BIOMONITORING OF WATER QUALITY OF DIKHU RIVER IN NAGALAND THROUGH MACROINVERTEBRATE FAUNA

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CERTIFICATE

This is to certify that the thesis entitled "Biomonitoring of Water Quality of Dikhu River in Nagaland through Macroinvertebrate Fauna" is a record of original research work done by Mr. Lanuyanger Longchar under my supervision. He is a registered research scholar (regd under Late Pof. S.U. Ahmed Regd. No.645/2015) of the Department and has fulfilled all the requirements of Ph.D. regulations of Nagaland University for the submission of the thesis. The work is original and neither the thesis nor any part of it has been submitted elsewhere for the award of any degree or distinctions. The thesis is therefore, forwarded for adjudication and consideration for the award of degree of Doctor of Philosophy in Zoology under Nagaland University.

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I, Mr. Lanuyanger Longchar hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University.

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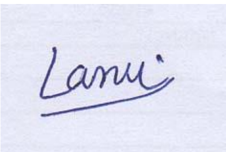

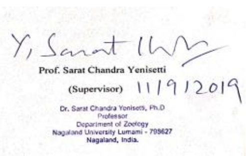

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DEDICATED TO

1. The Living God.
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INTRODUCTION

1. INTRODUCTION

Water being a prime natural resource, has many surprising properties that are important to life and it covers three fourth of earth's surface. Quality water is vital to the social, health and economic wellbeing of all people. Although they contain only about 0.0001% of the total amount of water in the world at any given time, rivers are vital carriers of water and nutrients to all areas around the earth. They are critical components of the hydrological cycle, acting as drainage channels for surface water. The world's rivers drain nearly 75% of the earth's land surface.

Rivers are vital and vulnerable freshwater ecosystems that are critical for the sustenance of all life. However, the declining water quality of these ecological systems threatens their sustainability and is therefore a matter of serious concern. Rivers are waterways of strategic importance across the world, providing main water resources for domestic, industrial and agricultural purposes (Jain, 2009). River, as the source of the social development, is the most active part of the topographic process and ecosystem (Mmopelwa, 2006). Rivers and streams are characterized by flowing waters and are called lotic systems. Usually rivers and streams have a one-way downhill flow and in these lotic environments, flow rate is of prime importance in determining the nature of plant and animal community (Osborne, 2000). Lotic environments have been described as having four dimensions: a longitudinal dimension with a pronounced zonation of chemical, physical and biological factors; a lateral dimension involving exchanges of organic matter, nutrients and biota between the stream channel and the adjacent floodplain; a vertical dimension consisting of a hydraulic connection linking the river channel with groundwater; and a fourth dimension of time which pertains to the velocity of the water flow. The run off rivers are wide and shallow in summers; as a result, water velocities are low. These low velocities allow the accumulation of fine silt and sand to the substrate. Rivers are not merely channels that transport water; they are complex ecological systems, which interact with their drainage basins collecting water, nutrients and organic matter from them and re-distributing these to the downstream. They support large biological diversity, support the humans and their activities and provide several services that no other ecosystems can (McCarteny, 2007).

The river ecosystem is formed by the interaction between river biota and their hydro-geochemical environment. It is characterized by the continuous transport of various substances, such as organic matter and the nutrients, from the soils of the drainage basin to the river and from there, downstream with the flowing water. River ecosystems are adapted to the natural hydrological regime and many components of these systems rely on floods for the exchange, not just of water, but also energy, nutrients, sediments and living organisms (Acreman, 2000). River ecosystem contains many other smaller types of ecosystems, including many of that which does not lie within the open-water channel. River ecosystem is also unique in that they are relatively small volume, but open, ecosystems with high rates of energy throughout. Therefore, understanding a river ecosystem is clearly a challenging and complicated task.

Nagaland is dissected by a number of seasonal and perennial rivers and rivulets. The major rivers of Nagaland are Doyang, Dikhu, Dhansiri, Tizu, Tsurong, Nanung, Tsurang or Disai, Tsumok, Menung, Dzu, Langlong, Zunki, Likimro, Lanye, Dzuza and Manglu. All these rivers are dendritic in nature. Of the rivers, Dhansiri, Doyang and Dikhu flow westward into the Brahmaputra. The Tizu River, on the other hand, flows towards east and joins the Chindwin River in Burma.

Dikhu River is one of the most prominent rivers of Nagaland. River Dikhu, which has a total length of about 160 km, originates from Nuroto Hill area in Zunheboto district. The river flows across the Mokokchung and the Longleng districts. The main tributaries of river Dikhu are Yangyu of Tuensang district and Nanung in the Langpangkong range in Mokokchung district.

The Dikhu River is one of the tributaries of Brahmaputra, one of the mightiest rivers of India. The Dikhu River is not only a prime tourist attraction, but also a significant source of livelihood for the people. The water makes the area around the river fertile. Since Longleng is primarily an agricultural district, the Dikhu River serves as a lifeline to its people.

1.1. Water quality parameters

The term "Water quality" refers for the physical, chemical and biological parameters of water and all these characteristics directly or indirectly influences the survival and production of aquaculture species (Boyd, 1998).The seasonal variation in the ecological parameters exerts a profound effect on the distribution and population density of both animal and plants (Odom, 1971). The physical and chemical characteristics of water are important parameters as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic animals (Moses, 1983). The physical and chemical limnology of a river is characterized by hydrologic impact, autogenic nutrient dynamic and biological aspects. These factors were used to determine the water quality and consequently community of the river (Mustapha and Osmotrosho, 2005; Sidnei *et al.*, 1992).

The seasonal variations in physico-chemical factors have a profound effect on the distribution and population density of both fauna and flora (Mahboob, 1986, 1988 b, 1989 a; Mahboob & Sheri, 2001). Temperature measurements occupy a central position in limnology and one of the most important and essential parameters of aquatic habitats because almost all the physical, chemical and biological properties are governed by it. It influences the oxygen contents of water quantity and quality of autotrophs, while affecting the rate of photosynthesis and also indirectly affecting the quantity and quality of heterotrophs (Barnabe, 1994).

Animals are stressed when temperature changes rapidly, because there is not enough time for physiological adaptation (Boyd, 1998). The intensity and seasonal variation in temperature of water directly affect the productivity of rivers. All organisms including fish possess limits of temperature tolerance and the seasonal fluctuation of temperature influences the feeding habits of the fish. Water temperature has direct relationship with phytoplankton population (Devika *et al.*, 2006). The temperature of about 35ºC is generally considered as maximum for survival of aquatic life. The temperature of water in a river changes with the seasons and often varies with depth. During spring and summer, the sun warms the upper layer of the waters. As the sun continues to warm the river surface, the temperature differences increase between the surface and deeper waters. Water temperature plays a driving role in most physicochemical processes in rivers (Fang and Stefan, 1999).

Turbidity or suspended solids is the measurement of inhibition of light passing through a water sample (Landau, 1992). Turbidity is the name given to the clarity of water which is affected by the amount of the suspended solids in it and turbidity reduces the light penetrating depth, and hence, reduces the growth of the plants (Landau, 1992). Turbidity by plankton is harmful to fish adaptations in water bodies due to the lack of biological oxygen demand. The pH expresses the acidity or alkalinity of water which is determined by means of hydrogen ion (H^+) and the hydroxyl ion (OH^-) in water. Hydrogen ion concentration plays an important role in the biological processes of almost all aquatic organisms (Welch, 1952). Waters of around pH 7 are called as neutral. The seasonal variation in pH is mainly affected by temperature, salinity, carbonate and bicarbonate system rather than the photosynthetic activity of the primary producers (Ezz El-Din, 1990). During day light, aquatic plants usually remove the CO_2 from the water quickly and pH increases. At night, carbon dioxide accumulates and pH declines in water bodies. The magnitude of daily fluctuation and pH depends on the buffering capacity total alkalinity of water and rates of photosynthesis respiration (Boyd, 1998).

Specific conductivity can be utilized as a rapid measurement of dissolved solids and is useful in monitoring waste streams and conducting field water quality studies (Frank *et al.*, 1994). The level of conductivity in water gives a good indication of the amount of joinable substances dissolved in it, such as phosphate, nitrate and nitrites. Conductivity of the natural water is directly proportional to the concentration of ions. Distilled water has a conductivity of about 1μmhos/cm, while natural water normally has conductivity of 20-1500 μmhos/cm (Boyd, 1998). Conductivity is a good and rapid method to measure the total dissolved solids and is directly related to total solids (Mishra and Saksena, 1993). The variation in electrical conductivity of the water depend on the climate, seasonal variation, soil source, geological origin and the content of the ionic salts such as calcium, magnesium etc. (Wetzel,1983). The conductivity of the inland water should range between 150 to 450 μs/cm to flourish flora and fauna in waters (Ellis, 1937).

Total dissolved solids refer to dissolved matter in water. They are very useful parameters describing the chemical constituents of the water and can be considered as a general of edaphic relations that contribute to productivity within the water body (Goher, 2002). Higher the value of dissolved solids, greater will be the amount of ions in water. Total dissolved solids indicate organic and inorganic matter in the sample. It is aggregated amount of the entire floating suspended solids present in water sample. A high concentration of dissolved solids increases the density of water, affects osmoregulation of fresh water organisms, reduces solubility of gases and utility of water for drinking, irrigational and industrial purposes (Boyd, 1998).

Oxygen content is important for direct need of many organisms and affects the solubility and availability of many nutrients and therefore the productivity of aquatic ecosystem (Wetzel, 1983). Dissolved oxygen in water is of great importance to all aquatic organisms and is considered to be the lone factor which to a great extent can reveal the nature of whole aquatic system. It is important in the production and support of life. It is also necessary for the decomposition and decaying of organic matter. This parameter can be used as an index for net production (Heyman, 1983). Dissolved oxygen concentration more than 5.00 mg/l favors good growth of flora and fauna (Das 2000). Thus, the dissolved oxygen varies greatly from one water body to other. In summer season dissolved oxygen decrease due to increased temperature of water (Naz and Turkmen 2005) and dissolved oxygen has primary importance in natural water. In all dissolved gases, oxygen plays the most important role in determining the potential biological quality of water. It is essential for respiration, helps the breakdown of organic detritus and enables completion of biochemical pathways (Boyd, 1998). Dissolved Oxygen has been attributed a great significance as an indicator of water quality especially the magnitude of eutrophication. Dissolved Oxygen in water depends mainly upon temperature, concentration of dissolved salts, wave action, velocity of wind, pollution load, photosynthetic activity, and respiration rate by organisms (Ganapati, 1943; Reid, 1961; Zutshi & Vass, 1978).

Chlorides occur naturally in all types of water. In natural fresh waters, however, their concentration remains quite low and generally less than that of sulphate and bicarbonate. High concentration of chloride in water is considered to be the indicator of pollution especially due to higher organic waste of animal origin or industrial effluents. Higher chloride content is due to contamination through large quantity of sewage input. Higher concentration of chloride in water is an indicator of eutrophy (Kausik, 1992).

The nitrate and phosphate are two important constituents that immensely help in the growth of plants. If they are present in the river they excessively promote the growth of aquatic weeds and pollute our aquatic resources. Presence of nitrate in water indicates the final stage of mineralization (Nema *et al.*, 1984). Phosphate has a few sources in nature and also acts as a regulating factor for productivity of water body. Higher concentration of phosphate is an indicator of pollution, which induce possibility of eutrophication (Singare *et al.*, 2011). Sulphate forms an important constituent of hardness and used by organisms for protein synthesis. It enters into water body by the weathering of sedimentary rocks, by bathing and washing clothes (Jain *et al.*, 1996).

1.2. Macrozoobenthos

The term benthos is widely referred to flora and fauna which are intimately associated with sediments in an aquatic ecosystem (Adoni, 1985). The physical bottom and chemical factors of a water body provide habitat for this animal group called as macrozoobenthos or simply benthos. Macrozoobenthos consists of groups of animals such as: insecta, oligochaeta, mollusca and some others. They may include larvae, pupae and adult insects. Some of them pass all their life in water and other only part of their developmental stage (Subramanian and Sivaramakrishnan, 2005). The distribution of benthic community directly gets affected by biotic environment of the water body (Nkwoji *et al*., 2010). Their distribution depends on substratum, quantity and composition of organic matter in sediments (Subramanian and Sivaramakrishnan, 2005). The habitats of different taxa of the benthic forms differ from one another. As per their breeding habitats, place of attachment, availability of food etc. the organisms are distributed from littoral zone up to profundal zone of the water body (Vyas and Bhat, 2010a).

Benthic fauna plays significant role in the functioning of aquatic community with their involvement in organic matter in mineralization and recycling (Allan, 1995). Therefore, a study on benthic community became a reliable source to provide the scenario of prevailing environment conditions and the impacts of changing hydrobiology of the water body (Ali *et al*., 2003). Several scientists have stressed the importance of benthic fauna as valuables indicators of environmental conditions of aquatic water bodies (Hynes, 1975).

Streams and rivers receive all types of discharges from human activities including food production, cultivation, collection of drinking water, harvesting of wood, forage and craft materials, and extraction of clay for pottery and brick making (Dixon and Wood, 2003). This leads to water pollution and aquatic ecology degradation, which can certainly affect human health. Despite the benefits and services that they provide for humans, wetlands as well as their streams/rivers all over the world are threatened (Schuyt, 2005).

In the past decades, however, countries and organizations worldwide have been developing indicators to identify and quantify the stressor effects. Particularly, metrics associated with biological communities (i.e. fishes, macroinvertebrates, diatoms, macrophytes) have been widely used, but they are usually calibrated over broad datasets considering both reference and impaired streams (Canobbio *et al*., 2013). Biological methods are valuable for determining natural and anthropogenic influences on water resources and habitats because biota respond to stresses from multiple spatial or time scales integratively (Weigel and Robertson, 2007; Resende *et al*., 2010). In addition, the use of aquatic organisms in ecological studies has proven more effective than environmental variables because the aquatic community integrates structural and functional characteristics and reflects the health of the studied streams (Rosenberg *et al.*, 1993; Bonada *et al*., 2006). Among others, macroinvertebrates are the most commonly used assemblages (Resh, 2008) because they integrate various desirable characteristics, such as ubiquity, different levels of tolerance to perturbations, and sampling cost-effectiveness (Rosenberg *et al.*, 1993; Li *et al*., 2012).

A great variety of biotic indices and scores based on macroinvertebrate community as indicators have been developed and applied for water quality assessment, such as the Extended Trent Biotic index (ETBi) (Chandler, 1970), Belgian Biotic index (BBi) (De Pauw and Vanhooren, 1983), Rapid Bioassessment Protocols (RBPS) (Barbour *et al*., 1999), Biological Monitoring Water Quality (BMWQ) (Camargo and Mu˜noz, 1989), Multimetric Macroinvertebrate Index Flanders (MMIF) (Gabriels *et al*., 2010), Family-level Biotic Index (FBI) (Hilsenhoff, 1988), Indice Biologique Global Normalis´e (IBGN) (C. G. Environnement, 2000), Average Score per Taxon (ASPT) (ing´enieur, 2002), and the Biological Monitoring Working Party (BMWP) (ing´enieur, 2002). Other methods can consist in the prediction of water quality by using a back propagation neural network (BP-NN) model (Ma *et al.*, 2014) or to estimate critical metal concentrations for good ecological water quality by using macroinvertebrate based biotic index (Van *et al*., 2015). An important advantage of multimetric indices is that they are flexible and can easily be adjusted by adding or removing metrics or fine-tuning the metric scoring system (Gabriels *et al*., 2010). Moreover, they allow objective classification of biological quality of sites belonging to different, natural, modified, artificial and variously degraded systems (Verneaux *et al*., 1982). Most interestingly, freshwater macroinvertebrate species vary in sensitivity to organic pollution and, thus, their relative abundances have been used to make inferences about pollution loads. In natural pristine rivers, high diversity and richness of species could be found (Sokal and Rohlf, 1995). However, high impact due to human activities caused many changes to the assemblages and biodiversity of the river fauna (Wright *et al*., 1993; Pinel *et al*., 1996). Literature provide little information on biological assessment and monitoring tools of freshwater quality (Dallas, 1997; Macroinvertebrates in the catchment streams of Lake Naivasha, 1998; Mansiangi, 1999; Mbadu, 2002; Mathooko, 2002; Beyene *et al*., 2009; Ambelu *et al.,* 2010; Negash *et al*., 2011; Getachew *et al*., 2012; Ansah *et al*., 2012; Koto-te niwa *et al*., 2013; Ndaruga *et al*., 2004; Mereta *et al*., 2013; Adams, 1993).

Water quality characteristics of aquatic environment arise from a multitude of physical, chemical and biological interactions. A regular monitoring of water bodies with required number of parameters in relation to water quality prevents the outbreak of diseases and occurrence of hazards. The systematic use of living organism for monitoring and analysis of water quality originated in Europe early in this century and is widely used (Cairns and Pratt, 1993; Metcalfe-Smith, 1994). Dudgeon *et al*. (1994) stressed the importance of biomonitoring and identifying areas of riverine biodiversity for long term accountability and conservation. Around the world, freshwater habitats are being subjected to increased levels of human disturbance (Saunders *et al*., 2002). Wetland ecosystems are inhabited by wide variety of organisms and are considered richest sources of biological diversity. Bellingham (2012) explained that in order to mitigate the impact human societies have on natural waters, it is becoming increasingly important to implement comprehensive monitoring regimes.

Zoobenthos is characterized as a group of invertebrates, which spend at least part of their life cycle at the bottom substrate in the water bodies. The biotic environment of the water body, directly affect in the distribution of population density and diversity of the macro benthic community. Due to anthropogenic pressure and rapid urbanization these water bodies act as reservoirs to organic wastes (Pani and Misra, 2000). The benthic communities are composed of a wide array of flora and fauna, links all levels of food web and inhabit different types of habitat such as mud, sand attached to rocks, stones, macrophytes and other solid organic matter. Freshwater benthic macro-invertebrates, or more simply “benthos”, are animals without backbones that are larger than ½ millimeters (the size of a pencil dot). These animals live on rocks, logs, sediment, debris and aquatic plants during some period in their life. The benthos includes crustaceans such as crayfish, molluscs such as clams and snails, aquatic worms and the immature forms of aquatic insects such as stonefly and mayfly nymphs.

Benthos is an important part of the food chain, especially for fish. Many invertebrates feed on algae and bacteria, which are on the lower end of the food chain. Some shred and eat leaves and other organic matter that enters the water. Because of their abundance and position as “middlemen” in the aquatic food chain, benthos plays a critical role in the natural flow of energy and nutrients. Some organisms serve as indicators of water pollution (organically or nutrient enriched waters) such as Oligochaeta, some Syrphidae (Diptera). It is predicted that a positive relationship exists between the densities of these organisms to the degree of organic pollution.

The lower species diversity index in general shows a more polluted water body. Tolerance to pollution is important for understanding the distribution of species. Benthic organisms take a great part in trophic relations, fluctuations and abundance of biomass, and water quality evaluation.

The marcoinvertebrates of freshwater wetlands provide significant support to the aquatic food web and contribute to ecosystem stability through sustenance of cultivatable fish, aquatic birds and other wild life. Their composition, abundance and distribution pattern acts as an ecosystem index, thereby indicating trophic structure, water quality and eutrophication level of the ecosystem (Mehdi *et al*., 2005).

1.3. Dikhu River

Dikhu River is one of the most prominent rivers of Nagaland. River Dikhu, which has a total length of about 160 km, originates from Nuroto Hill area in Zunheboto district. The river flows across the Mokokchung and the Longleng districts. The main tributaries of river Dikhu are Yangyu of Tuensang district and Nanung in the Langpangkong range in Mokokchung district. The Dikhu River is one of the tributaries of Brahmaputra, one of the mightiest rivers of India. The Dikhu River is not only a prime tourist attraction, but also a significant source of livelihood for the people. The water makes the area around the river fertile. Since Longleng is primarily an agricultural district, the Dikhu River serves as a lifeline to its people.

During the present investigation the river was studied for a period of 24 months. The river was divided into five collection sites on the basis of different types of substratum and ecology of the sites. As such the present river was divided into five sites shown in map.

Site I - Longmisa Noksen	(N 26° 31’ 30.953” E 94° 41’ 13.429”)
Site II - Longmisa- Chuchu	(N 36° 32’ 4.68” E 94° 41’ 46.027”)
Site III - Longkong	(N 26° 32’ 12.559” E 94° 42’ 4.721”)
Site IV - Changtongya Yaongyimsen	(N 26° 32’ 22.511” E 94° 42’ 15.381”)
Site V- Changtongya Longleng	(N 26° 20’ 9.078” E 94° 38’ 29.799”)

1.4. Objectives

Although there has been immense work done on the pollution and water quality parameters, but there is scare information on the correlation between the pollution status of various parameters sequentially and statistically. The present work gives a detailed account on various parameters correlated in the present study. The present work plan would be as under:

(a) To study the geomorphology and habitat inventory of Dikhu river

(b) To record the seasonal variations of the limnological parameters of the river

(c) To assess the benthic marcoinvertebrates diversity selected stretches of the river

(d) Bio-monitoring of 'river health' through molluscan/annelid species.

4-15The analysis and presentation of the data in the present thesis will be a basic platform for the researchers on the management aspects of the Dikhu River. The work may also be used to establish relations between the various physical, chemical and biological parameters existing within the river ecosystem.

Chapter 2

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Till date extensive work has been carried out in the field of limnology throughout the globe and as such a voluminous literature is available on the subject. In view of the objectives of the present research, a critical survey of literature was carried out to gather information on various aspects of limnology of various water bodies. Further, for the sake of convenience only the literature from late 1970 century is presented. The present review is dealt in the following four headings:

2.1 Geomorphology and habitat inventory of Dikhu river

2.2 Seasonal variations of the limnological parameters of the river

2.3 Benthic marcoinvertebrates diversity

2.4 Bio-monitoring of ‘river health’ through molluscan/annelid species

2.1 Geomorphology and habitat inventory

Hydrological survey of various rivers in different parts of the world has been carried out mostly in the latter half of the twentieth century. Probably the most extensively studied rivers of the world were the European rivers. Among the significant works made in the last 25 years include Backiel & Penczak (1989) on River Vistula; Lelek (1989) on River Rhine; Pavlov & Vilenkin (1989) on River Volga; Kajak (1992);

Vadineanu *et al*., (1992); Fruget (1993) on River Rhone; Gastescu (1993); Petts (1984, 1990 & 1994); and Whitehead & Noe, (1995) on rivers of Western Europe. On the other hand, the Murray-Darling River system of Australia, the fourth longest in the world, is also extensively studied by a large number of workers (Cadwallander, 1986; Mackay & Shafron, 1989; Pollard, 1990; Sharley, 1993 and Walker & Thomas, 1993). The fauna including the aquatic invertebrates from certain African rivers were reviewed by Lowe-McConnell (1987). Limnology of the North American rivers was a matter of attraction for a number of workers (Hesse *et al*., 1989; Benke, 1990). Karr (1993) in his extensive review documented rapid depletion of vertebrate and invertebrate, especially molluscan from the North American rivers. River degradation has severe effects on fish yields and fish stocking and habitat management program are being pursued in United States and Canada (Mitchell & Gardiner, 1983; Dodge & Biette, 1993) for the assessment of the ecological conditions and integrity of water resources.

Subsequently literature is also available on the riverine ecology of the different regions of Asia. Some classical works among them are: Satomi (1976) in Japan; Young (1976) in Korea; Qureshi (1976) in Pakistan; Datingaling (1976) in Philippines; Willey (1910) in Sri Lanka; Smith (1945); Brandt (1964); Hiranyawat (1968) and Boonsom (1976) in Thailand; Gopalakrishnan (1976) in the Indo-Pacific and Chowdhury & Bhuiya (1990) in Bangladesh. In Indian context, among all the rivers, the Ganga river received more attention from Indian workers (Jhingran & Chakravorty, 1958; Rai, 1974; Jhingran & Tripathi, 1976; Bilgrami & Datta Munshi, 1979; 1985; Sikandar & Tripathi, 1984; Chattopadhya *et al*., 1984; Choudhari & Ojha, 1985; Sikandar, 1987; Ghose & Sharma, 1988; Sengupta *et al*., 1988; Singh, 1988; Sinha *et al*., 1989; Shukla *et al*., 1989; Datta Munshi & Singh, 1991; Saxena *et al*., 1993; Khanna, 1993; Singh *et al*., 1994 and Madhyastha *et al*.,1999). The limnological studies on the other important rivers of India include the River Godavari (Bhimachar, 1959; Ganapati, 1964); River Yamuna (Chakrabarty *et al*., 1959; Chandraprakash and Grover, 1978; Bhargava, 1985; Saxena & Chauhan, 1993; Sharma *et al*., 2000); River Gomati (Bhaskaran *et al*., 1965; Arora *et al*. 1973); River Daha (David & Ray, 1966); River Tapti (Karamchandani & Bisolkar, 1967); River Hooghly (Ghose and Sharma, 1989); River Cauvery (Sampath *et al*., 1979 and Somasekhar, 1984); River Jhelum (Sundar, 1988) and River Narmada (Unni & Naik, 1997).

During the last three decades, the ecology of the Himalayan rivers has also been studied in detail (Badola and Singh, 1981; Nautiyal *et al*., 1986; Bhatt & Pathak, 1989; Pathak *et al*., 2001). There are substantial published works on the hydrobiology of the rivers and floodplain lakes of the Indian sub-continent and these were reviewed by Gulati & Wartz-Schulz (1980) and Michael (1980). The study of rivers and river basins from hydrologic, hydraulic and fluvial geomorphic point of view gained due importance through the pioneer works of Knighton (1984); Borah & Goswami (1988); Basu *et al*. (1996); Goswami (1998); McCully (1996) and Kar & Goswami (1997). Similarly many other Indian rivers have also been extensively studied for physico-chemical aspects. For example, Das and Srivastava (1965) on the rivers in Bihar; David & Ray (1966) on the

River Daha; Sankaranarayanan *et al*. (1986) on the River Periyar; Badola & Singh (1981) on the River Alakananda, Mitra (1982) on the rivers Godavari, Krishna and Tungabhadra, Singh & Hasnain (1999) on River Damodar, Kappor (1993) on the rivers in Uttar Pradesh, Guptachoudhury *et al*. (2011) on River Namdapha, Dutta & Dutta (2010) on Namsang stream, Pathak *et al*. (2001) and recently by Srivastava, (2000), Verghese (2005), Baruah (2007), Hazarika (2008), Baruah *et al*. (2008), Sarma, (2008), Hazarika *et al*. (2009), Baruah and Hazarika (2009); Hazarika *et al*., (2009), Dutta *et al*. (2010A), Dutta *et al*. (2010B), Hazarika & Bhuyan (2010), Baruah *et al*. (2011), Hazarika *et al*. (2011), Dutta *et al*. (2011A), Dutta *et al*. (2011B), Dutta and Sarma (2012) on the downstream of river. There are also a few reports available on the hydrobiology and fisheries of the Brahmaputra river basin (Dey, 1976, 1981 and 1984; Jhingran & Pathak, 1988; Chandra, 1988; Singh *et al*., 1988; Biswas & Michael, 1992; Biswas *et al*., 1995; Biswas, 1998; Biswas & Boruah, 2000; Boruah & Biswas, 2002; Biswas & Boruah, 2010; Das & Biswas, 2011).

2.2 Limnological Studies

Limnology is an inter-disciplinary science which involves a great deal of detailed field as well as laboratory studies to understand the structural, functional aspects and problems associated with the freshwater environment, from a holistic point of view. Many recent studies have highlighted research in the field of water quality monitoring and assessment (Yu *et al.*, 2003; Lambrakis *et al*., 2004; Simeonova, 2006; Shrestha and Kazama, 2007; Solanki *et al*., 2010: Juahir *et al.,* 2011; Malik and Nadeem, 2011). Comprehensive application of different multivariate statistical techniques in water quality assessment has been over a period of time (Liu *et al.*, 2003; Simeonov *et al.*, 2003; Singh *et al.*, 2005; Simeonova and Simeonov, 2006; Simeonova, 2007; Zhang *et al*., 2009; Dolotov *et al.*, 2010; Guyer and Ilhan, 2011).

Physico-chemistry of water provides important parameters for quantifying biogeochemical cycles and establishing management options in river systems and wetlands. Eduardo *et al.* (2014) worked on physico-chemical features of major Amazonian water typologies. The first scientific classification of Amazonian water bodies was elaborated in the 1950s by Sioli (1956a; 1956b). Attributes such as water color, transparency, pH and electrical conductance were studied to explain limnological characteristics of the large Amazonian rivers. The innovative aspect of his classification was the correlation of these characteristics to the geological and geomorphological properties of the river catchments, an approach used today in landscape ecology. This simplified classification has dominated until today the scientific discussion about limnology and ecology of the Amazon basin. Flura *et al*. (2016), on the other hand, evaluated the physico-chemical and biological properties of water from the river Meghna, Bangladesh.

In many countries including India, the rivers are not only being exploited but are also used as dumping grounds for effluents, sewage and solid wastes. Direct or indirect contact of chemicals or waste water to the sources of drinking water causes undesirable changes in its composition, which proves detrimental for all living organisms. Considerable investigations of physicochemical properties of the river water are carried out in India (Borse, *et al.* 2003, Singh and Gupta, 2004, Barai and Kumar, 2012, Deshmukh, 2012, Chaurasia and Karan, 2013, Kushram, 2013; Majumder and Dutta, 2014 and Sharma, 2015). A water body affects the environment in its vicinity, like changing of ground water tables, conditions of climate etc. Most of the people like washer man, and fisherman, living in the surrounding area depend on this source of water for their survival. Any damages to this water source by any agency will not only make life miserable but that will also disrupt the aquatic ecosystem. It is therefore necessary to study the quality of river water, on the basis of physico-chemical parameters so as to assess its portability (Parvati, 2016). On the same context, Xia Liu *et al* (2016) worked on the water quality characteristics of Poyang Lake, China, in response to changes in the water level.

2.3 Studies on macrozoobenthos fauna

Macrozoobenthos comprise of an important group of aqua fauna by way of their contribution to ecosystem stability, besides acting as potential bioindicators of trophic status. Being efficient energy converters, they constitute an important link in the aquatic food web. Odum (1971) described common inhabitants of sewage water with particular reference to oligochaetes. Learner *et al*. (1971) examined benthos assemblage above and below a point source of sewage and found upstream to be quite diverse while downstream to be left with only chironomids and oligochaetes. Dance and Hynes (1980) and Ajao and Fagado (1990) observed the distribution of macrozoobenthos in waters receiving complex mixtures of domestic waste. Seasonal dynamics of macrozoobenthic organisms in diverse water bodies were discussed by Munawar (1970 a,b); Mandal and Moitra (1975); Das (1979); Rai and Datta Munshi (1979); Chowdhary (1984); Sharma (1986); Kaushik *et al*. (1991); Dhillon *et al*. (1993a); Syal (1996); Singh (1982) and Yousuf *et al*. (2002). Rich vegetation provides food and shelter to the growing zoobenthos was suggested by Needham and Llyod (1916); Krecker (1939); Andrews and Hasler (1943); Tonapi (1980); Sharma (1988); Kaushik *et al*. (1991); Kumar (1996b); Bath and Kaur (1998) and Sajeev (1999). Cordery (1976) studied the impact of stress imposed by motor boats on the aquatic insects. The impact of silt on the aquatic organisms was reported by Kaul *et al*. (1978) and Pennak (1978).

In contaminated sections of the water body, chironomids and tubificid worms were the only taxa to survive (Winner *et al*. 1980). Chironomid larvae were found to be the most common component of benthos while toxicity of pesticides to benthic insect communities was discussed by William and Feltmate (1992). The stress of various environmental pollutants on the aquatic organisms was discussed by Kumar (1996a, b). The distribution of macrozoobenthos designated as an indicator of clean and eutrophicated water was described by Gaufin and Tarzwell (1956); Curry (1962); Schneider (1962); Shrivastava (1962); Hussainy (1965); Verma and Shukla (1969); Serruya (1978); Pennak (1978); Allanson (1979); Das and Bisht (1979); Pandit (1980); King (1981); Roy and Sharma (1983); Sharma (1986); Sinha and Prasad (1988); Das (1989); Rao *et al*. (1991); Dhillon *et al*. (1993a) and Kumar (1996b).

Arti and Vipulab (2014) assessed the correlations between abiotic (Physical and chemical) and biotic (macro-benthic invertebrates) variables of Ban- Ganga, Jammu. The authors studied both variables and concluded that the physico-chemical parameters were congenial in accordance to the result obtained from biological parameters. It was found that physico-chemical parameters play significant role in structuring the stream macro benthic invertebrate communities, because they are the determinants of colonization and persistence of organisms in the stream habitats. Thus, the invertebrates are useful as bio indicators to the health of the aquatic ecosystem, complementing water quality analysis.

Macroinvertebrates form an important constituent of aquatic ecosystems and have functional significance in assessing the trophic status, as the abundance of benthic fauna mainly depends on physical and chemical properties of the substratum and thus the benthic communities respond to changes in the quality of water and available habitat. Rafia and Pandit (2014) reviewed the occurrence, composition and distribution of macroinvertebrates of Kashmir lakes and analyzed the benthic community, which helps in the determination of trophic status of lakes because of their sensitivity to pollution and is, therefore, an important criterion in the ecological classification of lakes.

In a survey by Bhat *et al.*, (2015) benthic diversity of Upper Lake - a Ramsar site, was assessed with reference to habitat types of macrozoobenthos. It was observed during their study that macrophytes forms one of the favorable conditions for benthic diversity followed by stones/sand and mud, as the highest value for Shannon diversity index was calculated at macrophyte type habitat while lowest at mud type habitat. Muzamil *et al*., (2016) studied the macrozoobenthic community as biological indicators of pollution in Anchar Lake of Kashmir. A total of 21 taxa of macrozoobenthos were recorded from the system. Arthopoda was most dominant group constituting 45.7%, followed by Annelida 35.9% and Mollusca which contributed 18.4% of total macrozoobenthos. The bottom sites were dominated by insects belonging to orders Ephemeroptera, Tricoptera and Diptera. Significant changes in macrozoobenthic communities were primarily due to changes in water quality. As elsewhere, macrozoobenthic communities proved to be good indicators of water quality and should be used as bioindicators in long term monitoring of the lake. Recent contributions in the field of macrozoobenthos are those of Vitaliy *et al*. (2016); Ralf *et al*. (2016); Yung-Chul *et al*. (2016); Halliday *et al.* (2016); Stancheva and Sheath (2016); Jerry & Calagui (2017); Wibowo *et al*. (2017); Zulkifli *et al*. (2017); Kannika *et al*. (2017) and Maja *et al*. (2017).

2.4 Bio-monitoring of 'river health' through molluscan/annelid species

Freshwater molluscs--snails and bivalves--have been used frequently as bioindicator organisms. With increasing needs for research on effects of contaminant in freshwater ecosystems, this kind of biomonitoring is likely to develop further in the future. Molluscs can be used effectively for studies of both organic and inorganic contaminants. Two important advantages of snails and bivalves over most other freshwater organisms for biomonitoring research are their large size and limited mobility. In addition, they are abundant in many types of freshwater environments and are relatively easy to collect and identify. Biomonitoring studies with freshwater molluscs have covered a wide diversity of species, metals, and environments. Such attempt has been done by Araujo and Jong (2015), who worked on the biodiversity studies on bivalve (Mollusca) in Europe. On the other hand, Archambault *et al*. (2015) evaluated the sensitivity of freshwater molluscs to hydrilla targeting herbicides: providing context for invasive aquatic weed control in diverse ecosystems. The role of mollusks as bioindicators of pollution had been observed by Besser *et al*. (2015), who evaluated the toxicity of sediments from lead–zinc mining areas to juvenile freshwater mussels (*Lampsilis siliquoidea*) compared to standard test organisms.

Jasinska *et al*. (2015) used mollusks as the biomarkers for contaminants of emerging concern on aquatic organisms downstream of a municipal wastewater discharge. Similarly the effect of eutrophication on molluscan community composition in the Lake Dianchi (China, Yunnan) was carried out by Li-Na *et al*. (2015). The molluscs have been the animal of interest for biomonitoring. As such Roy *et al*. (2015) assessed the potential toxicity of chloride-affected groundwater discharging to an urban stream using juvenile freshwater mussels (*Lampsilis siliquoidea*). One such molluscan *Margaritifera margaritifera* (Linnaeus, 1758) was used for assessing the ecological status at the southern edge of its distribution (River Paiva, Portugal).

Polychaetes (Annelids) are usually the most abundant taxon in benthic communities and have been most often utilized as indicator species of environmental conditions. While the use of indicator species for a particular pollutant is not simple, polychaetes can provide a useful means of assessing the effects of poor environmental conditions. Polychaetes may be used as sensitive monitors of water quality especially in terms of the effects of pollutants on life history characteristics. They may also be utilized as general indicators of community diversity but those species indicative of lower diversity may differ geographically and temporally. Some species of polychaetes are able to live in sediments very high in trace metal content and body burden of these metals often does not reflect sediment concentrations due to regulation by these species. Many species seem relatively resistant to organic contaminants and pesticides and the effects of these pollutants on life history characteristics of these species may provide a more sensitive assay method. Recent studies using biomarkers in polychaetes to indicate general heavy metal or pesticide contamination has shown some success.

Somogyi *et al*. (2012) evaluated the comparative toxicity of the selenate and selenite to the potworm *Enchytraeus albidus* (Annelida: Enchytraeidae) under laboratory conditions. Al-Abbad *et al*. (2015) worked on the biodiversity of the macroinvertebrates in the Southern Iraqi Marshes, with a special reference to Oligochaeta. While as anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream was evaluated by Arimoro *et al*. (2015). Colombo *et al*. (2016), on the other hand, investigated the effects of *Lumbriculus variegatu*s (Annelida: Oligochaeta) bioturbation on zinc sediment chemistry and toxicity to the epi-benthic invertebrate *Chironomus tepperi* (Diptera: Chironomidae). On the same pattern, Yildiz (2016) evaluated the habitat preferences of aquatic oligochaeta (Annelida) species in the Lake District (turkey). Annelida have been the animal of choice for biomonitoring studies. One such work was executed by Buch *et al*. (2017), who worked on mercury critical concentrations to *Enchytraeus crypticus* (Annelida: Oligochaeta) under normal and extreme conditions of moisture in tropical soils Reproduction and survival. Structural and physiological characteristics of *Limnodrilus sulphurensis* (Oligochaeta, Annelida) thriving in high sulphide conditions were studied by Giere *et al*. (2017).

Chapter 3

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Study Area

Nagaland is dissected by a number of seasonal and perennial rivers and rivulets. The major rivers of Nagaland are Doyang, Dikhu, Dhansiri, Tizu, Tsurong, Nanung, Tsurang or Disai, Tsumok, Menung, Dzu, Langlong, Zunki, Likimro, Lanye, Dzuza and Manglu. All these rivers are dendritic in nature. Of the rivers, Dhansiri, Doyang and Dikhu flow westward into the Brahmaputra. The Tizu River, on the other hand, flows towards east and joins the Chindwin River in Burma.

Dikhu River is one of the most prominent rivers of Nagaland. River Dikhu, which has a total length of about 160 km, originates from Nuroto Hill area in Zunheboto district. The river flows across the Mokokchung and the Longleng districts. The main tributaries of river Dikhu are Yangyu of Tuensang district and Nanung in the Langpangkong range in Mokokchung district.

3.1.1 General description of Dikhu site:

The Dikhu River is one of the tributaries of Brahmaputra, one of the mightiest rivers of India. The Dikhu River is not only a prime tourist attraction, but also a significant source of livelihood for the people. The water makes the area around the river fertile. Since Longleng is primarily an agricultural district, the Dikhu River serves as a lifeline to its people.

3.1.2 Study Sites:

For the present investigation, five sampling sites were selected on the basis of accessibility and vegetation. The description of study sites is given as under:

3.1.2.1 Sampling site –1: Longmisa Noksen

Site I is located upstream. It has pebbles, sand and hard rock bed with vegetation covering at both sides of the river. It also has nearby agricultural lands and tree plantations. The land use pattern includes agricultural farmland and plantation. The watershed property of the water includes agricultural runoff. There were also no visible sources of waste disposal. It has a stretch of 2.18km and width varying from 9.56 to 40.29 m. It also is one of the sites with the nearest human settlement (Changtongya Town). The water is used mainly for drinking, irrigation and also fishing activities. The human habitations on river banks were the main source of discharging the sewage, farmyard washings, agricultural waste, pesticides etc into the river system. However, the human population size was found to be small, moderate and sparse. Hence, major pollution of the river was not encountered and it is also evident from the physico-chemical analysis of water samples. The watershed properties of the area are mostly agricultural, residential and animal runoff.

3.1.2.2 Sampling site – 2 Longmisa- Chuchu

Site II is located upstream. It has a stretch of 898.87 m and width varying from 12.56 to 32.29 m. It has pebbles, sand and hard rock bed with vegetation covering at both sides of the river. It also has nearby agricultural lands and tree plantations. The land use pattern includes agricultural farmland and plantation. The watershed property of the water includes agricultural runoff. There are no visible sources of waste disposal. The river bed is soft due to the presence of sand and clayey type of soil. The river banks are partly stable. The river also carried and deposited large and medium wood debris on the riverbed and bank. The Riparian zones were primarily composed of woody forests and shrubs. The watershed properties of the area are mostly agricultural.

3.1.2.3 Sampling site – 3 Longkong

Site III is located upstream. It has a stretch of 1.48km and width varying from 8.56 m to 42.29 m. The area is composed of pebbles, sand and hard rock bed with vegetations covering both sides of the river. The main types of vegetation include trees and shrubs. The watershed properties of the river include mainly agricultural runoffs. The water is used mainly for anthropogenic activities such as fishing and agricultural uses. Large plantation areas were observed adjacent to Site III. There is no direct disposal of waste in the study Site III.

3.1.2.4 Sampling site – 4 Changtongya Yaongyimsen

Site IV is located upstream. It has a stretch of 1.88 km and width varying from 7.56 to 39.29 m. The area is composed of pebbles, sand and hard rock bed with vegetations covering both sides of the river. The main types of vegetation include trees and shrubs. The watershed properties of the river include mainly agricultural runoffs. The water is used mainly for anthropogenic activities such as fishing and agricultural uses. Large plantation areas were observed adjacent to Station IV. There is no direct disposal of waste in the study area. The river bed had a strong flow regime which powers the transfer of smaller rocks and gravels within it. The river banks were partly stable and smaller wood debris were observed mostly. The Riparian zones were primarily composed of woody forests and shrubs. The watershed properties of the area are mostly agricultural and animal runoffs.

