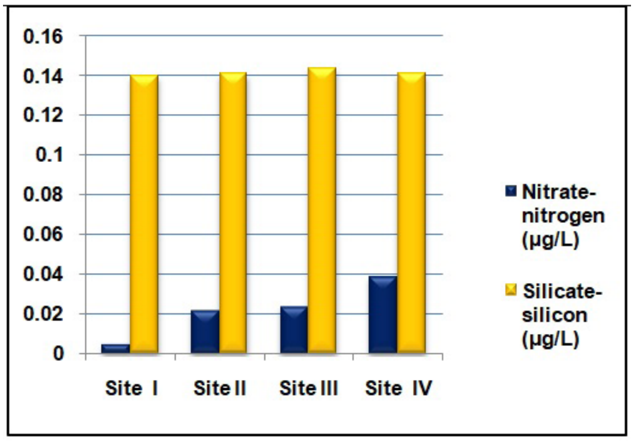

Fig. 9. Variation in surface water nitrate- nitrogen (µg/L) and silicate-silicon (µg/L)

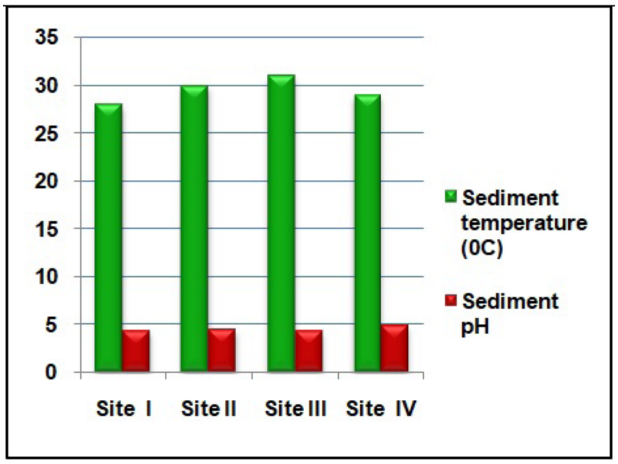

Fig. 10. Variation in the sediment temperature (^{0}C) and sediment pH.

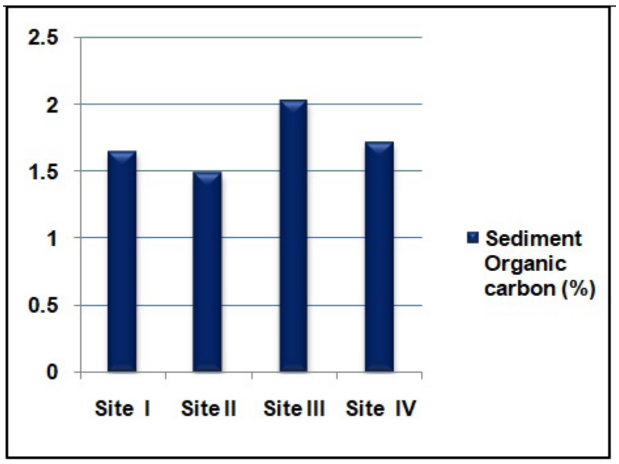

Fig. 11. Variation in the sediment organic carbon content (%)

addition of organic matter and solid waste into the wetland (Goher, 2002). The surface water salinity values in the wetland ranged from 6.7 mg/L at site IV to 5.1 mg/L at site I with a mean ± standard deviation of 5.7 ± 0.71. The low salinity was particularly due to excessive groundwater pumping (Green *et al*., 2017). Salinity is a critical factor in deciding the suitability of water for irrigation as well as consumption (Sujayakumari and Lisy, 2017).

