IMPACTS OF SERLUI-B HYDEL PROJECT ON WATER QUALITY AND ECOLOGY OF MACROPHYTES OF SERLUI RIVER IN KOLASIB DISTRICT, MIZORAM

THESIS

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IN

ENVIRONMENTAL SCIENCE

By

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DECLARATION

I, **Sangeeta Sunar** hereby declare that the subject matter of this thesis entitled "**IMPACTS OF SERLUI-B HYDEL PROJECT ON WATER QUALITY AND ECOLOGY OF MACROPHYTES OF SERLUI RIVER IN KOLASIB DISTRICT, MIZORAM**" is the record of work done by me. The content of the thesis does not form basis for the award of any previous degree or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me in any other University/ Institute for any research degree.

This is being submitted to the Mizoram University for the award of the degree of Doctor of Philosophy in Environmental Science.

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CERTIFICATE

This is to certify that the Ph.D. Thesis entitled "**IMPACTS OF SERLUI-B HYDEL PROJECT ON WATER QUALITY AND ECOLOGY OF MACROPHYTES OF SERLUI RIVER IN KOLASIB DISTRICT, MIZORAM**" submitted by **Sangeeta Sunar** for the award of the degree of Doctor of Philosophy in Environmental Science of the Mizoram University, is a record of original investigation carried out by her under my supervision. The authenticity and content of the thesis are the original work of the Research Scholar, and the nature and presentation of the work are the first of its kind in Mizoram. It is further certified that no portion(s) or part(s) of the content of the thesis has been submitted for any degree in Mizoram University or other University or Institute. She has been duly registered and the thesis presented is worthy of being considered for the award of the Doctor of Philosophy in Environmental Science.

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CHAPTER 1

INTRODUCTION

1.1 WATER

1.1.1 Basic concept

Water is one of the most essential natural resources for survival and sustainability of life on earth (FAO, 1997 and Lamikanra, 1999), both physiologically and ecologically, as it acts as a medium for the survival of life, helps in regulating temperature and has many uses inclusive of domestic, industrial, commercial, transportation, recreation and hydroelectric power projects. Water covers about 71% area of the Earth's surface (CIA, 2014). Despite this fact, relatively fresh water is very trace. About 97% of the earth's water is present in the oceans and only 3% is available as fresh water. Of 3% fresh water, 69% is held in the Northern and Southern icecaps and the glaciers, 30.1% as ground water and remaining 0.9% is available as surface water in the form lakes, swamps and rivers (Gleick, 1996). Most of the fresh water supply for drinking, irrigation, power supply, sanitation and other domestic purposes are present either in the soil (aquifers), or in the bedrock fractures beneath the ground (ground water) and in the lakes, swamps and rivers (surface water). The Global distribution of earth's water is shown in Table 1.1.

1.1.2 Water Quality

Water quality refers to the physical, chemical and biological characteristics of water (Diersing and Nancy, 2009) and is measured as the quality of water relative to the necessities of organisms in general and human beings in particular (Johnson *et al.*, 1997).

Water quality is dynamic in nature and its altering parameters necessitate proper management as any alteration in the normal quality of water may affect the stability of the system (Murhekar Gopalkrushna, 2011). The physical, chemical and biological properties of a river regulate the efficacy of its water for various purposes. The quality of water is highly influenced by the natural factors (topography, geology, hydrology) and seasonal variations in runoff volumes, weather conditions and water level.

Table 1.1: Global distribution of Earth's water

Sl. No.	Water Sources	Water volume in cubic mile	Water volume in cubic km	Per cent of fresh water	Per cent of total water
1	Oceans,Seas and bays	321,000,000	1,338,000,000	--	96.5
2	Icecaps,Glaciers and Permament Snow	5,773,00	24,064,00	68.7	1.74
3	Ground water	5,614,000	23,400,000	--	1.7
	• Fresh	2,526,000	10,530,000	30.1	0.76
	• Saline	3,088,000	12,870,000	--	0.94
4	Soil Moisture	3,959	16,500	0.05	0.001
5	Ground ice and permafrost	71,970	300,000	0.86	0.022
6	Lakes	42,320	176,400	--	0.013
	• Fresh	21,830	91,000	0.26	0.007
	• Saline	20,490	85,400	--	0.006
7	Atmosphere	3,095	12,900	0.04	0.001
8	Swamps	2,752	11,470	0.03	0.0008
9	Rivers	509	2,120	0.006	0.0002
10	Biological water	269	1,120	0.003	0.0001
	Total	332,500,000	1,386,000,000	--	100

Source: Gleick, 1996

1.1.3 Rivers

River constitutes only 0.0002% of the earth's total water yet it is one of the most important sources of fresh water available for our daily use (Gleick, 1996). India receives approximately an average of 4000 billion cubic meters (BCM) of annual rainfall. Of this, about 1900 BCM flow in the country's rivers, out of this only 690 BCM is utilisable (CWC, 1997). The river ecosystems have been greatly altered physically, chemically and biologically due to the various anthropogenic activities; therefore, there is an ample need to study the human-environment interaction for the conservation and to check further degradation of the river ecosystem. Some of the major threats to the lotic ecosystems are due to the changes in land-use system, habitat alteration, changes in the hydrologic characteristics of the rivers and streams and stress of pollution (Allan and Flecker, 1993). The increased concentration of organic and inorganic substances, pesticides, metals and heavy metals, nutrients, chemicals, chlorinated solvents causes deterioration of quality of surface water, leading to adverse effects on human beings and other domesticated animals and resulting into various kinds of diseases, if such polluted water is directly used for drinking purpose without treatment (Mishra, 2008).

In India, most of the rivers are facing different degrees of threat in terms of pollution, this may be due to the rapid urbanization and industrialization, direct discharge of domestic and industrial waste water into the river systems, lack of awareness and runoff from nearby agricultural areas (seasonal phenomenon). The main sources of surface water pollution are direct discharge/disposal of untreated domestic sewage, industrial effluents, land and agricultural drainages from cities, towns and villages. The availability of fresh water resources for sustainable development is an alarming issue at global level, as the properties of water are constantly being disturbed and most of the fresh water systems are under serious environmental stress, facing a risk of crisis due to the unintended development and urbanization. As the fresh water is directly related with the social well-being of mankind, it is of vital concern. However, an extreme stress is put on these irreplaceable water assets around the globe due to rapid urbanization and developmental activities such as agricultural expansion, damming, diversion and over-exploitation, and leading to deterioration in the physical, chemical, biological and ecological characteristics of the water systems, and resulting into pollution (Binu Kumari *et al.*, 2011).

Water pollution is a major hazard to the health, economic growth, and societal affluence apart from affecting the water quality (Milovanovic, 2007). Regular monitoring and implementation of pollution control measures for the rivers are the vital issues because the river basins are extremely susceptible to the pollution due to absorption and transference of domestic, industrial and agricultural waste water (Simeonova *et al.*, 2003). The paucity of potable water is yet another major problem in many parts of the world due to population explosion and constraint water resources (UNEP, 2001). The water problem is not only limited to the quantity of water, but also to the quality of water, so it is necessary to understand the importance of water. In India, during the year 1990, the total water withdrawal was about 518 BCM or 609m^3/capita/year for all usage which is estimated to be increased to 142 BCM by the year 2050 (National Commission for Water Resources Development Plan, 1999). Hence, the assessment of the quantity and quality of water is an imperative necessity for the expansion of civilization and establishment of database, for formulating appropriate management technique.

1.1.4 Water Quality Index (WQI)

Water Quality Index has emerged as one of the important and effective mathematical tools for providing general understanding of the overall status of the water quality in the past year by converting the calculated results of outsized water quality data on various water quality attributes (pH, dissolved oxygen, nitrate-N, sulphate, phosphate-P, chloride, total hardness, TDS and other parameters) in term of single index number. The WQI summarizes the bulk of information gathered over time from expressing the data in a more understandable and logical form and thus, delivers enhanced information on the water quality trends to the policy makers and helps in the better management and conservation of water resources. The calculation of WQI is based on the view of the suitability of the water for human consumption.

The quality of water cannot be restored into its original condition by simply discontinuing the pollutant source without proper management, if once it becomes contaminated. Therefore, regular monitoring of the water quality becomes imperative to sight appropriate means for the protection and further degradation of the water resource and also to retain the conditions of an aquatic system to an optimum level. The WQI has also been accepted as one of the 25 environmental performance indicates of holistic Environmental Performance Index (EPI), it delivers a simple and brief technique for communicating the quality of water for wide-ranging usages. The EPI is centered on firm policies covering all aspects of environmental public well-being and ecosystem vitality which emphasis on climate change, quality and quantity of water, air pollution, biodiversity, land-use changes, deforestation and sustainability of agriculture and fisheries (EPI, 2010).

The importance of the WQI can easily be valued as the water asset plays critical role in the overall environment. It is a helpful tool to summarize data regarding the quality of water into a simpler and understandable form (eg. excellent, good, bad) to the general public as consumer of the water resource for comparing the water quality trends of different sources and to decision makers for ecological management, but it is not a composite analytical model for scientific and technical applications as some parameters which may play an important role in determining the water quality status are sometimes not included in WQI, therefore, the information provided by this model is scant compared to the raw data available from the practical assessment of the water quality (McClelland, 1974). However, by selecting some of the most important water quality parameters for the calculation of the WQI, it can serve as a sole indicator for the health of a water body.

1.2 Aquatic Macrophytes

1.2.1 General features

Macroscopic form of aquatic vegetation is ecologically characterized by the presence of water (fresh, brakish, saline or euthropic) and known as "Aquatic Macrophytes" (Wetzel 1983). They grow for at least a part of their cycle in water, either completely submerged or emerged (Wetzel, 1983, Muenscher, 1944). They include a vast group of macroscopic organisms ranging from vascular plants, ferns, bryophytes, spermatophytes and macro algae flourishing either permanently or periodically in the wet ecosystems (Chambers *et al*., 2008).

The aquatic macrophytes are mainly classified into four different categories, namely **Submerged**-plants that mainly grow completely under the water; **Free floating**-plants with floating leaf on water surface; **Floating leaves**-plants that are rooted at the bottom but have their leaves floating on the water surfaces; **Emergent**-plants that are rooted in the sediments and protrude at the water surface (Sculthorpe, 1985).

Macrophytes are the vital constituent of the wetland habitats. A diverse macrophytic assemblage can increase habitat heterogeneity in a wetland (Cook, 1990). They are regarded as an important food reserve for the aquatic organisms due to their high rate of biomass production. The diversity and biomass of aquatic macrophytes influence the primary productivity at a large (Wetzel, 2001), nutrient cycling and complexities of trophic levels in the aquatic ecosystem (Peakall and Burger, 2003; Kumar and Singh, 1987), and therefore, play a vibrant role in the structure, functioning (Wetzel, 2001) and framing of the aquatic environment (Jeppensen *et al.*, 1998; Dibble and Harrel, 1997). They have the aptitude to absorb excessive nutrients from the water with their effective root system and help in improving the water quality, provide physical structure and substrate for aquatic invertebrates, harbor aquatic insects that serve as a food for fishes; provide cover, nurseries, habitat and spawning grounds for fishes, amphibian, zooplanktons and other aquatic organisms; produce oxygen, and act as a link between the littoral and pelagic zones, thus, they are essential for the proper functioning and balancing of a healthy and attractive aquatic ecosystem (Mitsch and Gosselink, 2000; Heegaard *et al*., 2001).

1.2.2 Aquatic macrophytes as a weed

The majority of aquatic macrophytes are proficient to colonize a wide range of aquatic environments from tiny living ponds to streams, lakes, rivers, lagoons, reservoirs, waterfalls, wetlands, marine ecosystems, this may be due to an extensive array of limnological characteristics with extreme plasticity and adaption aptitude attained over evolutionary period (Wetzel, 1983; Esteves, 1998), which intensify their invasive potential (Santamaria, 2002) and therefore, several species of the aquatic macrophytes are considered as **"Aquatic Weeds"** as under favorable conditions they can grow profusely and cause serious infestation problem and impart nuisance in aquatic environment, thereby misbalancing the proper functioning of the aquatic ecosystem (Camargo *et al*., 2003). Some of the natural ecological processes such as native generation, hydrological and nutrient cycles, sedimentation, erosion and fire regimes are altered due to the invasion of such aquatic weeds. They also pose a threat to the threatened and endangered species by deteriorating the quality of natural habitat, resulting into critical condition for survival of desirable species (Williamson, 1996).

Surface runoff, sewage discharge, agricultural wastes and failing septic systems, as a result of rapid urbanization and increasing anthropogenic pressure are some of the major ways that contributing excess nutrients to the water system leading nutrient enrichment condition referred to as "Eutrophication" and resulting into immense growth of weeds and ultimately causing severe choking of ecosystems (Sudhira and Kumar, 2000). Eutrophication also causes deterioration of major communities and leads to loss of functionally important species from the system (Bostrom and Bonsdorff, 1997), consequently also causes a shift in the community structure (Duarte, 1995).

1.2.3 Aquatic macrophytes as a Bio-indicator

The monitoring of environmental components is an important tool for the assessment of quality of water. Bio-monitoring introduces biological variables for assessment of the structural and functional aspects of aquatic ecosystem. Cumulative effects of majority of the pollutants and the overall health of the aquatic ecosystem could be properly assessed by introducing bio-monitoring. Bio-monitoring is based on those organisms, which are most likely to provide right minimalist effects of pollutants. Bio-monitoring is the latest emerging tool for instant and accurate monitoring of water quality. It not only acts as a supplement for physico-chemical and bacteriological characteristics, but also provides precious information about the overall health of a water body (Mishra, 2008).

The aquatic macrophytes are widely used for water quality assessment and environmental monitoring, as some of the physicochemical characteristics of water such as temperature, dissolved oxygen, inorganic carbon, pH, alkalinity, light intensity, water colour, substrate physiognomies, morphology of the surface water, intra and interspecific competitions and epiphytic loads, are highly influenced by the aquatic macrophytes (Caraco and Cole, 2002; Lodge, 1991). Aquatic macrophytes are also used as a useful tool to detect the consequences of anthropogenic activities and monitor the ecological status of the aquatic system, as they reflect the influence of human impacts on the water bodies (Solak *et al*. 2012). The presence, absence or abundance of aquatic macrophytes reflect the nutrient status of the immediate surrounding or habitat (Mitsch and Gosselink, 2000; Cronk and Fennesy, 2001), as they deliberately respond to any alteration in the nutrient content of any aquatic body (Melzer, 1999). Therefore, aquatic macrophytes are extensively used as a long-term indicator for water quality or habitat characteristics. Species richness and proportion of various macrophytic plants diligently reflect the trophic status of the aquatic system such as meso-eutrophic and eutrophic water bodies considerably support more species than oligotrophic (Sculthorpe, 1967; Toivonen and Huttunen, 1995). Variation in the abundance of individual species and community composition of aquatic macrophytes deliver valuable information on how and why an ecosystem might be changing.

1.3 Hydroelectric Power Project

Hydroelectric energy is the power captured from the falling water due to gravity, leads to the conversion of kinetic energy into mechanical energy, which in turn can be transformed into usable from of energy called electrical energy. Hydroelectric power plant can be of four different types based on size (Micro, Mini, Small and Large). A micro power plant generates less than 100KW of energy and can be used to provide electricity to 1-2 houses. The power plant which generates 100KW-1MW of electricity is termed as Mini hydroelectric power plant and can supply electricity to a small community. A small power plant generates 1MW-30MW and can be used to provide electricity to the local grid of an area. A large hydro-electric power plant generates more than 30MW of power. According to the World Commission on Dams (2000), the number of completed large dams estimated as about 45,000 in 140 countries with almost two-third being restricted to the developing countries during the twentieth century.

Global fresh water resource spatial-temporal distribution is erratic and unreliable (Saleh *et al*., 2005). Consequently, man has endeavored to harness the available surface water resources by building dams to store water for use especially in times of scarcity. The volume of global water resources held by built reservoirs is about 3,400 km annually (Saleh *et al.*, 2005). Throughout human history, dams have played the essential role of providing water for domestic and industrial uses, flood control, hydropower generation, irrigation and fisheries. Hydro-electricity is the main form of renewable source of energy world over and the world's HEP installed capacity and output increased by over 5.3% from the year 2009 to 2010 (Lucky, 2012). Currently, hydropower output is about 3,427 TWH, it's about 16.1% of the global electricity consumption and 20% of the worlds' electric generation. Hydropower supplies about 50% of electricity in 66 countries and 90% in 24 countries globally (Government of India, 2004). In Africa, it's recorded that the effects of climate change are severely affecting HEP plants especially in areas that experience low annual rainfall (Bowyer, 2005).

The world faces a great challenge for supply of energy needs of a growing population, as well as to keep climate change in check by reducing greenhouse gas emission. Hydro-power is one of a number of options for meeting this challenge. It supplies 19% of global energy needs but there remains a vast unexploited potential, particularly in developing countries. According to the World Energy Council (WEC), two-third of the economically feasible hydro-power plants with a total capacity of 1400 GW would have to be built at a cost of US $1500 billion (WEC, 2004). While this technical and economic potential is undeniably attractive, the big question is how much of this potential can be exploited without causing widespread environmental damage. The drive for more hydro-power comes at a time when many freshwater ecosystems are already in crisis, partially due to the development of dams and related activities such as water withdrawals for irrigation through canals. According to the United Nations, 60% of the world's 227 major rivers are already severely fragmented by dams, diversions and canals, leading to the degradation of ecosystem (UN, 2003). A particular problem is the cumulative impacts of dams on a particular river. A recent report by WWF (2004) identified 20 rivers where ecosystem is at risk because of large number of dams, for example Yangtze in China, La Plata in South America and the Tigris/Euphrates in the Middle East. Now days, dam construction has shifted from the developed to the developing world, with some countries such as China and India implementing large dam construction programs.

1.3.1 Impacts of hydro-electric power project on water quality

The construction of hydro-electric power projects is one of the major activities for the development and management of water resources; hence, it is imperative to study the impacts of hydro-electric power project and the existence of dams on a river system. The society is aided by the constructions of dams in various ways such as hydro-electric power supply, water level regulation, water supply, flood control, navigation and recreation. But, effects on the physical, biological and environmental factors in and around the dam site are relatively diverse. An alteration in the river ecosystem instigated by the dam is a paramount threat to the aquatic environment, affecting the riverine ecosystem in several ways such as habitat destruction, disruption of the river channel, channel shrinkage, loss of vegetation, erosion of top-soil, low water flow, sedimentation, deterioration of water quality, fragmenting the river continuity, devastation of the ecological balance, change in micro-climate, dislocation of people (HIYRCC, 1993). The flow regime in majority of the world's river systems is regulated by dams. More than 45,000 large dams and approximately 800,000 small dams obstruct approximately two-third of the fresh water flowing into the oceans (McCully, 1996).

With the construction of a dam, the free flowing river is abruptly disrupted as the water begins to accumulate in the reservoir submerging the surrounding land areas leading to habitat loss. The substrate of the river is affected by sedimentation as the reservoir acts as a sink for fine sediments. A decrease in the dissolved oxygen content and change in the thermal regime due to dam-induced modifications are some of the consequences of hydro-electric project on fresh water ecosystems (Ward and Stanford, 1987). Due to the variation in water release from the hydro-electric dam reservoir's thermocline a high variation and frequent depression in the water temperature during the summers is a frequent phenomenon also, to vastly increase fishing opportunities a considerable number of large dams throughout the world have deliberately managed thermal regimes by releasing cold water from deep reservoir. On contrary, small dams and diversions may discharge warm water directly from the reservoir surface that can lead to an increase in temperature of down-stream water. A rise in the temperature may have serious impacts on the aquatic ecology. Highly altered rivers with regulated flow lose their ability to support natural processes, therefore, many rivers have become dammed rivers and termed as **'Dead Rivers'**. Therefore, to safeguard an enduring ecological sustainability of our fresh water resources, humans and freshwater systems must coexist without exploiting the riverine ecosystems (Palmer *et al*., 2004).

1.3.2 Impacts of hydro-electric power project on aquatic macrophytes

The aquatic macrophytes play a key role in the functioning of an aquatic ecosystem therefore, to study the impacts of dam on the aquatic macrophytes is of prime importance. A substantial effect on aquatic biodiversity due to variation in the hydrological cycle is a major consequences of river regulation (Bunn and Arthington, 2002). The transformation of a flowing river into a reservoir often leads to a shift in the species composition. Precisely in reservoirs, amplification in eutrophication supports the establishment (Bini *et al*. 1999) and abundance (Pedralli, 2003) of macrophytic communities. In reservoirs for hydro-electricity generation, frequent fluctuation causes high variability in the hydrological regime and affects the diversity-distribution of aquatic plants and species richness (Thomaz and Bini, 1998, Maltchik *et al*., 2007).

1.3.3 Impacts of hydro-electric power project on vegetation

Biodiversity provides immense economic, ethical and aesthetical benefits, and is vital for survival of human beings, and also for the functioning and stability of the ecosystem (Singh, 2002). Loss of biodiversity is occurring on a global scale due to human activities (WCMC, 1992). Some of the major causes of biodiversity loss include habitat destruction, over exploitation, mining, pollution and dam construction (UNEP, 2001). One of the foremost threats to biodiversity is habitat loss and fragmentation. Fragmentation leads to replacement of large areas of native forest by other ecosystems leaving isolated forest patches, with deleterious consequences for most of the native forest biota causing serious impacts on species as well as ecosystem processes (Murica, 1995; Weinbauer and Rassoulzadegan, 2007). Introduction of species and altered disturbances rate may lead to increase in local diversity, but loss or modifications of habitat, tends to decrease species richness and heterogeneity (Lubchenco *et al*., 1991).

One of the major causes of habitat destruction is the construction of dams in the river valleys. Construction of hydro-electric power project on the river ecosystem have several benefits as power, irrigation, tourism, industrial development, but it causes loss of vegetation in the catchment area, resulting in the alteration in the floral and faunal characteristics, microorganisms and land use pattern near the dam site (Ogbeibu and Oribhabor, 2002; Sharma, 2006; Bhatt *et al*., 2011). An immense portion of the river valley having distinctive phytodiversity get submerged in these power projects (Bahuguna *et al*., 2011), leading to a complete alteration of a terrestrial habitat into an aquatic ecosystem (Gaur, 2007), thereby engulfing the productive agricultural areas, which amplifies the hardship of the local populace (Bhatt, 1997).

