COMPARATIVE STUDIES ON DIVERSITY AND DISTRIBUTION OF MESOZOOPLANKTON IN CHAPORA AND SAL RIVERS OF GOA

A Thesis submitted to Goa University for the Award of the Degree of
DOCTOR OF PHILOSOPHY
in
ZOOLOGY

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CERTIFICATE

This is to certify that, Ms. Alisha Eufemia Fernandes has worked on the thesis entitled "Comparative Studies on Diversity and Distribution of Mesozooplankton in Chapora and Sal Rivers of Goa" under my supervision and guidance.

This thesis being submitted to Goa University, Goa, for the award of degree of Doctor of Philosophy in Zoology, is an original record of the work, carried out by the candidate herself, during the period of study and has not been previously formed the basis for the award of any other degree, diploma, Associateship, fellowship or similar other titles of this or any other University in India or abroad.

Date:

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Research Guide

DECLARATION

I do hereby declare that, the thesis entitled " Comparative Studies On Diversity And Distribution Of Mesozooplankton In Chapora And Sal Rivers Of Goa", is my original contribution and the same has not been submitted on any previous occasion for any other degree or diploma, Associateship, fellowship or similar other titles of this or any other University in India or abroad. Further, literature conceiving the problem, investigated has been cited and due acknowledgement has been made wherever facilities and suggestions have been availed.

Date (Alisha Eufemia Fernandes)

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Preface

Mother Nature has gifted life with water, which is the most precious commodity to mankind. Life is sustained by water, without which, there would be no life. It is a home for various organisms including phytoplankton, zooplankton, micro-organisms, fishes, aquatic macrophytes, birds, aquatic mammals etc. Besides being the fulcrum of biochemical metabolism, man derives various benefits from water such as transportation, irrigation, power generation, fishing and so on. Apart from the above, the water is also used for recreational activities and water sports.

The freshwater, due to its low concentration of salts, is an ideal medium for many organisms. Being dynamic, the waves, tides and wind influence the physical and chemical properties of lotic water bodies tremendously and every ecosystem, whether terrestrial or aquatic, is an intricate web of physical environment, chemical factors and biological communities. Increase in human population, coupled with the greed of the mankind has led to over exploitation of freshwater bodies resulting in devastation of natural habitats and ecosystems. These water bodies face the highest anthropogenic pressure in terms of waste disposal, fishing activities, hydropower production, industrialization and recreational activities.

Zooplankton encompasses an array of macro and microscopic animals comprising of major invertebrate taxa. They play a vital role in aquatic food chains, as they serve as a link between primary producers and secondary producers. They feed on phytoplankton and are in turn preyed upon by various fishes. Their precise sensitivity and short life cycles aids in determination of water quality and hence as considered as best indication of pollution in water.

Besides, their abundance determines the availability of fish, making them important both ecologically and economically. Their ability to bio-accumulate metals and other pollutants creates a cause of concern to mankind. Though certain trace amounts of metals are essential for normal functioning of body, increased concentrations and heavy metals have deleterious effects on human and can even be fatal.

The typical zooplankton assemblage of an aquatic ecosystem comprises mainly of Rotifers, Cladocerans, Copepods, Protozoans and Ostracods. This assemblage differs in its diversity, density, distribution and abundance among various geographical regions, water bodies and from site to site, within a water body. They also exhibit diurnal variation patterns. Interplay of physical, chemical and biological properties is the root cause for structural assemblages in zooplankton.

The physico-chemical characteristics and zooplankton dynamics of marine waters and freshwater bodies have received considerable attention worldwide. The Arabian Sea also has been studied extensively for zooplankton dynamics. However there are a few reports on freshwater bodies in India in general, Goa in particular. The west coast being thickly populated, many people derive their livelihood from rivers. They harbor many tourist destinations. However, human voracity for urbanization has led to unplanned development and inadequate management. Anthropogenic waste produced by human habituation along the banks of the river is suffocating the river gravely.

The changes in aquatic environment caused due to anthropogenic pollution are a cause of rising concern and requires constant monitoring. Physico-chemical parameters such as, temperature, turbidity, alkalinity etc. affect population dynamics of zooplankton and factors like low DO and pH reduce their diversity and density. Therefore, study of physico-chemical parameters and diversity of freshwater zooplankton are unquestionably essential.

The present research work was undertaken to know the zooplankton diversity, density and abundance in correlation with water parameters and also to assess the heath of two economically important rivers in Goa viz., Sal and Chapora.

The thesis is divided into three chapters besides general introduction, materials and methods conclusion and references.

CHAPTER 1: Analyses of the Physico-chemical parameter of river Sal and Chapora

This chapter contains estimation of ten physico- chemical parameters of rivers Sal and Chapora for a period of two years from September 2015 to August 2017. All parameters were analyzed using standard methods as described by Trivedy and Goel (1984) and Anonymous (1992).

CHAPTER 2: Diversity and seasonal variation of Zooplankton in river Sal and Chapora

This chapter deals with zooplankton diversity, population density and diversity indices (Marglef's richness index, Simpson index, Shannon- Weiner index and Evenness) of zooplankton groups belonging to 5 major taxa viz., Rotifers, Cladocerans, Copepods, Protozoa and Ostracods.

CHAPTER 3:

This chapter throws light upon cross-covariance matrices between the abundance of zooplankton species collected and the environmental variables assessed.

INTRODUCTION

Water has always been nurturing and supporting a plethora of life, ever since life originated. It plays a crucial role in the ecosystem immensely supporting plants, animals and microorganisms. Only 2.5 % of the total surface water is freshwater, while, the remaining 97.5 % is saline water (Stiassny *et al.,* 1999). Out of this 2.5%, a major portion of the total surface freshwater is found locked up as ice, permafrost, glaciers etc. and only 0.49% of the total surface freshwater are in the form of lentic water bodies. It is not just the aquatic species, but all terrestrial life also is largely dependent on the functioning of these water bodies. Humans depend on freshwater resources for multifarious tasks ranging from supporting functions, such as primary production, nutrient recycling (Gomez-Baggethun and De Groot, 2010) to facilitating functions like drinking and consumption water supply, irrigation and sanitation. Rivers are crucial to mankind also for the economic services they provide, such as in industrial processes and hydroelectric generation. They are the centers for cultural, recreational and aesthetic heritage (Vorosmarty *et al.*, 2005).

Urbanization, industrialization and increasing need of water globally, is having intense effects on lakes, ponds, rivers and streams, immensely threatening freshwater biodiversity. Further, the demand for clean drinking water increases as unprecedented population is increasing (Engel *et al.,* 2011). Water source management and harnessing is one of the most important multipurpose human undertakings. The need for irrigation supply and hydropower generation also rises with strong development pressure (Anonymous, 2002). Flowing rivers are being abstracted and diverted for urban consumption, navigation, tourism and flood protection. Such constant efforts to improve living standards of mankind often comes with a significant environmental cost i.e. pollution. Metal discharges from mining, smelting and industrial manufacturing directly adds to surface water contamination (Moore *et al.*, 1998). Discharge of toxic chemicals and fertilizers used in farming get carried into rivers from surrounding catchment areas promoting algal growth which is a major cause for water quality dilapidation especially in rural areas. The worst affected by such anthropogenic activities is freshwater ecosystems specially lentic water bodies, deteriorating them (Finlayson *et al.,* 2005). Overuse and degradation of freshwater resources by humans is causing scarcity of safe water day by day and is likely to limit food production, ecosystem functioning and urban water supply (Jury and Vaux, 2007). No matter how beneficial these developments seem for the time being they are causing ripples of short as well as long term hazardous effects (Meng *et al.*, 2011).

Currently, riverine pollution is an alarming problem. Point and non-point sources of water pollution are causing deleterious effects on the quality and quantity of water, which in return is affecting sustainable development (Kumar, 1997). The diversity and abundance of riverine biota is also degrading. Domestic sewage, agricultural run-off, garbage dumping, religious waste, bathing of livestock, effluents from factories and industries etc., leads to increase in nutrient load in the water body, triggering eutrophication. This also makes the water unfit for human consumption. An anthropogenically enhanced alteration in nutrient influx disturbs the levels of biological oxygen demand and subsequently reduces the primary and secondary production of the aquatic ecosystem, which is reflected in the biota too (Jumppanen, 1976).

The natural flow of lotic water bodies helps in maintaining vital food webs and ecological balance in nature. A combination of magnitude, duration, frequency and rate of flows determines the natural flow regime of a river and any sort of diversions and alterations which change the natural flow regime of a river can significantly change the functioning of an ecosystem (Poff *et al.*, 1997). Modifications such as, alterations of water channels and water flows by building dams, weirs, barrages, culverts, bridges etc., and reformation of natural drainage basins disturbs the quality and quantity of water, causing it to shift away from natural variability (Nilsson and Renofalt, 2008). The flourishing of industrial establishments increased such derogatory effects many folds, thus turning originally flowing rivers into stagnant reservoirs. Pollution caused during such modification activities shows its effects on the physical, chemical and nutrient composition of the river. Accumulation of pollutants, over a period of time, aggravates the eutrophication process further especially during low flow phases (Lindqvist *et al.*, 2005).

Investigation conducted at Heinz Centre (2002) suggested that, construction of bridges, barrages, dams etc. reduces the biodiversity and productivity of natural fisheries. Changes in migration and fish habitat it has also been observed by Murchie *et al.*, (2008), however the severity and direction of the response varies widely from species to species. Regulatory structures like impoundments obstruct natural flow velocity and causes population fragmentation (Morita and Yakota, 2002). Also, construction of artificial fish and prawn farms along the banks of rivers causes an imbalance in nutrients thereby affecting the flora and fauna. A reduction in specialist species and domination of generalist species able to survive in toxic conditions was observed by Miranda *et al.*, (2009). Introduction of exotic species for high yield disrupts the existence of native species threatening ecosystem stability and ecological processes. Many researchers at various locations recorded a decrement in species richness, abundance, stability and diversity of zooplankton due to anthropogenic riverine alterations.

An aquatic ecosystem greatly depends on physical as well as chemical parameters of water (Sharmila and Rajeswari, 2015). The health of the water body can be determined by analyses of such physico-chemical parameters (Shinde *et al.,* 2011). They also provide significant data regarding the biological resources in the water body (Pandit and Solanki, 2004 and Thirupathaiah *et al.,* 2012). Hence the analysis of water quality is of utmost importance to preserve and protect aquatic ecosystems. Further, various metabolic activities can be understood by thorough study of water quality parameters (Rajan and Samuel, 2016). Certain parameters like temperature, pH, salinity and dissolved oxygen directly influence the survival of aquatic flora and fauna. The abundance, diversity and distribution of various organisms largely depend of the status of the water.

Monitoring of water bodies is the first step that can lead to management and conservation of ecosystems. In order to mitigate the impact of human development on natural waters, it is becoming increasingly important to implement comprehensive monitoring regimes. Thus, proper understanding of the water body and its productive potential can only be achieved by thorough analysis of physico- chemical and biological factors (Sreenivasulu *et al.,* 2014).

Among the biological component, zooplankton in freshwater ecosystems, contributes significantly to global diversity. They play an integral role in food webs as well as biological assessment of freshwater habitats (Shekar *et al.,* 2008). They are an important component of secondary production and an important link between producers and higher consumers (Pradhan, 2014) exhibiting cascading effects in the ecosystem. As far as ecological studies are concerned, zooplankton communities are excellent models for study because different species have different tolerable limits to a variety of pollutants and exhibit abrupt changes in their population if any disturbance. Hence, the overall health of the aquatic ecosystem can be detected right at the primary consumer level thereby monitoring the trophic status of the water body.

Goa, popularly known as `The Emerald of East' has many beautiful natural beaches. It is the smallest state in Goa yet the most popular tourist destination on the West Coast of India. It encompasses an area of 3,702 square kilometers and lies between the 14°53′54″ N and 15°40′00″ N latitudes and 73°40′33″ E and 74°20′13″ E longitudes. Out of the 11 rivers, that supports the land of Goa, river Sal is one the prominent rivers in the south; while the river Chapora is a lesser known river of north Goa.

River Sal

The third largest non-perennial River in Goa, the Sal is based in South Goa. It starts in Cavelossim and passes through Margao, Chinchinim, Navelim, Assolna etc., before leading into the Arabian Sea at Betul in Goa. The Sal River measures 35 kilometers in length and has a basin size of 301 square kilometers. Since fishing is the main coastal business of the local population, the river is a life line to people in South Goa specially Salcete taluka. Apart from the use of river water for irrigation in fields and pisciculture, the river also forms an integral part of tourism, as it adds to Goa's economy. The river also provides routes for transportation. However, a steady rising increase in urbanization has led to the river becoming an ecological tragedy. Heavy siltation, drastic use of land, reckless hill cutting, encroachments, waste dumping and constant human interference has substantially destroyed and is continuously destroying and polluting the pristine environment of River Sal. The Goa State Pollution Control Board (GSPCB), under the Central Pollution Control Board Program called National Water Quality Monitoring Program has categorized River Sal as priority III due to the high level of faecal coliforms (FC), far exceeding the prescribed limits.

River Chapora

Chapora River is a river in northern Goa, India. Originating from a small village in Maharashtra called Hajgoli near the town of Belgaum, the river Chapora flows through Tillari ghat and then enters Goa. It runs for approximately 21 kilometers in Goa before flowing into the Arabian Sea, at Vagator Beach. At the mouth of the Chapora River, is a working fishing harbor. The river forms an integral part of the villagers, due to its impact on fishing, trade, irrigation facilities, agriculture, coastal resources, and transportation of mining ores as well as providing portability. Many families are directly and indirectly dependent on the fishing activities carried out in this river thus supporting their livelihood. The port of Chapora is seasonal in character and caters to country rafts, trawlers and other small vessels. The disposal of untreated domestic sewage observed in urbanized areas like Siolim, Oxel, Colvale, Camurlim and Vagale on the Southern bank of the River destroys the health of the river. Open defecation from the residents along the bank is also a major source of the pollution. Bathing of domestic animals, is observed on the downstream of the river which contaminates the river further.. Apart infrastructure built along the river is sure to have an impact on the flora and fauna of the place. On the basis of GSPCB reports, Central Pollution Control Board (CPCB) has classified Chapora River under Priority V, and labeled it fit for bathing, contact water sports and commercial fishing.

In the backdrop of this, a comprehensive study had been designed for detailed investigation of stress on the ecology of rivers Sal and Chapora. The present work was carried out along the following objectives.

- To analyze physical and chemical parameters of these lotic water bodies.
- To study diversity, density and distribution pattern of meso-zooplankton as a representative for biological parameter.
- To evaluate species richness and population dynamics of zooplankton.
- To examine the seasonal variation of both physico-chemical and biological parameters, represented by Zooplankton.

This study will act useful in assessing the impact of anthropogenic activities if any on the already stressed rivers Sal and Chapora and will go a long way in formulation of policies for better utilization of the rivers as an aquatic source.

REVIEW OF LITERATURE

PHYSICOCHEMICAL PARAMETERS

River regulation is the only method to procure multitude of benefits from riverine systems. Major civilizations and reckless developments to reap maximum benefits for humans have led to significant destruction of environment specially water bodies. Poor management of water infrastructure development has led to further manipulation of riverine habitat.

Physico-chemical parameters reflect the status of an aquatic body and their determination is of immense significance to monitor the health of a water body. Study of physico- chemical parameters also provides in depth information of the available resources important for supporting life. Such information can be beneficial for conservation of ecosystem as well as increasing opportunities for use of such water in artificial fisheries. A survey of literature reveals that diverse physico-chemical parameters have been assessed by various workers viz. Willcocks (1903), Grover (1925), Ellis (1931, 1936 and 1942), Dutta and Malhotra (1986), March *et al.*, (2003) Kadam *et al.,* (2007) etc.,. in different global water bodies.

Comprehensive studies on the impact of reservoirs by Neel (1963) revealed that, alteration of flow patterns, reduction of turbidity, and growth of algae affects the mainstream dams.

Fossato (1971) studied hydro- biological, physical and chemical characteristics of Adige River at Boara Pisani and Po River at Polesella and concluded that absence of free carbon dioxide causes a slow transformation of the insoluble carbonates into soluble carbonates.

Adebisi (1980) while studying the physico-chemical parameters and hydrology of a seasonal river reported an inverse relationship of pH and alkalinity with water depth.

Zutshi *et al*., (1980) carried out a comparative study of 9 lakes of Jammu and Kashmir, which showed that low water depth and volume led to increase in temperature of water bodies. The study further indicated that, probably the pH value in water bodies increased due to the addition of hydroxyl, bicarbonate and carbonate ions.

A study conducted on water temperature by John (1984) exposed how construction of water level control structures alters the hydraulic regime of water thus altering its thermal regime.

While studying the effect of water pollution in Yamuna, Sangu and Sharma (1985) suggested that the highest concentration of dissolved oxygen was due to decrease in water temperature.

Trivedy and Goel (1986) reported that natural waters are mostly alkaline due to the presence of large amounts of carbonates. The authors are known for in scripting various chemical and biological methodologies for assessment of water pollution.

Bournaud *et al.,* (1987) while investigating the ecology of the Rhone river, indicated that the functional characteristics of a species is principally determined by various hydrological factors like water temperature, day length and rater of water flow.

During ecological studies on river Cauvery and Kapila, Karnataka, Somashekhar (1988) observed that, unpolluted stations showed lower values of hardness whereas polluted stations exhibited higher values of hardness. He further concluded that less polluted stations showed lower alkalinity; while stations which were highly polluted showed high alkaline values.

Katavkar *et al.,* (1989) while analyzing pollution status of two lentic water bodies at Kolhapur, observed that, dumping of sewage into water bodies was the major source for enrichment of nitrate.

Chopra *et al.,* (1990) observed maximum levels of dissolved oxygen during winter and minimum levels in monsoon, while studying abiotic variables of river Yamuna. During the investigation they found that free carbon dioxide was absent during December and January and was highest in monsoons.

In a case study worked out by Sinha *et al.*, (1991), to assess the impact of religious mass bathing in river Ganga on the eve of Mahashivratri indicated a significant change in water quality, which can cause health issues among the users.

While investigating effects of pollutant contamination due to urbanization on downstream sites in Hawaii, Anderson (1992) evidenced increased quantity of pollutants and accelerated rate of delivery of pollutants to downstream sites.

Kulshreshtha and Sharma (2006) affirmed that, the high levels of sulphate in monsoon at Manasarovar reservoir, Bhopal (MP) was due to the rain water bringing in high input of sulphate from the surrounding catchment area.

Studies conducted by Allan (1995) on stream ecology, structure and functions of running water, showed dramatic changes in physical, chemical and biological structure and function of rivers and streams.

Naiman *et al.,* (1995) by working on freshwater bodies, concluded that alteration of flow regimes is the most serious and continuing threat to ecological sustainability of rivers.

While working on water resources and biodiversity: past, present and future problems and solutions, Cullen and Lake (1995) stated that, regulation of flows is a major cause of declining conditions in many Australian rivers and floodplains.

Chapman (1996), while investigating impact of humans on the Waikato river system in New Zealand, emphasized that anthropogenic activity in catchment areas leads to large influxes of organic material and nutrients in the reservoir causing eutrophication.

Mukhopadhyay (1996) investigated the lotic and lentic freshwater bodies in and around Darjeeling, West Bengal and reported that pH was slightly acidic in relatively higher altitudes.

While analyzing physico-chemical parameters in Mahanadi estuary east coast of India, Das *et al.,* (1997) reported higher nitrate values in monsoon / post- monsoon season, which they attributed to the inflow of organic materials during rainfall from the catchment areas.

Poff *et al.,* (1997) during his studies on the natural flow regime of rivers, suggested that, a rivers natural flow dynamics helps in maintaining and supporting key ecosystem processes and vital life cycles. They further stated that, any alterations could significantly change the ecosystem and its functioning.

Studies carried out on the biodiversity of zooplankton by Karuppasamy and Perumal (2000) at Pichavaran mangroves, exhibited increasing nitrate levels. They ascribed this increase to inflow of freshwater containing nitrates, litter fall decomposition and terrestrial run off during monsoon and post- monsoon season.

Schlosser and Kallenmeyn (2000), while studying the impact of increased rate of sedimentation on dissolved oxygen concentration observed that, such conditions cause hypoxia in riverine conditions.

Comprehensive studies by Swami *et al.,* (1996), showed the influence of environmental conditions such as salinity, oxygen, temperature and nutrients on the composition, distribution and growth of its biota.

Pathak *et al.,* (2007) conducted ecological studies on river Mahanadi and recorded high transparency, alkaline pH and low FCO_2 in the river. They noticed an increasing trend in the parameters from upstream to downstream.

Arvind and Singh (2002), while studying the ecology, conservation and management of river Mayurakshi in Santhal Paragna (Jharkand state) due to sewage pollution recorded high dissolved oxygen values in winter. He attributed the increase in DO to reduction of water temperature which is inversely related to DO.

Rudolf *et al.,* (2002) used dissolved oxygen content as an index of water quality to assess the effect of individual and municipal effluents on the waters of San Vicente Bay in Chile.