3.1.2.5 Sampling site – 5 Changtongya Longleng

Site V is located midstream and doesn't not have any adjacent farmland, instead the riparian zone is covered by small shrubs. It has a stretch of 1.68 km and width varying from 7.56 to 33.29 m. The watershed properties of the river include mainly runoffs from adjacent soil and upstream agricultural runoffs. The river bed was mostly composed of sand, silt and clay. The river banks were partly stable and smaller wood debris were observed mostly. The Riparian zones were primarily composed of woody forests, grass, trees and shrubs. The watershed properties of the area are mostly agricultural and animal runoff, but not residential.

3.2 Drafting and mapping of Location map:

The location map was prepared using geographic information system (GIS). The project site with its subdivisions and grave sites was reconstructed by drafting it using a highly accurate computer aided drafting (CAD) program. Stringent drafting requirements were followed to digitize the boundaries and features. The location of the actual sites was positioned in the correct geographic space for our site locations. This was so that we could use the power of GIS and integrate aerial photography and other features to present an accurate view of the sites. At this level of conversion, the various sections, lots and grave site names were included as well as other structures on the sites which were important to operations. The second step to establish a GIS mapping base employed the information developed in the CAD program. This was done by converting the CAD drafted elements into a spatial geo-database format.

3.2.1 Satellite Data

The different satellite images were used for Dikhu river basin study

3.2.2 Image Processing and GIS systems:

Following hardware and software were used for image processing and GIS analysis:

A. Hardware:

During present study the image processing was carried out in a system with Core 2 Duo processor.

2GB RAM and 24 bits Graphics Windows acceleration Board with resolution of 1024 x 768.

B. Software:

a. ArcGIS for GIS analysis

b. HRDAS IMAGINF 9.0 software for image processing

c. MS Office XP: MS-Excel. Ms-Word for word processing

3.3. Limnological studies:

3.3.1 Sampling period:

Sampling was done on fortnightly basis.

3.3.2 Measurements of physico-chemical parameters of water

The physico-chemical parameters were analyzed by following methods for water chemistry as given in APHA (1998) and Adoni, A.D. (1985).

3.3.3 Water sample collection and analysis

Physico-chemical characteristics of water were investigated on fortnightly basis. Immediately air and water temperature were recorded on the sampling sites. The water samples were collected from the sampling sites by dipping one litre polyethylene bottle just below the surface of water. Special recommended glass bottles were used for the estimation of dissolved oxygen. For estimation of dissolved oxygen, samples were fixed at the sampling site in accordance with modified Winkler method. The analysis of water samples was done by adopting standard methods of Golterman and Clymo (1969), Adoni (1985), and APHA (1998). Water sample for other physico-chemical parameters were stored and carried to the laboratory for analysis. The methods employed for the determination of different physico-chemical parameters of water are enumerated as follows:

3.3.4 Physico-chemical Parameters:

3.3.4.1 Temperature:

The temperature of surface water and air was recorded by using standard Celsius mercury thermometer. The bulb of thermometer was dipped directly in surface water for at least two minutes for obtaining the water temperature. Air temperature was recorded in shady place to avoid direct exposure of the mercury bulb to the sunlight at the study site. The measurement range was from 0 ^{o}C to 50^{o}C.The results were expressed in ^{o}C.

3.3.4.2 Turbidity:

Turbidity was measured using an electronic turbidity meter. Turbidity is usually measured in nephelometric turbidity units (NTU) or Jackson turbidity units (JTLJ), depending on the method used for measurement. The two units are roughly equal. During the present study turbidity sensors were used which are also called as submersible turbidimeters (USGS, 2013)

3.3.4.3 Hydrogen ion concentration (pH):

pH was measured with the help of portable digital pH meter (OAKTON), in the field immediately after collection of sample. It has a single electrode and dry cell battery operation. The meter was standardized with buffer solution before operation.

3.3.4.4 Determination of Dissolved Oxygen:

Method used for the estimation of dissolved oxygen was modified Winkler's method,

The formula used for determining D.O is as follows:

$$\textbf{Dissolved Oxygen (mg/l)} = \frac{X \; x \; N \; x \; 8 \; x \; 1000}{Y}$$

Where, X = ml of titrant used

Y = ml of sample

N = normality of titrant

The result was expressed in D.O. mg/l.

3.3.4.5 Free Carbon dioxide: Carbon Dioxide (mg/l):

Free carbon dioxide was analyzed at the sites by using phenolphthalein indicator and sodium hydroxide titrant. Free CO_2 was calculated as follows:

$$\textbf{Free } \mathbf{CO_2}(mg/l) = \frac{X\ x\ N\ x\ 1000\ x\ 44}{Y}$$

Where, X = ml of titrant used

Y = ml of sample

N = normality of titrant

3.3.4.6 Current/Flow

The units that are typically used to express discharge include m^3/s (cubic meters per second (Dunne and Leopold, 1978). A commonly applied methodology for measuring, and estimating, the discharge of a river is based on a simplified form of the continuity equation. The equation implies that for any incompressible fluid, such as liquid water, the discharge (Q) is equal to the product of the stream's cross-sectional area (A) and its mean velocity ($\bar{u}$), and is written as:

$$Q = A\bar{u}$$

where,

- Q is the discharge ($[L^3T^{-1}]$; m^3/s
- A is the cross-sectional area of the portion of the channel occupied by the flow ($[L^2]$; m^2)
- $\bar{u}$ is the average flow velocity0 ($[LT^{-1}]$; m/s

3.3.4.7 Alkalinity

Procedure: For estimation of phenolphthalein alkalinity 50 ml of sample was taken in an Erlenmeyer flask and was titrated against 0.02N H_2SO_4 in the presence of phenolphthalein indicator till disappearance of pink colour. The calculation is as follows:-

$$\text{Phenolphthalein Alkalinity (P) as mg/l } CaCO_3 = \frac{\text{ml of titrant used X 1000}}{\text{ml of the sample}}$$

$$\text{Total Alkalinity (T) (mg/l) } CaCO_3 = \frac{\text{ml of titrant used X1000}}{\text{ml of the sample}}$$

Results were expressed mg/l

3.3.4.8 Hardness

Total hardness was determined by using titrimetric method. The total hardness was calculated as follows:

$$\textbf{Total hardness as } \mathbf{CaCO_3} (mg/l) = \frac{X\ x\ 1000\ x\ Z}{Y}$$

Where, X = ml of titrant used

Y = ml of sample

Z = mg of CaCO3 equivalent to 1.00 ml EDTA titrant

3.3.4.9 Determination of Nitrate: (Boyd, 1979)

For the determination of nitrate 25 ml of sample is taken in flask and evaporate to dryness on a hot water bath/suitable hot plate. The residue is rubbed thoroughly with 0.5 ml of phenol disulphonic acid reagent to dissolve all solids. 5 ml distilled water is added and 1.5 ml concentrated NH_4OH one after the other and stirred. A yellow colour is developed. The supernatant is taken avoiding the flocks and in spectrophotometer the reading is taken at 410 nm against distilled water blank. Results were expressed in mg/l.

3.3.4.10 Determination of Phosphate: (Boyd, 1979)

For the determination of phosphate 25 ml of water sample is taken in an Erlenmeyer flask. (A distilled water blank is also prepared simultaneously.1ml ammonium molybdate solution is added and 0.12 ml (3 drops) stannous chloride is added. Blue colour will appear gradually. The reading is taken at spectrophotometer at 690 nm after 10 minutes, but 15 minutes against a blank. The values are taken with the help of calibration curve and results were expressed in mg/l.

3.3.4.11. Electrical Conductivity:

Electrical conductivity was measured by Aquaread's EC Testing Equipment. The Aquaprobe AP-2000 and the Aquaprobe AP-5000 were efficiently used for the conductivity measurements.

3.3.4.12. Water Quality Index (WQI):

Fourteen water quality parameters were considered for calculation of water quality index (Harkins, 1974; Tiwari *et al*., 1986; Tiwari and Manzoor, 1988; Mohanta and Patra, 2000; Kesharwani *et al*., 2004; Padmanabha and Belagali, 2005). Mean value of each parameter was compared with the ICMR recommended standards for water quality parameters to compute water quality index-

$$\text{Water Quality Index (WQI)} = \sum q_i w_i$$

Where, q_i (water quality rating) = 100 x $(V_a-V_i) / (V_s-V_i)$,

Where V_a = actual value present in the water sample

V_i = ideal value (0 for all parameters except for pH and DO which are 7.0 and 14.6 mgl^{-1} respectively)

V_s = standard value

If quality rating $q_i = 0$ means complete absence of pollutants

While $0<q_i<100$ implies that the pollutants are within the prescribed standard

When $q_i>100$ implies that the pollutants are above the standards (Mohanty, 2004)

W_i (unit weight) = K/S_n

3.3.4.13 Water Pollution Indices

It is well established that environmental disturbance such as pollution induces changes in structure and function of the biological system and also changes the physico-chemical characteristics of the natural water quality. For the detection and evaluation of water pollution, the water pollution indices are commonly used. The indices are characterized into two parts: the physico-chemical indices and biological indices. Physicochemical indices are based on the values of various physicochemical parameters in a water sample while the biological indices are derived from the biological information. These indices are aimed at providing numerical version of the biological information and also physico-chemical information of the water. In this study the following two indices were taken into consideration for biological information based on algae and one index is considered for physico-chemical information for assessment of water quality of the Dikhu river. The indices are as follows:

(a) Diversity index (i>)

(b) Palmer's pollution index (P.P.l.)

(c) Organic pollution index (O.P.T.)

3.4.1 Diversity Index (DI)

A number of studies have showed the pollution produces striking changes in the biotic community. Some of the species may be unable to tolerate slightest of pollution while few species may persist in reduced coactions and then again certain species may be able to attain greater abundance under the same situation. This causes an imbalance in the system which could be monitored to detect the status of pollution. These structural changes can be quantified numerically and are very useful in assessment of water quality based on the principle that polluted water supports always low diversified flora and fauna while clean water supports high community diversity. The diversity index is calculated from the abundance data of organisms and serves as a very good indicator of pollution. Some of the common diversity indices are given below:

3.4.1.1 **Shannon-Wiener index :**

The Shannon and Weaver diversity indices 'H' (Shannon and Weaver, 1949) were used for the evaluation of species diversity in samples in Dikhu river. Diversity commonly depends on the number of species and individuals in the community at a given point in time and has been mathematically well documented.

The Shannon Weaver diversity Index 'H' equation is given as:

$$H = ABS (ni / N) \times (\log10 ((ni) / (N)$$

Where, Pi = n/N; n = diversity of individual; ni = Number of individuals in all the species; N = Total number of individuals in all the species; Log10 = Chosen logarithm with base of 10 (Pielou, 1977).

3.4.2 Palmer's Pollution Index

Palmer (1969) made the first major attempt to identify and prepare a list of genera of algae tolerant to organic pollution. He prepared a list of 60 genera and 80 species tolerant to organic pollution. He also developed Palmer algal genus index for the rating of organic pollution of a water body. For the calculation of this index, **Table A** is taken for use. The table provides 20 algal genera most tolerant to organic pollution and a number is assigned to each of them depending on their relative tolerance to pollution. The algae present in the water sample are identified and the genera present from the list are noted. The assigned number scored by each genus is summed up to get the value of algal genus index.

Table 1: Pollution Index of Algal Genera (Palmer, 1969)

S.N.	Genera	Pollution Index	S.N.	Genera	Pollution Index
1.	*Anacystis*	1	11	*Micractinium*	1
2.	*Ankistrodesmus*	2	12	*Navicula*	3
3.	*Chlamydomonas*	4	13.	*Nitzschia*	3
4.	*Chlorella*	3	14.	*Oscillatoria*	4
5.	*Closterium*	1	15.	*Phormidium*	1
6.	*Cyclotella*	1	16.	*Pandorina*	1
7.	*Euglena*	5	17.	*Phacus*	2
8.	*Gomphonema*	1	18.	*Scenedesmus*	4
9.	*Lepocinclis*	1	19.	*Stigeoclonium*	2
10.	*Melosira*	1	20.	*Synedra*	2

On the basis of the total score obtained from the assigned number to each genus for each sampling station, Palmer (1969) formulated the following pollution index scale for assessment of organic pollution of the water bodies. The pollution index scale is given below:

Pollution Index	**Status of Pollution**
<15	Very light organic pollution
15 to 20	Organic pollution
>20	High organic pollution

Algal pollution indices are also used for detection and evaluation of water pollution (Rai and Kumar, 1980; Gunale and Balakrishnan, 1981; Nandan and Patel, 1983, 1985, 1986).

3.4.3 Organic Pollution Index (OPI)

One of the most effective ways to communicate information on water quality trend is with indices. To evaluate the status of pollution of a water body, water quality yardstick as based on physico-chemical and biological data are important for water quality management. One such water quality target value as based on physico-chemical data is organic pollution index (OPI). The significant feature of the index is that a cluster of parameters are considered for evaluation of water quality rather than a single individual parameter. This index is expressed on a scale from 0 to 100, where 0 indicates the worst imaginable condition, and 100 stands for a totally natural environment which is entirely not influenced by human habitation. The organic pollution index is related to the availability of oxygen in a water body and is calculated from monthly measurement on the following parameters: ammonia, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen saturation and temperature. The formula used for combining the individual parameter values i.e.

$$\text{OPI} = e\left[\frac{1}{n}\sum_{1}^{\text{n}} \text{Ln}\,(\text{PQI})_{\text{n}}\,.\,\text{W}_{\text{n}}\right]$$

Where, OPI = Organic pollution index.

PQI_n = The quality index for the n^{th} parameter, a dimensionless number between 0 and 100, standing for very poor and excellent quality respectively with respect to the parameter under consideration. The quality index is derived from parameter quality curves which are constructed according to target value specified by Bach (1980).

Wn = The weightage factor for the n parameter. All the parameters have equal weightage : Wn is equal to 1/n = 1/5.

3.5 Macrozoobenthos

Five sampling sites (S1, S2, S3, S4 and S5) were identified keeping in view the accessibility, variations in the microhabitat and representativeness of the entire Dikhu river. These sites were given identification marks. Study of benthic macroinvertebrates and analysis of water quality were conducted from different study sites of Dikhu river Regular monthly sampling was undertaken between 9 and 11 am at each site throughout the study period. All the data were pooled and statistical mean and standard deviation were calculated. The macroinvertebrates colonizing the substrate and surface were collected with the help of the Surber sampler (0.50 mm mesh net) and by hand-picking from beneath the stones and macrophytes. The macroinvertebrates were preserved in 5% formalin at the sampling sites. For quantitative analysis, macroinvertebrates were examined using inverted microscope and identified with the help of standard monographs and identification keys. The benthic macroinvertebrates were identified up to genus level. Population of organisms were counted species wise i.e., no. of individuals of a species per sample and were expressed as number / m^2. During the course of study period, seasonal samplings were carried out, in which five samples were collected from each sampling session. From each sample the number of individuals of different species and group percentage were calculated per meter square (Welch, 1948) according to following formula:

3.5.1 Population density

Number of benthos per unit area was calculated as follows:-

$$N = O/AS \times 10^4$$

Where

N = Number of organisms per sample /m^2,

O = number of individuals actively encountered.

A = area of sampler (Ekman's Dredge in m^2).

S = number of samples taken at one sampling point.

3.5.2 Modified Family Biotic Index,

Tolerance values range from 0 to 10 for families and increase as water quality decreases. The index was developed by Hilsenhoff (1988) to summarize the various tolerances of the benthic arthropod community with a single value. The Modified Family Biotic index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI).The formula for calculating the Family Biotic Index is:

$$FBI = \frac{x_i t_i}{n}$$

Where,

xi = number of individuals within a taxon

ti = tolerance value of a taxon

n = total number of organisms in the sample (100)

3.5.3 Species equitability or evenness (E)

Species equitability or evenness (E) is determined by the equation:

$$E = \frac{H}{H_{max}} = \frac{H}{lnS'}$$

Where,

H is the Shannon–Weaver diversity index and

S is the number of species in the sample.

3.5.4 Capacite biogenique secondaire´ index (Cb2)

Capacite biogenique secondaire´ index (Cb2) was carried out by calculating

3.6 Statistical analysis of data:

3.6.1 Confidence Intervals:

95% confidence interval was used to estimate the accuracy level in fish population and abundance.

3.6.2 DIMO

DIMO model "Diversity Model" [Qinghong, 1995] was performed by using H', J' and S indices simultaneously in synthetic graphic representation, with the aid of OriginPro 8 SR4 program [2008]. In order to compare and visualize spatial evolution of assemblages of each river section, rank-frequency diagrams were used [Frontier, 1976].

Statistical analysis was carried out by standard computation by using microsoft word and Excel.

Chapter 4

RESULTS

4. RESULTS

4.1 Drafting and mapping of Location map:

Geospatial technologies, such as remote sensing, Geographical Information System (GIS) and Global Positioning System (GPS) provide vital support to collect, analyze and store all types of geospatial information. Vegetation characteristics derived from remotely sensed data are particularly important for both qualitative and quantitative assessment. Traditionally, watershed boundaries are drawn manually onto a topographic map. During the present research, computer aided programs were used to derive watershed. Using computer technology, preliminary watershed boundaries were generated in a very accurate way. Delineation of watersheds can take place at different spatial scales. According to Garbrecht and Martz (2000), a large watershed may cover an entire stream system. In the present research work, we used point based method, and derived a watershed for each select point. The select points were slow moving patches of the Dikhuriver.

4.1.1 Preliminary interpretation:

The study is primarily based on topographical sheets on scale 1:50.000. Near twenty five sheets has been used for study on (Scale 1: 50000) number, namely:

64-I/3, I/4, I/6, I/7, I/8, I/10, I/11 and I/12

64-J/1, J/2, J/5, J/6, J/7, J/8, J/9, J/10 and J/11

64-K/9 and K/10

The three (Scale 1: 250000) toposheet numbers covering the present study area are 64I, 64J and 64K. Pre field visual interpretation of imagery was carried out on False Colour Composites (FCC) using image elements such as tone, texture, pattern, location, association and shadow.

4.1.2 Geometric correction:

Subset of satellite images were rectified for their inherent geometric errors using digital topographic maps in Modified Universal Transverse Mercator coordinate system obtained as reference material. The common uniformly distributed Ground Control Points (GCPs) in Dikhu river stretch were marked and imagery was resampled by nearest neighbor resampling method. The resampling method used the nearest pixel without any interpolation to create the warped image (Richards. 1994; Jensen, 1996). Images through image-to-image registration technique with rectification error of 0.108 pixels were accepted during the process of geometric correction. A very high level of accuracy in georeferencing of the images were possible because of the use of digital source as the reference data that allowed zooming to the nearest possible point location. The reference points in area of study were extracted by overlaying the boundary. Digital data pertaining to Dikhu river basin and its watersheds were subjected to digital classification. The images used were scanned, saved in *.tiff format and registered to the digital topographic maps. This allowed direct comparison of features between the images during the selection of sample plots for use in image classification and accuracy assessment of classified images.

4.1.3 Satellite Data

The use of satellite imagery invoices for identification of water stretches in Dikhu river system of the present interest is presented in **Table 1A** and identified spots along with the geographical coordinates in **Table 1B**.

Table 1A: Satellite imagery sensor modules used during present study

S.No.	Satellite	Sensor	Path Row	Date of Pass	Spatial Resolution
01	LandSat+ETM	TM	142 44/45	14-11-2014	5.8m
02	LandSat ETM SLC – off	TM	142 44/45	26-03-2015	5.8m
03	LandSat ETM SLC-off	TM	142 44/45	24-06-2015	5.8m
04	IRS-P6	LISS 3	102 55/59 103 56/57	01-01-2016	23.5 m
05	Landsat 5	TM	142 44/45	22-04-2016	5.8m

Table 1B: Geographical location of the selected study sites of R. Dikhu

Study Site	Name of the Study Site	Location From source	Coordinates	Max. water depth (m) in dry spell at pools
Site 1	Longmisa Noksen	5 km	N 26° 31′ 30.953″ E 94° 41′ 13.429″	1.15±0.20
Site 2	Longmisa- Chuchu	5 km	N 36° 32′ 4.68″ E 94° 41′ 46.027″	1.10±0.18
Site 3	Longkong	6 km	N 26° 32′ 12.559″ E 94° 42′ 4.721″	0.50±0.25
Site 4	Changtongya Yaongyimsen	14 km	N 26° 32′ 22.511″ E 94° 42′ 15.381″	0.54±0.21
Site 5	Changtongya Longleng	15 km	N 26° 20′ 9.078″ E 94° 38′ 29.799″	1.14±0.19

Fig 1. Original satellite imagery of IRS-P6 LISS 3 (2015) covering the whole Dikhu river basin area

(View of Site 1)

Fig 2. Original satellite imagery of IRS-P6 LISS 3 (2015) covering the whole Dikhu river basin area

(View of Site 2)

Fig 3. Original satellite imagery of IRS-P6 LISS 3 (2015) covering the whole Dikhu river basin area

(View of Site 3)

Fig 4. Original satellite imagery of IRS-P6 LISS 3 (2015) covering the whole Dikhu river basin area

(View of Site 4)

Fig 5. Original satellite imagery of IRS-P6 LISS 3 (2015) covering the whole Dikhu river basin area

(View of Site 5)

4.1.4 Data generation:

For the present study a number of geographically analyzed layers were prepared. The digital satellite data of Indian Remote Sensing (IRS) acquired from National Remote Sensing Centre (NRSC) were evaluated on ArcGIS (Software). Digital Flevation Maps (DFM) was prepared by digital presentation on digitized contour lines of 1: 25000 scaled topographic maps in every 20 m interval in Dikhu river stretch.

4.1.5 Field survey:

A reconnaissance survey was carried out to the whole Dikhu basin area and then randomly selected areas (study sites) of the river were examined to recognize the variation of watersheds found on the ground to their respective tonal variation on satellite image (captured through Google Earth Pic 1-5). For identifying the actual location GPS (Global Positioning System) was used by feeding actual latitude and longitude which was calculated through toposheets and Google earth. All roads, major drainage, contours, canals and were traversed for collecting ground truth.

From the GPS and ground field survey, it was reported that the Dikhuriver is fed by so many tributaries. The Dikhu River in itself is one of the tributaries of Brahmaputra, one of the mightiest rivers of India. The Dikhu River is not only a prime tourist attraction, but also a significant source of livelihood for the people. The water makes the area around the river fertile.

Since Longleng is primarily an agricultural district, the Dikhu River serves as a lifeline to its people. Site I (LongmisaNoksen) is located upstream. Its bed consists of pebbles, sand and hard rock with vegetation covering at both the catchment areas of the river. It has adjacent agricultural lands and tree plantations in vicinity. The land use pattern includes agricultural farmland and plantation. The watershed property of the water includes agricultural runoff. There were also no visible sources of waste disposal. It has a stretch of 2.18 km and width varying from 9.56 m to 40.29 m. It also is one of the sites with the nearest human settlement (Changtongya Town). The human habitations on river banks were the main source of discharging the sewage, farmyard washings, agricultural waste, pesticides etc into the river system.

Site II (Longmisa- Chuchu) has a stretch of 898.87 m and width varying from 12.56 m to 32.29 m. It has pebbles, sand and hard rock bed with vegetation covering at both sides of the river. It also has nearby agricultural lands and tree plantations. The land use pattern includes agricultural farmland and plantation. The watershed property of the water includes agricultural runoff. There are no visible sources of waste disposal. The river bed is soft due to the presence of sand and clayey type of soil. The river banks are partly stable. The river also carried and deposited large and medium wood debris on the riverbed and bank. The Riparian zones were primarily composed of woody forests and shrubs. The watershed properties of the area are mostly agricultural.

Site III (Longkong) has a stretch of 1.48km and width varying from 8.56 m to 42.29 m.The area is composed of pebbles, sand and hard rocky bed with vegetations covering both sides of the river. The main types of vegetation include trees and shrubs. The watershed properties of the river include mainly agricultural runoffs. The water is used mainly for anthropogenic activities such as fishing and agricultural uses. Large plantation areas were observed adjacent to Site III. There is no direct disposal of waste in the study Site III.

Site IV (ChangtongyaYaongyimsen) has a stretch of 1.88 km and widths varying from 7.56 m to 39.29 m. Large plantation areas were observed adjacent to Station IV. There is no direct disposal of waste in the study area. The river bed had a strong flow regime which powers the transfer of smaller rocks and gravels within it. The river banks were partly stable and smaller wood debris was observed mostly. The Riparian zones were primarily composed of woody forests and shrubs. The watershed properties of the area are mostly agricultural and animal runoffs.

Site V (Changtongya Longleng) is located midstream and without any adjacent farmland but it consists of short shrubs. It has a stretch of 1.68 km and width varying from 7.56 m to 33.29 m. The watershed properties of the river include mainly runoffs from adjacent soil and upstream agricultural runoffs. The watershed properties of the area are mostly agricultural and animal runoff, but not residential.

4.2. Physico Chemical Parameters

The physico - chemical characteristics of the study sites in Dikhuriver was studied extensively with weekly/fortnightly collection of water samples and analysis thereof (Table 2).

4.2.1. Water Temperature:

During the present research work, the average air temperature ranged between 18.75±1.52 to 19.30±2.02°C, with lowest temperatures in winter and highest in summer months at all the study sites.The water temperature (°C) ranged between a minimum of 9.80±1.02°C to a maximum of 19.6±1.36°C during the study period from November 2014 to October 2016. At site 1, the minimum and maximum water temperature was recorded as 10.00±1.32 and 27.5±1.24 °C,. On the same site, the averages were 10.61±1.17, 23.50±1.21, 27.50±1.50 and 24.22±1.47 respectively. At site 2, the minimum and maximum water temperature was recorded as 9.80±1.42°C and 28.8±1.29°C, respectively. On the same site, the averages were 10.01±1.51, 22.90±1.23, 28.8±1.14 and 23.70±1.12°C respectively. At site 3, the minimum and maximum water temperature was recorded as 9.99±1.17°C and 27.9±1.13°C, respectively. On the same site, the averages were 10.50±1.54, 22.60±2.02, 27.9±1.01 and 23.25±1.12 respectively.

At site 4, the minimum and maximum water temperature was recorded as 10.30±1.42°C and 27.8±1.47°C, respectively. On the same site, the averages were 10.92±1.21, 22.00±2.15, 27.80±1.12 and 24.15±1.56 respectively. At site 5, the minimum and maximum water temperature was recorded as 10.25±1.32°C and 27.5±1.01°C, respectively, with a mean±SD of

18.87±2.96. On the same site, the averages were 10.95±1.58, 22.90±1.47, 27.50±1.26 and 23.84±1.59 respectively.

4.2.2. Turbidity:

The turbidity ranged between a minimum of 8.56 to a maximum of 90.22 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum turbidity was recorded as 8.56±2.7 and 85.65±1.3, respectively. On the same site, the averages were 9.97±3.6, 57.21±2.9, 77.56±1.7 and 24.71±3.5 respectively. At site 2, the minimum and maximum turbidity was recorded as 9.06±3.1 and 86.99±1.7. On the same site, the averages were 10.42±2.3, 60.24±4.6, 78.92±2.7 and 25.65±2.7 respectively. At site 3, the minimum and maximum turbidity was recorded as 9.01±3.5 and 90.22±1.4. On the same site, the averages were 9.82±1.9, 58.11±2.9, 80.12±2.1 and 28.72±4.7 respectively.

At site 4, the minimum and maximum transparency was recorded as 9.62±2.4 and 86.32±1.7. On the same site, the averages were 10.11±3.5, 59.34±3.7, 78.95±2.1 and 25.69±3.8 respectively. At site 5, the minimum and maximum transparency was recorded as 9.81±3.5 and 85.36±1.9, respectively. On the same site, the averages were 11.22±3.4, 61.25±2.1, 78.65±1.8 and 26.55±3.7 respectively.

4.2.3. pH:

The pH ranged between a minimum of 7.51±1.2 to a maximum of 8.32±0.7 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum pH was recorded as 7.59±1.1 and 8.30±0.4, respectively. On the same site, the averages were 8.20±0.7, 7.72±1.1, 7.68±0.4 and 8.23±0.3 respectively. At site 2, the minimum and maximum pH was recorded as 7.62±1.1 and 8.32±0.7, respectively. On the same site, the averages were 7.92±0.3, 7.75±0.5, 7.59±1.1 and 8.21±0.4 respectively. At site 3, the minimum and maximum pH was recorded as 7.51±1.3 and 8.15±0.3, respectively. On the same site, averages were 8.05±0.8, 7.80±0.4, 7.62±0.9 and 8.09±0.7 respectively.

At site 4, the minimum and maximum pH was recorded as 7.62±1.6 and 8.24±0.4, respectively. On the same site, the averages were 8.15±1.1, 7.69±1.4, 7.65±1.6 and 7.96±0.8 respectively. At site 5, the minimum and maximum pH was recorded as 7.62±1.7 and 8.26±0.4, respectively. On the same site, the averages were 8.20±1.3, 7.71±1.4, 7.70±2.7 and 8.12 ±0.5 respectively.

4.2.4. Dissolved oxygen:

The dissolved oxygen ranged between a minimum of 7.96±1.26 to a maximum of 12.55±1.06 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum dissolved oxygen was recorded as 8.05±1.26 and 12.55±1.04, respectively. On the same site, the averages were 12.45±1.03, 8.53±1.46, 8.33±1.39 and 9.37±1.06 respectively. At site 2, the minimum and maximum dissolved oxygen was recorded as 8.12±1.26 and 12.27±1.04, respectively. On the same site, the averages were 12.06±1.49, 9.03±1.34, 8.39±1.26 and 9.35±1.48 respectively. At site 3, the minimum and maximum dissolved oxygen was recorded as 8.24±1.09 and 12.12±1.03, respectively. On the same site, the averages were 11.59±1.39, 8.56±1.27, 8.45±1.32 and 8.71±1.19 respectively.

At site 4, the minimum and maximum dissolved oxygen was recorded as 7.99±1.48 and 12.49±1.32, respectively. On the same site, the averages were 12.42±1.37, 8.66±1.31, 8.03±1.37 and 9.20±1.06 respectively. At site 5, the minimum and maximum dissolved oxygen was recorded as 7.96±1.17 and 12.36±1.28, respectively. On the same site, the averages were 12.23±1.39, 8.79±1.54, 8.08±1.59 and 9.27±1.31 respectively.

4.2.5. Carbon dioxide:

The carbon dioxide ranged between a minimum of 5.11±1.26 to a maximum of 9.68 ±1.61 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum carbon dioxide was recorded as 5.21±1.52 and 9.58±1.96 respectively. On the same site, the averages were 5.33±1.41, 6.22±1.32, 6.27±1.47 and 9.33±1.16 respectively. At site 2, the minimum and maximum carbon dioxide was recorded as 5.20±1.54 and 9.54±1.39, respectively. On the same site, the averages were 5.25±1.59, 6.18±1.37, 6.32±1.06 and 9.21±1.04 respectively. At site 3, the minimum and maximum carbon dioxide was recorded as 5.24±1.57 and 9.68±1.01, respectively. On the same site, the averages were 5.35±1.43, 6.28±1.34, 6.42±1.29 and 9.34±1.08, respectively.

At site 4, the minimum and maximum carbon dioxide was recorded as 5.11±1.59 and 9.59±1.16, respectively. On the same site, the averages were 5.32±1.51, 6.34±1.37, 6.18±1.45

and 9.33±1.18, respectively. At site 5, the minimum and maximum carbon dioxide was recorded as 5.17±1.56 and 9.44±1.21, respectively, with a. On the same site, the averages were 5.40±1.51, 6.19±1.32, 6.21 ±1.29 and 9.17±1.24 respectively.

4.2.6. Current Flow (m/s):

The current flow ranged between a minimum of 0.171±0.10 to a maximum of 0.542±0.01 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum current flow was recorded as 0.182±0.10 and 0.530±0.01, respectively. On the same site, the averages were 0.196, 0.42±0.01, 0.518±0.01 and 0.287±0.09 respectively. At site 2, the minimum and maximum current flow was recorded as 0.185 and 0.535, respectively. On the same site, the averages were 0.192±0.11, 0.45±0.09, 0.520±0.01 and 0.292±0.11 respectively. At site 3, the minimum and maximum current flow was recorded as 0.179±0.10 and 0.531±0.09, respectively. On the same site, the averages were 0.186, 0.43±0.09, 0.519±0.01 and 0.289±0.10 respectively.

At site 4, the minimum and maximum current flow was recorded as 0.181±0.10 and 0.536±0.01, respectively. On the same site, the averages were 0.188±0.10, 0.42±0.10, 0.521±0.01 and 0.285±0.10 respectively. At site 5, the minimum and maximum current flow was recorded as 0.171±0.11 and 0.542±0.04, respectively. On the same site, the averages were 0.179±0.11, 0.45±0.10, 0.520±0.01 and 0.276±0.11 respectively.

4.2.7. Alkalinity:

The alkalinity ranged between a minimum of 70.21±39.9 to a maximum of 139.6±14.7 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum alkalinity was recorded as 71.21±36.2 and 136.8±16.2, respectively. On the same site, the averages were 89.31±55.9, 134.55±19.7, 72.95±67.9 and 77.00±59.7 respectively. At site 2, the minimum and maximum alkalinity was recorded as 71.60±45.8 and 137.2±19.9, respectively. On the same site, the averages were 90.12±39.1, 135.65±13.9, 73.50±69.2 and 75.65±49.9 respectively. At site 3, the minimum and maximum alkalinity was recorded as 73.65±43.4 and 139.6±12.9, respectively. On the same site, the averages were 89.65±37.3, 138.24±17.9, 75.65±59.4 and 75.55±58.6 respectively.

At site 4, the minimum and maximum alkalinity was recorded as 70.21±49.9 and 136.2±12.3, respectively. On the same site, the averages were 91.20±45.2, 133.60±15.2, 72.65±53.29 and 77.25±55.32 respectively. At site 5, the minimum and maximum alkalinity was recorded as 71.02±41.9 and 131.5±18.8, respectively. On the same site, the averages were 89.56±36.5, 129.50±25.8, 72.15±48.4 and 78.01±41.9 respectively.

4.2.8. Hardness:

The hardness ranged between a minimum of 12.03±3.1 to a maximum of 41.60±2.3 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum hardness was recorded as 13.85±2.6 and 40.50±1.2, respectively. On the same site, the averages were 38.5±1.6, 22.86±3.2, 14.20±4.1 and 19.83±3.9 respectively. At site 2, the minimum and maximum hardness was recorded as 13.21±4.2 and 41.60±2.1, respectively. On the same site, the averages were 39.6±2.3, 23.15±2.7, 14.35±4.2 and 20.01±2.7 respectively. At site 3, the minimum and maximum hardness was recorded as 12.86±4.9 and 41.00±2.8, respectively. On the same site, the averages were 38.0±3.2, 22.75±3.7, 14.01±3.7 and 20.12±3.1 respectively.

At site 4, the minimum and maximum hardness was recorded as 12.03±3.7 and 38.96±2.9, respectively. On the same site, the Winter, Spring, Summer and Autumn averages were 40.2±2.1, 23.60±3.2, 13.99±4.6 and 18.99±2.1 respectively. At site 5, the minimum and maximum hardness was recorded as 12.11±4.1 and 41.20±2.6, respectively. On the same site, the averages were 39.5±2.1, 23.41±3.2, 14.25±3.6 and 19.62±2.3 respectively.

4.2.9. Nitrate:

The nitrate ranged between a minimum of 0.009±0.005 to a maximum of 0.073±0.014 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum nitrate was recorded as 0.012±0.008 and 0.072±0.013, respectively. On the same site, the averages were 0.012±0.005, 0.035±0.008, 0.072±0.004 and 0.052±0.011 respectively. At site 2, the minimum and maximum nitrate was recorded as 0.011±0.008 and 0.062±0.013, respectively. On the same site, the averages were 0.011±0.006, 0.031±0.014, 0.062±0.011 and 0.054±0.019 respectively. At site 3, the minimum and maximum nitrate was recorded as 0.012±0.003 and 0.073±0.015, respectively. On the same site, the averages were 0.012±0.007, 0.038±0.018, 0.073±0.014 and 0.049±0.016 respectively.

At site 4, the minimum and maximum nitrate was recorded as 0.009±0.003 and 0.066±0.014, respectively. On the same site, the averages were 0.009±0.004, 0.025±0.011, 0.066±0.017 and 0.050±0.015 respectively. At site 5, the minimum and maximum nitrate was recorded as 0.009±0.003 and 0.057±0.019, respectively. On the same site, the averages were 0.009±0.002, 0.034±0.011, 0.057±0.013 and 0.054±0.016 respectively.

4.2.10. Phosphate:

The phosphate ranged between a minimum of 0.048±0.002 to a maximum of 0.087 ±0.001 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum phosphate was recorded as 0.051±0.002 and 0.073±0.001, respectively. On the same site, the averages were 0.051±0.002, 0.065±0.002, 0.073±0.001 and 0.062±0.002 respectively. At site 2, the minimum and maximum phosphate was recorded as 0.057±0.002 and 0.087±0.001, respectively. On the same site, the averages were 0.057±0.002, 0.063±0.002, 0.087±0.001 and 0.061±0.002 respectively. At site 3, the minimum and maximum phosphate was recorded as 0.050±0.002 and 0.080±0.001, respectively. On the same site, averages were 0.050±0.002, 0.064±0.002, 0.080±0.001 and 0.057±0.002 respectively.

At site 4, the minimum and maximum phosphate was recorded as 0.048±0.002 and 0.070±0.001, respectively. On the same site, the averages were 0.048±0.002, 0.065±0.002, 0.070±0.001 and 0.057±0.002 respectively. At site 5, the minimum and maximum phosphate was recorded as 0.052±0.002 and 0.086±0.001, respectively. On the same site, the averages were 0.052±0.002, 0.060±0.002, 0.086±0.001 and 0.053±0.002 respectively.

4.2.11. Conductivity:

The conductivity ranged between a minimum of 0.101±0.002 to a maximum of 0.217±0.001 during the study period from November 2014 to October 2016. At site 1, the minimum and maximum conductivity was recorded as 0.103±0.002 and 0.214±0.001, respectively. On the same site, the winter, averages were 0.176±0.002, 0.210±0.001, 0.170±0.002 and 0.112±0.002 respectively. At site 2, the minimum and maximum conductivity was recorded as 0.102±0.002 and 0.215±0.001, respectively. On the same site, the averages were 0.168±0.002, 0.211±0.001, 0.175±0.002 and 0.113±0.002 respectively. At site 3, the minimum and maximum conductivity was recorded as 0.104±0.002 and 0.217±0.001, respectively. On the same site, the averages were 0.171±0.002, 0.210±0.001, 0.179±0.002 and 0.113±0.002 respectively.

At site 4, the minimum and maximum conductivity was recorded as 0.102±0.002 and 0.214±0.001, respectively. On the same site, the averages were 0.172±0.002, 0.204±0.001, 0.169±0.002 and 0.114±0.002 respectively. At site 5, the minimum and maximum conductivity was recorded as 0.101 and 0.216±0.001, respectively. On the same site, the averages were 0.178±0.002, 0.211±0.001, 0.168±0.002 and 0.113±0.002 respectively.