1.4 Drainage system of North East India

The north eastern region of India consists of eight states namely, Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura and the Himalayan state of Sikkim. It covers a total area of 2, 62,179 sq. km with a population of 455, 87,982 (Census, 2011), which is 4% of the total population of India. It has a subtropical climate due to its relief and influence of the southwest and northeast monsoons with almost 90% of the annual rainfall being bought by the southwest monsoon (Dikshit and Dikshit, 2014). North East India receives abundant rainfall amounting to around 2500mm on an average.

The region is bestowed with profuse natural resource, especially with a massive water resource potential originating mainly from the Trans Himalaya, Middle Himalayas and the Sub-Himalayas, Patkai-Purbanchal hills on the northeast and karbi-Jaintia-Meghalaya-Garo hills on the southern peripheral which accounts for 34% of the total water wealth of India despite comprising of only 7.9% of the total landmass of the country. Conversely, less than 5% of total water assets has been utilized for societal use. The region carries about 37% of country's total hydro-power potential of which only 3% have been trapped for use. The rivers of this region sustain immense biodiversity as it is located in two biodiversity hotspot, the Indo-Burma Biodiversity hotspot and the Eastern Himalayas hotspot.

The river system of Assam is mainly classified as the Brahmaputra river system and Barak river system. The Brahmaputra is one of the major rivers in the world, fourth largest with regard to average water discharge at the mouth with a flow of 19,830m^3s^1 and is also one of the leading sediment carrier rivers of the world (Gazette of India Assam State, 1999). The Brahmaputra river basin covers part of Tibet (China), India and Bangladesh. In India, it is spread over the states of Arunachal Pradesh, Assam, Nagaland, Meghalaya, Sikkim and West Bengal. The Barak is the second largest river basin system in the northeastern region covering a total length of 900 km from source to mouth, draining a total area of 52,000sq.km.

The Barak river basin covers part of Tibet (China), India, Bangladesh and Myanmar. In India, it covers the state of Assam, Meghalaya, Manipur, Mizoram, Tripura and Nagaland. Some of the other rivers in Assam include Katakhal, Jatinga, Longai, Kushiara, Dihing. The major rivers draining the state of Arunachal Pradesh are Kameng, Subansiri, Lohit, Siang and Tirap. In Meghalaya, Ajagar, Chagua, Kalu, Dudnai, Krishnai and Ringgi are the important rivers in the northern region; Simsang, Dareng, Bhogai in southern region; the important rivers of the central and eastern regions of Meghalaya that path towards the north are Umkhri, Umiam and Digaru; rivers of the eatern regions that course towards south are Umiew, Mawpa, Kynchiang, Myngot and Myntdu. In Manipur, the two major river basins are the Barak river basin and Manipur river basin. Originating from the northern hills, the Barak is joined by a number of tributaries such as Irang, Maku, Tuivai. The major river of the Manipur river basin includes Imphal, Iril, Nambul, Sekmai, Chakpi, Thoubal, Khuga. In terms of annual yield, the total water resources of the two river basins have been estimated as 1.8487 million hectare metre. Dhansiri, Dikhu, Doyang and Jhanji are the four major flowing across the Mokokchung and Longleng districts of Nagaland. It flows in the westward direction and finally merges with the Brahmaputra river. Langa, Juri, Manu-deo, Dhalai, Khowai, Haora, Gumti, Muhuri, Burima and Fenni are the major rivers in the state of Sikkim. Some other important rivers in the state are Takcham chu, Aho khola, Lacung chu, Rate chu, Resh chu and Ongchu.

1.5 Drainage system of Mizoram

The hilly region of Mizoram falls under the direct influence of monsoon with heavy precipitation from the month of May to September with an annual average of 254m. It experiences early monsoon with June being the wettest month due to its close proximity to the Bay of Bengal (Dikshit and Dikshit, 2014). Most of the rivers in Mizoram originate in the central part and flow either north ward or south ward due to the major strike of Mizoram hills being north-south. Tlawng, Turirial, Tut, Tian, Tuichawng, Tuivawl, Teirei, Tuirini and Serlui are the major rivers flowing north word and finally drains the Barak river, whereas, the southern flowing rivers either drains the Bay of Bengal through Bangladesh or Myanmar. The major southern flowing rivers are Karnaphuli (flows towards north form the southern part and enters Bangladesh where it has been trapped for huge hydel project) and Kolodoyne river (originates from Myanmar and enters Mizoram and finally drains Myanmar again).

The major sources of drinking water in Mizoram include the rivers, lakes, ponds and spring. However, due to its hilly terrain the water retention capacity is very poor as rain water runoff swifts and most of the rivers and streams dry off during the dry season resulting into water scarcity. Less than 20% of the rural population of the state has access to proper drinking water, therefore, proper management and utilization of the potential water resources is a must following feasible water harvesting technique.

According to the Institute of Resource Development and Social Management, geomorphic parameters for 22 watersheds have been worked out (Rao *et al.*, 1994). The major watersheds in the state are presented in Table 1.2.

Table 1.2 Major Watersheds in Mizoram

SI. No	Catchments	Watershed area(km^2)	Length of watershed(km)	Maximum elevation(meters)	Total number of streams
1	Langkaih	394.6478	46.6329	2463	131
2	Teirei	678.2833	71.7235	2463	249
3	Tut	836.2900	98.3367	1200	372
4	Tlawng	1701.4500	157.3802	1536	702
5	Serlui	647.1796	60.6507	3813	326
6	Tuichhuahen	260.7131	31.6800	3622	76
7	Tuirial+Tuirini	1795.2799	107.4585	1400	709
8	Tuivai+Tuivawl	2309.7767	105.6844	2000	744
9	Mat	963.9056	102.6432	1423	342
10	Tuipui	879.3337	66.9081	1897	215
11	Tuichang	1600.9972	90.4780	1854	500
12	Ngenpui	711.7893	59.0510	1556	144
13	Tuilianpui	1270.0320	97.06752	990	523
14	Sazuklui(Bara Harina Chhara)	115.6117	33.7075	513	38
15	Khawthlangtuipui	149.0178	18.7545	6.6	30
16	Kau+Deh	977.1802	54.4890	1387	354
17	Tuichawng	1275.8204	109.7395	1106	272
18	Kawrpui	356.2095	76.0320	720	84
19	Chhimtuipui	2740.5582	137.6179	2158	629
20	Tiau	875.2657	87.9436	1962	212
21	Sakeilui	255.8567	41.8176	770	58
22	Salalui+Tinglo	289.8996	28.6387	600	68

Source: Rao *et al*. (1994)

Some of the major environmental concerns of the northeast India are deforestation, floods, landslides, unregulated dam construction, shifting cultivation, industrial operations in plains, coal mining, crude oil and natural gas exploration, fertilizer industries, Paper industries, Cement industries, Automobile Exhaust (Status report of the environment, 2012).

1.6 Dams in North East India

The Northeast India is described as the "Future Power House of India" by the Indian government as the region is blessed with abundant natural water resources suitable for the construction of dams. Major hydel projects are emerging as an alarming subject with over 168 large hydro-electric power (IPCC, 2001) projects set to majorly alter the riverine system of the region. Over 150 sites for large hydro-power projects in the Brahmaputra Basin alone has been identified by the Central Electricity Authority (2001) with 63,328MW total hydro-electric potential, of which more than 80 are located in the upstream Arunachal Pradesh promising a plus of more than 50,000 MW of energy in the coming years. The 450 MW Ranganadi dam and under construction 2,000 MW Lower Subansiri on the Subansiri river in Arunachal Pradesh are the major dam concerned in relation to their downstream impacts in the region. In Sikkim, there is provision for 26 large hydro-power projects on the Teesta river (Overdorf, 2012). Manipur river, Barak drainage system, rivers of Meghalaya, Tripura and Mizoram are also marked for hydro-electric generation.

Assam and Arunachal Pradesh are affected by major devastation due to the fissure of landslide dams in Bhutan and Tibet. A menacing upsurge in hydro-electric power plant construction in Arunachal Pradesh, annual floods in Assam due to unwarned release of water from the dams in Bhutan and within the region, construction of unauthorized dams in China and alleged attempt to divert the Brahmaputra within the country in China are some factors affecting water resources management in Northeast India. Inter country political issues between India, China, Bhutan and Tibet with lack of coordination and cooperation with regards to the water basin sharing are the major hindrance in tackling these issues.

The proposed mega dams in the northeastern region have escalated the concern regarding the probable negative impacts in terms of feasibility, sustainability, geo-environmental base, ecological balance, ethno-cultural heritage and the geophysical processes of the region in the near future. In terms of the inadequate base knowledge, lack of efficient data, and varied topography, the hydro-electric power project construction need serious environmental investigation in the northeastern region. To minimize ill effects of hydro-electric power project, suitable mitigation measures be adopted.

1.7 Dams in Mizoram

The two major completed hydro-electric power projects in Mizoram are Tuirial hydro-electric power project and Serlui-B hydro-power project. The 60 MW Tuirial hydel project was implemented by the North Eastern Electric Power Corporation Ltd. (NEEPCO). According to Aggrieved Dam Affected People (ADAP) of Turial hydro-electric power project, the villages affected by the hydel project are Ratu, Mauchar, Saipum, Palsang, N Khawdungsei, Serzawl, Lungmuat, Bukpui, Saiphai, Hlimen, Darlawn, Khawruhlian, N Chaltang, Nisapui and Thingtherh (Ministry of Forest and Environment, 2013).

The 12 MW Serlui-B hydel project is located in Bilkhawthlir, Kolasib district of Mizoram. The Builum village was submerged as a consequences of the construction of the dam and the affected villagers were rehabilitated at a new site Bawktlang near Kolasib. As per the Builum Inquiry Commission, it has the dubious distinction of creating the first official 'dam refugees' in the state.

Other major hydro-electric power projects proposed in the state are Bhairabi dam project, Tuivai hydel project, Boinu storage hydel project, Kolodyne storage hydel project-Stage II, Lungleng storage hydel project and kaldan storage hydel project.

Despite the fact that North eastern region harbors colossal water assets, the ongoing efforts to harness this cosmic hydro-power potential through a series of dams have posed an unparalleled threat to the water, social and ecological security of the region. Hydro-power dams involve the setting up of large infrastructure, which in turn lead to deterioration of water quality and pose adverse effects on aquatic macrophytes, resulting into nuisance in aquatic environment. Further, the widespread negative on the downstream flood plains, the river regime, aquatic biodiversity, ground water domain, wetlands and consequent effect on agriculture and environment can lead to loss of livelihoods and outmigration.

With the escalating population growth, the demand for fresh water also amplifies so water distillation and salvage become increasingly vital. Thus, there is a liberal compass of integrated research coalescing the impact of hydel project on the water quality and ecology of aquatic macrophytes. The information acquired by commencing this study may provide a needful dimension towards formulation of appropriate management strategies for minimizing the adverse impacts of hydro-electric power project on the aquatic environment and will also provide clean water to the people for different kinds of uses including drinking purpose.

It is clear from the available literature that the environmentalists have carried out extensive researches in the field of water pollution and management in India and abroad. But, there is paucity of data and lack of information on status of aquatic bodies and their management in northeast India in general and Mizoram in particular.

Objectives

In view of the above fact, the present work has been carried out with defined objectives.The major objectives of the present investigation envisage the followings:

1. To study the water quality of Serlui river in vicinity of Serlui B hydroelectric power project at selected sites.
2. To study diversity and distribution of aquatic macrophytes at selected sites.
3. To assess the impact of hydel project on water quality and ecology of aquatic macrophytes.
4. To formulate appropriate management strategies.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Water quality and pollution assessment

A clear understanding on the origin of water and its natural cycle was reached by the European scientists only during the late seventeenth century. Perrault (1674) wrote the first book on scientific hydrology ***De L'oigine des fontaines*** ('on the origin of springs'). The quality of water may affect human health was first stated by the Greek philosopher Alcmaeon during 470BC (Aetius, 1998). On the global scale, a number of scientists have carried out researches pertaining to the water quality of various rivers. Some of the notable works include Elosegui and Pozo (1992) on river Aguera, Spain; Olajire and Imeokparia, (2001) on river Osun, Nigeria; Iqbal *et al*. (2004) on river Soan, Pakistan; Shrestha and Kazama (2007) on river Fuji, Japan; Otieno (2008) on river Nairobi, Kenya; Ojutiku and Kolo (2011) on river Chanchaga, Nigeria; Mushahida and Kamruzzaman (2013) on river Rupsha, Bangladesh; Ali *et al*. (2014) on river Nile, Egypt; Halliday *et al*. (2014) on river Enborne, UK.; Omaka *et al*. (2014) on streams and river in Abakaliki, Nigeria; Edokpayi *et al*. (2015) on river Mvudi, South Africa; Islam *et al*.(2015) on river Menik, Sri Lanka; Ogendi *et al*. (2015) on river Riana, Kenya; Raji *et al*. (2015) on river Sokoto, Nigeria; Erick *et al*. (2016) on river Ngong, Kenya ; Hafizur *et al*. (2017) on river Turag, Bangladesh; Hassan *et al*. (2017) on river Diyali, Iraq; Otieno *et al*. (2017) on river Kisat, Kenya; Vadde *et al*. (2018) on river Tiaoxi, China.

Bajracharya and Tamrakar (2007) studied the environmental aspects of river Manahara, Katmandu, Nepal and reported that the decline in the quality of water from upstream to downstream is a result of the destruction of the riparian buffer zone, disposal of solid waste/ sewage effluents, change in the landuse pattern and excessive excavation of soil from the river. Ezzat *et al*. (2012) studied the impact of sewage discharge on the water quality of river Nile at Rosetta Branch (Egypt). Hasan *et al.* (2014) carried out a research on the pollution status of river Balu at Dhaka, Bangladesh and found that the deterioration of river water quality is mainly due to the direct discharge of large amount of untreated sewage and industrial waste into the river. Simonyan (2016) studied the water quality of river Voghji at Armenia and reported increase in intensity of pollutants from the source to the mouth of the river. Hassan and Ali (2016) have studied water quality of Zea river in Iraq. Rios-Villamizar *et al.* (2017) observed a decline in the pH, dissolved oxygen, electrical conductivity and total suspended solids and an increase in the turbidity from upstream to downstream of river Purus at Brazilian Amazon. Tawati *et al.* (2018) studied the physico-chemical properties of Sumber Maron river in Malang, Indonesia and reported that the COD and TDS contents were sharply and beyond the permissible limit, this could be attributed due to surface run-off from agricultural field, direct disposal of municipal/domestic waste from various localities.

Hippocrates in 450 BC was the first to recognize the water pollution problems and suggested both filtration and boiling as a remedial measure to improve the quality of water (Borchardt and Walton, 1971).Water pollution as a result of various anthropogenic activities such as agriculture, industries, developmental projects, human settlements, hydro-electric power projects has pose a serious threat to the aquatic ecosystem, human health and productive activities. Globally, 80% of the municipal waste is directly discharged into the water bodies without treatment, and million tons of heavy metals, toxic sludge and solvents released from various industries are dumped into the aquatic bodies each year.

On the global level, environmentalists have carried out extensive works on the aspects pertaining to the impacts of pollutants on the aquatic environment (El-Gamel and Shafik, 1985; Gil *et al.*, 1989; El-Sherbini, 1997; Onwudinjo, 1990; Tapp *et al.*, 1996; Kamal *et al.*, 1999; Williams *et al.*, 2000; Bordalo *et al.*, 2001; Daniel *et al.*, 2002; Rahman and Hadiuzzaman, 2005; Milovanovic, 2007; Spanhoff, 2007; Adekunle and Eniola, 2008; Akan *et al*., 2008; Moses *et al*., 2011; Kolawole *et al*., 2011; Giri and Singh, 2013; Brion, 2015; Kanda *et al*., 2014; Weerasekara *et al*., 2015; Essien, 2014; Ahammed *et al*., 2016; Glinska-Lewczuk *et al*., 2016; Moyo and Rapatsa, 2016).

Water pollution is a serious threat in India, as 70% of the surface water resources have become polluted due to the discharge of domestic sewage and industrial effluents into the natural aquatic bodies such as the rivers, streams as well as lakes (Sangu and Sharma, 1987). There is a sharp alteration in the physico-chemical characteristics of water, leading to make water unfit for use of livestock and other organisms. This may be due to continuous addition of industrial, sewage, municipal wastes into water bodies (Dwivedi and Pandey, 2002). Unregulated discharge of domestic waste water into water bodies leads to eutrophication, as indicated by substantial algal bloom, dissolve oxygen depletion in the subsurface water leads to killing of large fishes and other oxygen dependant organisms (Pandey, 2003).

In India, extensive researches on the aspects pertaining to the impact of pollutants on most of the important rivers have been carried out by several environmentalists (Olaniya *et al*. 1976; Ajmal *et al*. 1983; Raina *et al*. 1984; Somashekar, 1985; Ajmal and Raziuddin, 1988; Palhariya and Malviya, 1989; Singh and Singh, 1990; Datar and Vasistha, 1992; Kumar, 1995; Singh, 1995; Pande and Sharma, 1998; Mishra and Tripathi, 2000,2001,2003,2004; Jain, 2000; Singh and Rai, 2003; Tiwari, 2004; Sinha *et al*., 2005; Saksena *et al*., 2008; Chaurasia and Tiwari, 2011; Binu Kumari *et al*., 2011; Arora, 2012; Banerjee and Gupta, 2012; Pathak *et al*., 2012; Pawar, 2012; Verma and Singh, 2016)

Healthy aquatic ecosystem is dependent on the physico-chemical and biological characteristics at a large (Venkatesharaju *et al*., 2010). An immense array of researches have been conducted on physico-chemical and biological characteristics of water (Rajesh *et al.,* 2002; Jayaraman *et al.,* 2003; Sridhar *et al*., 2006; Pradhan *et al*., 2009; Srivastava *et al*., 2009; Damotharan *et al*., 2010; Manikannan *et al.,* 2011). Agarwal *et al*. (1976); Sangu and Sharma (1987); Joshi *et al*.(2009); Trivedi (2010); Khare (2011) studied the water quality of river Ganga; Yadav and Srivastava (2011) on river Ganga, Ghazipur; Sunder (1988) on river Jhelum, Kashmir; Malviya (1990) on river Narmada , Madhya Pradesh; Shukla *et al*. (1992) on river Ganga, Ghazipur; Bhuvaneswaran and Rajeswari (1999) on river Adyar, Tamil Nadu; Roy and Kumar (2002) studied the water quality of the rivers of Ranchi; Jayaraman *et al*. (2003) on river Kasmane, Thiruvanthapuram (Kerela); Dey *et al*. (2005) on river Brahmani, Rourkela; Khanna *et al*. (2005) on river Panv Dhoi, Saharanpur (U.P); Bhandari and Naval (2008) on river Kosi, Uttarakhand; Abida and Harikrishna (2008) studied the water quality of some of the streams connected to the river Cauvery; Suthar *et al*. (2010) on river Hindon, Ghaziabad; Shivayogimath *et al*. (2012) on river Ghataprabha, Karnataka; Jadhav (2013) on river Alandi, Pune; Vishen and Siddiqui (2014) on river Aami, Gorakhpur; Prasad *et al.* (2016) on river Penna, Andhra Pradesh; Singh *et al*. (2016) on river Gomati, U.P; Bhagde *et al.* (2016) on river Aadhala, Ahmednagar (Maharashtra); Sridhar and Ramaneswari (2017) on river Nagavali, Andhra Pradesh; Vaishnav (2017) on river Shivnath, Chhattisgarh.

In recent years, extensive investigation on the impact of sewage on the physicochemical quality of water have been carried out by Agrahari and Kushwaha (2012) on river Rapti, Gorakhpur; Gautam *et al*. (1993) on Alaknanda, Srinagar (Garwal); Malviya (1990) on river Narmada, Hoshangabad (M.P). Shrivastava *et al.* (2012) studied the effect of sewage disposal on the water quality of river Machna in Madhya Pradesh; Tewari *et al*. (2014) on river Arpa, Bilaspur.

The available literature reveals that quality of water in the north eastern region of the country has not been explored to a desired pace. In Assam, Dutta *et al*. (2016) reported that the various anthropogenic activities have resulted in degradation of the water quality of river Dikhow. A study on the limnochemistry of river Pagladia, Asaam had been conducted by Das *et al*. (2014). The investigation reveals that most of the water and sediment quality were within the permissible limits and can be used for fish production. In Meghalaya, several worker have reported that most of the rivers are badly affected due to open cast mining especially coal and limestone extraction (Swer and Singh 2003, 2004; Lamare and Singh 2014, 2015, 2016). In Manipur, the physico-chemical characteristics of Imphal, Iril, Thoubal and Manipur rivers were studied by Singh *et al*. (2010). The Nambul river in Imphal is reported under the heavy pollution stress, as untreated domestic wastes from the markets and household are directly discharged into the river (Singh and Gupta 2015; Singh *et al*., 2016). Dutta and Sarma (2013) studied the fluoride hydrochemistry of Dikrong river basin, Arunachal Pradesh. Sarkar and Mishra (2014) studied the water quality status of river Haora, Tripura and suggested that the river water should not be used without prior treatment as it has high concentration of iron, phosphate and turbidity.

The variation in the physico-chemical characteristics of some of the major water bodies in the region have been carried out by Dey and Kar (1987) on Sone Lake, Assam; Yadava and Dey (1990) on Dhir beel, Assam; Sharma (1995,1999) on some reservoirs in Meghalaya; Murugan (2008) on river Umkhrah, Meghalaya; Imnatoshi and Ahmed (2012) on river Doyang, Nagaland; Das *et al*. (2014) on river Siang, Arunachal Pradesh; Laishram and Dey (2014) on Loktak lake, Manipur; Debnath *et al.* (2015) on river Muhuri, Tripura; Karmakar and Biswas (2016) on river Meleng, Assam; Singh *et al*. (2016) on river Haora, Tripura; Nongmaithem and Basudha (2017) on various water bodies of Manipur.