Physico- chemical characteristics of a tropical lake, in Jodhpur Rajasthan were studied by Jakher and Rawat (2003). They observed maximum pH in summer and explained this by correlating the rise in temperature during this season to an increased rate of photosynthesis which resulted in higher consumption of carbon dioxide.

Rajasegar (2003) examined the physico- chemical characteristics of the Velar estuary in relation to farming. He reported low levels of phosphate during pre-monsoon and post- monsoon period which can be attributed to the limited rate of precipitation and utilization of phosphate by plankton.

Analyses of ecological parameters of Yamuna river by Ravindra *et al.,* (2003), indicated better quality of water in the upstream compared to downstream. The downstream water had low dissolved oxygen and high levels of total dissolved solids, electrical conductivity, total hardness, sodium, potassium, chloride, fluoride and sulphate.

Inspective studies of some physical and chemical parameters of water in Lake Isykli by Kara *et al.,* (2004) showed temperature above 30ºC causes regression in growth and decay in plants.

Kadam *et al.,* (2007), while studying Masoli reservoir in Maharashtra reported less transparency, during the monsoon, as compared to winter or summer season.

Comprehensive studies by Pathak *et al.,* (2007), on the ecological status and productivity potential of river Mahanadi revealed some physicochemical parameters like high dissolved oxygen, alkaline pH, higher values of alkalinity, conductance, dissolved solids, calcium and dissolved organic matter are affecting the productive nature of the river.

Bio monitoring studies conducted on river Tawi by Sawhney (2008), showed a rise in calcium levels in winter which was attributed to increased water solubility of calcium at low temperature.

Assessment of various physicochemical parameters by Shiddmallayya and Pratima (2008), to study the impact of domestic sewage on Bhalki town tanks, in Bidar showed increased concentration of pH, hardness, calcium, nitrates, phosphates and.

Buffagni *et al.,* (2009), while assessing the ecological quality of rivers, concluded that, anthropogenic pressure such as point source discharges, surface water abstractions and hydropower lines modifies the natural flow of the river with a negative impact on water quality. It affects the biotic composition, structure and functioning of the aquatic and riparian ecosystem.

Studies on fish diversity in relation to physicochemical characteristics of Bhadra reservoir in Karnataka by Thirumala *et al.,* (2011) showed that, dissolved oxygen plays an important role in the life of aquatic organisms surviving in the river and thus can be used as an index for water quality studies.

Bhat *et al.,* (2012) studied the seasonal variation of various physicochemical parameters in several ponds in Lucknow city and concluded that, most parameters were above the permissible limits range. They attributed the pollution to mainly sewage discharge, agricultural and urban runoff and continuous dumping of water materials especially sanitary drainage waste.

While analyzing the seasonal variation in physicochemical parameters like temperature, pH, transparency, dissolved oxygen, free carbon dioxide, hardness, Chloride, Phosphate, sulphate and nitrate of Pindavini Pond, Central India, Harney *et al.,* (2013) found the values of total alkalinity, chloride, phosphate and nitrate to be high, thus indicating the water is contaminated.

Prasath *et al.,* (2013) examined the open pond and ground water quality of Tiruchirapalli city of Tamil Nadu. On analyzing the physicochemical parameters like pH, total hardness, calcium, magnesium, chloride, carbonate, bicarbonate, nitrate and phosphate, they concluded that, the ground water could be considered suitable for human consumption, but the pond water available in and around the city was not fit for human consumption.

In an attempt to study the pollution status of four lakes of Udaipur by Lodh *et al.*, (2014) the physico-chemical parameters revealed the pollution load in various lakes. The Biochemical oxygen demand as well as ammonical nitrogen values were high which conveyed high bacteriological load, organic matter dispersal and animal waste contaminating the lakes.

Limnological studies conducted by Munyika *et al.,* (2014), on the effect of land used activities such as agriculture, irrigation, expansion of unplanned settlements, lack of proper sanitation, urbanization and weir construction along the banks of river Orange in Namibia showed high level of turbidity and chlorophyll much beyond permissible limits. However other physicochemical parameters were in moderately modified range.

Dixit *et al.*, (2015) investigated the physicochemical parameters of various ponds in Bilaspur district. They observed that, the pH value of different pond water samples ranged from 6.5 to 8.5, which is in compliance with the water quality criteria provided by CPCB, New Delhi. However, they noted that, the water samples of Mohra village, Parasahi village, Bhima Talab showed comparatively higher values of pH (> 9) indicating that, the water from these ponds was not suitable for drinking, bathing, propagation of wildlife and fisheries and irrigation.

Studies on the water quality index of Chandlodia Lake in Gujrat by Qureshimatva *et al.*, (2015) showed that, pH, alkalinity, total hardness, magnesium, calcium and dissolved oxygen values far exceeded the permissible limits as prescribed by Indian standards, while other parameters like electrical conductivity, chloride, nitrate and BOD, were within permissible limits. Based on all these values and high level of pollutants, they concluded that, the water quality of the lake was poor and unsafe for human consumption.

Noortheen *et al.*, (2016) analyzed the quality of surface and ground water samples in and around Salem District, Tamil Nadu and concluded that, the quality of water of the selected water bodies has deteriorated and eutrophicated, due to anthropogenic influence.

Assessment of various physicochemical parameters viz., temperature, pH, dissolved oxygen, total hardness, calcium, magnesium, chloride at Athiyannoor Panchayath was done by Sajitha and Vijayamma (2016) and showed that, all the water samples were under excellent category and hence is suitable for domestic purpose.

Zandagba *et al.*, (2016), while monitoring the temporal and spatial variation of physicochemical parameters of Nokoué Lake, Benin, Nigeria, for sustainable management revealed low concentration of dissolved oxygen and high concentration of phosphate and nitrates which is an indication of eutrophication.

Anbarasu and Anbuselvan (2017) analyzed the physicochemical parameters of ground and surface water of Musiri Taluk and concluded that the water from Cauvery was suitable for drinking purposes however the well and bore well water samples were not fit for drinking and utility purpose.

While assessing the seasonal variations in physicochemical parameter in Tuticorin water bodies, Balakrishnan *et al.*, (2017) reported no wide spatial variability. They concluded that, all the hydrographical parameters in the Bay of Bengal showed clear seasonal patterns, without any marked variation between the stations.

Nongmaithem and Basudha (2017) assessed the physicochemical properties of ten different water bodies in Manipur and concluded that, most of the physicochemical parameters were within the permissible limits of WHO for potable water and therefore can be considered suitable for domestic purpose.

ZOOPLANKTON

Zooplankton are the primary biotic components, known to influence all the functional aspects of an aquatic ecosystem such as, food chain, food web, energy flow and cycling of matter. They play an important role in the economy of the sea. Certain zooplankton species serve as bio indicators and thus, serve as a tool for understanding the status of water pollution. Researchers have done a lot of work, all over the world including India. Some of the significant contributions made were by Venkateswarlu (1968), Prabhavathy and Sreenivasan (1977), Badola and Singh (1981), Bilgrami and Munshi (1985), Saunders and Lewis (1988), Jeje (1989), Mishra and Sharma (1990) and Tayor and Segers (1999) Kulshrestha and Sharma (2006)

Sampath *et al.,* (1979), while investigating the hydrobiological parameters of river Cauvery, concluded that, the increase in total hardness and alkalinity during winters and summers lead to an increase in rotifer population growth.

Comprehensive studies by De Ruyter van Steveninck *et al.*, (1990) on the changes in plankton communities in the parts of the lower Rhine river which were highly regulated and modified by construction of weirs showed a peak in the population of phytoplankton, primarily diatoms in spring and summers, however, the regulated parts population was still lower, as compared to non- regulated parts of the river. Zooplanktonic mass increased in regulated regions, due to the increase in number of rotifers, crustaceans and molluscan larvae, while a reduction in population of arcellas and ciliates were noted in the modified parts of the river.

Gulati (1990), while studying the zooplankton structure, in relation to trophic status and recent restoration measures in the Loosdrecht lakes reported, highly eutrophic environments increased the concentration of detritus, which enhanced bacterial production, which in turn acts as an important food source for rotifers.

While investigating the community structure of crustacean plankton, in relation to trophic conditions, in 100 freshwater bodies of Kashmir Balki and Yousuf (1992) reported that, calanoids (copepods) were rich in oligotrophic / ultra- oligotrophic waters.

Subbama (1992) studied the plankton population of a temple pond, near Machili Patnam, Andhra Pradesh and reported Copepods viz., *Arctodiapotamus dorsalis*, *Cyclops sp*., *Diapotamus sp.*, *Mesocyclops hyalinus, Nauplius larvae*, *Thermocyclops crassus* and three species of Ostracoda viz., *Cyprinotus glaucus, Stenocypris malcomsoni* and *Stenocypris sp.* to be pollution indicator zooplankton.

Thorp *et al.*, (1994) conducted studies on zooplankton in Ohio river and reported that, the density of zooplanktons was minimum during high discharge and turbidity. Further, their studies on density showed positive correlation with temperature and negative correlation with water velocity.

While studying the peak abundance of freshwater copepods, in response to warm summers Gerten and Adrain (2002) noted that, the abundance of Cycloid copepods was related to water temperature in summers.

Hurtado-Bocanegra *et al.*, (2002) studied the combined effects of food levels and inoculation density on competition behavior between rotifers and Cladocerans and observed Cladocerans were competitively superior than, rotifers, due to their larger size and consumption of higher quantities of algal food.

Trivedi *et al.*, (2003), while studying the variations of plankton population, of two hill streams in Darjeeling district, West Bengal, reported less growth of zooplankton, during low temperature period, due to the fall in temperature, low light penetration and heavy flow of water.

While analyzing the seasonal fluctuations of zooplankton community, in relation to physico-chemical parameters, in river Ramjan, Bihar, Pandey *et al.*, (2004) reported rotifers to be dominant, followed by Cladocerans and copepods. They recorded negative correlation of rotifers with pH, dissolved oxygen and transparency and negative correlation was also reported between copepods and water temperature, nitrate and phosphate.

Sunkad and Patil (2004) analyzed the quality of water of Fort lake, in Belgaum with special reference to zooplankton. They reported, four major groups of zooplankton, in the following order of percent composition: rotifera (52.38%) copepod (26.5%), cladocera (16.45%) and ostracoda (4.67%). They attributed the dominance of rotifers to the continuous supply of food material into the lake.

While studying the effect of environmental factors, on the biodiversity of holozooplankton community, in lake Qarun, Mageed (2005) claimed that, the death of zooplankton in the lake occurred due to stress, high pH and high ammonia. He also noted a direct relationship between increases in water temperature and increase in zooplankton.

Zafar and Sultana (2005) worked on the density of zooplankton in river Ganga at Kanpur, India and recorded a peak in the density of zooplankton, during summers and lower values in monsoon season.

Thorp and Mantovani (2005), undertook studies on zooplankton, in turbid and hydrologically dynamic Prairie rives and recorded significantly abundant rotifers in turbid waters, whereas micro crustaceans were less in turbid rivers. They further added that, the density of crustaceans and rotifers was negatively correlated to current velocity.

Chowdhury and Mamun (2006), while studying the effect of physicochemical conditions, on zooplankton, in two fish ponds in Khulna, Bangladesh, recorded maximum diversity and abundance of zooplankton, in the months of August and September.

Langer *et al.,* (2007), in an attempt to study the effect of some abiotic factors, on zooplankton productivity, in a subtropical pond of Jammu, found that, *Moina* among Cladocerans and *Brachionus* among rotifers were present, at both high as well as low dissolved oxygen levels, thus revealing their wide tolerance level for oxygen variation. Further, the copepods present were declared as important pollution indicator species, as they were seen to survive in abundance during high pollution, high temperature, high free carbon dioxide and low level of calcium and magnesium.

While studying the zooplankton composition and diversity, in Paoay lake, Phillipines, Aquino *et al.,* (2008), recorded 27 species of zooplankton, out of which 45% wee rotifers, 29% were cladocerans and 26% copepods.

Dugel *et al.,* (2008), during their studies on species assemblages and habitat preferences of Ostracoda (Crustacea), mentioned that, ostracods were widely distributed in all types of aquatic environment and concluded that, water temperature, dissolved oxygen and electrical conductivity are the most effective factors influencing species composition of ostracods.

Paulose and Maheshwari (2008), while studying the seasonal variations, in zooplankton community structure of Ramgarh lake Jaipur, stated that, high temperature increases the multiplication and metabolic rates of rotifers resulting in excessive growth.

Zooplankton composition and distribution in vegetated and un-vegetated areas, in three reservoirs in Hatay, Turkey, was studied by Bozkurt and Guven (2009). They reported that, cladocerans were more abundant in vegetated areas, compared to un-vegetated areas. Further, they also pointed out that, distribution, reproduction and growth of zooplankton was adversely affected by dissolved oxygen.

While studying the impact of flood water, on the distribution of zooplankton, in the main channel of lake Nasser El-Serafy *et al.*, (2009), reported copepods to be the dominant group and attributed their rise to good environmental condition of the lake at the time of investigation.

Rajagopal *et al.*, (2010), studied the physicochemical parameters and zooplankton diversity in three perennial ponds of Virudhungar district of Tamil Nadu. They reported the positive correlation with zooplankton and physicochemical parameters like temperature, alkalinity, phosphate, hardness and BOD; while negative correlation was seen with rainfall and salinity. They further revealed the presence of certain species like *Monostyla sp., Keratella sp., Leppadella sp., Leydigia sp., Moinadaphnia sp., Diaptomus sp., Diaphanosoma sp., Mesocyclops sp., Cypris sp.* and *Brachionus sp.* as biological indicators of eutrophication.

Sharma and Sharma (2011), while studying zooplankton diversity of Loktak lake, in Manipur, India, reported Rotifers as the most dominant group, followed by Cladocera > Copepoda >Rhizopoda. Their findings also revealed the significant inverse correlation between zooplankton richness and water hardness and chloride. Inverse relation was observed between abundance of zooplankton and nitrates.

During the assessment of zooplankton population, in relation to physicochemical parameters, of Lal Diggi pond in Aligarh, Ahmad *et al.*, (2012), reported high number and density of *Brachionus sp*., indicating eutrophication, in the pond and tolerance of this genus to pollution.

Jose and Sanalkumar (2012) studied seasonal variations in the zooplankton diversity of river Achencovil and testified domination of rotifers (39.36%) in summer, followed by copepods (35.53%) and Cladocerans (27.11%). Abundance of cladocera was noted during the monsoon (45%) period, while copepods formed the dominant group, during the post-monsoon period (42.01%).

Koli and Mulay (2012), while studying the correlation between seasonal variation of zooplankton diversity and physicochemical parameters in Tulshi reservoir, recorded 39 species of zooplankton, out of which 15 species were rotifers, 12 species of copepods, 10 species of cladocera and 2 species belonging to ostracoda. Their findings further revealed the positive correlation of zooplankton with temperature, alkalinity, phosphate, hardness and BOD, while negative correlation was observed, with rainfall and salinity.

Jagadeeshappa and Vijaya (2013), assessed the relationship between plankton assemblages and physicochemical parameters, in wetlands of Tiptur taluka, Tumkur district, Karnataka and concluded that, an increase in concentration of physicochemical parameters and plankton diversity, was more in pre-monsoon, compared to post monsoon and monsoon season.

In a study, conducted by Shivashankar and Venkararamana (2013), on zooplankton species abundance and diversity of Bhadra reservoir, Chikkamagalur district, Karnataka, 23 species of zooplankton were recorded, of which group rotifera (8) were found to be the most abundant followed by Cladocera (5), Copepoda (3), Ostracoda (2) and Protozoa (5).

In an analytical study on zooplankton diversity by Pradhan (2014), on a freshwater lake Wunna, three genera of zooplankton viz., rotifera, cladocera and copepoda were recorded.. Their finding revealed that. rotifers dominated the zooplankton population and their number was highest in winter season.

Dede and Desmukh (2015) made an attempt. to study the zooplankton composition and seasonal variations in Bhima river, Solapur district (Maharastra), India and recorded a total of 21 species of zooplankton, out of which 9 species belong to rotifera, 5 species belong to copepoda, 5 species belong to cladocera and 2 species belong to ostracoda.

In an investigative study on zooplankton, Manjare (2015) carried out qualitative and quantitative study on freshwater tanks viz; Tamdalge tank, Laxmiwadi tank and Vadgaon tank of Kolhapur district (Maharashtra) and reported the order of dominance of various groups of zooplankton as:

Tamdalge tank- Copepoda (40.15%) > Rotifera (29.15%) > Cladocera (22.50%) > Ostracoda (8.7%).

Laxmiwadi tank- Copepoda (48.55%) > Rotifera (21.35%) > Cladocera (20.65%) > Ostracoda (9.74%).

Vadgaon tank- Rotifera (41.33%) > Cladocera (35.49%) > Ostracoda (18.75%) > Copepoda (9.41%).

Diversity and abundance of zooplankton, in river Narmada, at Jabalpur region, was studied by Shukla and Solanki (2016). Protozoa contributed dominantly to the zooplankton abundance followed by Copepoda > rotifera > Cladocera > Ostracoda. The Shannon Weiner Index (H=-0.839586), also indicated good variation.

Golmarvi *et al.,* (2017) investigated the interrelationship between physicochemical factors and zooplankton population in context of their seasonal abundance in Anzali International wetland, Iran and reported higher zooplankton in summer months and lower in winter. Moreover, the wetland was exposed to various anthropogenic activities such as domestic waste discharge, agricultural run-off, industrial wastes etc., and thus leading to large amount of nutrient inputs to the ecosystem, which indicated the eutrophic status of the wetland.

Sheikh *et al.,* (2017) conducted investigative studies on zooplankton diversity, in river Kali, Karwar, West coast of India and reported 42 species of zooplankton, represented by 11 groups, among which copepoda was the dominant one.

Chapter-I

ANALYSES OF PHYSICO CHEMICAL PARAMETERS OF CHAPORA AND SAL RIVERS OF GOA

ANALYSIS OF WATER PARAMETERS

Water Temperature

The Federal Water Pollution Control Administration (Anonymous,1967), referred to water temperature as one of the most important and influential water quality parameter. They further stated water to be a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller and also a killer. Aken (2008) emphasized on the influence of temperature on chemical processes, such as dissolution- precipitation, oxidation-reduction and physiology of biotic community. A rise in temperature of the water increases the rate of chemical reactions in water and reduces the solubility of gases. Aquatic organisms are highly sensitive to changes in water temperature (Trivedy and Goel, 1986). It affects the feeding and growth rate as well as reproduction, movements and distribution of aquatic organisms (Welch, 1952 and Quadri and Yusuf, 1980).

The surface water temperature of each station was recorded using centigrade mercury thermometer. The temperature was recorded at a depth of about 10 cm below the water surface level and expressed in ^{o}C.

pH (Potentio Hydrogeni)

The pH scale runs from 0 to 14, a pH value of 7 is neutral; a pH less than 7 is acidic and greater than 7 represents alkalinity. Since pH is dependent on many properties, processes and reactions occurring in water, Millero (1986) termed it as ‘a master variable’. Gupta *et al.*, (1996) also affirmed that, changes in pH of water are due to various biological activities. Jhingran (1978) stated that, pH range 6.0 to 8.5 indicates medium productivity, while pH higher than 8.5 is indicative of highly productive environment and less than 6.0 is low productivity of water body. According to Bell (1971) pH range 6.5 to 9.0 provides an adequate protection to the life in freshwater bodies.

The hydrogen ion concentration was measured by using pH probe (HANNA made). For this, water sample was taken in a clean glass beaker and calibrated pH probe was dipped into the sample and observed the readings.

Turbidity

Turbidity was measured using nephalometer (ELICO CL52D).

Electrical Conductivity

Electrical conductivity was measured on a conductivity meter (GLOBAL DCM 900).

Dissolved Oxygen (DO)

The health of an aquatic ecosystem mainly relies on the content of oxygen in it. All vital activities like metabolism in aerobic organisms and respiration is totally dependent on the amount of dissolved oxygen in the water. Optimum concentration of dissolved oxygen helps in maintaining the aesthetic qualities of water and supports a well-balanced aquatic life.

Thermal stratification produces marked difference in the dissolved oxygen levels in a water column. The oxygen content in the hypolimnion is comparatively lower than the surface layers. Tropical water bodies generally have lower levels of oxygen due to high temperatures in this area (Fritsch, 1907). Dissolved oxygen levels below 5.0 mg/l, put the aquatic life under stress (Aobnymous, 1991; Bandela *et al.,* 2005). Decrease in dissolved oxygen further, can be fatal to fish and other organisms present in water (Trivedy and Goel, 1986).

In the present study Wrinkler's method was used for estimation of dissolved oxygen. When Wrinkler's A ($MnSO_4$) and Wrinker's B (KI) is added to the water sample, Oxygen combines with Manganous Sulphate and forms a Manganous hydroxide to form a brown colored compound. After acidification (by using H_2SO_4) the solution liberates iodine ions equivalent to that of oxygen fixed. This iodine was titrated against standard sodium thiosulphate titrant by using starch as an indicator. The results were recorded in mg/L.

$$\text{DO mg/ l} = \frac{(\text{ 0.1 x ml of titrant x 8 x 1000})}{\text{ml of sample}}$$

Total Alkalinity

The alkalinity is defined as the equivalent of calcium carbonate and it expresses the buffering capacity of water. It is used interchangeably with acid neutralizing capacity (ANC), which is the capacity to neutralize strong inorganic acids. Total alkalinity is generally imparted by CO_3^{2-}, $HSiO_3$, $H_2PO_4^-$, HS^- , NH_3^o (Peavy *et al.,* 1985).

