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REVIEW ON INTERPLAY BETWEEN HYDRO-GEOCHEMISTRY, PLANKTON DYNAMICS AND AVIFAUNAL ASSEMBLAGE OF TWO SIGNIFICANT FRESHWATER INLAND WETLANDS OF NATIONAL IMPORTANCE, GUJARAT, INDIA

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ABSTRACT:

Limnology is the study of freshwaters. Such limnological studies are helpful in understanding interaction between climate, environmental conditions, and biological processes in the water. Water is vital entity for the existence of all life-forms on the earth, but this precious resource is continuously being threatened by increasing human population as the purpose of the usage of water has been increased such as water abstraction for domestic use, agricultural production, mining, industrial production, power generation and forestry practices. Wetlands being one of the most productive ecosystems in the biosphere, the high microbial and macrophyte productivity occurs at a high rate, which can be attributed partly to an adequate water supply, high organic loading, high sediment nutrients, and organic matter concentrations. Plankton are the microscopic organisms, drifts in the upper photic zone of the oceans, and freshwater water bodies that are unable to swim against a current. Plankton play vital role in the function of any aquatic ecosystem that is energy flow and material flow. Because of their high density, drifting nature, high group or species diversity, and varying stress tolerance, plankton populations are an essential link in the energy transition from producers to consumers. Birds are an excellent taxon to study in order to

track global environmental change. Birds are found all over the world, inextricably linked to their environments, sensitive to environmental changes, and their presence might indicate ecosystem function.

KEYWORDS: *Hydrochemistry, Geochemistry, Phytoplankton, Zooplankton, Avifauna, Inland Wetlands, Conservation, Management.*

INTRODUCTION:

"*Wetlands are the area of marsh, fen, peatland, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which allow tides does not exceed six meters*" (Ramsar Convention, 1971). The wetland ecosystem in India includes natural water bodies (such as rivers, lakes, coastal lagoons, mangroves, peat land, and coral reefs) as well as man-made wetlands (such as ponds, agricultural ponds, irrigated fields, holy groves, salt pans, reservoirs, gravel pits, sewage farms, and canals) (Ramsar Convention, 1971). Wetlands are believed to be the most productive ecosystems on the earth. Wetlands occur extensively throughout the world in all the climatic zones and are estimated to cover nearly 6.4% of the earth's surface. India is home to 18.4% of the world's wetlands, with Gujarat accounting for 36% of the country's wetlands (MoEF, 2020). According to State of the world's wetlands and their services to people (2018), global inland and coastal wetlands cover over 12.1 million km^2, with 54% permanently inundated and 46% seasonally inundated. Based on their ecological, hydrological and geological characteristics, wetlands are categorized into estuarine, marine, mangroves, riverine, lacustrine and palustrine ecosystems (Cowardin, 1995; Meena, 2019). Wetlands are the areas, where the environment is mainly controlled by water. The management of the aquatic environments require an understanding of the important linkage between ecosystem property and the way in which human activities can alter the interplay between physical, chemical and biological processes that drive ecosystem functioning. The major rivers, such as the Ganga, Brahmaputra, Godavari, Narmada, Krishna, Kaveri and Tapti, are directly or indirectly contributing to the majority of inland wetlands (Meena, 2019; Sharma 1991). They are found in the hot arid parts of Rajasthan and Gujarat, the east and west coast deltaic regions, the highlands of central India, the wet humid zones of south peninsular India and the Andaman and Nicobar Islands, and the Lakshadweep Islands (Meena, 2019; Sharma, 1991). Water is vital for the existence of all life forms on the earth, but this precious resource is continuously being threatened by increasing human population as the purpose of the usage of water has been increased such as water abstraction for domestic use, agricultural production, mining, industrial production, power generation and forestry practices. That can lead to deterioration of the water quality and quantity that have direct impact on

the structure and function of the aquatic ecosystem (Meena, 2019; Sharma, 1991). Water quality is not a static condition of any ecosystem not to be defined by measurement of only one single parameter. It can have relative change with respect to time and space. Hence, it requires routine monitoring to detect spatial and temporal change. There is a range of chemical, physical, and biological components that have direct impact on water quality and hundreds of variables that could be examined and measured. Measurement of some variables can give idea about the general indication of water pollution, whereas, others enable the direct tracking of pollution source. As the full impact of climate change on our ecosystem lifelines is felt, the ability of wetlands to adapt to changing conditions and accelerated rates of change will be critical for human populations and species worldwide. Till date, 46 wetlands have been included in Ramsar sites in India (Ramsar, 2021).