The surface water dissolved oxygen values in wetland ranged between 1.61 mg/L at site III and 4.84 mg/L at site I with a mean ± standard deviation of 3.23 ± 1.32. In the present study, the concentration of DO was inversely proportional to the temperature; hence, as temperature increased, the concentration of DO decreased accordingly. For maintaining aesthetic qualities of water as well as for supporting life, optimum concentration of dissolved oxygen is essential (Sujitha *et al*., 2012). In the present study, dissolved oxygen levels were too low when compared to a previous study conducted during 2006 which ranged from 5.99-8.56 mg/L in this wetland (George and Koshy, 2008). The surface water carbon dioxide in the water samples recorded its maximum value of 19.2 mg/L at site III and minimum value of 13.8 mg/L at site II with a mean ± standard deviation of 15.7 ± 2.4. There is no limit for CO_2 in drinking water but its presence affects the buffering capacity of water. Concentration of carbon dioxide in Sasthamkotta wetland was greater in the present study when compared to a study conducted during 2006 which ranged from 4.31 mg/L to 8.62 mg/L (George and Koshy, 2008). The surface water biological oxygen demand in the wetland ranged between 0.99 mg/L at site I and 3.23 mg/L at site III with a mean ± standard deviation of 1.86 ± 0.96. In the present study, BOD and DO levels were inversely related. Hence, a high amount of BOD indicated a decrease in DO levels. Higher BOD levels indicate that more oxygen is required, which suggests that there are fewer oxygen-demanding species to feed on and therefore water quality is poorer (Mishra *et al*., 2023). High BOD values were due to the dumping of domestic and sewage waste and also due to enhanced microbial activity. According to WHO, the maximum permissible BOD of drinking water is 2.0 mg/L (WHO, 2008). The surface water nitrates recorded maximum value of 0.039 µg/L at site IV and minimum value of 0.005 µg/L at site I with a mean ± standard deviation of 0.02 ± 0.01. High levels of nitrate-nitrogen in the wetland was due to large amount of sewage disposal in this region. Nitrate-nitrogen, considered as exceptionally important nutrient supplier of nitrogen in living organisms for protein synthesis, was found in relatively very low concentration in freshwater bodies (Maansi *et al*., 2022). The surface water silicate-silicon recorded its maximum value of 0.144 µg/L at site III and minimum value of 0.14 µg/L at site I with a mean ± standard deviation of 0.14 ± 0.001. Low values may be attributed by uptake of silicates by plankton for their biological activities (Saravanakumar *et al.,* 2008). The surface water phosphate-phosphorous values ranged from 0.038 µg/L at site II to 0.003 µg/L at site III with a mean ± standard deviation of 0.01 ± 0.01. High phosphate-phosphorous content was due to various anthropogenic interventions and also by soil leaching. Phosphate–phosphorous value of the present study was lower than the study conducted in 2006 in this wetland (George and Koshy, 2008). However the values obtained in the present study were within the permissible limits. Phosphates will stimulate the growth of planktonic forms and other aquatic plants which provide food for fish (Sujayakumari and Lisy, 2017). The sediment organic carbon ranged from 1.49 % at site II to 2.03 % at site III with a mean ± standard deviation of 1.72 ± 0.23. High organic carbon was due to various anthropogenic interventions such as sewage disposal, growth of aquatic algae and associated floating macrophytes. Organic carbon is also more in finer sediments which in turn supports the absorptive ability of organic colloids (Krishnakumar and Das, 2021).

3.1.1 PCA analysis for Hydrogeochemical Parameters

PCA analysis for hydrogeochemical parameters (Fig. 12) generated a total of five canonical axes that explained a cumulative variance of 97.8 %. Of the total variables analyzed, PC_1 and PC_2 explained about 87.0 % of variance (Table 1). Atmospheric, water and sediment temperatures, surface water pH, turbidity, conductivity, dissolved oxygen, carbon dioxide, BOD, silicate-silicon and sediment organic carbon had high loadings on PC_1 which accounted for 62.3 % of variance with Eigen value 9.97. Salinity, TDS, nitrate-nitrogen and sediment pH had high loadings on PC_2 which accounted for 24.7 % of variance with Eigen value