Alkalinity protects important fish and aquatic life in neutralizing rapid pH changes (Wright *et al.,* 1990 and Straus, 2003). Chowdhury and Al Mamun, 2006 also reported that the higher alkalinity favors fish production.

Total Alkalinity of samples was estimated by titrating against 0.1N HCl using phenolphthalein indicator and alkalinity due to bicarbonates was determined to second end point using methyl orange as an indicator. The results were recorded in mg/l.

$$\text{PA mg/l} = \frac{(\text{A x Normality}) \text{ of HCL x 1000 x 50}}{\text{ml of sample}}$$

$$\text{TA mg/l} = \frac{(\text{B x Normality}) \text{ of HCL x 1000 x 50}}{\text{ml of sample}}$$

Calcium

Calcium is considered to be an important ion because, it is required as a nutrient for various metabolic processes and assists in proper translocation of carbohydrates (Wetzel, 1975). It is also an integral part of plant tissue, as well as it increases the availability of other ions. The role of calcium has been implicated in the aging of rotifers, a process that affects longevity and morphology of the organism (Edmondson, 1948).

Calcium was determined by EDTA titrimetric method with 0.01M EDTA as titrant and Murexide as an indicator. The results were recorded in mg/l.

$$\text{Calcium, mg/l} = \frac{\text{ml of EDTA x 400.8}}{\text{ml of sample}}$$

Magnesium

Magnesium is essential for chlorophyll bearing plants as it is required during photosynthesis. Hence, it acts as a limiting factor for growth of Phytoplankton (Dagaonkar and Saksena, 1992). Magnesium is relatively conservative and rarely fluctuates in soft water streams and lakes (Likens *et al.*, 1985) and in hard water streams (Wetzel and Otsuki, 1975) due to its high solubility characteristics and minor biotic demand.

Magnesium hardness was determined by subtracting calcium hardness from total hardness. The results were recorded in mg/l.

$$\text{Magnesium Hardness, mg/l} = (\text{Total Hardness} - \text{Ca Hardness}) \text{x } 0.244$$

Phosphates

Phosphate is one of the growth limiting nutrient, as it the backbone of Kreb's cycle and DNA. It is a vital element for growth of freshwater plants and animals. Phosphates come from a range of sources like apatite rocks, run-off from agricultural lands treated with fertilizers; sewage, paper and pulp industry and house hold detergents.

Excess phosphate in water leads to massive growth of algae, which ultimately form algal blooms. The overproduction in a freshwater body can lead to an imbalance in the nutrient and re-cycling of materials (Ricklefs, 1993).This reduces the available sunlight to other plants and sometimes kills them. The bacteria that breaks down the dead algae use up dissolved oxygen in the water, depriving and suffocating other aquatic life.

Phosphates were estimated using the Stannous Chloride Method.

Nitrates

Nitrates are an important component of protein and exist in the environment in different forms. However, excessive concentration of nitrates can be hazardous to health, more specifically to pregnant women and infants.

Untreated sewage and run-off of nitrogenous fertilizers can add to the already existing nitrates in the water body leading to unchecked growth of algae.

Nitrates were estimated following the Brucine method. The absorbance of the treated samples were read at 410 nm. A standard curve was plotted.

SAMPLING DESIGN AND ANALYSES

The present study was conducted for a period of two years from October 2015 to September 2017. For each river, the water samples were collected fortnightly at three sampling sites. Samples were collected in 2-liter capacity, clean and sterilized plastic cans. The plastic cans were washed thoroughly with sampling water before using them. Separate samples were collected for dissolved oxygen in 300 ml amber colored stopper reagent bottle. Care was taken to prevent air bubbles. The oxygen was fixed at the site itself by adding Wrinkler A and Wrinkler B (Welsh and Smith, 1960). The samples were analyzed immediately after returning from the sampling.

The surface water temperature, pH, Turbidity and Electrical conductivity were measured on the site immediately after collecting the samples. Total Alkalinity, Calcium, Magnesium, Phosphates and Nitrates were analyzed in the laboratory using standard methods of Trivedy and Goel (1986) and Anonymous (2005)

Statistical analyses

The monthly data obtained for physico-chemical parameters were subjected to principal component analyses to determine which variables contributed significantly to the variation in water quality. Monthly data of the three points at each location were averaged to obtain a final monthly reading. The test was carried out using XLSTAT (AddinSoft Inc.) software. The interpretation of each PC axis was determined on the basis of the factor loadings of the variables as well as the monthly variations of each score.

RESULTS AND DISCUSSION

Analysis of physico-chemical parameters provides valuable information on the ecological conditions of the water body. Change in seasons, the flow of water, the influx of various materials and biotic interactions changes the water quality parameters. Analysis of these water quality parameters provides insight on the trophic status, productivity and sustainability of the aquatic ecosystem.

During the present investigation ten physico- chemical parameters i.e. water temperature, pH, Turbidity, Electrical conductivity, DO, Total Alkalinity, Calcium, Magnesium, Phosphates and Nitrates were estimated fortnightly for two years i.e. September,2015 to August,2017. Goa, being in the tropical zone and near the Arabian Sea, has a hot and humid climate for most of the year. The month of May is usually the hottest, coupled with high humidity. The state exhibits four seasons: Southwest monsoon period (June–August), post-monsoon period (September–November) winter (December-February) and summer (March–May).

1.Temperature

The temperature is described as “abiotic master factor” as it is one of the most essential physical parameter of water quality assessment. It directly or indirectly influences aquatic life by altering biochemical and metabolic processes as well as other physico-chemical parameters (Annalakshmii and Amsath, 2012). Temperature affects dissolution and saturation of various gases as DO, FCO_2 and other solutes (Tripathi *et al.,* 1991).

The monthly records of temperature at river Sal during September 2015- August 2016 and September 2016-August 2017 are depicted in Table 1.1 and 1.2 respectively. The monthly records for river Chapora during September 2015- August 2016 and September 2016-August 2017 are represented in Table 1.3 and 1.4 respectively. The average monthly variation in temperature during the two years period at river Sal and Chapora are shown in Fig.1.1 and Fig.1.11 respectively. The average seasonal record of temperature for river Sal and river Chapora is given in table 1.5 and 1.6 respectively.

During the first year of study, temperature at river Sal varied from minimum 27.16ºC (January) to maximum 31.33ºC (May) whereas minimum and maximum values during the second year ranged from 27.9ºC (January) to 31.96ºC (May). The average minimum temperature during the two years of study at River Sal was recorded in the month of January (27.53±0.52) and maximum in May (31.65±0.45). While river Chapora recorded the average minimum temperature in the month of January (27.62±0.53) and maximum in May (30.95±0.40). Summer the average temperature was found to be 31.42ºC. While, winter the average temperature recorded was 28.89ºC. Post- monsoon and monsoon recorded an average of 30.77ºC and 28.58ºC respectively.

The temperature of river Chapora in the first year of the investigation was the lowest in August (27.07ºC) and highest in April (31.67ºC); while lowest temperature in the second year was recorded in October as 27.67ºC and highest as 31.23ºC in May. Not much variation was noted in season wise average. Post- monsoon, winter, summer and monsoon recorded an average of 28.97ºC, 28.27ºC 29.92ºC and 29.36ºC respectively.

The present results both the rivers depicted maximum values in summer and minimum in winter season. The most important source of heat for freshwater is generally solar radiation. Maximum water temperature during summer could be due to high solar radiations and clear atmosphere during these months, which leads to rapid heat exchange between air and water (Ahmed, 2004; Kant and Raina, 1990 and Shinde *et. al.,* 2011). Also, longer day length in summers and the angle of incidence of sun rays causes evaporation which leads to decrease in depth of water column, which possibly could be causing rapid heating up of the whole water column. (Hutchinson, 1957; Kaushik and Saksena,1999 ; Sawney, 2008; Shinde *et. al.,* 2011 and Sharma, 2013). Water inputs in lakes, ponds and dams can also affect the temperature of the water.

Decline in temperature during winter may be due to reduced illumination and shorter days (Fassihuddin and Kumari, 1990; Sawhney, 2004; Kaur 2006 and Shinde *et. al.,* 2011).Oblique incident rays reaching the earth during winters also reduces the heating impact.

Water temperature affects chemical and biological processes, dissolved oxygen levels, water density and stratification (RAMP, 2015). Many aquatic species can survive only within a limited temperature range. The growth and death of micro- organisms and the kinetics of the biochemical oxygen demand are also regulated by temperature (Khuhawar and Mastoi, 1995). An increase in temperature leads to faster biochemical reactions. It also inversely affects the dissolved oxygen holding capacity of water.

Similar results were advocated by Zutshi, 1992; Sharma, 2001; Baba, 2002; Abdel-Satar, 2005, Anita *et al.,* 2005; Narayana *et al.,* 2005; Ogbuagu *et al.,* 2011 and Sharma, 2015.

2. pH

The pH of water is a measure of its acidity and alkalinity which can be determined by the production of hydrogen and hydroxyl ions. It serves as an index of pollution of water. The pH of an aquatic ecosystem is closely associated to biological productivity and photosynthetic activity, and hence, fluctuation of water pH can be caused by excessive primary production (Carr and Neary, 2008). pH in water bodies is also affected by removal of free carbon dioxide, bicarbonate degradation, dilution of water by influx of materials, temperature variation, decomposition activities (Karuppasamy and Perumal, 2000 and Rajasegar, 2003) and climate (Kant and

Kachroo, 1971). Water having an alkaline pH is favorable for good plankton growth (Bhatt and Negi, 1985; Mahajan and Kanhere, 1995; Rasool *et al.*, 2003) which makes the water suitable for fresh water fish culture.

The monthly records of pH during September, 2015 – August, 2016 and September, 2016 – August, 2017, at river Sal are depicted in Table 1.1 and Table 1.2 respectively. The records of river Chapora for the two years are presented in Table1.3 and 1.4. The average monthly variation in pH during the period of September 2015- August 2017 in river Sal and Chapora are illustrated in Fig.1.2 and Fig.1.12 respectively. Average seasonal record of pH during September 2015- August 2017 of river Sal and Chapora is given in Table 1.5 and 1.6 respectively.

In the present study, highest pH values for river Sal were recorded in December for both the years while the lowest pH value for the period of September 2015 – August 2016 was recorded in August (6.82) and the period of September 2016- August 2017 was recorded as 6.63 in March (Table 1.2). The average minimum pH during the two year study period at river Sal was recorded in the month of March (6.73±0.14) and maximum in December (8.01±0.09).While river Chapora recorded the average minimum pH in the month of September (6.74±0.48) and maximum in November (7.66±0.22).A look at the average seasonal record of pH of river Sal (Table 1.5) reveals slightly acidic pH during summer (6.87), post-monsoon (6.98) and monsoon (6.99). While slightly alkaline pH (7.59) was recorded during the winter season.

In river Chapora during the first year, the pH values fluctuated between 6.40 in September to 7.63 in January. Whereas in the second year the pH recorded was the lowest in May (6.85) and highest in November (7.82). Average seasonal record during the two years study period (Table) revealed pH was slightly alkaline during, post-monsoon season (7.34) followed by monsoon (7.37) and winter (7.46), while slightly acidic pH was recorded only in the summer (6.97).

Overall lowest pH values were observed in summers in both the rivers. Decrement in pH values during summers may be attributed to high temperature during these months which leads to accelerated rate of decomposition and respiration which results in free carbon dioxide content. Also, increased water temperature leads to decrement in dissolved oxygen content which leads to free carbon dioxide content in the water. Carbonic acid formed due to the mixing of carbon dioxide with water, dissociates to release H^+ ions which lead to decrement of pH. The negative relation between free carbon dioxide and pH has also been observed by Cole (1975), Reid and Wood (1976), Goldman and Horne (1983), Joshi (1996), Hassan *et al.,* (1998), Kaul (2000), Sharma (2002), Sawhney (2008), Sharma (2015).

High pH values were observed during winters at both the rivers, which may be attributed to lower water temperature and high dissolved oxygen content during these months, further leading to lower free carbon dioxide content and thus higher pH values. Also rate of decomposition and respiration is lower in colder months which again decreases the free oxygen content and increases pH values, as also observed by Sharma (2002), Sawhney (2008) and Sharma (2015). In addition a significant change in pH might also occur due to dumping of garbage in drainages.

The pH values observed at river Sal were slightly lower as compared to river Chapora, which may be attributed to high carbon dioxide content due to decay and decomposition of organic waste from housings and fish farms at or near the river banks.

The Federal Environmental Protection Agency (FEPA) recommended pH of 6.5-8.0 for drinking and 6.0-9.0 for aquatic life. Also, Boyd and Lichtkoppler (1979) reported that, pH range of 6.09-8.45 is ideal for supporting aquatic life. Accordingly, it can be concluded that, the pH range obtained in this study is within the acceptable limits of drinking and supporting aquatic life.

3. Electrical Conductivity (EC)

Conductivity is an important parameter used to determine the quality of water as it is an early indicator of change in a water system. It is the measure of water’s capacity to convey electrical flow. This ability depends on the concentration of ions in the water (Anonymous (EPA), 2012). Water containing conductive ions formed from dissolved salts and inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds are capable of conducting current (Miller *et al.*, 1988). The greater the numbers of ions that are present, the higher the conductivity of water. Distilled or deionized water can act as an insulator due to its negligible conductivity value (Perlman, 2014).

Conductivity is usually measured in micro- or millisiemens per centimeter (µS/cm or mS/cm). It can also be reported in micromhos or millimhos/centimeter (µmhos/cm or mmhos/cm).

Normal conductivity levels in streams and rivers come from the surrounding geology (Anonymous (EPA, 2012). Clay soils are known to ionize and contribute to conductivity. Groundwater influxes that are heavily ionized from dissolved minerals will also contribute to the conductivity. Increase or decrease in conductivity in a water body can indicate pollution. Run-off from Agricultural fields, riparian areas, catchment areas, sewage leakage and discharge of concrete waste will increase conductivity due to the additional chloride, phosphate and nitrate ions (Anonymous, EPA, 2012). The conductivity of the water body decreases in case of an oil spill as these elements do not break down into ions (Anonymous LCRA, 2014). In both situations, the added dissolved solids will have a negative impact on water quality.

According to water quality standards, the electrical conductivity of freshwater is usually between 0 and 1,500 µS/cm and sea water is about 50,000 µS/cm. Conductivity in the range of 0 – 800 µS/cm is considered good drinking water for humans (provided there is no organic pollution and not too much suspended clay material) and good for irrigation, though above 300µS/cm some care must be taken when used on salt sensitive plants. This range of conductivity is also considered suitable for all livestock. Water up to 2500 µS/cm can also be consumed by humans. Conductivity in the range 2500 -10,000 µS/cm and above is not recommended for human consumption. Such high conductivity is not normally suitable for irrigation, although water up to 6000 µS/cm can be used occasionally in emergency with care.

The monthly records of EC at river Sal during September 2015 to August 2016 and September 2016 to August 2017 are depicted in Table 1.1 and 1.2 respectively. The monthly records for river Chapora, during September 2015- August 2016 and September 2016 to August 2017 are represented in Table 1.3 and 1.4respectively. The average monthly variation in EC during the two years period at river Sal and Chapora are shown in Fig. 1.3and Fig. 1.13 respectively. The average seasonal record of EC for river Sal and river Chapora is given in Table 1.5 and 1.6 respectively.

EC values during September 2015 - August 2016, in river Sal varied between 601.93 µS/cm in July to 30422.36 µS/cm in March and in September 2016- August 2017 the levels varied between 1223.59 µS/cm in July to 16304.08 µS/cm in February. In river Chapora, during September 2015- August 2016 EC varied between 226.63 µS/cm in July to 1399.85 µS/cm in November and for the period of September 2016 - August 2017 the levels varied between 316.42 µS/cm in November to 3892.64 µS/cm in May. The average maximum EC quantity in river Sal was recorded in March (21273.01±12939.13) and minimum in July (912.76±439.58). While the average maximum EC quantity in river Chapora was recorded in May (2094.88±2542.42) and minimum in July (272.50±64.86). Both the rivers showed minimum average seasonal value in monsoon and maximum average seasonal value in summer.

Sharma *et al.,* (1978), reported that, the high values of conductivity may be due to the entry of waste water effluents, sewage and organic matter from nearby residential areas which brings along with them ionized substances. Water temperature also influences the dissolution of ionic substances, which increases as temperature increases (Shanthi *et al.,* 2006). Hence summer season recorded the highest values of EC. High rate of evaporation and consequently decreased water level also may have led to accumulation of ions (Paka and Rao, 1997).

Increase in water level during the monsoons may have diluted the inorganic materials thereby decreasing the level of EC drastically (Mishra and Saksena, 1989). The dissolved salts may have possibly got flushed out by the high velocity of water in the monsoon. Since temperature also affects dissolution of ionic substances, decrease in temperature also lowers the EC levels. Allogenic inflow of inorganic matter from construction activity (Ayoola and Kuton, 2009) and sewage from catchment areas specially fish farms along the banks also may have been the cause for high values.

In the present investigation, river Sal exhibited a higher level of EC as compared to river Chapora. But, evidently both the rivers crossed the human consumption limits in winter and summer season.

4. Dissolved Oxygen

Dissolved oxygen is the basic requirement for life and metabolism of aerobic aquatic biota that poses aerobic respiratory organs (Wetzel, 1975). It is also an important water quality indicator thereby directly influencing the survival of aquatic organisms as well as indicating the pollution status of a water body. It is a strong indicator of distribution pattern of aquatic biota, their diversity as well as abundance acting as a barometer for testing the ecological health of the river. Moreover it plays an important role in dissolution of organic substances in water (Anonymous, NEERI, 1998) and availability of many nutrients thereby affecting the productivity of aquatic ecosystems (Nduka *et al.,* 2008). DO of natural water is dependent on temperature, surface area exposed to atmosphere, amount of oxygen in the surrounding air, turbulence at the surface and atmospheric pressure (Kumar *et al.*, 2014). It shows diel as well as seasonal variations along with variations across the longitudinal profile of the river. A low oxygen value indicates the biodegradation of organic matter and decay of vegetation (Jameel, 1998).

The monthly records of dissolved oxygen during September 2015 - August 2016 and September 2016 - August 2017 at river Sal are depicted in Table 1.1 and Table 1.2 respectively. The records of river Chapora for the two years are presented in Table 1.3 and 1.4.The average monthly variation in dissolved oxygen during the period of September 2015 - August 2017 in river Sal and Chapora are illustrated in Fig.1.4 and Fig.1.14 respectively. Average seasonal record of dissolved oxygen during September 2015- August 2017 of river Sal and Chapora is given in table 1.5 and 1.6 respectively.

The monthly average value of dissolved oxygen in river Sal varied from 3.75mg/l in November to 5.89 mg/l in February during September 2015 - August 2016, and from 3.85 mg/l in March to 6.25 mg/l in January during September 2016 - August 2017.In river Chapora monthly average DO values ranged from minimum of 5.49 mg/l in December and maximum of 7.59 mg/l in January during the first year, and the second year recorded a minimum of 5.33 mg/l in May and maximum of 6.86 mg/l in August. The average minimum DO during the two year study period at river Sal was recorded in the month of August (4.27±0.15) and maximum in October (5.50±.52).While river Chapora recorded the average minimum DO in the month of March (5.55±0.04) and maximum in January (7.16±0.60).

Perusal through the tables showed the same pattern of DO at both rivers which depicted winter maxima and summer minima.

Summer minima in dissolved oxygen values may be attributed to increased day length and light intensity during this period which after reaching optimal limits begins acting as a limiting factor for photosynthesis. Thus showing an overall decrease in oxygen production by aquatic flora (Sehgal, 1980; Pandey *et al.,* 1991 and Singh, 2004). The increased day length and light intensity raises the water temperature, and as the water temperature increases the solubility of oxygen in water decreases thereby affecting its availability to aquatic organisms. (Ueda *et al.*, 2000; Ahmed, 2004; Dallas, 2008 and Sahni and Yadav, 2012). Less flow of water during summers also enhances rapid heating up of water which could be another cause for decrease in dissolved oxygen levels. High water temperature also increases various respiratory processes and biochemical processes of decomposition by biota (Sahu *et al.,* 2000). Increase in metabolic rate during this period further adds to free carbon dioxide content and consumption of dissolved oxygen (Tripathi *et al.,* 1991). Microbial breakdown of organic matter also increases as water temperature increases which results in comparatively faster consumption of dissolved oxygen (Ueda *et al.*, 2000; Abdel-Satar and Elewa, 2001 and Karoosh *et al.,* 2009).