In recent years, researches have paid attention on exploration of pollution and management of aquatic bodies in Mizoram. Mishra and Lalhruaizeli (2009) have studied the status of quality of spring water in western part of Aizawl city; Lalchhingpuii *et al.* (2011a, b) have assessed water quality of Tlawng river in Aizawl; Lalparmawii and Mishra (2012) have conducted a study on seasonal variation in water quality of Tuirial river in vicinity of the hydel project in Mizoram; Thasangzuala and Mishra (2014) studied physical characteristics of public drinking water in Aizawl city; Thasangzuala *et al.* (2014) have explored chemical characteristics of public drinking water in Aizawl city; Mishra and Lalzahawmi (2014) Physicochemical characteristics of Tamdil lake; Mishra and Premeshowri (2014) have assessed impact of sandstone quarry on water quality of Tlawng river in Aizawl district; Premeshowri and Mishra (2014) have studied water quality of Tlawng river in Aizawl district. Lalparmawii (2012) have conducted a study on bio-monitoring of Tuirial river in vicinity of the hydel project.

2.2 Water Quality Index (WQI)

The concept of WQI was first developed by Horton (1965) in the United States which was later accepted and applied in the European, African and Asian countries. Brown *et al*. (1970) developed a WQI similar to Horton's index based on the weight of individual parameter which was later improved by Deininger for the Scottish Development Department. Furthermore, a number of indices namely, Weight Arithmetic WQI (Brown *et al*., 1972), National Sanitation Foundation WQI (Sharifinia, 2013), Canadian Council of Ministers of the Environment WQI (CCME, 2001; Lumb, 2006), British Columbia WQI (1996) and Oregon WQI (Cude, 2001; Kannel *et al*., 2007) have been framed by numerous national and international organizations to summarize the bulk of water quality data into a simple and easily understandable format (Couillard and Lefebvre, 1985). In the recent years, Water Quality Index has emerged as one of the most effective tools to describe the quality and sustainability of water for human consumption, recreation, swimming, irrigation, fish swamping etc. (Tiwari and Mishra, 1985; Adak *et al.,* 2001; Mishra and Patel, 2001). WQI reduce the complex data of various water quality parameters into a single value to communicate information on the quality of water in a simplified and logical form (Bordalo *et al*, 2006; Babaei-Semiromi *et al.,* 2011) to the concerned citizen and policy makers.

Various studies pertaining to the application of Water Quality Index for the water quality monitoring have been carried out by several workers (Stojda, 1985; Miller, 1986; House, 1990; Dojlido *et al*., 1994; Pesce and Wunderlin, 2000; Debels *et al.,* 2005; Abrahao *et al.,* 2010; Akoteyon *et al*., 2011; Al-Heety, 2011; Khwakaram *et al*., 2012; Damo and Icka, 2013; Abdulwahid, 2013; Sadat-Noori *et al*., 2014; Boah *et al*., 2015).

In India, assessment of the water quality using Water Quality Index studied by Bhargava (1983), Panda *et al*. (1991), Singh (1992), Chetana and Somashekar (1997), Chatterjee and Raziuddin (2002), Kalavathy *et al*. (2005), Avvannavar and Shrihari (2008), Kumar and Dua (2009), Samantray *et al*. (2009), Ramakrishnaiah *et al*. (2009), Vasanthavigar *et al*. (2010), Chaturvedi and Bassin (2010), Chauhan and Singh (2010), Reza and Singh (2010), Parmer and Parmer (2010), Sharma and Kansal (2011), Kankal *et al*. (2012), Ravikumar *et al*. (2013), Jagadeeswari and Ramesh (2012), Jena and Dixit (2013), Srinivas *et al*. (2013), Mazhar *et al*. (2013), Patil and Patil (2013), Bhadra *et al.* (2014), Panda *et al*. (2016) and Vijai *et al*. (2017).

2.3 Aquatic Macrophytes

Warming (1892) has made the first inferences about the zonation and succession of the aquatic plants in the Neotropical region in his book ***"Lagoa Santa et Bidrag til den biologiske Plantegeografi"*** (Thomas and Bini, 2003). Hooker (1872-1897) gave a general list of the aquatic flora in his work on floral diversity of the Indian subcontinent. However, a pronounced escalation in the literature concerning macrophytes ensued only after 1960 which maybe due to the increasing recognition of the importance of aquatic macrophytes in the structural and functioning of the fresh water systems vital for many aquatic organisms including aquatic invertebrates, fish and aquatic birds.

Arber (1920) defined aquatic plants as any plant species growing in the water. According to Cook *et al*. (1974), plants whose active photosynthetic part is either permanently or at least for few months each year is submerged in water or floats on the water surface are termed as aquatic plants. "Aquatic Plant Book" (Cook, 1990) and "Wetland plants of India" (Cook, 1996) are some of the notable contribution to the study of aquatic macrophytes.

Aquatic macrophytes are the key component of the aquatic ecosystem (Jeppensen *et al.* 1998), as they play major role in primary productivity and nutrients cycling (Carignan and Kalff, 1982; Twilley *et al.* 1987; Peakall and Burger, 2003); habitat heteroginity (Cronk and Fennessy, 2001; Grenouillet *et al*. 2002; Taniguchi *et al*. 2003) structuring (Tokeshi and Pinder, 1985). Several studies have been carried out by various workers on the aquatic plants (Pearsall and Hewitt, 1933; Maristo, 1941; Hutchinson, 1975; Cowardin *et al*., 1979; Carpenter and Lodge, 1986; Klosowski, 1992; Thomas and Bini, 1998; Bini *et al.,* 1999; Thomas *et al*., 1999; Melzer, 1999; Keddy, 2000; Nurminen, 2003; Burlakoti and Karmacharya, 2004; Geest *et al*., 2005; Moreno and Callisto, 2006; Hrivnak *et al*., 2006; Maltchik *et al*., 2007; Chambers *et al*., 2008; Papastergiadou *et al*., 2010; Mormul *et al.,* 2010; Pirini *et al*., 2011; Niroula and Singh, 2011; da Silva *et al*., 2014; Weekes *et al*., 2014; Ghimire, 2016).

In India, the floristic diversity of aquatic macrophytes was first studied by Biswas and Calder (1936). Several other notable works have been carried out on the phytosociology of different macrophytic species in different fresh water bodies of India (Misra,1946; Mirashi, 1954; Sen and Chatterjee, 1959; Maheshwari, 1960; Seerwani, 1962; Subramanyam, 1961; Vyas, 1964; Jha, 1965; Trivedi and Sharma, 1965; Unni, 1971; Paul, 1973; Deb, 1976 ; Shah and Abbas, 1979; Billore and Vyas, 1981; Purohit and Singh, 1981; Singh and Tomar, 1982; Handoo and Kaul, 1982; Biswas and Calder, 1984; Kumar and Singh, 1987; Samant *et al*., 1988; Dey and Kar, 1989; Baruah and Baruah, 2000; Ravinder and Pandit, 2006; Kar and Barbhuiya, 2007; Sharma *et al*., 2007; Bhat *et al*., 2007; Dhote and Dixit, 2007; Chandra *et al*., 2008; Reddy *et al*., 2009; Misra and Sharma, 2009; Chowdhury and Das, 2010; Dinesh *et al*., 2012; Kshirsagar and Gunale, 2013; Ahmad *et al*., 2015; Misra, 2015; Kumar and Chelak, 2015; Murkute and Chavan, 2016; Sen and Karkun, 2017).

Many researchers have studied the invasive nature of the aquatic macrophytes (Mitchell, 1974; Ashton and Mitchell, 1989; Bickel and Closs, 2008; Thomaz *et al.*, 2009; Thiebaut *et al.*, 2011; Michelan *et al.*, 2010) and their impact on the ecosystem (Pieterse and Murphy, 1990; Madsen *et al.*, 1991; Theel *et al.*, 2008; Yarrow *et al*., 2009; Strayer, 2010). Engelhardt (2011) and Manolaki and Papastergiadou (2012) have reported that fresh water ecosystems are highly threatened due to various anthropogenic activities that increases the invasibility of these systems by macrophytic species which can lead to severe damage to the rivers, wetlands, lakes and reservoirs.

Aquatic Macrophytes are commonly used for environmental monitoring and water quality assessment (Tremp and Kohler, 1995; Robach *et al*., 1996; Ali *et al*., 1999; Amoros *et al*., 2000; Haury *et al*., 2002; Schneider and Melzer, 2003; Toso, 2005) as they serves as good indicators of any alteration occurring in an aquatic ecosystem as a result of human-induced acidification and eutrophication (Roelofs, 1983; Lehmann and Lachavanne, 1999). The aquatic macrophytes respond to any change in water quality and have been used as bio-indicator of pollution (Tripathi and Shukla, 1991; Pedralli, 2003). Melzer (1999) developed a macrophyte index based on indicator species groups. The hydrological dynamics of rivers influence the species composition, mountain streams are characterized by the absence of trachaeophytes and the dominance of cryptogams, whereas lowland rivers are characterized by tracheophytic vegetation (Tremp and Kohler, 1995). These aspects show that macrophytes indicators are also influenced by type of river and nature of landscape. In contrast to diatoms, the submerged macrophytes are capable of taking up nutrients from both the sediment pore water and the overlying water (Denny, 1972; Carignan and Kalff, 1980). Several workers have performed tremendous studies pertaining to the use of aquatic macrophytes as bio-indicator of water quality and pollution (Onaindia *et al*. 2005; Lukacs *et al*. 2009; Demars and Tremolieres, 2009; Ladislas *et al*., 2012; Pereira *et al*., 2012).

The available literature depicts that extensive researches have been carried out on aquatic macrophytes by the scientists at international and national levels, but there is paucity of information on the subject with respect to Northeast India in general and Mizoram in particular. Macrophytic diversity in certain wetlands of Barak valley region in Assam was studied by Kar and Barbhuiya (2001, 2002). Deka and Sarma (2014) reported 137 species of aquatic macrophytes belonging to 114 genera and 53 families from the wetlands of the Nalbari district of Assam. In Manipur, Devi (1993) studied the phytosociology, primary productivity and nutrient status of the aquatic macrophytes of Loktak Lake. Dutta *et al*. (2014) studied the diversity of aquatic macrophytes of Kapla beel of Barpeta district, Assam and reported a total of 68 species belonging to 49 genera and 28 families. The phytosociology of aquatic macrophytes of Poiroupat Lake, Manipur was studied by Usha *et al*. (2012). The seasonal distribution (Singh *et al*., 2010) and ecological productivity (Singh and Sharma, 2012) of aquatic macrophytes in Kharungpat lake, Manipur were also studied in details.

With reference to Mizoram, the researches pertaining to aquatic macrophytes are sparse. This highlights the importance and urgency of the assessment of the ecological studies on the aquatic macrophytes in the state as macrophytes play a significant role in transforming aquatic ecosystems.

2.4 Hydroelectric Power Projects

The invention of the steam engines in 1775 (Thurston, 1939) marked a new era in water technology with the use of water as steam to power sophisticated engines in industries, draining swamps, lifting water and transportation (Pirenne, 1969). The hydro-electric power came to the fore in 1881, and within a decade large dams were constructed in the United States and soon spread to the rest of the world. Globally, there are more than 45,000 large dams in over 150 countries (WCD, 2000) and it is estimated that another 1,500 or so are currently under construction, nearly 400 of which are over 60 meter high (IJHD, 2004). Large dams have caused considerable environmental damages, and decline of freshwater biodiversity in recent decades. Sixty percent of the world's largest rivers are already severely fragmented by dams. World Resources Institute developed an analysis of dams on a river basin scale, using the level of river fragmentation and flow regulation at the river basin level (Revenga *et al.*, 2000). Each dam site may have its own unique set of geologic and geotechnical challenges since the design requirement are different for dams of different size, purpose and hazard potential classification (Tabwassah *et al*., 2012).The large and medium hydro-electric projects have been in the line of fire for their harmful environmental impacts; the small hydroelectric projects of less than 5 MW capacities seem to have escaped the lens. However, these small hydropower plants also influence the microclimate as well as spatial distribution of macro invertebrate of the project site and surrounding area of hydro power projects (Xiaocheng *et al.,* 2008).

The environmental impacts of dam are well documented. With changes in both upstream and downstream hydrology dam affects the freshwater ecosystems along the river and as far as its estuaries (Vannote *et al.,* 1980; Junk *et al.,* 1989; McCartney *et al.,* 2000; Bergcamp *et al.,* 2000). People are equally vulnerable, not only those who are displaced by dams, but also those who depend on these freshwater ecosystems for their livelihoods. The people affected by dams still do not necessarily benefit directly and often remain without access to power and clean water. While the obvious and often irreversible impacts of large impoundments are well recognized, there is also growing awareness of the pivotal role of the flow regime as a key driver of ecology of rivers and their associated floodplain wetlands (Junk *et al.,* 1989; Poff *et al.,* 1997). In the 1980's, over 200 rivers and streams were blocked by hydroelectric projects (Rosenberg *et al*., 1987).

Hydro-electric developments normally involve blockage of river channels, impoundment of rivers, and regulation of discharge. These modifications inevitably cause major changes in the aquatic ecosystem in which fish live. In addition to ecological impacts, social and economic problems are causes for concern, such as high mercury levels in the hair of native peoples, or the collapse of local communities (Wagner, 1984; Berkes, 1988, 1990; Dickman, 1991). Compared with other forms of pollution, less concern has been expressed for the environmental changes caused by hydro-electric development, although they may be just as serious, probably because effects on the ecosystem and humans are usually not displayed immediately.

Some scientists have argued that experience and expertise lead to minimal impacts from hydro-electric development (Abelson, 1985: Kiesans, 1988), ignoring evidence of severe environmental and social problems that have emerged around the world (Goldsmith and Hildyard, 1984, 1986, 1992).

2.5 Impact of Disturbances on Floristic Diversity

Biodiversity plays an important role for the survival of life and provides immense economical, ethical and aesthetical values, and is essential for the stability and functioning of the ecosystem (Holdgate, 1996; Tilman, 2000; Singh, 2002). Forest ecosystem provides many benefits such as purification of air, temperature regulation, helps control soil erosion, aids in the fertility of soil and also helps regulates the hydrology (Clarke *et al*., 1996); provides food, timber, fodder, fuel medicinal plants and non-timber forest products (NTFP) and hence it plays a vital role to sustain the livelihoods of several communities and in the economic development of many countries (Kumar *et al*., 2006; Subukeera *et al*., 2006). According to the estimation of the Convention on Biodiversity (Negi, 2011), 40% of the world's economy are derived from the biological products and processes, however, several human-induced activities such as urbanization, developmental activities and over-exploitation of this natural asset have resulted into an alteration in the biodiversity (Vitousek, 1994) and ultimately leading to biodiversity loss (WCMC, 1992) which may negatively affect the functioning and stability of the ecosystem (Schulze and Mooney, 1994; Steffan-Dewenter and Tscharntke, 1999).

In general, free-flowing rivers have species-rich riparian vegetation (Tabacchi *et al*., 1990; Nilsson *et al*., 1994), however, construction of hydroelectric projects creates major environmental issues and submergence of large area including forest causing a great threat to the biodiversity (Nair and Balasubrammanyam, 1985; Mohanty and Mathew, 1987). Any alteration in the vegetation composition may serves as one of the best indicators for any environmental change as terrestrial vegetation is often regarded as the most explicit evidence of biological response to climatic and other environmental factors that reflects the effects of the entire environment (Billings, 1952; Lindquist *et al*., 2008) and is significantly correlated with the prevailing environmental as well as anthropogenic variables (Gairola *et al*., 2008; Ahmad *et al*., 2010; Bisht and Bhat, 2013).

Floristic diversity is the sum total of floras covering an area consisting of a variety of plant communities. Many studies pertaining to the floristic diversity of different zones have been reported by several workers. Hayat and Kudus (2010) recorded 120 tree species belonging to 81 genera and 31 families from the Pasir Tengkorak forest reserve, Malaysia. Sobuj and Rahman (2011) from their study on the assessment of plant diversity of Khadimnagar National Park, Bangladesh reported a total of 74 plant species (26 trees, 17 shrubs, 31 herbs) from the region. Ndah *et al*. (2013) reported a total of 99 species belonging to 87 genera and 34 families from their study on the floristic diversity of a disturbed Takamanda rainforest in the Southwest Cameron. Lee *et al*. (2014) recorded 490 taxa of vascular plants from the Chilgapsan provincial park, Korea. Goncalves *et al.* (2017) from their study on the floristic diversity of Miombo woodlands reported a total of 51 woody species belonging to 38 genera and 19 families. Similarly, Hailu (2017) has recorded 58 herbaceous and 11 woody species from the Harishin rangelands of eastern Ethiopia.

In India, Brandis (1906) in his book "Indian Trees" reported a total of 4,400 woody species (trees, shrubs and woody climbers) from the then British India. A number of researches pertaining to the impacts of disturbance on vegetation have been carried out by several workers such as Shankar *et al*. (1998), Awasthi *et al*. (1999), Goel (2000), Sagar *et al*. (2003), Kumar and Shahabuddin (2005), Mishra *et al.* (2004, 2005), Sharma and Kuniyal (2005), Mehta *et al*. (2008), Renofalt and Nilsson (2008), Singh *et al.* (2011), Pitopang (2012), Nang and Dioggban (2015), Mishra (2016), Egbe and Tsamoh (2018).

The literature on impacts of dam construction on the terrestrial floras is limited. Harris *et al*. (1987) have observed impact of dam construction on trees in surroundings. Unniyal *et al*. (1995) reported the plant diversity of the Tehri dam submergence zone. Samant *et al*. (2007) studied the impact of Parbati hydroelectric power project on the medicinal plants and recorded a total of 104 species of medicinal importance and suggested management plans for the cultivation and conservation of highly valuable medicinal plants. Bahuguna *et al*. (2011) have reported 133 plant species belonging to 113 genera and 65 families from the submergence area of Srinagar hydroelectric power project in Garhwal Himalaya and suggested the implementation of the hydel project would result in a total loss of biodiversity in the area. Adhikari *et al*. (2009) conducted a study to assess the vegetation structure and community pattern of Tehri Dam submergence zone in Uttarakhand. Chikodzi *et al*. (2013) studied the impacts of Ruti dam construction in Zimbabwe and revealed a decline in the tree diversity as a result of the construction of the dam. Some other sigficant studies have also carried out by New and Xie (2008), Merrit and Copper (2000), Nilsson and Berggren (2000).

2.6 Correlation and Linear Regression

Regular monitoring and regulation of the river systems are of utmost importance as the river basins are extremely susceptible to pollution due to the absorption and transportation of domestic, industrial and agricultural waste water (Simeonov *et al*., 2003). The problematic degradation of river ecology has requisite checking of the numerous rivers throughout the country to assess their utility potential, production capacity and to plan proper management and restoration strategies (Datar and Vashistha, 1992; Das and Sinha, 1993). For determination of the water quality parameters, analytical methods are used to produce dependable outcomes but usually the laboratory approaches are time consuming and very expensive (Agarwal and Agarwal, 2013). However, in recent years, an easier and advanced method based on statistical tools has been developed to gather data and to provide necessary information on various parameters using mathematical relationships between the parameters (Joshi *et al*., 2009; Khatoon *et al*., 2013; Patel and Vaghani, 2015). The degree of association that exists between two variables, taking one as dependent variable and other as independent is measured by the correlation coefficient (r). A direct correlation exists between two variables, when the increase or decrease in the value of one is associated with the corresponding increase or decrease of the other (Jothivenkatachalam *et al*., 2010). If the calculated correlation coefficient between two variables is nearer to +1 or -1, there is a probability of linear relationship between the two variables in such case a linear regression equation is established (Heydari *et al*., 2013). The regression equation is a statistical tool used to predict the unknown values of one variable from the known value of another variable. The statistical analysis attempts to establish the nature of the relationship between the variables using the correlation coefficient and linear regression method, and thus provides an implement for prediction and forecasting of the variables (Kumar and Sinha, 2010).

CHAPTER 3

STUDY AREA AND STUDY SITES

3.1 MIZORAM

3.1.1 Geographical location, area and boundary

Mizoram is geographically located between 21.58˚ to 24.35˚N latitude and 92.15˚ to 93.29˚E longitude on the extreme south corner of north-eastern India. The former Lusai Hill district of Assam became Union Territory on 21st January 1972, and later on the 23rd State of the Indian Union on 20th February 1987, with an area of 21,087 km^2 consisting of eight districts and 3 autonomous councils. The southern part of the state shares 722km long international border with Myanmar (404km) and Bangladesh (318km), and northern part shares 284km domestic border with Assam (123km), Manipur (95km), and Tripura (66km). The maximum north-south distance is 285km, while east-west stretch is 115km.

The state capital Aizawl (21˚56'-24˚31'N latitude and 92˚16'-93˚26'E longitude) with a mean elevation of 1132 m asl (above sea level), falls under Indo Burma hotspot.

3.1.2 Topography

The hilly ranges of Mizoram with steep and rocky physical set-up consist of the most variegated topography in the north-eastern part of India. Inclined from north to south in parallel or sub-parallel series, these mountain ranges grow higher in the eastern sides and taper off to the north and south with an average height of 1000meters and are separated by rivers flowing both north and south word creating deep and narrow gorges and valleys. The elevation ranges from 40 m asl at Bairabi in Kolasib district to 2157 m asl at Phawngpui or Blue Mountain in Lawngtlai district. The landform of the state based on the relief, drainage, lithological and structural setup can broadly be classified as:

i. ***Mountains Terrain province:*** It consists of the eastern half of the state with an altitude ranging from 400 to 2157m asl and an average elevation of 1500m asl. The drainage flows either towards north or south, due to the overall structural and lithological control on the drainage.

ii. ***Ridge and Valley province:*** It consists of the western part of the state covering nearly half of the area of the state with an altitude ranging from 40-1550m asl and an average elevation of 700m asl.

iii. ***Plains:*** There are only few small patches of flat lands which are mostly interment valley plains positioned in the midst of hills and narrow valleys. Champhai is the largest plain in the state located about 195km east of Aizawl followed by North Vanlaiphai in the south- eastern corner and Thenzawl in the southern part of the state capital. Small patches of flat plains like Chemphai and Chhimluang are there in the west of Bilkhawthlir in the Kolasib district.

3.1.3 Climate

The climate of the state is moderate owing to its tropical location characterized by short winter and long summer. Peak temperature is observed during the months of May, June and July and it is minimum during the months of December and January (Pachuau, 1994). The ambient temperature ranges from 10˚C to 17˚C during winter to 20˚C to 30˚C in summer. The highest temperature during summer is observed at relatively lower areas such as Zawlnuam, Bairabi, Vairengte in the northern part; Tlabung, Chawngte, Tuipang, Tuipuibari in the south and west end, whereas the lowest temperature is observed at places with high altitude such as Champhai, Zote, Ngur in the east, Bualpui and Phawngpui area in the South.