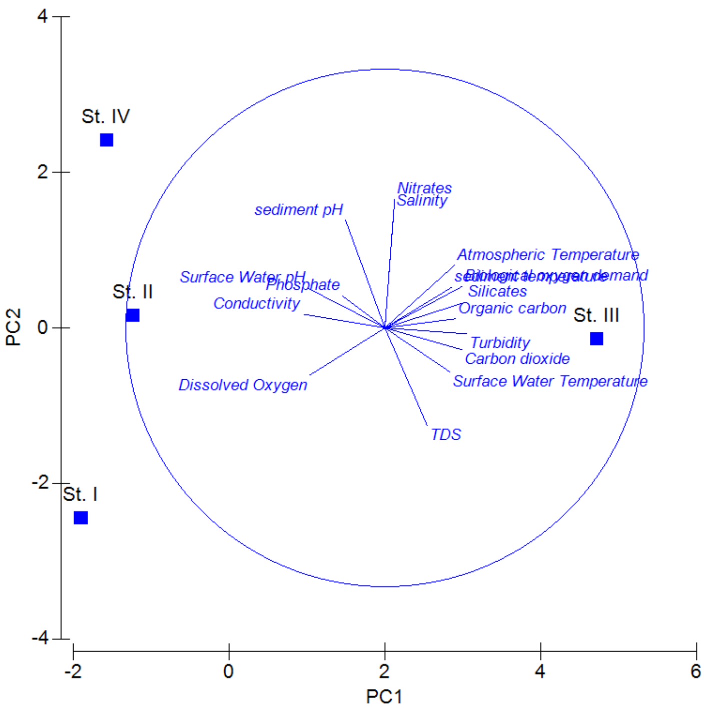

Fig. 12. Principal Component Analysis Plot for hydrogeochemical variables

Table 1.. PCA values for hydrogeochemical variables

PC	Eigen values	% Variation	Cum.% Variation
1	9.97	62.3	62.3
2	3.95	24.7	87.0
3	2.08	13.0	97.8

3.95. Phosphate-phosphorus had high loadings on PC_3 which accounted for 13.0 % of variance with Eigen value 2.08. The most significant variables in the components represented by high loadings were taken into consideration in the evaluation of the components (Nair *et al*., 2020). PCA plot illustrated the distribution of atmospheric, water and sediment temperatures, turbidity, TDS, carbon dioxide, BOD, silicate-silicon and sediment organic carbon which ordinate towards right of the PCA plot had higher values at site III. The positive loading of silicate-silicon reflected the dissolution of silica minerals and high temperature (Papachristou *et al.,* 2014). Surface water pH, conductivity and phosphate ordinated towards the left, had higher values at site IV. The high loading of pH indicated that the water was slightly alkaline. pH change was influenced by the presence of free CO_2 and had a direct effect on alkalinity (Murugesan and Rajesh, 2014). High positive loading of conductivity, indicated the probable contribution of soil erosion (Gholikandi *et al.*, 2011). Dissolved oxygen ordinated towards bottom left of the PCA plot had higher values at site I. The increased concentrations of dissolved oxygen might have subsequently resulted due to the influx of oxygenated water (Dzakpasu *et al.* 2014).

3.2. Bacteriological Parameters: Total Coliform and Faecal Coliform Count

Variation in the total coliform and faecal coliform counts is given in figures 13-14. The coliform bacteria included the genera Escherichia, Citrobacter, Enterobacter etc. Coliform bacteria are used as one of the indicators of pathogenic contamination that can cause different diseases like dysentery, intestinal infections, typhoid fever, hepatitis, cholera, and other illness (Athira and Jaya, 2014). The total coliform count of the wetland ranged between 1600/100 mL and 350/100 mL. Highest value was recorded at site III (1600/100 mL) whereas lowest value was recorded at site II (350/100 mL). In the present study the total coliform count was greater when compared to the previous observation that ranged from 5 to 17 count /100 mL during pre monsoon (Divya and Kani, 2018) and also greater than 2006 study in this wetland (George and Koshy, 2008). Faecal count of the wetland ranged between 260/100 mL and 160/100 mL. Highest value was recorded at site III (460/100 mL) whereas lowest value was recorded at site IV (160/100 mL). High coliform count was due to human excreta which are the main source of faecal pollution in the wetland. Samples showed the presence of total coliforms and also faecal counts in a study conducted during 2016 due to the contamination of faecal matters released into the soil and water. (Sujayakumari and Lisy, 2017). The high total coliform and faecal counts indicated that the wetland was exposed to human faecal contamination, animal waste and chemical waste because of human settlements near the lake (Divya and Kani, 2018).