The level of dissolved oxygen showed an increasing trend from monsoon to post – monsoon before acquiring maximum values in winter. High wind action and strong currents during monsoon may be responsible for aiding in physical aeration of water which led to an increase in dissolved oxygen content (Hutchinson, 1957; Gonjari and Patil, 2008; Tidame and Shinde, 2012 and Singh *et al.,* 2013). Similar pattern was observed by Gupta *et al.*, (1996) and Singh *et al*., (2013). Moderately high Dissolved oxygen values during the post- monsoon period may be attributed to decreasing water temperature which is inversely proportional to dissolve oxygen. A higher level of pH and transparency during this period also causes an increment in photosynthetic activity by aquatic flora resulting in increased dissolved oxygen (Iqbal *et al.*, 2004 and Sachindanandmurthy and Yajurvedi 2006)

Winter maxima in dissolved oxygen values may be ascribed to shorter photoperiods. A negative relation exists between photoperiod and dissolved oxygen as also established by Iqbal *et al.,* (2004). Shorter photoperiods further lead to low water temperature resulting in increased solubility of oxygen in water as well as increased dissolved oxygen retaining capacity (Luker, 2000 and Suthar *et al.*, 2005). The low temperature during this period also decreases the rate of decomposition as well as respiration leading to less utilization of dissolved oxygen by aquatic organisms (Sharma, 2002).

Similar observations of maxima DO in winter and minima in summer has also been observed by Chakraborty *et al.,* (1959), Pehwa and Mehrotra (1966), Tripathi *et al.,* (1991), Bisht (1993), Singh *et al.,* (1998), Abdel-Satar and Elewa (2001), Iqbal *et al.,* (2004), Salve and Hiware (2006), Saksena *et al.,* (2008), Sawhney (2008), Garg *et al.,* (2009), Moustafa *et al.*, (2010), Harney *et al.*, (2013), Sharma (2013) and Sharma (2015).

5. **Turbidity**

Turbidity is an optical property of water which measures water clarity (Anonymous, EPA, 2012). It is based on the amount of suspended sediments and other material present in water which scatters light (Perlman, 2014). The amount of suspended solids in the water column is directly proportional to the amount of light that will be scattered in the water. Material that causes water to be turbid includes silt or clay, inorganic materials, or organic matter such as algae, plankton, other microscopic organisms and decaying material which can come from soil erosion, runoff, discharges, disturbed bottom sediments or algal blooms (Anonymous, EPA, 2012).Turbidity can also be caused due to humic stain, fluorescent dissolved organic matter and other dyes (Anderson, 2005).

An increase in turbidity can affect photosynthetic processes due to obstruction of light. This reduces the productivity of the water bodies (Anonymous (Washington State Department of Ecology, 1991). A hindrance in photosynthesis can affect plant survival which affects the output of dissolved oxygen in return (Anonymous (Chesapeake Bay Program), 2012). The consequent decomposition of the organic material can drop dissolved oxygen levels even lower. This drop in dissolved oxygen affects the survival of underwater plants which are necessary food sources for many aquatic organisms. As they perish off, the amount of vegetation available for other aquatic life to feed on is reduced. This can cause population regressions up the food chain (Mid-America Regional Council).

A number of factors are responsible for increase in turbidity levels, such as water flow, point source pollution, land use and re-suspension. Water flow especially during rainy season causes erosion of stream banks which seems to be one of the most important causes for turbidity. Due to suspended sediment by erosion, the penetration of light is reduced, reducing the ability of aquatic organisms to find food (Murphy, 2007). These suspended particles can also clog fish gills, suffocate fish eggs, smother insect larvae and thus affect growth rates (MDEQ). Pollutants such as bacteria, protozoa, pesticides, mercury, lead and other metals also add to the turbidity of fresh water bodies (Murphy, 2007). Addition of nutrients like nitrates and phosphorus boost the development of harmful algal blooms detrimental and often toxic to aquatic life. Heavy metals which also add to turbidity levels can impact not only aquatic organisms, but drinking water as well (Anonymous USGS, 2013).Hence, Turbidity is an important test when trying to determine the quality of water.

The monthly records of turbidity of river Sal during September 2015 - August 2016 and September 2016 - August 2017 are depicted in Table 1.1 and Table 1.2 respectively. The records of river Chapora for September 2015 - August 2016 and September 2016 - August 2017 are presented in Table 1.3 and 1.4. The average monthly variation in turbidity during the period of September 2015 - August 2017, in river Sal and Chapora are illustrated in Fig.1.5 and Fig1.15 respectively. Average seasonal record of turbidity during September 2015- August 2017 of river Sal and Chapora is given in table1.5 and 1.6respectively.

In the present investigation at river Sal, the turbidity during September 2015- August 2016 ranged between 7.91 NTU in August and 54.12 NTU in September. During September 2016- August 2017, the turbidity of river Sal varied between 2.46 NTU in March and 37.06 NTU in July. In River Chapora the turbidity during September 2015 - August 2016 varied between 5.28 NTU in October to 19.96 NTU in July and during September 2016- August 2017 between 9.69 NTU in February to 24.86 NTU in June. The average minimum turbidity during the two year study period at river Sal was recorded in the month of March (5.65±4.50) and maximum in June (45.12±12.73).While river Chapora recorded the average minimum turbidity in the month of January (9.01±1.98) and maximum in June (22.41±5.58). Average seasonal record of turbidity at river Sal showed minimum values in winter season (8.74 NTU) and maximum in monsoon (29.64 NTU) and river Chapora showed minimum values in winter season (10.47 NTU) and maximum in winter (20.68 NTU).

Seasonal variation in river Sal depicted lowest turbidity in winter, followed by post-monsoon, summer and monsoon, while river Chapora recorded lowest values in winter followed by summer, post-monsoon and highest in monsoon. High turbidity values in monsoon may be attributed to increased water volume and velocity which erodes the banks riparian area and catchment areas (Singh *et al.*, 2010). Low sedimentation rate during this season as well as turbulent flow causes suspension of dissolved particles which acts as additional factors loading turbidity to the river (Kaul, 2000).

Antagonistically, absence of rains and low velocity of water in winter reduces the turbidity of water bodies (Singh 2004). Reduced inflow of turbid run-off from catchment areas in winters reduces suspended matter and turbulence (Sharma, 1999 and Kaul, 2000). Macrobenthic fauna and plankton also flourishes in the winter season which feed on suspended organic matter as a food source (Vagun and Hakenkamp, 2001). This is another cause for decrease in turbidity.

River Chapora showed higher values of turbidity compared to river Sal which probably is due to the construction work of the bridge at river Chapora. River dredging and deepening causes re- suspension of sediments which increases the turbidity.

Turbidity is inversely proportional with transparency (Saksena, 1987). Fall of transparency during the monsoon season was earlier reported by Zutshi (1992); Nath and Srivastava (2001) and Verma and Saksena (2010). While high values of transparency during winters was witnessed by Shinde and Deshmukh (2008) and Sharma (2015).

6. Total Alkalinity

Alkalinity of water is its ability to neutralize a strong acid. It is characterized by presence of hydroxyl ions capable of combining with hydrogen ions (Koshy and Nayar, 2000). Alkalinity in known to neutralize acidity and thus maintains the pH around an ecologically favourable value (Tripathi *et al*., 1991). Lind (1974) stated that alkalinity is the capacity to accept protons to shift the pH to the alkaline side which depends on the quantity and kinds of compounds present in the water. Bicarbonates along with carbonates and hydroxide are the basic anions which contribute to the alkalinity of water (Murthuzasaab *et al.*, 2010). Alkalinity values in fresh water bodies is influenced by surface run off during rains through weathering of rocks and soil containing bicarbonate minerals or by inflow of underground water into the water body (Wetzel, 1975). Decomposition of organic matter also enhances the alkalinity content in the form of bicarbonates (Goel *et al.*, 1984). Jhingran (1982) suggested total alkalinity as a parameter for measuring productivity. According to UN Department of Technical Co-operation for Development (Anonymous, 1985), water having alkalinity up to 50mg/l is considered to be weakly alkaline, up to 100mg/l is considered to be medium alkaline and above 200mg/l is considered as highly alkaline. According to Alikunhi (1957), alkalinity of water greater than 100mg/l is productive, while, W.H.O has prescribed 120mg/l as the alkalinity level, which shows signs of nutrient richness. Eutrophic water bodies have very high values of alkalinity.

The monthly records of total alkalinity during September 2015 - August 2016 and September 2016 - August 2017 at river Sal are depicted in Table 1.1 and Table 1.2 respectively. The records of river Chapora for the two years are presented in Table 1.3 and 1.4. The average monthly variation in total alkalinity during the period of September 2015 - August 2017 in river Sal and Chapora are illustrated in Fig.1.6 and Fig.1.16 respectively. Average seasonal record of total alkalinity during September 2015 - August 2017 of river Sal and Chapora is given in Table 1.5 and 1.6 respectively.

In the present investigation at river Sal, the total alkalinity during the first year varied between 11.5 mg/l in March and 547.9 mg/l in November. During the second year of sampling, the total alkalinity of river Sal varied between 8.89 mg/l in September and 889.12 mg/l in February. In River Chapora the total alkalinity during the first year varied between 10.32 mg/l in

July to 837.99 mg/l in February and second year between 71.33 mg/l in July to 840.32 mg/l in October. The average minimum total alkalinity during the two year study period at river Sal was recorded in the month of May (28.2±2.19) and maximum in February (885.33±116.55). While river Chapora recorded the average minimum total alkalinity in the month of July (40.83±14.14) and maximum in December (465.16±55.95). Average seasonal record of total alkalinity at river Sal showed minimum values in summer season (88.14 mg/l) and maximum in winter (366.43 mg/l) and river Chapora showed minimum values in summer season (84.17 mg/l) and maximum in winter (345.38 mg/l).

River Sal and Chapora exhibited highest total alkalinity values in winter which may be ascribed to reduced photosynthetic activity due to low temperatures which results in reduced consumption of bicarbonates usually used as a source of photosynthetic carbon (Sharma *et al.*, 2009 and Sharma, 2013). Raja *et al.*, (2008) and Sharma (2015) in their studies reported direct relationship with bicarbonates and pH. The present investigation also showed highest pH and alkalinity values in winter. Alkalinity also bears a positive correlation with dissolved oxygen (Ishaq and Khan, 2013) which is also noted in the current study. Reduced water level and velocity (Kousar, 2015) and lower free carbon dioxide content due to uptake by phytoplankton and macrophytes during winter (Ahmed, 2004) may also be responsible for high levels of alkalinity during this season. Dissolution of calcium carbonate or lime rich marlstones is also responsible for addition of carbonates to water (Singh, 1988). Furthermore, pollution from organic origin is also responsible for increase in alkalinity levels (Phillips, 1977). During the peak tourist season, which concurs with the winter, cruises are held along river Chapora on a regular basis which may be a source of sewage and organic pollution. Apart the construction activities also release carbonates and bicarbonates from the sediments. A number of shacks and hotels located along the banks of river Sal receive a lot of foreign tourists during winters. Untreated sewage dumping into the river during this period could be another reason for increase of alkalinity during this time.

The fall in alkalinity during summer season at both river Sal and Chapora may be due to maximum utilization of carbonates and bicarbonates by growing phytoplankton and macrophytes for photosynthesis (Kaul *et al.*, 1980; Chandrakiran, 2011; Harney *et al.*, 2013 and Naik *et al.*, 2015). High free carbon dioxide content due to increased decomposition of organic matter and high respiratory and metabolic rate during summers may be another cause for decrease in alkalinity (Prashar *et al.,* 2006). Low levels of calcium and magnesium is also responsible for decrease in alkalinity which was also noted by Balkhi *et al.,* (1987).

Present findings of winter maxima and summer minima also get strengthened by works of Latha and Ramchandra (2010); Garizi *et al.,* (2011); Manjare (2015); Naik *et al.,* (2015) and Sharma (2015).

7. Calcium

Calcium in the form of Ca^{2+} is one of the major inorganic cations influencing the biotic fauna of freshwater bodies. It is an important micronutrient and plays a crucial role as a structural element and as a cofactor in many biochemical reactions. It affects growth and population of freshwater flora by participating in the photosynthesis process and fauna by entering in their bone structure and also plays a part in their metabolism. Crustaceans and invertebrates with calcified exoskeletons require calcium and form a determining factor in zooplankton community structure (Hessen, 2003).

Calcium concentrations in riverine systems are determined by numerous factors like catchment area, soil class and type, macrophyte cover, weather conditions (precipitation-evaporation), seasonal variation, land relief, type and intensity of water supply (surface runoffs and ground water inflows) etc. (Potasznik and Szymczyk, 2015). Limestone ($CaCO_3$), Dolomite ($CaCO_3$- $MgCO_3$) and Gypsum ($CaSO_4.2H_2O$) are natural minerals containing calcium.

Calcium ions play a significant role in the buffering of pH and also affect carbonate-bicarbonate balance in freshwater systems (Goldman and Horne, 1983). It is also known to contribute to hardness of water (Bura, 2002).

During the present study, extending from September 2015 - August 2017, calcium showed monthly as well as seasonal fluctuations at both the rivers. The monthly records of calcium during September 2015 - August 2016 and September 2016 - August 2017 at river Sal are depicted in Table 1.1 and 1.2 respectively. The monthly records for river Chapora during September 2015 - August 2016 and September 2016 - August 2017 are represented in Table 1.3 and 1.4 respectively. Fig.1.7 and Fig.1.17 illustrates the average monthly variation in calcium during the two years period at river Sal and Chapora respectively. Average seasonal record of calcium during the study period for river Sal is given in Table 1.5 and for river Chapora is given in Table 1.6.

The levels of calcium in river Sal, during the first year, fluctuated between 50.33 mg/l in April to 1338.66mg/l in January and during the second year between 471.32 mg /l December to 1683 mg/l in June. In river Chapora, the lowest calcium level recorded during the first year was 43 mg/l in March and through the second year was 23.36 mg/l in May. While the highest calcium levels during the first and second year were 3052.99 mg/l in January and 2140.42 mg/l in June respectively. The average minimum calcium quantity was found to be 648.17±32.76 mg/l (February) and 222.95±82.25 mg/l (May) in river Sal and Chapora respectively. The average maximum calcium quantity was recorded as 1203.83±77.65 (June) and 2461.50±36.51 (January) in river Sal and Chapora Respectively. The minimum average seasonal value of calcium was recorded in summer in both the rivers, while the maximum average seasonal value in river Sal was recorded in monsoon and at Chapora in winter.

Decrease in calcium levels at both the rivers during summers may be ascribed to uptake of calcium by increasing population of molluscs as summer is the best favourable environment for high rate of reproduction for mollusc species. (Dutta and Malhotra, 1986 and Sharma *et al.*, 2010). High temperatures during summer season decreases water solubility of calcium which could be another reason for reduction in calcium (Otuski and Wetzel, 1974 and Abdel-Satar, 2005). Calcium taken up by rich phytoplankton growth in that period and plants also causes decrease in quantity of calcium in water (Zafar, 1964; Munawar, 1970; Sawhney, 2008 and Ganai and Praveen, 2014).

Elevation in calcium levels in river Sal during the monsoons, may be due to weathering of calcium bearing minerals in sedimentary rocks. Shear- force of fast moving water in the upper reaches of the river is the main cause for weathering of rocks. Contact of the water with acid solutions, typically carbonic acid (H_2CO_3), derived from the dissolution of atmospheric CO_2 in rain also releases calcium ions in the water (Riebeek, 2011). Mixing of domestic waste, industrial waste and hotel sewage in to the river from the village may be another cause for increase in calcium levels (Bano *et al.,* 2016).Surface run–off from agricultural fields, along or near the banks and run-off from catchment areas is also responsible for high calcium values (Bhandarkar and Bhandarkar, 2013). Yet another possibility is the decay of dead molluscan shells during this period. Above all, a comparatively low temperature during the monsoons increases solubility of calcium ions in water (Sunder, 1988; Sawhney, 2004 and Abdel-Satar, 2005).

The present investigation showed very high values of calcium throughout the year. A careful observation at the different sites selected for the study of river Sal revealed that site Cuncolim and the site near Orlim Bridge showed high values of calcium. Cuncolim being a tourist locality has on its banks a lot of shacks and hotels which probably drain their waste in to the river, thereby polluting it. A couple of prawn and fish farms have been constructed along the banks of the river near the Orlim Bridge. These farms receive the water and drain their waste in to the river Sal. Maintenance activities such as dredging and pond liming probably adds to the large amount of calcium in the river. Besides fish feed more particularly prawn feeds are rich in calcium. Unused feeds were seen being drained into the river. Besides, faecal matter also contains calcium which is yet another possibility in contributing to the high levels of calcium.

The maximum content of calcium in river Chapora was recorded during the winter was mainly due to high values of calcium in two stations of study. These stations were in close vicinity to the bridge construction work site. Various construction materials, such as cement, brick lime and concrete contain calcium in them which could have been the reason for very high values of calcium. Furthermore, disturbance to the sediments by removal by dredging and river bed deepening activities associated with the construction may have resulted in mixing of calcium from sediments in water column. Calcium is also present in fertilizers as it is known to affect the soil positively. A lot of agricultural fields are present along the banks of river Chapora which release their effluents in the river. Apart, low temperature during the winters enhances the solubility of calcium further (Sawhney, 2004; Mahdi *et al.,* 2006; Sawhney, 2008; Garg *et al.*, 2009; Chowdhary, 2011 and Gupta, 2017)

The acceptable limit of calcium for domestic use is up to 75 mg/l in ground water whereas in case of non- availability up to 200 mg/l could be accepted (Gupta *et al.,* 2009). According to Spence (1971), freshwater bodies can be classified as poor if the calcium level is up to 15 mg/l, moderately nutrient rich is calcium is between 15 mg/l to 60 mg/l and nutrient rich if it's above 60 mg/l. Sahai and Sinha (1969) have affirmed that high calcium content is an indication of eutrophic water. During the present investigation both rivers showed very high levels of calcium, much beyond acceptable limits. Thus, both rivers can be categorized as Eutrophic water bodies and are unfit for human consumption.

Umerfaruq and Solanki (2015) have also reported maximum values of calcium in monsoon and lowest in summer. While Sharma (2013), Brraich and Saini (2015) and Sharma (2015) showed a trend of high calcium during winter and low calcium during monsoon. Goa pollution board in its National Water Monitoring Programme also reported similar high values at both river Sal and Chapora.

8. Magnesium

Magnesium is an equally important ion, present along with calcium in natural waters albeit in lower concentration than calcium (Venkatasubramani and Meenambal, 2007). It is more soluble than calcium. Natural minerals like calcium Magnesium Carbonate (Ca Mg $(CO_3)_2$) and Magnesium Carbonate ($MgCO_3$) contain magnesium. Just like calcium, magnesium concentrations are determined mainly by weather conditions (seasonal variations), the type of drainage system, soil type and mineral fertilizers used (Potasznik and Szymczyk, 2015). Major anthropogenic sources of both these ions are fertilizers and liming (Reimann and Caritat, 1998). It forms the core component of photosynthetic machinery as it is the central metal atom in porphyrin head of chlorophyll molecule producers and is also a cofactor in key biochemical reactions (Dagaonkar and Saksena, 1992). Therefore it acts as a limiting factor for growth of phytoplankton and primary producers (Welch, 1960). In the form of magnesium pectate, it is also known to strengthen the lamella of plant cell wall. Magnesium is also a vital micronutrient for animals. However its tolerance by human body is lower than calcium. In higher concentrations magnesium acts as a laxative and gives an unpleasant taste to water.

Hardness of water depends on the amount of both calcium and magnesium salts dissolved in water (Samrat *et al.*, 2012). Both these ions together play an important role in antagonizing the toxic effects of various ions by neutralizing excess acid produced (Munawar, 1970).

The monthly records of magnesium during September 2015 - August 2016 and September 2016 - August 2017 at river Sal are depicted in Table 1.1 and 1.2 respectively. The monthly records for river Chapora during September 2015- August 2016 and September 2016 - August 2017 are represented in Table 1.3 and 1.4 respectively. The average monthly variation in magnesium during the two years period at river Sal and Chapora are shown in Fig. 1.8 and Fig. 1.18 respectively. The average seasonal record of magnesium for river Sal and river Chapora is given in table 1.5 and 1.6 respectively.

During September 2015 - August 2016, magnesium in river Sal varied between 20.06 mg/l in March to 935.63 mg/l in January and in September 2016- August 2017 the levels varied between 20.90 mg/l in May to 939.60 mg/l in December. In river Chapora, magnesium varied between 45.82 mg/l in April to 1103.20 mg/l in January during September 2015- August 2016 and for the period of September 2016- August 2017 the levels varied between 61.99 mg/l in January to 1580.66 mg/l in December. The average maximum magnesium quantity in river Sal was recorded in January (1054.15±167.61) and minimum in May (198.29±21.30). While the average maximum magnesium quantity in river Chapora was recorded in December (1265.67±45.48) and minimum in April (239.01±73.21). Both the rivers showed minimum average seasonal values in summer, while maximum average seasonal values were recorded in winter.

Lower levels of Mg during summers may be ascribed to reduction of solubility due to higher temperatures since magnesium shares an inverse relation with temperature. Retention of magnesium by phytoplankton and macrophytes for chlorophyll molecules (Bhatnagar and Garg, 1998; Pandit and Solanki 2004; Sawhney, 2008 and Gupta, 2017) and biochemical utilization of magnesium by all organisms could lead to decrease of magnesium in summer (Pathak and Bhat, 1993 and Wetzel, 2001). Also accumulation of magnesium in bottom deposits decreases the amount of it in suspended form.