Plankton are the microscopic organisms drifts in upper photic zone of the oceans and freshwater water bodies that are unable to swim against a current. Plankton play vital role in the function of any aquatic ecosystem, which is energy flow and material flow. Planktons are good bioindicators of the stability of the ecosystem. The whole biota of aquatic ecosystem is depending upon the ecological balance and interrelationship between different factors of the ecosystem for their regulatory Processes. Phytoplankton is a microscopic organism that lives in aquatic environments, both salty and fresh. It is derived from the Greek terms *phyto* (plant) and *plankton* (made to wander or drift). As a result, plankton are more vulnerable to currents than fish and other larger organisms. It comprises of chlorophyll-producing organisms (phytoplankton) and animal (zooplankton) (Erondu, 2017). Phytoplankton consists mainly of algal components such as diatoms, dinoflagellate, and a variety of life forms from other divisions of the plant kingdom. The principal primary producers are phytoplankton, which influence the structure and density of consumers as well as the hydro-chemical qualities of water. Due to the availability of planktonic communities in the water body that represent average ecological conditions, phytoplankton, and zooplankton are indicators of ecological circumstances (Vandysh, 2004). Phytoplankton are responsible for the majority of biological production in natural environments such as oceans, lakes, rivers, and wetlands (Nirmal Kumar, 2012). Besides acting as bioindicators, these microscopic organisms are integral parts of the food web and food chain including fishes. Planktons in the aquatic ecosystem are important group of organisms as primary producers as well as primary consumers. In the case of zooplankton are the major consumers and prey of higher creatures in aquatic ecosystems. As a result, zooplankton is well recognised as a fish food source in any aquatic ecosystem (Tiwari, 2020). A study on zooplankton population in relation to physico-chemical parameters of Lal Diggi Pond in Aligarh was carried out by Uzma *et al*. (2012).

Birds are exceptional barometer for the health of the environment (Gregory and Van, 2010). They are also more sensitive to environmental contaminants than other vertebrates on the earth, therefore can act as bioindicators (Vashishat and Kler, 2015, Webber, 2015). Birds are found all over the world, inextricably tied to their habitats, sensitive to environmental changes, and their presence may indicate ecosystem function (Cerwinka, 2019). Birds are excellent taxa for monitoring global environmental change, since they have been studied extensively over the world. According to State of Indian Birds (2020), 48% of avian species are stable or increasing in the long term, and 79% have been decreased during the last five years (2015-2020). Birds' cultural significance is balanced by their ecological significance. Pollinators, seed dispersers, predators, scavengers, and prey for other species are all important roles that birds play in ecosystem health (SoIB, 2020). Migratory birds use the wetlands as stopover habitats and resident birds use them as foraging and nesting habitats. Hence, assessment of avifaunal communities reflects the facts about the health of concerned aquatic ecosystem.

LACUSTRINE ECOSYSTEM

Wetlands are of immense socio-economic and ecological importance to humankind, for the survival of natural biodiversity, and are recognized as sources, sinks and transformers of chemical and biological matters (Wetzel, 1991). As the limno-biological and limno-chemical components of the ecosystem plays a vital role in hydrochemistry, it is impossible to fully comprehend biological phenomena without understanding the water chemistry (Agarwal, 2010). Limnology is the study of freshwaters. Such limnlogical studies are helpful in interaction between the climate, surrounding environmental conditions and biological processes in the water (Pathak, 2013). Lakes and ponds are important habitats as they provide water and food for home, industrial, and agricultural purposes. Wetlands are vital to biodiversity protection and the long-term viability of ecosystems, both of which are economically essential to the local population. Biologically, wetlands are the most productive aquatic ecosystem in the world, and various globally threatened avian species depend on them (Green, 1996). Wetlands are the most important conservation sites because they support a complex food chain and a diverse range of wildlife (Getzner, 2002). Diverse wetland complexes are of great value in providing habitat for wetland bird species (Miller, 2003). Wetlands are considered as one of the world’s most productive environments. Not only the birds, but also all the organisms, belonging to the plant and the animal communities are affected by the physico-chemical properties of their environment. Changes in major physical and chemical factors have an impact on wetlands, because they are linked systems. As a result, wetland-dependent communities as well as ecosystem variables such as species richness, distribution, and density are affected (Balapure and Vyas, 2013). At the primary and secondary production levels, these alterations eventually modify the corresponding food

web structures. The climatic, geochemical, geomorphological, and pollution factors influence the physical and chemical qualities of freshwater bodies. The quality of water is determined by these features, as well as natural and man-made changes. Because of the multiple interactions between the components such as water, soil, biosphere, and atmosphere, wetlands are highly complex ecosystems. Understanding the community structure of an ecosystem also needs the study of interactions between biotic and abiotic components. Wetlands are essential indicators of environmental change, but they are not taken into account substantially that much in study.