Table 2: Physico Chemical Parameters of various study sites of Dikhu river system

	Sites	Average ± SD	Min	Max	Winter Av	Spring Av	Summer Av	Autumn Av
Water Temperature	**Site 1**	18.75±1.52	10.00	27.5	10.61	23.50	27.5	24.22
	Site 2	19.30±2.02	9.80	28.8	10.01	22.90	28.8	23.70
	Site 3	18.94±1.40	9.99	27.9	10.50	22.60	27.9	23.25
	Site 4	19.05±1.97	10.30	27.8	10.92	22.00	27.8	24.15
	Site 5	18.87±2.96	10.25	27.5	10.95	22.90	27.5	23.84
Turbidity	**Site 1**	47.10±8.5	8.56	85.65	9.97	57.21	77.56	24.71
	Site 2	48.02±10.2	9.06	86.99	10.42	60.24	78.92	25.65
	Site 3	49.61±9.5	9.01	90.22	9.82	58.11	80.12	28.72
	Site 4	47.97±8.65	9.62	86.32	10.11	59.34	78.95	25.69
	Site 5	47.58±10.2	9.81	85.36	11.22	61.25	78.65	26.55
pH	**Site 1**	7.94±1.55	7.59	8.30	8.20	7.72	7.68	8.23
	Site 2	7.97±1.38	7.62	8.32	7.92	7.75	7.59	8.21
	Site 3	7.83±1.12	7.51	8.15	8.05	7.80	7.62	8.09
	Site 4	7.93±1.59	7.62	8.24	8.15	7.69	7.65	7.96
	Site 5	7.94±1.11	7.62	8.26	8.20	7.71	7.70	8.12
Dissolved Oxygen	**Site 1**	10.3 ± 1.48	8.05	12.55	12.45	8.53	8.33	9.37
	Site 2	10.2 ± 1.60	8.12	12.27	12.06	9.03	8.39	9.35
	Site 3	10.2 ± 1.49	8.24	12.12	11.59	8.56	8.45	8.71
	Site 4	10.2 ± 1.67	7.99	12.49	12.42	8.66	8.03	9.20
	Site 5	10.1 ± 1.49	7.96	12.36	12.23	8.79	8.08	9.27
Carbon dioxide	**Site 1**	7.39 ± 1.27	5.21	9.58	5.33	6.22	6.27	9.33
	Site 2	7.37 ± 0.98	5.20	9.54	5.25	6.18	6.32	9.21
	Site 3	7.46 ± 1.11	5.24	9.68	5.35	6.28	6.42	9.34
	Site 4	7.35 ± 1.16	5.11	9.59	5.32	6.34	6.18	9.33
	Site 5	7.30 ± 1.12	5.17	9.44	5.40	6.19	6.21	9.17
Water velocity (m/s)	**Site 1**	0.356 ± 0.01	0.182	0.530	0.196	0.42	0.518	0.287
	Site 2	0.360± 0.10	0.185	0.535	0.192	0.45	0.520	0.292
	Site 3	0.355± 0.09	0.179	0.531	0.186	0.43	0.519	0.289
	Site 4	0.358± 0.08	0.181	0.536	0.188	0.42	0.521	0.285
	Site 5	0.356± 0.00	0.171	0.542	0.179	0.45	0.520	0.276

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	Sites	Average ± SD	Min	Max	Winter Av	Spring Av	Summer Av	Autumn Av
Alkalinity	**Site 1**	104.0±65.2	71.21	136.8	89.31	134.55	72.95	77.00
	Site 2	104.4±59.9	71.60	137.2	90.12	135.65	73.50	75.65
	Site 3	106.6±41.9	73.65	139.6	89.65	138.24	75.65	75.55
	Site 4	103.2±25.29	70.21	136.2	91.20	133.60	72.65	77.25
	Site 5	101.2±36.2	71.02	131.5	89.56	129.50	72.15	78.01
Hardness	**Site 1**	27.17±2.2	13.85	40.50	38.5	22.86	14.20	19.83
	Site 2	27.40±3.2	13.21	41.60	39.6	23.15	14.35	20.01
	Site 3	26.93±2.7	12.86	41.00	38.0	22.75	14.01	20.12
	Site 4	25.49±2.9	12.03	38.96	40.2	23.60	13.99	18.99
	Site 5	26.65±2.9	12.11	41.20	39.5	23.41	14.25	19.62
Nitrate	**Site 1**	0.042±0.018	0.012	0.072	0.012	0.035	0.072	0.052
	Site 2	0.036±0.016	0.011	0.062	0.011	0.031	0.062	0.054
	Site 3	0.042±0.018	0.012	0.073	0.012	0.038	0.073	0.049
	Site 4	0.030±0.018	0.009	0.066	0.009	0.025	0.066	0.050
	Site 5	0.033±0.014	0.009	0.057	0.009	0.034	0.057	0.054
Phosphate	**Site 1**	0.062±0.000	0.051	0.073	0.051	0.065	0.073	0.062
	Site 2	0.072±0.002	0.057	0.087	0.057	0.063	0.087	0.061
	Site 3	0.065±0.002	0.050	0.080	0.050	0.064	0.080	0.057
	Site 4	0.059±0.001	0.048	0.070	0.048	0.065	0.070	0.057
	Site 5	0.069±0.000	0.052	0.086	0.052	0.060	0.086	0.053
Conductivity (mS/cm)	**Site 1**	0.158± 0.001	0.103	0.214	0.176	0.210	0.170	0.112
	Site 2	0.158± 0.000	0.102	0.215	0.168	0.211	0.175	0.113
	Site 3	0.160± 0.002	0.104	0.217	0.171	0.210	0.179	0.113
	Site 4	0.158± 0.000	0.102	0.214	0.172	0.204	0.169	0.114
	Site 5	0.158± 0.002	0.101	0.216	0.178	0.211	0.168	0.113

4.3. Pollution Indices

In order to establish the level of pollution at different sampling stations of Dikhu river, the pollution indicators were used for the assess, which revealed the level of pollution in Dikhu River owing to the combined effect produced by different factors (**Table 3**). The Site 1 (LongmisaNoksen) showed moderate pollution level, documented by indices, which include WQI (78), D (0.77), OPI (3.12) and PPI (15), which was followed by Site 2 (Longmisa-Chuchu), which showed most congenial condition with water quality index value of 90, pertinent to Site 1. However Simpson's Diversity Index (D), was comparatively lower (0.71) than site 1. Similarly organic pollution index was lower (1.03) at site 2 than site 1, along with Palmer's pollution index (2). Site 3 (Longkong) showed WQI of 69, D value of 1.65, OPI value of 4.84 and PPI value of 12. As compared to site 1, site 3 showed much lower index values, showing lesser pollution status. As compared to site 3, site 4 (Changtongya Yaongyimsen) showed linearly low value for WQI (86), Simpson's D (0.83), OPI value (1.91) and PPI value (5). Site 5 (Changtongya Longleng) was comparatively less polluted than sites 2 and 4 with WQI value of 84, Simpson's D value of 0.79, OPI value of 2.23 and PPI value of 5.

Table 3: Organic Pollution index values of different sampling stations of Dikhu River

Sampling station	Name	WQI	D	OPI Value	PPI
1	Longmisa Noksen	78	0.77	3.12	10
2	Longmisa- Chuchu	90	0.71	1.03	2
3	Longkong	69	1.65	4.84	12
4	Changtongya Yaongyimsen	86	0.83	1.91	3
5	Changtongya Longleng	84	0.79	2.23	5

WQI = Water Quality Index; D = Shannon's Diversity Index; OPI = Organic Pollution Indicator; PPI = Palmer's Pollution Index

4.5. Macrozoobenthos

The macrozoobenthos population in a river ecosystem is witnessed by the diverse population of pollution resistant species in different river zones. The macrozoobenthos diversity at five different sites in Dikhu River is depicted. During the present study, three broad groups of macrozoobenthos were observed, which included Arthropoda, Annelida and Mollusca. The Arthropoda comprised of the dominant species with over 15 taxa at site 1, followed by Annelida, which constituted of 3 taxa. Mollusca were more or less had same number of taxa (3) as Annelida. Arthropoda dominated the macrozoobenthos population at site 1, with abundance (%) of 41.4. The Shannon *H* was highest (1.58), with Evenness (e H/S) of 0.98 and Margalef Richness (*S*) of 0.5155. While as Simpson's dominance (1-D) showed a value of 0.2017. Annelida followed the dominant macrozoobenthos population at site 1, with abundance (%) of 40.7. The Shannon *H* was (1.528), with Evenness (e H/S) of 0.95 and Margalef Richness (*S*) of 0.5168. While as Simpson's dominance (1-D) showed a value of 0.2029, which was higher than the dominant Arthropoda. Mollusca followed the two dominant macrozoobenthos population at site 1, with abundance (%) of 17.9. The Shannon *H* was (1.594), with Evenness (e H/S) of 0.99 and Margalef Richness (*S*) of 0.5781. While as Simpson's dominance (1-D) showed a value of 0.2054, which was higher than the dominant Arthropoda and Annelida (**Table 4**).

At site 2, the number of taxa for five macrozoobenthos was higher in comparison to other sites. Arthropoda dominated the macrozoobenthos population, with abundance (%) of 51.1. The Shannon *H* was highest (1.588), with Evenness (e H/S) of 0.99 and Margalef Richness (*S*) of 0.4454. While as Simpson's dominance (1-D) showed a value of 0.2092, which was lesser than Annelida. Annelida followed the dominant macrozoobenthos population Arthropoda, with abundance (%) of 28. The Shannon *H* was (1.551), with Evenness (e H/S) of 0.96 and Margalef Richness (*S*) of 0.4751. While as Simpson's dominance (1-D) showed a value of 0.2229, which was higher than the dominant Arthropoda. Mollusca followed the two dominant macrozoobenthos population at site 2, with abundance (%) of 20.9. The Shannon *H* was (1.464), with Evenness (e H/S) of 0.91 and Margalef Richness (*S*) of 0.4945. While as Simpson's dominance (1-D) showed a value of 0.2518, which was lower than the dominant Arthropoda and Annelida (**Table 5**).

At site 3, the taxa composition for all the three species was least than other sites. Arthropoda dominated the macrozoobenthos population, with abundance (%) of 51.0. The Shannon *H* was highest (1.607), with Evenness (e H/S) of 1.01 and Margalef Richness (*S*) of 0.518. While as Simpson's dominance (1-D) showed a value of 0.2004, which was higher than

Annelida. Annelida followed the dominant macrozoobenthos population Arthropoda, with abundance (%) of 31.1. The Shannon *H* was (1.602), with Evenness (e H/S) of 0.99 and Margalef Richness (*S*) of 0.5533. While as Simpson's dominance (1-D) showed a value of 0.2022, which was lower than the dominant Arthropoda. Mollusca followed Annelida population at site 3, with abundance (%) of 17.9. The Shannon *H* was (1.572), with Evenness (e H/S) of 0.98 and Margalef Richness (*S*) of 0.5993. While as Simpson's dominance (1-D) showed a value of 0.2149, which was higher than the dominant Arthropoda (**Table 6**).

Similarly, at site 4, the Arthropoda comprised of the dominant species with 15 taxa, followed by Annelida and Mollusca, which constituted of 3 taxa each. Arthropoda dominated the macrozoobenthos population, with abundance (%) of 40.1. The Shannon *H* was highest (1.608), with Evenness (e H/S) of 1.00 and Margalef Richness (*S*) of 0.4762. While as Simpson's dominance (1-D) showed a value of 0.2003. Annelida followed the dominant macrozoobenthos population Arthropoda, with abundance (%) of 32.5. The Shannon *H* was (1.605), with Evenness (e H/S) of 1.01 and Margalef Richness (*S*) of 0.4883. While as Simpson's dominance (1-D) showed a value of 0.2015, which was lower than the dominant Arthropoda. Mollusca followed Annelida population at site 4, with abundance (%) of 27.4. The Shannon *H* was (1.505), with Evenness (e H/S) of 0.94 and Margalef Richness (*S*) of 0.4989. While as Simpson's dominance (1-D) showed a value of 0.2322 (**Table 7**).

At site 5, the Arthropoda yet again comprised of the dominant species with over 15 taxa, followed by Annelida and Mollusca, which constituted of 3 taxa each. Arthropoda dominated the macrozoobenthos population, with abundance (%) of 44.0. The Shannon *H* was highest (1.605), with Evenness (e H/S) of 1.00 and Margalef Richness (*S*) of 0.4913. While as Simpson's dominance (1-D) showed a value of 0.2015, which was higher than Annelida. Annelida followed the dominant macrozoobenthos population Arthropoda, with abundance (%) of 32.9. The Shannon *H* was (1.599), with Evenness (e H/S) of 0.99 and Margalef Richness (*S*) of 0.5096. While as Simpson's dominance (1-D) showed a value of 0.2039, which was higher than the dominant Arthropoda. Mollusca followed the two dominant macrozoobenthos population at site 5, with abundance (%) of 23.1. The Shannon *H* was (1.603), with Evenness (e H/S) of 1.00 and Margalef Richness (*S*) of 0.5335. While as Simpson's dominance (1-D) showed a value of 0.202, which was higher than the both Arthropoda and Annelida (**Table 8**).

Table 9 depicts the site wise macrozoobenthos diversity indices of Dikhu river, studied during the present research work. It is clear from the table that the species richness was 3 for all the study sites. The Shannon Entropy (*H'*) was highest for site 2, followed by other subsequent sites. The Shannon equitability (H'/H_{max}) was 98.9% for site 2, followed by site 4 (97.6%). Linearly lower values for Shannon Entropy (*H'*) and Shannon equitability (H'/H_{max}) were recorded in other sites, with higher values at site 2. Similar results were observed for Gini-Simpson Index (*1*-□), with 65.9% for site 2 and 64.7% for site 4, followed by other sites. Gini equitability (□□□□□□$_{max}$)) and predicted equitability for unbiased finite samples lent the same results. However, Berger Parker Index (max(p_i)) showed varied values for all sites. The three dominant sites showed the Berger Parker Index values of 65.4 (site 2), 61.1 (site 4) and 60.4 (site 5).

Macrozoobenthos true diversity (${}^{q}D$) and Renyi Entropy (${}^{q}H$) calculated during the present research work is presented in **Table 10**. The generalized mean for infinite orders (*q*) was calculated using species diversity calculator. The true diversity (${}^{q}D$) and Renyi Entropy (${}^{q}H$) at all the sites for q = 0 (harm) was 3.00 and 1.10 respectively, which showed lower values for infinite samples.

Table 4: Species diversity and richness indices of macrozoobenthos species at Site 1

Parameters	Arthropoda	Annelida	Mollusca
Taxa_S (no. of species)	15	3	3
Individuals (nos./ sampling area)	2342	2300	1012
Abundance%	41.4	40.7	17.9
Simpson _ 1-D	0.2017	0.2029	0.2054
Shannon _ H	1.5810	1.528	1.594
Eveness _ e H/S	0.98	0.95	0.99
Margalef	0.5155	0.5168	0.5781
FBI	7.01	6.25	5
Cb2	7.59	7.42	6.09

Table 5: Species diversity and richness indices of macrozoobenthos species at Site 2

Parameters	Arthropoda	Annelida	Mollusca
Taxa_S (no. of species)	15	3	3
Individuals (nos./ sampling area)	5813	3931	3124
Abundance%	51.1	28	20.9
Simpson _ 1-D	0.2092	0.2229	0.2518
Shannon _ H	1.588	1.551	1.464
Eveness _ e H/S	0.99	0.96	0.91
Margalef	0.4454	0.4751	0.4945
FBI	8.2	7.5	5.9
Cb2	9.01	8.54	7.21

Table 6: Species diversity and richness indices of macrozoobenthos species at Site 3

Parameters	Arthropoda	Annelida	Mollusca
Taxa_S (no. of species)	15	3	3
Individuals (nos./ sampling area)	2256	1378	813
Abundance%	51.0	31.1	17.9
Simpson _ 1-D	0.2004	0.2022	0.2149
Shannon _ H	1.607	1.602	1.572
Eveness _ e H/S	1.01	0.99	0.98
Margalef	0.518	0.5533	0.5993
FBI	6.56	5.97	4.69
Cb2	7.55	6.98	5.89

Table 7: Species diversity and richness indices of macrozoobenthos species at Site 4

Parameters	Arthropoda	Annelida	Mollusca
Taxa_S (no. of species)	15	3	3
Individuals (nos./ sampling area)	4367	3617	3089
Abundance%	40.1	32.5	27.4
Simpson _ 1-D	0.2003	0.2015	0.2322
Shannon _ H	1.608	1.605	1.505
Eveness _ e H/S	1.00	1.01	0.94
Margalef	0.4762	0.4883	0.4989
FBI	8.1	8.0	6.02
Cb2	8.91	8.08	7.21

Table 8: Species diversity and richness indices of macrozoobenthos species at Site 5

Parameters	Arthropoda	Annelida	Mollusca
Taxa_S (no. of species)	15	3	3
Individuals (nos./ sampling area)	3432	2564	1804
Abundance%	44.0	32.9	23.1
Simpson _ 1-D	0.2015	0.2039	0.202
Shannon _ H	1.605	1.599	1.603
Eveness _ e H/S	1.00	0.99	1.00
Margalef	0.4913	0.5096	0.5335
FBI	7.01	7.05	5.1
Cb2	8.06	8.01	6.59

Table 9: Macrozoobenthos Diversity Indices of R. Dikhu

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5
Richness $R = {}^0D$**:**	**3.00**	**3.00**	**3.00**	**3.00**	**3.00**
Shannon Entropy $H' = \ln({}^1D)$**:**	**1.010**	**1.007**	**1.006**	**1.016**	**1.013**
Shannon's equitability (%) H'/H_{max}	92.9	98.9	91.5	97.6	95.4
Simpson Dominance (%) $\lambda=1/{}^2D$	**35.3**	**38.9**	**33.1**	**37.6**	**36.4**
unbiased (finite samples): (%)	35.8	38.9	34.5	37.7	36.4
Gini-Simpson Index (1- λ**)** (%)	**62.9**	**65.9**	**61.1**	**64.7**	**64.2**
unbiased (finite samples): (%)	61.9	64.5	60.1	63.7	63.1
equitability $\lambda/(1-\lambda_{max})$: (%)	94.8	98.7	91.6	97.5	96.7
Berger-Parker Index $\max(p_i)=1/{}^{\infty}D$(%)	**54.1**	**65.4**	**51.5**	**61.1**	**60.4**

Table 10: Macrozoobenthos true diversity and Renyi Entropy for Dikhu River

Sample sites	Parameters	Diversity Indices					
	Order *q*:	**0**	**1**	**2**	**3**	**4**	∞
	Generalized Mean:	harm	geom	avg	rms	-	inf
1	**Hill Numbers -True Diversity ^qD:**	**3.00**	**2.87**	**2.66**	**2.67**	**2.69**	**2.26**
	Renyi Entropy ^qH:	**1.10**	**0.93**	**0.91**	**0.81**	**0.81**	**0.72**
2	**Hill Numbers -True Diversity ^qD:**	**3.00**	**2.98**	**2.93**	**2.89**	**2.86**	**2.50**
	Renyi Entropy ^qH:	**1.10**	**1.09**	**1.07**	**1.06**	**1.05**	**0.91**
3	**Hill Numbers -True Diversity ^qD:**	**3.00**	**2.81**	**2.58**	**2.61**	**2.61**	**2.17**
	Renyi Entropy ^qH:	**1.10**	**0.86**	**0.84**	**0.77**	**0.79**	**0.69**
4	**Hill Numbers -True Diversity ^qD:**	**3.00**	**2.94**	**2.83**	**2.75**	**2.81**	**2.48**
	Renyi Entropy ^qH:	**1.10**	**1.06**	**1.02**	**0.97**	**0.95**	**0.88**
5	**Hill Numbers -True Diversity ^qD:**	**3.00**	**2.91**	**2.77**	**2.72**	**2.78**	**2.41**
	Renyi Entropy ^qH:	**1.10**	**1.01**	**0.97**	**0.89**	**0.85**	**0.77**

4.6. Correlation between water parameters and Macrozoobenthos abundance

To study the relationship between the Physico-chemical parameters and freshwater Benthic macro-invertebrates Pearson's correlation coefficient (r) was used. Correlation analysis provides us information about the relationship between the two variables but it does not tell us about the cause and effect of relationship. If both the variables are changing in the same direction, that means both are increasing or both are decreasing, then there is a positive correlation between the two variables. If the two variables change in opposite direction, then they possess negative correlation.

r = 1 is considered to be perfect positive correlation.

0 < r < 0.39 is considered to be low positive correlation.

0.40 < r < 0.69 is considered to be moderate positive correlation.

0.70< r< 0.99 is considered to be high positive correlation.

-0.39< r< -0.1 is considered to be low negative correlation.

-0.69< r< -0.40 is considered to be moderate negative correlation.

-0.99< r< -0.70 is considered to be high negative correlation.

4.6.1 Correlation between Physico- chemical parameters and benthic macro invertebrates at site 1 in Dikhu River:

Negative correlation (r = -0.009) between temperature and arthropoda was observed however temperature and Annelida was positively correlated (r = 0.212). Low negative correlation between Temperature and Mollusca was observed (r = -0.007). Positive correlation between pH and Arthropoda (r = 0.009) and Annelida (r = 0.114) was observed. Correlation between pH and Mollusca was negatively correlated (r = -0.023). Correlation between transparency and Arthropoda was observed as r = 0.752. Correlation between transparency and Annelida was observed as r = 0.579. Thus Annelida showed moderate positive correlation with transparency. Correlation between transparency and Mollusca was observed as r = 0.657. Thus Mollusca showed moderate positive correlation with transparency. Correlation between Dissolved oxygen and Arthropoda was observed as r = 0.212. Thus Arthropoda showed low positive correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Annelida was observed as r = -0.512. Thus Annelida showed moderate negative correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Mollusca was observed as r = 0.221. Thus Mollusca showed low positive correlation with Dissolved oxygen. Correlation between Biological oxygen demand and Arthropoda was observed as r= -0.501. Thus Arthropoda showed moderate negative correlation with biological oxygen demand. Correlation between Biological oxygen demand and Annelida was observed as r = 0.279. Thus Gastropods showed low positive correlation with biological oxygen demand. Correlation between Biochemical oxygen demand and Mollusca was observed as r = -0.498. Thus Mollusca showed moderate negative correlation with Biological oxygen demand. Correlation between Total hardness and Arthropoda was observed as r = 0.412. Thus Arthropoda showed moderate positive correlation with Total hardness. Correlation between Total hardness and Annelida was observed as r = 0.568. Thus Total hardness showed moderate positive correlation with Total hardness. Correlation between Total hardness and Mollusca was observed as r = 0.354. Thus Mollusca showed low positive correlation with Total hardness. Correlation between Alkalinity and Arthropoda was observed as r = 0.796. Thus Alkalinity showed high positive correlation with Alkalinity. Correlation between Alkalinity and Annelida was observed as r = -0.212. Thus Annelida showed low negative correlation with Alkalinity. Correlation between Alkalinity and Mollusca was observed as r = 0.771. Thus Mollusca showed high positive correlation with Alkalinity. Correlation between Chloride and Arthropoda was observed as r = - 0.198. Thus Arthropoda showed low negative correlation with Chloride.

Correlation between Chloride and Annelida was observed as r = -0.589. Thus Annelida showed moderate positive correlation with Chloride. Correlation between Chloride and Mollusca was observed as r = -0.123. Thus Annelida showed low negative correlation with Chloride. Correlation between Nitrate and Arthropoda was observed as r = 0.767. Thus Arthropoda showed high positive correlation with Nitrate. Correlation between Nitrate and Annelida was observed as r = 0.555. Thus Annelida showed moderate positive correlation with Nitrate. Correlation between Nitrate and Mollusca was observed as r = 0.754. Thus Annelida showed high positive correlation with Nitrate. Correlation between Phosphate and Arthropoda was observed as r = 0.771. Thus Arthropoda showed high positive correlation with Phosphate. Correlation between Phosphate and Annelida was observed as r = 0.721. Thus Annelida showed high positive correlation with Phosphate. Correlation between Phosphate and Mollusca was observed as r = 0.712. Thus Annelida showed high positive correlation with Phosphate.

4.6.2 Correlation between Physico- chemical parameters and benthic macro invertebrates at site 2 in Dikhu River:

Correlation between Temperature and Arthropoda was observed as r = 0.022. Thus Arthropoda showed low positive correlation with Temperature. Correlation between Temperature and Annelida was observed as r = 0.057. Thus Annelida showed low positive correlation with Temperature. Correlation between Temperature and Mollusca was observed as r = 0.011. Thus Mollusca showed low positive correlation with Temperature. Correlation between pH and Arthropoda was observed as r = 0.071. Thus Arthropoda showed low positive correlation with pH. Correlation between pH and Annelida was observed as r = -0.002. Thus Annelida showed low negative correlation with pH. Correlation between pH and Mollusca was observed as r = 0.001. Thus Mollusca showed low positive correlation with pH. Correlation between Transparency and Arthropoda was observed as r = 0.781. Thus Annelida showed high positive correlation with Transparency. Correlation between Transparency and Annelida was observed as r = 0.578. Thus Annelida showed moderate positive correlation with Transparency. Correlation between transparency and Mollusca was observed as r = 0.712. Thus Mollusca showed moderate positive correlation with transparency. Correlation between Dissolved oxygen and Arthropoda was observed as r = 0.212. Thus Arthropoda showed low positive correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Annelida was observed as r = 0.121. Thus Annelida showed low positive correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Mollusca was observed as r = 0.212. Thus Mollusca showed low positive correlation with Dissolved oxygen. Correlation between Biological oxygen demand and Arthropoda was observed as r= -0.521. Thus Arthropoda showed low negative correlation with Biological oxygen demand. Correlation between Biological oxygen demand and Annelida was observed as r = -0.501. Thus Annelida showed low negative correlation with Biological oxygen demand. Correlation between Biochemical oxygen demand and Mollusca was observed as r = -0.602. Thus Mollusca showed low negative correlation with Biological oxygen demand. Correlation between Total hardness and Arthropoda was observed as r = 0.125. Thus Arthropoda showed low positive correlation with Total hardness. Correlation between Total hardness and Annelida was observed as r = 0.245. Thus Total hardness showed low positive correlation with

Total hardness. Correlation between Total hardness and Mollusca was observed as r = 0.212. Thus Mollusca showed low positive correlation with Total hardness. Correlation between Alkalinity and Arthropoda was observed as r = -0.055. Thus Alkalinity showed low negative correlation with Alkalinity. Correlation between Alkalinity and Annelida was observed as r = -0.025. Thus Annelida showed low negative correlation with Alkalinity. Correlation between Alkalinity and Mollusca was observed as r = -0.088. Thus Mollusca showed low negative correlation with Alkalinity. Correlation between Chloride and Arthropoda was observed as r = 0.501. Thus Arthropoda showed moderate positive correlation with Chloride. Correlation between Chloride and Annelida was observed as r = 0.502. Thus Annelida showed moderate positive correlation with Chloride. Correlation between Chloride and Mollusca was observed as r = 0.487. Thus Annelida showed low positive correlation with Chloride. Correlation between Nitrate and Arthropoda was observed as r = 0.701. Thus Arthropoda showed high positive correlation with Nitrate. Correlation between Nitrate and Annelida was observed as r = 0.617. Thus Annelida showed moderate positive correlation with Nitrate. Correlation between Nitrate and Mollusca was observed as r = 0.666. Thus Annelida showed high positive correlation with Nitrate. Correlation between Phosphate and Arthropoda was observed as r = 0.661. Thus Arthropoda showed high positive correlation with Phosphate. Correlation between Phosphate and Annelida was observed as r = 0.802. Thus Annelida showed high positive correlation with Phosphate. Correlation between Phosphate and Mollusca was observed as r = 0.802-. Thus Annelida showed high positive correlation with Phosphate.

4.6.3 Correlation between Physico- chemical parameters and benthic macro invertebrates at site 3 in Dikhu River:

Correlation between Temperature and Arthropoda was observed as r = -0.212. Thus Arthropoda showed low negative correlation with Temperature. Correlation between Temperature and Annelida was observed as r = -0.11. Thus Annelida showed low positive correlation with Temperature. Correlation between Temperature and Mollusca was observed as r = 0.225. Thus Mollusca showed low positive correlation with Temperature. Correlation between pH and Arthropoda was observed as r = 0.017. Thus Arthropoda showed low positive correlation with pH. Correlation between pH and Annelida was observed as r = -0.055. Thus Annelida showed low negative correlation with pH. Correlation between pH and Mollusca was observed as r = 0.085. Thus Mollusca showed low positive correlation with pH. Correlation between Transparency and Arthropoda was observed as r = 0.910. Thus Annelida showed high positive correlation with Transparency. Correlation between Transparency and Annelida was observed as r = 0.821. Thus Annelida showed moderate positive correlation with Transparency. Correlation between transparency and Mollusca was observed as r = 0.552. Thus Mollusca showed moderate positive correlation with transparency. Correlation between Dissolved oxygen and Arthropoda was observed as r = -0.512. Thus Arthropoda showed low negative correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Annelida was observed as r = -0.337. Thus Annelida showed low negative correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Mollusca was observed as r = -0.127. Thus Mollusca showed low negative correlation with Dissolved oxygen. Correlation between Biological oxygen demand and

Arthropoda was observed as r= -0.555. Thus Arthropoda showed low negative correlation with Biological oxygen demand. Correlation between Biological oxygen demand and Annelida was observed as r = -0.422. Thus Annelida showed low negative correlation with Biological oxygen demand. Correlation between Biochemical oxygen demand and Mollusca was observed as r = -0.087. Thus Mollusca showed low negative correlation with Biological oxygen demand. Correlation between Total hardness and Arthropoda was observed as r = 0.578. Thus Arthropoda showed low positive correlation with Total hardness. Correlation between Total hardness and Annelida was observed as r = 0.782. Thus Total hardness showed high positive correlation with Total hardness. Correlation between Total hardness and Mollusca was observed as r = 0.910. Thus Mollusca showed high positive correlation with Total hardness. Correlation between Alkalinity and Arthropoda was observed as r = 0.540. Thus Alkalinity showed low positive correlation with Alkalinity. Correlation between Alkalinity and Annelida was observed as r = 0.452. Thus Annelida showed low positive correlation with Alkalinity. Correlation between Alkalinity and Mollusca was observed as r = 0.315. Thus Mollusca showed low positive correlation with Alkalinity. Correlation between Chloride and Arthropoda was observed as r = -0.252. Thus Arthropoda showed low negative correlation with Chloride. Correlation between Chloride and Annelida was observed as r = -0.122. Thus Annelida showed low negative correlation with Chloride. Correlation between Chloride and Mollusca was observed as r = 0.091. Thus Annelida showed low positive correlation with Chloride. Correlation between Nitrate and Arthropoda was observed as r = 0.662. Thus Arthropoda showed high positive correlation with Nitrate. Correlation between Nitrate and Annelida was observed as r = 0.683.

Thus Annelida showed moderate positive correlation with Nitrate. Correlation between Nitrate and Mollusca was observed as r = 0.567. Thus Annelida showed high positive correlation with Nitrate. Correlation between Phosphate and Arthropoda was observed as r = 0.457. Thus Arthropoda showed high positive correlation with Phosphate. Correlation between Phosphate and Annelida was observed as r = 0.662. Thus Annelida showed high positive correlation with Phosphate. Correlation between Phosphate and Mollusca was observed as r = 0.685. Thus Annelida showed high positive correlation with Phosphate.

4.6.4 Correlation between Physico- chemical parameters and benthic macro invertebrates at site 4 in Dikhu River:

Correlation between Temperature and Arthropoda was observed as r = 0.001. Thus Arthropoda showed low positive correlation with Temperature. Correlation between Temperature and Annelida was observed as r = 0.296. Thus Annelida showed low positive correlation with Temperature. Correlation between Temperature and Mollusca was observed as r = 0.569. Thus Mollusca showed low positive correlation with Temperature. Correlation between pH and Arthropoda was observed as r = -0.125. Thus Arthropoda showed low negative correlation with pH. Correlation between pH and Annelida was observed as r = -0.187. Thus Annelida showed low negative correlation with pH. Correlation between pH and Mollusca was observed as r = -0.115. Thus Mollusca showed low positive correlation with pH. Correlation between Transparency and Arthropoda was observed as r = 0.802. Thus Annelida showed high positive correlation with Transparency. Correlation between Transparency and Annelida was observed as r = 0.555. Thus Annelida showed moderate positive correlation with Transparency. Correlation between transparency and Mollusca was observed as r = 0.268. Thus Mollusca showed moderate positive correlation with transparency. Correlation between Dissolved oxygen and Arthropoda was observed as r = -0.121. Thus Arthropoda showed low negative correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Annelida was observed as r = 0.215. Thus Annelida showed low positive correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Mollusca was observed as r = 0.512. Thus Mollusca showed low positive correlation with Dissolved oxygen. Correlation between Biological oxygen demand and Arthropoda was observed as r= -0.657. Thus Arthropoda showed low negative correlation with Biological oxygen demand. Correlation between Biological oxygen demand and Annelida was observed as r = -0.689. Thus Annelida showed low negative correlation with Biological oxygen demand. Correlation between Biochemical oxygen demand and Mollusca was observed as r = -0.521. Thus Mollusca showed low negative correlation with Biological oxygen demand. Correlation between Total hardness and Arthropoda was observed as r = 0.331. Thus Arthropoda showed low positive correlation with Total hardness. Correlation between Total hardness and Annelida was observed as r = 0.666. Thus Total hardness showed high positive correlation with Total hardness. Correlation between Total hardness and Mollusca was observed as r = 0.796. Thus Mollusca showed high positive correlation with Total hardness. Correlation between Alkalinity and Arthropoda was observed as r = 0.056. Thus Alkalinity showed low positive correlation with Alkalinity. Correlation between Alkalinity and Annelida was observed as r = 0.521. Thus Annelida showed low positive correlation with Alkalinity. Correlation between

Alkalinity and Mollusca was observed as r = 0.655. Thus Mollusca showed low positive correlation with Alkalinity. Correlation between Chloride and Arthropoda was observed as r = 0.058. Thus Arthropoda showed low negative correlation with Chloride. Correlation between Chloride and Annelida was observed as r = 0.315. Thus Annelida showed low positive correlation with Chloride. Correlation between Chloride and Mollusca was observed as r = 0.551. Thus Annelida showed low positive correlation with Chloride. Correlation between Nitrate and Arthropoda was observed as r = 0.512. Thus Arthropoda showed high positive correlation with Nitrate. Correlation between Nitrate and Annelida was observed as r = 0.518. Thus Annelida showed moderate positive correlation with Nitrate. Correlation between Nitrate and Mollusca was observed as r = 0.465. Thus Annelida showed high positive correlation with Nitrate. Correlation between Phosphate and Arthropoda was observed as r = 0.536. Thus Arthropoda showed high positive correlation with Phosphate. Correlation between Phosphate and Annelida was observed as r = 0.702. Thus Annelida showed high positive correlation with Phosphate. Correlation between Phosphate and Mollusca was observed as r = 0.788. Thus Annelida showed high positive correlation with Phosphate.

4.6.5 Correlation between Physico- chemical parameters and benthic macro invertebrates at site 5 in Dikhu River:

Correlation between Temperature and Arthropoda was observed as r = 0.012. Thus Arthropoda showed low positive correlation with Temperature. Correlation between Temperature and Annelida was observed as r = 0.212. Thus Annelida showed low positive correlation with

Temperature. Correlation between Temperature and Mollusca was observed as r = 0.446. Thus Mollusca showed low positive correlation with Temperature. Correlation between pH and Arthropoda was observed as r = -0.025. Thus Arthropoda showed low negative correlation with pH. Correlation between pH and Annelida was observed as r = -0.215. Thus Annelida showed low negative correlation with pH. Correlation between pH and Mollusca was observed as r = -0.215. Thus Mollusca showed low positive correlation with pH. Correlation between Transparency and Arthropoda was observed as r = 0.745. Thus Annelida showed high positive correlation with Transparency. Correlation between Transparency and Annelida was observed as r = 0.621. Thus Annelida showed moderate positive correlation with Transparency. Correlation between transparency and Mollusca was observed as r = 0.365. Thus Mollusca showed moderate positive correlation with transparency. Correlation between Dissolved oxygen and Arthropoda was observed as r = -0.215. Thus Arthropoda showed low negative correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Annelida was observed as r = 0.325. Thus Annelida showed low positive correlation with Dissolved oxygen. Correlation between Dissolved oxygen and Mollusca was observed as r = 0.448. Thus Mollusca showed low positive correlation with Dissolved oxygen. Correlation between Biological oxygen demand and Arthropoda was observed as r= -0.612. Thus Arthropoda showed low negative correlation with Biological oxygen demand. Correlation between Biological oxygen demand and Annelida was observed as r = -0.712. Thus Annelida showed low negative correlation with Biological oxygen demand. Correlation between Biochemical oxygen demand and Mollusca was observed as r = -0.602. Thus Mollusca showed low negative correlation with Biological oxygen demand.

Correlation between Total hardness and Arthropoda was observed as r = 0.335. Thus Arthropoda showed low positive correlation with Total hardness. Correlation between Total hardness and Annelida was observed as r = 0.511. Thus Total hardness showed high positive correlation with Total hardness. Correlation between Total hardness and Mollusca was observed as r = 0.774. Thus Mollusca showed high positive correlation with Total hardness. Correlation between Alkalinity and Arthropoda was observed as r = 0.045. Thus Alkalinity showed low positive correlation with Alkalinity. Correlation between Alkalinity and Annelida was observed as r = 0.444. Thus Annelida showed low positive correlation with Alkalinity. Correlation between Alkalinity and Mollusca was observed as r = 0.625. Thus Mollusca showed low positive correlation with Alkalinity. Correlation between Chloride and Arthropoda was observed as r = 0.066. Thus Arthropoda showed low negative correlation with Chloride. Correlation between Chloride and Annelida was observed as r = 0.312. Thus Annelida showed low positive correlation with Chloride. Correlation between Chloride and Mollusca was observed as r = 0.521. Thus Annelida showed low positive correlation with Chloride. Correlation between Nitrate and Arthropoda was observed as r = 0.501. Thus Arthropoda showed high positive correlation with Nitrate. Correlation between Nitrate and Annelida was observed as r = 0.601. Thus Annelida showed moderate positive correlation with Nitrate. Correlation between Nitrate and Mollusca was observed as r = 0.442. Thus Annelida showed high positive correlation with Nitrate. Correlation between Phosphate and Arthropoda was observed as r = 0.524. Thus Arthropoda showed high positive correlation with Phosphate. Correlation between Phosphate and Annelida was observed as r = 0.580. Thus Annelida showed high positive correlation with

Phosphate. Correlation between Phosphate and Mollusca was observed as r = 0.675. Thus Annelida showed high positive correlation with Phosphate.

Chapter 5
DISCUSSION

5. Discussion

Rivers are designated as some of the last global frontiers of rich freshwater diversity, endangered and threatened species. At the same time, these support millions of livelihoods and indigenous people. Rivers flowing through Eastern and North Eastern Himalayas and Western Ghats and its associated wetlands have been designated as global hotspots of freshwater biodiversity. The dynamic ecosystem of a river is viewed as a system operating in its natural environment, and includes biotic (living) interactions amongst plants, animals and micro-organisms, as well as abiotic (nonliving) physical and chemical interactions (Angelier, 2003; Campbell, 2009). River ecosystems are prime examples of lotic ecosystems. Lotic refers to flowing water, from the Latin lotus. Lotic waters range from springs only a few centimeters wide to major rivers kilometers in width (Allan, 1995). Lotic ecosystems can be contrasted with lentic ecosystems, which involve relatively still terrestrial waters such as lakes and ponds.

One of the most negative anthropogenic impacts is the so-called straightening and the construction of embankments in the mid and lower streams of almost all large rivers. The main purpose of these actions was to provide more farmlands for developing the economy and to combat flooding. The consequences of these activities are very serious and in many cases do not solve, but intensify the problems. The main consequence of river “straightening” by building dikes and cutting off meanders from the rivers is that the river becomes shorter and steeper. The new river is narrower due to the dikes built on its banks. All of this result in faster water flow and higher water levels during floods. The faster flow itself results in intensified erosion of both the river banks and bottom, i.e. the river starts “eating” its own bed and digs into the ground until it reaches harder bedrock. The increased erosion results in higher water turbidity, which is a big constrain for all aquatic organisms because it reduces the penetration of sunlight into the water. Fine particles clog to the gills of the animals that breathe dissolved oxygen. Another, even more serious problem related to riverbed incision is the lowering of groundwater levels. The problem is particularly exacerbated where these processes are combined with the gravel extraction. The river and neighboring groundwater are interconnected bodies, and the drop of water levels in the river (in some cases down 5 or 6 m) leads to a parallel decrease in the groundwater level because the river acts as a draining channel.

5.1. Geographic Information System for Site mapping

During the present research period, GIS and Google Earth were used to analyze the spatio-temporal analysis of the study sites. Satellite imageries which are visible (0.38 µm-0.72 µm) to near infrared (0.2 µm-0.2 µm) region of electromagnetic spectrum are very much useful in extracting information on aerial aspects of drainage basin and various hydro geomorphic features. Watershed management has become an increasingly important issue in many countries as government agencies and nongovernmental group struggle to find appropriate management approaches for improving productions from natural resources system. In watershed management principles, concepts and approaches with vast experiences change during the past few years but yet there is no universal methodology for achieving effective watershed management (Naiman *et al.*, 1997: Bhatta *et al*., 1999; Robinson, 2004; Gallopin, 2006).

It is mostly agreed that sustainable development and management of upland natural resources for the welfare and local populations should be the key objective of watershed management (Kammerbauer, 1999; Maarleveled, 2003; Immink. 2005 and 2007; Hosper *et al*., 2007). This objective includes sustainable utilization of watershed level as one of its important components (Sharma and Krosschell, 1996). Effective management of natural water resources in turn requires an understanding of the variability in time and space of these sources and the role of human cultures and institutions in bringing those variations (Naiman *et al*., 1997; German and Stroud, 2003; FAO, 2000; IIED, 2004; Reddy, 2000; Pandey and Yadama, 1990, Singh and Singh, 2010).

Remote sensing and GIS play an important role in the management of natural resources and helps in planning water resources development. One of the important advantages of using remote sensing data for hydrological investigations and monitoring its ability to generate information in spatial and temporal domain which is very crucial for successful analysis, prediction and validation (Saraf, 1999; Choudhary, 1999; Gautam *et al*., 2003; Prenzel, 2004; Giriraj *et al*. 2008). Geographical Information Systems is an excellent tool for assessing the land use/land cover changes using different kinds of data such as satellite images, aerial photos and maps. There are various methods that can be used in the collection, analysis and presentation of resource data but the use of remote sensing and geographic information system (RS/G1S) technologies can greatly facilitate the process. Geographical data can be collected, stored, analyzed and displayed in a wide variety of environments.

5.2. Physico-Chemical Analysis of Water

The annual thermal regime of a river, according to Smith (1981), is one of the important water quality parameters and most of the physical, chemical and biological properties of water are dependent on it. Several observers have kept a stretch of stream under observation for a period and have found, that superimposed upon the seasonal changes, there are diurnal cycles in temperature. These may amount to 6˚C in small streams in summer time (Edington, 1966), with lower values in large rivers. In winter time, however, ice and snow form an insulating layer, and even in extreme climates such as that of Alaska, the water temperature does not fall below 0˚C

(Sheridan, 1961). In spring time snow melt water may keep the temperature below that of the air for quite some time (Sheridan, 1961). Streams flowing underground or through man-made culverts may be cooled or warmed in the process according to the season, and wind or shade may cause considerable changes. In contrast to lakes, rivers normally show little stratification because of their turbulent flow (Hynes, 1970).

5.3 Physico Chemical Features

5.3.1 Water Temperature

During the present research work, the average air temperature ranged between 18.75±1.52 to 19.30±2.02°C, with lowest temperatures in winter and highest in summer months at all the study sites. The water temperature (°C) ranged between a minimum of 9.80±1.02°C to a maximum of 19.6±1.36°C (Fig 6) during the study period Water temperature has been observed to follow the general atmospheric temperature. This has widely been observed by Rice (1938); Welch (1952); Rao (1955); Zafar (1955); Macan (1963); Venkateshwarlu and Jayanti (1968); Munawar (1970a); Hannan and Young (1974); Qadri and Yousuf (1978); Swarup and Singh (1979); Sharma *et al*. (1981); Harshey *et al*. (1982); Mahadevan and Krishnaswamy (1983); Bagde and Varma (1985 a,b); Palharya and Malviya (1988); and Shyam Sunder (1988). Special effect of temperature on the intensity of pollution via enrichment of organic matter have been reported by Jeelani *et al*. (2008), Irshad *et al*. (2012), Jeelani & Kaur (2012), Bhat *et al.* (2013), Parveen *et al*. (2013), Patel & Patel (2013), Salim *et al*. (2013), Arti and Vipulab (2014), Mudasir *et al*. (2014), Tehmina *et al*. (2015), Jyoti *et al*. (2015), and Sharma *et al*. (2015).