A higher level of magnesium during winter months at both the rivers is due to the increased solubility of magnesium in water at lower temperatures (Otsuki and Wetzel, 1974; Sawhney, 2008; Chowdhary, 2011 and Sharma 2015). Decline in depth of water column also increases the concentration of magnesium (Baba, 2002).

Present findings are supported by the works of many other researchers such as Venkateswarlu *et al.,* (2002); Chavan *et al.,* (2004); Abdel-Satar, (2005); Murthuzasab *et al.*, (2010); Chowdhary, (2011); Brraich and Saini (2015) and Sharma (2015).

The high average values of magnesium are mainly due to two stations at both rivers, Sal and Chapora. As stated earlier Cuncolim and surrounding areas houses a lot of tourists all year round. Discharge of huge domestic sewage enriched with Mg^{+} ions from the shacks leads to high increase of these ions. Abdel-Satar (2005) also reported high magnesium in river Nile due to discharge of domestic waste in to. Orlim has a lot of farms along the banks. Fertilizers used in these farms get leached into the river body directly increasing the levels of calcium. Hay and Anthony (1958) also stated increase in magnesium could be due to discharge and accumulation and subsequent release of salts during microbial decomposition of dead organic matter.

Disturbances to the river bed by dredging or deepening activities and other activities associated with the construction of the Chapora Bridge probably resulted in mixing of magnesium from sediments into the water thereby leading to higher values of magnesium compared to river Sal. International Hydrological Programme (IHP), (Anonymous, 1997) also reported similar findings.

9. Phosphate

Phosphate is one of the important anion of aquatic ecosystems biologically found in the form of orthophosphate. Organically bound phosphate is also present. Phosphate has a very significant role in primary production, growth of plants and phytoplankton inhabiting freshwater bodies. It is an important nutrient among all other essential plant nutrients and hence plays a role of a limiting factor (Agarwal and Rajwar, 2010).

Naturally phosphates enter freshwater bodies through atmospheric precipitation, weathering and leaching of phosphate rocks, decay and decomposition of detritus. Soil erosion from riparian areas is also a major contributor of phosphates to river bodies. The chief anthropogenic source of phosphates in riverine systems is agricultural run-off. Water bodies do require phosphate, but in limited quantity. Overabundance causes excessive algal growth and their subsequent die-off and decomposition reduces the levels of dissolved oxygen which affects aquatic life. It is estimated that 50- 70% of nutrients reaching surface water is from agricultural land surface run-off. Apart effluent discharge from factories, industries, domestic sewage, animal feeds, sanitary landfills and garbage dumps further increases the level of phosphates in the water body. Accelerated rate of nutrient enrichment caused by humans in rivers is called "cultural eutrophication" and is an indicator of pollution. Thus, phosphate levels can be used as an indicator of nutrient enrichment of water bodies.

Table 1.1 and 1.2 depicts the monthly variation of phosphate during September 2015 - August 2016 and September 2016 - August 2017 at river Sal. The monthly records of phosphate for river Chapora during September 2015 - August 2016 and September 2016 - August 2017 are represented in Table 1.3 and 1.4 respectively. The two years average monthly records of phosphate during at river Sal and Chapora are shown in Fig.1.9 and Fig. 1.19 respectively. The average seasonal data of phosphate for river Sal and river Chapora is given in Table 1.5 and 1.6 respectively.

For the period of September 2015 - August 2016, phosphate in river Sal varied between 0.02 mg/l in February to 0.59 mg/l in August and during September 2016- August 2017 the levels varied between 0.04 mg/l in January as well as May to 0.40 mg/l in April. In river

Chapora, phosphate varied between 0.01 mg/l in February as well as May to 0.09 mg/l in October during September 2015 - August 2016 and for the period of September 2016 - August 2017 the levels varied between 0.009 mg/l in June to 0.08 mg/l in July. The average minimum phosphate record in river Sal was recorded in January (0.04±0.01) and maximum in April (0.37±0.04). While the average minimum phosphate quantity in river Chapora was recorded in December and June as 0.01±0.01 and maximum in March (0.08±0.06). Both river Sal and Chapora recorded minimum average seasonal values in winter, while maximum average seasonal values were recorded in summer

In summers, high temperature accelerates the rate of mineralization of organic matter which ultimately increases levels of phosphate in water bodies (Chourasia and Adoni, 1985; Ahwange *et al.*, 2012; Ganai and Praveen, 2013 and Harney *et al.*, 2013). Relatively low water level due to high rate of evaporation during this period maximizes the concentration of phosphates (Chourasia and Adoni, 1985; Swaranlatha and Rao, 1998 and Garg *et al.*, 2009). Ahwange *et al.*, (2012) highlighted that, low water velocity and circulation and thus higher residence periods during summer may also be the cause of high levels of phosphate in a fresh water body. Summer peak may also be due to autochthonous effluent discharge from factories, industries, domestic sewage, animal feeds (Swaranlatha and Rao, 1998 and Sharma, 2015) and influx of allochthonous agricultural and domiciliary surface run-off (Kaul, 2000 and Mishra *et al.*, 2008). In addition, phosphates have a negative correlation with dissolved oxygen (Bordoloi and Baruah, 2014 and Gupta, 2017) which was also seen in the present study.

Lowest values of phosphate in winter might be due to slow rate of decomposition and higher levels of water, thus diluting it (Sharma, 2015). Assimilation by phytoplankton and rapid utilization of aquatic plants also decreases the level of available phosphate in the water body (Bhandarkar and Bhandarkar, 2013).

The observations of Shrishail and Mathad (2008); Chavan *et al.*, (2012); Bhandarkar and Bhandarkar (2013); Mishra *et al.*, (2013) and Gourkar *et al.*, (2015) also support the current results.

10. Nitrate

The Nitrate (NO_3^-) is a highly oxidized form of nitrogen. It is an essential nutrient for aquatic as well as terrestrial plants and animals. Nitrate is the end product of aerobic decomposition of nitrogenous waste by nitrifying bacteria. Nitrate in the form of inorganic nitrogen is utilized by phytoplankton for growth and is essential in the production of chlorophyll. Usually, nitrates in natural waters are deficient or present in very low quantities due to low solubility (Chavan *et al.*, 2012). The principal source of nitrates in a water body is leaching of fertilizers and decomposition of organic excretory matter from aquatic organisms (Toetz, 1976). Apart, the collective function of precipitation, sedimentation, nitrogenous effluents influx, nitrogen fixation and nitrification–denitrification balance adds to the nitrate levels in the water. It is considered as one of the important factors for water quality assessment (Johnes and Burt, 1993).

The monthly records of nitrate during the first year and second year are September at river Sal is given in Table 1.1 and 1.2 respectively. The monthly records for river Chapora during September 2015 - August 2016 and September 2016 - August 2017 are presented in Table 1.3 and 1.4 respectively. The two years average monthly variation in nitrate at river Sal and Chapora are illustrated in Fig.1.10 and Fig. 1.20 respectively. The average seasonal record of nitrate for river Sal and river Chapora is given in Table 1.5 and 1.6 respectively.

For the period of September 2015 - August 2016, nitrate in river Sal varied between 0.02 mg/l in January to 5.13 mg/l in May and during September 2016 - August 2017 the levels varied between 0.11 mg/l in August to 4.91 mg/l in March. During September 2015 - August 2016, nitrate levels in river Chapora, varied between 0.02 mg/l in February as well as August to 0.45 mg/l in June and for the period of September 2016- August 2017 the levels varied between 0.06 mg/l in February and August to 0.27 mg/l in August. The average minimum nitrate record in river Sal was recorded in January (0.12±0.14) and maximum in March (2.54±3.35). While the average minimum nitrates quantity in river Chapora was recorded as 0.04 mg/l in February, March and August and maximum in April (0.36±0.12). Both river Sal and Chapora recorded minimum average seasonal values in winter (0.31±0.26 in Sal and 0.06±0.02 in Chapora), while maximum average seasonal values were recorded in summer (1.84±1.46 in Sal and 0.17±0.16 in Chapora).

The rate of aerobic decomposition of excretory products of aquatic organisms and detritus from phytoplankton is higher in summer due to the increased bacterial activity during this season. This process of decomposition increases the nitrates content in water (Majumder *et al.,* 2006 and Mustapha *et al.*, 2013). Oxidation of ammonia in organic nitrogenous matter to nitrates by nitrifying bacteria is another cause for higher values of nitrate (Swami *et al.,* 1996 and Govindaswamy *et al.*, 2000). Adeyemo *et al.*, (2008) and Ahwange *et al.*, (2012) pointed out that increased evaporation during dry season leads to nitrate build up. The concentration of nitrates also increases further due to low depth of water (Garg *et al.*, 2009).

A similar summer maxima was also reported in the works of Tamot and Sharma (2006); Banerjee and Gupta (2010); Murthuzasab *et al.*, (2010); Sahni and Yadav (2012); Bhandarkar and Bhandarkar (2013); Khatoon *et al.*, (2013); Singh *et al.,* (2013); Upadhyay and Gupta (2013); Sakhare and Kamble (2014); Barman *et al.,* (2015) and Sharma (2015).

The winter minima in the values of nitrates during the study period may be due to the slow rate of decomposition at low temperature (Tamot and Sharma 2006). The observations of Sahni and Yadav (2012); Harney *et al.*, (2013); Upadhyay and Gupta (2013); Sakhare and Kamble (2014) and Barman *et al.*, (2013) were also in conformity to the present findings.

River Sal showed higher levels of nitrate compared to river Chapora. Influx of nitrogenous fertilizers from agricultural fields, fish farm feeds and animal excreta from the banks of the river may be the source of nitrates (Royer *et al.*, 2004 and Singh *et al.*, 2010).

CHAPTER-II

Zooplankton diversity and population density

The word `Plankton' was first used by Victor Hensen, to describe aquatic communities of small floating or weakly swimming organisms, that drift with water currents, rather than their own swimming ability. A few of them are capable of slow movement, but cannot progress against the predominant current or flow of the water. The name plankton comes from the Greek word '*planktos*' meaning wanderers.

Plankton can be divided based on various functional categories. One such classification divides plankton into meroplankton and holoplankton. The temporary plankton, or meroplankton, such as benthic worms, molluscs, crustaceans, echinoderms, corals, and even insects, as well as the eggs and larvae of many fishes which spend part of their life cycle as plankton, until they leave to become adults, in their proper habitats. Permanent plankton or holoplankton such as some members of protozoan community, diatoms, radiolarians, some groups of dinoflagellates, chaetognaths, pteropods and copepods which spend their entire lives as plankton. Size is another basis of catergorizing plankton. A commonly accepted size cataloging structure includes: picoplankton (<2 micrometers), nanoplankton (2–20 µm), microplankton (20–200 µm), mesoplankton (0.2–20 mm), macroplankton (20–200 mm), and megaplankton (>200 mm). Depending on the nature of their origin there are two types of plankton; phytoplankton and zooplankton. Phytoplanktons are plant plankton and zooplanktons are animal planktons.

In aquatic food webs, zooplankton plays an essential role in linking trophic levels, as they consume the primary producers (phytoplankton), which are in turn ingested by fishes. Thus, they act as a major form of food source for tertiary producers. In fish farms, zooplankton is also considered as the chief natural fish feed for young and some adult fishes (El Serafy *et al.*, 2009). Zooplankton constitutes a versatile component of secondary production in aquatic ecosystems. They play a key role in energy transfer from primary to higher levels in the ecosystems. The most significant feature of zooplankton is its enormous diversity, over space and time (Sehgal *et al.,* 2013). Distribution of these depends on multifarious factors, such as change of climatic conditions, physical and chemical parameters and vegetation cover (Rocha *et al.,* 1999 and Neves *et al.,* 2003)

Zooplankton are of great significance as pollution bio-indicators, due to their dramatic changes in response to the changes in the physico chemical parameters of the aquatic environment (Gannon and Stemberger, 1978; Gajbhiye and Desai, 1981; Telkhade *et.al.,* 2008 and Davies *et al*., 2009). Furthermore, several species of zooplankton have a special competence to detect and monitor pollution in the early stages. They also play a significant role in water purification. Research on these organisms is gaining lot of importance the recent years also due to their role in regulating algal microbial productivity (Dejan *et al.,* 2004) and being the reproductive base for all ecosystems (Mahboob and Sheri, 1993 and Mahboob and Zahid, 2002). Hence, zooplankton abundance, evenness, seasonal variation, richness and diversity are essential for the assessment of water pollution and for pisciculture management practices (Koli and Muley, 2012). Their assessment also helps in assessing the trophic status of the water body.

Freshwater zooplankton comprises of a wide array of taxonomic groups which principally includes Rotifera, Cladocera, Crustacea Copepoda and Protozoa. Their dominance and seasonality are highly variable depending on the nutrient status, weather, morphometric, location and other factors. they plays an important role in open water fisheries production, since their abundance largely enhance the fisheries production, through improving the decomposition and mineralization process of organic matters accumulated in the river systems, inhibiting the growth of different microalgae and pests, and stabilizing certain water quality parameters (Das and Bhuyan, 1974). Therefore, changes in aquatic environment accompanying anthropogenic pollution are a cause of growing concern and require monitoring of surface water and zooplankton inhabiting them (Jose and Sanalkumar, 2012). Thus, to maintain a healthy aquatic ecosystem, qualitative and quantitative study of zooplanktons is of great importance.

ROTIFERA

Rotifers also called as ‘wheel animalcule’ because of the presence of a ciliated structure, called corona, on the head region is cosmopolitan in nature. They are present in freshwater bodies, throughout the world, with a few saltwater species. With over 2000 species identified, rotifers are short-lived, free-swimming, aerobic and bisexual animals. Rotifers are primarily omnivorous, but some species have been known to be cannibalistic. The diet of rotifers most commonly consists of dead or decomposing organic materials and hence contributes to the decomposition of organic matter in soil (Howey, 1999). They also feed on unicellular algae and other phytoplankton that are primary producers in the aquatic system. Rotifers are also a major source of food to carnivorous secondary consumers, including shrimp and crabs. Rotifers are divided into two classes, viz. Monogononta and Digononta. Monogononta is the largest group with around 1500 different species. Digononta is a special note because of the absence of males in this class (George *et al.,* 2011). The female members of this class are able to produce daughters from unfertilized eggs. This class is also known for their remarkable ability to survive in extremely dry conditions a process known as cryptobiosis (George *et al.*, 2011).

Morphology

Most rotifers are around 0.4 to 2.5mm in size. They have a transparent body and are bilaterally symmetrical displaying a variety of forms with an amazing alacrity in movement and behavior. The body is divided into head, trunk and food and is lined with a thin cuticle secreted by syncytial hypodermis called 'lorica'. The head of a rotifer consists of a characteristic retractile ciliary crown or disc called 'corona' or 'trochal disc' which is used for locomotion and sweeping of food particles towards the mouth. Corona has anterior lines of cilia called 'trochus' and posterior lines of cilia called 'cingulam'. The structure of corona and the arrangement of cilia get modified according to the mode of feeding and locomotion. Modifications to the basic body plan of the corona include variation of the cilia into bristles or large tufts, and either extension or loss of the ciliated band around the head. The trunk of the organism is transparent and encloses the visceral mass. The foot in several rotifers has foot glands which serve for cementing to a base (Dhanapathi, 2000). Since rotifers have short reproductive stages, they increase in abundance rapidly, under favorable environmental conditions.

Importance of Rotifers

Rotifers serve as living capsules of nutrition, hence play a vital role in aquatic systems (Suresh Kumar *et al.*, 1999). They are responsible for increase in transfer of energy from primary to higher levels in the ecosystems as many species of invertebrates predate heavily on them (Williamson, 1983).Copepods are the most widespread and abundant predators of rotifers (Brandl and Fernando,1979 and Williamson, 1983). Rotifers were among the first zooplanktons to be studied (Plate, 1886). A lot of research is still undertaken on rotifers, as they play a significant role in biological production and serve as good bio-indicators of pollution (Arak and Mokashe, 2014).

COPEPODA

Order Copepoda belonging to phylum Arthropoda and class Crustacea, includes free living and parasitic forms. Copepods are probably the most common and abundant holoplanktonic organisms worldwide, occurring in all oceans, seas, estuaries, rivers and lakes. Out of the 11,432 species of copepods known as of date, around 2,800 of them are freshwater species.

According to Johannes and Künnemann (1997) copepods form the largest animal biomass on earth. Because of their smaller size, relatively faster growth rates, and even distribution throughout the world's oceans, copepods are usually the dominant members of the zooplankton community. They contribute enormously to the secondary productivity of the world's oceans, and to the global ocean carbon sink. Copepods are the chief food organisms for small fish and other crustaceans. They mostly feed on unicellular plants and animals using a sophisticated 'fling and clap' technique. They also feast on small metazoans especially other crustaceans and organic debris. Copepods also show cannibalism under stressful circumstances (Pennak, 1953).

Morphology

The size of copepod ranges from 0.1 to 13 mm. Although considerable variation exists in their shape, most free living copepods have a teardrop-shaped body and two pairs of antennae. The first antennae are one of the notable appendages and have a role in reproduction, locomotion and feeding. The two orders of free living copepods- Calanoids and Cyclopoids can be distinguished by the first antenna, with calanoids possessing longer antennae. The second pair on antennae are comparatively shorter and may either be biramous or uniramous. Copepods usually have 9 trunk segments. From these, one or two thoracic segments fuse with head whiles the next three to five thoracic segments, bear the appendages. The first pair of thoracic appendages is modified to form maxillipede, which helps during feeding. The posterior segments taper, ending in a pair of caudal rami at the base of the abdomen. Most copepods have a single median naupliar eye in the middle of their head. Parasitic copepods undergo modifications depending on their habitat. Adult copepods exhibits well marked sexual dimorphism. They can be distinguished by their size, males being slightly smaller than females. Their first pair of antennae also gets modified to aid in grasping the female during mating. The 5th segment also gets greatly modified for transfer of sperm packets (spermatophores) during mating. Copepods only reproduce sexually.

Importance of Copepods

Copepods have a special ability to encapsulate nutrients and transfer them to higher trophic levels in the food chain. This specialty is a major advantage for their use as feed in aquaculture. Their high protein content increases their nutritive value further (Altaff and Chandran, 1989 and Rajendran *et al.*, 1993). They also contain essential amino acids (Kraul *et al.*, 1993) which enhances their value as live feed in aquaculture. They are known to improve survival, growth and development of fish larvae. Copepods are also use in industries and medicines as a source of chitin (Jeuniaux and Thome, 1990), vitamin A (Fisher *et al.,* 1964) and sex steroid hormones (Hara and Williams, 1979).

CLADOCERA

Cladocerans are commonly called water fleas, also belonging to phylum Arthopoda and class Crustacea. They are generally transparent, with very little pigmentation. Over 650 species have been identified so far. They are ubiquitous in freshwater bodies. Cladocerans move with short, jerky hopping movements in water. They are usually quite selective in their feeding preferring certain species of phytoplankton but occasionally also grazes on organic detritus, bacteria and microzooplankton including protozoans. Certain Cladocerans such as daphnia are used as live fish feed in fish farms and aquariums. Cladocerans mostly live in almost clean or slightly polluted water bodies and hence are considered good indicators of water pollution. Environmental stress is known to induce females to produce male offspring, thus leading to bisexual reproduction. In some cases, cladocerans exhibit paedomorphosis where in the developing embryos in the mother's brood pouch become sexually mature and can themselves carry eggs.

Morphology

Majority of the cladocerans, except for two species, range in size from 0.2 -3.0 mm. (Pennak, 1953). Their head is usually in a down-turned position and bears a single median compound eye. The thorax and abdomen is covered with a carapace which is folded along the back, giving a bivalve appearance and terminates posteriorly with an apical spine. The first antenna is uniramous and short bearing olfactory setae while the second antenna is biramous and used for swimming. The thorax bears five or six pairs of lobed appendages, each with numerous setae. Most species reproduce asexually with cyclical sexual reproduction, which produces resting eggs that allow them to survive and disperse to distant habitats in harsh conditions (Decaestecker *et al.,* 2009).

Importance of Cladocera

The group cladocera is a crucial group among zooplankton and occupies a prime place in pisciculture activity because of two reasons viz., i) they are the most useful and nutritive group of crustaceans for fishes in the food web (Sontakke and Mokashe, 2014) ii). They attain a maximum population within a short time. Their response to environmental stress and fluctuating environments makes them even more interesting models for research. Among cladocerans, the genus *Daphnia* receives special attention from researchers due to its toxicological reactions to environmental pollutants (Sarma *et al.,* 2005). Attempts are also on to study prospects of Daphnia on human health. Till date this research is still in infancy, but there are good approaches that could be satisfactory to find this relationship.