3.3 Zooplankton species composition and numerical abundance

In the present study, the zooplankton assemblages (figures 15-19) of the Sasthamkotta Ramsar Site included four groups - Rotifers, Cladocerans, Copepods and Cheatognathans belonging to seven species viz; *Daphnia pulicaria, Thermocyclops crassus, Acartia southwelli, Cypridopsis vidua, Parasagitta elegans, Asplanchna priodonta* and *Mesocyclops leukarti*. Among this, *Mesocyclops leukarti* contributed to greater numerical abundance at site I whereas *Daphnia pulicaria* and *Asplanchna priodonta* contributed to the least abundance at site II and III respectively. *Mesocyclops leukarti*, a bio-indicator and reported potential candidate for the biological control of Aedes vectors (Udayanga *et al.,* 2019) showed a wide range of tolerance to the fluctuations in the physico-chemical parameters of the wetland and this species contributed to greater abundance in the wetland. The dominance of *Mesocyclops* sp. was reported in water bodies of the Bankura district of West Bengal (Majumder *et al.,* 2015). The present study shows that Mesocyclops leukarti can be safely used as a bio-control agent against mosquito propagation in the study area as it is a freshwater resource. Regarding the percentage composition, site I contributed to the greater dominance of *Mesocyclops leukarti* (29.78%) followed by *Acartia southwelli* (25%), *Thermocyclops crassus* (22.42%), *Parasagitta elegans* (9.19%), *Cypridopsis vidua* (7.36%), *Asplanchna priodonta* (3.68%) and *Daphnia pulicaria*

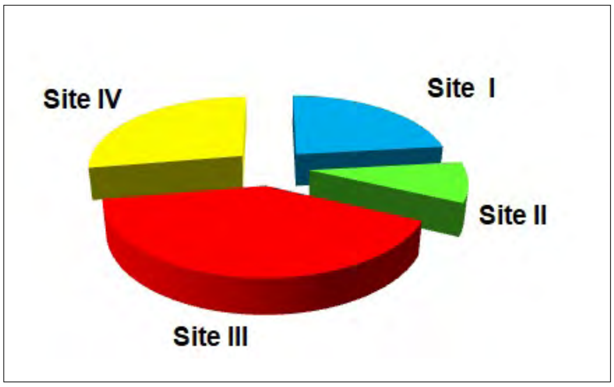

Fig. 13. Variation in the total coliform count (No./100 mL)

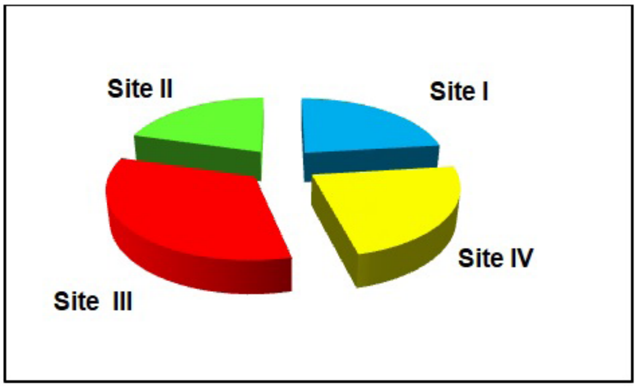

Fig. 14. Variation in the faecal coliform count (No./100 mL)