HYDROCHEMISTRY

Dissolved oxygen (DO) is an important characteristic in aquatic systems that are required for all aquatic organisms' aerobic metabolism. Free CO_2 is commonly detected in water bodies when oxygen levels are low or non-existent, owing to the breakdown of organic materials by bacteria at the bottom, which results in rapid creation of Free Carbon Dioxide. Wetlands are intricate and prolific ecosystems that occupy about 6% of the earth's land surface (Maltby and Turner, 1983). Surface water from streams (surface run-off), precipitation, overland flow, and subsurface water from surface infiltration, stream hyporheic zones, and ground water are all received by wetlands. These various inputs are critical to wetland productivity because they include significantly variable amounts of transported nutrients (Mann and Wetzel, 1995) and organic matter (Stanley and Ward, 1997). As a result, temperature has a direct impact on key aspects like growth, oxygen consumption, food requirements, and food conversion efficiency of the numerous biotic communities that exist there. Water quality of any wetland influences feeding and microhabitat requirements for innumerable microscopic and macroscopic organisms inhabiting the wetland (Bedford, 1999). Freshwater resources have deteriorated both in quality and quantity in many ways, and harbour various pathogens responsible for causing diseases like dysentery, typhoid, cholera etc., which are attributed to the specific water quality. Seasonal variations in physico-chemical parameters of Kontagora reservoir, Niger State, Nigeria, were explored by Ibrahim *et al*. (2009). Hamaidi *et al*. (2013) conducted research to investigate the monthly fluctuations of physico-chemical characteristics in water samples collected from the Chiffa River in Blida, Algeria. Mann (1958) studied annual fluctuations in sulphate and bicarbonates hardness in four ponds of England, where sulphate content was high during spring, and low in autumn, while bicarbonates were minimum in spring and maximum during autumn. The reduction to sulphide ions, which locked up in the mud as ferrous sulphide, caused the sulphate concentration to drop. The decrease in bicarbonates was caused in part by the removal of carbon dioxide during photosynthesis and in part by the action of sulphuric acid when the sulphide was oxidised during the colder winter months. Calcium and magnesium are crucial in neutralising excess acid created by antagonising the harmful effects of different ions

(Munawar, 1970). Water temperature is extremely important because it governs a variety of abiotic and biotic activities in an aquatic habitat. It also depicts aquatic ecosystems' metabolic and physiological behaviour, as well as the dynamics of living species. In the presence of nitrate in the water, bacteria are active and growing. At Ramsagar Reservoir in Datia, Madhya Pradesh, Garg *et al*. (2006) looked into trophic status, water quality, as well as conservation and management methods. Jayakumar *et al*. (2009) assessed the pollution status of a lentic water body in Tamil Nadu. Lakes, *jheels*, ponds, and other freshwater wetlands have a variety of energy and nutrient exchange linkages with neighbouring watersheds and air sheds (Patra *et al*., 2010). In India, river and lake pollution is very severe and critical problem due to huge amount of pollutants discharged by urban activities. Water quality has become a major global concern due to increasing human developmental activities (Mangukiya, 2012). Phosphate is a key nutrient that keeps a water body fertile. The total concentration of all ions in water is referred to as salinity. The physical and chemical properties of freshwater bodies are greatly impacted and characterized by climatic, geochemical, geo-morphological and pollution conditions of surface water quality (Sahni and Yadav, 2012).

Shaji (1990) studied the ecology of certain polluted waters of Gujarat. Nirmal Kumar *et al*. (1991) investigated the extent of pollution caused by industrial effluents in several areas of Central Gujarat. Nirmal Kumar (1992) investigated at the trophic condition of some lentic waters in Gujarat's Kheda District. Rana and Nirmal Kumar (1993) conducted a composite trophic status assessment of a number of freshwater ponds in Central Gujarat, India. Nirmal Kumar *et al*. (2005) conducted extensive environmental investigations on the Rathreshwar wetland, with a focus on surface water hydrochemistry. Soni (2007) investigated the surface water quality of two internationally renowned wetlands (Pariej and Kanewal Community Reservoirs). Nirmal Kumar *et al*. (2008) examined temporal and regional variability in hydro-chemical parameters of a sewage-fed wetland in Anand, MSW Station, Central Gujarat. Kumar *et al*. (2010) assessed the water quality index and hydro-biological parameters of the Sabarmati River and the Kharicut Canal in Ahmedabad, Gujarat. Physico-chemical analysis is critical for determining the quality and stability of water for residential, agricultural, and industrial use (Mangukiya, 2012). As a result, water quality monitoring is now required in order to conduct further management activities. The water contains a variety of dissolved and suspended elements. As a result, many research investigations look at dissolved oxygen, pH, chloride, total hardness, phosphate, turbidity, electrical conductivity, nitrite, total suspended solids, total soluble solids, total solids, acidity, alkalinity, and nitrate. The physico-chemical research could aid in the understanding of the pond ecosystem's structure and function (Mangukiya, 2012). Quantity and quality are two characteristics of water that are inextricably linked. The physical, chemical, and biological qualities of water are referred to as water quality (Parikh, 2012). Over 1 billion people in