OSTRACODA

Ostracods are small bivalve crustaceans, typically around 1mm in size, found in both fresh and marine water. Ostracoda comes from the Greek word óstrakon meaning shell or tile and are more commonly called as ‘seed shrimps’. Ostracods belong to phylum Arthopoda and class Crustacea. Most of the ostracods are benthic. About 1700 species of freshwater ostracods mainly belonging to order Podocopa (Altaff, 2004) have been identified living in freshwater bodies like pools, ponds, swamps, streams and polluted areas. Food of ostracods mostly consists of bacteria, algae and detritus but some larger ostracods have been observed feeding on living and dead animals (Pennak, 1953). Ostracods are preyed upon by clams, amphibians and newts (Hogan 2008). Few ostracods, such as *Vargula hilgendorfii* have a light organ in which they produce luminescent chemicals, used for predation defense and occasionally to find mates (Shimomura 2006).

Morphology

Ostracods range in length from 0.35mm to about 7mm (Edmondson, 1959). Their bodies are laterally compressed and protected by a bivalve-like, chitinous or calcareous carapace or valve or shell. The hinge of the two valves is in the dorsal region of the body. The body of ostracods is divided into head and thorax, the abdomen is regressed or absent. There are seven pairs of modified biramous appendages. The first four are cephalic; first antennae, second antennules, third and fourth mandibles and maxillae respectively. The thorax bears 3 pair of appendages which may be reduced or completely absent in many species. Two projections called furcal rami are attached to the posterior end of the shell. A single or double eye is prominent through the carapace.

Importance of Ostracods

Martens *et al.,* (2008) suggested the possible use of ostracods, as bio-indicator species of climate and ecosystem changes. Since ostracods are found in heavily polluted area (Edmondson, 1959), quantitative studies on seasonality, life history and distribution of freshwater ostracods will be of great importance (Geiger, 1990a and 1990b). If the relationship between disturbance and habitat requirements of ostracods is well studied, characterization of water quality can be completed in a short period of time. Thus, to use this group as a useful tool in multiple disciplines, detailed studies on the ecology and environmental requirements of ostracods is necessary.

MATERIALS AND METHODS

Monthly zooplankton samples were obtained from the three sampling sites of both the rivers Sal and Chapora from September 2015-August 2017. For zooplankton samples, 50L of water was filtered, using plankton net (30cm in mouth opening diameter, 1-m long, 55μ in mesh size). The zooplankton samples obtained were immediately preserved in 4% formalin in 250 ml polyethylene bottles. The samples were then transported to the laboratory, for further processing and identification of the species. The quantitative analyses of planktonic organisms were carried out using Sedgwick Rafter's plankton counting cell (Adoni *et al.,* 1985). Observations were carried out by using Olympus Stereoscopic Dissection Microscope and later, taxonomic identification was done by using keys from standard literature such as Edmondson (1959), Needham and Needham (1962), Pennak (1978), Battish (1992), Bhouyain and Asmat (1992), Sharma (1998) and Dhanapathi (2000).

RESULTS AND DISCUSSION

Every water body is a network of various physical, chemical and biological parameters forming an ecosystem. Zooplankton are the most basic component of the biological parameter, on which the entire food web is based. They are good indicators of water quality changes as they are strappingly affected by environmental conditions and respond rapidly to changes in water quality. The interaction of zooplankton communities and water quality parameters directly or indirectly is subjected to complex influences. Variations in limnological features results in quantitative changes like increase or decrease in size of zooplankton population (Welch, 1952) and affects abundance and diversity of zooplankton (Jeppesen *et al.,* 2002). In a community, each species behaves differently to the varying environmental conditions (Soininem, 2007 and Shah *et al.,* 2013). Abiotic (Charles *et al.,* 2006) as well as biotic factors (Coleman, 2002) are equally responsible to cause diverse communities. Diversity indices are important tools to characterize richness and evenness of the species in the community (Magurran, 1988). It provides useful information regarding the health of the ecosystem (Norris and Georges, 1993;

Schmitz and Nadel, 1995 and Guerold, 2000). Purvis and Hector (2000) are of the opinion that, one index is not sufficient for a vindicated estimation; hence, to overcome this limitation in the current investigation, various diversity indices were carried out.

The zooplankton community of river Sal and Chapora showed seasonal and spatial variations in distribution and abundance during the present investigation period i.e. September 2015-August 2017. The zooplankton species observed during the two years at river Sal and Chapora are depicted in Table 2.1 and Table 2.2 respectively. Monthly records of zooplankton population density group wise (org/l) during September 2015- August 2016 and September 2016- August 2017 of river Sal are presented in Table 2.3 and 2.4 respectively and of river Chapora are presented in table 2.5 and 2.6. Average seasonal abundance of the zooplankton for the two years of study in river Sal is given in Fig. 2.1 and of river Chapora in table 2.2. Average seasonal population density (zooplankton group wise) of river Sal during September 2015-August 2017 is given in Fig 2.3. Figure 2.7 to 2.11 illustrates percentage average seasonal population density of zooplankton groups. Average seasonal population density (zooplankton group wise) of river Chapora during September 2015- August 2017 is given in Fig 2.4. Figure 2.12 to 2.16 illustrates average seasonal population density percentage of zooplankton groups. Average seasonal diversity indices for the various zooplankton groups for river Sal and Chapora are given in table 2.7 and 2.8 respectively.

The zooplankton groups studied from river Sal and Chapora was represented by rotifera, cladocera, copepoda, protozoa and ostracoda. River Sal recorded a total of 33 species during the present study period from September 2015 to August 2017. Group rotifera in river Sal was represented by 10 species, copepoda 9 species, cladocera 12 species, protozoa 2 species and Ostracoda 2 species. Rotifera contributed to 64.67% of the total zooplankton composition at river Sal followed by 15.66% copepoda, 10.32% cladocera, 7.44% protozoa and 1.90% ostracoda(Fig 2.3). Total 38 species were recorded at river Chapora during the current study period from September 2015 to August 2017. Out of these, rotifera comprised 13 species, copepoda 10 species, cladocera 11 species, protozoa 2 species and ostracoda 2 species. Rotifera contributed to 60.54% of the total zooplankton composition at river Chapora followed by 18.30% copepoda, 11.66% cladocera, 7.47% protozoa and 2.03% ostracoda (Fig. 2.4).

ROTIFERA

Rotifera are generally present in large numbers in tropical areas. They are found colonizing in a wide variety of habitats; ranging from large river, lakes and reservoirs (Sendacz *et al.*, 2006; Almeida *et al*., 2009 and Borges and Pedrozo, 2009) to flooded areas (Martinez *et al.*, 2000). In the present investigation, group rotifera dominated the zooplankton community at river Sal as well as Chapora during both the years of study. During the first year of study, at river Sal, rotifers contributed 64.08% of zooplankton population and 65.37% during the second year. While, in river Chapora, rotifers comprised of 54.96% of zooplankton population and during the second year it increased to 66.42% of the total population. Such dominance of rotifers was also reported by Neves *et al.* (2003); Koli and Muley, (2012); Tyor *et al.* (2014) and Prudence *et al.* (2015).

In river Sal, rotifers were taxonomically represented by 6 families viz; Family-Asplanchnidae (single species: *Asplanchna priodonta*), Family-Brachionidae (5 species, Viz., *Brachionus angularis, Brachionus calyciflorus, Brachionus forficula, Keratella tropica and Keratella cochlearis*), Family-Filinidae (single species-*Filinia opoliensis*) Family-Lecanidae (single species-*Lecane bulla*) Family-Testidinellidae (single species-*Testudinella patina*) and Family-Trichocercidae (single species- *Trichocera rattus*).

In river Chapora, 5 families of rotifers were recorded viz; Family- Asplanchnidae (single species-*Asplanchna sp.*), Family-Brachionidae (9 species- *Brachionus bidenta, Brachionus calyciflorus, Brachionus falcatus, Brachionus plicatilis, Brachionus angularis, Keratella tropica, Keratella quadrata, Platyias patulus and Platyias quadricornis*), Family- Filinidae (single species-*Filinia longiseta*) Family-Lecanidae (single species-*Lecane luna*) and Family-Euchlanidae (single species-*Euchlanis sp.)*

Monthly rotifer population density at river Sal during the first year study period (September 2015- August 2016) was maximum value 216.42org/l in the month of December and minimum value 55.43org/l in the month of June, while during the second year maximum organisms were recorded as 161.43org/l in February and minimum as 37.14org/l in June. The monthly average rotifer population density during the two years was highest in December (186.38±42.48) and lowest in June (46.29±12.93).

Monthly population density of rotifera at river Chapora during September 2015-August 2016 was the highest in February (146.11org/l) and lowest in August (24.46org/l). During the second year the highest monthly population density was noted in December (162.32org/l) and lowest was noted in August (21.98org/l). The average monthly record of rotifer population density during September 2015-August 2017 was maximum in December (149.58±18.01) and minimum in the month of August (23.22±1.75).

The total average seasonal record of rotifers at river Sal, during the investigation period, was 64.67%. During the post monsoon period, at river Sal, rotifers contributed 25.06% of the total rotifer population. Winter recorded 13.41% rotifer population while summer and monsoon recorded 17.70% and 12.38% respectively. River Chapora recorded the total average seasonal record of rotifers during the two years as 60.54%. The maximum average seasonal rotifera population at river Chapora was recorded during the winter season (45.73%) followed by post-monsoon (28.12%), summer (16.99%) and monsoon (9.14%).

The average seasonal species diversity indices of rotifers at river Sal, during September 2015 to August 2017 showed Marglef's index was highest in summer (1.40) and lowest in monsoon (1.02). Shannon-Weiner index was the maximum in the post-monsoon and summer season (0.69) and minimum (0.67) in the monsoon in river Sal. Evenness index also was the maximum in the post-monsoon and summer season and lowest in the monsoon season (0.97). Simpson diversity index in river Sal was the highest in post- monsoon season (0.50) followed by winter as well as summer (0.49) and least in monsoon (0.48).

The average seasonal species diversity indices of rotifers at river Chapora during the two years investigation period showed Marglef's index was highest in post-monsoon (2.01) and lowest in monsoon (1.49). Maximum values of Shannon-Weiner index in river Sal was recorded in three seasons viz; winter, summer and monsoon season (0.69) and minimum (0.68) in the post-monsoon. Evenness index also was the maximum in three seasons viz., winter, summer and monsoon season (1). Post-monsoon recorded an evenness index value 0.98. Simpson diversity index in river Chapora was the highest in monsoon season (0.51) followed by winter as well as summer (0.50) and least in post-monsoon (0.49).

The ability of group rotifera to adapt to fluctuations in physico-chemical parameters and resistance of several species to hypoxic and anoxic conditions favors the success of rotifer population. Besides, less specialized feeding habits of group rotifera, a short life cycle, high fecundity and frequent parthenogenic reproduction also supports in increasing the population further (Rodriguez and Matsumura-Tundisi, 2000). A special ability of rotifers to form cysts in unfavorable conditions makes them opportunists (Almeida *et al.*, 2010). The winter maxima in rotifer population at both rivers Sal as well as Chapora may be due to their preference for lower temperature (Gupta, 2017). Higher dissolved oxygen recorded at both sites during winters boosts the growth of rotifers which was also noted by Singh (2004). Williamson (1983) and Kour *et al.,* (2015) attributes higher number of rotifers in winter to low predation pressure during that time. Antagonistically high predation pressure and less preference for higher temperature decrease the rotifer density in summer (Williamson, 1983; Herkloss *et al.*, 2005 and Gupta 2017). Moreover, lowest dissolved oxygen values were recorded in summer at both the rivers which are known to exert a detrimental impact on their abundance (Singh 2004). Very high current velocities and water mass during rainfall decreases rotifer density significantly. Such reports were also published by Thorp and Mantovani (2005).

Rotifer species like *Brachionus calyciflorus, Brachionus forficula* and *Trichocera rattus* were present throughout the sampling period at river Sal. While in river Chapora *Brachionus calyciflorus, Brachionus bidentata* and *Keratella tropica* were recorded almost throughout the sampling period. *Brachionus sps*, are considered as an important link in the food chain of freshwater bodies. They are preferred food material for many fish larvae (Guerguess, 1993). *Brachionus sps*. and *Keratella sps.* are considered as pollution indicator species. Their presence suggests a decline in water quality indicating eutrophication at both river Sal and Chapora (Pejler, 1957; Arora, 1966; Gannon and Stemberger, 1978; Maemets, 1983; Srivastava *et al.,* 1990 and Gochhait, 1991). *Filinia longiseta* recorded in river Chapora is also considered as an indicator of eutrophication (Baloch *et al.,* 2008). On the basis of the presence of these species during the study period, it may be concluded that, both rivers Sal and Chapora are slightly eutrophic. Agricultural run-off, organic pollutants from sewage drains, municipal garbage, run-off from fish farms at rive Sal and construction dumps at river Chapora probably caused this significant decrease in water quality.

Marglef's Richnness index is the simplest and most frequently used diversity index which measures the number of different species of a particular type of organism present in a particular area. Highest value of rotifer species richness at river Sal was observed in summer (1.4) and lowest value in monsoon (1.02). This means, the number of species observed in summer was higher compared to other seasons. In river Chapora, the rotifer species richness varied between 2.01 (post-monsoon) to 1.49 (monsoon). Inflow of rain water and high velocities during monsoon probably caused the decrease in rotifer diversity and richness. Dube (2016) also reported similar findings.

Shannon-Weiner diversity index (H) ranges from 0 to 5 for biological communities. According to this index, Shannon-Weiner diversity index values less than 1 portrays heavily polluted conditions, values in the range of 1 to 2 characterizes moderate polluted conditions, while values above 3 signifies stable biological communities (Stub *et al.*, 1970). In the present investigation, Shannon-Weiner diversity index of rotifer in river Sal ranged from 0.67 (monsoon) to 0.69 (post- monsoon and summer). Shannon- Weiner diversity index of group rotifera in river Chapora was 0.69 through three seasons; while post-monsoon recorded 0.68. Since the current investigation values are below 1 it indicates that, both rivers Sal and Chapora are heavily polluted. The values of rotifer Species Evenness (E) attained its maximum values in winter, summer and monsoon (1). Post-monsoon Species Evenness values decreased a little but did not change much (0.98).

Generally, Simpson's diversity index ranges from 0 indicative of no diversity to 1, which represents infinite diversity. Diversity value 0.6 to 0.9 indicates mature and stable community having high diversity whereas conditions under environmental stress exhibits lower values close to zero (Dash, 2003). In the present investigation, Simpson's diversity index group rotifer in rivers Sal and Chapora did not differ much. River Sal showed same values (0.49) for winter as well as summer. Monsoon and post- monsoon recorded values as 0.48 and 0.50 respectively. In river Chapora post-monsoon recorded Simpson's diversity index as 0.49, while winter and summer recorded the same value (0.50). In monsoon the value went a little higher (0.51). Baloch *et al.*, 2008 also recorded maximum Simpson's diversity index in monsoon.

COPEPODA

Huys and Boxshall (1991) believed that, copepods had their origin in the marine hyper benthic environment, but today, approximately 2800 species are known to inhabit freshwater bodies (Boxshall and Defaye, 2008). Within the freshwater habitats, copepods are so diverse and found to be present right from ancient lakes to subterranean water, from pools to glacial melts to hot springs to hypersaline lakes. In India, about 120 species of freshwater copepods have been identified (Uttangi, 2001). Out of the 10 order, calanoids are the most abundant and successful because of their moving speed and size (McMahon, 1973 and Schmidt and Nielsen, 1984)

In the current study, at both the rivers, the occurrence of copepods formed the second dominant group among the zooplankton. During September 2015-August 2016 copepods constituted 15.30% of the total zooplankton population in river Sal while river Chapora recorded 19.23%. In the second year of study, from September 2016 to August 2017, river Sal recorded 16.09% and river Chapora recorded 17.31% of copepods.

In river Sal, copepods were taxonomically represented by 2 orders viz., Cyclopoida and Calanoida belonging to 3 families along with Nauplius larvae viz; Family- Cyclopidae (5 species-*Mesocyclops leuckarti, Mesocyclops hyalinus, Microcyclops varicans, Eucyclops serrulatus* and *Thermocyclops hyalinus,*), Family-Diaptomidae (2 species- *Undinula valgaris* and *Heliodiaptomus viduus*), and Family- Pseudodiaptomidae (single species- *Pseudodiaptomus Nostradamus*).

River Chapora too recorded 2 orders Cyclopoida and Calanoida belonging to 3 families along with Nauplius larvae viz; Family- Cyclopidae (6 species namely *Mesocyclops leuckarti, Mesocyclops hyalinus, Microcyclops varicans, Eucyclops serrulatus, Thermocyclops hyalinus,* and *Trophocyclops prascinus*), Family-Diaptomidae (2 species- *Undinula valgaris* and *Neodiaptomus lindbergi*), and Family- Pseudodiaptomidae (single species- *Pseudodiaptomus Nostradamus*).

The Monthly population density of copepods at river Sal during September 2015-August 2016 was minimum in December (12.34org/l) and maximum in April (41.45org/l). During the second year minimum organisms were recorded in December (9.07org/l) and maximum in March (41.78org/l). The monthly average copepod population density during the two years was highest in April (39.88±2.22) and lowest in December (10.71±2.31).

At river Chapora the Monthly population density of copepoda was lowest during September 2015- August 2016 in December (8.94org/l) and during September 2016- August 2017 in February (10.13org/l). Maximum monthly copepod population density during both the years of study recorded May (40.41during September 2015- August 2016 and 36.14 during September 2016- August 2017). The average monthly record of copepod population density during September 2015- August 2017 was maximum in May (38.28±3.01) and minimum in the month of December (10.45±2.12).

The total average seasonal record of copepods, at river Sal during the analysis period was 15.66%. The maximum average seasonal population of copepods at river Sal was recorded during the summer season (37.45%), followed by post-monsoon (29.62%), monsoon (19.50%)

and winter (13.41%). The total average seasonal record of copepods, at river Chapora, during September 2015 to August 2017 was 18.30%. Of which, the highest seasonal copepod population was noted in summer season (38.66%) followed by post-monsoon (29.52%), monsoon (19.15%) and winter (12.66%).

The average seasonal species diversity indices of copepods at river Sal during September 2015- August 2017 showed Marglef's index was minimum in monsoon (1.35) and maximum in post- monsoon (2.38). Maximum values of Shannon-Weiner index in river Sal were recorded in winter as well as summer season (0.69) followed by 0.68 in post-monsoon and monsoon. Evenness index reached its peak (1) in winter and summer season and lower in the post-monsoon and monsoon season (0.98). Simpson diversity index in river Sal did not differ much. It increased from 0.50 in post-monsoon and monsoon to 0.51 in winter and summer.

Marglef's index of copepods at river Chapora during the two years investigation period was the highest in post- monsoon (2.7) and lowest in monsoon (1.72). Shannon-Weiner index in river Chapora ranged from 0.68 in post-monsoon to 0.69 in winter, summer and monsoon. Evenness index in river Chapora for copepods followed the same pattern as rotifers. A maximum value (1) was recorded in three seasons: winter, summer and monsoon season. Post-monsoon recorded an evenness index value 0.98. Simpson diversity index in river Chapora was the highest in winter (0.52), followed by monsoon (0.51), summer (0.50) and least in post- monsoon (0.49).

Nutrients are the chief ingredients for zooplankton survival and reproduction. Copepod species respond differently to changing water nutrient levels. Xie *et al.*, (1996) reported that, when levels of nutrients change, from moderate to rich, their species diversity decreases i.e., nutrient enrichment decreases zooplankton diversity. Because, in nutrient rich habitats, resistant species become dominant and the growth of other species is inhibited. At times eutrophication also shifts the usual dominance of copepods to rotifers (El- Shabrawy, 2000 and Emam, 2006) as was the case in the current investigation. A surge in copepod population, during summers, may be due to availability of food, which is higher in summers, due to the increase in production of organic matter caused by decomposition (Kiran *et al.*, 2007). Koli and Muley (2012) also testified negative correlation of copepods with pH which is also evident in the current studies. Copepods also prefer and flourish in higher temperatures (Bera *et al.*, 2014 and Gupta, 2017). Scarcity of food during monsoons, higher dilution and velocity of water decreases copepod population (Welcomme, 1975 and Ekpo, 2013). Winter minima may be ascribed to decline in water temperature and lesser availability of food (Koli and Muley, 2012).

In the present study Cyclopoids and Calanoids showed nearly equal occurrence. *Mesocyclops leuckarti, Eucyclops serrulatus, Thermocyclops hyalinus* and *Heliodiaptomus viduus* were present throughout the study period in river Sal. In river Chapora *Mesocyclops leuckarti, Thermocyclops hyalinus* and *Neodiaptomus lindbergi* were recorded all through the study period. Hutchinson (1967) pointed out a typical association of *Mesocyclops leuckarti,* and *Thermocyclops hyalinus.* Arcifa (1984) and Sampaio *et al.,* (2002) also confirmed such associations in freshwater bodies studied in Sao Paulo state. Guangjun (2013) reported *Mesocyclops leuckarti* as a dominant and widely distributed species in his studies at a nutrient rich Daoguanhe reservoir. This proposes the possible use of *Mesocyclops leuckarti* as a pollution indicator species. Industrial effluents and chemical fertilizer nutrients received from the surrounding catchment areas, might be the contributing source of contamination. But, the occurrence of copepodite nauplii throughout the study period, at both river Sal and Chapora showed an active continuous reproductive phase of copepods. However, Allan (1976) noted that copepods have larger generation intervals as they develop through a series of stages that require different physiological and ecological requirements, which affects the survival of adult copepods. Their existence is affected further, as they undergo obligate sexual reproduction which is adversely affected by heat, high concentration of suspended solids and pollutants (Nimbalkar *et al.,* 2013). Activities connected to construction of bridge at Siolim led to re-suspension of sediments and mixing of construction material in the water column resulting in higher turbidity affecting copepods. The presence of partially eaten calanoid adults indicates a high rate of predation.