Temperature constrains the various processes in aquatic ecosystems differently and therefore, a general warming of the water column will change trophic interactions and ecosystem functioning (Beaugrand and Reid, 2003; Alheit *et al*., 2005). Increasing temperatures could also change the balance between pelagic and benthic secondary production. Sedimentation rate of organic matter during the spring bloom has been shown to decrease due to higher zooplankton grazing effect and bacterial respiration in the water column if the temperature increases (Keller *et al*., 1993 and Müren *et al*., 2005). Thus, the total sedimentary input to sustain the benthos may decrease if more material is channeled through the pelagic grazing food chain (ErikssonWiklund *et al*., 2009). Higher bottom water temperatures will also increase pelagic microbial remineralization of the settling particulate organic matter and this effect will be more pronounced in the deeper water column and the longer the sinking material is exposed to pelagic respiration (Hansen and Bendtsen, 2006). Changes in the temperature could probably also change the species composition of the benthos according to their feeding ecology (Coyle *et al*., 2007). While benthic filter feeders have first access to the sedimenting food and therefore probably will be less affected by a lower food supply, deposit feeders are more likely to experience food limitation (Josefson and Conley, 1997). Altogether, increasing temperatures may alter the functioning of all trophic levels in a cascade from the primary producers to the higher trophic levels such as fish (Alheit *et al*., 2005).

In an aquatic ecosystem, the influence of temperature is due to the fact that the body temperature of aquatic organisms varied with and is almost the same as that of the environment. A rise in temperature of the water leads to the speeding up of the chemical reactions in water, reduces the solubility of gases and amplifies the taste and odour (Trivedy and Goel, 1984). According to Kumar *et al*. (1996), temperature is one of the most important factors in aquatic environment, since it regulates various physico-chemical as well as biological activities. Change in temperature govern water mixing, turbulence, formation of currents (Birge, 1916; Hutchinson, 1957 and Ruttner, 1963) and biological processes like the growth, development, reproduction and other life processes of biota (Wetzel, 1983). Fluctuation in temperature of an aquatic medium regulates the biological composition of that ecosystem (Banerjee *et al*., 1989). The disease resistances in fishes also decrease with temperature.

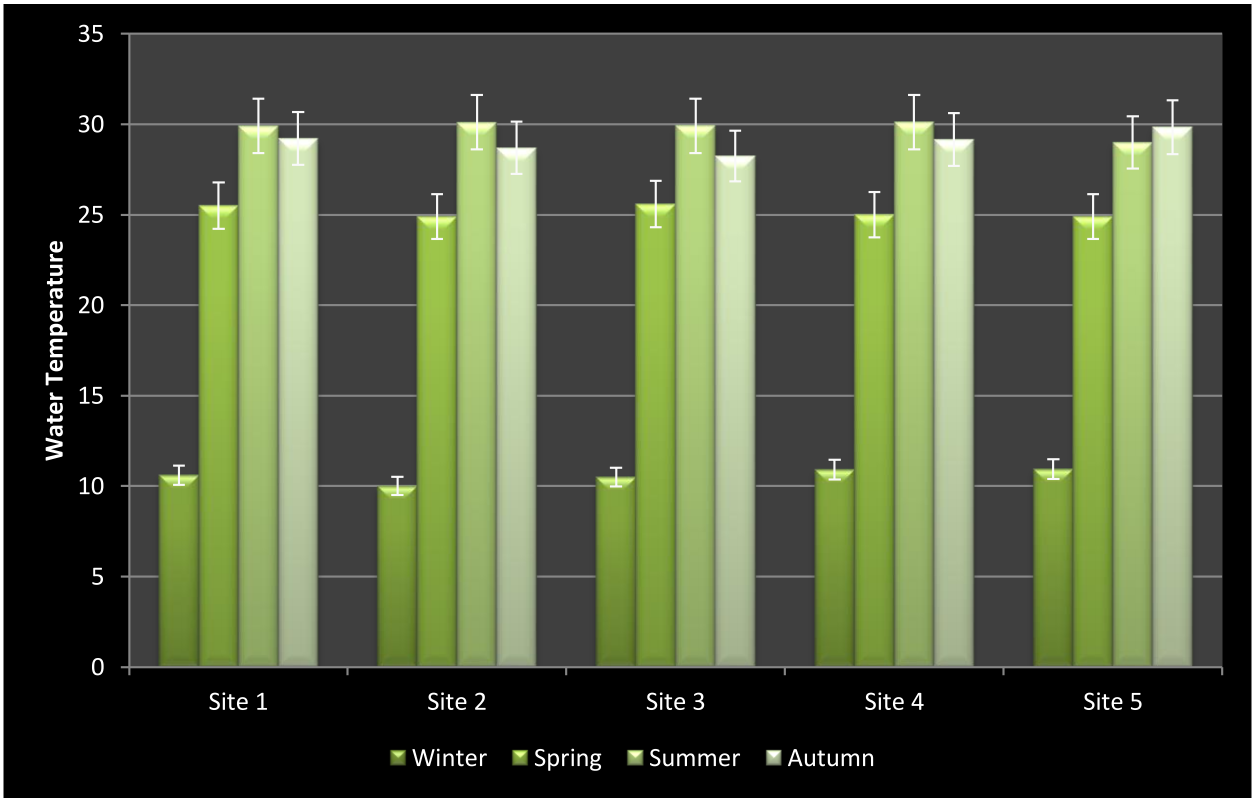


Fig. 6: Water temperature fluctuations at various study sites in Dikhu River

5.3.2. pH

In present study, pH of water fluctuated from 7.83 to 7.97 (Fig 7) throughout the course of study. The pH is very important chemical characteristic of natural water and is closely related to many biological phenomena, mineralization, oxidation and reduction in water bodies. pH indicates the concentration of hydrogen ions in water. It expresses the intensity of acidity or alkalinity which depends upon the amount of absorbed CO_2, on H^+ ion arising from the dissociation of carbonic acid (H_2CO_3) and OH^- ions arising from the hydrolysis of bicarbonates buffering the water. According to Welch (1952) it is an important means of understanding the chemical conditions prevailing in the natural waters. pH of water is considered to be one of most important chemical factor affecting the productivity of the water body. In general pH is influenced directly by the carbon dioxide concentration in the water, which in turn regulates photosynthetic and respiratory activities (Talling, 1976). However, the range of pH tolerance varies among different species. Biological conditions become better when pH of aquatic environment is constant. The pH of water body depended on the flow of effluents with high alkalinity, and the assimilation of the carbon dioxide reserve in it. Therefore, the determination of pH may serve as an index of other environmental conditions, like quantity of CO_2 and O_2.

Verma and Shukla (1970) believed that the pH would prove to be an ecological factor of major importance in controlling the activities and distribution of aquatic flora and fauna. However, Mehra (1986) suggested that pH of environment has little or no importance. To achieve good fish production, pH of water should be monitored regularly to ensure its optimum range. Alikunhi (1957) has demonstrated that pH between 6.5- 8.5 with large variations play a pivotal role in the productivity of water. pH range from 5 to 6.6 and 9.1 to 11.0 results in low productivity (Sreenivasan, 1964). According to Vegas-Villarubia *et al.* (1988) low alkalinity and pH values are indicators of low mineralization and high humic substances. Bell (1991) has stated that pH range between 6.5 to 9.0 provide an adequate environment for the well being of freshwater fish, bottom dwelling invertebrates and fish food organisms. Singh *et al*. (1982); Sharma and Dheneshwar (1986); Mishra (1988); Gopal (1990); Jindal and Kumar (1993); Khalique (1995); Bath (1996); Islam and Islam (1996); Syal (1996); Sarwar (1999); Narain and Chauhan (2000); Saha *et al*. (2000) and Valermathi *et al*. (2002) recorded change in pH values with addition of sewage and agricultural effluents. Qadri and Yousuf (1978); Khan (1979);

Zutshi *et al*. (1980); Sarwar (1987 and 1991 a,b) investigated the impact of macrophytic vegetation on pH values of water.

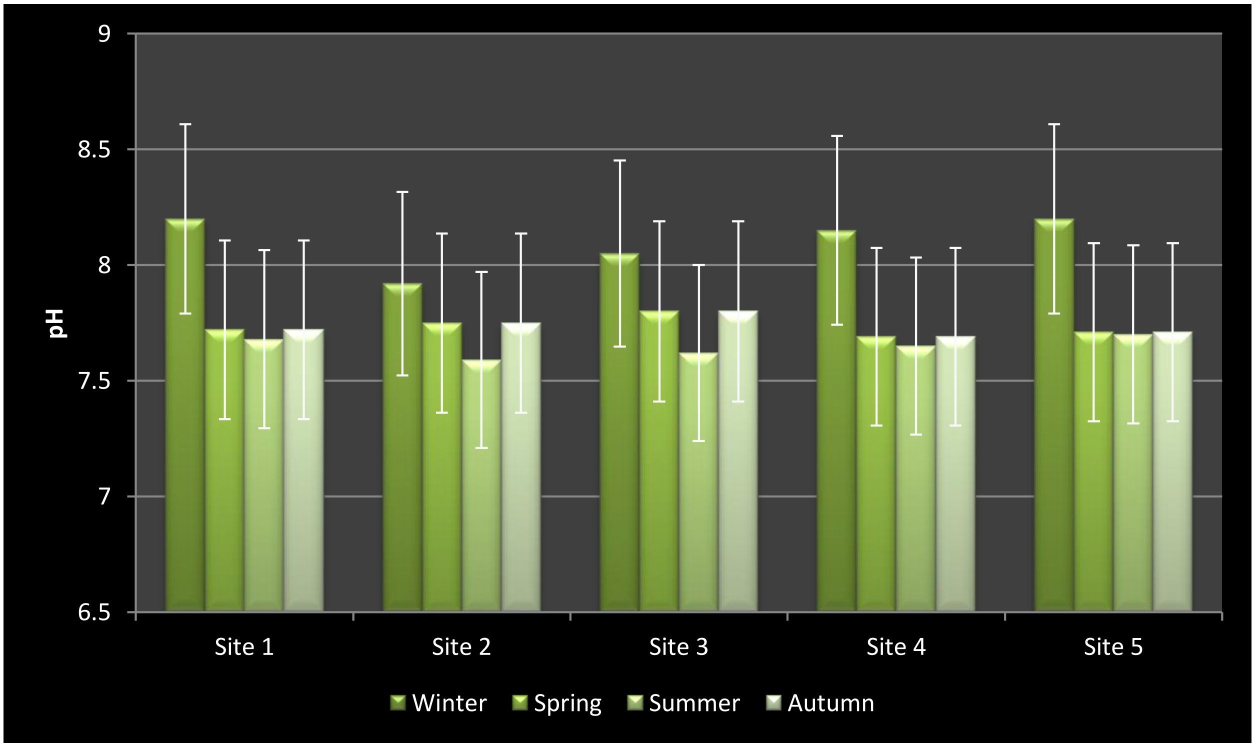


Fig. 7: Seasonal fluctuations of pH at various study sites in Dikhu river

5.3.3. Dissolved Oxygen

Dissolved oxygen is essential for the respiratory metabolism of organisms. The dissolved oxygen ranged between a minimum of 7.96±1.26 to a maximum of 12.55±1.06 (Fig 8) during the study period. The effects of waste discharge in the water body are largely determined by the oxygen balance of the system (Trivedy and Goel, 1984). The rates of supply of dissolved oxygen from the atmosphere and from the photosynthetic inputs and the hydro-mechanical distribution of oxygen are counter balanced by consumptive metabolism by biota and non-biotic chemical reactions. Dissolved oxygen influences many chemical and biological reactions and thus, is important for the hydrochemistry of aquatic ecosystem. It directly affects the survival and distribution of fauna and flora in an ecosystem (Vijay Kumar *et al*., 1999). Aquatic organisms have specific requirement of oxygen (Trivedy and Goel, 1984). The concentration of oxygen also reflects whether the processes undergoing are aerobic or anaerobic. Low oxygen concentrations are generally associated with heavy contamination by organic matter. Higher concentration of dissolved oxygen in water is an indication of better health and constantly high content allows a water body to support more members and variety of aquatic organisms (Parveen, 2003). Tarzwell (1957) has suggested that a minimum of 3.0 mg/l dissolved oxygen is necessary for healthy fish life. George (1961) has mentioned that the concentration of 1.4 mg/l is sufficient to maintain life in water. According to Das *et al*. (1995) dissolved oxygen concentration greater than 5.0 mg/l favours good growth of fauna and flora.

DattaMunshi and Singh (1991); Goel and Chavan (1991); Jhingran (1991 a,b); Shastree *et al*. (1991); Tripathi *et al*. (1991); Mathuthu *et al*. (1993); Anjana and Kanhere (1998); Kumar (1995 a,b); Bath (1996); Kaur *et al*. (1996a); Syal (1996); Bath and Kaur (1998); Jameel (1998); Shivanikar *et al*. (1999); Valarmathi *et al*. (2002); Kumar *et al*. (2003); Kaur *et al*. (2003), Prasannakumari *et al*. (2003), Jeelani *et al*. (2008), Irshad *et al*. (2012), Jeelani & Kaur (2012), Bhat *et al.* (2013), Parveen *et al*. (2013), Patel & Patel (2013), Salim *et al*. (2013), Arti and Vipulab (2014), Mudasir *et al*. (2014), Tehmina *et al*. (2015), Jyoti *et al*. (2015), and Sharma *et al*. (2015) carried out investigation on effects of sewage effluents on dissolved oxygen contents. Sculthrope (1967), Sarwar (1987); Roy (2000); Kaur *et al*. (2001) and Khatri and Dhankhar (2003) carried out studies on the impact of various anthropogenic activities on dissolved oxygen contents of water.

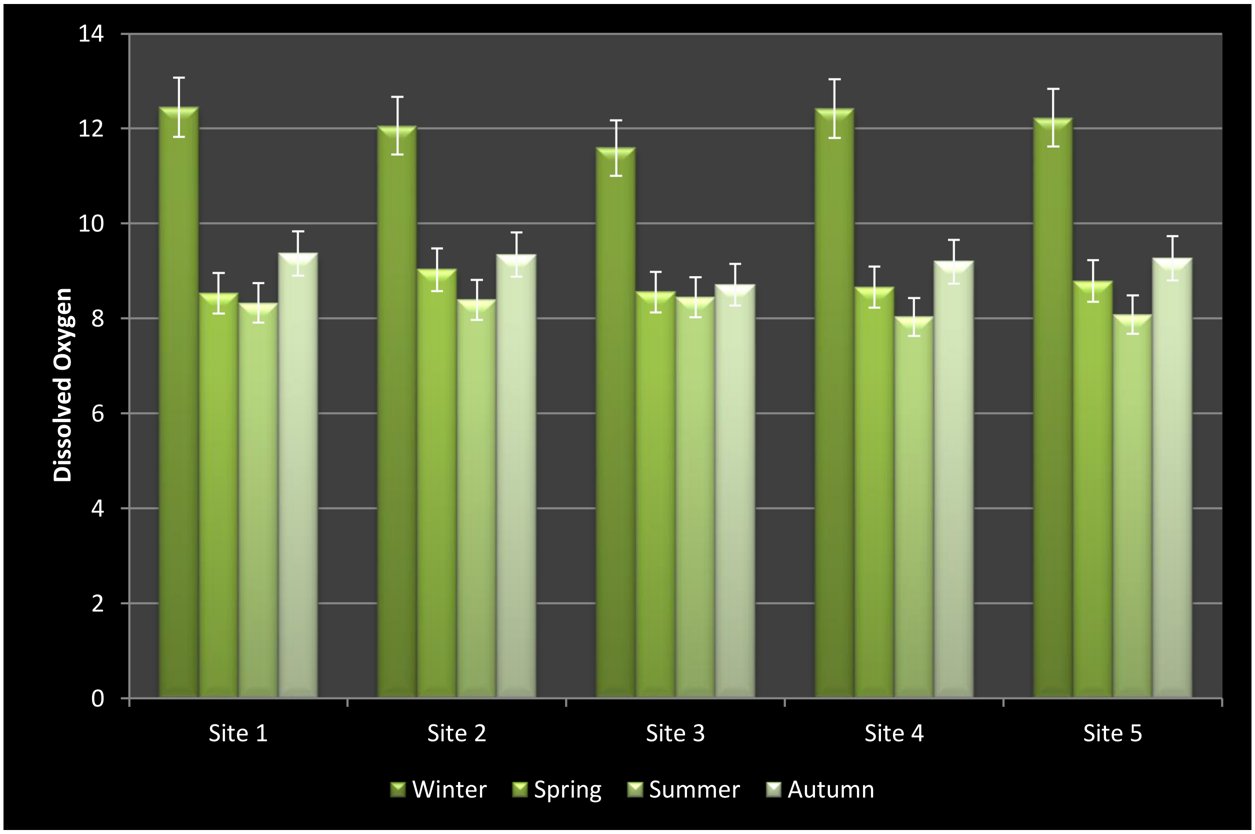


Fig. 8: Seasonal variation of Dissolved Oxygen in Dikhu river

5.3.4. Free Carbondioxide:

Carbon dioxide is an extremely important constituent of an aquatic environment (Welch, 1952). The concentration of free carbon dioxide during the study by Irshad *et al.* (2012) ranged from 0.40 mg/L to 34.00 mg/L with an average of 18.05±1.56. The carbon dioxide ranged between a minimum of 5.11±1.26 to a maximum of 9.68 ±1.61 (Fig 9). This gas is very much necessary for bacterial growth and green plants. The primary source of inorganic carbon for photosynthesis and the generation of organic substance in an aquatic ecosystem are largely dissolved carbon dioxide and bicarbonates (Wetzel, 2001). The presence of carbon dioxide in the environment, gives the opportunity to plants and phytoplankton to synthesize their food and produce oxygen, which is the basic need for all life forms. Variation in CO2 concentration may have an adverse effect on physiological functions of the biotic lives present in aquatic ecosystem.

Inorganic carbon utilization in natural water is balanced by respiratory generation of carbon dioxide by aquatic organisms and by influxes of carbon dioxide and bicarbonates with incoming surface run off and from atmosphere.

The presence of free CO_2 in the surface water is essential for photosynthesis. However, large amount of free carbon dioxide available in the ecosystem is harmful for animals as excess dissolved carbon dioxide is usually accompanied by a much reduced dissolved oxygen content and other important conditions. Besides, it regulates the pH of water which goes a long way in influencing the mode of biota and their life processes. It is well known that the carbon dioxide is the best single index of the suitability of water. Carbon dioxide is the chief source needed for photosynthesis process in plants. In aquatic ecosystems carbon dioxide reacts with water and forms carbonic acid which soon dissociates into carbonates and bicarbonates, thus altering pH of water. The behavior of carbon dioxide with pH is that an increase in carbon dioxide concentration in water results in decrease of its pH due to the formation of carbonic acid (Chandler, 1970. The authors reported that the free carbon dioxide was high during autumn and winter seasons. High concentration of free carbon dioxide during the warmer period may be due to the decomposition of organic matter, utilizing dissolved oxygen and liberating carbon dioxide. The higher concentration of free carbon dioxide in warmer months is indication of pollution, as witnessed by Jeelani & Kaur (2012), Bhat *et al.* (2013), Parveen *et al*. (2013), Salim *et al*. (2013), Mudasir *et al*. (2014), Tehmina *et al*. (2015) and Sharma *et al*. (2015).

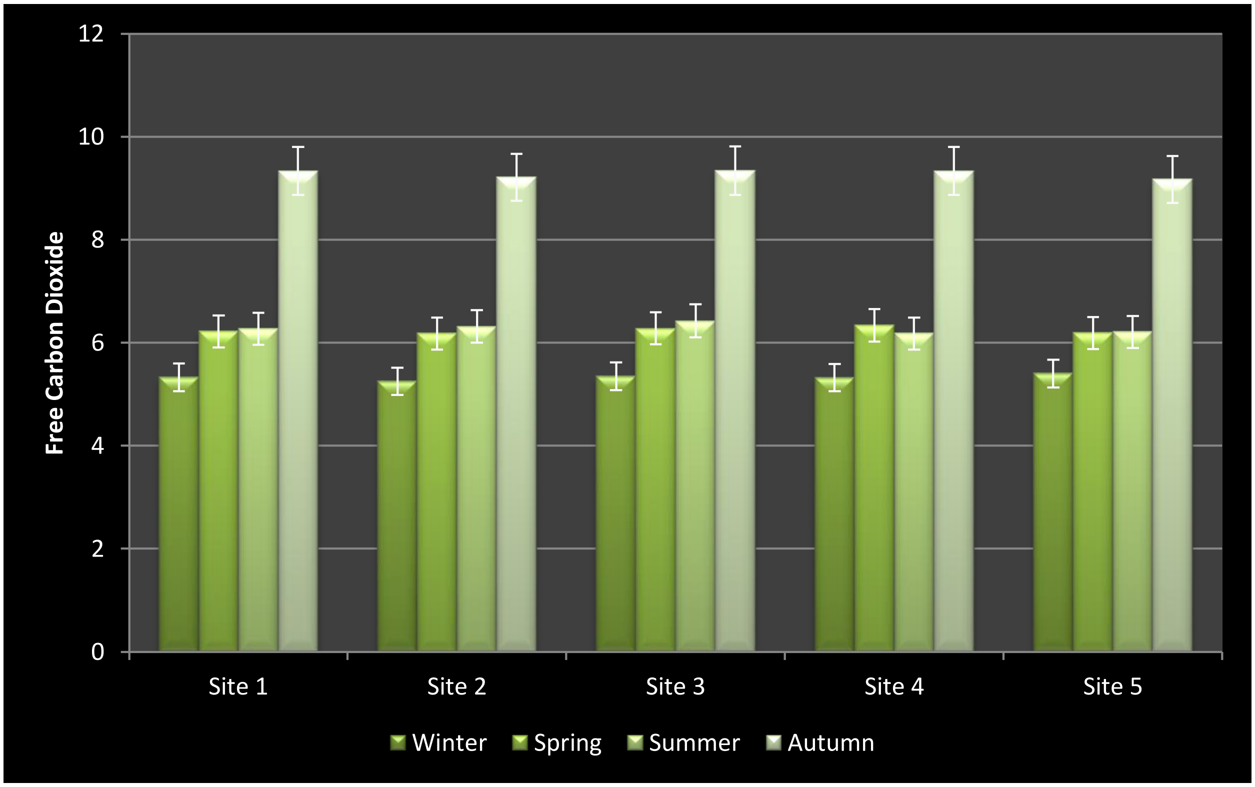


Fig. 9: Free Carbon Dioxide fluctuations at various study sites in Dikhu river

5.3.5. Total Alkalinity

The range of alkalinity in Indian waters varied from 40 to 1000 mg/l (Jhingran, 1991). Alikunhi (1957) considered alkalinity as a measure of productivity. In the present study alkalinity ranged between a minimum of 70.21±39.9 to a maximum of 139.6±14.7 (Fig 10). According to Hutchinson (1975), alkalinity is the total quantity of base that can be determined by titration with strong acid. Alkalinity of water, as usually interpreted refers to the quantity and quality of compounds present, which collectively shift the pH to the alkaline side of the neutrality (Wetzel, 1983). Though alkalinity is usually caused by the presence of hydroxides, carbonates and bicarbonates of the cations viz., Ca, Mg, Na, K, NH_4 and Fe in combined state yet it is also caused though less frequently by borates, silicates and phosphates (Wurts and Durborow, 1992). It is expressed in terms of equivalent bicarbonate or carbonate, although other ions could contribute to it. According to Jhingran (1991) total alkalinity of high range is encountered in waters having pH value ranging from 8.4 to 10.5. Natural water bodies show a wide range of fluctuation in total alkalinity values depending upon the location, season, plankton population, rainfall, human activity and nature of bottom deposits etc. Spence (1964) divided south Scottish water bodies into three major categories on the basis of alkalinity viz. nutrient poor, moderately rich and nutrient rich.

Alkalinity of water is its capacity to neutralize acid and is a measure of productivity as has been suggested by Moyle (1946). Its relationship with pH of water has been investigated by Freiser and Fernando (1966); Qadri and Yousuf (1980 a,b) and Zutshi *et al*. (1980). Water (1957); Zutshi *et al*. (1980); Patra and Nayak (1982); Trivedy and Goel (1986); Sarwar and Zutshi (1987 a,b); Weiler (1988); Sarwar and Zutshi (1989); Sarwar (1991 a,b); Chapman and Kimstach (1992); Meybeck *et al*. (1992); Syal (1996); Sarwar *et al*. (1996); Sarwar (1999); Valarmathi *et al*. (2002); Kumar *et al*. (2003), Prasannakumari *et al*. (2003), Jeelani *et al*. (2008), Irshad *et al*. (2012), Jeelani & Kaur (2012), Bhat *et al.* (2013), Patel & Patel (2013), Salim *et al*. (2013), Arti and Vipulab (2014), Mudasir *et al*. (2014), Tehmina *et al*. (2015) and Jyoti *et al*. (2015) recorded changes in alkalinity values in relation to levels of organic wastes discharged into water.

The factors responsible for higher alkalinity are entry of sewage leading to organic pollution, excessive release of soap and detergents through cloth washing within, bathing these ponds of cattle's and decomposition of organic matter in sediment. These finding agreed with Hayes and Anthony (1959). In present study maximum values of total alkalinity were recorded in summer which could be attributed to accelerated rate of photosynthesis leading to greater utilization of carbon dioxide and bicarbonates as source of inorganic carbon by phytoplankton and release carbonates which can cause pH to rise dramatically (Wurts and Durborow, 1992). However, higher values of alkalinity recorded in monsoon which could be related to greater agitation of water leading to decrease in CO_2 content, leaching of carbonates and bicarbonates from catchments and organic pollution. The observations are in agreement with the findings of Chourasia and Adoni (1985), Kumar (1990) and Khajuria (1992) but in total contrast to the observation of Jhingran (1991) and Gochhait (1991).

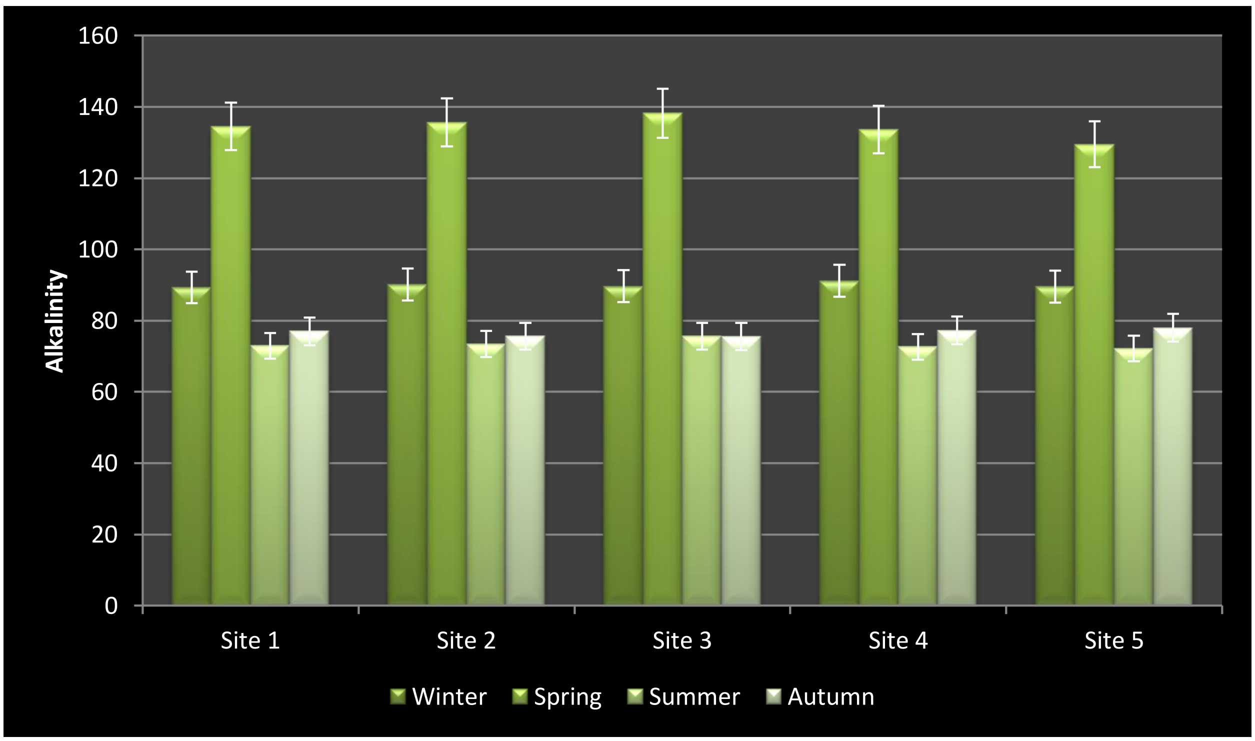


Fig. 10. Alkalinity fluctuations at various study sites in Dikhu river

5.3.6. Total Hardness

Mairs (1966) suggested total hardness to be a complex mixture of cations and anions while Cole (1975) recorded calcium and magnesium to account for most of the hardness. Zutshi (1968); Vass (1973); Zutshi *et al*. (1980); Kundanger and Zutshi (1985); Sarwar (1987 and 1991 a,b); Sarwar and Wazir (1988); Sarwar and Rifat (1991) and Sarwar *et al*. (1996) discussed the role of rocks in contributing hardness to water of various Kashmir lakes. Gopal (1990); Sinha *et* *al*. (1991); Chapman and Kimstach (1992) and Meybeck *et al*. (1992). Syal (1996) and Kaur *et al*. (2003) investigated the impact of sewage on the hardness values of water. The concentration of total hardness during the study period ranged from The hardness ranged between a minimum of 12.03±3.1 to a maximum of 41.60±2.3 mg/L (Fig 11) during the study period. Higher values were recorded during summer season and lower during autumn and winter season. The decrease in the concentration of bicarbonates during summer confirm the findings of Sahai and Srivastava (1976) who recorded low concentrations of bicarbonates from June to October owing to its increased use in carbon assimilation by phytoplankton and submerged macrophytes during photosynthesis.

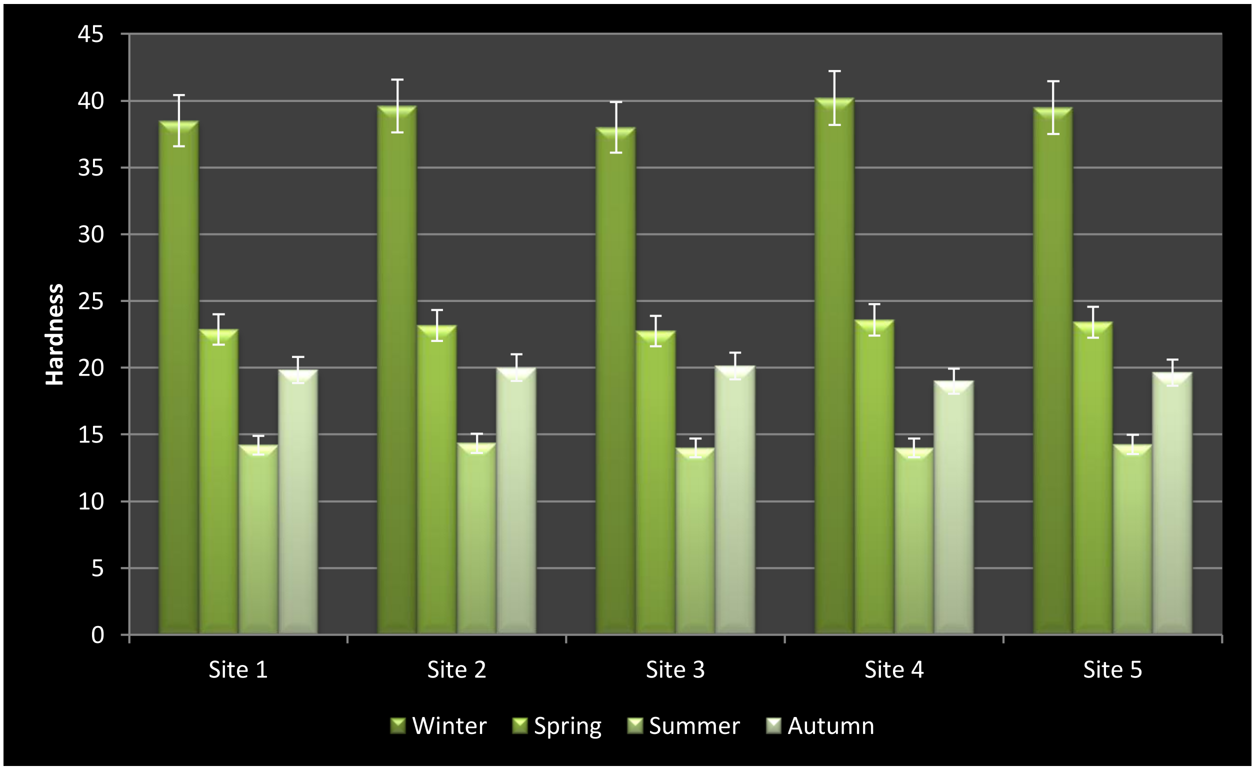


Fig. 11. Hardness fluctuations at various study sites in Dikhu river

5.3.7. Nitrate Nitrogen

Nitrate content is an excellent parameter to judge the organic pollution and it represents the highest oxidized form of the nitrogen. All biological growth processes require nitrogen in some form or the other for synthesis of cellular protein and nucleic acids, and hence, nitrogen plays an important role in the biological productivity of aquatic ecosystem. Being responsible for the formation of chlorophyll (Rhode, 1948), nitrate is one of the most important limiting factors in the development of phytoplankton (Welch, 1952). The sources of nitrogen into inland waters are N_2-fixation, surface and ground water inflow, diffusion, transport from sediment and bottom waters, microbial magnification, animal excretion etc. The nitrate ranged between a minimum of 0.009±0.005 to a maximum of 0.073±0.014 (Fig 12) during the study period. In natural aerobic waters, most nitrogen occurs as nitrates (Maitland, 1978) in varying amount depending upon the nature of water shade, seasons, degree of pollution and the abundance of Plankton (Rhode, 1969; Sommer, 1989). Excess of organic pollution leads to eutrophication. Barg (1992) opined that nitrogen pollution not only alters the water quality but also influence the primary productivity, growth of aquatic weeds, benthos, epiphytes and toxic algae. According to Mohanty (2000), a part of unutilized nitrogen is also lost into the sediments, which alters the soil nutrients status and benthic community.

Nitrogen is one of the major constituent of cellular protoplasm of photosynthetic organisms. Occurrence of nitrate form of nitrogen in various water bodies has been reported by Thrash *et al*. (1944); Sylvester (1961); Jolly and Chapman (1966); Willen and Evens (1972); King (1981); Ramakrishnaiah and Sarkar (1986); Shah (1988); Shyamsunder (1988) and Shastree *et al*. (1991). Harold (1934); Harvey (1940); Vashisht and Sharma (1975); Ajmal *et al*. (1985); Trivedy and Goel (1986); Adoni and Joshi (1987); Das (1989); Bandopadhyay and

Gopal (1991) and Bath (1996) recorded nitrate concentration in water bodies rich in macrophytic vegetation and phytoplanktons. Sarwar and Zutshi (1989) and Sarwar (1991 a,b) recorded nitrate nitrogen in water harboring rich growth of macrophytes. The impact of sewage on nitrate nitrogen was observed by Zutshi and Vass (1971); Seenayya (1971); King (1981); Ramakrishnaiah and Sarkar (1986); Trivedy and Goel (1986); Das (1989); Sarwar (1991 a,b); Bath (1996) and Savarna Somashekar (2000) and Kaur *et al*. (2002).

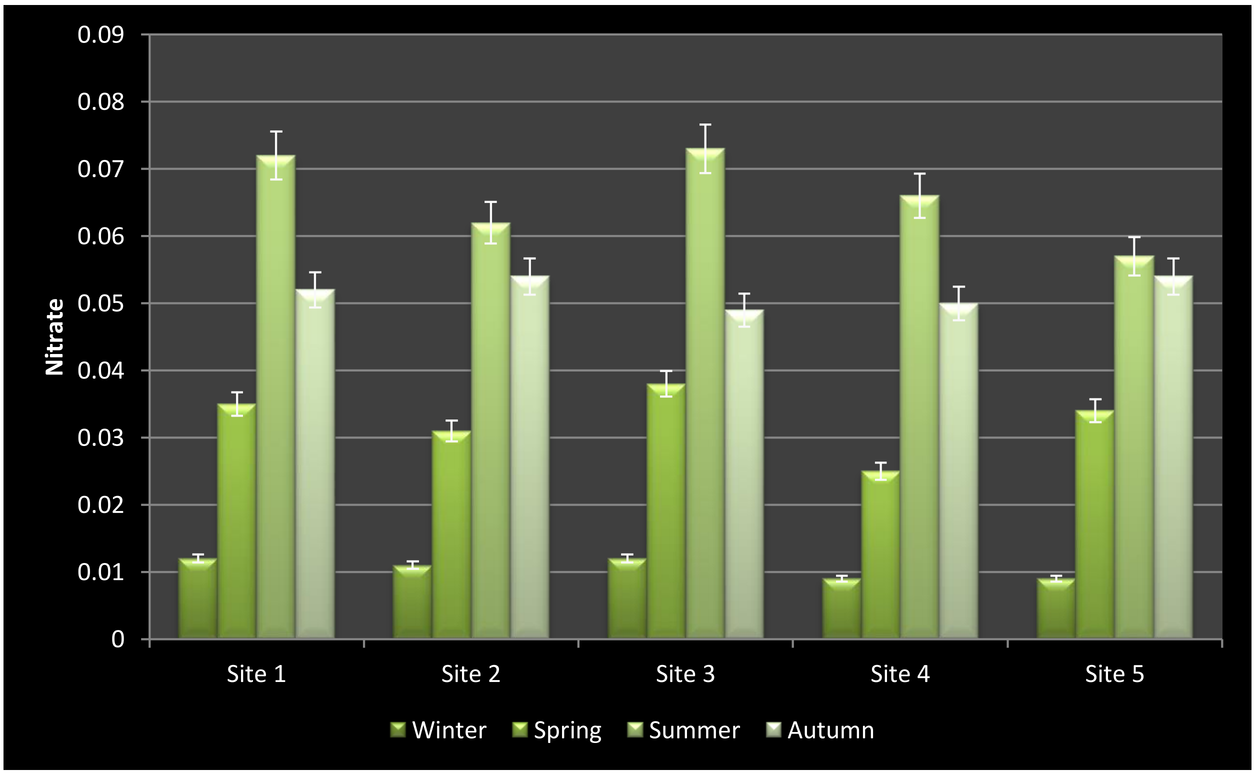


Fig. 12. Nitrate fluctuations at various study sites in Dikhu river

5.3.8. Total Phosphate

Phosphorus is one of the most important nutrients of the living organisms. It is found in meteorites, rocks soil and even in the sun's atmosphere. It is much scarcer than the other principal atoms of living biota such as carbon, hydrogen, oxygen, nitrogen, and sulphur. Its abundance at the surface of the earth is about one tenth of 1 % by weight. It is taken up rapidly and concentrated by living organisms (Cole, 1979). The phosphate content in aquatic medium is considered to be nutrient of major importance in the production process (Vollenwider, 1968). The increased application of fertilizers, use of detergents and domestic sewage play a great role in contributing the heavy loading of phosphorus in the water (Golterman, 1975). Phosphates play an incredible role in biochemical pathways of respiration and carbon dioxide assimilation, being an indispensable constituent of cellular components like nucleic acids (DNA, RNA, phosphoproteins), enzymes, vitamins, nucleotide phosphates (ADP, ATP) etc. (Wetzel, 2001). Though relatively small amount of phosphates are available in hydrosphere, yet it is of considerable significance in limiting the biological productivity (Rawson, 1939; Wetzel, 2001). The increase in its concentration not only leads to pollution (Vollenweider, 1975; Wetzel, 1983) but also affects the aquatic biota (Upadhyay, 1998).

The phosphate ranged between a minimum of 0.048±0.002 to a maximum of 0.087 ±0.001 (Fig 13) during the study period. Phosphorus is one of the major nutrients responsible for biological productivity as has been demonstrated by Hutchinson (1957). Michael (1969); Kaul (1977); Zutshi and Vass (1978); Harshey *et al*. (1982); Bath (1996); Bhatt *et al*. (1999) and Kumar *et al*. (2003) recorded seasonal variations in phosphate phosphorus values. Wanganeo *et al*. (1996) recorded concentration phosphate phosphorus across the water column in a limnological study on a dimictic Himalayan lake. Welch (1952); Ruttner (1953); Zutshi and Vass (1978); Trivedy and Goel (1986); Mishra (1988); Sarwar and Zutshi (1989); Das (1989); Kannan (1991); Sarwar (1991 a,b); Bath (1996); Bath and Kaur (1998); Khabade *et al*. (2003) and Prasannakumari *et al*. (2003) studied the impact of domestic sewage on phosphate phosphorus concentration of water. Heron (1961); Singh and Roy (1990); Bandopadhyay and Gopal (1991); Sarwar (1991 a,b); Thomas and Azis (1996); Bhatt *et al*. (1999) and Khabade *et al*. (2003) observed the impact of agricultural effluent on the concentration of phosphorus in various water bodies. Sawyer (1947), US department of interior division of technical support (1969) and Vollenweider (1972) have prescribed maximum permissible limits of phosphate phosphorus in water.