the developing world still lack access to safe drinking water, 2.5 billion do not have proper sanitation, and over 3 million people die each year from water-borne diseases, the majority of whom are children under the age of five (Tailor, 2013). Around 80% of urban water supply returns to the drainage system as a result of home and industrial trash. Continuous discharge of industrial water and home sewage has deteriorated the quality of Indian water bodies during the last several decades. The growth of aquatic plants and algae is mostly caused by sewage and fertilisers containing nutrients such as nitrates and phosphates. Depletion of dissolved oxygen happens as a result of plant overgrowth, posing a threat to aquatic life in the ecosystem. Many of the ponds and lakes in developing countries have become so polluted that reconstruction is impossible, and these water bodies will eventually be gone permanently. When the level of dissolved oxygen in the water lowers, a variety of fish and bottom-dwelling organisms cannot live (Tailor, 2013).

GEOCHEMISTRY

Reddy and Patrick (1984) studied the nitrogen loss in soils and sediments of freshwater wetlands of United States. A study on mechanism controlling sediment phosphorous retention of freshwater wetland was carried out in USA by Faulkner and Richardson (2020). Relationships between CO_2 evolution, moisture content, and temperature for from soil samples was delineated by Howard and Howard (1993). Organic carbon content was analysed in depth by Davidson *et al*. (2000). The characteristics of water and sediments also determine the survival of different aquatic organisms inhabiting the wetland (Keddy, 1999). Wetland soils are classified as either organic or mineral. Organic soils have a maximum content (greater than a third) of organic material. Compared with mineral soils, their tendency to hold water is high. Koschorreck and Darwich (2003) studied nitrogen fluctuations in seasonally flooded soils in the Amazon floodplain by comparing the effect of vegetation on soil nitrogen dynamics at three sites with different vegetation (forest, aquatic macrophyte stand, and sediment with annual herbs). Wetlands are featured by soils known as hydric soils, which are formed under conditions of saturation and flooding long enough during the growing season to develop anaerobic conditions in the saturation zone. On the other hand, mineral soils have less than one-third organic content and holds less water compared to organic soils, and have relatively low permeability. Hasegawa and Okino (2004) investigated the seasonal variation of denitrification rate in sediments in the central station of Lake Suwa, Japan. It would not be an exaggeration to state that the whole food web occurring in a wetland ecosystem is based on the physico-chemical characteristics of water and sediments of particular wetland. Wetlands, being one of the most productive ecosystems in the biosphere, have the highest microbial and macrophyte productivity at a high rate, which can be attributed partly to an adequate water supply, high organic loading, high sediment nutrients and organic matter concentrations Nutrients and organic matters are

transported into wetland ecosystems through agricultural drain-off and run-off of water during monsoon, which are important to wetland productivity (Stanley and Ward, 1997). Bragazza *et al*. (1998) compared the seasonal patterns of Na, K, Ca and Mg concentrations, and pH and electrical conductivity in water and sediments of Southern Alps of Italy. The study showed the high content of Ca and Mg dining summer, and decline in pH from spring to autumn. The study showed that the wetlands are very efficient in recycling of nutrients, suggesting the organic matter accumulation within the basin aquifers. Sharip (2018) have worked on inorganic nutrient fluxes across the sediment-water of shallow tropical wetland. According to Sharip (2018), no studies are available to account for the nutrient exchanges at the sediment-water interface that may affect the nutrient cycling and contribute to the observed shift in macrophyte dominance in Chini Lake.