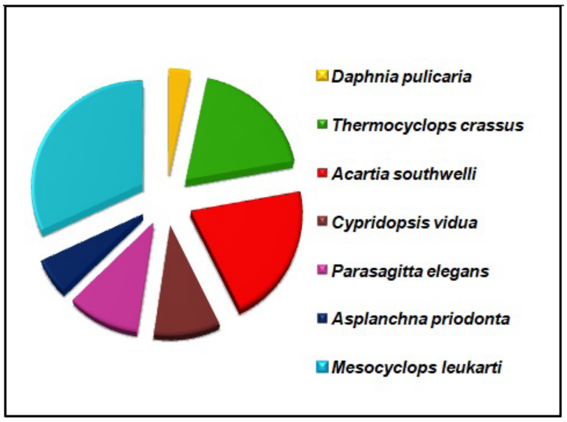

Fig. 15. Composition and abundance (No/mL) of zooplankton at Site I

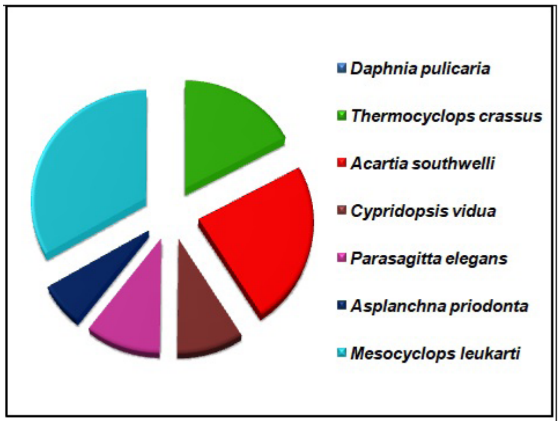

Fig. 16. Composition and abundance (No/mL) of zooplankton at Site II

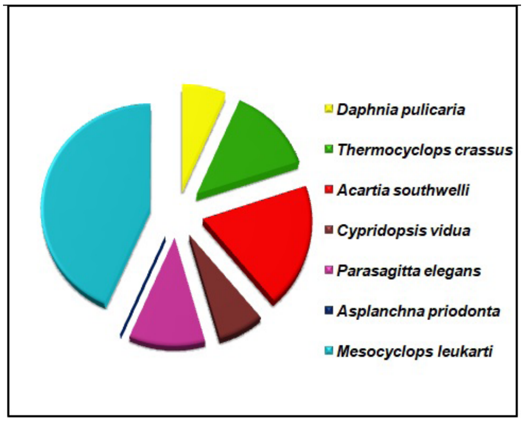

Fig. 17. Composition and abundance (No/mL) of zooplankton at Site III

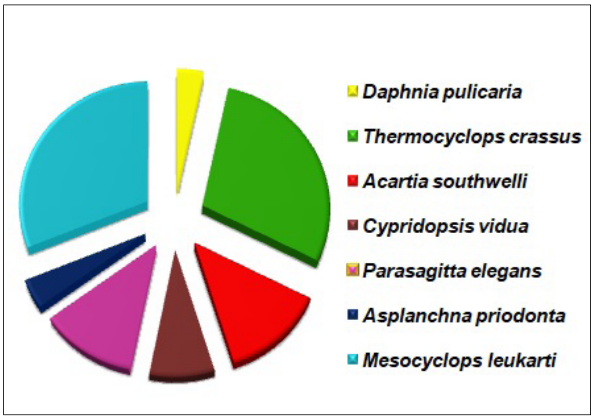

Fig. 18. Composition and abundance (No/mL) of zooplankton at Site IV

(2.57%). Site I was characterized by high dissolved oxygen content with low salinity, low turbidity, low BOD, low nitrate-nitrogen, low silicate-silicon and low sediment temperature. Most of the zooplanktons obtained in the present study belonged to calanoid copepods. The calanoid copepods are generally omnivorous (feed on ciliates, rotifers, algae, bacteria and detritus. However their food intake is dependent on their age, sex, season and food availability (Majumder *et al*., 2015). Site II revealed a high dominance of *Mesocyclops leukarti* (36.36%) followed by *Acartia southwelli* (27.27%), *Thermocyclops crassus* (17.12%), *Parasagitta elegans* (9.63%), *Cypridopsis vidua* (6.95%) and *Asplanchna priodonta* (2.67%). Site II had high phosphate-phosphorous value with low carbon dioxide, low TDS, low turbidity and low organic carbon content. *Daphnia pulicaria,* a herbivorous zooplankton, which plays an important role in controlling algal populations, was absent in this site. Site III revealed a high dominance of *Mesocyclops leukarti* (45.81%) followed by *Acartia southwelli* (19.35%), *Thermocyclops crassus* (15.48%), *Parasagitta elegans* (9.03%), *Daphnia pulicaria* (5.81%) and *Cypridopsis vidua (*4.52%). Site III had high atmospheric, water and sediment temperatures, high turbidity, high TDS, high carbon dioxide, high BOD, high silicate-silicon and high sediment organic carbon with low water and sediment pH, low conductivity, low dissolved oxygen and low phosphate-phosphorous. *Asplanchna priodonta* was absent in this site. *Thermocyclops