The climate of this region is humid and characteristically monsoonic. The region receives adequate amount of rainfall as it falls under the direct influence of south-west monsoon with an annual average rainfall of 250cm (Pachuau, 1994). The precipitation is normally higher during May to September and lasts till the end of October. Based on the climatic settings, this region experiences distinct seasons i.e., Summer (March-June), Rainy (July-October) and Winter (November-February).

Mizoram has both temperate and semi tropical climates with tropic and temperate zones. Several rivers are used to irrigate the land that makes state agriculturally productive with almost 70% of the total population being engaged in agriculture, and a major portion of the rural people perform jhum cultivation.

3.1.4 Soil

The hilly terrain of Mizoram mostly consists of sandstone and shale of tertiary age which are thrown in long folds. The soil of Mizoram is generally young, immature and sandy (Pachuau, 1994) without much hard rocks and limestone depositions and mainly dominated by loose sedimentary formations. The texture of the soil varies from sandy loam and clayey loam to clay and usually leached due to steep gradient and heavy rainfall. The soil is porous with poor water holding capacity, low in humus content, nitrogen, phosphorus and potassium. However, nitrogen is quite high in the uneroded soil due to accumulation of organic matters. The soils in the river valleys are very fertile and heavier as they are brought down by rainwater from high altitudes through surface run-off. The soil is mostly acidic in nature, which may be attributed to the excessive leaching (Anon, 2003).

According to Sarkar and Nandy (1976), the soil of Mizoram can be categorized into three types namely Entisols, Inceptisols and Ultisols.

i. ***Entisol:*** This type of soil is characterized by lack of profile development. It occurs on steep slope, actively eroding slopes and ridges, or on flood plains that receives new deposits of alluvium at frequent intervals. If properly managed it supports healthy vegetation.

ii. ***Inceptisol:*** It is commonly found in the sub-humid region on steep slopes, narrow valleys and on terraces. The soil is fine, loamy in texture with few rocks fragments and best suited for forest species and generally covered with dense shrubs and grasses and have well developed horizon sequence.

iii. ***Ultisol:*** It is commonly found on the foot slopes and has well developed horizons. The soil is fine loamy, rich in translocate silicate clays and humus, if not severely drained.

In general, the soil of Mizoram is well drained and has the capability to retain soil moisture and providing substantial oxygen supply for plant growth.

3.1.5 Vegetation

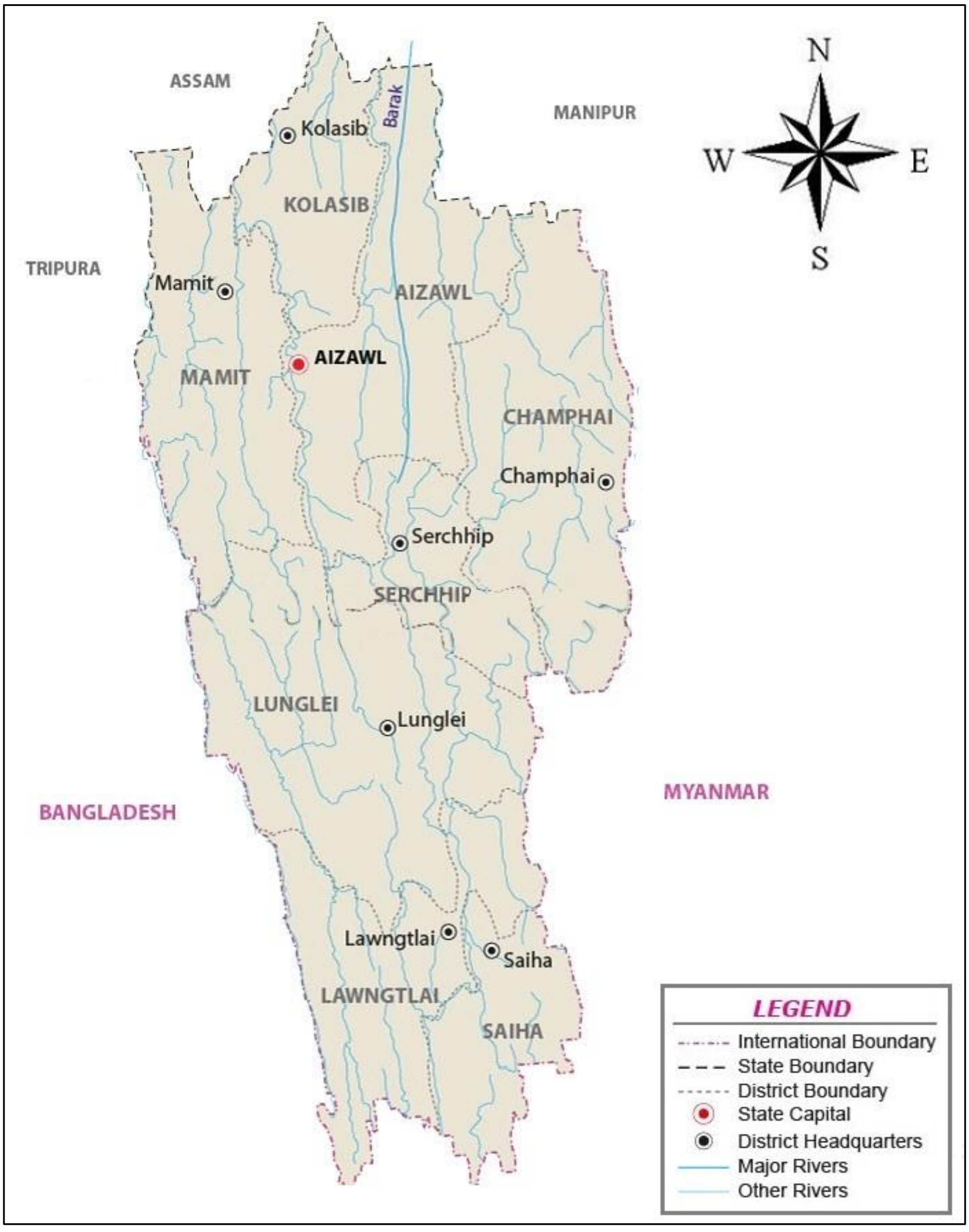
The major geographical aspects influencing the distribution of forests in Mizoram are latitude, elevation, rainfall and nature of soil. Aided by its tropical location which equips favorable climatic conditions such as adequate rainfall and moderate temperature the area is rich with copious growth of vegetation. The total forest cover in Mizoram is amounting to 19,240 km^2 which is about 91.27% of the total geographical area of state (Forest Survey of India, 2009). The forests of Mizoram can be classified into three broad categories, namely Tropical Wet Evergreen Forest, Tropical Semi Evergreen Forest and Mountain Sub-Tropical Forest (Pachuau, 1991).

Some of the common species found in Mizoram include *Tectona grandis* (Tlawr) *Michelia Champaca* (Ngiau), *Anthocepphalus maculate* (Banphar), *Ficus benghalenis* (Hmawng), *Artocarpus chaplasha* (Tatkawng), *Schima wallichii* (Khiang), *Emblica officinalis* (Sunhlu), *Rhus javanica* (Khawmhma). Bamboos are the most abundant floral group in the entire state and covering almost 80% of the total vegetation of Mizoram. The temperate evergreen forest in the state serves as a large store house of numerous striking orchid species accounting to approximately 150 identified species.

Anthropogenic disturbances such as traditional jhum or shifting cultivation, clearing of forest for developmental activities, over exploitation, damage due to fire and over-grazing have led to serious threat to the valuable forest assets.

3.1.6 Drainage System

The development and pattern of drainage system of the area are affected by surface configuration like relief, slope and dissection. A number of rivers of innumerable length flow throughout the state of Mizoram. Some of the important rivers are Tlawng (Dhaleswari), Tuirial (Sonai), Serlui (Rukni), and Tuivawl, which drain the northern part of the state and eventually fall in the Barak river in Cachar district of Assam. The southern part of Mizoram is drained by the Chimtuipui (Kolodyne) river which originates in the Myanmar. It has four major tributaries namely, Mat, Tuichang, Tiau and Tuipui. The Khawthlangtuipui (Karnaphuli) along with its tributaries drains the western part. All rivers in the state are monsoon fed and transient in nature which swell swiftly during the rainy season and recede shortly after the rain. Numerous lakes are found in the state of Mizoram which are located at several places where hills and ridges serve as a natural embankment on all sides. Palak, Tamdil, Rengdil and Rungdil are the most important lakes of the state.



Map 3.1: Drainage Map of Mizoram

3.2 KOLASIB

3.2.1 Geographical location, area and boundary

Kolasib (24˚13' 52'' N latitude and 92˚40'34''E longitude) is one of the eight districts of Mizoram, and located in the northern most part of the state. The district is bound on the west by Mamit district of Mizoram, on the south and east by Aizawl district of Mizoram, on the north and northwest by Hailakandi district of Assam, and on the northeast by Cachar district of Assam. The district occupies an area of 1382.51 km^2 which is 6.56% of the state total geographical area, and the altitude ranges from 36-900 m asl. Of the total geographical area, the reserved forest constitutes of 54.39%, and followed by forest plantation (20.74%), non-agricultural land (9.11%), cultivation area (9.22%), current fallows (5.75%) and barren and uncultivated land (0.79%).

Kolasib town is the administrative headquarters of the district. It is covered by humid subtropical hill zone and humid mild tropical zone. The district consists of two Rural Development Block (Thingdawl and Bilkhawthlir) and 31 villages with a total population of 83054 which is 7.6% of the state population. The total number of household is 12255. The population density is 60.07 per km^2 against the state average of 51.73 km^2 (Census, 2011). The average literacy rate of the district is 94.54% which is higher than the state average literacy rate i. e., 91.85%.

3.2.2 Topography

The topography of the area is undulating with parallel and sub-parallel mountainous ranges. The north-south direction is segregated by rivers which flow either north or south creating deep gorges. Owing to the forest cover, the soil is rich in humus. However, the situation is reverse in abandoned jhum lands. The soils in general is acidic in nature-pH ranging between 4.5-6, the water retention capacity is low due to high porosity, deficient in base material, medium in organic carbon, low in available phosphorus and high in potassium.

3.2.3 Climate

Kolasib district comes under the tropical monsoon climate zone and experience direct influences of southwest monsoon which receive an adequate amount of rainfall during the monsoon season. The average rainfall is 2703mm per annum. Rainfall during May-September alone contributes to 76% of the total annual rainfall. The temperature ranges between 11˚C-34˚C (average) with June and July being the warmest month and mean daily maximum of 26˚C and mean daily minimum of 23˚C which starts declining from the month of November and is minimal during December and January. The relative humidity (%) varies from 69 to about 80%.

3.2.4 Vegetation

Over 70% of the total area of the district is under forest cover consisting mainly of tropical wet evergreen forest and tropical semi evergreen forest associated with moist deciduous forests and bamboo forests. Depending on the density of the canopy cover the forest have been divided into dense/closed, medium dense and open forest.

3.2.5 Drainage System

A number of streams, rivulets, and a few rivers of various length and pattern drain the Kolasib district. Some of the major rivers flowing through the district are Tlawng, Tuirial, Chhimluang, Chempui, Serlui etc which flows from south to north and finally confluences to Barak river of Assam. According to the Watershed Atlas of India, the entire district of Kolasib is divided into two sub-catchments based on the geomorphology of the area namely the Eastern Drainage System (Tuirial and Serlui drainage system) and Western Drainage System (Tlawng, Meidum and Tuichhuahen drainage system).

3.3 Serlui River

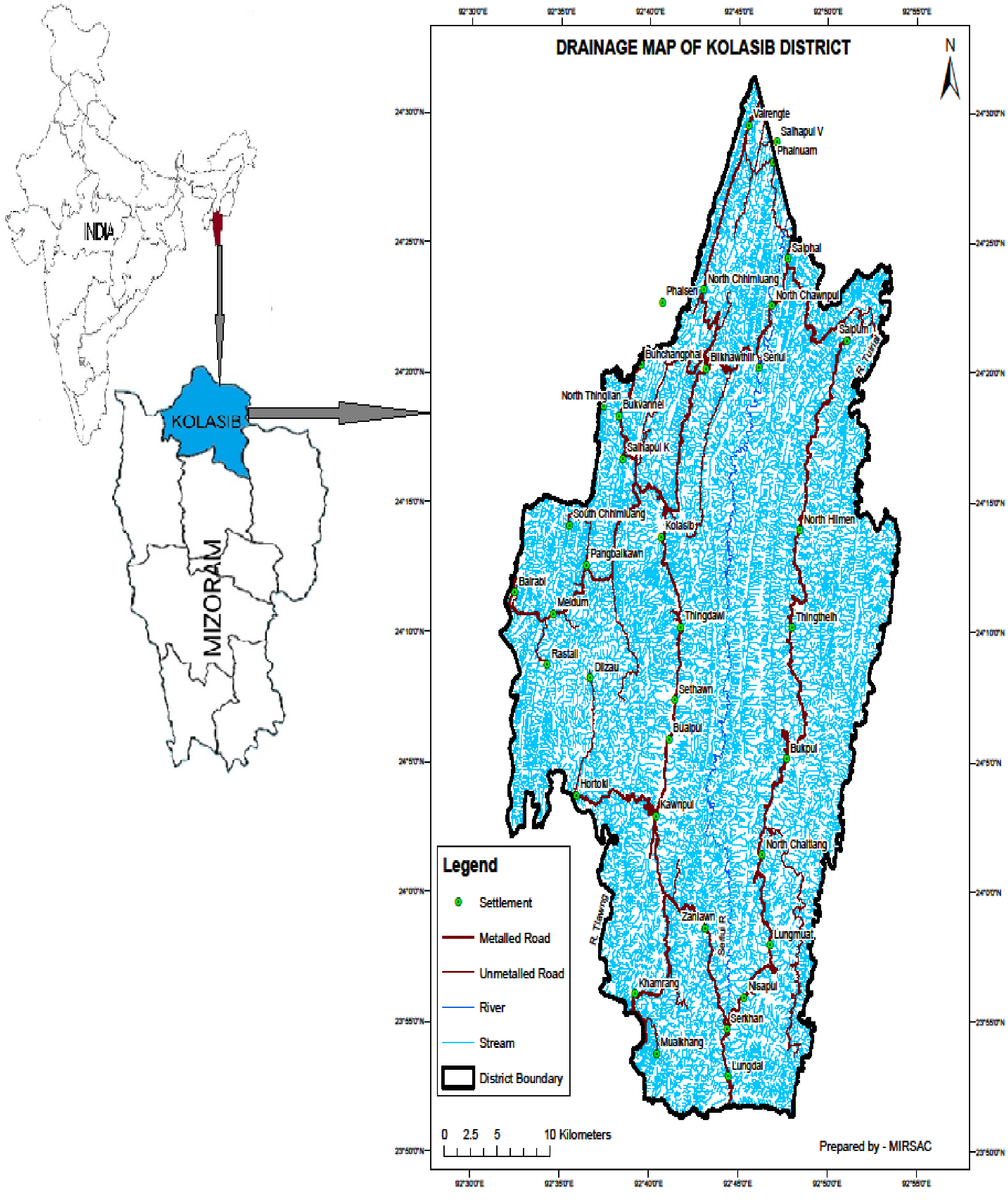
The Serlui (Rukni) river originates from the Serkhan village in the southern part of Kolasib district of Mizoram, and flows in the northward direction till it confluence with the Tuirial river in the Cachar district of Assam and finally discharges into the Barak river. Among the various drainage systems, Serlui River is one of the major sources of water within the district with a length of about 55km and width of 1.5km. From the agricultural outlook, it is the single most important water system in the district with an immense fluvial plain along its course providing a productive agricultural land. The major tributaries of the Serlui river are Chemlui, Saihapui lui and Builum lui which are confined to the northern part of the district and have an important characteristic as sub-dendritic pattern creating fluvial fertile plain along their course.

3.4 Serlui- B Dam

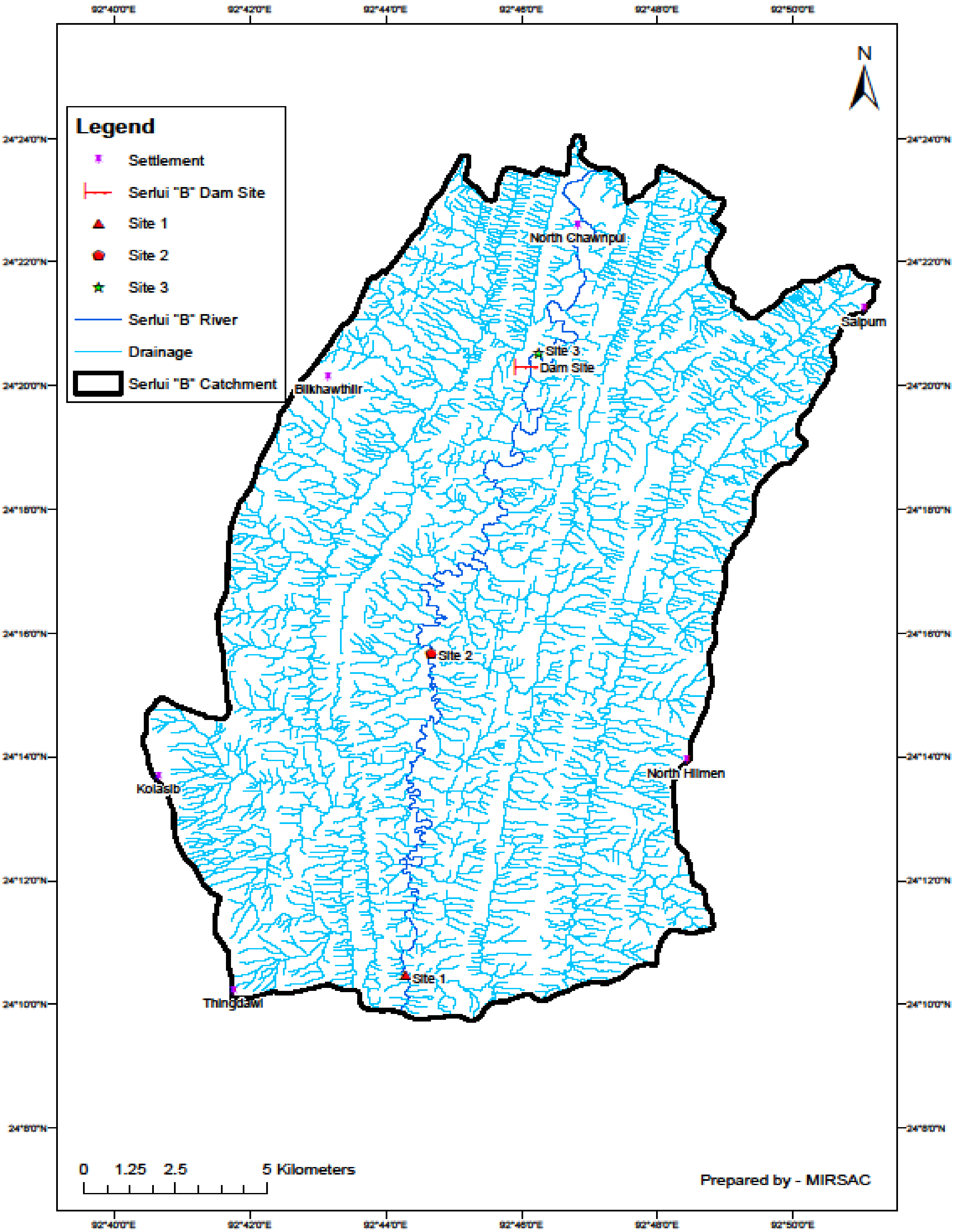
The Serlui river is impounded by the Serlui-B dam (24˚20̓18'' N latitude and 92˚46'48''E longitude), located at 12km from the Bilkhawthlir village in the Kolasib district of Mizoram. It is a 293m (961 feet) long, 51m (167 feet) high, 8m narrow top and 394.2m wide bottomed earthfill embankment dam with a 135m pressure tunnel, 415m headrace tunnel and a semi-ground power house. The hydel project has 3 units with a capacity to generate 12MW power. The dam creates a reservoir catchment area of 53 square kilometers with life storage capacity of 453.59 cubic million. The Builum village is completely submerged due to the construction of the dam, and the affected villagers are rehabilitated to a new location Bawktlang near Kolasib. As per the Builum Inquiry Commission, it has the dubious distinction of creating the first official 'dam refugees' in the state.

Keeping in view, the components of the hydro-electric power project, following three sampling points along the river were selected to study the water quality of Serlui river and diversity-distribution of aquatic macrophytes as per the objectives of study.

1. **Site 1-** Situated at the upstream of the dam with least anthropogenic activities and maintains its natural flow, and is demarcated as reference site (Control site) to compare the findings recorded at other sites, for impact analysis.
2. **Site 2-** Reservoir where the flow of the water recedes with the development of the dam.
3. **Site 3-** Downstream of the river, where **c**onfluence of diversion outlet, spillover and power house meets.



Map 3.2 Location Map of study area



Map 3.3 Location map of study sites

Photo plate 3.1: Site 1- Control site, situated at the upstream of the dam

Photo plate 3.2: Site 2- Reservoir, where the flow of the water recedes with the development of the dam.

Photo plate 3.3: Site 3: Downstream of river where confluence of diversion outlet, spillover and power house join together

Photo plate 3.4: Power house outlet

CHAPTER 4

METHODOLOGY

4.1 Collection of water sample

The water samples were collected from selected study sites on monthly interval (in triplicates) for two consecutive years (i.e. March 2015- February 2017) using 5 liter non-transparent plastic container with necessary precautions. After collection and proper labelling, the water samples were transported to the laboratory in ice box within 24 hours for analysis of various physico-chemical characteristics namely, Electrical Conductivity, Dissolved Oxygen, Biological Oxygen Demand, Total Hardness, Acidity, Total Alkalinity, Turbidity, Total Solids, Total Suspended Solids, Total Dissolved Solids, Chloride, Nitrate-N, Phosphate-P and Sulphate contents. Temperature and pH were recorded on spot at sampling site, and samples were fixed at site for DO estimation. The samples were stored in 4˚C for further analysis. The findings were computed and expressed seasonally i.e., Summer season (March-June), Rainy season (July-October) and Winter season (November- February).

4.2 Analytical Methods

For analysis of the various physico-chemical characteristics of the water samples, the methods as described in 'Standard Methods for Examination of Water and Wastewater' (APHA, 2005) and 'Handbook of Methods in Environmental Studies, Water and Waste Water Analysis (Maiti, 2001) were adopted.