In India, handful of literature is available particularly on water quality, water, and sediment chemistry, recycling of nutrients and their budget, and their relationship associated with environmental conditions of different wetlands. Ecological study of Keoladeo National Park, Bharatpur, Rajasthan, was investigated by Vijayan (1991). Physico-chemical characteristics of Pichhola and Fatehsagar lakes of Udaipur, Rajasthan (Kumar and Sharma, 1991), Purnea Lake (Pandey *et al*, 1991), lotic ecosystem of Doodhganga River, Kashmir (Sarwar and Rifat, 1991) and sources and causative factors of water pollution at Machilinipatam, Andhra Pradesh (Murali and Satyanarayana, 2001) were examined. Sediment acts as a substrate for various biological and chemical reactions; it plays a paramount role in numerous biogeochemical processes, and serves as a surface for adsorption processes and bacterial activity. A comparative evaluation of the organic carbon content of the Cochin harbour area indicated substantial increase during the last two decades (Seralathan *et al*., 1993). The sediments are both carriers and potential sources of natural geochemical constituents derived principally from rock weathering (Sobha *et al*., 2009). The sediments mostly govern the nutrient economy of an aquatic system and knowledge on the role of sediment-nutrient is especially needed in determining the hydro-geo interaction, which ultimately affects the productivity. The sediments act as a sink and play a vital role in changing the quality of the overlying water column. Statistical application on geochemical speciation of heavy metals in sediments of a lake system Chilika, India, was conducted by Panda *et al*. (2010). A study on geochemical distribution of heavy metals in sediments from sewage fed fishponds in Kolkata wetlands was studied by Kumar *et al*. (2011).

Nirmal Kumar *et al*. (1989) carried out EDAX analysis of mud of four ponds from Central Gujarat. Nirmal Kumar and Rana (1994) investigated seasonal distribution of nutrients in sediments of two ponds around Anand District. Nirmal Kumar *et al*. (2006) carried out a detailed environmental study at Nal Sarovar Bird Sanctuary with reference to geochemical assay. Soni (2007) studied detailed

geochemistry of two significant community reservoirs of Central Gujarat. Nirmal Kumar and Viyol (2008) studied the influence of hydro-geochemistry on methane emission from two contrasting tropical wetlands of Central Gujarat. Nirmal Kumar and Viyol (2009) assessed short-term diurnal and temporal measurement of Methane emission in relation to organic carbon, sulphate, and phosphate contents of two wetlands of central Gujarat.

PHYTOPLANKTON

Phytoplankton are the autotrophic components of the plankton community and a key factor of oceans, seas and freshwater basins ecosystems. The name comes from the Greek words (*phyton*), meaning "plant" and (*planktons*), meaning "wanderer" or "drifter. Similarly, algae can be considered as a potential indicator of aquatic pollution. Palmer (1969) made the first and foremost attempt to recognize and categorize a list of genera and species of algae tolerance to organic pollution. In accordance, a score list of 60 genera and 80 species were tolerant to organic pollution. A pollution index factor was assigned to each genus and species by determining the relative number of total points scored by each algal species. According to Palmer (1969), scores of 20 or more indicates the high intensity of organic pollution in an aquatic body. The use of phytoplankton as biological indicators of aquatic pollution has been studied by rating pollution tolerant algae in the water body (Palmer, 1969). Plankton are the primary producers act as chief constituent of ecological pyramids; few genera aid as biological indicators of water quality (Odum, 1971; Patrick, 1971). Nygaard (1976) studied various planktonic algae and their tolerance level in organically polluted aquatic body, and accordingly proposed five indices to evaluate the organic pollution of water bodies based on occurrence of various groups of planktonic algae. These indices are Cyanophycean or Myxophycean Index, Chlorophycean Index, Bacillariophycean or Myxophycean Index, Euglenophycean index and a combination of these indices known as Compound Coefficient Index, which aids in determining the trophic status of the particular water body. Moreover, Nygaard's trophic state index is a handy tool in determining the status of pollution in lakes, ponds and reservoirs (Nygaard, 1976). A pre-impoundment survey of the fauna and flora of any water body is necessary because it provides a checklist of organisms present in the water for subsequent exploitation, conservation, and sustainable management of the resources. The maintenance of a healthy aquatic ecosystem is highly depending on the physico-chemical properties of water and the biological diversity. The fish fauna of a reservoir represents the fish diversity and their abundance. Prescott (1978) delineated identification keys for microscopic proofing of algal taxa. The grazing pressure depends on the zooplankton composition, since the nature of food selection varies among herbivores taxa. In the past, Mittal and Pandey *et al*. (1993) carried out research work on qualitative abundance of planktons in Bhatghar Reservoir, Pune, Maharashtra. Hanson and Butler (1994)