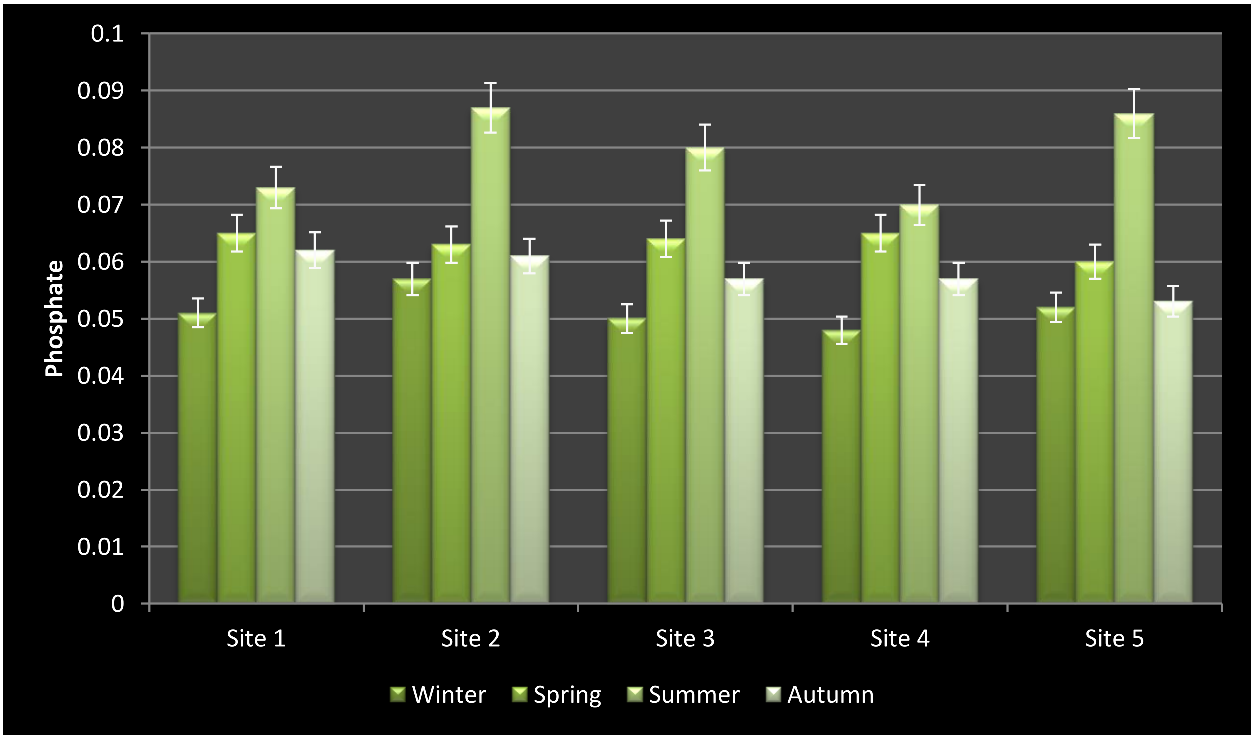


Fig. 13. Phosphate fluctuations at various study sites in Dikhu river

5.3.9. Conductivity:

Conductivity is a good major of concentration of charged ions in waters and is strongly influenced by landscape scale conditions. The geology in the catchment is the source of the ions that act as conductors of electricity (Golterman, 1975). Urban and agricultural land uses have been shown to increase conductivity levels (Gray, 2004). It has been established that there are seasonal differences in conductivity that generally result from a negative relationship with discharge volume (Caruso, 2002; Gray, 2004). The conductivity ranged between a minimum of 0.101±0.002 to a maximum of 0.217±0.001 (Fig 14) which is considerable.

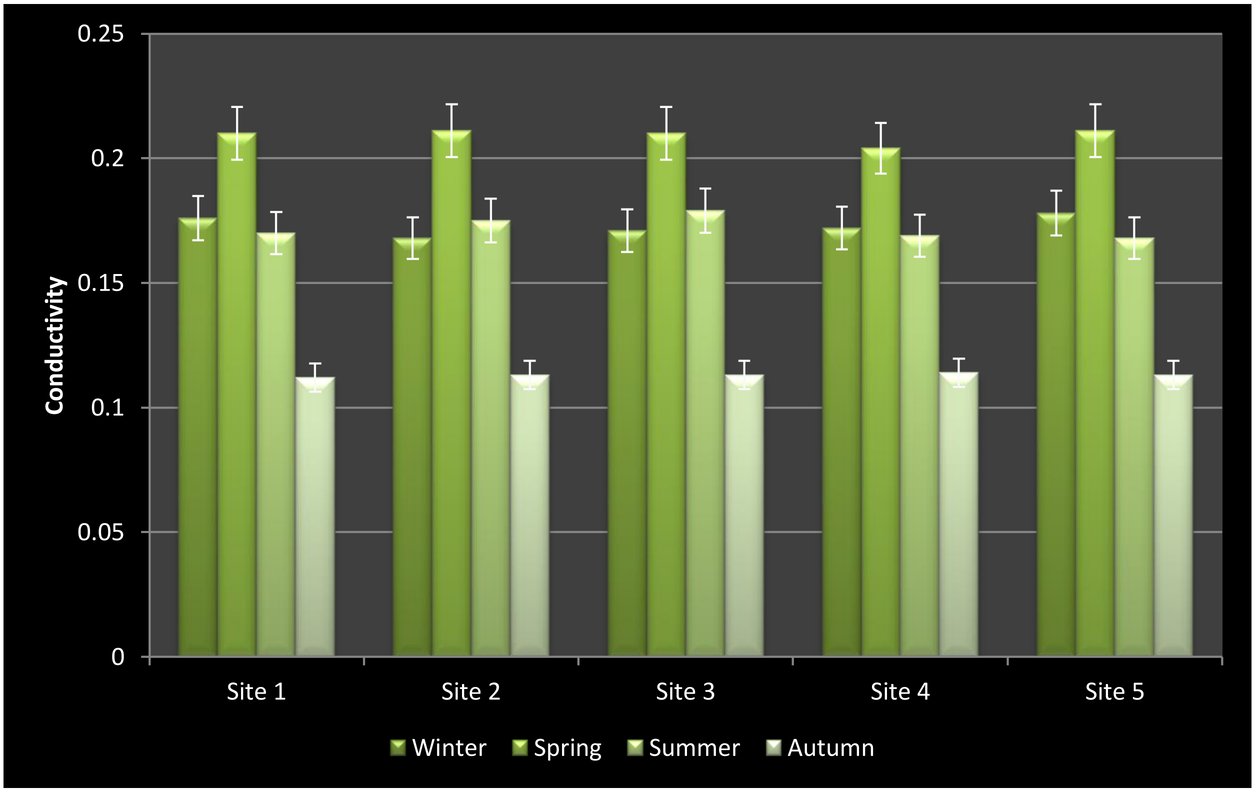


Fig. 14. Conductivity fluctuations at various study sites in Dikhu river

5.4 Pollution Indices

Tewari *et. al*. (1986) suggested calculating the water quality index from the data on various physical, chemical and biological characteristics of the Jhelum river. These indices clearly show that the Jhelum is least polluted in April, while the pollution is most severe in the month of December at all sampling stations. Nandan *et. al*. (1986) assessed the water quality of Vishwamitri river using Palmer's pollution index and confirmed that this river was highly polluted on the basis of Palmer's assigned number to each genus depending on their relative tolerance. Venkateswarlu and Reddy (1987) studied for the assessment of water quality and pollution in the river Tungabhadra near Kurnool (Andhra Pradesh) with the help of physico-chemical, heavy metals, and phycological analysis. After the investigation, they reported that the

Biological factors, especially the algae can be used as good indicator in assessing the quality of water. Kakati and Bhattacharjya (1989) studied the water quality of Deepar Beel and stated that the self purification capacity of the beel was still largely effective. They however, took into consideration the physico-chemical aspect of the water only by applying some 34 parameters and did not apply any biological index. Tripathy and Adhikary (1990) studied on the water pollution of the river Nandira and observed that phytoplanktons such as algae, protozoa, rotifera, and copepoda occurring in the unpolluted sites disappear with a proportionate increase in pollution load.

Baruah and Bordoloi (1990) made an investigation to ascertain the pollution status of the water of the Deepar Beel. The physico-chemical characteristics of the water body as well as biotic factors were taken into consideration for the study. Shaji and Patel (1991) conducted a study for assessment of pollution in the Subarmati river at Ahmedabad with the help of chemical and biological parameters. They employed Nygaard's trophic state indices, Palmer's pollution indices and Pantle and Buck's saprobity indices for assessment of pollution and reported that the values of all the 5 quotients of Nygaard's indices clearly indicated eutrophication in the river. Palmer's generic and species indices values confirmed high organic pollution in all the sites of the river. Pal *et. al.* (1992) studied the organic pollution level of Hugli estuary using algae as pollution monitor. They observed a large number of pollution tolerant species like *Nitzschia*, *Navicula*, *Oscillatoria*, *Cyclotella* and *Gomphonema*. They observed the diversity index was always less than 3 denoting the polluted status. From the study it was found that Site II (Longmisa- Chuchu), which showed most congenial condition with optimum value of pollution indices and Site III (Longkong) was most polluted in comparison to other sites.

5.5 Macrozoobenthos

Diversity is an important structural attribute of a natural or organized community, which is related to other structural and functional properties such as productivity, niche structure, competition, stability and integration of the community. The sustaining of the so-called biological diversity is a priority of nature conservation in terrestrial, marine and freshwater environments (Brooks *et al*., 2006). Therefore, the assessment of biological diversity and its probably most important element – taxonomic diversity plays a very significant role as the basis for nature protection. Various indices expressing the biological diversity of chosen groups of organisms are used as common metrics in biological assessment of environmental quality (Brooks *et al*., 2006). During the present investigation, three broad groups of macrozoobenthos were observed, among which Arthropoda was dominant followed by Annelida and Mollusca in the all the sites. Based on the diversity indices the site 2 has the maximum diversity followed by sites 4, sites 5, sites 1 and site 3 has least diversity. Kaul and Pandit (1982) while describing the biotic factors and food chain structure in different wetlands of Kashmir observed the macrozoobenthos to be limited in number of species. They also observed summer predominance of annelids and molluscan predominance in winter. *Tubifex tubifex* and *Glossiphonia weberi* exhibited highest abundance during summer, where as *Chironomus plumosus* and *Viviparus bengalensis* revealed highest values during winter (Gupta and Pant, 1983b). The physical bottom and chemical factors of a water body provide habitat for macrozoobenthos or simply benthos. Macrozoobenthos may include larvae, pupae and adult insects. Some of them pass all their life in water and other only part of their developmental stage (Subramanian and Sivaramakrishnan, 2005).

Tehmina *et al* (2013) ascertained the health status of three important wetlands of Kashmir valley, viz. Hokersar, Hygam and Mirgund, by using the macrozoobenthic community assessment system. The authors reported that the macrozoobenthic community in the wetlands belonged to Annelida, Arthropoda and Mollusca, with 9, 7 and 6 species respectively. Overall the zoobenthic community was dominated by Oligochaeta and Chironomids in all the wetlands. The abundance of pollution tolerant/indicator species depicted eutrophic conditions of all the wetlands. Rafia and Pandit (2014) depicted macroinvertebrates (oligochaetes) as indicators of pollution in Dal Lake Kashmir and found Arthropoda, Annelida as the most dominant species, which are in coherence with the present findings. The Diversity indices used in biological assessment studies are calculated for highly important indicator groups like Chironomidae (Cranston, 1995) and EPT (larval Ephemeroptera, Plecoptera and Trichoptera) or for a selected part of macrobenthic taxa (Barbour *et al*., 1996), identified on the level of genus or family (Fleituch *et al*., 2002), and much more rarely for all macrobenthos (Johnson and Hering, 2009). The assumption that habitat degradation results in significant and predictable decrease in taxonomic diversity is an important objective of various methods of biological assessment based on freshwater organisms, especially on benthic invertebrates (Lenat, 1988; Jüttner *et al*., 1996; Carlisle, 2008). The decrease in taxonomic diversity due to habitat degradation could be assessed as reduced species richness as e.g. stressors do not allow less tolerant species to colonize or to persist in degraded sites (Townsend and Hildrew, 1994). Stress condition in a pond eliminates sensitive taxa and results in reduced diversity and numerical dominance of those able to persist (Jones, 2008). Similarly, Bhat *et al*. (2015) enumerated the habitat preference of macrozoobenthos in Upper Lake. The authors observed that macrophytes forms one of the favorable conditions for benthic diversity followed by stones/sand and mud, as the highest value for Shannon diversity index was calculated at macrophyte type habitat while lowest at mud type habitat. The macrophytes density during the present research period and the association of macrozoobenthos is well documented by the work of above authors.

Some changes in biological diversity of aquatic organisms are based on data in which neither Insecta nor Oligochaeta are identified (Leppakoski *et al*., 1999). The large, sometimes predominant part of total taxonomic diversity of stream macrobenthos is included within the groups that are difficult to identify, like Chironomidae, Limoniidae, Tipuliidae, Tabanidae and Oligochaeta. The so-called "lowest practical taxonomic level" used for identification by certain stream ecologists (Waite *et al*., 2004; Adams *et al.*, 2005) as a pragmatic compromise between increasing information content and increasing time and costs along the level of taxonomic detail (Jones, 2008) is very insufficient for the needs of biodiversity studies.

In numerous papers analyzing the relationships between environmental parameters and the diversity of some benthic invertebrate groups, have been typically omitted or treated as a single taxon (Jones, 2008). Unfortunately, those groups, more difficult than others to identify on the species level, are at once extremely rich in species and very important in terms of trophic function, e.g., larval Diptera. Therefore, conclusions from such studies about the reaction of diversity of macrobenthos to changes in environmental parameters seem to be controversial, when the most diverse taxonomic groups are identified on the level of genus or tribe (Statzner *et al*., 2008). Differences in taxonomic diversity of stream fauna due to environmental patterns have been documented in numerous studies, e.g., as the effect of moderate pollution (Barbour *et al*., 1996; Koperski, 2005, 2009), climatic differences (Heino, 2002), oxygen depletion (Jacobsen, 2008), water flow velocity (Strzelec and Królczyk, 2004), organic matter accumulation and substratum characteristics (Graça *et al*., 2004), type of bottom substrate

(Jähnig and Lorenz, 2008) and type of land-use in catchment area (Utz *et al*., 2009). A potentially great influence of a certain pattern on the results of diversity assessment, commonly neglected by researchers as diverse "attractiveness" and "accessibility" of sampling sites are presented by Sanchez-Fernandez *et al*. (2008). The diversity of Odonata seems to be strongly correlated with the local climatic specifics (Eversham and Cooper, 1998). Differences between the diversities of higher taxa as a result of divergence have been presented by Benke *et al*. (1984) and Jähnig *et al*., (2008). The richness of four insect orders studied by Rosemond *et al*. (1992) was affected in different ways by chemical parameters of stream waters. The species richness and the values of Shannon-Weaver index were affected by various ecological variables and to the largest extent by chemical parameters of water (Beketov, 2004).

Odum (1971) described common inhabitants of sewage water with particular reference to oligochaetes. Learner *et al*. (1971) examined benthos assemblage above and below a point source of sewage and found upstream to be quite diverse while downstream to be left with only chironomids and oligochaetes. Dance and Hynes (1980) and Ajao and Fagado (1990) observed the distribution of macrozoobenthos in waters receiving complex mixtures of domestic waste. Seasonal dynamics of macrozoobenthic organisms in different water bodies were discussed by Munawar (1970a , b); Mandal and Moitra (1975); Das (1979); Rai and Datta Munshi (1979); Chowdhary (1984); Sharma (1986); Kaushik *et al*. (1991); Dhillon *et al*. (1993a); Syal (1996); Singh (1982) and Yousuf *et al*. (2002). Rich vegetation provides food and shelter to the growing zoobenthos was suggested by Needham and Llyod (1916); Krecker (1939); Andrews and Hasler (1943); Tonapi (1980); Sharma (1988); Kaushik *et al*. (1991); Kumar (1996b); Bath and Kaur (1998) and Sajeev (1999). The impact of silt on the aquatic organisms was reported by Kaul *et* *al*. (1978) and Pennak (1978). In contaminated sections of the water body, chironomids and tubificid worms were the only taxa to survive (Winner *et al*. 1980).

Chironomid larvae were found to be the most common component of benthos while toxicity of pesticides to benthic insect communities was discussed by William and Feltmate (1992). The stress of various environmental pollutants on the aquatic organisms was discussed by Kumar (1996a , b). The distribution of macrozoobenthos designated as an indicator of clean and eutrophicated water was described by Gaufin and Tarzwell (1956); Curry (1962); Schneider (1962); Shrivastava (1962); Hussainy (1967); Verma and Shukla (1969); Serruya (1978); Pennak (1978); Allanson (1979); Das and Bisht, 1979); Pandit (1980); King (1981); Roy and Sharma (1983); Sharma (1986); Sinha and Prasad (1988); Das (1989); Rao *et al*. (1991); Dhillon *et al*. (1993a) and Kumar (1996b).

Macroinvertebrate's ability to indicate various types of anthropogenic stressors is widely recognized as an integral component of freshwater biomonitoring. In case of pollution, biodiversity of the aquatic community can be affected and the species composition changes from natural species to tolerant species. Most interestingly, freshwater macroinvertebrate species vary in sensitivity to organic pollution and, thus, their relative abundances have been used to make inferences about pollution loads. In natural pristine rivers, high diversity and richness of species could be found (Sokal and Rohlf, 1995). However, high impact due to human activities caused many changes to the assemblages and biodiversity of the aquatic fauna (Wright *et al*., 1993, Pinel *et al*., 1996). Lang (1985) studied the eutrophication of lake Geneva and recorded species like *Potamothrix hammoniu*, *P. Heuscheri* and *Tubifex tubifex* to be numerically dominant ones as compared to *P. veidovskyi* (mesotrophic), *Stylodrillus heringianus* (oligotrophic) in the community structure indicating a meso- eutrophic sta-tus of lake. The emergence of species like

Tubifex sp. and *Chironomus* sp. in Nilnag lake indicated the eutrophic status of the lake as reported by Yaqoob *et al*. (2007). Benthoses of the Shallabugh wetland were represented by Arthopoda (10), Annelida (7) and Mollusca (6). The abundance of some specific pollution indicator species, especially annelids such as *Limnodrilus* sp, *Tubifex tubifex* and *Branchiura sowerbyii*, is depictive of transition in trophic status of the wetland from meso- to eutrophy (Siraj *et al*., 2010). Dar *et al.* (2010) reported a few species of annelids like *Tubifex tubifex*, *Limnodrilus* sp. and *Erpobdella octoculata* to be dominant in terms of taxa and abundance Awal and Svozil (2010) identified 481 to 629 organisms in three constructed wetlands in South East metropolitan Melbourne comprising of 16 taxa, the dominant among them representing the pollution tolerant species. The distribution of benthic community directly gets affected by biotic environment of the water body (Nkwoji *et al*., 2010). Their distribution depends on substratum, quantity and composition of organic matter in sediments (Subramanian and Sivaramakrishnan, 2005). The habitats of different taxa of the benthic forms differ from one another. As per their breeding habitats, place of attachment, availability of food etc. the organisms are distributed from littoral zone up to profundal zone of the water body (Vyas and Bhat, 2010a).

Biological indicators have the advantage of monitoring water quality over a period of time, providing more exact measures of anthropogenic effects on aquatic ecosystems, where physical and chemical data provide momentary evidence (Camargo *et al.*, 2004). Benthic macroinvertebrates have been documented as the best indicators of Water quality as evidenced by Mutonkole *et al*. (2015), while working on urban fauna stream (in Kinshasa, Democratic Republic of Congo). The authors reported forty-seven species from 3624 specimen dominated by Odonata, Achaeta and Diptera, out of which four taxa displayed higher relative abundances: Glossiphonidae (20%), Chironomidae (9%), Lumbriculidae (9%) and Hirudidae (8%). Some of the noteworthy contributions in the use of biological indices for establishing the relation between water quality index and macrozoobenthos population are those of Gabriels *et al*. (2010), Resende *et al*. (2010), Negash *et al*. (2011), Ansah *et al*. (2012), Hannigan and Kelly-Quinn (2012), Li *et al*. (2012), Getachew *et al*. (2012), Canobbio *et al*. (2013), Mereta *et al*.(2013), Lewin *et al*. (2014), Ma *et al*. (2014), Koto-te *et al*. (2014), Kibena *et al*. (2014), Xu *et al*. (2014), Schneider *et al*. (2014), Singh and Mishra (2014), Sajad *et al*. (2015), Van *et* al. (2015). The study reveals that pollution of the aquatic habitat have a significant affect on the assemblage of macro benthos community.

CONCLUSION

CONCLUSION

Biodiversity is one of the most significant attributes of sustainable development and represents the biological wealth of a given nation. In the present era the world is facing its greatest ever biodiversity crisis. Flora and fauna are becoming extinct at an alarming rate because of habitat loss, overexploitation and global climate changes. The present study advocated the present status of macrobenthic structure of Dikhu river of Nagaland and the factors governing its sustainability in long run. As well as to assess the environmental pollution of water body, macrobenthic structure of those water bodies is used as bioindicator. Due to the lack of detailed study on the macrobenthic structure of those areas the present work laid the foundation for further effective work as future prospect. Therefore, it can be concluded that the macrobenthic community explained in the present study might be a key future outline to assess the status of water pollution of many concerned areas of Nagaland.

REFERENCES

6. References

- Acreman, M. (2000). Managed flood releases from reservoirs: Issues and guidance. WCD Thematic Review: II-1: 1-88.
- Acreman, M. and Sullivan, C. (1999). Lower Indus case study mission report. Institute of Hydrology. pp.7.
- Adams, S.M, Ryon, M.G. and Smith, J.G. (2005). Recovery in diversity of fish and invertebrate communities following remediation of a polluted stream: investigating causal relationships. *Hydrobiologia*. 542: 77-93.
- Adams, W. M. (1993). Indigenous use of wetlands and sustainable development in West Africa. *Geographical Journal*. 159: 209–218.
- Adams, W. M. (1999). Economics and hydrological management of African floodplains. In: Acreman, M.C., Hollis, G.E. (Eds.), Water Management and Wetlands in Sub-Saharan Africa. IUCN, Gland. pp. 21– 33.
- Adoni, A. D., G. Joshi, K. Ghosh, S. K. Chourasia, A. K. Vaishya, M. Yadav and H.G. Verma (1985). In: Work book on Limnology. Dr. Harishingh Gour Vishwa Vidyalyay, Sagar Publication.
- Agassi, L. (1850). Lake superior: Its physical character, vegetation and animals. Boston: Gould, Kendal and Lincon. pp.428.

- Agbaire, P. O. and C. G. OBI (2009). Seasonal variation of some physico-chemical properties of River Ethiope water in Abraka, Nigeria. *J. of Applied Sci. Environ. & Management.* 13(1): 55-57.
- Ahangar, I.A., Saksena, D. N., Mir, M.F., & Ahangar,M. A. (2012). Seasonal variations in physic-chemical characteristics of Anchar Lake, Kashmir. *International Journal of Advanced Biological Research.* 3(2): 352-357.
- Ahmed, N. and Younus, M. (1979). Aquatic plants of Lahore, Pakistan. *Jour. Adv. Sci.* pp.1-79.
- Ajao, E. A., & Fagado, S. O. (1990). A study of sediment and communities in Lagos Lagoon, Nigeria. *Oil and Chemical Pollution.* 19: 123–130.
- Ajmal, M., Razuiddin, & Khan, A. V. (1985). Physico-chemical aspects of pollution in Kalinadi. IAWPC. *Technical Annual.* 12: 106–114.
- Al-Abbad, M.Y., Salman, S.D. and Al-Qarooni, I.H. (2015). Biodiversity of the macroinvertebrates in the Southern Iraqi Marshes, with a special reference to Oligochaeta. *Journal of Biodiversity and Environmental Sciences*. 7(1): 61-71.
- Alheit, C. Mollmann, J., Dutz, G., Kornilovs, P., Loewe, V., Mohrholz and Wasmund, N. (2005). Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. *ICES J. Mar. Sci.* 62**:** 1205–1215.
- Alikunhi, K.H. (1957). Fish culture in India. *Bulletin of Indian Council of Agricultural Research.* 20: 1-150.

- Allan, G.F., Moriarty, D.J.W. and Maguire, G.B. (1995). Effects of pond preparation and feeding rate on production of invertebrate community of a mountain stream. *Ecology*. 63(5): 1445-1455.
- Allan, J. (1995). Stream Ecology: Structure and Function of Running Waters. Chapman and Hall.
- Allan, J. D. and Flecker, A. S. (1993). Biodiversity conservation in running waters. *Bioscience*. 43: 32–43.
- Allanson, B. R. (1979). *Lake Sibaya*. (Monographiae Biologicae. 36(364). The Hague: W. Junk.
- Allee, W.C. (1912). Seasonal succession in old forest ponds. *Trans. III, Acad. Sci*., 4: 126-131.
- Alvim, MCC and Peret, AC. (2004). Food resources sustaining the fish fauna in a section of the Upper São Francisco River in Três Marias, MG, Brazil. *Braz. J. Biol*. 64(2): 195-202.
- Ambasht, R. S. (1970). Conservation of soil through plant covers of certain alluvial slopes in India. *Proc. Nat. Acad. Sc*. X1 Tech. Meeting, Switzerland, pp.44 - 48.
- Ambelu, A., K. Lock, and P. Goethals (2010). Comparison of modeling techniques to predict macroinvertebrate community composition in rivers of Ethiopia. *Ecological Informatics*. 5(2): 147–152.

- Ambrose, Jr. and Renaud, W.G. (1997). Does a pulsed food supply to the benthos affect polychaete recruitment patterns in the Northeast Water Polynya? *J. Mar. Syst*. 10: 483–495.
- Ambrose, Jr., Renaud, W.G. (1995). Benthic response to water column productivity patterns: evidence for benthic–pelagic coupling in the Northeast Water Polynya. *J. Geophys. Res.* 100: 4411–4421.
- Anand, V. K. (1982). Studies on primary productivity of Gadigarh Stream, Jammu (J and K State). *I. Journal of Inland Fisheries Society of India*.14: 1-5.
- Anderson, R.V. and Day, D.M. (1986). Predictive quality of macroinvertebrate habitat association in lower navigation pools of the Mississippi River. *Hydrobiologia*. 136: 101-112.
- Andersson, E.; Nilsson, C and Johansson, M. E. (2000). Effects of river fragmentation on plant dispersal and riparian flora. *Regulated Rivers: Research and Management.* 16: 83–89.
- Andrews, J. D., & Hasler, A. D. (1943). Fluctuations in the animal populations of the littoral zone in lake Nendota. *Transactions of Wisconsin Academy of Sciences, Arts and Letters.* 35: 175–185.
- Angelier, E. (2003). Ecology of Streams and Rivers. Enfield: Science Publishers, Inc.,. p. 215.

- Anjana, S., & Kanhere, R. R. (1998). Seasonal dynamics of phytoplankton population in relation to abiotic factors of a fresh water pond at Barwani (M.P.). *Pollution Research.* 17(2): 133–136.
- APHA (1989). Standard Methods of Water and Wastewater Analysis. Washington DC: American Public Health Association,
- Araujo, R., and Y. de de Jong. (2015). Fauna Europaea: Mollusca – Bivalvia. *Biodiversity Data Journal.*5211. p.18.
- Archambault, J.M., C.M. Bergeron, W.G. Cope, R.J. Richardson, M.A. Heilman, J.E. Corey III, M.D. Netherland, and R.J. Heise. (2015). Sensitivity of freshwater molluscs to hydrillatargeting herbicides: providing context for invasive aquatic weed control in diverse ecosystems. *Journal of Freshwater Ecology*. 30(3): 335-348.
- Arimoro, F.O.; Odume, O.N.; Uhunoma, S.I.; Edegbene, A.O. (2015). Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream. *Environmental Monitoring and Assessment*. 187(2): 14.
- Armour, C. L., K. P. Burnham, and W. S. Platts. (1983). Field methods and statistical analyses for monitoring small salmonid streams. U.S. Fish and Wildlife Service. FWS/OBS- 83/33.
- Arora, H. C., Chattopadhyaya, S. N.; Sharma, T. R. and Elyas, S. R. (1973). A short term study on the eutrophication of Gomti river in Lucknow region. *Proc. Sym. Env. Poll*. pp .44-58.

- Arthaud, D., Kratz, K., Vandemoer, K., and Grady, M. (2001). Protocol for estimating tributary streamflow to protect salmon listed under the Endangered Species Act - Draft: National Marine Fisheries Service, Habitat Conservation Division, Northwest Region. p.24.
- Arthington,A.H., Bunn,S.E., Poff, N.L., Naiman, R.J. (2006). The challenge of providing environmental flow rules to sustain river ecosystems. *Ecol Appl*. 16: 1311–1318
- Arthington,A.H., Naiman,R.J., Mc Clain,M.E., Nilsson,C. (2009). Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshw Biol.* 55: 1–16.
- Atkinson, E.G. and Wacasey, J.W. (1987). Seasonal variability of sediment trap collections in the Northeast Water polynya. Part 2. Biochemical and microscopic composition of sedimenting matter. *J. Mar. Syst*. 10: 371–389.
- Atkore, V.M. (2005). Conservation status of fishes in the tributaries of Ramganga with special reference to golden mahseer (*Tor putitora*) Hamilton. Dissertation submitted to Saurashtra University, Rajkot, India.
- Bacher, C., Bioteau, H. and Chapelle, A. (1995). Modelling the impact of a cultivated oyster population on the nitrogen dynamics — the Thau Lagoon case (France). *Ophelia*, 42: 29–54.
- Backiel, T. and Penezak, T. (1989). The fish and fisheries in the Vistula River and its tributary, the Pilica River. In; Proc International Large River Symposium (LARS). D.P.Dodge (Ed) Can. Sp. Publ. *Fish. Aquat. Sc*. pp.106 .

- Badola, S. P. and Singh, H. R. (1981). Hydrobiology of River Alokananda of the Garwal Himalaya. *Indian J. Eco*. 8: 269-276.
- Bagde, U. S., & Verma, A. K. (1985a). Physico-chemical characteristics of water of J. N.U. lake at New Delhi. *Indian Journal of Ecology*. 12(1): 151–156.
- Bagde, U. S., & Verma, A. K. (1985b). Limnological studies on J.N.U. lake, New Delhi, India. *Bulletin of Botanical Society Sagar.* 32: 16–23.
- Bagnoulus, F. & Meher Homji, V. M. (1959). Bioclimatic types of South-East Asia Travaux dela section scientific et. technique. Institute Francais De Pondicherry. p.227 .
- Baker E.A., and Coon, T.G. (1997). Development and evalua- tion of alternative habitat suitability criteria for brook trout. *Transactions of the American Fisheries Society*. 126: 65-76.
- Bandopadhyay, S., & Gopal, B. (1991). Ecosystem studies and management problems of a coastal lagoon. The lake Chika. In B. Gopal & V. Asthana (Eds.), *Aquatic sciences in India* (pp. 117–172). New Delhi: Indian Association of Limnology and Oceanography
- Banerjee, R.K., Saha, S.K., Sen, P.R. and Srinivasan, K. (1989). Ecological studies on town refuse in the context of environment pollution abatement and fish production. *J. Inland Fish. Soc. India.* 21(2): 25-30.
- Barai SR, Kumar Satish (2012). Evaluation of the physicchemical characteristics of river Varuna at Varanasi, India. *J. Environ. Biol*. 34: 259-265.
- Barbour, M. T., B. Gerritsen, and B. Snyder (1999). Benthic Macroinvertebrate Protocols. *In* Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton,

Benthic Macroinvertebrates and Fish, U.S. Environmental Protection Agency, Office of Wate.

- Barbour, M.T., Swietlik, W. F., Jackson, S. K., Courtemanch, D. I., Davies, S. P. and Yoder, C. O. (2000). Measuring the attainment of biological integrity in the USA: A critical element of ecological integrity. *Hydrobiol.* 422/423: 453-464.
- Barbour, M.T.J., Gerritsen, G.E., Griffith, R., Frydenborg, E. McCarron, J.S., White, M.L. and Bastian, A. (1996). Framework for Biological Criteria for Florida Streams Using Benthic Macroinvertebrates. *J. N. Am. Benthol. Soc*. 15: 185-211.
- Barg, U.C. (1992). Guidelines for the promotion of environmental management of coastal aquaculture development. Rome: FAO, *Fisheries Technical Paper* – 328.
- Baron ,J.S., Poff, N.L., Angermeier,P.L., Dahm, C.N., Gleick, P.H., Hairston, N.G., Jackson, R.B., … Johnston, C.A., Richter,B.D. and Steinman,A.D., (2002). Meeting ecological and societal needs for freshwater. *Ecol Appl.* 12: 1247–1260.
- Bartel, R., Jelonek, M. & Epler, P. (2016). The influence of small hydroelectric plants on ichthyofauna and environmental condition in the upper Vistula catchment basin and their share in total electricity production in Poland. Symposium on Hydropower, Flood control and water abstraction: Implications for Fish and Fisheries. Mondsee, Austria, 14-17 June 2016.
- Bashir, M., Chauhan, R., Khan, S., Mir, M. F. and Amin, N. (2016). Macrozoobenthic community as biological indicators of pollution in anchar lake of Kashmir. *International Journal of Current Research*. 8(02): 26994-26999.

- Bath, K. S. (1996). Limnological studies on the Harike wetland ecosystem. Ph.D. thesis. Patiala: Punjabi University.
- Bath, K. S., & Kaur, H. (1997). Aquatic insects as bioindicators at Harike reservoir in Punjab India. *Indian Journal of Environmental Science.* 2(1): 133–138.
- Bath, K. S., & Kaur, H. (1998). Seasonal distrubution and population dynamics of aquatic insects in Harike reservoir (Punjab). *Journal of Ecobiology*. 10(1): 43–46.
- Bauernfeind, E. and Moog, O. (2000). Mayflies (Insecta: Ephemeroptera) and the assessment of ecological integrity: a methodological approach. *Hydrobiologia*. 422/423: 71- 83.
- Baxter R. M. (1977). Environmental effects of dams and impoundment. *Annual Review of Ecology and Systematics.* 8: 255–283.
- Beaugrand, G. and Reid, P.C. (2003). Long-term changes in phytoplankton, zooplankton and salmon related to climate. *Glob. Change Biol*. 9: 801–817.
- Beitinger, T.L., Bennett, W.A., and McCauley, R.W. (2000). Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes*. 58: 237-275.
- Beketov, M.A. (2004).Different sensitivity of mayflies (Insecta, Ephemeroptera) to ammonia, nitrite and nitrate: linkage between experimental and observational data. *Hydrobiologia.* 528: 209-216.
- Bemvenuti, C.E. (1987). Predation effects on a benthic community in estuarine soft sediments. *Atlantica.* 9: 33– 63.

- Bemvenuti, C.E., Capitoli, R.R. and Gianuca, N.M. (1978). Estudos de ecologia bentoˆnica na regia˜o estuarial da Lagoa dos Patos: II. Distribuic_ a˜o quantitativa do macrobentos infralitoral. *Atlantica.* 3: 23– 32.
- Benke, A. C. (1990). A perspective of America's Vanishing Streams. *J. North Amer. Benth. Soc*. 9: 77-88.
- Benke, A.C., Van Arsdall, T.C., D.M. Gillespie and Parrish, F.K. (1984). Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecol. Monogr*. 54: 25-63.
- Benson, M.A., and Dalrymple, T., (1967). General field and office procedures for indirect discharge measurements: *U.S. Geological Survey Techniques of Water-Resources Investigations*. 3(1): 30.
- Berg, K. (1938). Studies on the bottom animals of Esron Lake. Mem. *Acad. R. Sci. Lett.* 8: 255.
- Besser, J.M., C.G. Ingersoll, W.G. Brumbaugh, N.E. Kemble, T.W. May, N. Wang, D.D. MacDonald and A.D. Roberts (2015). Toxicity of sediments from lead–zinc mining areas to juvenile freshwater mussels (*Lampsilis siliquoidea*) compared to standard test organisms. *Environmental Toxicology and Chemistry*. 34(3): 626–639.
- Beyene, A., Addis,T., Kifle,D., Legesse,W., Kloos,H. and Triest,L. (2009). Comparative study of diatoms and macroinveretebrates as indicators of severe water pollution: Case study of the Kebena and Akaki rivers in Addis Ababa, Ethiopia. *Ecological Indicators*. 9(2): 381–392.

- Bhargava, D. S. (1985). A water quality variations and central technology of Yamuna River. *Env. Pollution.* 37: 355-376.
- Bhaskaran, T. R., Chakrabarty, R. N. and Trivedy R. E. (1965). Studies pollution: Pollution and self purification of Gomti river near Lucknow. *J. Inst. Eng. India*. 45(6): 39-50.
- Bhat Tanveer, H., Arnold, R. and Mishra, R.M. (2013). Trophic status of Dal Lake, Kashmir, India. *International Journal of Current Research.* 5(07): 1763-1765.
- Bhat, Ahmad, M., Thoker, F., Dar, ,H., Bhawsar, ,A.,Vyas,V., (2015). Habitat Preference of Macrozoobenthos in Upper Lake - A Ramsar Site. *International Journal of Scientific Research in Environmental Sciences*. 3(12): 0431-0435.
- Bhatt, L. R., Lacoul, P., Lekhak, H. D., & Jha, P. K. (1999). Physico-chemical characteristics and phytoplanktons of Taudaha lake, Kathmandu. *Pollution Research.* 18(4): 353–358.
- Bhatt, S. D. and Pathak, J. K. (1989). Hydrological profile of river Saraju of the Kumaun Himalaya. *J. Fresh Wat. Biol*. 1: 22-33.
- Bhimachar, B. S. (1959). Inland fisheries of India and their problems. *Proc. Indian Sci. Cong*. 46(2): 1-16.
- Bigelow, N.K. (1928).The ecological distribution of microscopic organisms in Lake Nipigon. *Univ. Toronto Stud. Boil. Ser*. 31: 57-74.
- Bilgrami, K. S. and Dutta Munshi, J. S. (1979). Limnological survey and its impact of human activities on the river Ganges, Barauni to Farakka, Technical Report, DST, Govt. of India, New Delhi.

- Bilgrami, K. S. and Dutta Munshi, J. S. (1985). Ecology of river Ganges. Patna- Farakka. MAB- Final Technical Report. p.97.
- Billett, D. S. M., Bett, B. J. Rice, A. L., Thurston, M. H., Galeron, J., Sibuet, M. and G. A. Wolff. (2001). Long-term change in the megabenthos of the Porcupine Abyssal Plain (NE Atlantic). *Progress in Oceanography*. 50: 325–348.
- Birge, E.A. (1916). The work of wind in warming lake. *Trans. Wis. Acad. Sci. Arts Lett.*, 18: 341-391.
- Birge, E.A. and Juday, C. (1911). The dissolved gases of the water and their biological significance. *Wisc. Goel. and Nat. Hist. Sur. Bull*. 22: 259.
- Biswas, S. P. (1998) Ecology of *chars* or river islands of the Brahmaputra with special reference to fisheries, Final Technical Report, Submitted to the Ministry of Environ. & Forest, Govt. of India, New Delhi. pp.55.
- Biswas, S. P. and Boruah, S. (2000). Fisheries Ecology of the North-Eastern Himalayas with special reference to the Brahmaputra River. *Ecol. Eng*. 16: 39-50.
- Biswas, S. P. and Boruah, S. (2010). Natural and anthropogenic hazards on the hydrobiology of the Brahmaputra River system. In. Natural and Anthropogenic Hazardson Fish and Fisheries (ed. U. C. Goswami). Delhi:Narendra Publishing House. pp.233-244.
- Biswas, S. P. and Michael, R. G. (1992). Fishery characteristics and the present status of fisheries of the Brahmaputra. Proc. Seminar on Conservation of river dolphin in Indian sub-continent, New Delhi.18-19 Aug (Abst.).

- Biswas, S. P.; Borbora, S. H. and Duta, B. C. (1995). Present status of capture fisheries in the upper stretches of the Brahmaputra. *Bull. Life Sci*. 5: 31-40.
- Blake, J.A. (1993.: Life history analysis of five dominant infaunal polychaete species from the continental slope off North Carolina. *J. Mar. Biol. Assoc.* U.K. 73: 123–141.
- Blanch, S. J., Ganf,G. G. and Walker, K. F. (1999). Tolerance of riverine plants to flooding and exposure indicated by water regime. *Regulated Rivers: Research and Management.* 15: 43–62.
- Blanch, S. J.; Walker, J., K. F. and Ganf, G. G. (2000). Water regimes and littoral plants in four weir pools of the River Murray, Australia. *Regulated Rivers: Research and Management.* 16: 445–456.
- Blanchet, H., Lavesque, N., Ruellet, T., Dauvin, J.C., Sauriau, P-G., Desroy, N., Desclaux, C., … Leconte, M., Bachelet, G., Janson, A.L., Bessineton, C., Duhamel, S., Jourde, J., Mayot, S., Simon, S. and De Montaudouin, X. (2008). Use of biotic indices in semi-enclosed coastal ecosystems and transitional waters habitats—implications for the implementation of the European Water Framework Directive. *Ecol. Indicators.* 8: 360–372.
- Bledsoe, B.P., Brown,M.C., Raff,D.A. (2007).Geotools: a toolkit for fluvial system analysis. *J Am Water Resour Assoc*. 43: 757–772.
- Bochechas, J.H. (2016). Behavioural patterns of iberian barbels’ upstream movements through an artificial pool-type fishway. Symposium on Hydropower, Flood control and water abstraction: Implications for Fish and Fisheries. Mondsee, Austria, 14-17 June 2016.

- Bohlen, C. and Lewis, L. (2008). Examining the Economic Impacts of Hydropower Dams on Property Values Using GIS. *Journal of Environmental Management*, doi: 10.1016/j.envman.2008.07.26.
- Bohlke, J. K. (2002). Groundwater recharge and agricultural contamination. *Hydrogeology Journal*. 10: 153-179.
- Bohlke, J.E., Weitzman, S.H. and Menezes, N.A. (1978). Estado atual da sistemática dos peixes de água doce da América do Sul. *Acta Amaz.* 8(4): 657-677.
- Bohn, C.C., and King, J.G. (2000). Stream channel responses to streamflow diversions on small streams of the Snake River drainage, Idaho: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Res. Pap. RMRS-RP-20, Ogden, Utah. p.19.
- Bolam, S.G., Fernandez, T.F.and Huxham, M. (2002). Diversity, biomass, and ecosystem processes in the marine benthos. *Ecological Monographs*. 72(4): 599–615.
- Bonada, N., Prat, N., Resh, V. H. and Statzner,B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annual Review of Entomology*. 51: 495–523.
- Boonson, J. (1976). Studies on benthic animals in the Chao Phya River using multiplate sampling. Proc. 17th Indo-Pacific Fisheries Council at Colombo, Sri Lanka, FAO, Bangkok. 3: 132-137.
- Borah, A.K. and Goswami, D. C. (1988). Some observations on the flow characteristics of the Jia Bharali River in Assam. *Indian Journal of Landscape Systems and Ecological Studies.* 11(2): 103-111.

- Borja, A., Dauer, D., Dıaz, R., Llanso, R.J., Muxika, I., Rodrıguez, J.G. and Schaffner, L. (2008) .Assessing estuarine benthic quality conditions in Chesapeake Bay: a comparison of three indices. *Ecol. Indicators.* 8: 395–403.
- Borja, A., Muxika, I. and Franco, J. (2003). The application of a Marine biotic index to different impact source affecting soft-bottom benthic communities along European coasts. *Marine Pollution Bulletin.* 46: 835-845.
- Borja, Á., Rodríguez, J.G., Black, K.D., Bodoy, A., Emblow, C., Fernandes, T.F., Forte, J., … Karakassis, I., Muxika, I., Nickell, T.D., Papageorgiou, N., Pranovi, F., Sevastou, K., Tomassetti, P. and Angel, D. (2009). Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe. *Aquaculture*. 293: 231–240.
- Borse, S.K., Lohar ,P.S., Bhave,P.V. (2003). Hydrobiological study of algae of Aner River, Jalgaon (Maharashtra). *J Aqu Bio*. 18(1): 15-18**.**
- Boruah, S. and Biswas S. P. (2002). Ecohydrology and fisheries of the upper Brahmaputra basin. *Environmentalist.* 22: 119–131.
- Borysova, O., Kondakov, A., Paleari, S., Rautalahti-Miettinen, E., Stolberg, F. and Daler, D. (2005). Eutrophication in the Black Sea region; Impact assessment and Causal chain analysis.Kalmar, Sweden:University of Kalmar.
- Boubée, J., Jellyman,D. & Sinclair, C. (2014). Eel protection measures within the manapouri hydro-electric power scheme, south island, New Zealand. *Hydrology*. 12(5): 12-15.