crassus, Cypridopsis vidua* and *Parasagitta elegans* recorded least abundance in this site when compared to other sites during the study. Zooplanktons respond quickly to environmental changes like alterations in the water quality parameters, being the best water quality indicators (Jha and Barat, 2003). Site IV revealed a greater dominance of *Mesocyclops leukarti* (35.16%) followed by *Thermocyclops crassus* (28.02%), *Acartia southwelli* (15.38%), *Parasagitta elegans* (8.79%), *Cypridopsis vidua* (6.05%), *Asplanchna priodonta* (3.85%), *Daphnia pulicaria* (2.75%). Site IV recorded alkaline nature of water and sediment, high salinity, high conductivity, high nitrate-nitrogen with low water temperature. Zooplankton are commonly included in bio monitoring programs, because their densities and species decomposition are sensitive to changes in environmental conditions and they also play an important role in freshwater foodweb (Dobson *et al*., 2006).

3.3.1 Diversity Indices of Zooplankton Species in the Wetland.

The diversity indices (Fig. 20) for zooplankton assemblages revealed that Shannon diversity (H') and Margalef richness (d) recorded high values at site IV (H'=1.67 and d = 1.15 respectively) whereas low value of Shannon diversity, Pielous evenness (J') and Simpson's dominance (λ) were recorded at site I (H' =1.49, J' = 0.82 and λ = 0.72 respectively). High diversity of zooplankton indicated the fact that the site was least polluted and showed the prevalence of proper biogeochemical cycles (Majumder

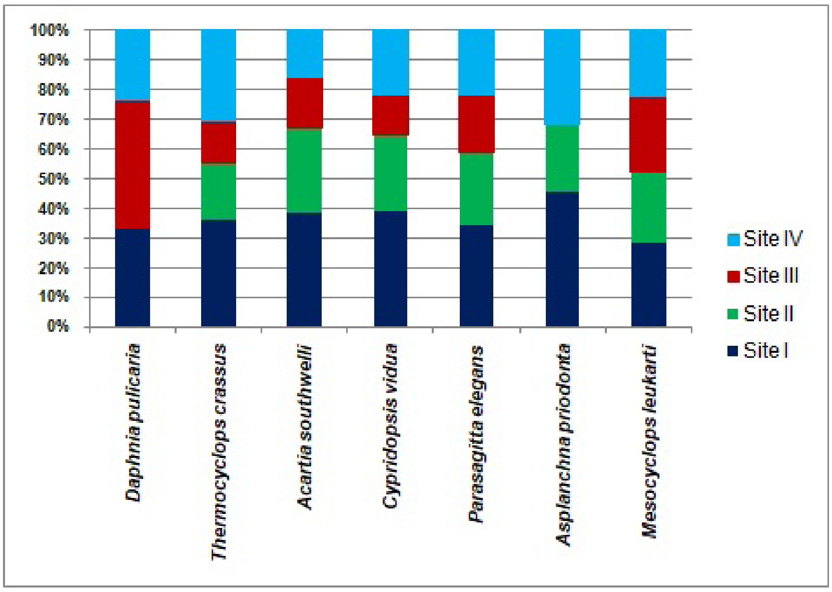

Fig. 19. Percentage variation in the composition and numerical abundance (No. /ml) of zooplankton assemblages

et al., 2015). Pielous evenness (J') recorded its high value at site II (J' = 0.86) whereas Simpson's dominance (λ) recorded high value at site III (λ = 0.78). The Simpson index is one of the most meaningful diversity measures available (Magurran, 2004). Margalef richness (d) recorded its low value at site II (d = 0.96).