delineated the response of plankton and turbidity level to bio manipulation of ortho-phosphate and ammonia in shallow eutrophic lakes in Minnesota. Food selection by zooplankton is a significant mechanism to control the overall phytoplankton communities (Prins *et al*., 1995). The physico-chemical means are useful in detecting the effects of pollution on the water quality but changes in the trophic conditions of water are reflected in the biotic community structure including species pattern, distribution, and diversity (Kaushik and Saxena, 1995). Gopal and Zutshi (1998) studied community structure, dominance, and seasonality of phytoplankton in tropical wetland in context of nutrient status and water level. Indian freshwater micro-algae were well documented by Plankton has been used recently as an indicator to observe and understand changes in the aquatic ecosystem as is strongly influenced by climatic features (Beaugrand *et al*., 2000; Li *et al*., 2000). Using the similar trophic status index, Misra *et al*. (2001) assessed the trophic status of Bhoj Wetland, Madhya Pradesh, with reference to Nygaard's Index, to determine and interpret the nutrients contents and pollution status. Reservoirs have social and economic importance for human societies, as they bring industrial, agricultural, and urban development, contributing with electric power and supplying water for human consumption and irrigation (Tundisi, 2003). Aquatic ecosystem harbours a variety of communities, which constitutes the characteristics and functioning of the ecosystems in terms of maintaining production and food chain. Phytoplankton are the primary producers and constitute the first level in aquatic food chain for all aquatic animals. The linkage and interdependence between phytoplankton and zooplankton is a dynamic process mainly controlled by several factors, including the ecological and biological factors, which affect the growth of each community and the interaction between them (Aziz *et al*., 2006). Jafari and Gunale (2006) undertook hydro-biological study of algae of an urban freshwater river of Pune City, India, with special context to Palmer Index and Nygaard's Trophic State Index. Most phytoplankton are too minute to be individually seen with the unaided eye. However, when present in high enough numbers, some varieties may be noticeable as a green discoloration of the water; this is due to the presence of chlorophyll pigment within their cells, and in some species also due to the presence of accessory pigments such as phycobiliproteins, xanthophylls, etc. (Thurman, 2007). Studies on phytoplankton community structure in a high land temple pond of Assam, India, was conducted by Baruah and Kakati (2009). Presence of rich planktonic community can be attributed to a-biotic factor and nutrient availability (Goswami, 2012).

ZOOPLANKTON

Zooplankton are heterotrophic (sometimes detritivorous) plankton. The word "zooplankton" is derived from the Greek word *zoon*, meaning "animal", and *planktons*, meaning "wanderer" or "drifter". Zooplankton diversity is one of the most important ecological parameters as these are the intermediate linkage between phytoplankton and fish, and plays a key role in cycling of organic

materials in an aquatic ecosystem. Although zooplankton are primarily transported by ambient water currents, many have locomotion, used to avoid predators (as in diel vertical migration) or to increase prey encounter rate (Edmondson, 1963). Alan (1976) studied the Interactions between zooplankton and phytoplankton profiles in the eastern tropical Pacific Ocean. Gulati and DeMott (1977) studied the role of food quality especially the requirement of Poly-Unsaturated Fatty Acids (PUFA) for Zooplankton. Effect of Temperature on development and growth of Cladocera and Copepod from Tjeukemeer, the Netherlands was studied by Vijverberg (1980). Kerfoot and DeAngelis (1989) studied scale dependent dynamics, the interactions, stability between Zooplankton, and other different food web communities. Havens (1991) investigated the role of Rotiferan and crustacean zooplankton as algae grazers in a freshwater estuary. Pandey et. al. (1994) have worked on physico-chemical factors of Koshi swamps in relation to certain zooplanktonic community in Bihar. Reckendorfer *et al*. (1999) examined the zooplankton density in free-floating section of River Danube, Austria, and their spatial and temporal pattern to identify mechanisms regulating the zooplankton dynamics. David *et al*. (2000) in Central Spain carried out a research work delineating the significance of water inputs to plankton biomass and trophic relationships in a semi-arid freshwater wetland. Influence of temperature on exotic zooplankton species and implications for invasion success in eutrophic Kansas Reservoir (USA), and under laboratory condition was studied by Lennon *et al*. (2001). Wetzel (2001) focused on the biological productivity of zooplankton, stating that they not only form an integral part of the lentic community but also contribute to the biological productivity of the freshwater ecosystem. According to Ferrari (2002), changes in environmental conditions and grazing by zooplankton affect primary productivity. Pandey *et al*. (2004) studied Seasonal fluctuation of zooplanktonic community with respect to certain physicochemical parameters of river Ramjan of Kishanganj in Bihar. Sharma (2005) studied the Rotifer community's species composition, distribution, and ecology in 15 floodplain lakes in the Brahmaputra basin's lower Assam region. Nirmal Kumar *et al*. (2005) undertook a detailed environmental study at Nal Sarovar Bird Sanctuary with particular reference to zooplankton of surface water. Similar sort of interaction pattern between zooplankton and phytoplankton in Lake-Sea connection, Alexandria, Egypt, was carried out by Aziz *et al*. (2006). In depth study on zooplankton density and diversity at two significant wetlands was carried out by Soni (2007). Soni (2007) investigated temporal and geographical variations in community composition and zooplankton population dynamics in relation to nutrients status for two community reservoirs in Central Gujarat (Pariyej and Kanewal Community Reserves). Individual zooplankton is usually microscopic, but some (such as jellyfish) are larger and visible with the naked eye (Thurman, 2007). Howaida *et al*. (2007) focused on the environmental assessment of spatial distribution of