Marglef's index showed that, both river Sal and Chapora were richer in species diversity during the post-monsoon season; while the richness value was the least in monsoon season. Changes in physico-chemical parameters of water such as, water temperature, pH and DO are known to affect the diversity of copepod species. Similar reports were also published by Rajashekar *et al.,* (2009).

Shannon-Weiner diversity index (H) connotes seasonal fluctuations of zooplanktons (Sibel, 2006). Since no much variation was seen in the index value through the seasons, it means copepod diversity was unvarying. This could suggest that, copepods prefer nutrient rich environment for growth. Peet (1974) reported that, species diversity caused both richness and evenness, which was also seen in the current study. Evenness was at its maximum (1) and no much deviation was noted. Whittaker (1965) suggested that, when dominance is shared by larger number of species, Simpson's index is low, while the index would be higher if the community has less species. Since the Simpsons index was 0.50 to 0.51, it was evident that, calanoid and cycloid species were present in almost equal numbers through all the seasons.

CLADOCERA

Cladocerans are commonly called as water fleas, because of the way it swims. They mainly prefer freshwater habitats ranging from lakes, ponds, streams, and rivers (Uttangi, 2001). They produce resistant and long lasting eggs which help them survive in temporary ponds. Cladocerans reproduce mainly by asexual reproduction, which is occasionally supplemented by sexual reproduction, producing dormant eggs. They undergo several molts before forming mature adults. The adult female produces a brood of eggs, every time they molt. Cladocerans are considered important from the ecological point of view, as they are indicator species used in water toxicity testing. Since certain species of Cladocerans are very sensitive to toxins and pollutants, their presence indicates the water body is uncontaminated and not harmful to the environment.

In the present analyses, at both rivers Sal and Chapora, copepods formed the third prominent group among the zooplankton. During the first year, cladocerans documented at river Sal was 10.56% of the total zooplankton population. The second year 10.03% population was of Cladocerans. While the river Chapora recorded 14.33% and 8.82% cladoceran population in the first and second year respectively. .

In river Sal, group Cladocera was taxonomically represented by 5 families viz; Family: Bosminidae (2 species viz., *Bosmina longirostris* and *Bosmina fatalis)* Family:Chydoridae (4 species viz., *Chydorus ventricosus, Alona quadrangularis, Alona rectangular* and *Alona verrucosa*), Family:Daphinidae (2 species viz., *Ceriodaphnia cornuta* and *Daphnia carnita*).and Family:Sididae (single species ie., *Diaphanosoma sarsi*).

River Chapora recorded 4 families viz; Family:Chydoridae (5 species viz., *Chydorus sphaericus, Alona quadrangularis, Alona costata, Scapholeberis kingi,* and *Pleuroxus aduncus*), Family:Daphinidae (3 species viz., *Ceriodaphnia cornuta Simocephalus vetulus* and *Daphnia sp.*), Family:Sididae (2 species namely *Diaphanosoma senegal* and *Sida crystallina*) and Family: Monidae (single species ie., *Moina micrura*).

The Monthly cladocera population density at river Sal during September 2015 to August 2016, was lowest in July (5.78org/l) and during September 2016 to August 2017, was lowest in

August (5.30 org/l). The monthly cladocera population density during the first year was highest in December (36.78 org/l) and during the second year in January (26.72 org/l). The average monthly cladocera population density was minimum in August (5.73±0.68) and maximum in December (30.57±8.78).

In river Chapora the Monthly population density of cladocera was lowest in August (4.99org/l) during September 2015 to August 2016, and during September 2016 to August 2017, in June (3.22org/l). Maximum monthly cladocera population density during both the years was recorded in February (37.41org/l and 22.62org/l respectively). The average monthly record of cladocera population density during September 2015 to August 2017 was maximum in February (30.02±10.45) and minimum in the month of August (4.49±0.70).

The total average seasonal record of clacodera in river Sal, during the analyses period was 10.32% and in river Chapora was 11.66%. The maximum average seasonal population of copepods at both the rivers Sal and Chapora was recorded during winter (Sal-44.85% and Chapora-46.29%) followed by post-monsoon (Sal-30.64% and Chapora- 31.36%), summer (Sal-12.77% and Chapora-14.48%) and monsoon (Sal-11.75% and Chapora-7.85%).

The average seasonal species diversity indices of cladocera at river Sal during September 2015 to August 2017, showed Marglef's index was maximum in monsoon (2.97), followed by summer (2.85), winter (1.78) and post-monsoon (1.68). The values of Cladocera Shannon-Weiner index in river Sal remained constant throughout (0.68). Accordingly, Evenness index also did not vary (0.98). Statistical computation indicated that, the diversity of cladocera species was evenly distributed. Simpson diversity index in river Sal varied between 0.49 in post-monsoon and winter to 0.53 in summer.

Marglef's index of Cladocerans in river Chapora, during the two years study period was the highest in monsoon (3.22) and lowest in post-monsoon (1.7). Maximum values of Shannon-Weiner index for Cladocerans in river Sal was recorded in summer as well as monsoon season (0.68), followed by 0.66 in winter and least in post-monsoon (0.65). Minimum Evenness index values in river Chapora for cladocera was recorded during post-monsoon (0.94), followed by winter (0.95), summer and monsoon (0.98). Simpson diversity index in river Chapora was the highest in monsoon (0.54), followed by summer (0.51), winter (0.48) and post- monsoon (0.46).

Higher availability of Cladocerans during winter may be attributed to their preference of lower temperatures, as also stated by Jyoti *et al.,* (2009). Higher dissolved oxygen content during winters also boosts the growth of many cladoceran species (Sawhney, 2008). Such findings were also reported by Viroux (2002), who ascribed their increase in winters to higher phytoplanktonic mass during this period. Rotifers, which are their preferred prey were also present in copious amounts in winter. Most adult copepod species are efficient predators and exhibit unique hunting and feeding techniques which enables them to prey on wide range on planktonic animals especially protozoans and Cladocerans. During the present study, copepods were found in least amounts in winter. Hence, low predation pressure during this time helped Cladocerans to flourish. Similar results were also reported by Becker *et al.,* (2004).

Decrease in concentration of Cladocerans, in summer, may be due to the considerable increase in water temperature. This increase in temperature accelerates the rate of evaporation there by decreasing the level of water and increasing the concentration of many nutrients. Since cladoceran species are highly sensitive to contamination, their survival becomes challenging. During monsoons, density of Cladocerans decreases further due to rapid currents and high turbidity. Erosion from catchment areas, as well as influx of surrounding domestic, agricultural, industrial, fish farm and hotel waste during monsoons inhibits their growth and development (Sharma, 2013). High riverine velocity also flushes away rotifers, their food source, thereby reducing their population density (Shadin, 1962 and Viroux, 2002).

The number of species in a given area is the most basic and natural measure of biodiversity. Marglefs index of cladocera at both the rivers was the highest in monsoon and lowest in post-monsoon. Less anthropogenic activities during monsoon and flushing out of pollutants by the water velocity during these months improves the quality of available water. Since Cladocerans prefer good environmental conditions, higher diversity was observed during this season. Koli and Muley (2012) and Ndebele (2012) also reported higher species richness in monsoon season.

Shannon-Weiner index, which measures species diversity, is directly proportional to the number of species in the sample and the uniformity of distribution of the species (Krebs, 1994). The Shannon-Weiner diversity index for group Cladocera in river Sal was constant throughout indicating uniformity of species. The Shannon-Weiner diversity index of River Chapora showed high diversity in summer and monsoon and patchy occurrence during the remaining seasons. However Shannon-Weiner diversity index for group Cladocera throughout the study period at both the rivers was less than one, indicating both the rivers are contaminated. It is noted that, higher the evenness value more the species richness and diversity. Constant Evenness values of Cladocera at river Sal indicated uniform richness. When Species diversity values are less, evenness is more, which might be due to high numerical dominance. Similar lines of reports were published by Vanjare (2010), which is corroborating with the present findings. Current investigations in river Chapora showed that, when Simpsons index for group cladocera increases, the evenness index goes in antagonistic directions and vice versa. Similar results were recorded by Walting *et al.*, (1979).

PROTOZOA

The growth of protozoan population is usually dependent on the availability of organic matter and detritus, on which these organisms feed (Sorokin and Paveljeva, 1972 and Kumar, 1997). During the first year of study, at river Sal, protozoans contributed 8.02% of zooplankton population and during the second year 6. 74%. While in river Chapora, protozoans comprised of 9.28% of zooplankton population and during the second year it decreased to 5.54% of the total population.

In river Sal, protozoans were taxonomically represented by 2 families viz; Family:Difflugidae (single species ie., *Difflugia sp.*) and Family:Centropyxidae (single species- ie., *Centropyxis aculeate*). River Chapora too was represented by 2 families viz; Family:Difflugidae (single species ie., *Difflugia sp.*) and Family:Centropyxidae (single species ie., *Centropyxis ecornis*).

Monthly protozoan population density at river Sal during the first year (September 2015-August 2016) was highest in the month of April (27.47org/l) and minimum in August 5.17org/l while during the second year highest number of organisms was recorded in May (19.75org/l) and least in July (3.61org/l). The monthly average protozoan population density during the two years was highest in April (23.39±5.76) and lowest in August (4.50±0.95).

Monthly population density of protozoa at river Chapora during both the years was highest in May. During September 2015 to August 2016 25.67org/l was recorded and during September 2016 to August 2017, 12.44org/l was recorded. Lowest values of monthly population density of protozoa at river Chapora was noted in August (3.12org/l During September 2015 to August 2016 and 3.05org/l during September 2016 to August 2017). The average monthly record of protozoa population density during September 2015 to August 2017 was maximum in May (19.06±9.35) and minimum in the month of August (3.09±0.04).

The total average seasonal record of protozoans at river Sal, during the investigation period, was 7.44%. During the post-monsoon period, at river Sal, group protozoa contributed

15.34% of the total zooplankton population. Winter recorded 26.74% protozoa population; while summer recoded 47.49% and monsoon recorded 10.42%. River Chapora recorded a total average seasonal record of protozoans during the two years as 7.47%. Through post-monsoon period at river Sal group protozoa population was recoded as 15.20%. Winter recorded 31.15% protozoa population; while summer and monsoon recoded 44.61% and 9.01% respectively.

The average seasonal species diversity indices of protozoans at river Sal during September 2015 to August 2017 showed Marglef's index did not differ much. Highest value of Marglef's Index was recorded in monsoon (0.63) and lowest in summer (0.32). Shannon-Weiner index was the maximum in the post-monsoon and summer season (0.68), followed by winter and monsoon (0.68). Evenness index also was the maximum in the post-monsoon and summer season (0.98) and lower in winter and monsoon season (0.97). Simpson diversity index in river Sal for protozoans ranged from 0.53 in post- monsoon and monsoon season to 0.49 in winter.

The average seasonal species diversity indices of protozoan population at river Chapora during the two years of investigation period, showed Marglef's index to be zero during monsoon season; while the highest value was recorded in post-monsoon (0.56). Maximum values of Shannon-Weiner index in river Sal was recorded in monsoon season (0.69) and minimum (0.64) in winter. Evenness index was at its highest (1) in monsoon and lowest (0.92) in winter. Simpson diversity index in river Chapora ranged from 0.46 in winter and summer to 0.58 in monsoon.

An increase in protozoan population was recorded during summer. High organic matter and abundance of food brought in from various sources into the river gets accumulated, due to decreasing the level of water in summer, leading to a rise in protozoan population (Wetzel, 1975 and Gupta *et al.,* 2015). Increased bacterial growth during summers, increases the production of detritus, which also ensures abundant availability of food (Zutshi, 1992; Sladeck, 1983; Sharma, 1999 and Wetzel, 2001). Protozoans are also known to multiply rapidly at higher temperatures (Shukla and Gupta, 2001 and Dutta and Verma, 2010). Rotifers prey upon Protozoans, which cannot endure well in higher temperatures. Hence, reduced rate of predation increases the population of protozoans (Kour *et al.,* 2015). Besides the capability of protozoans to tolerate physiological stress caused by pollution and other perturbations, favors their growth and flourishment (Sharma, 1992; Shafiq, 2004 and Sawhney, 2008). A decrease in protozoan abundance during monsoon, may be due to high velocity of water, which flushes away the food of protozoans (Sharma, 2013).

Kaushik and Saksena (1991) listed *Difflugia sps*. and *Centropyxis sps*., as pollution indicator protozoans. *Centropyxis aculeate* was found throughout the sampling period at river Sal, while in river Chapora *Centropyxis ecornis* was recorded throughout the study period. Both the species of *Centropyxis* were recorded in higher quantity at heavily polluted sites. *Difflugia sps.* was not recorded during monsoon period in river Chapora. Similar results were reported by Gochhait (1991).

On the basis of the presence of these species, during the study period, it may be concluded that, both rivers Sal and Chapora are polluted. Various kinds of anthropogenic waste construction dumps particularly at river Chapora possibly caused a significant diminution in water quality.

Since rivers are dynamic water bodies, their physico-chemical parameters are not uniform. The current investigation also showed wide variation in physico-chemical parameters which affected the population of zooplankton greatly. Since only two species of protozoans were recorded during the investigation, at both the rivers. Marglef's Index values did not differ much. The species richness index for river Chapora during monsoon was zero as only one protozoa was recorded during this season.

Shannon-Weiner diversity index (H) varied from 0.64 to 0.69 at river Chapora and 0.68 to 0.69 at river Sal. Since both the rivers exhibited Shannon-Weiner diversity index below 1, it can be concluded that, the rivers are contaminated. The values of protozoa Species Evenness (E) attained its maximum value at river Sal in post-monsoon and summer (0.98). In river Chapora Species Evenness value reached its maximum limit in monsoon (1), indicating high species diversity. Simpson's diversity index values at both river Sal and Chapora were below 0.6, which clearly indicates environmental stress on the species inhabiting that water body (Dash, 2003).

OSTRACODA

Ostracods inhabit all kinds of marine and freshwater bodies, but grow better in hard water (Harshey *et al.*, 1987). They are commonly found where weed and algae is abundant. Nagorskaya and Kyese (2005) specified that, distribution of freshwater ostracods is dependent on the type of water body and habitat.

During the present investigation, group ostracoda occupied the last position in terms of population and diversity. Both rivers Sal and Chapora had least number of ostracods and contributed only 1.90% and 2.03% of the total zooplankton population respectively.

Only 2 species were recorded at both the rivers belonging to family:Cyprididae. In river Sal, group ostracoda was represented by *Cypris sps*. and *Heterocypris sps*. River Chapora was represented by *Stenocypris fontinalis* and *Hetrocypris sps.*

Maximum density of ostracods (6.87org/l) in river Sal was recorded in May during the first year of investigation. In the next year, maximum number of Ostracods (4.35org/l) was also recorded in May. The minimum density of Ostracods in river Sal, during the first and second year was recorded in December (0.98org/l) and February (0.25org/l) respectively. The monthly average ostracod population density during the two years was highest in March (6.14±1.03) and lowest in January (0.82±0.61).

The Monthly population density of Ostracoda in river Chapora during September 2015 to August 2016 was the highest in March (5.42org/l) and during September 2016 to August 2017 was the highest in March (4.36org/l). The lowest monthly population density during both the years was recorded in December (0.53org/l and 0.65org/l respectively). The average monthly record of ostracod population density during September 2015 to August 2017 was maximum in March (4.89±0.74) and minimum in the month of December (0.59±0.08).

The average seasonal record of ostracods at river Sal during September 2015 to August 2016 was 2.01% and during September 2016 to August 2017 it decreased to 1.76%. The maximum average seasonal population of ostracods at river Sal was recorded during the summer season (45.56%), followed by monsoon (29.95%), post-monsoon (16.88%) and winter (7.59%).

The average seasonal record of ostracods at river Chapora during September 2015 to August 2016 was 2.17% and during September 2016 to August 2017, it decreased to 1.88%. of which, the highest seasonal ostracoda population was noted in summer season (42.19%), followed by monsoon (30.86%), post-monsoon (19.70%) and winter (7.23%).

The average seasonal species diversity indices of copepods at river Sal during September 2015 to August 2017 showed Marglef's index was zero in winter and maximum in post-monsoon (1.45). Maximum values of Shannon-Weiner index in river Sal were recorded in winter, summer and monsoon (1.1) post-monsoon recorded Shannon-Weiner index value as 1.08. Evenness index reached its peak (1) in winter, summer and post-monsoon while post-monsoon recorded a slightly lower value (0.98). Simpson diversity index in river Sal varied from 0.7 in summer to 1 in winter.

Marglef's index of copepods at river Chapora during the two years investigation period was zero in winter and monsoon season and maximum in post-monsoon (1.38). Shannon-Weiner index in river Chapora did not differ much, though it increased from 1.09 post-monsoon, summer and winter to 1.1 in monsoon. Evenness index also followed the same pattern as Shannon-Weiner diversity index. The value was the highest (1) in post-monsoon and decreased slightly (0.99) in post-monsoon, winter and summer. Simpson diversity index in river Chapora was the maximum in winter (1) followed by post-monsoon (0.78), monsoon (0.74) and least in summer (0.71).

Studies on species composition and abundance of Ostracods revealed the direct relation of ostracods with physico-chemical parameters. Kumar (2009) also had reported correlation of ostracods and zooplankton. The high diversity of ostracods in the present study sites may be due to the presence of high levels of calcium and magnesium, which is preferred by ostracods. Both the rivers seem to be receiving organic sewage causing enrichment of the river and slowly progressing towards degradation. The use of calcium rich fish feeds and liming of aquaculture ponds adds to the hardness of the water in river Sal. While, the construction waste flown into river Chapora and the bathing of farming animals along the banks enhances to the hardness.

In the present investigation, river Sal recorded only one species of ostracod during winter hence the value of Marglef's index during winter in river Sal is zero. Similar situation was observed during winter and monsoon season in river Chapora hence the value for species richness was zero.

According to Sibel (2012) Shannon-Weiner diversity index (H) connotes seasonal fluctuations of zooplanktons. Since no much variation was seen in the index value through the seasons, which means ostracoda diversity was unvarying. Since the level of calcium was highest in monsoon, growth of ostracod species was probably favored. Diversity and Evenness was highest in monsoon, while Simpson diversity index reached its peak in winter.

SEASONAL VARIATION IN ZOOPLANKTON FAUNA

The density of zooplankton at both river Sal and Chapora revealed a well marked seasonal variation as depicted in Figure 2.5 and 2.6 respectively. A peak in zooplankton density was observed in the winter followed by post-monsoon, summer and monsoon. In river Sal the population density recorded was highest in the winter season 37.86%, followed by 25.47% during post-monsoon, 23.03% during summer and least in monsoon 13.62%. In river Chapora, the total average seasonal record during the winter, was 37.87% followed by 27.62 % during post-monsoon, 23.24% during summer and 11.25% during monsoon.

Maximum abundance of zooplankton faunal assemblage at both the rivers during the winter season was primarily due to contribution the Rotifers and Cladoceran population during this period. Favorable environmental conditions, lower water temperature and higher dissolved oxygen and pH during winter boost the growth of both rotifers and Cladocerans. This has also been confirmed by Agarwal *et al.,* (2009) and Kour *et al.,* (2015). Lower predation pressure on rotifers as well as Cladocerans and during this time also increased their population density significantly. Similar observations of high zooplankton population density in winter have been made by Das (2002).

A moderate abundance of zooplankton fauna during post-monsoon may be attributed to nutrient inflow, abundance of food supply in the form of bacteria, suspended detritus and macrophytes (Ahmed *et al.,* 2010 and Rathod *et al.,* 2016).

A marked decrease in zooplankton population during the monsoons, could be ascribed to dilution of water which destabilizes the river, thereby affecting the habitat of zooplankton fauna (Rathod *et al.,* 2016). Increased flow of water also during this period washes away the detritus which disturbs the feeding habit of zooplankton (Gochhait, 1991 and Sawhney, 2004). High turbidity interferes with the photosynthetic activity of phytoplankton thus inhibiting their multiplication and ultimately causing scarcity of food (Shadin, 1962; Viroux, 2002 and Kumar *et al.,* 2011)

Similar reports of decline of zooplankton during monsoon has also been reported by Godhantaraman (2001); Karuthapandi *et al.,* (2013); Sharma (2013); Dede and Deshmukh (2015); Manjare (2015); Vasanthkumar *et al.,* (2015) and Rathod *et al.,* (2016).