- Bovee, K.D., Milhous, R. (1978). Hydraulic simulation in instream flow studies: theory and techniques. FWS/OBS 78/33. U.S. Fish and Wildlife Service, Fort Collins.
- Bovee, K.D. (1997). Data collection procedures for the Physi- cal Habitat Simulation System: Fort Collins, Colo., U.S. Geological Survey, Biological Resources Division. p.141.
- Bovee, K.D., and Cochnauer, T. (1977). Development and evaluation of weighted criteria, probability of use curves for instream flow assessments–fisheries: U.S. Fish and Wildlife Service FWS/OBS-77/63. p.39.
- Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, J., and Henricksen, J. (1998). Stream habitat analysis using the instream flow incremental methodology: U.S. Geological Survey Biological Resources Division Informa- tion and Technology Report USGS/BRD/ITR—1998-0004. p.130.
- Brandt, R. A. M. (1964). Survey of fresh water mollusks of Thailand, Bangkok. First Medical Research Laboratory, Dec.17, 1964.
- Bravard, J. P., Amoros, C., Pautou, G., Bornette, G., Bournaud, M., Creuze´ des Chaˆtelliers , M., Gibert, J., … Peiry, J.U., Perrin, J.F. and Tachet, H. (1997). River incision in South-East France: morphological phenomena and ecological effects. *Regulated Rivers: Research & Management*. 13: 75–90.
- Breukelaar, A.W., Kemper, J. & de Vaate, A. (2015). Functioning of fish ladders in the river Meuse for upstream migration of salmonids and the effect of management of the nearby weir. *Hydrological Science.* 128 (5): 3225-3229.

- Brinkhurst, R.O. and Cook, D.G. (1974).Aquatic earthworms (Annelida, Oligochaeta). In: *Pollution ecology of freshwater invertebrates* (Eds. Harl and Fuller). London:Academic Press.
- Brisbane Declaration (2007). Retrieved from http://www.nature.org/initiatives/freshwater/files/brisbane_declaration_with_organizations_final.pdf.
- Brooks, T.M., Mittermeier, R. A., Da Fonseca, G. A. B., Gerlach, J., Hoffmann, M., Lamoreux, J. F., Mittermeier., C. G., Pilgrim, J. D … and Rodrigues, A. S. L. (2006). Global Biodiversity Conservation Priorities. *Science*. 313 (5783): 58.
- Bryan, B.A., Higgins, A., Overton, I.C., Holland,K., Lester,R.E., King,D., Nolan,M.,… Hatton MacDonald, D., Connor, J.D., Bjornsson,T., and Kirby,M. (2013). Ecohydrological and socioeconomic integration for the operational management of environmental flows. *Ecol Appl*. 23: 999–1016.
- Buch, A.C., Schmelz, R.M., Niva, C.C., Correia, M.E.F. and Silva, E.V. (2017). Mercury critical concentrations to *Enchytraeus crypticus* (Annelida: Oligochaeta) under normal and extreme conditions of moisture in tropical soils Reproduction and survival. *Environmental Research*. 155: 365-372.
- Buchanan, T.J. and Somers, W.P. (1969). Discharge Measurements at Gaging Stations: U.S. Geological Survey Techniques of Water-Resources Investigations. 3(A8): 1.
- Bunn,S.E. and Arthington,S.H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environ Manag.* 30: 492–507.

- Cadwallander, P. (1986). Fish of the Murrey- Darling System. In: The ecology of river systems. B.R.Davies and K.F. Walker, (eds). Dordrecht: Dr. W.Junk Publishers. 679-694.
- Cairns, J. Jr. & Pratt, J. R. (1993). A history of biological monitoring using benthic macroinvertebrates. pp. 10 – 27 in: V.H. Resh & D.M. Rosenberg (eds.). Freshwater biomonitoring and benthic macroinvertebrates.New York: Chapman & Hall.
- Callier, M.D., McKindsey, C.W. and Desrosiers, G. (2007). Multi-scale spatial variations in benthic sediment geochemistry and macrofaunal communities under a suspended mussel farm (Great-Entry Lagoon, Canada). *Mar. Ecol., Prog. Ser.* 348: 103–115.
- Callier, M.D., McKindsey, C.W. and Desrosiers, G. (2008). Evaluation of indicators used to detect mussel farm influence on the benthos: two case studies in the Magdalen Islands, Eastern Canada. *Aquaculture.* 278: 77–88.
- Callier, M.D., Weise, A.M., McKindsey, C.W. and Desrosiers, G. (2006). Sedimentation rates in a suspended mussel farm (Great-Entry Lagoon, Canada): biodeposit production and dispersion. *Mar. Ecol., Prog. Ser*. 322: 129–141.
- Camargo, J., and Mu˜noz ,M. (1989). A biological index to assess freshwater quality in the Iberian Peninsula, related to the continental fish production. *In* Proceedings of the International Symposiums of Inland Aquaculture, Madrid (Spain), Madrid Complutense University, Spain.
- Camargo, J. A., Alonso, A. and De La Puente, M. (2004). Multimetric assessment of nutrient enrichment in impounded rivers based on benthic macroinvertebrates. *Environmental Monitoring and Assessment, Dordrecht.* 96: 233-249.

- Campana,P., Knox,J., Grundstein,A. and Dowd,J. (2012). The 2007–2009 drought in Athens, Georgia, United States: a climatological analysis and an assessment of future water availability. *J Am Water Resour Assoc.* 48: 379–390.
- Canobbio, S., A. Azzellino, R. Cabrini, and V. Mezzanotte (2013). A multivariate approach to assess habitat integrity in urban streams using benthic macroinvertebrate metrics. *Water Science & Technology*. 67(12): 2832–2837.
- Capitoli, R.R., Bemvenuti, C.E. and Gianuca, N.M. (1978). Estudos de ecologia bentoˆnica na regia˜o estuarial da Lagoa dos Patos: I. As comunidades Bentoˆnicas. *Atlantica*. 3: 5 – 22.
- Carey Jr, A.G. (1991). Ecology of North American Arctic continental shelf benthos: a review. Cont. *Shelf Res*. 11: 865–883.
- Carle, F. L., and Strub ,M. R. (1978). A new method for estimating population size from removal data. *Biometrics*. 34: 621-630.
- Carlisle, D.M., Hawkins, C.P., Meador, M.R., Potapova, M. and Falcone, J. (2008). Biological assessments of Appalachian streams based on predictive models for fish, macroinvertebrate, and diatom assemblages. *J. N. Am. Benthol. Soc*. 27: 16-37.
- Carpenter, S. R. and Lodge,D. M. (1986). Effects of Submerged Macrophytes on Ecosystem Processes. *Aquat. Bot.* 26: 341-370.
- Carroll, M.L., Carroll, J. (2003). The Arctic seas. In: *Biogeochemistry of marine systems* (Eds. Black, K.D., Shimmield, G.B.). *Blackwell.* pp.127–156.

- Cartlon, R. and Wetzel, R. (1988). Phosphorus flux from Lake sediments; effect of epipelic algal oxygen production. *Limnol. Oceanogr*. 33 (4): 562-570.
- Carvalho, E.D., Da Silva ,V.F.B., Fujihara, C.Y., Henry,R. & Foresti, F. (2010). Diversity of fish species in the River Paranapanema-Jurumirim Reservoir transition region (São Paulo, Brazil). *Italian Journal of Zoology*. 65(1): 325-330.
- Carvalho, E.D., Marcus, L.R., Foresti, F. and Silva, V.F.B. (2005B). Fish assemblage attributes in a small oxbow lake (Upper Paraná River Basin, São Paulo State, Brazil): species composition, diversity and ontogenetic stage. *Acta Limnol. Bras*. 17(1): 45-56.
- Chakrabarty, R. D., Roy, P. and Singh, S.B. (1959). A quantitative study of the plankton and physico-chemical conditions of the river Yamuna at Allahabad in 1954-55. *Indian J. Fish.* 6(1): 186-203.
- Chandler, J. (1970). A biological approach to water quality management. *Water Pollution Control*. 69(2): 415–422.
- Chandra, R. (1988). Riverine fisheries resources of the Ganga and the Brahmaputra. Lecture delivered in the summer institute on “Resource Management and conservation of Inland Capture Fisheries of India”. 4-23 July, 1988. CIFRI, Barakpore.
- Chandran, R., Thangaraj, G.S., Sivakumar, V. Srikrishnadhas, B. and Ramamoorthi, K. (1982). Ecology of macrobenthos in the Vellasr Estuary. *Indian J. Mar. Sci.* II: 122-127.
- Chandraprakash, D. C. and Grover, P. P. (1978): Ecological study of Yamuna, IAWPC, Tech Report. pp.32- 45.
- Chapman, D. (1996). Water Quality Assessment, 2nd edn. EPFN, London.

- Chapman, D. G. (1951). Some properties of the hypergeometric distribution with applications to zoological censuses. Univ. *California Publ. Stat*. 1(7): 131-160.
- Chapman, D.W. (1986). Salmon and steelhead abundance in the Columbia River in the nineteenth century: *Transactions of the American Fisheries Society*. 115: 662-670.
- Chattopadhaya, S. N., Routh, T.; Sharma, V. P., Arora, H. C. and Gupta, R. K. (1984). A short term study on the pollution status of river Ganges in Kanpur region. *Indian J. Env. Health.* 20: 224-225.
- Chaurasia, S., and Raj,K. (2013). Water quality and pollution load of river Mandakini at Chitrakoot, India. *Int. Res. J. Environ. Sci.* 2(6):13-19.
- Chebanov, M.S., Galich, E.V. & Ananyev, D.V. (2016). Strategy for the mitigation of the effect of the Kuban river flow regulation on sturgeon reproduction. Symposium on Hydropower, Flood control and water abstraction: Implications for Fish and Fisheries. Mondsee, Austria, 14-17 June 2016.
- Chen, X. (2001). Human impacts on the Changjiang (Yangtze) River basin, China, with special reference to the impacts on the dry season water discharges into the sea. *Geomorphology*. 41: 111–123.
- Chen, Y. (2004). Effect of Three Gorges Project on the sustainable development in the Yangtze River basin. *Journal of Resources and Environment in Yangtze Basin*. 13(1): 109-113.
- Chen, Z., Li, J., Shen, H., and Wang, Z. (2001). Yangtze River of China: historical analysis of discharge variability and sediment flux. *Geomorphology*. 41: 77–91.

- Choudhury, K. R. and Bhuiya, A. H. (1990). Environmental processes: Flooding, river erosion, siltation and accretion-physical impacts. In: Environmental Aspects of Surface Water System of Bangladesh. A.A. Rahman, S.Haque and G.R. Conway (eds) Dhaka, Bangladesh: University Press. pp.93-103.
- Choudhury, U. K. and Ojha, C. S. P. (1985). Environmental Impact Assessment of River Ganga at Varanasi. In: International seminar on Environmental impact assessment of water resource project. University of Roorkee (India). pp.760-771.
- Chourasia, S.K. and Adoni, A.D. (1985). Zooplankton dynamics in a shallow eutrophic lake. In (Ed. A.B. Adoni Proc. Nat. Symp). *Pure and Appl. Limnology. Bull Bot.* Soc. Sagar, India. 32: 30-39.
- Chovanec, A., Schiemer, F., Cabela, A., Gressler, S., Grotzer, C., Pascher, K., Raab, R., … Teufl, H. & Wimmer, R. (2000). Constructed in shore zones as river corridors through urban areas- the Danube in Vienna: preliminary results. *Regul. Rivers: Res. Mgmt.* 16: 175-187.
- Chowdhary, S. K. (1984). Studies on bio-ecology of aquatic insects of Sind and Lidder streenss of Kashmir. *Indian Journal of Ecology*. 11(1): 160–165.
- Christensen, P.B., Rysgaard, S., Sloth, N.P., Dalsgaard, T. and Schwaerter, S. (2000). Sediment mineralization, nutrient fluxes, denitrification and dissimilatory nitrate reduction to ammonium in an estuarine fjord with sea cage trout farms. *Aquatic Microbial Ecology*. 21: 73–84.
- Cole G.A. (1979). *Text book of limnology*. London: The C.V. Mosby Company. p.426.

- Cole, G.A. (1983): *Textbook of Limnology*. (3rd ed.). London: The C.V. Mosby Company. pp.401.
- Colinjin, F. and de Jonge, V.N. (1984) Primary production of microphytobrnthos in the EMS-DOLL and Estuary. *Mar. Ecol. Prog. Ser*. 14: 185-196.
- Cole, G. A. (1975). *Text book of limnology.* Saint Louis: The C.V. Mosby company.
- Collen ,B., Whitton, F., Dyner ,E.E., Baille, J.E.M., Cumberlidge,N., Darwall, W.R.T., Pollock,C., …Richman,N.I., Soulsby, A.M., Bohn, M. (2014). Global patterns of freshwater species diversity, threat, and endemism. *Glob Ecol Biogeogr.* 23: 40–51.
- Collier M., Webb, R.H. and Schmidt, J.C. (1996). Dams and rivers: primer on the downstream effects of dams. Reston (VA): US Geological Survey. Circular nr 1126.
- Colombo, V., Pettigrove, V.J., Hoffmann, A.A., Golding, L.A. (2016). Effects of *Lumbriculus variegatus* (Annelida, Oligochaete) bioturbation on zinc sediment chemistry and toxicity to the epi-benthic invertebrate *Chironomus tepperi* (Diptera: Chironomidae). *Environmental Pollution*. 216: 198-207.
- Cook, C. D. K. (1996). *Aquatic and Wetland Plants of India*. A Reference Book and Identification Manual for the Vascular Plants Found in Permanent of Season Fresh Water in the Subcontinent of India South of the Himalayas. New York: Oxford Univ. Press Inc. p.304.
- Cooper, C.F. (1969). Nutrient output from managed forests. In: *Eutrophication: Causes, Consequences, and Correctives*. Washington, D.C: National Academy of Science. pp.446-463.

- Cordery, I. (1976). Some effects of urbanisation on streams. *Civil Engineering Transactions.* 18: 7–11.
- Coyle, K. O., Bluhm, B., Konar, B., Blanchard, A. and Highsmith, R. C. (2007). Amphipod prey of gray whales in the northern Bering Sea: comparison of biomass and distribution between the 1980s and 2002–2003, *Deep sea research Part II*: Tropical studies in Oceanography.
- Cranford, P., Anderson, R., Archambault, P., Balch, T., Bates, S., Bugden, G., Callier, M.D., … Carver, C., Comeau, L., Hargrave, B., Harrison, G., Horne, E., Kepay, P.E., Li, W.K.W., Mallet, A., Ouellette, M. and Strain, P. (2006). Indicators and thresholds for use in assessing shellfish aquaculture impacts on fish habitat. *DFO Can. Sci. Advis*. *Sec. Res. Doc.* 2006/034. p.166.
- Cranston, P.S. (1995). Introduction: The Chironomidae. In: *The biology and ecology of non-biting midges* (Eds, Armitage, P., P.S. Cranston & L.C.V. Pinder). London: Chapman & Hall, pp.1-7.
- Craven,S.W., Peterson,J.T., Freeman,M.C., Kwak,T.J., Irwin, E. (2010). Modeling the relations between flow regime components, species traits, and spawning success of fishes in warmwater streams. *Environ Manag*. 46: 181–194.
- Cromey, C.J., Nickell, T.D., Black, K.D. (2002a). DEPOMOD-modelling the deposition and the biological effects of waste solids from marine cage farms. *Aquaculture.* 214: 211–239.

- Cronk, J. K. and M. S. Fennessy. (2001). Wetland Plants: Biology and Ecology. USA: CRC Press LLC. pp.462.
- Cross, W.F., Baxter, C.V., Donner, K.C., Rosi-Marshall,E., Kennedy,T.A., Hall,R.O., Wellard Kelly,H.A. … and Rogers,R.S. (2011). Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon. *Ecol Appl*. 21: 2016–2033.
- Crow, J. H. and MacDonald, K. B. (1979). Wetland values: Secondary production. In: *Wetland functions and values: The State of our Understanding.* Greeson, P. E., Clark, J. R. and Clark, J. E. (eds.), American Water Resource Association, Minneapolis. pp. 146-161.
- Cuadrado, J. T. and Calagui, L.B. (2017). Aquatic Macroinvertebrates composition, diversity and richness in Agusan river tributaries, Esperanza, Agusan del Sur, Philippines. *Journal of Biodiversity and Environmental Sciences (JBES)*. 10(03): 25-34.
- Curry, L. L. (1962). A survey of environmental requirements for the midge (Diptera-Tendipedidae). In C. M. Tarzweli, P. H. S. Usdhew, & A. Robert (Eds.), *Biological problems in water pollution. Transactions of 3rd seminar*. Cincinnati: Taft Sanitary Engineering Centre.
- Cushing, C.E. and Allan, J.D. (2001). Streams: their ecology and life. Academic Press, San Diego. pp. 366.
- Daimari, P., Choudhury, M. and Dutta, A. (2005). Ecology and Fishery of River Subansiri (Arunachal Pradesh). *Environment and Ecology*. 23(1): 49-54.

- Dallas, H. (1997). A preliminary evaluation of aspects of SASS (South Africa Scoring System) for rapid bioassessment of water quality in rivers. *Southern African Journal of Aquatic Science*. 23(1): 79–94.
- Dance, K. W., & Hynes, H. B. N. (1980). Some effects of agricultural land use on stream insect communities. *Environmental Pollution Series A*. 22: 19–28.
- Danvind, M. & Nilson, C. (1997). Seed floating ability and distribution of alpine plants along a northern Swedish river. *Journal of Vegetation Science.* 8: 271– 276.
- Das, A.K. (2000). Limno- chemistry of some Andhra Pradesh Reservoirs. *J. Inland Fish. Soc*. *India*. 32: 37-44.
- Das, J. N. and Biswas, S. P. (2011). Ecology and Diversity of Fishes in the Lotic Habitats of Upper Brahmaputra Basin, In. *Biodiversity, Ecology and Conservation of Rivers and Streams of North-East India* (ed. L. Kosygin). New Delhi: Akansha Publishing House. pp. 25-41.
- Das, S. M. (1979). Effects of increased land use upon freshwater in the Central Himalayas. *Procedings of Water Technical.* 11(6): 195–208.
- Das, S. M. (1989). *Handbook of limnology and water pollution*. New Delhi: South Asian Publishers Pvt. Ltd.
- Das, S. M. and Srivastava, K. (1956). Quantitative studies on fresh water plankton of the fish tank in Lucknow, India. *Proc. Nat. Acad. Sci.* 25: 82-89.
- Das, S. M., & Bisht, R. S. (1979). Ecology of some hemiptera and coleoptra of Kumaun lakes. *Indian Journal of Ecology*. 6(1): 35–40.

- Datingaling, B. Y. (1976). The potential of the freshwater fish culture resources of the Phillipines. Proc. 17th Session of Indo-Pacific Fisheries Council at Colombo, Sri Lanka. FAO. Bangkok. 3: 120-126.
- Datta Munshi, J. S. and Singh, D. K. (1991). Physico-chemical profiles of river Ganga at Kahalgaon, Bihar, India. In: Aquatic sciences in India. (Eds. Gopal, B. & Asthana, V.), New Delhi: *Indian Association of Limnology and Oceanography*.
- Dauer, D.M., Llanso, R.J., Lane, M.F. (2008). Depth-related patterns in benthic community condition along an estuarine gradient in Chesapeake Bay, USA. *Ecol. Indicators*. 8: 417–424.
- David, A., & Ray, P. (1966). Studies on the pollution of the river Daha (N-Bihar) by sugar and distillery wastes. *Environmental Health*. 8: 6–35.
- Davies, P.M, Naiman,R.J., Warfe,D.M., Petit,N.E., Arthington,A.H., Bunn,S.E. (2013). Flow-ecology relationships: closing the loop on effective environmental flows. Mar Freshw Res.
- Davis, W. S. and Simon T. P. (1995). Biological assessment and criteria: Tools for water resource planning and decision making. Boca Raton, Florida: Lewis Publisher.
- Dayton, P.K. and Oliver, J.S. (1977). Antarctic soft-bottom benthos in oligotrophic and eutrophic environments. *Science*. 197: 55–58.
- de Mérona, B., Vigouroux, R. and Tejerina-Garro, F. L. (2005). Alteration of fish diversity downstream from Petit-Saut dam in French Guiana: Implication of ecological strategies of fish species. *Hydrobiologia*. 55: 33-47.

- De Pauw, N. and Vanhooren,G. (1983). Method for biological quality assessment of water courses in Belgium. *Hydrobiologia*. 100(1): 153–168.
- De Sosta, A. and Lobon- Cervia, J. (1989). Fish and Fisheries of the River Ebro: actual state and recent history. In: Historical change of large alluvial rivers: Western Europe, G.A. Petts., H. Moller and A.L. Roux (eds). Chichester: John Wiley and Sons. pp.233-247.
- Deshmukh, B.S. (2012). Hydrobiological study of river Pravara in Ahmednagar district (Maharashtra), Bionano Frontier. *Eco. Revolution. Colombo*. pp.89-92.
- Devika, R., Rajendran, A. and P. Selvapathy (2006). Variation studies on the physico-chemical and biological characteristics at different depths in model waste stabilisation tank. *Pollut.Res*. 24: 771 774.
- Dey, S. C. (1976). Studies on probable origin and distribution of the ichthyofauna of the river Brahmapura, India. Rev. Des.Trav. DeL' Ins teech. Des Proches Marit, Paris.
- Dey, S. C. (1981). Studies on hydrobiological conditions of some commercially important lakes (beels) of Kamrup district of Assam and their bearng on fish production. Final Technical Repot, North Eastern Council. p.177.
- Dey, S. C. (1984). Ichthyological developments in Assam during Nineteenth Century. *Ind. J. Hist. Sc*. 19(4): 297-313.
- Dey, S. C. (1976). Studies on probable origin and distribution of the ichthyofauna of the river Brahmapura, India. Rev. Des.Trav. DeL' Ins teech. Des Proches Marit, Paris.
- DFID (1999). *A Simple Methodology for Water Quality Monitoring*. (G. R. Pearce, M. R. Chandhry and S. Ghulum, ed.) Wallingford:Department for international Development.

- Dhillon, S. S., Kaur, H., Bath, K. S., Mander, G., & Syal, J. (1993a). The impact of effluence of on the zooplankton population of Beas river. *Journal Of Ecotoxicology and Environmental Monitoring.* 3(2): 177–120.
- DIas, J.H.P. and Garavello, J.C. (1998). Ecological studies on the fish community of Salto Grande Reservoir, Paranapanema River Basin, São Paulo, Brazil. *Verh. Int. Verein. Limnol.* 26: 2228-2231.
- Dixon, A. B. and Wood, A. P. (2003). Wetland cultivation and hydrological management in Eastern Africa: Matching community and hydrological needs through sustainable wetland use. *In Natural Resources Forum*. 27: 117–129.
- Dodge , D. P. and Biette, M. R. (1993). River protection in Ontario, Canada: a case for holistic catchment management. In: River conservation and management. P.J. Boon, P. Calow and G.E.Petts (eds) Chichester: John Wiley and Sons. pp.57-79.
- Dolotov, A. V., Gapeeva, M. V and Kozlovskii, E. V. (2010). Assessment of the Uvod reservoir pollution with heavy metals. *Journal of Water Resources.* 37(1): 58-64.
- Garrone-Neto1, D., Haddad Jr, V. and Gadig, O.B.F. (2014). Record of ascending passage of potamotrygonid stingrays through navigation locks: implications for the management of non-native species in the Upper Paraná River basin, Southeastern Brazil. *Management of Biological Invasions*. 5(2): 113–119.
- Dowd, M. (2005). A bio-physical coastal ecosystem model for assessing environmental effects of marine bivalve aquaculture. *Ecol. Model*. 183: 323–346.

- Doyle, M.W. and Shields, C.A. (2008). An alternative measure of discharge effectiveness. *Earth Surf Process Land.* 33: 308–316.
- Doyle, M.W., Shields, D., Boyd, K.F., Skidmore, P.B. and Dominick, D. (2007). Channel-forming discharge selection in river restoration design. *J Hydraul Eng*. 133: 831–837.
- Doyle, M.W., Stanley, E.H., Strayer, D.L., Jacobson, R.B. and Schmidt, J.C. (2005). Effective discharge analysis of ecological processes in streams. *Water Resour Res*. 41: W11411.
- Draštík, V., Kubečka, J. & Tušer, M. (2014). Effect of flow regulation on the distribution of fish abundance and biomass; comparison of cascade and non cascade reservoirs. *Journal of Hydrology*. 122(2): 225-229.
- Dudgeon, D. (1994). Research strategies for the conservation and management of tropical Asian streams and rivers. *International Journal of Ecology and Environmental Sciences*. 20: 255-285.
- Dügel, M. (1995). Köyceğiz Gölü'ne dökülen akarsuların su kalitelerinin fiziko-kimyasal ve biyolojik parametrelerle belirlenmesi, Bilim Uzmanlığı Tezi, Hacettepe Üniversitesi, Fen Bilimleri Enstitüsü, Ankara, 88s.
- Dunne T. & Leopold L.B. (1978). Water in Environmental Planning. San Francisco: W. H. Freeman and Co.
- Dunstan, P.K., Johnson, C.R. (2003). Competition coefficients in a marine epibenthic assemblage depend on spatial structure. *Oikos.* 100: (1), 79–88.

- Dutta, A. C. (1985). Dictionary of Economic and Medicinal Plants. Jorhat, Assam, India: Assam Printing Works.
- Dutta, R. and Dutta, A. (2010). Study on certain physic-chemical parameters of Namsang stream, Arunachal Pradesh. In, Biodiversity and Human Welfare, (eds.) Goswami, U. C., Sharma, D. K., Kalita, J. and Saikia, P. K., Narendra Publishing House. pp. 259-263.
- Dutta, R. and Sarma, S. K. (2012). Lower Subansiri Hydroelectric Power Project and future of the Subansiri River Ecosystem. *Annals of Biological Research*. 3 (6): 2953-2957.
- Dutta, R., Baruah, D. and Sarma, S. K. (2011A): Influence of riparian flora on the river bank health of a Himalayan River before being regulated by a large dam in North East India. *Annals of Biological Research*. 2(4): 268-280.
- Dutta, R., Baruah, D. and Sarma, S. K. (2011B): Botanical composition and ecological responses of certain riparian flora in the tailrace of river Subansiri. *Journal of Advanced Plant Sciences*. 5(3&4): 59-64.
- Dutta, R., Baruah, D., Sarma, S. K. and Hazarika, L. P. (2010A): Pre-impact studies of the 2000 MW Lower Subansiri Dam on certain aquatic environmental aspects of downstream of the river Subansiri with special reference to plankton and fishes. *Nature Environment and Pollution Technology*. 9(2): 283-291.
- Dutta, R., Baruah, D., Sarma, S. K., Hazarika, L. P. and Bakalial, B. (2010B): A statistical overview of certain physico-chemical parameters of river Subansiri in Northeast India. *Eco. Env. & Cons.* 16 (2): 313-318.

- Dwivedi, R. K., Karamchandani, S. J. and Joshi, H. C. (1986): Limnology and productivity of Kulgarji reservoir, Madhya Pradesh. *J. Inland Fish Soc. Ind.* 18(2): 65-70.
- Dynesius, M. and Nilsson, C. (1994): Fragmentation and flow regulation of river systems in the northern 3rd of the world. *Science*. 266 (5186): 753-762.
- Dyson, M., Bergkamp, G. and Scanlon, J. (eds.) (2003). Flow- The Essentials of Environmental Flows. Gland, Switzerland: IUCN.
- Dzeroski S., Grbovic T. and Demsor D. (2002). Predicting chemical parameters of river quality from bioindicator data. Applied intelligence.
- Eckman, J.E. (1996). Closing the larval loop. linking larval ecology to the population dynamics of marine benthic invertebrates. *J. of Exp. Mar. Biol. and Ecol*. 200 (1–2), 207–237.
- Eggleton, F.E. (1936).The deep water bottom fauna of Lake Michigan. Pap. Mich. *Acad. Sci. Arts. Let*. 21: 499-612.
- Elliot, A. J. and May, L. (2008). The sensitivity of phytoplankton in Loch Leven (U.K.) to changes in nutrient load and water temperature. *Freshwater Biology*. 53 (1): 32-41.
- Eriksson Wiklund, A.K., Dahlgren, K., Sundelin, B. and Andersson, A. (2009). Effects of warming and shifts of pelagic food web structure on benthic productivity in a coastal marine system. *Mar. Ecol. Prog. Ser*. 396: 13–25.
- Ellis, M. M (1937). Detection and measurement of stream pollution U.S. *Fish Bull.* 48: 356-437.

- Encina, L., Rodríguez, A. & Granado-Lorencio, C. (2006). The Iberian ichthyofauna: Ecological contributions. *Limnetica*. 25(1-2): 349-368.
- Enders, E.C., Stickler, M., Pennell, C.J., Alfredsen, K. & Scruton, D.A. (2014). Winter mobility patterns of Juvenile Atlantic Salmon in relation to turbulence and ice information in a regulated river. *Journal of Environmental Research and Development.* 23(1): 22-24.
- Ensign, S., Siporin,K., Piehler,M., Doyle,M., and Leonard, L. (2013). Hydrologic versus biogeochemical controls of denitrification in tidal freshwater wetlands. *Estuaries Coasts*. 36: 519–532.
- Ensign, S.H. and Doyle, M.W. (2006). Nutrient spiraling in streams and river networks. J Geophys Res 111:G04009. doi:10.1029/2005JG000114.
- Environnement, C. G. (2000). Indice Biologique Global Normalis (I.B.G.N), NF-T90350.
- Eversham, B.C. and Cooper, J.M. (1998). Dragonfly species richness and temperature: national patterns and latitude trends in Britain. *Odonatologica*. 27: 287-414.
- Ezz El-Din, O. (1990). Some ecological studies on phytoplankton of Lake Bardawil, Ph. D. Thesis, Fac. of Sci. Suez Canal Univ., Egypt.
- Fang, X., Stefan, H.G. (1999). Projections of climate change effects on water temperature characteristics of small lakes in the contiguous US. *Clim Change*. 42: 377–412.
- Feder, H.M., Paul, A.J. and Paul, J.M. (1979). The pinkneck clam *Spisula polynyma* in the eastern Bering Sea: growth, mortality, recruitment and size at maturity. In: Proceeding of the 29th Alaska Science Conference, *Sea Grant Report.* 79-6:717–738pp .

- Ferro,V. and Porto,P. (2012).Identifying a dominant discharge for natural rivers in southern Italy. *Geomorphology*. 139: 313–321.
- Fischer, D., Cathleen, W., M. Finn, M., and Findlay, S. (2001).Submersed macrophyte effects on nutrient exchanges in riverine sediments. *Estuaries.* 24: 398–406.
- Flosi, G. and F.L. Reynolds (1994). California salmonide stream habitat restoration manual. Sacramento: California Department of Fish and Game, Technical Report.
- Flura, Alam, M.A., Nima, A.,Tanu, M.B. and Khan, M. H. (2016). Physico-chemical and biological properties of water from the river Meghna, Bangladesh. *International Journal of Fisheries and Aquatic Studies*. 4(2): 161-165.
- Focken, U., Groth, A., Coloso, R.M. and Becker, K. (1998). Contribution of natural food and supplemental feed to the gut content of *Penaeus monodon fabricius* in a semi-intensive pond system in the Philippines. *Aquaculture*. 164: 105–116.
- Frank, L., Cross, J. P.E. (1994). Management primer on water pollution control. West Port: Technomic publishing Co., Inc.
- Freeman, M.C.and Marcinek, P.A. (2006). Fish assemblage responses to water withdrawals and water supply reservoirs in Piedmont streams. *Environ Manag.* 38: 435–450.
- Freiser, H., & Fernando, Q. (1966). Ionic equilibra in analytical chemistry. New York: Wiley and Sons.

- Froend, R. H. and McComb, A. J. (1994). Distribution, productivity and reproductive phenology of emergent macrophytes in relation to water regimes at wetlands of Southwestern Australia. *Australian Journal of Marine and Freshwater*.
- Fruget, J. F. (1993). Ecology of lower Rhone after 200 years of human influence: a review. *Regulated River Res. and Management.* 7: 133-146.
- Fuggle, R. and Smith, W.T. (2000). Large Dams in Water and Energy Resource Development in The People's Republic of China, World Commission on Dams Country Review Paper. Cape Town: World Commission on Dams.
- Gaarder, T. and Gran, H. H. (1927). Investigation on the production of plankton in the Oslo Fjord. P-V Reun. Commn. *Inter. Explor. Sci. Mer. Medieterr.* 42**:** 1-48.
- Gabriels, W., K. Lock, N. De Pauw, and P. L. Goethals (2010). Multimetric Macroinvertebrate Index Flanders (MMIF) for biological assessment of rivers and lakes in Flanders (Belgium). *Limnologica-Ecology and Management of Inland Waters*. 40(3): 199–207.
- Gams, H. (1918). Prinzipienfragen der Vegetationsferschung. Vjschr. *Natur. Ges. Zurich*. 63: 293-493.
- Ganapati, S. V. (1943). Final report on the hydrobiological and faunatic survey of Godavori estuarine system. Dept. of Zool. Andhra University. pp.1-54.
- Ganapati, S. V. (1956). Hydrobiological investigations of the Hope reservoirs and of Thambaraparni river at Papanasam Tirunalveli Dt. Madras State India. *Geogr. J*. 31: 1–2.

- Ganapati, S. V. (1964). Final report on the hydrobiological and faunatic survey of Godavori estuarine system. Dept. of Zool. Andhra University. pp.1-54.
- Ganapati, S.V. (1960). Ecology of tropical waters. Proc. *ICAR Symp on Algology*, New Delhi (1958). pp.200-218.
- Gasim, M. B., Mir, S.I. and Chek, T.C. (2007). A physico-chemical assessment of the Bebar river, Pahang, Malaysia. *Global Journal of Environmental Research*. 1(1): 07-11.
- Gastescu, P. (1993). The Danibe Delta: Geographical characteristics and ecological recovery. *Geob. Jour*. 29 (1):57-67.
- Gauffin, A.R. and Tarzwell, C.M. (1952). Aquatic invertebrates as indicators of stream pollution. *Pub Health Rep*, **67:** 57-64.
- Gaufin, A. R., & Tarzwell, C. M. (1956). Aquatic invertebrates as indictors of organic polution in Lytte Creak. *Sewage and Industrial Wastes*. 28: 906–924.
- Geeraerts, C., Verbiest, H., Ovidio, M., Buysse, D., Coeck, J., Belpaire, C. & Philippart, J.-C. (2013). Mobility and spawning migration of Roach (*Rutilus rutilus*) in three weir fragmented Belgian rivers. *Journal of Hydrology.* 12(5): 222-228.
- Gehrke, P. C., Brown, P., Schiller, C. B., Moatt, D. B., and Bruce, A. M. (1995). River regulation and fish communities in the Murray-Darling River system, Australia, *Regulated Rivers: Research and Management*. 11: 363–375.
- George, M.G. (1961). Diurnal variations in two shallow ponds in Delhi, India. *Hydrobiologia*. 18: 256-273.

- Georgia Department of Natural Resources (GA DNR) (2001). Interim instream flow protection strategy. Appendix B of the Water Issues White Paper. www.gaepd.org/
- Getachew, M., A. Ambelu, S. Tiku, W. Legesse, A. Adugna, and H. Kloos (2012). Ecological assessment of Cheffa Wetland in the Borkena Valley, northeast Ethiopia: Macroinvertebrate and bird communities. *Ecological Indicators*. 15(1): 63–71.
- Ghose, N. C. and Sharma, C. B. (1989). Pollution of Ganga River. New Delhi: Ashish Publishing House.
- Giere, O., Wirkner, C.S., Steinmann, D., Fend, S., Hoeger, U. (2017). Structural and physiological characteristics of *Limnodrilus sulphurensis* (Oligochaeta, Annelida) thriving in high sulphide conditions. *Hydrobiologia*. 790(1): 109-123.
- Gilvear, D. J., Cecil, J., Parsons, H. (2000). Channel change and vegetation diversity on a low-angle alluvial fan, River Feshie, Scotland. *Aquatic Conservation-Marine and Freshwater Ecosystems*. 10 (1): 53-71.
- Gochhait, B. C. (1991). Studies on limnological factors of river Buddhabalangaat Baripada (Orissa). *Ph.D thesis,* Utkal University.
- Goldman, C.R. (1960). Primary productivity and limiting factors in three lakes of the Alashan Peninsula. *Ecol. Monogr*. 30: 207-270.
- Goel, P. K., & Chavan, V. R. (1991). Limnological study of a polluted fishery tank at Kolhapur. In Proceedings of national symposium planning for environment sustainable development. New Delhi.

- Goldsmith, E. and Hildyard, N. (1984). Social and Environmental Effects of Large Dams: Overview, Waderbridge Ecological Center, Camelford, UK, vol. 1.
- Gopal, B. (1990). Indian subcontinent and the aquate habitats. In *Ecology and management of aquate vegetation in the Indian subcontinent* (pp. 7–28). Netherlands: Kluwer Academic Publ.
- Gopalakrishnan, V. (1976). Management of estuaries fisheries; a coordinated plan of research and development.Proc.17th session of Indo-Pacific Fisheries Council at Colombo, Sri Lanka. FAO, Bangkok. 3: 138-148.
- Gopalkrishnan, T.C. and Nair, K.K. (1998). Subtidal benthic macrofauna of the Mangalore coast, west coast of India. *Indian J. Mar. Sci*. 27: 351-355.
- Goswami, D. C. (1998). Fluvial regime and flood hydrology of the Brahmaputra River, Assam. Memoir Geological Society of India. 41: 53-75.
- Goswami, U. C., Sarma, J. N. and Patgiri, A. D. (1999). River channel changes of the Subansiri in Assam, India. *Geomorphology*. 30(3): 227-244.
- Graff, W. L. (2002). Dam removal, research, status and prospects. Proceedings of the Heinz Center's Dam Removal Research Workshop. Washington, D.C: The H. John Heinz III Center for Science, Economics and the Environment.
- Grant, J. and D. L. Kramer. (1990). Territory size as a prediction of the upper limit to population density of juvenile salmonids in streams. *Can. J. Fish. Aquat. Sci*. 47: 1724-1737.

- Grant, J., Cranford, P., Hargrave, B., Carreau, M., Schofield, B., Armsworthy, S., Burdett-Coutts, V. … and Ibarra, D. (2005). A model of aquaculture biodeposition for multiple estuaries and field validation at blue mussel (*Mytilus edulis*) culture sites in eastern Canada. *Can. J. Fish. Aquat. Sci*. 62: 1271–1285.
- Grant, J., Hargrave, B. and MacPherson, P. (2002). Sediment properties and benthic–pelagic coupling in the North Water. *Deep-Sea Res*., *Part 2, Top. Stud. Oceanogr*. 49: 5259–5275.
- Grasmuck, N., Haury, J., Leglize, L., and Muller, S. (1993). Analyse de la vegetation aquatique fixee des cours d'eau lorrains en relation avee les paramettres d'environment. *Ann. Limnol.* 29: 223-237.
- Grebmeier, J.M. and Barry, J.P. (1991). The influence of oceanographic processes on pelagic–benthic coupling in polar regions: a benthic perspective. *J. Mar. Syst*. 2: 495–518.
- Grebmeier, J.M., Feder, H.M. and McRoy, C.P. (1989). Pelagic–benthic coupling on the shelf of the northern Bering and Chukchi Seas. II. Benthic community structure. *Mar. Ecol., Prog. Ser*. 51: 253–268.
- Grebmeier, J.M., McRoy, C.P. and Feder, H.M. (1988). Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food supply source and benthic biomass. *Mar. Ecol. Prog. Ser.* 48: 57–67.
- Gregory, S., H. Li, and J. Li. (2002). The conceptual basis for ecological responses to dam removal. *Bioscience*. 52: 713-723.

- Gulati, R. D. and Wart-Shchulz, G. (1980). Remarks on the present status of limnology in India based mainly on the Indian Publications in Hydrobiologia and suggestion for future approach. *Hydrobiol*. 72: 211-222.
- Gupta, P.K. and Pant, M.C. (1983b). Seasonal variation in the energy content of benthic macroinvertebrates of Lake Nainital U.P, India. *Hydrobiologia*. 99: 19-22.
- Gupta, B. P. (1982). Studies on primary production in Bhabanisagar reservoir (Tamil Nadu). *Journal of Inland Fisheries Society India*. 34: 49-54.
- Guptachoudhury, A., Singh, A. S., Biswas, S. P. and Gupta, A. (2011). Investigation on certain limnological parameters of Namdapha River in Arunachal Pradesh. *Geobios*. 38: 91-95.
- Guyer, G. T and Ilhan, E. G. (2011). Assessment of pollution profile in Buyukcekmece Watershed, Turkey. *Environmental Monitoring and Assessment*. 173: 211-220.
- Haeckel, E. (1891). Plankton studies. Jenaische Zeitschr. *F. Naturw*. 25: 232-336.
- Haflinger, K. (1981). A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In: *The Eastern Bering Sea Oceanography and Resources* (Eds. Hood, D.W., Calder, J.A.). Office of Marine Pollution Assessment, NOAA. Seattle: University of Washington Press. pp. 1091–1103.
- Hagler, M.M. (2006). Effects of natural flow variability over seven years on the occurrence of shoal-dependent fishes in the Etowah River. Master's Thesis, University of Georgia.