4.2.1 Water Quality Analysis

The detailed procedures for analysis of the various physico-chemical characteristics of water are described below:

a. Temperature

Water Temperature represents one of the most important biophysical characteristics of surface water quality as it is an important factor which affects vertical mixing, dissolved oxygen and most of the biological and biochemical processes (Abdo, 2005 and Bhatt *et al.*, 2011). Temperature of water was measured by using a centigrade thermometer with a precision of 0.1degree Celsius and the result was noted in ^{0}C.

b. pH

The pH of the natural water is an important index for nature of water either acidic or basic. It is a significant indicator of water quality as all the chemical and biological reactions are governed by pH. The measurement of the pH of water is required to determine the corrosiveness of the water. pH of water was measured using Digital pH meter.

c. Electrical Conductivity (EC)

Electrical conductivity is a measure of the capacity of water to conduct an electric current, and it depends on the concentration of ions and intensity of nutrients. The EC of water was measured using HI 98312 portable EC/TDS water proof tester and the result was expressed in μS.

d. Dissolved Oxygen (DO)

Dissolved oxygen content is the concentration of oxygen in dissolved form, and is essential for the sustenance and survival of oxygen-demanding aquatic organisms. It is an important parameter which determines the purity of water. The DO content of water samples was measured by following "Modified Winkler's Azide Method". This azide titrimetric procedure is based on the oxidizing property of oxygen dissolved in water. The DO content of water was calculated using the following formula, and result was expressed in mgL^{-1}.

$$\text{DO content } (\text{mgL}^{-}1) = \frac{\text{VxNx8x1000}}{\text{mL of water sample used}}$$

$$\text{Where, V} = \text{volume of titrant used; N} = \text{normality of titrant.}$$

e. Biological Oxygen Demand (BOD)

Biological Oxygen Demand determines the amount of oxygen required by aerobic biological organisms (microorganisms) for decomposition of organic matter present in water. For estimation of BOD content of water, initial and final DO content of water samples were determined just after collection of sample and after 5 days incubation in BOD incubator at 20°C, respectively. Calculation of BOD content of water was done using the following formula and the result was expressed in mgL^{-1}.

BOD content (mgL^{-1}) = DO(I) – DO(F)

Where, DO (I) = Dissolved Oxygen content of water before incubation.

DO (F) = Dissolved Oxygen content of water after incubation.

f. Total hardness

Total hardness of water is primarily the measure of the concentration of calcium and magnesium ions in water. Total Hardness is defined as the sum of calcium and magnesium hardness in mgL^{-1} as $CaCO_3$. Total Hardness was measured using Ethylene-Diamine-Tetra-Acetic (EDTA) titration method. In alkaline condition, EDTA or its sodium salt (Na_2EDTA) react with Ca^{++} and Mg^{++} to form a soluble complex. The Ca^{++} and Mg^{++} develop a wine red colour when small amount of dye such as Erichrome Black T is added under alkaline condition. When EDTA is used as a titrant, the Ca^{++} and Mg^{++} are complexed with EDTA, and resulting into a sharp change from wine red to blue colour which indicates the end point. The Total hardness was calculated by using the following formula, and values were expressed in $mgl^{-1}CaCO_3$.

$$\text{Total Hardness } (mgl^{-1}CaCO_3) = \frac{CXDX1000}{\text{Volume of water sample used}}$$

Where,

C = Vol. of EDTA required by sample.

D = mg $CaCO_3$ equivalent to 1ml EDTA titrant (1ml for 0.01N EDTA).

g. Acidity

Acidity of water is its quantitative capacity to react with a strong base to a designated pH. The water sample with a pH lowers than 8.5 contains acidity. The total acidity of water sample was measured by using potentiometric titration method. Sodium hydroxide (0.02N) was used as a titrant. Acidity is mainly of two types namely: Methyl orange acidity or mineral acidity and Phenolphthalein acidity or CO_2 acidity. Both mineral acidity and CO_2 acidity can be measured by means of standard solutions of alkaline reagents. The concentration of minerals acids can be measured by titration or neutralizing the samples to pH 4.3. The CO^2 and bicarbonates (carbonic acid) acidity can be neutralized by continuing the titration to pH 8.3. Acidity was calculated using the following formula, and values were expressed in $mgL^{-1}CaCO_3$.

$$\text{Acidity } (mgL^{-1}CaCO_3) = \frac{\text{Vol.of titrant used } (0.02N\ NaOH)x1000}{\text{Vol.of water sample used}}$$

h. Total Alkalinity

Total alkalinity is primarily defined as a measure of the acid neutralizing capacity of water. The total alkalinity of water samples was measured using potentiometric titration method. Standard sulphuric acid (0.02N) was used as a titrant to lower down the pH of sample at 8.3(phenolphthalein alkalinity) and to pH 3.7 (methyl orange alkalinity). Total alkalinity was calculated using the following formula, and values were expressed in $mgL^{-1}CaCO_3$.

$$\text{Total Alkalinity } (mgL^{-1}CaCO_3) = \frac{(A-B) \times 1000}{\text{Volume of sample taken}}$$

Where,

A = Alkalinity due to Phenolphthalein

B = Alkalinity due to Methyl Orange

i. Turbidity

Turbidity is the cloudiness or haziness of a water sample caused by a number of individual particles usually invisible to the naked eyes. It is the scattering of the beam of light on water surface, showing Tyndall phenomenon. The turbidity of the water samples was determined using Nephalometer which measures the intensity of light scattered at 90 degrees as a beam of light passes through the water sample. The higher the intensity of scattered light the higher is the turbidity. The values were expressed in NTU.

j. Total solid (TS), Total suspended solid (TSS) and Total dissolved solid (TDS)

Total Solid, Total suspended solid and Total dissolved solid were measured by using filtration and evaporation methods. Total solids includes all the solids present in a water sample and is determined directly by evaporating and subsequent drying of a known volume of unfiltered sample in an oven at 105˚C. Total Solids was calculated by using following formula, and vales were expressed in mgL^{-1}.

$$TS\ (mgL^{-1}) = \frac{A-B}{V} X 1000$$

Where,

A = Final weight of the crucible

B = Initial weight of the crucible

V = Volume of water sample evaporated (ml)

Total dissolved solid is the amount of total mobile ions including minerals, salts or metals dissolved in a given volume of water and is determined by evaporating a known volume of filtrate solution in an oven at 105˚C. Total Dissolved Solid was calculated by using the formula, and vales were expressed in mgL^{-1}.

$$TDS\ (mgL^{-1}) = \frac{A-B}{V} X 1000$$

Where,

A = Final weight of the crucible

B = Initial weight of the crucible

V = Volume of water sample evaporated (ml)

Total Suspended Solid includes all particles suspended in water. TSS is determined as the difference between the Total Solids and Total Dissolved Solid. TSS was calculated by using following formula, and vales were expressed in mgL^{-1}.

$$TSS\ (mgL^{-1}) = TS - TDS$$

Where,

TSS = Total Suspended Solids

TS = Total Solids

TDS = Total Dissolved Solids.

k. Chloride

Chloride in the form of chloride ion (Cl^-) is one of the major inorganic anions present in water and waste water. The chloride content of water was determined by using modified Mohr's Argentometric titration method. Silver Nitrate (0.041N) solution was used as a titrant. $AgNO_3$ reacts with chloride to form slightly soluble silver salts in a weak acid solution which precipitate as AgCl. The brick red silver chromate is formed at the end point. Chloride content of water was calculated using the following formula, and result was expressed in $mgL^{-1}CaCO_3$.

$$\text{Chloride}(mgL^{-1}) = \frac{\text{Vol.of titrant used x 0.0141 x 35.45}}{\text{Vol.of water sample used}} X1000$$

Where, 0.041 = Normality of Titrant

35.45= Atomic weight of Chlorine

l. Nitrate-N

Nitrate is a naturally occurring oxide of Nitrogen and is an essential component of all living organisms. Nitrate-N was measured by using Ultra Violet Spectrophotometric Method. An UV spectrophotometric technique measures the absorption at Nitrate-N at 220 nm OD which is suitable for screening uncontaminated water (low in dissolved organic matter). A second measurement made at 275nm OD maybe used to correct the nitrate-N value as 275nm is not absorbed by NO_3^- , but absorbed by other matter. The results were expressed in mgL^{-1}.

m. Phosphate-P

Phosphate is an element that occurs naturally in water in low concentration which governs the reproduction and growth of aquatic organisms. The stannous chloride colorimetric method was used for the determination of phosphate-P content of the water samples. The absorbance of colour was observed at 690nm OD in a spectrophotometer and compared with a calibration curve. Phosphate-P content was calculated using the following formula, and result was expressed in mgL^{-1}.

$$\text{Phosphate } (mgL^{-1}) = \frac{\text{mg of P (in approx.104.5ml final volume)x 1000}}{\text{ml of water sample used}}$$

n. Sulphate

Sulphate is widely distributed in nature and may be present in natural water in wide ranging concentration. The Sulphate content of water was measured by using Spectrophotometric method. Sulphate ion (SO_4^{2-}) in water has a tendency to precipitate as a uniform suspension of $BaSO_4$, on reaction with $BaCl_2$ under acidic conditions in which the tendency increases in the presence of conditioning agent. The amount of precipitation is proportional to the concentration of Sulphate ions in the sample. The absorbance of the $BaSO_4$ was observed at 420nm using spectrophotometer, and the Sulphate concentration was determined by comparison of reading with standard curve. The result was expressed in mgL^{-1}.

4.2.2 Water Quality Index (WQI)

Water Quality Index may be defined as an overall rating of the water quality status which reflects the combined effect of various water quality parameters. The calculation of WQI was carried out using Arithmetic index method (Brown *et al.,* 1972). The WQI is calculated by using the expression as follows.

$$\mathrm{WQI} = \sum_{n=1}^{n} q_n W_n / \sum_{n=1}^{n} W_n$$

Where, qn= Quality rating of nth water quality parameter.

Wn= Unit weight of nth water quality parameter.

Quality rating (q_n): The quality rating is calculated using the formula given below:-

$$q_n = [\ (V_n - V_{id}) / (S_n - V_{id})] \times 100$$

Where, V_n= Estimated value of nth water quality parameter at a given sampling site.

V_{id}= Ideal value for nth parameter in pure water.

(In most cases Vid= 0, except for pH= 7.0 and D.O= 14.6)

S_n= Standard permissible value of nth water quality parameter.

Unit Weight (Wn): The unit weight is calculated using the formula:-

$$W_n = k/S_n$$

Where,

S_n= Standard permissible value of nth water quality parameter.

k= Constant of proportionality and it is calculated by using the formula:-

$$k = [1/(\Sigma 1/S_{n=1,2,..n})\ ]$$

4.2.3 Diversity-distribution of Aquatic Macrophytes

4.2.3.1 Sampling, Identification and Enumeration of Aquatic Macrophytes

The sampling technique used to study phytosociological attributes was the Standard Quadrat Method (Curtis 1959 and Misra, 1968). A total of 270 quadrats of 1m x 1m size laid randomly (90 in each season and 30 at each sampling site). The aquatic macrophytes present at each quadrat were collected, enumerated and identified taxonomically unto the species level by field observation, herbarium specimens, and with the help of experts from Botanical Survey of India, Eastern Circle, Shillong, and counter-checked with standard literature (Cook, 1996).

4.2.3.2 Analysis of Phytosociological Characteristics

Phytosociological attributes are the pre-requisite for understanding the vegetation structure and dynamics of any ecosystem. A community population is characterized by its species diversity, growth forms and structure, dominance and successional trends. To study the details of these aspects of any community a series of attributes (parameters) are taken into consideration. These are then used to express the diversity-distribution of the community.

A detailed investigation on various quantitative characteristics comprising of frequency, density, abundance, ratio of abundance to frequency, relative frequency, relative density, relative abundance and importance value index (IVI) was conducted. The calculation for the frequency, density, abundance was done for each species individually (Misra, 1968 and Ambasht, 1969). Importance value index was computed by considering the values of relative frequency, relative density and relative abundance (Cottam and Curtis, 1956). The following formulae were used for the calculation of the various attributes.

a. Frequency

Frequency is the degree of dispersal of individual species in an area and is usually expressed in terms of percentage occurrence. Frequency of each species was calculated as follows.

$$\text{Frequency (\%)} = \frac{\text{Number of quadtrats in which the species occurs}}{\text{Total number of quadrats studied}} \text{ x } 100$$

b. Density

Density represents the numerical strength of a species in the community. It defines number of individuals per unit area. Density gives an idea of degree of competition. Density of each species was calculated as follows, and the values were expressed as number of individuals per unit area.

$$\text{Density} = \frac{\text{Total number of individuals of a species in all the quadrat}}{\text{Total number of quadrats studied}}$$

c. Abundance

It is the number of individuals of any species per sampling unit of occurrence. The value of abundance along with the frequency gives an idea of the distribution pattern of the species in a community.

Abundance of each species was calculated as follows.

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all the quadrats}}{\text{Numberof quadrats of occurrence}}$$

d. Relative Frequency (%)

It is the degree of dispersion of individual species in relation to the total number of individual of all the species occurred, and it can be calculated as follows.

$$\text{Relative Frequency (\%)} = \frac{\text{Number of occurence of a species}}{\text{Number of occurence of all species}} \text{ x } 100$$

e. **Relative Density (%)**

Relative density is the study of numerical strength of a species in relation to total number of all species, and it can be calculated as follows.

$$\text{Relative Density} = \frac{\text{Number of individuals of a species in all the quadrats}}{\text{Number of individuals of all species in all the quadrats}} \times 100$$

f. **Relative Abundance (%)**

Determination of the basal area for the estimation of dominance is often inconvenient in the aquatic community because the aquatic species have different life forms (emergent, free-floating, rooted with floating leaves and submerged). Therefore, to evade the shortcomings in the determination of the basal area of the aquatic plants, Relative Dominance has been replaced by Relative Abundance. The abundance value of a species in relation to the total abundance of all the species gives the relative abundance of the species. The Relative Abundance of a species can be calculated as follows.

$$\text{Relative Abundance (\%)} = \frac{\text{Abundance of a species}}{\text{Abundance of all species}} \times 100$$

g. **Importance Value Index (IVI)**

The Importance Value index is used to determine the overall importance of a species in the community. The IVI can be calculated summing the values of relative density, relative frequency and relative abundance, species-wise. The IVI of a species can be calculated as follows.

IVI = Relative Density + Relative Frequency + Relative Abundance

h. Distribution pattern

The possible nature of distribution pattern of a species is expressed by the ratio of Abundance to Frequency (A/F ratio). The distribution pattern of the aquatic macrophytes was computed using A/F ratio (Whitford, 1948). A ratio less than 0.025 indicates regular distribution, 0.025-0.05 random distribution and >0.05 indicates contagious (clumped) distribution. The distrution pattern of a species can be calculated as follows.

$$\text{A/F ratio} = \frac{\text{Abundance of a species}}{\text{Frequency of a species}}$$

i. Shannon's diversity Index (H_S)

One of the most enduring measures for denoting diversity is the Shannon Index. The index assumes that individuals are randomly sampled from an infinitely large community (Shannon and Weaver, 1963), and that all species are represented in the sample. The Shannon Index is calculated using following equation.

$$H' = - \sum p_i l_n p_i$$

Where,

H'= Shannon index of diversity

p_i = the proportion of importance value of the ith species

Or $p_i = n_i/N$

Where, n_i = importance value index of the i^{th} species.

N = importance value index of all species.

The values of the Shannon's diversity index for real communities are often found to fall between1.5 to 3.5 and rarely surpass.

j. **Menhinick diversity index (D_{mn})**

The Menhinick diversity index (Menhinick, 1964) was calculated using the following formula.

$$d = S/\sqrt{N}$$

Where,

S= total number of species

N= total number of individuals of all the species

k. **Simpson Dominance Index (D_S)**

Simpson (1949) gave the probability of any two individuals drawn at random from an infinity large community belonging to the same species. The form of the index appropriate for a finite community is represented by following.

$$D_S = \sum (pi)^2$$

Where, p_i = the proportion of importance value of the ith species

Or $p_i = n_i/N$

n_i = importance value index of the i^{th} species.

N = importance value index of all species.

As the Simpson's index values increases, diversity decreases. Simpson index is therefore usually expressed as "1 – D" or "1/D".

l. **Species richness (D_{mg})**

The species richness of the aquatic macrophytes was calculated by following Margalef (1958) with equation as given below.

$$\text{Species richness } (D_{mg}) = \frac{S-1}{\ln N}$$

Where, S= total number of species

N= total number of individuals

m. Species Evenness Index (E)

The evenness index (Pielou's index, 1966) was calculated following the equation as given below.

$$J' = H'/\ln S$$

Where, H'= Shannon's diversity index

S= total number of species

n. Similarity and Dissimilarity Indices

Similarity and dissimilarity indices were computed for aquatic macrophytes between different study sites. The calculation was made as per equation given by Sorensen (1948).

$$\text{Index of Similarity (S)} = \frac{2C}{A+B}$$

Where, A= Number of species in the community A

B= Number of species in the community B

C= Number of species common in both the communities

4.2.4 Floristic Analysis of Catchment Area

Extensive field survey was made for documentation of plant species found in undisturbed and disturbed (clearing of vegetation for dam construction) patches of vegetation in the catchment area of river, to assess the impact hydro-elecric project on composition of plants in catchment area. The specimen of each species from the selected study sites was collected, enumerated and identified taxonomically unto the species level by field observation, herbarium specimens, and with the help of experts from Botanical Survey of India, Eastern Circle, Shillong and counter-checked using various regional floras namely, Flora of Assam, Vol. 1-5 (Kanjilal *et al.* 1934) and Flora of Mizoram, Vol. 1 (Singh *et al.* 2002). The ethno-botanical important plants were identified with the help of various literature namely, Ethno-Medicinal Plants of Mizoram (Lalramnghinglova, 2003); the book of Mizoram Plants (Sawmliana, 2013); Herbal Wealth of North-East India (Bhutani, 2008).

The similarity index between the selected study sites was calculated using Sorenson's similarity index (1948).

$$\text{Index of Similarity (S)} = \frac{2C}{A+B}$$

Where,

A= Number of species in the community A

B= Number of species in the community B

C= Number of species common in both the communities

Statistical analyses

The statistical analyses were performed for all possible aspects of study to check the significance and validity of observations recorded so far especially on physico-chemical characteristics of water (significance level 0.05), the correlation coefficient (r) was calculated using the computer software SPSS 16.0. The linear regression model was developed for water quality parameters having highly significant correlation coefficients (r) using SPSS 16.0 and MS-Excel 2013.The findings on water quality attributes were expressed as average mean values for two years data (March 2015 to February 2017). Two way ANOVA was also calculated with respect to water quality attributes within and between sites.

CHAPTER 5

RESULTS

The findings on the water quality characteristics of Serlui river, phytosociology of aquatic macrophytes and floristic diversity in the catchment area of river are presented as follows.

5.1 Water Quality Analysis

5.1.1 Physico-chemical Characteristics

a. Temperature

The water temperature ranged from 22.5 ˚C to 35.1 ˚C during the study period (Table 5.1). The lowest value (23.9˚C) was recorded at Site 1 in the winter season, and it was highest (33.8˚C) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the water temperature was lowest (22.5˚C) at Site 1 in the winter season, and highest (35.1˚C) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The water temperature was recorded to be lower during the winter and higher during the rainy seasons in both the years and at all the study sites (Fig: 5.1).

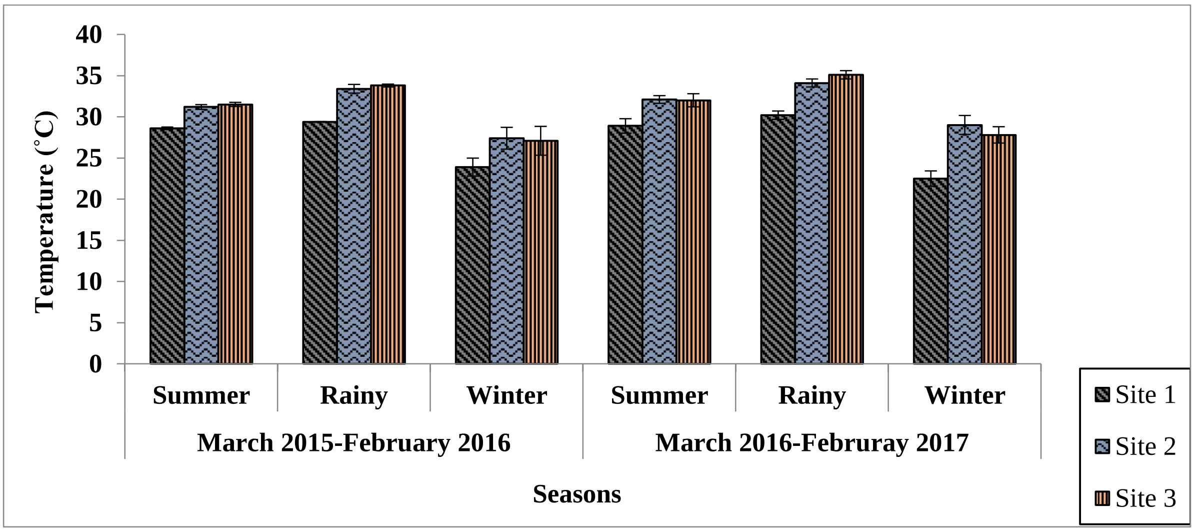


Fig 5.1: Seasonal variation in Temperature of water at selected study sites

b. pH

The water pH ranged from 5.9 to 7.5 during the study period (Table 5.1). The lowest value (6.2) was recorded at Site 3 in the rainy season, and highest (7.5) at Site 2 in the winter season during the year 2015-2016 (Table 5.2). Similarly, the water pH was lowest (5.9) at Site 3 in the rainy season, and highest (7.5) at Site 2 in the winter season during the year 2016-2017 (Table 5.3). The water pH was recorded to be lower during the rainy season and higher during the winter season in both the years and at all the selected study sites (Fig: 5.2). The results reveal that the values were lower than the prescribed limit of water quality as prescribed by various scientific agencies (Appendix I).