zooplankton community in Lake Manzalah, Egypt. Zooplankton communities, which are cosmopolitan in nature and inhabit all freshwater habitats around the world, are an important link in the transformation of energy from producers to consumers due to their large density, drifting nature, high group or species diversity, and different tolerance to stress (Jalilzadeh *et al*., 2008).Taxonomic composition of zooplankton in three freshwater lakes in relation to the trophic status of some selected ponds of Gulbarga District, North-East Karnataka, South India, was studied by Rajashekhar *et al*. (2009). Dar and Dar (2009) found that due to zooplankton's short life span, their community often exhibits rapid and dramatic changes in reaction to changes in the aquatic habitat's hydro-chemical cycle. Seasonal dynamics of zooplankton in a shallow eutrophic, man-made hyposaline lake in Delhi were studied by Arora and Mehra (2009). Zooplankton is a classification that encompasses a wide variety of organism sizes, from microscopic protozoans to huge metazoans. It includes holoplanktonic organisms, whose complete life cycle lies within the plankton, as well as meroplanktonic organisms that spend part of their lives in the plankton before graduating to either the nekton or a sessile, benthic existence. Nirmal Kumar *et al*. (2011) investigated the spatial composition and species interactions of the zooplankton population of a shallow tropical lake (Thol Bird Sanctuary, Central Gujarat). Sharma and Mankodi (2011) studied a detailed study on diversity of various species of zooplankton at river Narmada near Bharuch in Gujarat.

AVIFAUNAL COMMUNITIES

One in eight of the world's birds are globally threatened with extinction (Bird Life International, 2004). About 150 species of birds have gone extinct from the earth in the last 500 years - a rate of one species extinction every 3.3 years. At present, 179 species of birds are critically endangered *i.e.* facing a high risk of extinction in the immediate future (Bird Life International, 2004). Birds are one of the good indicators of environmental changes, which take place due to human interventions such as intensive farming practices, unsustainable forestry, and habitat fragmentation (Bird Life International, 2004). Paracuellos (2006) studied the factors regulating the distribution of dabbling and diving water birds were studied, taking into account habitat selection by the species in a wetland complex in south-eastern Spain. According to Jathar and Rahmani (2006) very few studies have been carried out on the endemic birds of India. Many researchers have studied the endemic birds of the Indian subcontinent, with Ripley (1961) publishing the early data, followed by Ali and Ripley (1974), Grimmett *et al*. (1998). Birds are excellent barometer for the health of the environment (Gregory and van Strien, 2010). Birds are a good candidate taxon for monitoring global environmental change, because they have long been monitored worldwide Ecological studies on avifaunal diversity have occupied an important place in mainstream ecological research for several

decades. Several avifaunal community studies have shown impacts of anthropogenic activities on ecosystem Structure and Function *viz*. energy flow and material flow.

As India is one of the mega diversity countries (Gadgil and Rao 2013) and harboring two global biodiversity hotspots and seven endemic bird areas of the world (Grimmett *et al*., 1998), India has about 12 % (1,224 species) of the world's avifaunal richness. Of these, 141 species are endemic to the Indian sub-continent (Grimmett *et al*., 1998) and 50 species are endemic to India. Considering the wealth of bird species and the diversity of habitats, studies on forest bird communities are few in India (Trivedi, 2006). Birds are vital to human society's economic well-being. They are crucial in regulating the proliferation of many insects and pests. They play the role of scavengers and pollinating agents and helps in dispersal of seeds of different vegetation (Rasal, 2011). Birds are also more sensitive to toxins in the environment than other vertebrates; therefore, they can serve as bio-indicators (Vashishat and Kler, 2015).

According to State of Indian Birds (2020), 48% of species stable or increasing in the long term and 79% decreasing in the last five years (2015-2020). Birds' cultural significance is matched by their ecological significance. Birds play vital roles in the health of ecosystems through their actions as pollinators, seed dispersers, predators, scavengers, and as prey for other species (SoIB, 2020).