3.3.2 Inter relationship of environmental parameters and zooplanktons : CCA analysis

CCA plot was used to find out the relation of environmental variables in the distribution of selected zooplankton species. In the CCA biplot (Figure 21), axis 1 of the CCA plot explained 56.75% of species variation with an Eigen value of 0.029 whereas axis 2 explained 35.09% of species variation with an Eigen value of 0.01. Axis 3 of the CCA plot explained 8.17 % of species variation with an Eigen value of 0.004 (Table 2). Zooplankton act as best indicators of water quality (Jindal *et al*., 2014). In CCA plot, Site III had high atmospheric, water and sediment temperatures, turbidity, TDS, carbon dioxide, BOD, silicate-silicon and sediment organic carbon, positioned at lower right quadrant had more influence in the distribution of *Mesocyclops leukarti*. Site IV positioned at upper quadrant had high nitrate-nitrogen, salinity and pH which influenced the species such as *Daphnia pulicaria* and *Thermocyclops crassus.* Site I had high values of dissolved oxygen. The species *Asplanchna priodonta* was more influenced by high dissolved oxygen content. Site II had high values of phosphate-phosphorous positioned at lower left quadrant which influenced the distribution of *Parasagitta elegans, Cypridopsis vidua* and *Acartia southwelli.* The planktonic communities have very short life cycle and increase rapidly under favourable environmental conditions (Dhanapathi, 2000).