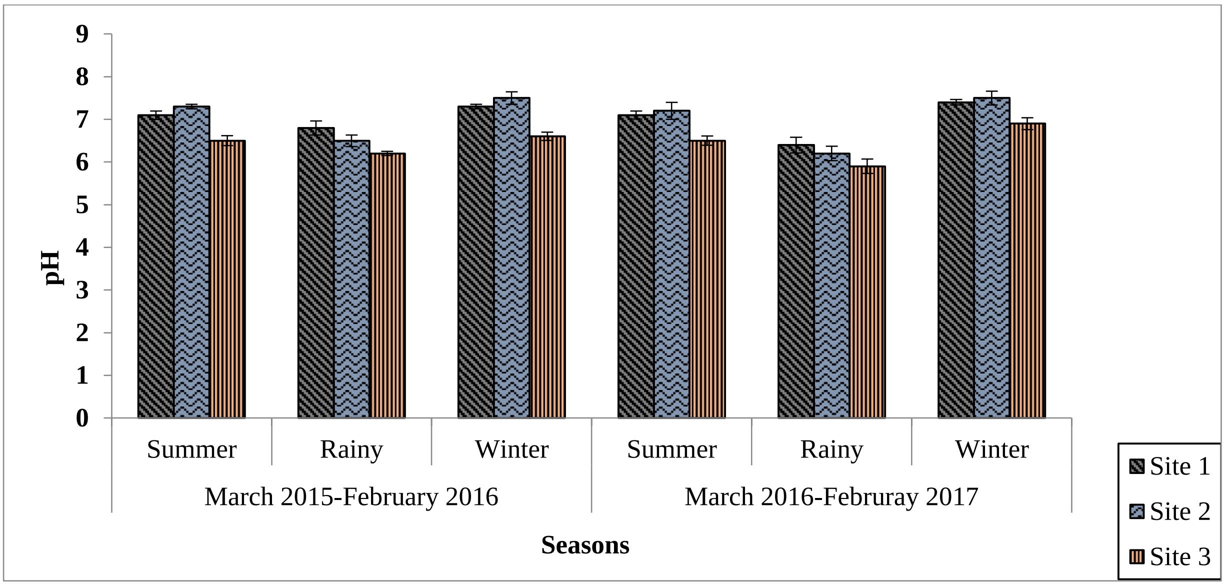


Fig 5.2: Seasonal variation in pH of water at selected study sites

c. Electrical Conductance (EC)

The Electrical Conductance (EC) ranged from 94 µS -186 µS during the study period (Table 5.1). The lowest value (94µS) was recorded at Site 1 in the winter season, and highest (142µS) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the water EC was lowest (100µS) at Site 1 in the winter season, and highest (186µS) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The EC was observed to be lower during the winter and higher during the rainy season in both the years and at all the selected study sites (Fig: 5.3). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

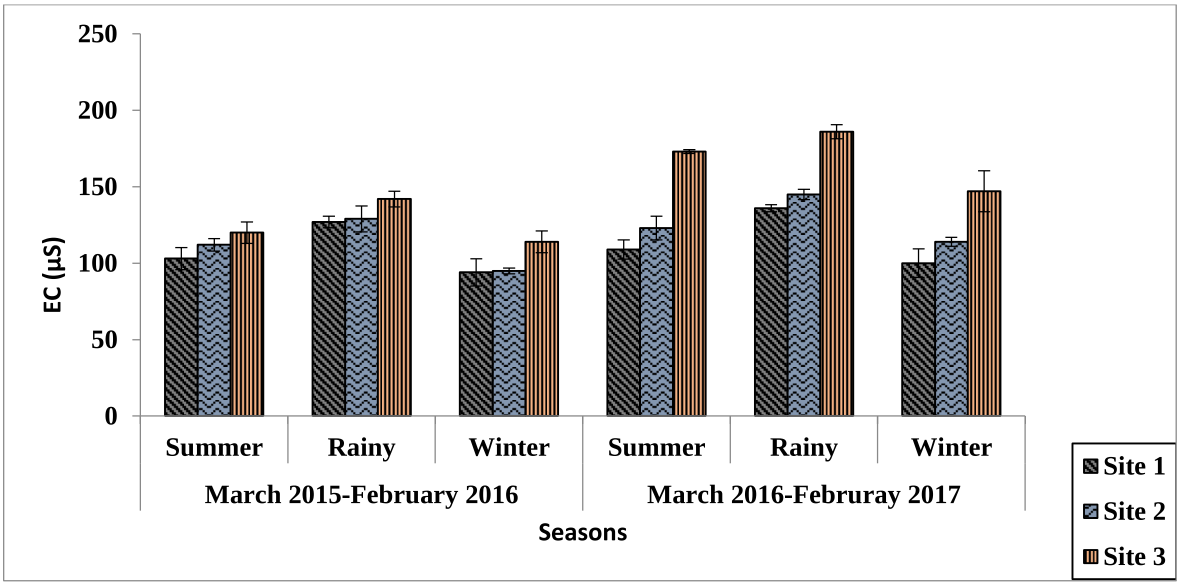


Fig 5.3: Seasonal variation in EC of water at selected study sites

d. Dissolved Oxygen (DO)

The DO content of water ranged from 4.6 mgL^{-1} to 8mgL^{-1} during the study period (Table 5.1). The lowest value (6.2 mgL^{-1}) was recorded at Site 3 in the rainy season, and highest (7.5 mgL^{-1}) at Site 2 in the winter season during the year 2015-2016 (Table 5.2). Similarly, the water DO was lowest (4.6 mgL^{-1}) at Site 3 in the rainy season, and highest (8 mgL^{-1}) at Site 2 in the winter season during the year 2016-2017 (Table 5.3). The DO content was recorded to be lower during the rainy seasons and higher during the winter season at all the selected study sites (Fig: 5.4). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

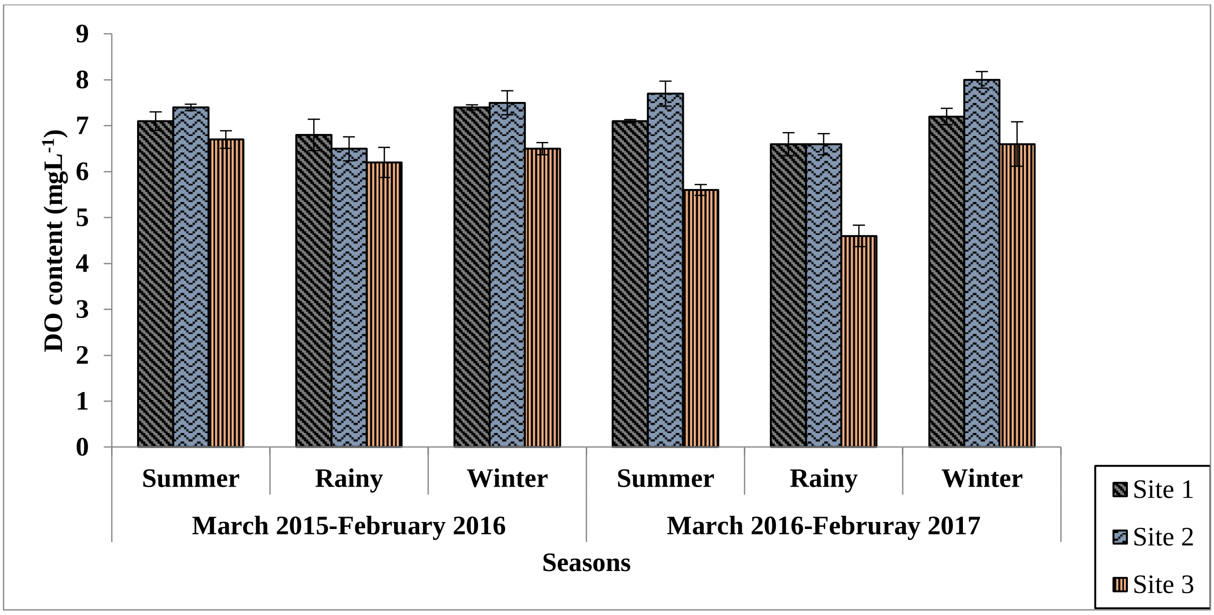


Fig 5.4: Seasonal variation in DO content of water at selected study sites

e. Biological Oxygen Demand (BOD)

The BOD content of water ranged from 0.7 mgL^{-1} to 2.9 mgL^{-1} during the study period (Table 5.1). The lowest value (0.8 mgL^{-1}) was recorded at Site 1 in the winter season, and highest (1.9 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the value was lowest (0.7 mgL^{-1}) at Site 2 in the winter season, and highest (2.9 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The BOD was recorded to be lower during the winter and higher during the rainy seasons at all the selected study sites (Fig: 5.5). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

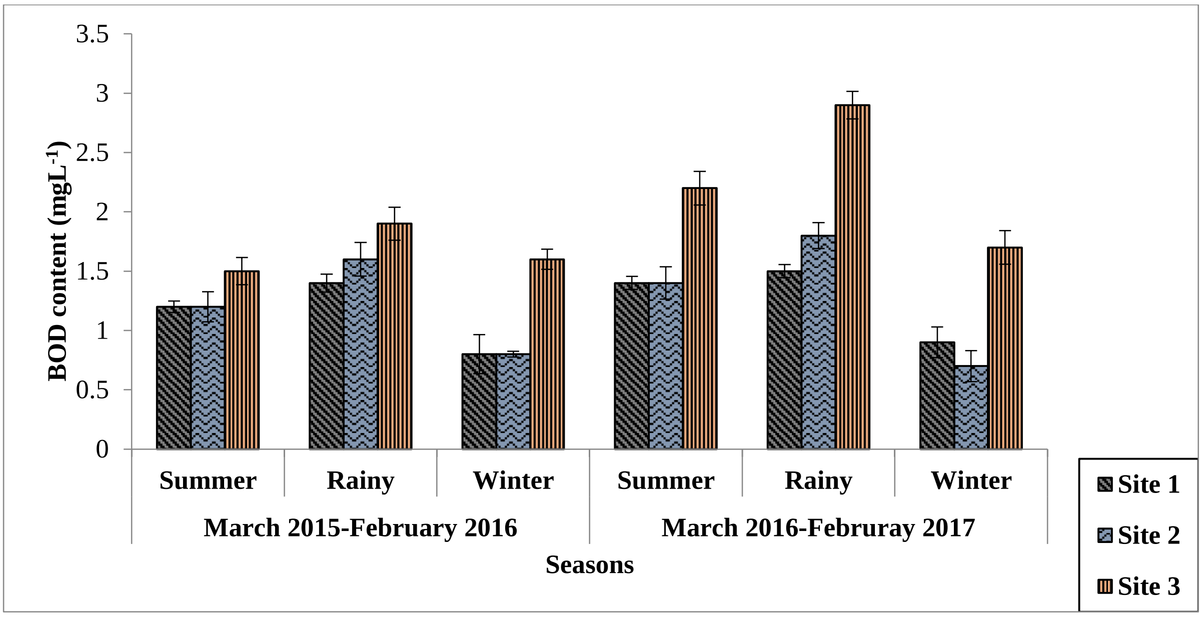


Fig 5.5: Seasonal variation in BOD content of water at selected study sites

f. Total Hardness

Total Hardness ranged from 47 mgL^{-1} to 253 mgL^{-1} during the study period (Table 5.1). The lowest value (47 mgL^{-1}) was recorded at Site 1 in the summer season, and highest (232 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the lowest value (55 mgL^{-1}) was recorded at Site 1 in the summer season, and highest (253 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The value was recorded to be lower during the summer and higher during the rainy seasons at all the selected study sites Fig: 5.6). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

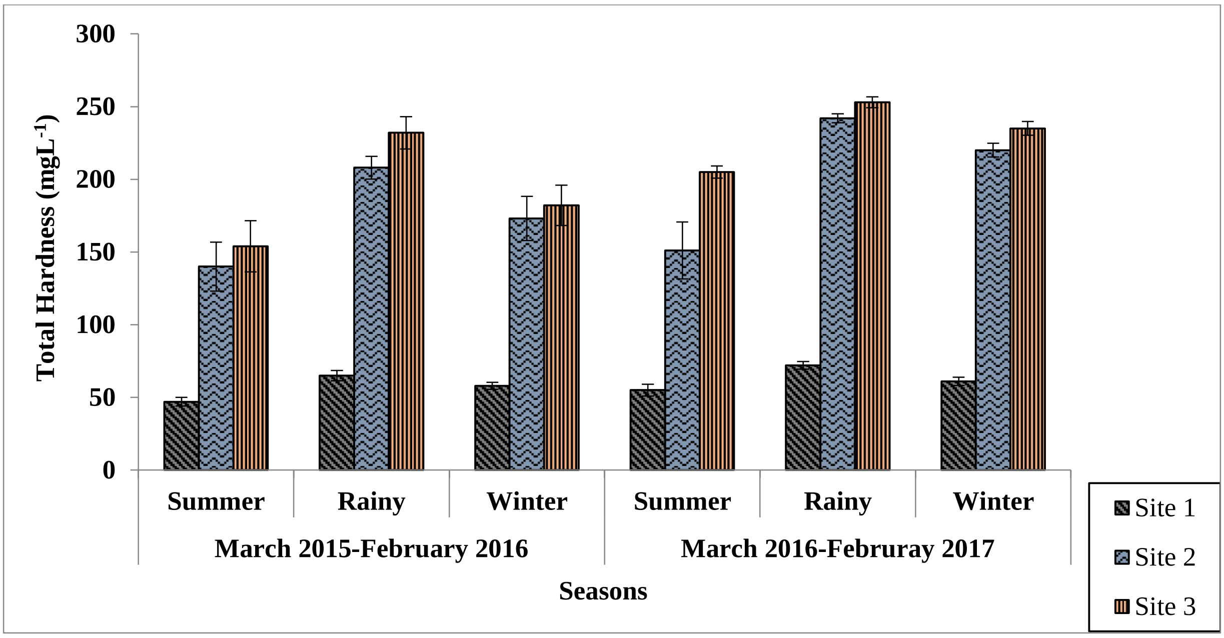


Fig 5.6: Seasonal variation in Total Hardness of water at selected study sites

g. Acidity

Acidity value of water ranged from 36 mgL^{-1} to 72 mgL^{-1} during the studied period (Table 5.1). The lowest value (36 mgL^{-1}) was recorded at Site 1 in the summer season, and highest (66 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the acidity was lowest (37 mgL^{-1}) at Site 1 in the summer, and highest (72 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The acidity content of water was recorded to be lower during the summer and higher during the rainy seasons at all the selected study sites (Fig: 5.7).

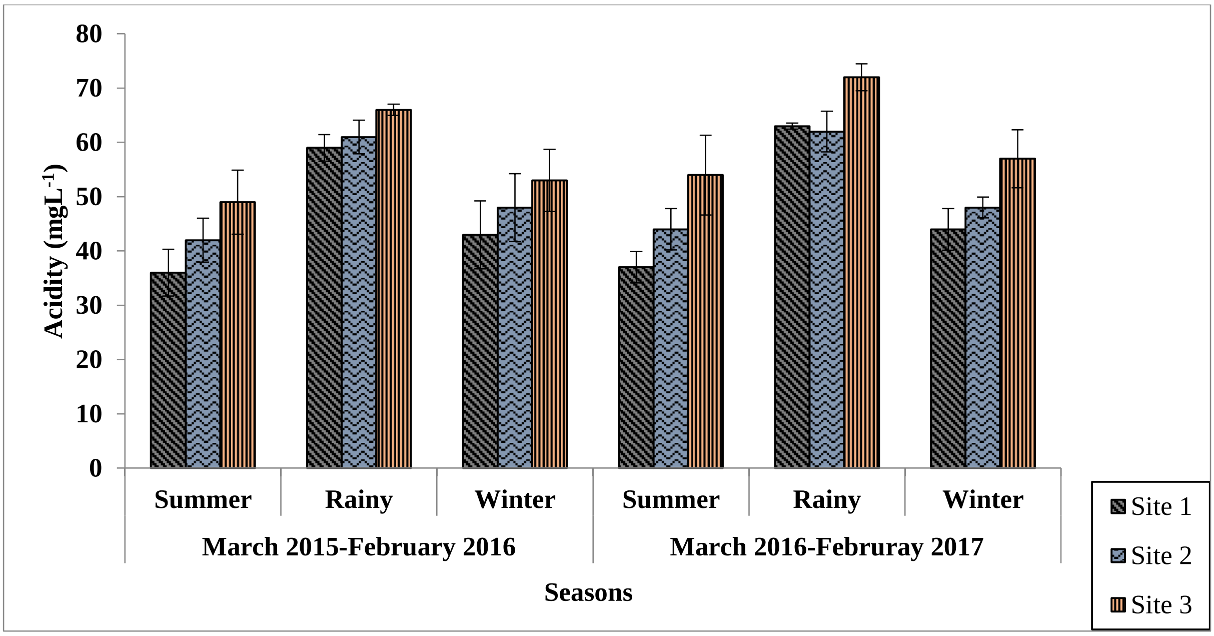


Fig 5.7: Seasonal variation in Acidity of water at selected study sites

h. Total Alkalinity

Total Alkalinity of water ranged from 34 mgL^{-1} to 67 mgL^{-1} during the study period (Table 5.1). The lowest value (34 mgL^{-1}) was recorded at Site 3 in the winter season, and highest (59 mgL^{-1}) at Site 2 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the value was lowest (34 mgL^{-1}) at Site 1 in the winter season, and highest (67 mgL^{-1}) at Site 2 in the rainy season during the year 2016-2017 (Table 5.3). The alkalinity was recorded to be lower during the winter and higher during the rainy seasons at all the selected study sites (Fig: 5.8). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

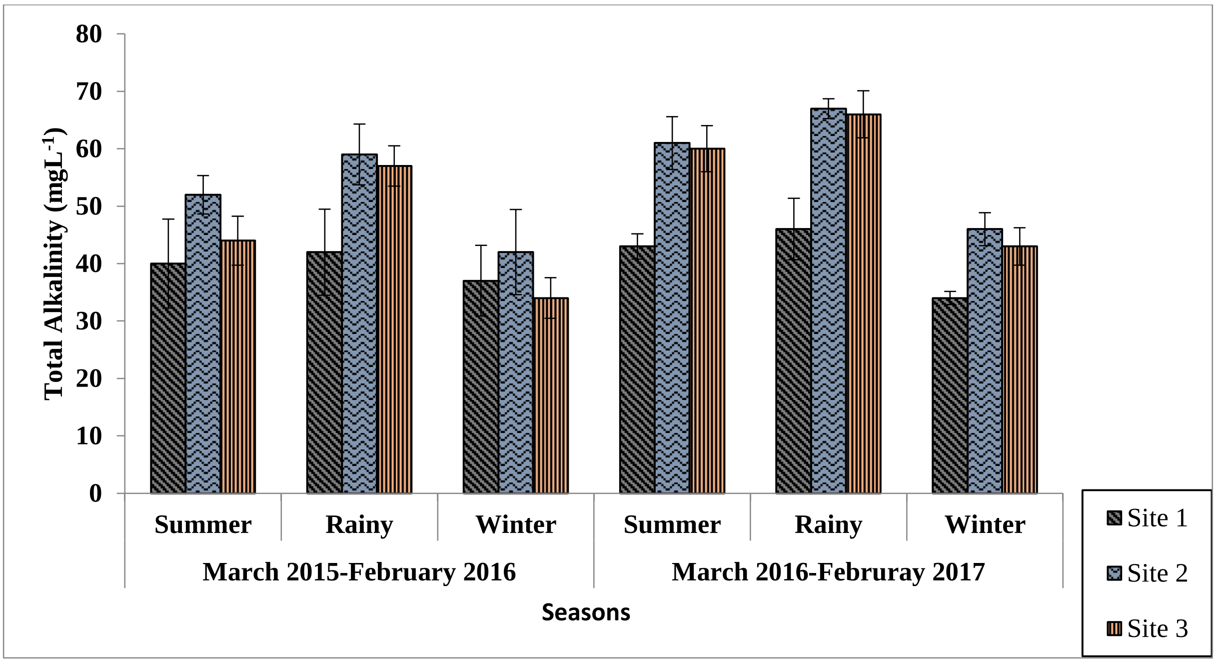


Fig 5.8: Seasonal variation in Total Alkalinity of water at selected study sites

i. Turbidity

Turbidity of water ranged from 0.8 NTU to 14.4 NTU during the study period (Table 5.1). The lowest value (0.8 NTU) was recorded at Site 1 in the winter season, and highest (10.5 NTU) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the value was lowest (1.0 NTU) at Site 1 in the winter, and highest (14.4 NTU) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The values were recorded to be lower during the winter season and higher during rainy season at all the study sites (Fig: 5.9). The results reveal that all the values of turbidity recorded were higher than the prescribed limit of water quality as prescribed by BIS (Appendix I).