CHAPTER-III

PCA AND CCA ANALYSIS OF CHAPORA AND SAL RIVERS OF GOA

PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal Component Analysis (PCA) is a multivariate analysis method, used to analyze numerical data and extract important variables from a large set of data. It projects observations from a p- dimensional space with p variables to a k- dimensional space where $k<p$. this helps to conserve maximum information from the initial information. PCA variable charts are portrayed through axes or factors. Usually, the first two or three axes represent sufficient percentage of total variability on a scree plot with the rest providing little additional information. The eigenvalues in a PCA corresponds to a factor and reflects the quality of the projection.

The map in PCA called the correlation cycle is used for interpreting the projection of initial variables in the factor spaces. If two variables are far from the center and close to each other they are significantly positively correlated (r close to 1) and if two variables are orthogonally oriented they are not related (r close to 0). Two variables lying on the opposite sides of the center are significantly negatively correlated (r close to -1). When two variables are in close proximity to the center point, it is safer to consider the next axes as broader information will be carried on to the next axis. A square cosine value is helpful in confirming the linkage of a variable to the axis. The greater the squared cosine value the stronger is the link with the corresponding axis.

Principal Component Analysis thus helps in visualization of correlations between variables in 2 or 3-dimensional spaces.

RESULTS AND DISCUSSION

The monthly data obtained for physico-chemical parameters were subjected to principal component analyses, to determine which variables contributed significantly, to the variations in water quality. Monthly data of the fortnight collection at different sites of water sampling were averaged to obtain a final monthly reading. PCA test was carried out using XLSTAT (AddinSoft Inc.) software.

Principal Component Analysis on the dataset of river Sal during the first year of study i.e. September 2015- August 2016 resulted in four significant PCs (eigenvalues > 1) that explained 74.58% of the cumulative variance in the data (Table 3.1 and Fig 3.1). PC1 accounted for

31.08% of the total variance, because of strong positive loadings of pH, calcium and magnesium and negative loading of phosphate. December, January and February had high positive scores for PC1. PC2 which accounted for 19.53 % of total variance showed positive loading of DO, turbidity and nitrates. The months of May and June had the highest positive scores with PC2. PC3 accounted for 13.76% of the total variance with moderately positive loadings of temperature and total alkalinity. November, February and March had higher positive scores with PC3. PC4 contributed to 10.20% variation.

Principal Component Analysis on the dataset of river Sal during the second year of study i.e. September 2016- August 2017 resulted in four significant PCs (eigenvalues > 1) that explained 82.60% of the cumulative variance in the data (Table 3.2 and Fig 3.2). PC1 accounted for 31.65% of the total variance because of strong positive loadings of pH and DO. Strong negative loading of temperature and calcium was noted for PC1. The highest positive scores for PC1 were seen in January followed by December and February. PC2 accounted for 24.50 % of total variance with strong positive loading of turbidity. The months of June and July had the highest positive scores with PC2. PC3 accounted for 16.21% of the total variance with strong positive loadings of phosphate and moderately negative loading by magnesium and nitrates. April had the highest positive scores with PC3. PC4 contributed to 10.23% variation due to moderate loadings of total alkalinity.

Principal Component Analysis on the dataset of river Chapora during the first year of study i.e. September 2015- August 2016 resulted in four significant PCs (eigenvalues > 1) that explained 81.29% of the cumulative variance in the data (Table 3.3 and Fig 3.3). PC1 contributed 28.13% of the total variance with strong positive loadings of magnesium and moderate loading by total alkalinity. Strong negative loading of temperature and moderately negative by nitrates was noted for PC1. December and February had high positive scores for PC1. PC2 accounted for 22.43 % of total variance with positive loading of Calcium and DO and negative loadings from turbidity. January had high positive scores for PC2. PC3 accounted for 18.39% of the total variance with strong positive loadings of phosphate and moderately negative loading of nitrates. October had the highest positive scores with PC3. PC4 contributed to 12.33% variation due to high positive loadings of total alkalinity.

Principal Component Analysis on the dataset of river Chapora during the second year of study i.e. September 2016- August 2017 resulted in five significant PCs (eigenvalues > 1) that explained 85% of the cumulative variance in the data (Table 3.4 and Fig 3.4). PC1 contributed

25.73% of the total variance with strong positive loadings of pH and moderately strong negative loading of EC and temperature. High positive scores for PC1 were noted in October. PC2 accounted for 18.67% of total variance with strong positive loading of turbidity. June had high positive scores for PC2. PC3 accounted for 15.90% of the total variance with moderately strong positive loadings of magnesium. December had the highest positive scores with PC3. PC4 contributed to 13.33% variation with moderately high positive loadings of nitrates. PC5 accounted for 11.36% of variance due to weak negative loadings of EC.

CANONICAL CORRESPONDENCE ANALYSIS (CCA)

Canonical Correspondence Analysis (CCA) is a tool for assessing the relative abundance of organisms to various environmental variables. It helps in visualization of objects, sites and variables in a single map.in the present study the five groups of zooplankton were taken for analysis along with the ten environmental variables.

RESULTS AND DISCUSSION

The biplot of CCA for the first year in river Sal explained 93.28% variance in axis 1 and 2 (Fig 3.5). pH, calcium, magnesium, total alkalinity and DO showed significant positive correlation with axis 1 while temperature and turbidity exhibited significant negative relation in both axis 1 and 2. EC, phosphates and nitrates showed significant positive and negative correlation in axis 1 and 2 with high correlations. Rotifers showed positive correlation in axis 1 and 2 and were highly associated with DO in axis 1 which indicates a close association of rotifers with DO. Negative association is seen between Rotifers and temperature. Cladocerans having principal coordinates 0.292 and -0.159 with axis 1 and 2 respectively were closely associated with higher levels of total alkalinity and lower levels of pH. Negative correlation was explained by CCA between copepods (principal coordinates -0.471 and -0.203 with axis 1 and 2) and turbidity and temperature. Thus the observed negative relation elucidates the impression that temperature and turbidity act as limiting agents for certain zooplankton community. Copepods are also sensitive to higher levels of nutrients which are clearly evident in the CCA analysis. Ostracods and protozoans showed negative and positive correlation with axis 1 and 2 and showed association with phosphates, nitrates and EC.

CCA for the second year in river Sal explained 95.50% total variance in axis 1 and 2 (Fig 3.6). Turbidity, nitrates and calcium showed significant positive relation with both axis 1 and 2 while DO, pH, total alkalinity and EC showed significant negative relation with both the axis. Phosphates and temperature exhibited significant positive and negative relation with axis 2 and axis 1. Ostracods showed close association with calcium. Calcium is necessary for the growth and development of calcareous ostracods and hence flourishes when calcium levels are high. Copepods showed positive correlation in axis 1 and 2 and were closely associated with nitrates. Rotifers exhibited negative correlation (principal coordinates -0.179 and -0.013).

The biplot of canonical correspondence analysis for the first year in river Chapora of zooplankton and physico-chemical parameters is illustrated in (Fig 3.7). The CCA analyses explained 93.06% variance.DO, temperature, turbidity and phosphates exhibited significant positive and negative relation in axis 2 and 1. pH alone exhibited a significant negative correlation in both axis 1 and axis 2. Calcium, magnesium and total alkalinity showed significantly positive and negative relation in axis 2 and axis 1. Copepods and Ostracods were seemed to prefer turbid waters and higher temperature. Abundance of rotifers and cladocerans was collateral. Since cladocerans prey upon rotifers both were seen in copious amounts in winter. Negative correlation was observed between pH and cladocerans (Principal components -0.277 and -0.100) while rotifers (Principal components -0.207 and 0.006) were seen to be weakly associated with calcium and magnesium and were negatively correlated to turbidity. Total alkalinity did not seem to be affecting the zooplankton population in river Chapora.

CCA for the second year in river Chapora explained 96.97% variance (Fig 3.8). DO, pH, calcium, magnesium and total alkalinity exhibited significantly positive correlation in axis 1 and axis 2 while nitrates and temperature exhibited significantly negative relation in axis 1 and axis 2. Turbidity alone exhibited positive relation with axis 2 and negative relation with axis 1 while EC alone exhibited positive relation with axis 1 and negative relation with axis 2. As in year 1 again rotifers and cladocerans were growing collaterally upholding the food chain. There were seen to grow well in association with magnesium and DO. Negative correlation was seen between protozoans, temperature and nitrates. Ostracods (Principal components -0.667 and -0.250) were noticed to increase in number in turbid waters.

SUMMARY AND CONCLUSION

Freshwater management and conservation is the need of the hour. Threats to aquatic environment such as degradation, overexploitation, pollution, anthropogenic pressure, industrial effluents and agricultural runoffs are increasing and thus having deleterious effects on floral and faunal communities both qualitatively and quantitatively.

During the study period viz., September 2015 to August 2017, investigations were carried to study the association of physico- chemical parameters with zooplankton in river Chapora and Sal. These studies were pursued under the following lines:

- Seasonal variations in physico- chemical parameters of the selected water bodies.
- Seasonal diversity, density and distribution pattern of meso-zooplankton.
- Species richness and population dynamics of zooplankton.
- Association of zooplankton and physico-chemical parameters.

During the study period, ten physico-chemical parameters viz., surface water temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total alkalinity, calcium, magnesium, phosphates and nitrates were analyzed fortnightly by following standard methods. Further diversity, density and distribution patterns of meso-zooplankton including seasonal variations were studied. Important indices such as Margalef's Index for species richness, Simpson's diversity index and Shannon Weiner index of evenness was also worked out. The results obtained are discussed in the light of available literature.

River Sal

Water quality parameters viz; water temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total alkalinity, calcium, magnesium, nitrate and phosphate were analyzed for two years at four stations in the river. The physico-chemical parameters showed well marked seasonal fluctuations. The average seasonal record of temperature during the study period in river Sal is was found to be maximum in summer and minimum in winter season. Summer the average temperature was 31.42ºC. In winter the average temperature recorded was 28.89ºC. Seasonal record of pH of river Sal ranged from (6.87) during summer to (7.59) in the winter season. Electrical conductivity was the lowest in monsoon (3311.65 μS/cm), followed by post-monsoon (3847.14 μS/cm), winter (9946.91 μS/cm) and maximum average seasonal value in summer (10728.39 μS/cm). Summer minima (4.56) and winter maxima (5.21mg/l) was observed in the values of DO. Average seasonal record of turbidity at river Sal showed minimum values in winter season (8.74 NTU) and maximum in monsoon (29.64 NTU). Average seasonal record of total alkalinity ranged from 88.14 mg/l in summer to 366.43 mg/l in winter. The minimum average seasonal value of calcium was recorded in summer (768.94 mg/l) while the maximum average seasonal value was recorded in monsoon (1079.83 mg/l).Magnesium levels varied between 295.89 mg/l in summer to 846.38mg/l in winter. Minimum average seasonal values of phosphate were recorded as 0.07 mg/l in winter and maximum average seasonal values were recorded as 0.20 mg/l in summer. Nitrate levels ranged from 0.31mg/l in winter to 1.84 mg/l in summer.

From the above results it can be concluded that the water temperature of river Sal was within the range which is suitable for survival of zooplankton. pH varied from faintly acidic to slightly alkaline. Fluctuations in pH can be stressful to zooplankton; hence necessary measures need to be taken to maintain a constant pH. Disposal of domestic sewage and agricultural run-off into the river should be prohibited. Conductivity is affected by temperature; the higher the temperature, higher was the levels of conductivity. Significant changes in the levels of conductivity may be due to discharge of sewage or run- off from agricultural fields. The high level in river Sal indicates pollution. A negative relation exists between photoperiod and dissolved oxygen. Winter maxima in DO values may be ascribed to shorter photoperiods. Lower values of DO during the dry season, might be due to slightly eutrophic conditions of the river. A number of factors may have been responsible for increase in turbidity levels, such as flow of water, pollution re-suspension of suspended particles, addition of nutrients like nitrates and phosphorus from agricultural fertilizers which enhance the growth of harmful algal blooms. These can be toxic and have a detrimental effect on aquatic life. Total alkalinity levels were the highest in winter. The running of numerous shacks along the length of the river specially during the tourist season in winter probably release their untreated sewage and waste into the river which could be the reason for increase in total alkalinity levels. The present investigation showed very high values of calcium and magnesium throughout the study period especially at site Cuncolim and the site near Orlim Bridge. The prawn and fish farms along the banks of the river drain their waste directly into the river. Apart, maintenance activities and discharge of calcium rich unused feed from the culture units probably adds to the large amount of calcium in the river. The shacks and hotels waste also possibly enhances the levels of calcium. In summers, high temperature accelerates the rate of mineralization of organic matter and bacterial activity which most likely caused an increase in levels of phosphates and nitrates in the water body.

The zooplankton community of river Sal showed seasonal and spatial variations in distribution and abundance during the present investigation period. A total of 33 species were recorded in River Sal belonging to 5 major taxonomic groups: Rotifera (10 species), Copepoda (9 species), Cladocera (12 species), Protozoa (2 species) and Ostracoda (2 species). Rotifera contributed to 64.67% of the total zooplankton composition at river Sal followed by Copepoda (15.66%) > Cladocera (10.32%) > Protozoa (7.44%) > Ostracoda (1.90%). Rotifera showed greatest density while cladocera showed wide diversity. Ostracoda showed poor contribution towards the overall density of zooplankton. Copepoda and Cladocera are present in moderate range in terms of abundance. The density of zooplankton was found to be higher during winter season and lowest in monsoon season.

Zooplankton showed polymodal occurrence in river Sal. The variations of water conditions resulted in noticeable changes in the zooplankton community. In summer, an alteration in hydrological condition was seen, which was probably due to the eutrophic conditions. This in turn altered the functioning of biological cycles in the river. Rotifer species like *Brachionus* and *Keratella,* copepod species like *Mesocyclops leuckarti and* protozoan species like *Difflugia* and *Centropyxis* are considered as pollution indicator species and their presence suggests a decline in water quality, thereby indicating eutrophication at river Sal. The presence of copepodite nauplii throughout the two year study period showed an active continuous reproductive phase of copepods. The presence of partially deformed organisms indicate high rate of predation by invertebrates.

River Chapora

The physico-chemical parameters during the two years study period showed well marked seasonal fluctuations. The average seasonal record of temperature varied between 28.97ºC during post-monsoon to 29.92ºC in summer. The average seasonal record of pH showed a slightly alkaline pH during post-monsoon season (7.34); while slightly acidic pH was recorded only in the summer (6.97). River Chapora showed minimum average seasonal value of EC in monsoon (327.17µS/cm) and maximum average seasonal value in summer (1493.40µS/cm). DO was the lowest in summer (6.07 mg/l) followed by monsoon (6.14 mg/l), post-monsoon (6.17 mg/l) and winter (6.40 mg/l). Average seasonal record of turbidity at river Chapora showed minimum values in winter season (10.47 NTU) and maximum in winter (20.68 NTU). The minimum average seasonal value of total alkalinity was recorded in summer season (84.17 mg/l) while the maximum average seasonal value was recorded in winter (345.38 mg/l). Average seasonal record of total alkalinity ranged from (88.14 mg/l) in summer to (366.43 mg/l) in winter. Average seasonal record of calcium ranged from 364.59 mg/l in summer to 1313.30 mg/l in winter. The minimum average seasonal value of magnesium was recorded in summer (482.62 mg/l) while the maximum average seasonal value was recorded in winter (890.94mg/l). The average seasonal phosphate levels varied between 0.02 mg/l in winter to 0.05 mg/l in summer. Minimum average seasonal values of nitrate were recorded as 0.06 mg/l in winter and maximum average seasonal values were recorded as 0.17 mg/l in summer.

Based on the present studies on river Chapora, it can be concluded that, temperature was within the limit suitable for zooplankton growth. pH levels were close to neutral with slight deviation. EC fluctuated across different season attaining its maximum in summer. High rate of evaporation during summer and increase in sewage and pollutants release during this season were the probable causes for the increase in EC. A decrease in dissolved oxygen levels may be ascribed to a decrease in flow of water during summers, which in turn enhances rapid heating up of water, which could be another cause for decrease in dissolved oxygen levels. Higher water temperature increases the metabolic rate, which increases the demand for oxygen. The decrease in temperature during this period, results in decrease in the rate of decomposition, as well as respiration leading to less utilization of dissolved oxygen by aquatic organisms. Winter maxima in dissolved oxygen values may be attributed to shorter photoperiods. Increased volume of water and velocity in monsoon erodes the banks of the river, which increases the turbidity of the river. Pollution and re-suspension of suspended solids also increases the turbidity of the water further. Winter being the peak tourist season, anthropogenic activity intensifies along the banks of the river. The cruises plying in the river release their untreated sewage directly in the river. This probably led to the increase in levels of total alkalinity. Apart construction material, such as cement, brick lime and concrete used for the renovation of the Chapora bridge during the study period added to the calcium content. Furthermore, disturbance to the sediments by removal by dredging and river bed deepening activities associated with the construction may have resulted in mixing of calcium and magnesium ions from sediments in water column increasing their levels in the suspended form. The increase in temperature in summer accelerates the rate of rate of aerobic decomposition and bacterial activity which may be the probable cause for the increase in phosphate and nitrate levels of in river Chapora.

A total of 38 species were recorded at river Chapora, which exhibited seasonal and spatial variation in distribution and abundance. They belonged to 5 major taxonomic groups viz., Rotifera (13 species), Copepoda (10 species), Cladocera (11 species), Protozoa (2 species) and Ostracoda (2 species). The order of abundance of the taxonomic groups were recorded as: Rotifera (60.54%) > Copepoda (18.30%)>Cladocera (11.66%) >Protozoa (7.47%) >Ostracoda (2.03%). Overall Rotifera showed great diversity and density whereas, ostracoda showed poor contribution. The abundance of Copepoda and Cladocera were in moderate range. Seasonal variations in the abundance of zooplankton recorded a well-marked peak winter, moderate in post-monsoon and summer with a fall in monsoon season.

Consequential responses to zooplankton to different kinds of perturbations were apparent as altered patterns in diversity, richness and abundance were noted. Stress on the riverine ecology by habitat destructive activities due to repair of bridges and pollution seemed to be the main cause for such effects. During the bridge construction work, various construction materials, such as cement, brick lime and concrete led to decrease in the diversity and density of zooplankton. Furthermore, disturbance to the sediments by dredging and river bed deepening activities associated with the construction may have resulted in mixing of sediments in water column affecting the growth and survival of zooplankton. Presence of Rotifer species like *Brachionus, Keratella* and *Filinia* suggests a decline in water quality, indicating eutrophication. Copepod species like *Mesocyclops* and Protozoan species like *Centropyxis* were recorded in higher quantity at heavily polluted sites. *Difflugia sps.* was not recorded during monsoon period in river Chapora.

Correlation coefficient between biotic components and physico-chemical variables at both the rivers exhibited a positive as well as negative correlation. In order to determine the ecological amplitude of organisms and compare the biotic structure of communities quantitatively various diversity indices viz; Margalef's Richness Index, Simpsons Index, Shannon- Weiner Index and Evenness were applied, which showed variations among seasons.

The overall view in the study reveals that, the fluctuations in zooplankton community in river Sal and Chapora occurs due to variations in biotic and abiotic factors, which directly affects the zooplankton. Invariable presence of tolerant taxa at both rivers and polymodal occurrence of zooplankton depicted the accentuation of stress caused due to various reasons on the riverine ecology suggesting a decline in water quality indicating eutrophication at river Sal and Chapora.

Recommendations

Regular monitoring of lotic aquatic ecosystems is crucial to detect the impact of any kind of perturbation to a population, community or ecosystem as a whole. For sustainable management of water infrastructure development and harnessing the riverine ecosystem, certain measures should be followed viz;

- Proper management of point and non-point sources of sewage and solid waste disposal after suitable treatment. Disturbances tend to accentuate or aggrandize the impacts of pollution which was very apparent at both the rivers under study.
- Proper implementation of laws and safety measures by environment protection agencies.
- Proper analyses of environmental Impact Assessment report and implementation of necessary measures to restore the integrity of the rivers is necessary.
- Herbicides and algaecides are the most effective and commonly used measures to control aquatic vegetation, which should be used in such a manner, so as not to harm aquatic organism.
- Installation of waste treatment plants along the banks of the rivers.
- Environmental awareness education should be encouraged among the masses to understand the intricacies of ecosystem health and sustainable usage of riverine resources.
- Government and non-government agencies and private professional consultants must be utilized for service information about aquatic environment.
- Data and information generated must be propagated to the citizens and school going children to heighten the awareness among them.
- The immersion of sacred idols should be channelized and proper arrangements should be made for its immersion.
- Reducing the disturbance to hydro-morphology to stabilize biotic habitat.

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APPENDIX

RESEARCH PAPERS PUBLISHED

Fernandes, A. and **I. K. Pai** (2017) Zooplankton Diversity and Physico-Chemical Conditions of River Chapora, Goa. Vasantrao Dempo Education Research Journal of Arts, Science and Humanities 3(1):9-12.

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Fernandes, A. and **I. K. Pai** (2016) Limnological studies of river Chapora. International Symposium Understanding the molecules of life in the era of new biology & 28th All India Congress of Zoology (AICZ), Davangere University, Karnataka, India. Oct. 20- 22, 2016. Pp:58

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