Table 2. CCA values for zooplankton assemblages and hydrogeochemical variables

Axis	Eigen value	%
1	0.029036	56.75
2	0.017952	35.09
3	0.004179	8.167

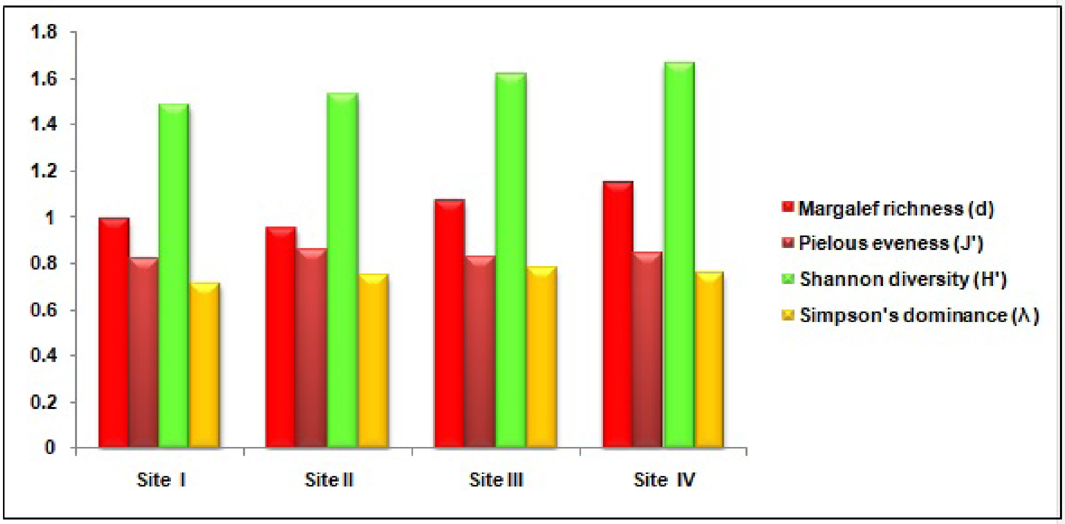

Fig. 20. Variation in the diversity indices of zooplankton species

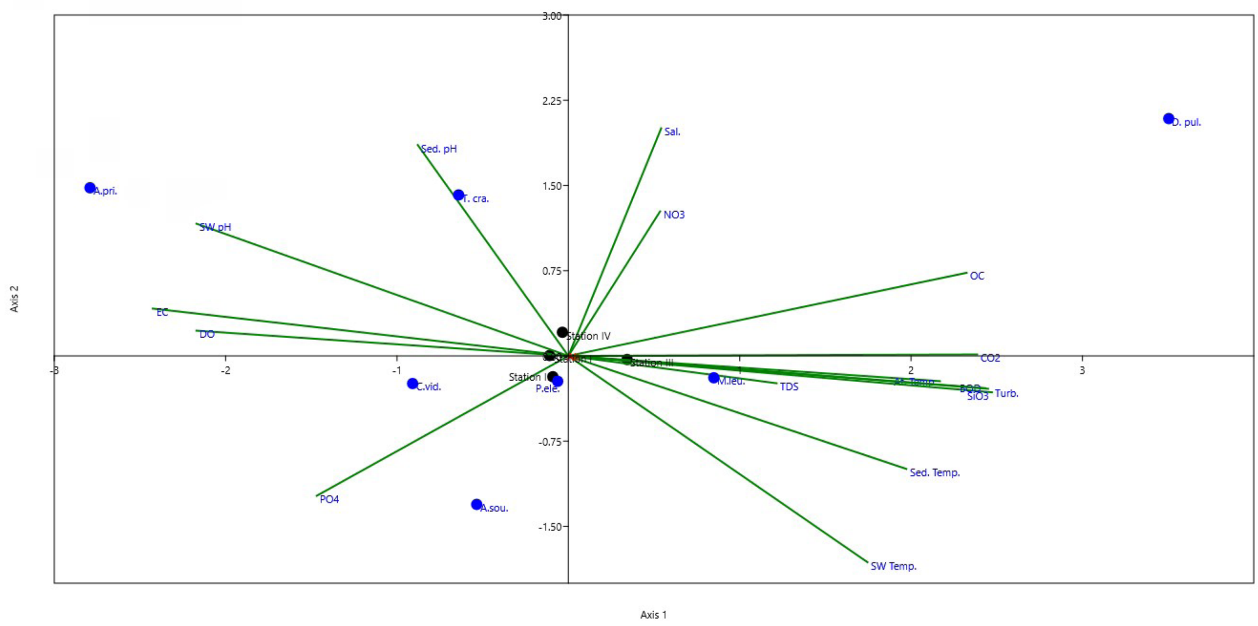

Fig. 21. CCA ordinations for zooplankton assemblages and hydrogeochemical parameters.

4. Conclusion

From the present study, analysis of the physical and chemical parameters of water and sediment along with zooplanktons and bacteriological parameters indicated slight deterioration of this Ramsar Site due to pilgrim influx and various other anthropogenic interventions, which also reflected in the zooplankton assemblages. This may adversely affect the biodiversity of this wetland and it will upset the ecological balance in nearby future. Sasthamkotta Ramsar Site is now facing threats from various natural (soil erosion and resultant siltation) as well as anthropogenic sources (local encroachment, pilgrim influx, tourist's influx, residential waste disposal and sewage outlets etc.). All the sampling sites had bacteriological contamination, which is a serious threat to human health. Site III was the most deteriorated among all the sites due to its scenic beauty along with the presence of pilgrim centre which attracts both tourists and pilgrims to visit the area throughout the year. It is essential to protect this valuable freshwater ecosystem and its water resources for preserving it for future generations. Sasthamkotta Ramsar Site is a major freshwater source in Kollam District, and it meets the drinking water needs of more than half a million people and provides fishing resources also. It is recommended that regular bio monitoring of this Ramsar Site is the necessity of the hour to minimize the incidence of pollutant-oriented problems and to safeguard public health. It is essential to protect this valuable Ramsar Site and its biotic resources to cope with the rising water needs in the area that is still unresolved.

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