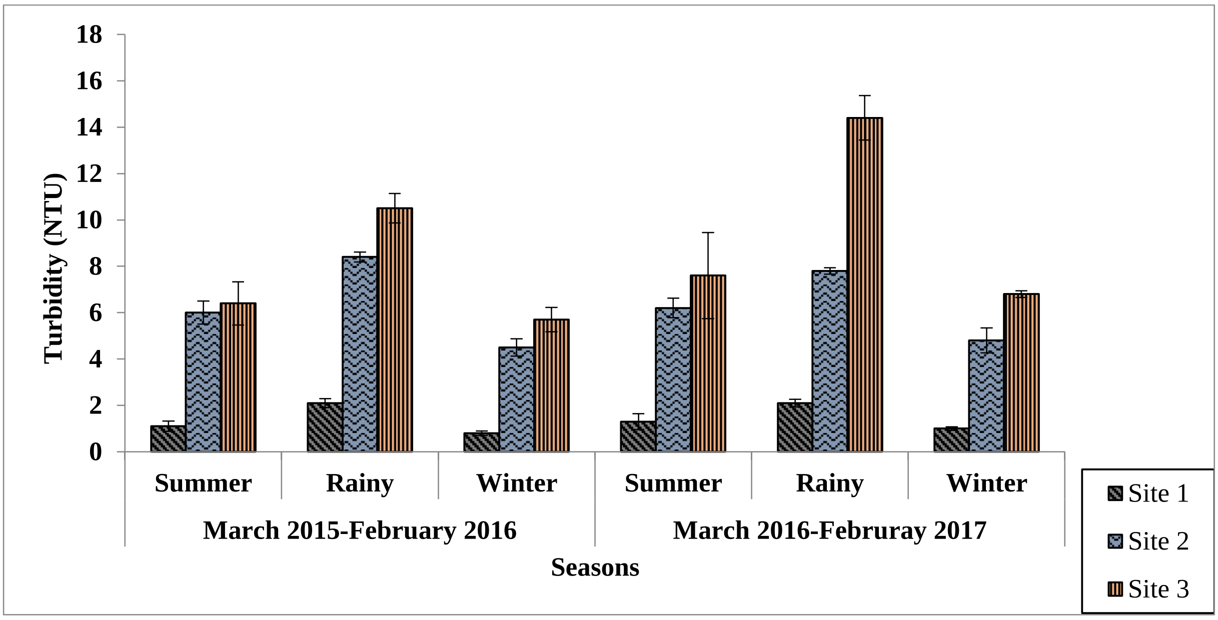


Fig 5.9: Seasonal variation in Turbidity of water at selected study sites

j. Total Solid (TS)

The total solid value ranged from 85 mgL^{-1} to 384 mgL^{-1} during the study period (Table 5.1). The lowest value (85mgL^{-1}) was recorded at Site 1 in the winter season, and highest (326 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, value was lowest (99 mgL^{-1}) at Site 1 in the winter season, and highest (384 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The values were recorded to be lower during the rainy at all the selected study sites (Fig: 5.10). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

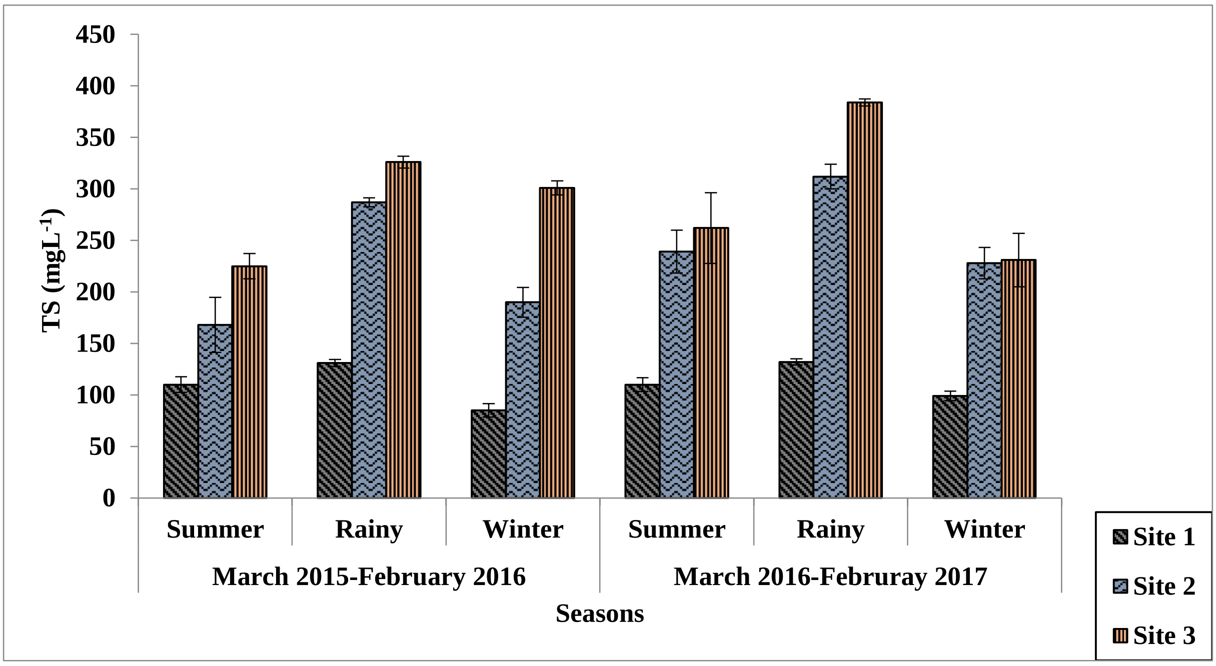


Fig 5.10: Seasonal variation in Total Solid content of water at selected study sites

k. Total Suspended Solid (TSS)

The value ranged from 28 mgL^{-1} to 82 mgL^{-1} during the study period (Table 5.1). The lowest value (28mgL^{-1}) was recorded at Site 1 in the winter season, and highest (66 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, it was lowest (29mgL^{-1}) at Site 1 in the winter season, and highest (82mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The water total suspended solid was recorded to be lower during the rainy seasons at all the selected study sites (Fig: 5.11). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

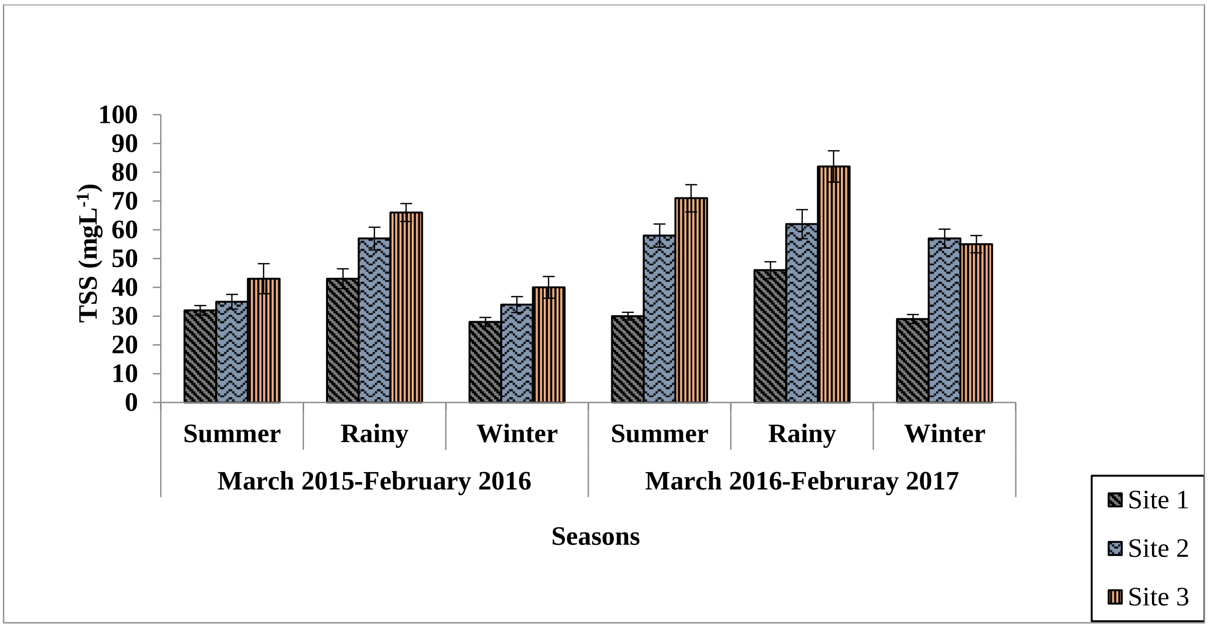


Fig 5.11: Seasonal variation in TSS content of water at selected study sites

l. Total Dissolved Solid (TDS)

The value ranged from 57 mgL^{-1} to 302 mgL^{-1} during the study period (Table 5.1). The lowest value (57 mgL^{-1}) was recorded at Site 1 in the winter season, and highest (260 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the TDS was lowest (70 mgL^{-1}) at Site 1 in the winter season, and highest (302 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The values recorded were lower during the winter season, and higher during the rainy seasons at all the selected study sites (Fig: 5.12). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

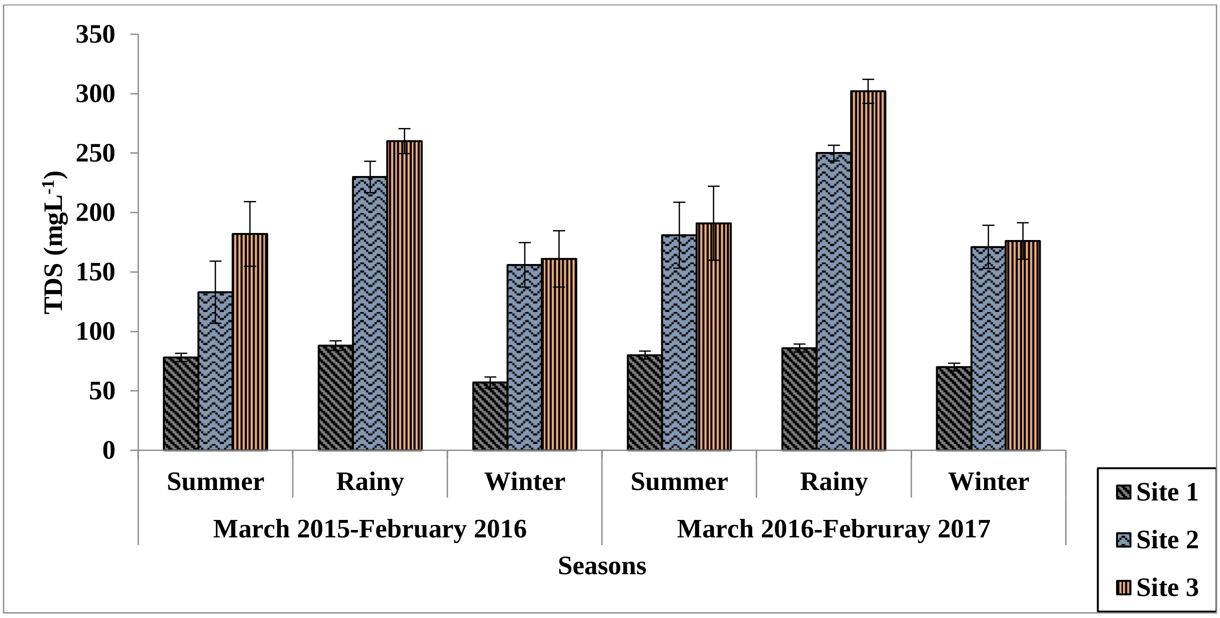


Fig 5.12: Seasonal variation in TDS of water at selected study sites

m. Chloride

The Chloride content of water ranged from 34.8 mgL^{-1} to 132.9 mgL^{-1} during the study period (Table 5.1). The lowest value (34.8 mgL^{-1}) was recorded at Site 1 in the rainy season, and highest (128.8 mgL^{-1}) at Site 3 in the winter season during the year 2015-2016 (Table 5.2). Similarly, value was lowest (36.4 mgL^{-1}) at Site 1 in the rainy season, and highest (132.9 mgL^{-1}) at Site 3 in the winter season during the year 2016-2017 (Table 5.3). The values were recorded to be lower during the rainy seasons and higher during the winter seasons at all the selected study sites (Fig: 5.13). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

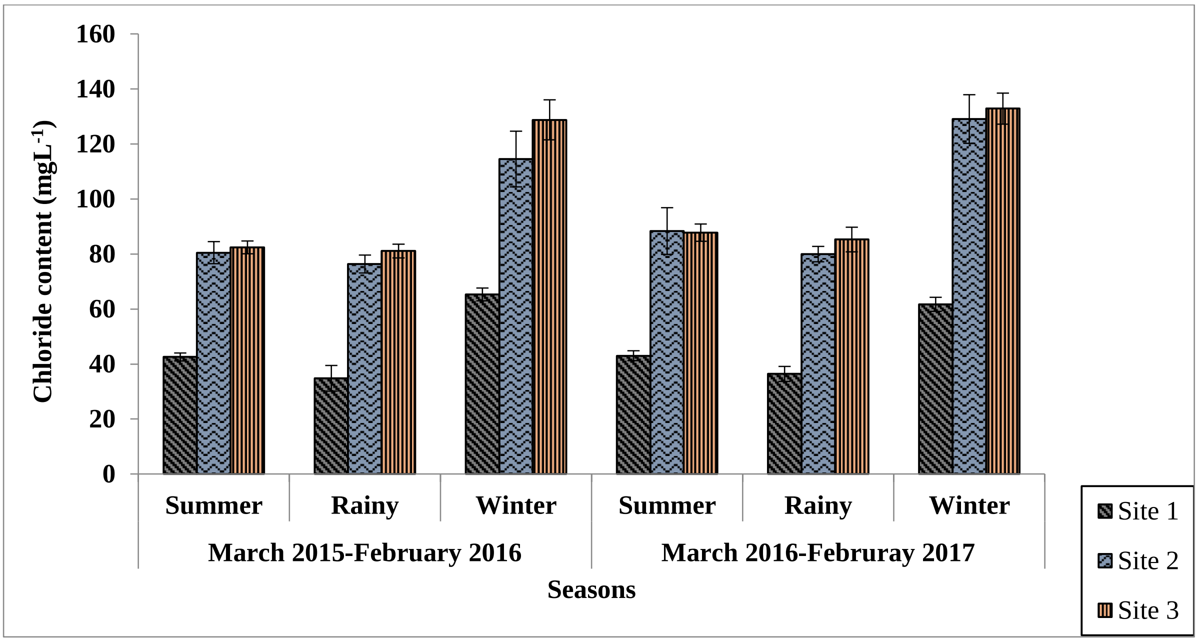


Fig 5.13: Seasonal variation in Chloride content of water at selected study sites

n. Nitrate-N

The Nitrate-N content ranged from 0.19 mgL^{-1} to 0.58 mgL^{-1} during the study period (Table 5.1). The lowest value (0.19 mgL^{-1}) was recorded at Site 1 in the winter season, and highest (0.52 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, the value was lowest (0.25 mgL^{-1}) at Site 1 in the winter season, and highest (0.58 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The Nitrate-N content was recorded to be lower during the winter and higher during the rainy seasons at all the selected study sites (Fig: 5.14). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

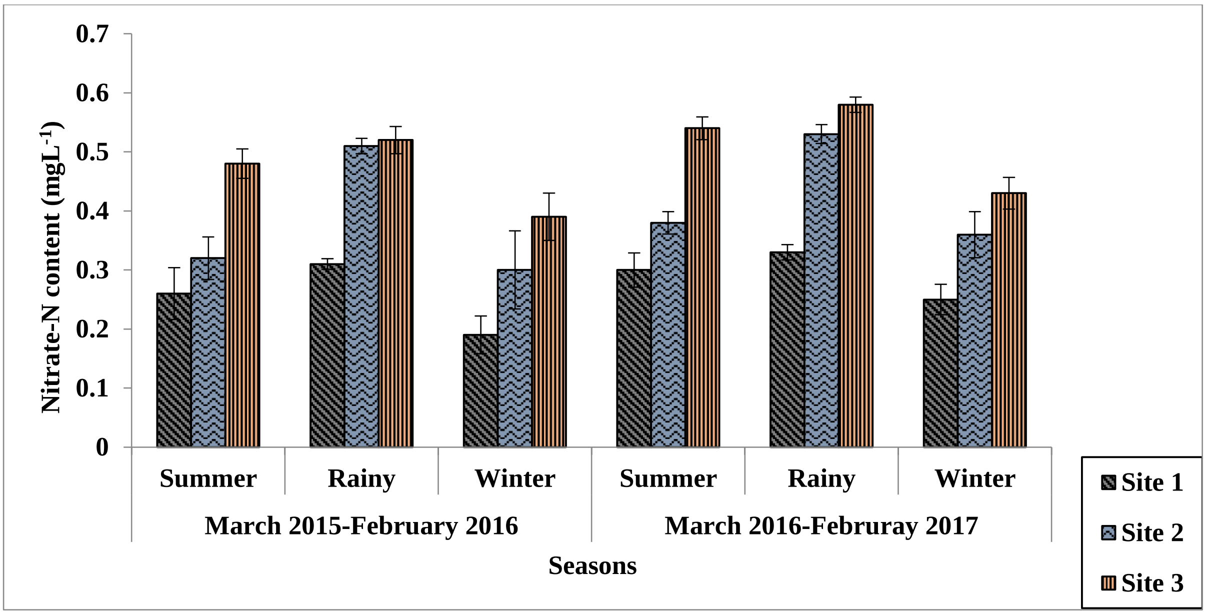


Fig 5.14: Seasonal variation in Nitrate content of water at selected study sites

o. Phosphate-P

The Phosphate-P content of water ranged from 0.026 mgL^{-1} to 0.244 mgL^{-1} during the study period (Table 5.1). The lowest value (0.026 mgL^{-1}) was recorded at Site 1 in the winter season, and highest (0.17 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, value was lowest (0.029 mgL^{-1}) at Site 1 in the winter season, and highest (0.244 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The Phosphate-P content was recorded to be lower during the winter and higher during the rainy seasons at all the selected study sites (Fig: 5.15). The results reveal that the values were higher than the prescribed limit of water quality as prescribed by USPH (Appendix I).

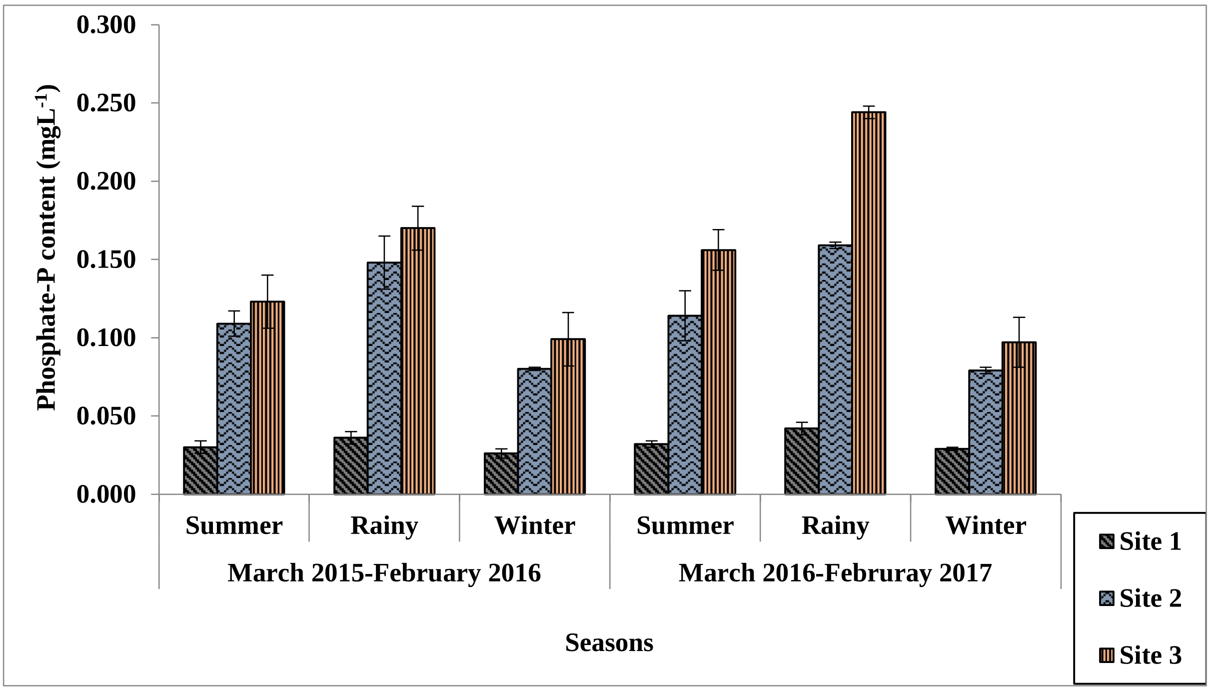


Fig 5.15: Seasonal variation in Phosphate-P content of water at selected study sites

p. Sulphate

The Sulphate content of water ranged from 1.67 to 6.63 during the study period (Table 5.1). The lowest value (1.84 mgL^{-1}) was recorded at Site 1 in the winter season, and highest (6.63 mgL^{-1}) at Site 3 in the rainy season during the year 2015-2016 (Table 5.2). Similarly, value was lowest (1.67 mgL^{-1}) at Site 1 in the winter season, and highest (6.43 mgL^{-1}) at Site 3 in the rainy season during the year 2016-2017 (Table 5.3). The values were recorded to be lower during the winter and higher during the rainy seasons at all the selected study sites (Fig: 5.16). The results reveal that all the values fall within the prescribed limit of water quality as given by various scientific agencies (Appendix I).