- Halder, G. C., Mazid, M. A. and Ahmed, K. K. (1990). Limnology and primary productivity of Katpal lake, Bangladesh. *Proc. 2nd Asian Reservoir Fisheries Workshop*, Hangzhou, China, 1-19 Oct, 1990, pp. 2-11.
- Hall, R.O., Bernhardt, E.S., Likens, G.E. (2002). Relating nutrient uptake with transient storage in forested mountain streams. *Limnol Oceanogr.* 47: 255–265.
- Halliday, S. J., Skeffington, R. A., Wade, A. J., Bowes, M. J., Read, D. S., Jarvie, H. P. and Loewenthal, M. (2016). Riparian shading controls instream spring phytoplankton and benthic algal growth. *Environ. Sci.: Processes Impacts*. 18: 677–689.
- Halls, A. (2015). Impacts of flood control schemes in Bangladesh and guidelines for mitigation. *Journal of Research.* 1(1): 222-247.
- Hall-Spencer, J., White, N., Gillespie, E., Gillham, K. and Faggo, A. (2006). Impact of fish farms on maerl beds in strongly tidal areas. *Marine Ecology Progress Series*. 326: 1–9.
- Hannan, H. H., & Young. W. J. (1974). The influence of a deep storage reservoir on the physico-chemical limnology of central Texas river. *Hydrobiologia.* 44(2–3): 177–207.
- Hannigan E., and M. Kelly-Quinn (2012). Composition and structure of macroinvertebrate communities in contrasting open-water habitats in Irish peatlands: implications for biodiversity conservation.Wet services and management. *Hydrobiologia*. 692(1): 19–28.
- Hansen and Bendtsen, J. (2006). Klimabetingede effekter på marine økosystemer. Faglig rapport fra DMU no. 598, *the Ministry of Environments*. 50: pp.
- Hargrave, B.T. (1972). Seasonal changes in oxygen uptake by settled particulate matter and sediments in a marine bay. *J. Fish Resch*. *Bd. Canada*. 35: 1621-1628.

- Hargrave, B.T., Walsh, I.D. and Murray, D.W. (2002). Seasonal and spatial patterns in mass and organic matter sedimentation in the North Water. *Deep-Sea Res*., Part 2, *Top. Stud. Oceanogr.* 49: 5227–5244.
- Harkantra, S.N., Nair, A., Ansari, Z.A. and Parulekar, A.H. (1980). Benthos of the shelf infaunal community surrounding a Hawaiian mariculture operation. *Marine J. Mar. Sci*. 16: 60-64.
- Harold, C. H. M. (1934). 29th Annual *report Metropolitan water Board.* London.
- Harris, R. R., Fox, C. A and Risser R. (1987). Impacts of Hydroelectric Development on Riparian Vegetation in the Sierra Nevada Region, California, USA, *J. Environmental Management*. 11(4): 519-527.
- Harrison, E. T., Norris, R. H. and Wilkinson, S. N.(2008). Can an indicator of river health be related to assessment from a catchment's scale sediment model. *Hydrobiol.* 600: 49-64.
- Harshey, D. K., Patil, S. G., & Singh, D. F. (1982). Limnological studies on a tropical fresh water fish tank of Jabalpur, India. *Geobios New Reports.* 1(2): 98–102.
- Hart, D.D., Biggs, B.J.F., Nikora, V.I., Flinders, C.A. (2013). Flow effects on periphyton patches and their ecological consequences in a New Zealand river. *Freshw Biol.* 58: 1588–1602.
- Hart, D. D., Johnson, T. E.; Bushaw-Newton, K. L., Hor-witz, R. J., Bednarek, A. T.. Charles, D. F., Kreeger, D. A. … and Velinsky, D. J. (2002). Dam removal: challenges and opportunities for ecological research and river restoration. *Bioscience*. 52: 669-68.

- Harvey, H. W. (1940). Nitrogen and phosphorus required for the growth of phytoplankton. *Journal of Marine Biological Association UK.* 24: 115–123.
- Hayes, F.R. and Anthony, E.H. (1959). Lake water and sediments and its place in the classification of lakes. *Limnol. Oceanogr*. 4: 299-315.
- Haynes, R. R. (2001). Alismataceae. In T. Santisuk and K. Larsen (eds.). Flora of Thailand, Prachachon Co. Ltd., Bangkok. 7(3). 351-358.
- Hazarika, L. P. (2008). Status of resident population of Gangetic river dolphin, *Platanista gangetica,* in the river Subansiri, a tributary of Brahmaputra, Assam, India, M.Phill. Dissertation, Periyar University, India.
- Hazarika, L. P. and Bhuyan, B. (2010). Hydrography of River Subansiri. *Indian Journal of Env. Sci*. 14(1): 31-38.
- Heino, J. (2002). Concordance of species richness patterns among multiple freshwater taxa: a regional perspective. *Biodiv. Conserv*. 11: 137-147.
- Heron, J. (1961). Phosphorus adsorption by lake sediments. *Limnology and Oceanography*. 6: 338.
- Hesse, L. W., Koulging, G. and Harris, F. (1989). Missouri River fishery resources in relation to past, present and future stresses. In: Proc. International Large Rivers Symposium (LARS). D.P. Dodge (ed.) *Can.Spl. Publ.Fish. Aquat. Sci*. p.106.
- Hester, E.T. and Doyle, M.W. (2011). Human impacts to river temperature and their effects on biological processes: a quantitative synthesis. *J Am Water Resour Assoc.* 47: 571–587.

- Heut, M. (1949): La pollution des eaux. L Analyse biologique des aeux polluees. *Bull. Centr. Belg. Etude Doc. Eaux*. 5&6: 1-31.
- Heyman, U. (1983). *Hydrobiol*. 101: 89-104.
- Highsmith, R.C. and Coyle, K.O. (1990). High productivity of northern Bering Sea benthic amphipods. *Nature*. 344: 862–864.
- Hilsenhoff, W. L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society*. 7(1): 65–68.
- Hiranyawat, S. (1968). Fishery biological survey in the Mae Klong, Kwai Yai and Kwai Noi. Ann. Rep. Fish. Biol. Surv. Unit. Inland Fish Div. Fish. Bangkok. 10-32.
- Hladík, M. & Kubečka, J. (2017). The effect of the construction of artificial reservoir on the fish population in the inflowing river. *Journal of Environment and Ecology*. 32(1): 323-327.
- Hobson, K.A., Ambrose Jr., W.G. and Renaud, P.E. (1995). Sources of primary production, benthic–pelagic coupling, and trophic relationships within the Northeast Water Polynya: Insights from δ13C and δ15N analysis. *Mar. Ecol., Prog. Ser*. 128: 1–10.
- Hobson, K.A., Fisk, A., Karnovsky, N., Holst, M., Gagnon, J.-M. and Fortier, M. (2002). A stable isotope (δ13C, δ15N) model for the North Water food web: implications for evaluating trophodynamics and the flow of energy and contaminants. Deep-Sea Res., Part 2, Top. Stud. *Oceanogr.* 49: 5131–5150.
- Hoff, C.C. (1943). Seasonal changes in the ostracod fauna of temporary ponds. *Ecology*. 24: 116-118.

- Hoffmann, AC., Orsi, M.L. and Shibatta, O.A. (2005). Diversidade de peixes do reservatório da UHE Escola Mackenzie (Capivara), rio Paranapanema. *Iheringia Ser. Zool*. 95(3): 319-325.
- Holmes, N. T. H. & Whitton, B. A. (1977). Macrophyte vegetation of the River Swale, Yorkshire. *Freshwater Biology*. 7: 545–558.
- Holmes, N. T. H. (1983). *Typing British Rivers According to Their Flora*. Focus on Nature Conservation, 4. Nature Conservancy Council, Peterborough.
- Hooker, J. D. (1982). *Flora of British India*. Vol. I-VII, London- Reprinted, Bishen Singh & Mahendra Pal Singh, Dehradun, India.
- Hoy, P.R. (1872). *Deep water fauna of Lake Michigan.* Trans.Wls. Acad. Sci. Arts Let., **1:** 98-101.
- Huang, Z. (2001). Impact of Aswan high dam on the ecology and environment. *Journal of Resources and Environment in the Yangtze Basin.* 10(1): 82-88.
- Hughes, D.A and Mallory, S.J.L. (2008). Including environmental flow requirements as part of real-time water resource management. *River Res Appl.* 24: 852–861.
- Hughes, R. M. and Noss, R. F. (1992). Biological diversity and biological integrity: current concerns for lakes and streams. *Fisheries*. 17:11–19.
- Hupp, C. R. & Osterkamp, W. R. (1985). Bottom land vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology*. 66: 670–681.
- Hurter, E. (1928). Beobachtunger an den Litoralalgen des Vierwaldstattersses. *Milt. Naturforsch. Geo. Luzern.* 10: 142-400.

- Hussainy, S. U. (1967). Studies on limnology and primary production of a tropical lake. *Hydrobiologia*. 30: 335–352.
- Hustedt, F. (1922). Die Bacillariaceen-Vegetation des Lunzer Seengebietes. *Int. Rev. Geramten Hydrobiol*. 10: 40-74.
- Hutchinson, G.E. (1957). *A Treatise on Limnology*: Geography, Physics and chemistry, Vol. **I,** John Wiley & Sons Inc., New York, USA. pp.1016.
- Hutchinson, G.E. (1967). *A Treatise on Limnology*: An Introduction to Lake Biology and the Limnoplankton. Vol. **2**. New York: John Wiley & Sons Inc., .pp.115.
- Hynes, H. B. N. (1970). *The ecology of running waters*. Liverpool: Liverpool University Press. pp.555.
- Hynes, H. B. N. (1975). The stream and its valley. Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie 19:1-15.
- Hynes, H.B.N. (1961). The invertebrate fauna of a Welsh Mountain Stream. Arch. *Hydrobiol.* 57: 344-388.
- Ib `a˜nez, C., Prat, N., and Canicio, A. (1996). Changes in the Hydrology and Sediment Transport Produced by Large Dams on the Lower Ebro River and its Estuary. *Regulated Rivers: Research & Management*. 12: 51–62.
- Iken, K., Brey, T., Wand, U., Voigt, J. and Junghans, P. (2001). Food web structure of the benthic community at the Porcupine Abyssal Plain (NE Atlantic): a stable isotope analysis. *Progress in Oceanography*. 50 (1–4): 383–405.

- Ing´enieur ISIM sciences et technologies de leau (2002). Etude dIndices Biologiques: comparaison et am´elioration de l´echantillonnage. 48.
- Islam, M. F., & Islam, S. (1996). Surface water quality of water bodies of chalan beel area in Nator district, Bangladesh. *Journal Bulletin of Environmental Science.* 14: 1–3.
- Jähnig, S.C. and Lorenz, A.W. (2008). Substrate-specific macroinvertebrate diversity patterns following stream restoration. *Aquat. Sci*. 70: 292-303.
- Jain, S. K. and Rao, R. R. (1976). A hand book of field and Herbarium methods.New Delhi: Today & Tomorrow Printers & Publishers.
- Jain, S.M., Sharma, M. And Thakur, R. (1996). Seasonal variation in physico-chemical parameters of Halali reservoir of Vidisha.
- Jameel, A. A. (1998). Physico-chemical studies in Uyyakondan, C. water of river Cauvery. *Pollution Research.* 17(2): 111–114.
- Janáč, M., Jurajda P., Prášek, V. & Kružíková L. (2013). Entrainment and damage of young-of-the-year fish by the power station on the dyje river, Czech Republic. *Journal of Hydrology*. 12(5): 218-221.
- Janauer, G. and Dokulil, M. (2006). Biological Monitoring of Rivers. Edited by G. Ziglio, M. Siligardi and G. Flaim, John Wiley & Sons, Ltd.
- Järvekülg, R. (2016). Hydropower and the fish fauna on Estonian Rivers. Symposium on Hydropower, Flood control and water abstraction: Implications for Fish and Fisheries. Mondsee, Austria, 14-17 June 2016.

- Jeelani and Kaur (2012). Ecological understanding of Anchar, lake, Kashmir. *Bionano Frontier*. 5(2): 57-61.
- Jhingran, A. G. (1991). Fish in relation to water quality paper. *Presented at* Indo-Dutch Meet. *On* Biomon, Yard Dev. New Delhi.
- Jhingran, A. G. (1991b). Challenging frontiers in freshwater fisheries in India. In B. Gopal & V. Asthana (Eds.), *Aquatic sciences in India*. New Delhi: Indian Association for Limnology and Oceanography.
- Jhingran, A. G. and V. Pathak. (1988). Impact on man-induced environmental modifications on productivity potential and energy dynamics of river Ganga. *Journal of Inland Fisheries Society of India*. 20: 43- 53.
- Jhingran, V. G. and Chakroborty, R. D. (1958). Destruction of major carp fingerlings in a section of River Ganga and its probable adverse effects on fish production. *Indian J. Fish.* 5(2): 291-299.
- Jhingran, V. G. and Tripathi, S. D. (1976). Naional perspective of inland fisheries of India. Proc. 17th session of Indo-Pacific Fisheries Council at Colombo, Srilanka, FAO, Bangkok. 3: 42-58.
- Jimmie P., Mark S. C., Jay W., and Robert G. (1998). An ecological investigation of the Ichthyofauna in the Deep Fork River, Central Oklahoma: 1976 to 1996. *Proc. Okla. Acad. Sci.* 78: 67-110.

- Jindal, R., & Kumar, R. (1993). Limnology of a freshwater pond of Nalagarh. I. Physico-chemical complexes. In N. K. Shastree (Ed.). *Advances in Limnology* (pp. 107–112). Delhi: Narendra Publishing House.
- Johnson, R.K., Wiederholm, T. and Eriksson, L. (1993). Classification of littoral macroinvertebrate communities of Swedish reference lakes. *Int. Verh. Ver. Limnol.*, **25:** 512-517.
- Jolly, V. H., & Chapman, V. A. (1966). A preliminary biological study of the effects of pollution on farmers Creek and Cox's river, New South Wales. *Hydrobiologia.* 27: 160–187.
- Jones and Stokes Associates (1989). Downstream effects of hydroelectric development on riparian vegetation: a joint PG&E /SCE research project. Sacramento: Jones and Stokes Associates.
- Jones, F.C. (2008). Taxonomic sufficiency: the influence of taxonomic resolution on freshwater bioassessments using benthic macroinvertebrates. *Environ. Rev.*, **16:** 45-69.
- Jordaan J. M. (1995). Fresh Surface Water – Vol. III - The Uses of River Water and Impacts.
- Josefson, A.B. and Conley, D.J. (1997). Benthic response to a pelagic front. *Mar. Ecol. Prog. Ser*. 147: 49–62.
- Joseph R. and P. P. Tessy (2010). Water quality and pollution status of Chalakudy River at Kathikudam, Thrissur District, Kerala, India. *Nature Environment and pollution Technology*. 9 (1): 113-118.

- Josson, B. (1991). A C14 incubation technique for measuring microphytobenthic primary productivity in intact sediment crores. *Limnol. Oceanogra*. 36 (7): 1485-1499.
- Jowett, I.G. (1997). Instream flow methods: a comparison of approaches. *Regul Rivers Res Manag.* 13: 115–127.
- Jowett, I.G., Hayes, J.W, and Duncan, M.J. (2008). A guide to instream habitat survey methods and analysis. NIWA Science and Technology Series, No. 54
- Juahir, H., Zain, S. M., Yusoff, M. K., Hanidza, T. I. T., Armi, A. S. M., Toriman, M. E and Mokhtar, M. (2011). Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental Monitoring and Assessment*. 173: 625-641.
- Juday, C. (1922). Quantitative studies of the bottom fauna in the deeper waters of Lake Mendota. *Trans. Wis. Acad. Sci. Arts, Let*. 20: 461-493.
- Julian, J.P., Seegert, S.Z., Powers, S.M., Stanley, E.H. and Doyle, M.W. (2011). Light as a first-order control on ecosystem structure in a temperate stream. *Ecohydrology*. 4: 422–432.
- Junk, W. J., Bayley, P. B. and Sparks R. E. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences*. 106: 110–127.
- Junk, W. O. (1973). Limnological Studies in Bung Boraped, A Reservoir in Central Thailand. Progressive Report. West Germany: Max-Plank Inst. For Limnology. p.245.

- Jüttner, I., Rothfritz, H. and Ormerod, S.J. (1996). Diatoms as indicators of river quality in the Nepalese Middle Hills with consideration of the effects of habitat-specific sampling. *Freshwat. Biol*. 36: 475-486.
- Kaczkowski, Z., Frankiewicz, P., Malgorzata, Ł. & Zalewski, M. (2017). Assessing and restoring good ecological status in impounded water courses – grabia river (Poland) perspective. *Journal of Environment and Ecology.* 32(1): 169-173.
- Kajak, Z. (1979). *Eutrofication of Lakes, WYD*. Nauk. PWN, Warszawa, (In polish), 233pp.
- Kajak, Z. (1980). Influence of phosphorus loads and of some limnological processes on the purity of lake water. *Hydrobiologiic*. 72: 43-50.
- Kajak, Z. (1992). The River Vistula and its floodplain valley (Poland): its ecology and importance for conservation. In: *River Conservation and Management*. P. J.Boon; P. Calow and G.E.Petts (eds). Chichester: John Wiley and Sons. pp.35-50.
- Kakati, G. and Bhattacharjya, K.G. (1989).Physico-chemical properties of Deepar Beel water. *Jr. Assam Sci. Society*. 31 (3): 15 - 20.
- Kamat, N. D. (1982). Diatoms and Diatom Populations Indication. In Water Quality and Pollution. Proceeding of the workshop on Biological Indicators and Indices of Environmental Pollution, Osmania University, India. pp.77-83.
- Kannan, K. (1991). *Fundamental of Environmental Pollution*. New Delhi: S. Chand and company Ltd.

- Kanno, Y. and Vokoun, J.C. (2010). Evaluating effects of water withdrawals and impoundments on fish assemblages in southern New England streams, USA. *Fish Manag Ecol*. 17: 272–283.
- Kant, S. and Raina, A.K. (1990). Limnological studies of two ponds in Jammu. II. Physico-chemical parameters. *J. Environ. Biol*. 11: 137-144.
- Kapoor, P. (1993). Physicochemical and biological study of four rivers a Bareilly (UP). *Poll. Res.* 12(4): 122-129.
- Kar, D. & Arbhuiya, M. H. B. (2001). Ecology of aqautic macrophytes of Chatla Haor, a floodplain wetland in Cachar district of Assam. *Environment & Ecology*. 19: 231–233.
- Kar, G. K., P. C. Mishra, M. C. Dash and R. C. Das (1987). Pollution studies in river Ib. III: Plankton population and primary productivity. *Indian Journal of Environmental Health.* 29: 322-329.
- Kar, M. and Goswami, D. C.(1997). Evaluating alternative techniques for flood frequency analysis: A case study of the Kapili river, Assam. *Indian J. Geomorpho.* 2: 71-91.
- Karamchandani, S. J. and Bilosker, M. D. (1967). Survey of the fish and fisheries of the Tapti river. *Surv. Rep. Cent. Inland fish. Res. Inst., Barakpore*. 4: 29.
- Karr, J. R. (1991). Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications*. 1: 66-84.
- Karr, J. R. (1993). Protecting ecological integrity: an urgently social goal. *Yale J. Intl. Law*. 18(1): 297-306.

- Karr, J. R. and Rossano, E. M. (2001). Applying public health lessons to project river health. *Ecol. Civil Eng.* 4(1): 3-18.
- Karr, J. R.; Toth, L. A. and Dudley D. R. (1985). Fish communities of mid western rivers: a history of degradation. *BioScience*. 35: 90–95.
- Kaul V, Pandit AK (1982). Biotic factors and food chain structure in some typical wetlands of Kashmir. *Pollut. Res.* 1(1-2): 49-54.
- Kaul, V. (1977). Limnological survey of Kashmir lakes with reference to trophic status and conservation. *Indian Journal Ecology and Environmental Sciences*. 3: 29–44.
- Kaul, V., Fotedar, D. N., Pandit, A. K., & Trisal, C. L. (1978). A Comparative study and plankton populations of some typical freshwater bodies of Jammu and Kashmir state. In D. N. Sen & R. P. Bansal (Eds.), *Environmental physiology and ecology of plants*. Dehra Dun: B. Singh, M. Pal Singh.
- Kaur, H., Dhillon, S. S., Bath, K. S., & Mander, G. (1996a). Abiotic and biotic components of a fresh water pond of Patiala (Punjab). *Pollution Research.* 15(3): 253–256.
- Kaur, H., Syal, J., & Dhillon, S. S. (2001). Water quality index of the river Satluj. *Pollution Research*. 20(2): 199–204.
- Kaur, H., Syal, J., & Dhillon, S. S. (2003). Impact of fertilizer factory wastes on physicochemical and biological features of Satluj river. In A. Kumar (Ed.), *Aquatic ecosystems* (pp. 71–81). New Delhi: A.P.H. Publishing Corporation.

- Kaushik, B., Sharma, S., & Saxena, D. N. (1991). Ecological studies of certain polluted lentic waters of Gwalior region with reference of aquatic insect communities. In N. K. Shastree (Ed.). *Current Trends in Limnology-I* .pp. 185–200.
- Kaushik, S., Sharma, S. and Saksena, D.N. (1989). Aquatic insect population in relation to physico-chemical characteristic of Chandanpura pond, Gwalior, M.P. In: *Environmental Risk Assessment*. (Eds. V.N. Sahai, P.B. Deshmukh, T.A. Mathai and K.S. Pillai). Academy of Environmental Biology, India, 243-254.
- Keller, W., Yan, N.D., Howel, T., Molat, L.A. and Taylor, W.D. (1993). Changes in zooplankton during the experimental nutrilization and early reacidification of Bowland lake, near Sudbury, Ontario. *Canadian J. Fish. Aquat. Sci*. 49: 52-62.
- Khabade, S. A., Mule, M. B., & Sathe, S. S. (2003). Studies on physico-chemical parameters of Lodhe water reservoir from Tasgaon Tahsil (Maharashtra). In A. Kumar (Ed.), *Aquatic ecosystems* (pp. 201–206). New Delhi: A.P.H. Publishing corporation.
- Khajuria, A. (1992). *Studies on the nekton and benthos of lake Mansar*. Ph. D thesis, University of Jammu.
- Khan, A.A. and Siddiqui, A.Q. (1974). Seasonal changes in limnology of a perennial fish pond at Aligarh. *Indian J. Fish*. 21: 463-478.
- Khan, S. and Halim, M. (1987). Aquatic Angiosperms of Bangladesh. Bangladesh Agri. Res. Coun., Bangladesh.

- Khanna, D.R. and Badola, S.P. (1994). Foothill section of river Ganga – Habitat of adult mahseer. In: Nautiyal P (ed.) Mahseer the game fish. Dehradun: Jagdamba Prakashan. pp. B98-101.
- Khanna, D. R. (1993). Ecology and pollution of Ganga River (A limnological study at Haridwar). New Delhi: Ashish Publishing House.
- Khatri, S. K., & Dhankhar, R. (2003). Evaluation of sewage waste water as a source of irrigation and manure of Rohtak city of Harayana. *Pollution Research*. 22(4): 549–552.
- Kibena, J., I. Nhapi, and W. Gumindoga (2014). Assessing the relationship between water quality parameters and changes in land use patterns in the Upper Manyame River, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*. 67(69): 153–163.
- Kiernan, J.D., Moyle, P.B. and Crain, P.K. (2012). Restoring native fish assemblages to a regulated California stream using the natural flow regime concept. *Ecol Appl.* 22: 1472–1482.
- King, J. M. (1981). The distribution of invertebrate communities a small South African river. *Hydrobiologia*. 83: 43–65.
- Kingsford, R. T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Australian Ecology*. 25: 109–127.
- Klages, M., Boetius, A., Christensen, J.P., Deubel, H., Piepenburg, D., Schewe, I. and Soltwedel, T. (2004). The benthos of the Arctic seas and its role for the organic carbon cycle at the seafloor. In: *The organic carbon cycle in the Arctic Ocean.* Stein, R., MacDonald, R.W. (Eds.). *Springer–Verlag*. pp.139–167.

- Klonsky L, Vogel RM (2011).Effective measures of 'effective' discharge. *J Geol.* 119: 1–14.
- Knighton, D. (1984). *Fluvial forms and processes*. London: Edward Arnold.
- Koperski, P. (2005). Testing the suitability of leeches (*Hirudinea, Clitellata*) for biological assessment of lowland streams. *Pol. J. Ecol*. 53: 65-80.
- Koperski, P. (2009). Reduced diversity and stability of chironomid assemblages (Chironomidae, Diptera) as the effect of moderate stream degradation. *Pol. J. Ecol.* 57: 125-138.
- Koto-te niwa, N., S. Mutonkole, and M. Tshitenge (2014). Analysis of Structure and Composition of Macro-Invertebrate Assemblages in Natural Lukaya River Stream. *Journal of Advanced Botany and Zoology*. 1(4): 2348– 7313.
- Kottelat, M. and Whitten, A. J. (1996). Freshwater biodiversity in Asia, with special reference to fish. World Bank Technical Paper No. 343, Washington D.C., i-ix: 1-59.
- Kotze, P.J., Ross, M.J., Deacon, A.R. & Niehaus, B.H. (2017). The use of a portable fishway to test the swimming ability of migrating fish in rivers. *Journal of Environment and Ecology*. 32(1): 241-248.
- Krebs, C. J. (1999). Ecological methodology. New York, USA: A. Wesley Longman.
- Krecker, F. H. (1939). A comparative study of the animal population of certain submerged aquatic plants. *Ecology*. 20: 553–562.
- Kreger, C. (2002). Water quality control and assessment, centre for education technologies. USA: Wheeling Jesuit University. Website report published, May 5, 2002.

- Kroes, M., Wanningen H., Vriese, T., Ordeix M. & Roura M. (2016). From sea to source: manual of fish migration in Europe. *Hydrological Science*. 128(5): 1510-1515.
- Kubečka, J., Draštík, V., Jůza, T. & Jarolím, O. (2013). Patterns of distribution and species composition of fry communities in reservoirs under different level of hydropower effects. *Journal of Hydrology*. 12(5): 45-49
- Kumar, A. (1995a). Some limnological aspects of freshwater tropical wetland of Santhal Pargana (Bihar) India. *Journal of Environment and Pollution*. 2(3): 137–141.
- Kumar, A. (1995b). Studies on pollution in river Mayurakshi in South Bihar. *Indian Journal of Environment and Pollution*. 2(1): 21–26.
- Kumar, A. (1996a). Comparative studies on diel variations of abiotic factors in lentic and lotic fresh water ecosystems of Santhal Parganas (Bihar). *Indian Journal of Environment and Pollution*. 3(1): 53–56.
- Kumar, A. (1996b). Impact of organic pollution on macro-zoobenthos of the river Mayurakshi of Bihar. *Pollution Research*. 15(1): 85–88.
- Kumar, B. A., Choudhury, A., & Mitra, A. (2003). Seasonal distribution of nutrients its biological importance in upper stretch of Gangetic West Bengal. In A. Kumar (Ed.), *Aquatic ecosystems* (pp. 29–36). New Delhi: A.P.H. Publishing Corporation.
- Kutti, T., Ervik, A., Kupka Hansen, P. (2007). Effects of organic effluents from a salmon farm on a fjord system. I. Vertical export and dispersal processes. *Aquaculture* 262: 359–373.

- Lamb, E.G., Bayne, E.M., Holloway, G., Schieck, J., Boutin, S., Herbers, J. and Haughland, D.H. (2009). Indices for monitoring biodiversity change: Are some more effective than others? *Ecol. Indic*. 9: 432-444.
- Lambrakis, N., Antonakos, A and Panagopoulos, G. (2004). The use of multicomponent statistical analysis in hydrogeological environmental research. *Water Research*. 38: 1862-1872.
- Landau, M. (1992). Introduction to Aquaculture. New York:John Willay and sons, Inc.
- Larson, D.W. (1972) .Temperture, Transparency and phytoplankton productivity in Crater lake Oregon. *Limnol. Oceanogr*. 17: 410- 417.
- Learner, M. A., Williams, R., Harcup, M. and Hughes, B. D (1971).A survey of the macro-fauna of the River Cynon, a polluted tributary of the River Taff (South Wales). *Freshwater Biol*. 1: 336-367.
- Lee, H.W., Bailey-Brock, J.H. and Mc-Gurr, M.M. (2006). Temporal changes in the polychaete infaunal community surrounding a Hawaiian mariculture operation. *Marine Ecology Progress Series*. 307: 175–185.
- Lewis, J.R. (1986). Latitudinal trends in reproduction, recruitment and population characterstics of some rocky littoral mollusc and cirripedes. *Hydrobiologia*. 142: 1-13.
- Lewis, O.T. and Gripenberg, S. (2008). Insect seed predators and environmental change. *Journal of Applied Ecology*. 45 (6): 1593-1599.

- Li, F., Q. Cai, X. Qu, T. Tang, N. Wu, X. Fu, S. Duan, and S. C. J¨ahnig (2012). Characterizing macroinvertebrate communities across China: Large-scale implementation of a self-organizing map. *Ecological Indicators*. 23: 394–401.
- Liebmann H (1951). Handbuch der Frishwasser und Abwasserbiologie. Munich Oldenbourg.
- Ligon, F.K., Dietrich, W.E., and Trush, W.J. (1995). Downstream ecological effects of dams: a geomorphic perspective. *BioScience.* 45: 183-92.
- Lillie, R. and Budd, J. (1992): Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. *J. freshwater Ecology*. 7: 113-125.
- Li-Na, D., L. Yuan, C. Xiao-Yong, and Y. Jun-Xing (2011). Effect of eutrophication on molluscan community composition in the Lake Dianchi (China, Yunnan). *Limnologica.* 41(3): 213-219.
- Liu, C. W., Lin, K. H and Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. *Science of the Total Environment*. 313(1-3): 77-89.
- Lukatelich, R.J. and Mc Comb, A.J. (1986). Distribution and abundance of benthic microalgae in a shallow south western Australian estuarine system. *Marine Ecological Progress*. *Series*. 27: 287-297.
- Love, G. J., & Godwin, M. H. (1959). The effects of natural winter temperatures on the development of Anopheles quadrimaculatus in South-Western Georgia. *Ecology*. 40(2): 198–205.

- Lovejoy, T. E. (1995). The quantification of biodiversity- an esoteric quest or a vital component of sustainable development. *In* Biodiversity measurement and estimation (D. L. Hawksworth, ed.). London: Chapman and Hall, and the Royal Society. pp.81–87.
- Lowe-McConnel, R. H. (1987). Ecological studies of tropical fish communities. London: Cambridge University Press. p.381.
- Lu, X. X. and Siew R. Y. (2005). Water discharge and sediment flux changes in the Lower Mekong River. *Hydrol. Earth Syst. Sci. Discuss*., 2: 2287–2325.
- Lyons, J., and P. Kanehl. (1993). A comparison of four electroshocking procedures for assessing the abundance of smallmouth bass in Wisconsin streams. U. S. Department of Agriculture, Forest Service, General Technical Report NC-159, St. Paul, Minnesota.
- Lytle DA, Poff NL (2004). Adaptation to natural flow regimes. Trends Ecol Evol 19:94–100.
- Ma, Z., X. Song, R. Wan, L. Gao, and D. Jiang (2014). Artificial neural network modeling of the water quality in intensive *Litopenaeus vannamei* shrimp tanks. *Aquaculture*. 433: 307–312.
- Macan, T. T. (1963). *Freshwater ecology* London: Longmans Green and Co. Ltd. p. 1338.
- Mackay, N. J. M. and Shafron, M. (1989). Water quality. Proc. Workshop on native fish management. Murrey –Darling Basin Commission, Canberra. pp.137-147.
- Macro-invertebrates in the catchment streams of Lake Naivasha, Kenya. *Revue d'Hydrobiologie Tropicale*. 21(2): 127–134.

- Majumder S, Dutta TK (2014). Studies on seasonal variations in physic-chemical parameters in Bankura segment of the Dwarakeshwar River (W.111B) India. *IJAR*. 2(3): 877-881.
- Malik, R. N and Nadeem, M. (2011). Spatial and temporal characterization of trace elements and nutrients in the Rawal Lake Reservoir, Pakistan, using multivariate analysis techniques. *Environmental Geochemistry and Health*. doi:10.1007/s10653- 010-9369-8.
- Mandal, B. K., & Moitra, S. K. (1975). Seasonal variations of benthos and bottom soil edaphic factors in a freshwater fish pond at Burdwan, West Bengal. *Tropical Ecology*. 16: 43–48.
- Mandaville, S. M. (2002). Benthic Macroinvertebrates in Freshwater – Taxa Tolerance Values, Metrics and Protocols, Project H-1. (Nova Scotia: Soil & Water Conservation Society of Metro Halifax).
- Mansiangi, P. (1999). Evaluation biologique de la qualit´e de leau par lutilisation des macroinvertbrs benthiques: cas de la rivi`ere Kemi.
- Mare, M.F. (1942). A study of marine benthic community with special refrences to the micro-organisms. *J. Mar. Biol. Ass. U.K*. 25: 517-554.
- Mathooko, J. M. (2002). The sizes, maturity stages and biomass of mayfly assemblages colonizing disturbed streambed patches in Central Kenya. *African Journal of Ecology*. 40(1): 84–93.

- Mathuthu, A. S., Zaranyika, F. M., & Jannalagadde, S. B. (1993). Monitoring of water quality in upper Kukuvisi river in Harare, Zimbabwe. *Environment International*. 19(1): 51–61.
- Matthews R, Richter BD (2007). Application of the indicators of hydrologic alteration software in environmental flow setting. *J Am Water Resour Assoc.* 43: 1400–1413.
- Mazhar, M. D and Kapoor, C. P. (1992). Limnological studies on Dornia River at Barielly (U.P), *J. Freshwater Biol.* 4(2): 155-158.
- Mbadu, Z. (2002). Le bassin versant de la rivi`ere Lukunga, impacts de son utilization sur son environment.
- McAllister, D. E.; Hamilton, A. L. & Harvey, B. (1997). Global freshwater biodiversity: Striving for the integrity of freshwater ecosystems. *Sea Wind.* 11(3): 1-140.
- Mehdi M.D, Bhat F.A, and Yousuf A.R (2005). Ecology of macrozoobenthos in Rambiara Stream, Kashmir. *J. Res. Dev.* 5: 95-100.
- Mehra, N. K. (1986). Studies of primary productivity in a sub-tropical comparison between experimental and periodicity values. *Indian Journal of Experimental Biology*. 24: 189–192.
- Mereta, S. T., P. Boets, L. De Meester, and P. L. Goethals (2013). Development of a multimetric index based on benthic macroinvertebrates for the assessment of natural wetlands in Southwest Ethiopia. *Ecological Indicators*. 29: 510–521.
- Mohanty, R.K. (2000). Activated microbial suspension and nitrogen control in aquaculture. *Fishing Chimes*. 20(9): 50-51.

- Michael Anderson (2006). Technical analysis of the potential water quality impacts of the leaps project on Lake Elsinore. *Analysis of the Potential Water Quality Impacts of LEAPS*. pp.01-30.
- Michael, R. G. (1969). Seasonal trends in physico-chemical factors and plankton of a freshwater fish pond and their role in fish culture. *Hydrobiologia*. 33(1): 144–160.
- Michael, R. G. (1980). A historical resume of Indian limnology. *Hydrobiol.*, 72:15-20.
- Micheal K. S. (1992). *Fish Medicine.* W.B Saunders Company. pp.881.
- Mishra, K. K. (1988). Nutrient management in fresh water lakes. *I.J.E.P.* 9(5): 358–361.
- Mitchell, B. and Gardiner, J. (eds) (1983): *River basin management:* Canadian experiences. Department of Geography, University of Waterloo, Ontario.
- Mitra, A. K. (1982). Chemical characteristics of surface waters at selected sampling station in the river Godavari, Krisna and Tungabhadra. *Indian J. Env. Hlth.* 24 (2): 165-179.
- Moss, B. (1980). *Ecology of Fresh waters*. Oxford: Blackwell Scientific Pub., p.332.
- Mubashir, J., Kaur, H. and Kumar,R. (2008). Impact of climate warming on the biodiversity of freshwater ecosystem of Kashmir, India. *Proceedings of Taal 2007.* 1103-1109.
- Muxika, I., Borja, A. and Bonne, W. (2005). The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. *Ecological Indicators.* 5: 19-31.
- Naeem, S., and Li, S.(1997). Biodiversity enhances ecosystem reliability. *Nature*. 390: 507-509.

- Naiman, R. J., Elliott, S. R., Helfield, J. M. and O"Keefe, T. C. (2000). Biophysical interactions and the structure and dynamics of riverine ecosystems: The importance of biotic feedbacks. *Hydrobiologia*. 410: 79-86.
- Naz, M. and Turkmen, M. (2005). Phytoplankton Biomass and species composition of lake Golbasi (Hatay-Turkey). *Turk. J. Biol*. 29: 49-56.
- Ndaruga, A. M., Ndiritu, G. G., Gichuki, N. N. and Wamicha W. (2004). Impact of water quality on macroinvertebrate assemblages along a tropical stream in Kenya. *African Journal of Ecology*. 42(3): 208–216.
- Needham, J. G., & Llyod, J. J. (1916). The life in inland waters. New York: The Comstock Publishing Company.
- Needham, J.C., Galtsoff, P.S., Welch, P.S. and Lutz, F.E. (1959). *Culture methods for Invertebrate animals.* S-526- Dover Press. pp.101.
- Nunes, A.J.P., Gesteira, T.C.V. and Goddard, S. (1997). Food ingestion and assimilation by the Southern brown shrimp *Penaeus subtilis* under semi-intensive culture in NE Brazil. *Aquaculture*. 149: 121– 136.
- Negash, A., D. Eshete, and V. Jacobus (2011). Assessment of the Ecological status and threats of Welala and Shesher Wetlands, Lake Tana Sub-Basin (Ethiopia). *Journal of Water Resource and Protection*. 3(7): 540–547.
- Negishi JN, Sagawa S, Kayaba Y, Sanada S, Kume M, Miyashita T (2012). Mussel responses to flood pulse frequency: the importance of local habitat. *Freshw Biol*. 57: 1500–1511.

- Nema P., Rajgopalan S. and Mehta C.G. (1984). Quality and treatment of Sabarmati river water Ahmedabad. *JIWWA*. 16(I): 99-107.
- Newberry, R. (1995). Rivers and the art of stream restoration. Natural and anthropogenic influences in fluvial geomorphology: *Geophysical Monograph*. 89: 137-149.
- Odum, E.P (1971). Fundamental of Ecology. W.B. Sunders. Tokyo, Japan:Toppan Co. Ltd.
- Olden, J.D. and Naiman, R.J. (2010). Incorporating thermal regimes into environmental flow assessments. *Freshw Biol*. 55:86–107.
- Olsen, N. R. B. (1999). Two-dimensional numerical modeling of flushing processes in water reservoirs. *Journal of Hydraulic Research*. 37(1): 3–16.
- Olsen, S. (1950). Aquatic plants and hydrosheric factors-I. Aquatic plants in Swjutland, Denmark. *Svensk Botanisk Tidskrift*. 44: 1-34.
- Oosting, H. J. (1965): The Study of Plant Communities (2nd eds), W. H. Freemand, San Francisco, p.480.
- Ordner, M.T., Lawrence, A.L. (1987). Importance of polychaetes to penaeid prawn culture. *J. World Aquac. Soc*. (Aquaculture Communique´s). 18: 36A– 37A.
- Pathak, S.K. and Mudgal, L.K. (2002). A prerliminary survey of zooplankton of Virla Reservoir of Khargone (Madhya Pradesh), India. *Indian J. Environ. & Ecoplan*. 6: 267-300.
- Pennak, R.W. (1978). *Freshwater invertebrates of United States*. 2nd Ed. New York: Johan Wiley and Sons Inc.,. pp.803.

- Perus, J., Ba¨ck, S., Lax, H.G., Westberg, V., Kauppila, P. and Bonsdorff, E. (2004). Coastal marine zoobenthos as an ecological quality element: a test of environmental typology and Europeaan Water Framework Directive. *Coastline Reports.* 4: 27–38.
- Pal, Ruma,J Chatterjee, P. and Das, T.M. (1992). Algological evaluation of organic pollution level of Hugli estuary, West Bengal, India. *Phykos*. 31 (1 and 2): 69- 75.
- Palharya, J. P., Siriah, V.K., and Malvia Shobha (1993). Environmental impact of sewage and effluent disposal on the river system. Ashish Publishing House. pp.01-791.
- Palharya, J.P., & Malviya, S. (1988). Pollution of Narmada river at Hoshangabad in M.P. and suggested measure for control. In R. K. Trivedy (Ed.). *Ecology and pollution of Indian rivers* . New Delhi: Asian Publishing House. pp. 55–85
- Pandey. J., U Pandey and H.R. Tyagi (1999). The relation of algal productivity to the nature of physicochemical environment of a fresh water tropical lake. *Ecol. Env. And Cons.* 5(4): 365-368.
- Pandit, A. K. (1980). Biotic factors and food chain structure in some typcial wetlands of Kashmir. Ph.D. thesis. Srinagar: Kashmir University.
- Pani S.and Misra, S.M. (2000). Biodiversity and trophic status of two tropical lakes of Bhopal. *Proc. of Nat. Sem.* 247-255.
- Parvati, K. (2013). Study of physico-chemical and biological analysis of drinking water of Dindori town with special reference to quality status. Ph. D. thesis. Rewa (M.P.): A.P.S. University.

- Parveen, M., Shafi Bhat, M. and Haq, S. (2013). Studies on physico-chemical characteristics of Dal lake, Srinagar Kashmir. *International Journal of Current Research*. 5(6): 1352-1354.
- Patel, A. C. and R. S. Patel (2013). Comparison of the physicochemical parameters of two lakes at Lodra and Soja under biotic stress. *International Journal of Innovative Research in Science, Engineering and Technology*. 2(5): 1860-1864.
- Pathak, V., Sarkar, A., Mahavar, L. R. and Bhattacharjya, B. K. (2001). Ecological status and fish production potential of Siang, Dibang and Lohit-the three forerunners of river Brahmaputra. *J. Inland fish. Soc. India*. 33(2): 23-28.
- Patra, A. K. (1985). Studies on the primary production of river Mahanadi at Sambalpur. Proceedings of National Academy of Science India. (B) IV: 290-295.

Patra, A. K., & Nayak, L. D. (1982) Limnobiotic survey of river Mahanadi during winter. *Geobios New Reports.* 1(1): 20–23.