As Gujarat Provides major wintering ground for the Demoiselle Crane (*Anthropoides virgo*), Common Crane (*Grus grus*), and Sarus Crane (*Grus antigone*), and a crucial nesting area for the Greater and the Lesser flamingos (*Phoeniconaias spp*.). Gujarat is a world-renowned avian hotspot (Khacher, 1996). Its location on the Indus Flyway - an important route for migratory birds and variety of habitats make it an important place on the ornithological map of India. Several studies have shown that group of birds are adapted for the habitat having combination of characteristics. Birds are more active and susceptible to landscape structure in the highlands, and they are more visible among faunal groupings. Loss, fragmentation, and degradation of habitat caused by humans have been regarded as important factors for species extinctions with respect to Indian ornithogeography, Gujarat is an important region. For many forest areas in this region, even basic presence/absence data on bird species is unavailable (Trivedi, 2006). Habitats are the resources and conditions in a location that allow a specific organism to live there, including survival and reproduction, and so include more than just plants and vegetation structure. A habitat is the collection of certain resources that an organism need. Habitat associations for poorly studied species are necessary for assessing their relative sensitivity to a multitude of potential factors. Among the diverse biota supported by the water birds, that are known as indicators of health of wetlands, form a prominent component used for the assessment of a habitat. Hence, in depth study of birds are

important with reference to biotic and abiotic parameters known that have direct impact on the productivity of wetland (Deshkar *et al.*, 2008).

CONSERVATION AND MANAGEMENT STRATEGIES

Inland freshwater ecosystems are progressively being stressed as a result of a variety of human activities (Wood and Gibson, 1974). Wetland loss has been a trend in the past, particularly in the developed world, where a variety of other land uses competes for wetland space. The most serious concerns now, however, are in the developing world, where the disconnection of traditional human-ecosystem relationships is likely to result in irreversible losses (Maltby, 1991). In the developed world, where wetlands have lost much of their original area and where environmental concerns are fast growing, sound management and conservation are critical. They are, nonetheless, critical in the developing world, where wetland function is intricately related to human survival as well as environmental and genetic resources (Maltby, 1991). According to Maltby (1991), wetlands have traditionally been protected as a result of their distinctive, unusual, or endangered flora and fauna. Wetlands, on the other hand, support a variety of biological, hydrological, chemical, and physical processes that result in ecosystem functioning and the provision of valuable goods or services for: (i) wildlife welfare and gene pool maintenance; (ii) direct and indirect human use; and (iii) environmental maintenance and quality. Wetland protection has become a major concern in recent years, and many natural wetlands are heavily used by waterfowl (Petrie, 1998). In India, wetlands can be found in a variety of natural zones. Wetlands have long been recognized for their importance, but their function in preserving ecological balance is less well understood. The IUCN Ramsar Convention, held in Iran in 1971, enhanced global awareness of the need of wetlands conservation and management (Chopra, 2001).

Maltby (1991) mentioned that wetland scientists are now faced with the task of translating increased knowledge into positive action. It signifies that the following items must be prioritized.

(1) Continued development of the science base, which must underpin management and conservation strategies with special reference to identification of options for sustainable utilization.

(2) Specific research into the ways in which wetlands are used or are necessary for life and economic support particularly in the Third World nations and development of functional analysis procedures appropriate to these needs.,

(3) Full assessment of the significance of wetlands on a global scale with particular reference to the carbon balance.

(4) Implementation of policies for wetlands management and use, which recognize their international importance and the existence of cross-sectoral interest groups.

(5) Active rehabilitation, restoration or creation of wetlands in the industrialized world to replace the huge extent of resources that have been lost.

(6) Demonstration projects to establish practical ways of using wetlands sustainably and meeting the demands of different interest groups.

CONCLUSION:

This review study will contribute in the field of wetland ecology, ecosystems complexes, aquatic biology and biodiversity conservation, water pollution, and ecological sustainability. This base-line information on wetland ecosystem will also be helpful in providing the timely information to conserve, protect, and manage the freshwater wetland ecosystems. The review will also provide an idea about interrelationship and interaction between hydro-chemistry, geo-chemistry, plankton dynamics, and avifaunal assemblage of significant inland wetlands of Gujarat. In order to draw out the health status of any ecosystem, the interrelationships of physical, biological, and chemical components of a wetland are integral part of the ecological study. The whole biota of aquatic ecosystem is depending upon the ecological balance and interrelationship between different factors of the ecosystem for their regulatory processes.

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