Patrick, M.S., Jean-Marie ,T.M.,and Nadine, M. L. (2015). Benthic Macroinvertebrates as Indicators of Water Quality: A Case-study of Urban Fauna Stream (in Kinshasa, Democratic Republic of Congo). *Open Journal of Water Pollution and Treatment.* 2(1): 8-24

- Pavlov, D. S. and Vilenkin, B. Y. (1989). The present state of the environment, biota and fisheries of the Volga River. In: International Large River Symposium (LARS). D.P.Dodge(ed) Can. Spl. Publ.; *Fish. Aquat. Sci.*,160: 504-514.
- Pennak, R. W. (1978). *Freshwater invertebrates of the U.S. 2nd*, New York: Wiley.
- Peterson, J.T., Wisniewski, J.M., Shea, C.P. and Jackson, C.R. (2011). Estimation of mussel population response to hydrologic alteration in a southeastern U.S. stream. *Environ Manag*. 48: 109–122.
- Peterson, G. S.,Johnson, L. B., Axler, R. P. and Diamond, S. A. (2002). Assessment of the risk of solar ultraviolet radiation to amphibians. II. In situ characterization of exposure in amphibian habitats. *Environmental Science & Technology.* 36: 2859-2865.
- Peterson, N. P., and Cederholm, C. J. (1984). A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in small stream. *North American Journal of Fisheries Management*. 4: 99-102.
- Piepenburg, D., Ambrose Jr., W.G., Brandt, A., Renaud, P.E., Ahrens, M.J. and Jensen, P. (1997). Benthic community patterns reflect water column process in the Northeast Water Polynya (Greenland). *J. Mar. Syst*. 10: 476–482.
- Pillai, N. G. (1977). Distribution and seasonal abundance of macrobenthos of Cochin backwaters, Cochin. *Indian J. Mar. Sci*., **6:** 1-5.
- Porrello, S., Tomassetti, P., Manzueto, L., Finoia, M.G., Persia, E., Mercatali, I. and Stipa, P. (2005). The influence of marine cages on the sediment chemistry in the Western Mediterranean Sea. *Aquaculture*. 249: 145–158.

- Prabadevi, L. (1994). Ecology of Coleroon Estuary: Studies on Benthic fauna. Thiruvananthapuram. *J. Mar. Biol. Ass. India*. 36 (1-2): 260-266.
- Puente, A., Juanes, J.A., Garcıa, A., Alvarez, C., Revilla, J.A. and Carranza, I. (2008). Ecological assessment of soft bottom benthic communities in northern Spanish estuaries. *Ecol. Indicators*. 8: 373–388.
- Pinel-Alloul, B., G. M´ethot, L. Lapierre, and A. Willsie (1996). Macrobenthic community as a biological indicator of ecological and toxicological factors in Lake Saint-Francois (Quebec). *Environmental Pollution*. 91(1): 65–87.
- Pizzuto, J. (2002). Effects of dam removal on river form and process. *BioScience*. 52: 683-691.
- Poff N. L. and Ward J. V. (1989). Implications of stream flow variability and predictability for lotic community structure: a regional analysis of stream flow patterns, *Canadian Journal of Fisheries and Aquatic Sciences*. 46: 1805–1818.
- Poff N. L., Allen J. D., Bain M. B., Karr J. R., Prestegaard K. L., Richter B. D., Sparks R. E. and Stromberg J. C. (1997). *The natural flow regime: a paradigm for river*, conservation and restoration. *Bioscience*. 47: 769–784.
- Prasad, D. Y. (1990). Primary Productivity and Energy Flow in Upper Lake, Bhopal. *Indian J. Environ Health*. 32(2): 132-139.
- Prasannakumari, A. A., Devi, G. T., & Sukeskumar, C. P. (2003). Surface water quality of river Neyyar_Thiruvanan tha puram, Kerala. *Pollution Research.* 22(4): 515–525.

- Qadri, M. Y., & Yousuf, A. R. (1978). Seasonal variations in the physico- chemical factors of a sub- tropical lake of Kashmir. *Journal of the Inland Fisheries Society of India.* 10(2): 89–96.
- Qadri, M. Y., & Yousuf, A. R. (1980a). Limnological studies on lake Malpur Sar I. *The Biotope. Geobios.* 7(3): 117–119.
- Qadri, M. Y., & Yousuf, A. R. (1980b). Influence of physico-chemical factors on the seasonality of cladocera in lake Manasbal. *Geobios.* 7(6): 273–276.
- Qureshi, M. R. (1976). Development and utilization of the inland fishery resources of Pakistan. Proc. 17th session of Indo-Pacific Fisheries Council at Colombo, Sri Lanka, FAO, Bangkok. 3: 112-119.
- Rabeni, C.F. and Wang, N. (2001). Bioassessment of streams using macroinvertebrates: Are the chironomidae necessary? *Environ. Monit. Assess.* 71: 177-185.
- Rafia Rashid and Ashok K. Pandit (2014). Macroinvertebrates (oligochaetes) as indicators of pollution: A review. *Journal of Ecology and the Natural Environment*. 6(4): 140-144.
- Rai, D. N., & Duttamunshi, J. S. (1979). The influence of thick floating vegetation (Eichornia cressipes) on the physico-chemical environment of a freshwater wetland. *Hydrobiologia*. 65: 65–69.
- Rai, H. (1974). Limnological studies on the Yamuna at Delhi, India. Part 2. The dynamics of potamoplankton populations in the river Yamuna. *Arch. Hydrbiol*. 73: 492-517.
- Rajyalashmi, T. and T. V. Premswarup (1975). Primary productivity in river Godavari. *Indian Journal of Fisheries*. 22: 205-214.

- Ralf C. M. Verdonschot. Jochem Kail, Brendan G. McKie. Piet F. M. Verdonschot (2016).The role of benthic microhabitats in determining the effects of hydromorphological river restoration on macroinvertebrates. *Hydrobiologia*. 769: 55–66.
- Ramakrishnaiah, M., & Sarkar, S. K. (1982). Plankton productivity in relation to certain hydrobiological factors in Konar reservoir (Bihar). *Journal of the Inland Fisheries Society of India*. 14(1): 58–68.
- Ramakrishnaiah, M., & Sarkar, S. K. (1986). Plankton productivity in relation to certain hydrobiological factors in Konar reservoir (India). *Journal of the Inland Fisheries Society of India*. 14(1): 58–68.
- Ramarao, S. V., V. P. Singh and L. P. Mall (1979). The effect of sewage and industrial waste discharges on the primary production of a shallow turbulent river. *Water Research*. 13: 1017-1021.
- Rao V. V. R. (2006). Hydropower in the North East: Potential and harnessing strategy framework Study on Natural Resources, Water and the Environment Nexus for Development and Growth in Northeast India., draft for discussion: Background paper no 6.
- Rao, K. K. C., Rao, N. K., Rao, P. L. K. M., & Rao, S. C. (1991). Studies on groundwater quality in the industrial areas in and around Hyderabad, A. P., India (Part-II). *Pollution Research*. 10(2): 75–91.

- Rawson, D. A. (1939b). Physical and chemical studies. Plankton and bottom fauna of Okanagan lake, B.C. in 1935 with appended data from adjacent smaller lakes *Bull*. *Journal of Fisheries Research Board of Canada*. 56: 3–70.
- Rawson, D.S. (1930) .The bottom fauna of Lake Simcoe and its role in the ecology of the Lake. Univ. Toronto Stud. Pub. *Ont. Fish. Res. Lab*. 40: 1-183.
- Reid, G.H. (1961) –.*Ecology of Inland Waters and Estuaries*. New York: Reinhold Publishing Crop.,. pp.378.
- Rea, N., and Ganf, G. G. (1994). The role of sexual reproduction and water regime in shaping the distribution patterns of clonal emergent aquatic plants. Australian *Journal of Marine and Freshwater Research*. 45: 1469–1479.
- Reed, P. B. (1997). *Revision of the National List of Plant Species that Occur in Wetlands*. U.S. Department of Interior, U.S. Fish and Wildlife Service, Washington D.C. 209 p. 186.
- Reid, G. K. (1961). *Ecology of inland water and estuaries*. New York: Reinhold Publishing Corporation. p. 375
- Resende, P. C., P. Resende, M. Pardal, S. Almeida, and U. Azeiteiro (2010). Use of biological indicators to assess water quality of the Ul River (Portugal). *Environmental Monitoring and Assessment*. 170(1-4): 535–544.
- Resh V.H. (1995). Fresh water macroinvertebrates and rapid assessment procedure for quality of water monitoring in developing and newly industrialized countries. In *Bilogical Assessment and criteria* (Davis W.S., Simon, T.P. eds), Lewis Publishers, England; 167-177.

- Resh, V. H. (2008). Which group is best? Attributes of different biological assemblages used in freshwater biomonitoring programs.*Environmental Monitoring and Assessment*. 138(1): 131–138.
- Rhode, W. (1948): Environmental requirements of freshwater plankton algae. *Symbolae Botanicae Upsalienses*. 10: 1-149.
- Rhode, W. (1969). Crystillization of eutrophic concepts in Northern Europe. In: *Eutrophication: causes, consequences, correctives*. National Acad. of Sci., Washigton. D.C. pp.50-64.
- Ritzrau, W. and Thomsen, L. (1997). Spatial distribution of particle composition and microbial activity in benthic boundary layer (BBL) of the Northeast Water Polynya. *J. Mar. Syst*. 10: 415–428.
- Rice, C. H. (1938). Studies in the phytoplankton of the river Thames, I and II. *Annals of Botany*. 2: 539–581.
- Richards, C. and Minshall, G.W. (1992). Spatial and temporal trends in stream macroinvertebrate species assemblages: The influence of watershed disturbance. *Hydrobiologia.* 241: 173 – 84.
- Richter B. D., Baumgartner J. V., Powell J. and Braun D.P. (1996). A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*.10: 1163–1174.
- Ríos-Villamizar, E.A., Silva, S.R., Adeney, J.M., Junk, W.J. and Piedade, M.T.F. (2014). Physico-chemical features of major Amazonian water typologies: subsidies for the

improvement of river classification. 3rd International Conference - Water resources and wetlands. 8-10 September, 2014 Tulcea (Romania).

- Rizzo, W.M. (1990). Nutrient exchanges between the water column and a subtidal benthic microalgal community. *Estuaries*. 13: 219-226.
- Roberts, T. (1993). Just another Dammed River? Negative Impacts of Pak Mun Dam on Fishes of the Mekong Basin. *The Natural History Bulletin of the Siam Society*. 41: 105-133.
- Rokop, F.J. (1974). Reproductive patterns in deep-sea benthos. *Science*. 186: 743–745.
- Roll, H. (1939). Zur Terminologic des periphyton. *Arch. Hydrobiol*. 35: 59-69.
- Rosemond, A.D., Reice, S.R., Elwood, J.W. and Mulholland, P.J. (1992). The effects of stream acidity on benthic invertebrate communities in the south-eastern United States. *Freshwat. Ecol*. 27: 193-209.
- Rosenburg, R. (1995). Benthic marine fauna structured by hydrodynamic processes and food availability. *Neth. J. Sea Res.* 34: 303–317.
- Ruhl, H.A. and Smith, K.L. (2004). Shifts in deep-sea community structure linked to climate and food supply. *Science*. 305: 513–515.
- Ruttner, F. (1963). *Fundamentals of limnology*. University of Toronto Press, Toronto, 259 pp.
- Ruttner-Kolisco, A. (1974). Plankton rotifers: Biology and taxonomy. *Die Binnengewasser*, *Suppl.* 26: 1-146.

- Rysgaard, S., Thamdrup, B., Risgaard-Petersen, N., Fossing, H., Berg, P., Bondo, P.B. and Dalsgaard, T. (1998). Seasonal carbon and nutrient remineralization in a high-Arctic coastal marine sediment. *Mar. Ecol., Prog. Ser*. 175: 261–276.
- Rosenberg, D. M., V. H. Resh, *et al*. (1993). Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall.
- Roy, D. (2016). *Macrobrachium gangeticum* bate is on the verge of extinction due to Farakka dam in Ganga river. Symposium on Hydropower, Flood control and water abstraction: Implications for Fish and Fisheries. Mondsee, Austria, 14-17 June 2016.
- Ruttner, F. (1953). Fundamentals of Limnology. University of Toronto Press, Toronto, Ontario, Canada.
- Sabo, J.L. and Post, D.M. (2008). Quantifying periodic, stochastic, and catastrophic environmental variation. *Ecol Monogr.* 78:19–40.
- Saha, L. C., S. K. Chowdhury and N. K. Singh (1985). Factor affecting phytoplankton productivity and density in the river Ganges Bhagalpur. *Geobios*. 12: 63-65.
- Saha, T., Ghosh, P. B., & Bandyopadhyay, T. S. (2000). Waste water characteristics of some canals of Calcutta. *Journal of Environmental Research*. 10(2): 97–101.
- Sajeev, K. I. D. K. (1999). Analytical studies on the ecosystem of the Ropar headworks reservoir. Ph.D. thesis. Patiala: Punjabi University.
- Salim Aijaz Bhat *et al*. (2013):. Assessing the impact of anthropogenic activities on Spatio-Temporal variation of water quality in Anchar lake, Kashmir Himalayas. *International Journal of Environmental Sciences.* 3(5):16-38.

- Sameera, S., Yousuf, A. R., Bhat F. A. and M.Parveen (2010). The ecology of macrozoobenthos in Shallabugh wetland of Kashmir Himalaya, India. *Journal of Ecology and the Natural Environment*. 2(5): 84-91.
- Sampath, V., Sreenivasan, A. and Ananthanarayan, R. (1981): Molluscs as indicators of organic enrichment and pollution in the Cauvery River system, Proccedings of workshop, Cent. Bd. Prev. Cont. Water Pol. Hyderabad, India: Osmania University. pp.149-162.
- Sand-Jensen, K., and Madsen, T. V. (1992). Patch dynamics of the stream macrophyte, Callitriche cophocarpa. *Freshwater Biology*. 27: 277–282.
- Sarwar, S. G. (1987). Species composition and seasonal variation of periphyton on *Ceratophyllum demersum* in Waskur lake, Kashmir. *Geobios New Reports.* 6(2): 114–115.
- Sarwar, S. G. (1991a). *Trophic status of Dal lake (Kashmir)*. In Proceedings national conference on aquatic sciences in India. New Delhi.
- Sarwar, S. G. (1991b). Studies on periphyton communities of marsh lands around Srinagar. *Geobios New Report.* 10: 22–27.
- Sarwar, S. G. (1999). Water quality and periphytic algal component of Anchar lake, Kashmir. In K. Vijay Kumar (Ed.). *Freshwater ecosystem of India*. Delhi: Daya publishing House. pp. 237–250
- Sarwar, S. G., & Zutshi, D. P. (1987a). Primary productivity of periphyton. *Geobios.* 14: 127–129.

- Sarwar, S. G., & Zutshi, D. P. (1987b). Studies on periphyton population of Himalayan lake I. Species composition and community structure on natural and artificial substrates. *Proceedings of Indian National Science Academy*. 52(3): 239–243.
- Sarwar, S. G., Naqshi, A. R., & Mir, G. R. (1996). Impact of floating gardens on the limnological features of dal lake. *Pollution Research.* 15(3): 217–221.
- Sass, J. E. (1958). *Botanical Microtechnique*. The Iowa State College Press, Iowa. 228 p.
- Satomi, Y. (1976): The future of fresh water fisheries and aquacultural technology in Japan. Proc. 17th session of Indo-Pacific Fisheries Council at Colombo, Sri Lanka, FAO, Bangkok. 3:67-70.
- Satyanarayana, D., Panigrahy, P.K. and Sahu., S.D. (1994). Metal pollution in harbour and coastal sediments of Visakhapatnam, east coast of India. *Indian J. Mar. Sci*. 23: 52-54**.**
- Saunders, D.L., Meeuwig, J.J and Vincent, A.C.J. (2002). Freshwater protected areas: Strategies for Conservation. *Conservation Biology*. 16(1): 30-41.
- Sawant, R.S., Telave, A.B., Desai, P.D. and Desai, J. S. (2010). Variation IN hydrobiological characters of Atyal pond in Gadhinglaj Tahsil, Kolahpur, and Maharastra. *Nat. Env. Pollut. Tech*. 9(2): 273-278.
- Saxena, K. K. and Chauhan, R. S. (1993). Physico-chemical aspects of pollution in river Yamuna at Agra. *Poll. Res.* 12(2):101-104.
- Schwoerbel, J. (1987). *Handbook of Limnology*. Chichester, England: Ellis Hoorwood Limited Publ., p.228.

- Seenayya, G. (1971). Ecological studies in the plankton of certain fresh water ponds of Hyderabad. India. I. Physico-chemical complexes. *Hydrobiologia*. 37: 7–31.
- Shaffer, G.P. and Onuf, C.P. (1983). An analysis of factors influencing the primary production of the benthic microflora in a southern California lagoon. *Netherlands Journal of Sea Research*. 17: 126-144.
- Shafroth, P. B., Friedman, J. M., Auble, G. T., Scott, M. L. and Braatne, J. H. (2002). Potential responses of riparian vegetation to dam removal. *BioScience*. 52: 703-72.
- Shah, A. R. (1988). Physico-chemical aspects of pollution in river Jhelum (Kashmir) during 1981-83. In R. K. Trivedy (Ed.), *Ecology and pollution of Indian rivers*. New Delhi: Asian Publishing House. pp. 163–207
- Shaji, C. and Patel, R.J. (1991). Chemical, Biological evaluation of pollution in the river Sabarmati at Ahmedabad, Gujrat. *Phykos*. 30 (1&2): 91 - 100.
- Shannon, C.E. and Weaver, W. (1963). *The mathematical theory of communication*. Urbana (USA): University of Illinois Press. p.117.
- Sharma,A. and Sharma,V. (2014). Correlations between Abiotic and Biotic Variables of Stream Ban- Ganga, Katra, Reasi, (J&K). *Journal of Chemical, Biological and Physical Sciences*. 4(1): 797-803.
- Sharma N. and Yadav I. (2006). Primary productivity of Kayad Lake in Ajmer, Rajasthan. *Nature Env. And Pollut. Tech*., 5(3): 417-419.

- Sharma, P. (2015). Seasonal Variations in Physico- Chemical Properties of Narmada River in Dindori Madhya Pradesh, India. *International Journal for Research in Applied Science & Engineering Technology (IJRASET).* 3(12): 285-288.
- Sharma, H. B., Agarwal, P. K. and Prabha, S. (2000). Water quality of sewage drains entering Yamuna river, Mathura (UP). *Env. Biol.* 21(4): 375-378. 189
- Sharma, J., Parashar, A., Bagre, P. and Qayoom, I. (2015). Phytoplanktonic Diversity and Its Relation to Physico-chemical Parameters of Water at Dogarwada Ghat of River Narmada. *Current World Environment*. 10 (1): 206-214.
- Sharma, J. N., Raj Shailesh Kanakiya, Dr. S. K. Singh (2015). Limnological Study of Water Quality Parameters of Dal Lake, India. *International Journal of Innovative Research in Science, Engineering and Technology*. 4(2): 381-386.
- Sharma, S. (1986). Effect of physico-chemical factors on benthic fauna of Bhagirathi river, Garhwal Himalayas. *Indian Journal of Ecology.* 13(1): 133–137.
- Sharma, S. (1988). *Potamological studies of Morar (Kalpi) river*. Gwalior. M. Phil. thesis. Gwalior: Jiwaji University.
- Shishehchian, F., Yusoff, F.M. (1999). Composition and abundance of macrobenthos in intensive tropical marine shrimp culture ponds. *J. World Aquac. Soc*. 30: 128– 133.
- Shishehchian, F., Yusoff, F.M. and Shariff, M. (2001). The effects of commercial bacterial products on macrobenthos community in shrimp culture ponds. *Aquac. Int*. 9: 429– 436.

- Solan, M., Cardinale, B.J., Downing, A.L., Engelhardt, K.A.M., Riesink, J.L. and Srivastava, D.S. (2004). Extinction and ecosystem function in marine benthos. *Science.* 306: 1177–1180.
- Sommer, V. (1989). Nutrient status and nutrient competition of phytoplankton in a shallow hyper eutrophic lake. *Limnol. Oceanogr*. 34: 1162-1173.
- Sreenivasan, A. (1964). Limnological features and primary production in a pointed moat at Vellore, Madras State. *J. Environ. Hlth*., 6: 237-245.
- Statzner, B., Bonada, N. and Doledec, S. (2008). Predicting the abundance of European stream macroinvertebrates using biological attributes. *Oecologia.* 156: 65-73.
- Strzelec. M. and Królczyk, A. (2004). Factors affecting snail (Gastropoda) community structure in the upper course of the Warta River (Poland). *Biologia*. 59: 159-163.
- Talling, J.F. (1976). The depletion of carbon dioxide from lake water by phytoplankton. *J. Ecol*. 64: 79-121.
- Tarzwell, C.M. (1957). *Biological problems in water pollution*. U. S. Deptt. of Health Education and Welfare. P. H. S., pp.246-272.
- Teixeira, H., Salas, F., Borja, A., Neto, J.M. and Marques, J.C. (2008). A benthic perspective in assessing the ecological status of estuaries: the case of the Mondego Estuary (Portugal). *Ecol. Indicators*. 8: 404–416.
- Shivanikar, S. V., Patil, P. M., Vaidya, D. P., & Bandela, N. N. (1999). Environmental temperature fluctuation determines dissolved oxygen level in Godavari river water. *Pollution Research.* 18(4): 415–418.

- Shrestha, S and Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling and Software*. 22: 464-475.
- Shrivastava, H. N. (1962). Aquatic fauna as indicator of pollution. *Environmental Health*. 4: 106–113.
- Shukla, S. C., Kant R. and Tripathi, B. D. (1989). Ecological investigation on physico-chemical characteristics and phytoplankton productivity of river Ganga at Varanasi. *Geobios*.16: 20-27.
- Shukla, S. C., Tripathi, B. D., Kant, R., Kumari, D. and Pandey V.S. (1989). Physico-chemical characteristics of river Ganga from Mizapur in Ballila. *Indian J. Env. Health.* 31(3): 218- 227.
- Shyamsunder (1988). Monitoring the water quality of river Jhelum, Kashmir. In R. K. Trivedy (Ed.), *Ecology and pollution of Indian rivers*. New Delhi: Asian Publishing House. pp.131–161
- Sikandar, M. (1987). Ecology of river Ganga in Baranasi with special reference to pollution, unpublished Ph.D. thesis. Varanasi: BHU.
- Sikandar, M. and Tripathi, B. D. (1984). Physico-chemical characteristics of Ganga water at Varanasi, *River Ecology and Human Health* (Eds, Ambust & ripathi) National Environmental Conservation Association. pp. 53-61.
- Silva, A.T., Franco, A.C., Santos, J.M., Ferreira, M.T., Pinheiro, A.N., Melo, J.F. & Simpson, D. A. … and Koyama, T. (1998). Cyperaceae. Flora of Thailand. 6(4): 248-485.

- Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofonioub, M. … and Kouimtzis, T. (2003). Assessment of the surface water quality in Northern Greece. *Water Research*. 37(17): 4119-4124.
- Simeonova, P. and Simeonov, V. (2006). Chemometrics to evaluate the quality of water sources for human consumption. *Microchimica Acta*. 156(3-4): 315-320.
- Simeonova, P. (2007). Multivariate statistical assessment of the pollution sources along the stream of Kamchia river, Bulgaria. *Ecological Chemistry and Engineering*. 14(8): 867-874.
- Singare, P, Trivedi, M. And Mishra, R. (2011). Assessing the Physico-chemical parameters of Sediment Ecosystem of Vasai Creek at Mumbai, India. *Marine Sciences*. 1(1): 22-29.
- Singh M, Gupta KC. (2004). Physico-chemical studies of water of river Yamuna at Mathura. *Ecol. Envi. And Cons.* 10(2):193-196**.**
- Singh S. and A. Mishra (2014). Spatiotemporal analysis of the effects of forest covers on stream water quality in Western Ghats of peninsular India. *Journal of Hydrology*. 519: 214–224.
- Singh, H. R. (1988). Pollution study of upper Ganga and its tributaries, FTR submitted to the Ganga Project Directorate, Govt. of India, New Delhi.
- Singh, H. R., Nautiyal, P., Dobriyal, A. K., Pokhriyal, R. C., Negi, M., Baduni,V., Nautiyal, R., … Agarwal, N. K., Pand Gautam, A. (1994). Water quality of river Ganga (Garhwal Himalaya). *Acta hydrobiol.* 36(1): 3-15.

- Singh, J. P., & Roy, S. P. (1990). Investigations of limnological profiles of Kawar lake (Bagusarai, Bihar). In V. P. Agrawal & P. Das (Eds.), *Recent trends in limnology*. Muzzaffarnagar: Society of Biosciences. pp. 457–467
- Singh, K. P., Malik, A and Sinha, S. (2005). Water quality assessment and appointment of pollution sources of Gomti River (India) using multivariate statistical techniques: A case study. *Analytica Chimica Acta*. 538(1&2): 355-374.
- Singh, R. K. and Desai, V. R. (1980). Limnological observations on Rihand reservoir. III. Primary productivity. *J. Inland Fish Soc. Ind.* 12(2):121-125. 190.
- Sinha, A. K., Srivastava, S., Srivastava, K. N. and Pandey D. P. (1989). Water quality index of river Ganga between Shuklaganj and Kalakankar (Pratapgarh), In: *Ecology and Pollution of Indian Rivers* (eds.R.K.Trivedy). 219-246.
- Sinha, R. K. & Prasad, K. (1988). *Ganga basin reseach project. BuxarBarh*. Final technical reports. Patna: Patna Univ.
- Sirisinthuwanich, K., Sangpradub, N. and Hanjavanit, C. (2017). Impact of anthropogenic disturbance on benthic macroinvertebrate assemblages in the Phong River, Northeastern Thailand. *AACL Bioflux*. 10 (2): 421-434.
- Snedecor, G. W., and W. G. Cochran. (1991). Statistical methods, eighth edition. Ames, Iowa: Iowa State University Press.
- Sokal R. R. and F. J. Rohlf (1995). Biometry. Freeman.

- Solanki, V. R., Hussain, M. M and Raja, S. S. (2010). Water quality assessment of Lake Pandu Bodhan, Andhra Pradesh State, India. *Environmental Monitoring and Assessment*. 163: 411-419.
- Somashekar, R. K. (1984). Studies on water pollution of the river Cauveri, Physicochemical characteristics. *Intl. J. Environ. Stud.*, 23:209-216.
- Somogyi, Z., Kadar, I., Kiss, I., Jurikova, T., Szekeres, L., Balla, S., Nagy, P., … and Bakonyi, G. (2012)/. Comparative toxicity of the selenate and selenite to the potworm *Enchytraeus albidus* (Annelida: Enchytraeidae) under laboratory conditions. *European Journal of Soil Biology*. 50: 159-164.
- Stancheva, R. and Sheath, R.G. (2016). Benthic soft-bodied algae as bioindicators of stream water quality. *Knowledge and Management of Aquatic Ecosystems*. 417: 15.
- Strayer, D.L., Dudgeon, D. (2010). Freshwater biodiversity conservation: recent progress and future challenges. *J N Am Benthol Soc*. 29: 344–358.
- Subramanian, K.A., Sivaramakrishnan, K.G. (2005). Habitat and microhabitat distribution of stream insect communities of the Western Ghats. *Curr. Sci*. 89: 976-987.
- Sugunan, V. V. (1992), Biotic communities and their role in production dynamics – Benthos. In: *FAO sponsored Training Programme on Floodplain Fisheries Management.* September 1 to December 31, 1992 (Compendium editors : Yadav, Y. S. and Sugunen, V. V.).

- Sundar, S. (1988). Monitoring of water quality in a stretch of river Jhelum, Kashmir, In: Ecology and pollution of Indian rivers. (ed. Trivedy, R.K.) New Delhi: Ashish Publ. House. pp.131-162.
- Swarup, K., & Singh, S. R. (1979). Limnological studies of Suraha lake (Ballia). I. Variations in the water quality. *Journal of the Inland Fisheries Society of India*. 2(1): 22–23.
- Syal, J. (1996). Present ecological status of river Satluj in the region of Punjab. Ph.D. thesis. Patiala: Punjabi University.
- Sylvester, R. O. (1961). Nutrient content of drainage water from forested, urban and agricullural areas. *Technical report of Taft Sanitary Engineering Center*. W 61-3, 80–88.
- Yousuf, T., Mushtaq, B. and Yousuf, A. R. (2013). Comparative Account on Macrozoobenthic Communities of Three Wetlands of Kashmir Valley. *International Journal of Modern Biology and Medicine*. 4(2): 96-109.
- The Nature Conservancy (TNC) (1996). Status of aquatic invertebrates. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 38. Davis: University of California, Centers for Water and Wild land Resources. pp. 2410–2423.
- Tripathy, P.K. and Adhikary, S.P. (1990). Studies on Nandira River. *Ind. Jr. Env. Health.* 32 (4): 363 - 368.
- Trivedy, R. K., & Goel, P. K. (1986). *Chemical and biological methods for water pollution studies*. Karad: Environmental Publications.

- Trivedy, R. K., P. K. Goel & C.L.Trisal (1987). *Practical Methods in Ecology and Environmental Science.* Karad, India: Enviro Media Publication.
- Trivedy, R.K. and Goel, P.K. (1984). *Chemical and biological methods for water pollution studies.* Karad, India. pp.215.
- Tyler, J.A., Gage, J.D. and Billett, D.S.M. (1992). Reproduction and recruitment in deep-sea invertebrate populations in the NE Atlantic Ocean: a review of options. In: *Marine Eutrophication and Population Dynamics* (Eds., Colombo, G., Ferrari, I., Ceccherelli, V.U., Rossi, R., Olsen and Olsen). Fredensburg. pp. 158–178.
- Tyler, J.A., Grant, A., Pain, S.L. and Gage, J.D. (1982). Is annual reproduction in deep-sea echinoderms a response to variability in their environment? *Nature.* 300: 747–749.
- Uitto, A. and Sarvala, J. (1991). Seasonal growth of the benthic amphipods *Pontoporeia affinis* and *P. femorata* in a Baltic archipelago in relation to environmental factors. *Mar. Biol*. 111: 237–246.
- Upadhyay, N. (1998). *Physico- chemical analysis of Kaliasote dam water to evaluate its versatile potentiality including irrigation use.* Ph.D Thesis. Bhopal: Barkatullah University.
- Utz, R.M., Hilderbrand, R.H. and Boward, D.M. (2009). Identifying regional differences in threshold responses of aquatic invertebrates to land cover gradients. *Ecol. Indicat*., **9**: 556-567.
- Vashisht, H.S. and Sharma, B.K. (1975). Ecology of typical urban pond in Ambala city of the Haryana state. *Indian J. Ecol.* 2: 79-86.

- Vijaykumar, K. (1996). Rotifer fauna of Devikoppa tank, Dharwad, Karnataka, India. 14th Chapter. In: *Advances in Fish and Wildlife Ecology and Biology* (Ed. B.L. Kaul). B.L. Daya Publishing House. pp.187-192.
- Vijaykumar, K., Holkar, D. and Kaur, K. (1999). Limnological studies on Chandrampalli reservoir, Gulbarga. In: *Freshwater Ecosystems of India* (Ed. K. Vijayakumar). Delhi: Daya Publishing House. pp.59-108.
- Vaidya. S., Dhilipkumar, R., Swain, K.K., Prabhakar, V.M.and Basu, A.K. (2007). Factors influencing primary productivity in Panshet and Ujjani Reservoirs, India. *Lakes and Reservoirs: Research and Management*. 12: 203-208.
- Valarmathi, S., Azariah, J., & Govindasamy, C. (2002). Seasonal variation of physico-chemical parameters in estuarine and coastal waters samples of Madras coast, Bay of Bengal, India. *Pollution Research*. 21(2): 177–185.
- Van Ael, E., W. De Cooman, R. Blust, and L. Bervoets (2015). Use of a macroinvertebrate based biotic index to estimate critical metal concentrations for good ecological water quality. *Chemosphere*. 119: 138–144.
- Verma, S. R., & Shukla, G. R. (1969). Pollution in a perennial stream, Khala Laksar, Shaharanpur, India. *Environmental Health*. 11: 145–162.
- Vijaykumar, R., Ansari Z. A. and Palekar, A.H. (1991). Benthic fauna of Kakinada bay and back waters, east coast of India. *Indian J. of Mar. Sci*. 20: 195-199.
- Vinson, M. R. (2001): Long-term dynamics of an invertebrate assemblage downstream from a large dam. *Ecological Applications*. 113: 711-730.

- Semenchenko, V., Son, M.O., Novitski, R., Kvach Y. and Panov V. E. (2016). Checklist of non-native benthic macroinvertebrates and fish in the Dnieper River basin. *BioInvasions Records*. 5(3): 185–187.
- Vogel, R.M., Stedinger,J.R., Hooper,R.P. (2003). Discharge indices for water quality loads. Water Resour Res 39:1273.
- Waite, I.R., Herlihy, A.T., Larsen, D.P., Urquhart, N.S. and Klemm., D.J. (2004). The effects of macroinvertebrate taxonomic resolution in large landscape bioassessments: an example from the Mid-Atlantic Highlands, USA. *Freshwat. Biol.* 49: 474-489.
- Ward, E.B. (1940). A seasonal population study of pond entromostraca in the Cincinnati region. *Am. Midl. Nat*. 23: 635-691.
- Wani, M.A., Dutta, A., Wani, M.A. and Wani, U.J. (2014). Towards Conservation of World Famous Dal Lake – A Need of Hour. 1(1): 24-30.
- Wanganeo, A., Wangneo, R., & Zutshi, D. P. (1996). Limnological studies on a dimictic Himalayan Lake. In S. Nath (Ed.), *Recent advances in fish ecology limnology and eco-conservation* . Delhi. 110035: Daya Publishing House. pp. 37–54
- Weisse, T. (2003). Pelagic microbes – Protozoa and the microbial food web. In: *The lakes handbook* (P.E.O. Sullivan and C.S. Reynolds, eds.), V.I, *Blackwel* .pp.417-460.
- Welch, P.S. (1952). *Limnology*. New York: McGraw Hill Book Co. Inc., pp.538.
- Wenzhöfer, F. and Glud, R.N. (2004). Small scale spatial and temporal variability in coastal benthic O2 dynamics: effects of fauna activity. *Limnol. Oceanogr.* 49: 1471–1481.

- Webber, E.C., Bayne, D.R. and Seesock, W.C. (1989). Macroinvertebrate communities in Wheeler reservoir (Albama) tributaries after prolonged exposure to DDT contamination. *Hydrobiol.* 183: 141-155.
- Weigel, B. M. and Robertson, D. M. (2007). Identifying biotic integrity and water chemistry relations in nonwadeable rivers of Wisconsin: toward the development of nutrient criteria. *Environmental Management*. 40(4): 691–708.
- Weiler, R. R. (1988). Chemical limnology of Georgian Bay and the north channel between 1974 and 1980. *Hydrobiologia.* 163: 77–83.
- Welch, P. S. (1952). Limnology. New York: McGrew Hill Book Company, Inc.,
- Wetzel, R. G. (1983): *Limnology*. 2nd Ed. New York: Saunders College Publishing Co., pp.767.
- Wetzel, R.G. (2001). *Limnology—Lake and River Ecosystems*. San Diego: Academic Press. pp.1006.
- Wilhm, J.L. and Dorris, T.C. (1968). Bilogical parameters for quality criteria. *Bioscience.* 18: 477-81.
- Wibowo Dwi Nugroho, Setijanto, Slamet Santoso (2017). Benthic macroinvertebrate diversity as biomonitoring of organic pollutions of river ecosystems in Central Java, Indonesia. *Biodiversitas.* 18 (2): 671-676.
- Wilhm, J.L. and Dorris, T.C. (1968). Bilogical parameters for quality criteria. *Bioscience.* 18: 477-81.
- Willey, A. (1910). Note on the freshwater fisheries of Ceylon. *Spolia Zeylan*. 7: 88-106.

- William, D. D., & Feltmate, B. W. (1992). *Aquatic insects*. Oxon: C.A.B. International Walling Ford.
- Wiltshire, K.H. (1992). The influence of microphytobenthos on oxygen and nutrient fluxes between eulittoral sediments and associated water phases in the Elbe Estuary. *Proceedings of the 25th EMBS*, Colombo. Fredensborg, Denmark, pp. 63-70.
- Winner, J. M., Patrick, P. H., & Wallen, D. G. (1980). Zooplankton species diversity in lake St. Clair, Ontario, Canada. *Hydrobiologia*. 75: 57–63.
- Wollenburg, J.E. and Kuhnt, W. (2000). The response of benthic foraminifers to carbon flux and primary production in the Arctic Ocean. *Mar. Micropaleontol*. 40: 189–231.
- Word, J.Q. (1978). The infaunal trophic index. Annual Report 1978. *CoastalWater Research Project.* pp.13–39.
- Wurts, W. A. and Durborow, R. M. (1992). Interaction of pH, carbon dioxide, alkalinity and hardness in fish ponds. *Southern regional Aquaculture Center*, publication No. 464.
- Liu, X., Teubner, K. andChen, Y. (2016). Water quality characteristics of Poyang Lake, China, in response to changes in the water level. *Hydrology Research.* 47: 238-248.
- Xie, P. (2003). Three-Gorges dam: risk to ancient fish. *Science*. 302: 1149. 197
- Xu, M., Wang, Z., Duan, X. and Pan, B. (2014). Effects of pollution on macroinvertebrates and water quality bioassessment. *Hydrobiologia.* 729(1): 247–259.
- Yildiz, S. (2016). Habitat preferences of aquatic oligochaeta (annelida) species in the lake district (Turkey). *Fresenius Environmental Bulletin*. 25(10): 4362-4373.

- Yousuf A.R., Balki, M.H. Qadri, M.Y. (1986). Limnological features of a forest lake of Kashmir. *J. Zool. Soc. India*. 2: 29-42.
- Yung-Chul, J., Nan-Young, K., Sang-Hun, K., Young-Seuk, P., Dong-Soo, K. and Soon-Jin, H. (2016). Spatial distribution of benthic macroinvertebrate assemblages in relation to environmental variables in Korean Nationwide streams. *Water*. 8: 27.
- Yusop, Z., Kadir, A.A. and NoorbZ.Z. (2017). Benthic Macroinvertebrate Composition and Water Quality Status in Sungai Johor, Johor, Malaysia. *Chemical Engineering Transactions.* 56: 187-192.
- Zafar, A. R. (1955). On the periodicity and distribution of algae in certain fish ponds in vicinity of Hyderabad, India. Ph.D. thesis. Hyderabad: Osmania University.
- Zutshi, D. P and Khan, M. A. (1978). Limnological studies of Dal lake II chemical features. *Indian Journal of Ecology*. 5: 90-97.
- Zutshi, D. P, Subla, B. A, Khan, M. A and Wanganeo, A. (1980). Comparative limnology of nine lakes of Jammu and Kashmir Himalayas. *Hydrobiologia*. 72: 101-112.
- Zutshi, D. P. (1968). *Ecology of some Kashmir lakes*. Ph. D. thesis. Srinagar: J & K University.
- Zutshi, D. P., & Vass, K. K. (1971). Ecology and production of *Salvinia natans* in Kashmir. *Hydrobiologia*. 38: 303–320.
- Zutshi, D. P., & Vass, K. K. (1978). Limnological studies on Dal lake, II- Chemical features. *Indian Journal of Ecology*. 5: 90–97.

APPENDIX

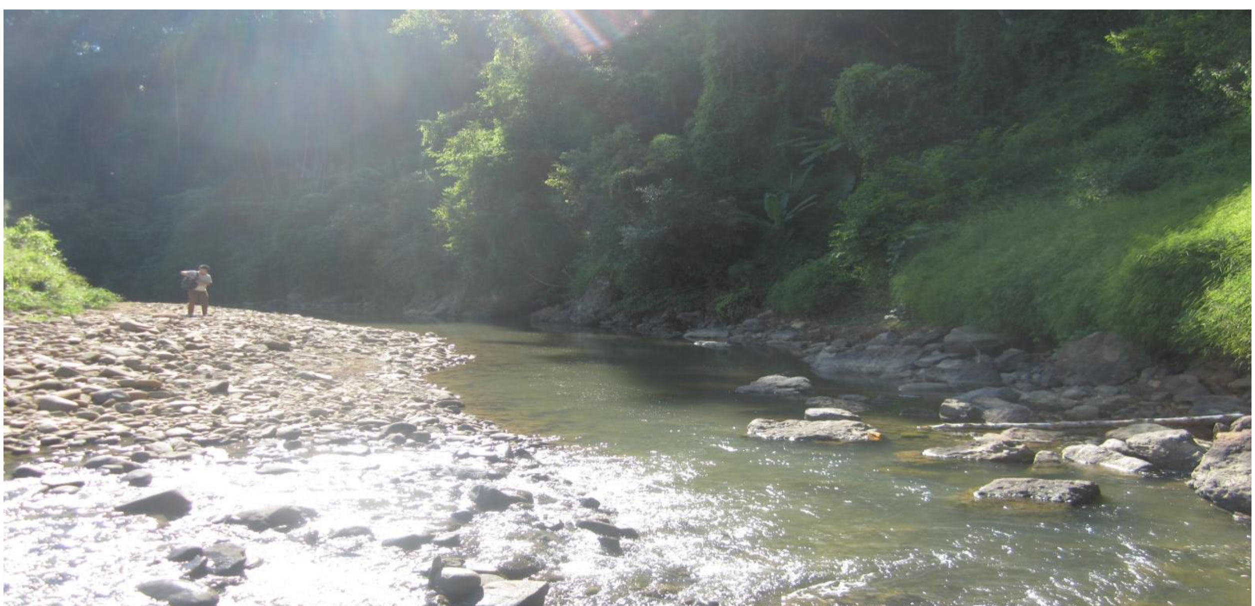
PLATE I

SITE 1: LONGMISA NOKSEN

SITE 2: LONGMISA CHUCHU

PLATE II

SITE 3: LONGKONG



SITE 4: CHANGTONGYA YAONGYIMSEN

PLATE III

SITE 5:CHANGTONGYA LONGLENG

PLATES IV

Pictorial Representation of Arthropods present at all sampling Sites

Baetidae

Caenidae

Chaoborida

Chironomini

Ephemerellidae

Heptageniidae

Leptohyphidae

Leptophlebiidae

Tanypodinae

Tricorythidae

PLATE V

Pictorial representation of some Molluscs present at all sampling Sites

Bothynidae

Corbiculidae

Lymnaeidae

Physidae

Pleuroceridae

Sphaeriidae

Unionidae

Valvatidae

Viviparidae

PLATE VI

Pictorial representation of Annelids present at all sampling Sites

Enchytraeidae

Haplotaxida

Lumbriculida

Tubificidae

PHOTO GALLERY

PHOTO GALLERY