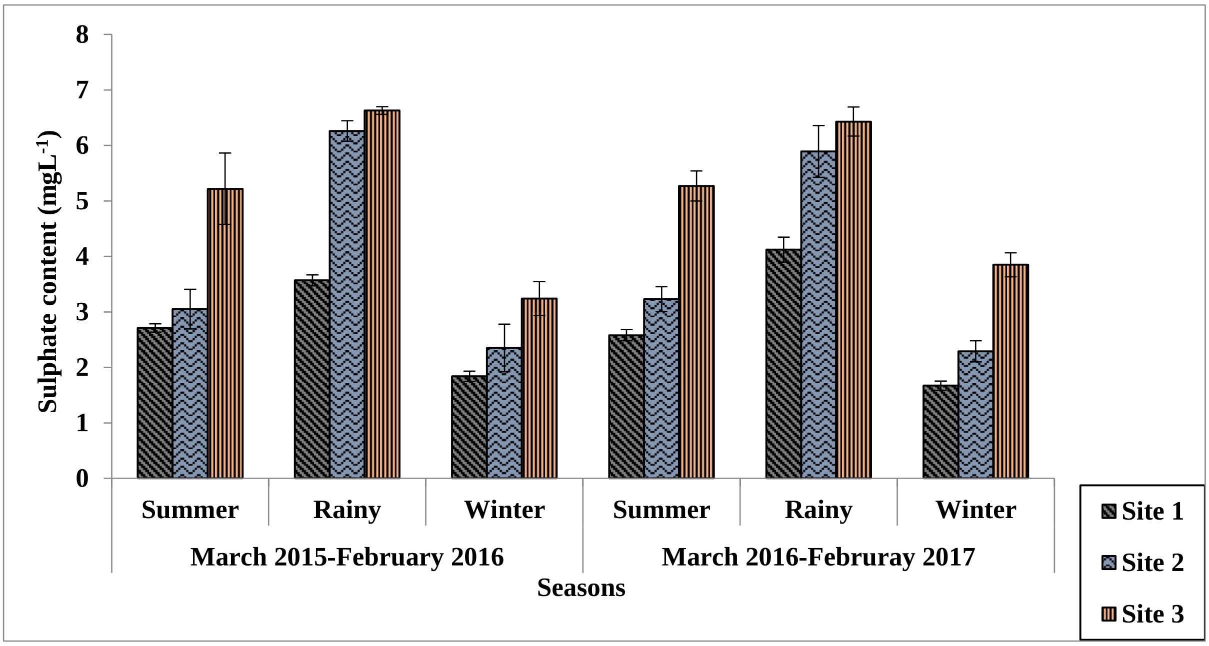


Fig 5.16: Seasonal variation in Sulphate of water at selected study sites

Table 5.1: Descriptive Statistics of the water quality characteristics for two years data (Mar 2015- Feb 2017)

Sl. No.	Parameters	Minimum	Maximum	Mean	Standard Deviation	Standard Error
1	Temperature (^{0}C)	22.5	35.1	29.89	3.419	0.806
2	pH	5.9	7.5	6.83	0.495	0.117
3	EC (µS)	94.0	186.0	126.05	25.419	5.991
4	DO (mgL^{-1})	4.6	8.0	6.78	0.795	0.187
5	BOD (mgL^{-1})	.7	2.9	1.47	0.538	0.127
6	Total Hardness (mgL^{-1})	47.0	253.0	152.94	74.814	17.634
7	Acidity (mgL^{-1})	36.0	72.0	52.11	10.312	2.431
8	Total Alkalinity (mgL^{-1})	34.0	67.0	48.50	10.667	2.514
9	Turbidity (NTU)	.8	14.4	5.42	3.677	0.866
10	TS (mgL^{-1})	85.0	384.0	212.22	89.188	21.022
11	TSS (mgL^{-1})	28.0	82.0	48.22	15.976	3.765
12	TDS (mgL^{-1})	57.0	302.0	158.44	72.202	17.018
13	Chloride (mgL^{-1})	34.8	132.9	80.61	30.885	7.279
14	Nitrate-N (mgL^{-1})	.19	.58	0.39	0.116	0.027
15	Phosphate-P (mgL^{-1})	.026	.244	0.10	0.061	0.014
16	Sulphate (mgL^{-1})	1.67	6.63	3.90	1.647	0.388

Table 5.2: Descriptive Statistics of the water quality characteristics (Mar 2015- Feb 2016)

Sl. No.	Parameters	Minimum	Maximum	Mean	Standard Deviation	Standard Error
1	Temperature (^{0}C)	23.9	33.8	29.59	3.218	1.079
2	pH	6.2	7.5	6.87	0.450	0.150
3	EC (µS)	94.0	142.0	115.11	16.159	5.386
4	DO (mgL^{-1})	6.2	7.5	6.90	0.469	0.156
5	BOD (mgL^{-1})	.8	1.9	1.33	0.371	0.124
6	Total Hardness (mgL^{-1})	47.0	232.0	139.89	68.131	22.710
7	Acidity (mgL^{-1})	36.0	66.0	50.78	9.846	3.282
8	Total Alkalinity (mgL^{-1})	34.0	59.0	45.22	8.786	2.929
9	Turbidity (NTU)	.8	10.5	5.05	3.293	1.098
10	TS (mgL^{-1})	85.0	326.0	202.56	87.623	29.207
11	TSS (mgL^{-1})	28.0	66.0	42.00	12.329	4.109
12	TDS (mgL^{-1})	57.0	260.0	149.44	68.597	22.865
13	Chloride (mgL^{-1})	34.8	128.8	78.49	30.061	10.020
14	Nitrate-N (mgL^{-1})	0.19	0.52	0.36	0.1172	0.039
15	Phosphate-P (mgL^{-1})	.026	0.170	0.09	0.052	0.018
16	Sulphate (mgL^{-1})	1.84	6.63	3.87	1.735	0.578

Table 5.3: Descriptive Statistics of the water quality characteristics (Mar 2016- Feb 2017)

Sl. No.	Parameters	Minimum	Maximum	Mean	Standard Deviation	Standard Error
1	Temperature (^{0}C)	22.5	35.1	30.19	3.779	1.260
2	pH	5.9	7.5	6.79	0.562	0.187
3	EC (µS)	100.0	186.0	137	29.026	9.675
4	DO (mgL^{-1})	4.6	8.0	6.67	1.045	0.348
5	BOD (mgL^{-1})	.7	2.9	1.61	0.660	0.220
6	Total Hardness (mgL^{-1})	55.0	253.0	166	82.878	27.626
7	Acidity (mgL^{-1})	37.0	72.0	53.44	11.182	3.727
8	Total Alkalinity (mgL^{-1})	34.0	67.0	51.78	11.851	3.950
9	Turbidity (NTU)	1.0	14.4	5.78	4.188	1.396
10	TS (mgL^{-1})	99.0	384.0	221.89	94.949	31.650
11	TSS (mgL^{-1})	29.0	82.0	54.44	17.415	5.805
12	TDS (mgL^{-1})	70.0	302.0	167.44	78.677	26.226
13	Chloride (mgL^{-1})	36.4	132.9	82.73	33.366	11.122
14	Nitrate-N (mgL^{-1})	0.25	.58	0.41	0.116	0.039
15	Phosphate-P (mgL^{-1})	0.029	.244	0.11	0.0713	0.024
16	Sulphate (mgL^{-1})	1.67	6.43	3.93	1.659	0.554

5.1.2 Water Quality Index (WQI)

The WQI of Serlui river was calculated to determine the impact of Serlui-B dam on the water quality and the suitability of the river water for drinking purpose. The standard values and their corresponding ideal values, recommending agencies and k value of water quality parameters are presented in Table 5.4. The calculation was done following Arithmetic Index method (Table 5.5 to Table 5.7).

Table 5.4: Standard values and their corresponding ideal values, recommending agencies and k value of water quality parameters

Sl. No.	Parameters	S_n	Recommending Agencies for S_n	Ideal Value (V_{id})	k value
1	pH	6.5-8.5	ICMR/BIS	7	0.094
2	EC	300	ICMR	0	0.094
3	DO	5	ICMR/BIS	14.6	0.094
4	BOD	5	ICMR	0	0.094
5	Hardness	300	ICMR/BIS	0	0.094
6	Alkalinity	120	ICMR	0	0.094
7	TDS	500	ICMR/BIS	0	0.094
8	TSS	500	WHO	0	0.094
9	Chloride	250	ICMR	0	0.094
10	Phosphate-P	0.1	USPH	0	0.094
11	Nitrate-N	10	USPH	0	0.094
12	Sulphate	150	ICMR/BIS	0	0.094

Table 5.5: Water Quality Index (WQI) of Serlui river at Site 1

Sl. No.	Parameters	Observed value	Unit Weight (W_n)	q_n	W_nq_n
1	pH	7	0.011	0	0
2	EC	112	0.0003	37.33	0.0112
3	DO	7	0.0188	79.17	1.4884
4	BOD	1.2	0.0188	24	0.4512
5	Hardness	59.7	0.0003	19.9	0.0059
6	Alkalinity	40.7	0.0008	33.92	0.0271
7	TDS	76.7	0.0002	15.34	0.0031
8	TSS	34.7	0.0002	6.94	0.0014
9	Chloride	47.7	0.0004	19.08	0.0076
10	Phosphate-P	0.033	0.94	33	31.02
11	Nitrate-N	0.27	0.0094	2.7	0.0254
12	Sulphate	2.75	0.0006	1.83	0.001
			ΣW_n=1.0008		**Σq_nW_n=33.0423**

Table 5.6: Water Quality Index (WQI) of Serlui river at Site 2

Sl. No.	Parameters	Observed value	Unit Weight (W_n)	q_n	W_nq_n
1	pH	7.1	0.011	6.67	0.007
2	EC	120	0.0003	40	0.012
3	DO	7.3	0.0188	76.04	1.4295
4	BOD	1.3	0.0188	26	0.4888
5	Hardness	189	0.0003	63	0.0189
6	Alkalinity	54.7	0.0008	45.58	0.0365
7	TDS	187	0.0002	37.4	0.0075
8	TSS	50.5	0.0002	10.1	0.002
9	Chloride	94.9	0.0004	37.96	0.0152
10	Phosphate-P	0.116	0.94	116	109.04
11	Nitrate-N	0.4	0.0094	4	0.0376
12	Sulphate	3.85	0.0006	2.57	0.0015
			ΣW_n=1.0008		**Σq_nW_n=111.10**

Table 5.7: Water Quality Index (WQI) of Serlui river at Site 3

Sl. No.	Parameters	Observed value	Unit Weight(W_n)	q_n	W_nq_n
1	pH	6.5	0.011	33.33	0.367
2	EC	147.3	0.0003	49.1	0.0147
3	DO	6.1	0.0188	88.54	1.6645
4	BOD	2	0.0188	40	0.752
5	Hardness	210.2	0.0003	70.07	0.021
6	Alkalinity	51.7	0.0008	43.08	0.0345
7	TDS	212.3	0.0002	42.46	0.0085
8	TSS	59.5	0.0002	11.9	0.0024
9	Chloride	99.7	0.0004	39.88	0.0159
10	Phosphate-P	0.148	0.94	148	139.12
11	Nitrate-N	0.49	0.0094	4.9	0.0461
12	Sulphate	5.11	0.0006	3.41	0.002
			ΣW_n=1.0008		**Σq_nW_n=142.05**

Table 5.8: Water quality rating as per Weighted Arithmetic Water Quality Index Method

Sl. No.	WQI value	Water quality rating	Grade	Serlui river water Grade
1	0-25	Excellent Water Quality	A	
2	26-50	Good Water Quality	B	Site 1
3	51-75	Poor Water Quality	C	
4	76-100	Very Poor Water Quality	D	
5	>100	Unsuitable for Drinking	E	Site 2 and Site 3

Source: Brown *et al*. (1972), Chatterji and Raziuddin (2002)

The WQI at Site 1 was found to be **33**. The computation reveals that the water quality of Site 1 (Control site) falls within Grade B (26-50) of the water quality classification based on weighted arithmetic WQI method as given in Table 5.8, therefore, indicating good quality of the water at Site 1.

The WQI at Site 2 and Site 3 were found to be **111** and **142,** respectively**.** The computation reveals that the water quality of Site 2 and Site 3 falls within Grade E (>100) of the water quality classification based on weighted arithmetic WQI method as given in Table 5.8, therefore, indicating that the water of river at Site 2 and Site 3 is unfit for drinking purpose and prior treatment is recommended before it use.

5.1.3 Pearson's Correlation and Analysis of Variance (ANOVA)

All the data relating to physico-chemical characteristics for two year were pooled together to calculate correlation coefficient (Appendix II). The correlation coefficient among the different parameters at the selected study sites are presented in Appendix III-V. Two-way ANOVA was conducted to show the significant variation in concentration of various water quality parameters between different seasons and sites.

a. Temperature

A positive and significant correlation of temperature was established with BOD ($r=0.917$, $p<0.05$), Alkalinity ($r=0.935$, $p<0.01$), Nitrate-N ($r=0.912$, $p<0.05$), Phosphate-P ($r=0.922$, $p<0.01$) and Sulphate ($r=0.942$, $p<0.01$). On other hand, a negative and significant correlation of temperature was established with pH ($r=-0877$, $p<0.05$), DO ($r=-0.848$, $p<0.05$), Chloride ($r=-0.956$, $p<0.01$) (Appendix II).

Statistically, two-way ANOVA on temperature of water as a function of variation between seasons ($F=81.13$, $p<0.01$) and between sites ($F=39.6$, $p<0.01$) is significant (Table 5.9).

Table 5.9: Two-way Anova for temperature as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	64.20389	2	32.10194	81.12812	0.000579	6.944272
Between Sites	31.33722	2	15.66861	39.59775	0.002312	6.944272
Error variance	1.582778	4	0.395694			
Total	97.12389	8				

b. pH

A positive and significant correlation of pH was established with DO (r=0.984, p<0.01). On the contrary, a negative and significant correlation of pH was established with EC (r=-0.814, p< 0.05), BOD (r=-0.921, p<0.01), Acidity (r=-0.837, p< 0.05), TA (r=-0.860, p<0.05), Turbidity (-0.965, p<0.01), TS (r=-0.926, p<0.01), TDS (r=-0.941, p<0.01), Nitrate-N (r=-0.893, p<0.05), Phosphate-P (r=-0.977, p<0.01) and Sulphate (r=-0.916, p<0.05) (Appendix II).

Statistically, two-way ANOVA on pH of water as a function of variation between seasons (F=29.44, p<0.01) and between sites (F=17.27, p<0.05) is significant (Table 5.10).

Table 5.10: Two-way Anova for pH as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	1.193889	2	0.596944	29.43836	0.004047	6.944272
Between Sites	0.700556	2	0.350278	17.27397	0.010768	6.944272
Error variance	0.081111	4	0.020278			
Total	1.975556	8				

c. EC

A positive and significant correlation of EC was established with BOD (r=0.940, p<0.01), TA (r=0.938, p<0.01), Turbidity (r=0.892, p<0.05), TSS (r=0.976, p<0.01), TDS (r=0.898, p<0.05) Nitrate-N (r=0.952, p<0.01) and Phosphate-P (r=0.906, p<0.01). On the contrary, a negative and significant correlation was seen between EC with pH (r=-0.814, p<0.05) and DO (r=-0.883, p<0.05) (Appendix II).

Statistically, two-way ANOVA on EC of water as a function of variation between seasons (F=167.94, p<0.01) and between sites (F=202.90, p<0.01) is significant (Table 5.11).

Table 5.11: Two-way Anova for EC as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	1716.722	2	858.3611	167.9402	0.000139	6.944272
Between Sites	2074.056	2	1037.028	202.8967	0.0001	6.944272
Error variance	20.44444	4	5.111111			
Total	3811.222	8				

d. DO Content

A positive and significant correlation of DO was established with pH (0.984, p<0.01). On the contrary, a negative and significant correlation of DO was established with Temperature (r=-0.848, p<0.05), EC (r=-0.883, p<0.05), BOD (r=-0.953, p<0.01), Acidity (r=-0.839, p<0.05), TA (r=-0.889, p<0.05), Turbidity (r=-0.966, p<0.01), TS (r=-0.944, p<0.01), TDS (r=-0.950, p<0.01), Nitrate-N (r=-0.909, p<0.05) Phosphate-P (r=-0.985, p<0.01) and Sulphate (r=-0.870, p<0.05) (Appendix II).

Statistically, two-way ANOVA on DO of water as a function of variation between seasons (F=21.65, p<0.01) and between sites (F=36.63, p<0.01) is significant (Table 5.12).

Table 5.12: Two-way Anova for DO as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	1.551667	2	0.775833	21.65116	0.007151	6.944272
Between Sites	2.625	2	1.3125	36.62791	0.002681	6.944272
Error variance	0.143333	4	0.035833			
Total	4.32	8				

e. BOD content

A positive and significant correlation of BOD was established with Temperature (r=0.917, p<0.05), EC (r=0.940, p<0.01), TA (r=0.983, p<0.01), Turbidity (r=0.916, p<0.05), TDS (r=0.890, p<0.05), Nitrate-N (r=0.947, p<0.01), Phosphate-P (r=0.976, p<0.01) and Sulphate (r=0.865, p<0.05). On the contrary, a negative and significant correlation of BOD was established with pH (r=-0.921, p<0.01) and DO (r=-0.953, p<0.01) (Appendix II).

Statistically, two-way ANOVA on BOD of water as a function of variation between seasons (F=25.41, p<0.01) and between sites (F=31.79, p<0.01) is significant (Table 5.13).

Table 5.13: Two-way Anova for BOD as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	0.882222	2	0.441111	25.408	0.005325	6.944272
Between Sites	1.103889	2	0.551944	31.792	0.003503	6.944272
Error variance	0.069444	4	0.017361			
Total	2.055556	8				

f. Total Hardness

A positive and significant correlation of total hardness was established with Acidity (r=0.868, p<0.05), TS (r=0.786). On the contrary, a negative correlation of total hardness was established with pH (r=-0.537), and DO (r=-0.609) (Appendix II).

Statistically, two-way ANOVA on total hardness of water as a function of variation between seasons (F=7.76, p<0.05) and between sites (F=72.17, p<0.01) is significant. (Table 5.14).

Table 5.14: Two-way Anova for Total Hardness as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	4282.722	2	2141.361	7.761289	0.04198	6.944272
Between Sites	39825.39	2	19912.69	72.17287	0.000727	6.944272
Error variance	1103.611	4	275.9028			
Total	45211.72	8				

g. Acidity

A positive and significant correlation of Acidity was established with TH ($r=0.868$, $p<0.05$), TS ($r=0.951$, $p<0.01$) and TDS ($r=0.929$, $p<0.01$). On the contrary, a negative and significant correlation of Acidity was established with pH ($r=-0.837$, $p<0.05$), DO ($r=-0.839$, $p<0.05$) (Appendix II).

Statistically, two-way ANOVA on acidity of water as a function of variation between seasons ($F=89.11$, $p<0.01$) and between sites ($F=27.84$, $p<0.01$) is significant (Table 5.15).

Table 5.15: Two-way Anova for Acidity as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	658.3889	2	329.1944	89.10526	0.000482	6.944272
Between Sites	205.7222	2	102.8611	27.84211	0.004492	6.944272
Error variance	14.77778	4	3.694444			
Total	878.8889	8				

h. Total Alkalinity

A positive and significant correlation of Alkalinity was established with Temperature ($r=0.935$, $p<0.01$), EC ($r=0.938$, $p<0.01$), BOD ($r=0.983$, $p<0.01$), Turbidity ($r=0.876$, $p<0.05$), TDS ($r=0.848$, $p<0.05$), Nitrate-N ($r=0.956$, $p<0.01$), Phosphate-P ($r=0.939$, $p<0.01$) and Sulphate ($r=0.868$, $p<0.05$). On the contrary, a negative and significant correlation of Alkalinity was established with pH ($r=-0.860$, $p<0.05$) and DO ($r=-0.889$, $p<0.05$) (Appendix II).

Statistically, two-way ANOVA on TA of water as a function of variation between seasons ($F=23.11$, $p<0.01$) and between sites ($F=18.83$, $p<0.01$) is significant (Table 5.16).

Table 5.16: Two-way Anova for Total Alkalinity as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	435.1667	2	217.5833	23.10619	0.006346	6.944272
Between Sites	354.6667	2	177.3333	18.83186	0.009217	6.944272
Error variance	37.66667	4	9.416667			
Total	827.5	8				

i. Turbidity

A positive and significant correlation of Turbidity was established with temperature ($r=0.863$, $p<0.05$), EC (0.892, $p<0.05$), BOD ($r=0.916$, $p<0.05$), Acidity ($r=0.892$, $p<0.05$), TS ($r=0.942$, $p<0.01$), TDS ($r=0.991$, $p<0.01$), Nitrate-N ($r=0.956$, $p<0.01$), Phosphate-P ($r=0.972$, $p<0.01$), and Sulphate ($r=0.940$, $p<0.01$). On the contrary, a negative and significant correlation of Turbidity was established with pH (-0.965, $p<0.01$) and DO ($r=-0.966$, $p<0.01$) (Appendix II).

Statistically, two-way ANOVA on turbidity of water as a function of variation between seasons is not significant and between sites ($F=19.71$, $p<0.01$) is significant (Table 5.17).

Table 5.17: Two-way Anova for Turbidity as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	21.52167	2	10.76083	5.273841	0.075602	6.944272
Between Sites	80.42167	2	40.21083	19.70717	0.008489	6.944272
Error variance	8.161667	4	2.040417			
Total	110.105	8				

j. Total Solid

A positive and significant correlation of TS was established with EC ($r=0.840$, $p<0.05$), BOD ($r=0.847$, $p<0.05$), Acidity ($r=0.951$, $p<0.01$), Turbidity ($r=0.942$, $p<0.01$), TDS ($r=0.968$, $p<0.01$), Nitrate ($r=0.862$, $p<0.05$), Phosphate-P ($r=0.899$, $p<0.05$) and Sulphate ($r=0.813$, $p<0.05$). On the contrary, a negative and significant correlation of TS was established with pH ($r=-0.926$, $p<0.01$) and DO ($r=-0.944$, $p<0.01$) (Appendix II).

Statistically, two-way ANOVA on TS of water as a function of variation between seasons ($F=9.38$, $p<0.05$) and between sites ($F=41.86$, $p<0.01$) is significant (Table 5.18).

Table 5.18: Two-way Anova for TS as a function of variation between different seasons Vs variation amongdifferent sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	11166.89	2	5583.444	9.381531	0.030879	6.944272
Between Sites	49831.06	2	24915.53	41.86409	0.002079	6.944272
Error variance	2380.611	4	595.1528			
Total	63378.56	8				

k. Total Suspended Solid (TSS)

A positive and significant correlation of TSS was established with EC (r=0.976, p<0.01), BOD (r=0.880, p<0.05), TA (r=0.887, p<0.05), Turbidity (r=0.881, p<0.05), TDS (r=0.910, p<0.05) and Nitrate-N (r=0.942, p<0.01). On the contrary, a negative and significant correlation of TSS was established with DO (r=-0.839, p<0.05) (Appendix II).

Statistically, two-way ANOVA on TSS of water as a function of variation between seasons (F=24.87, p<0.01) and between sites (F=40.40, p<0.01) is significant (Table 5.19).

Table 5.19: Two-way Anova for TSS as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	583.7222	2	291.8611	24.86864	0.005541	6.944272
Between Sites	948.3889	2	474.1944	40.40473	0.002224	6.944272
Error variance	46.94444	4	11.73611			
Total	1579.056	8				

l. Total Dissolved Solid (TDS)

A positive and significant correlation of TDS was established with BOD (r=0.890, p<0.05), Acidity (r=0.929, p<0.01), Turbidity (r=0.991, p<0.01), TS (r=0.968, p<0.01), TSS (r=0.910, p<0.05), Nitrate-N (r=0.946, p<0.01), Phosphate-P (r=0.945, p<0.01) and Sulphate (r=0.908, p<0.05). On the contrary, a negative and significant correlation of TDS was established with pH (r=-0.941, p<0.01) and DO (r=-0.950, p<0.01) (Appendix II).

Statistically, two-way ANOVA on TDS of water as a function of variation between seasons is not significant and between sites (F=21.29, p<0.01) is significant (Table 5.20).

Table 5.20: Two-way Anova for TDS as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	8921.722	2	4460.861	6.093148	0.06107	6.944272
Between Sites	31167.06	2	15583.53	21.28574	0.007377	6.944272
Error variance	2928.444	4	732.1111			
Total	43017.22	8				

m. Chloride content

A positive and significant correlation of Chloride was established with pH (r=0.758). On the contrary, a negative and significant correlation of Chloride was established with Temperature (r=-0.956, $p<0.01$) and Sulphate (r=-0.870, $p<0.05$) (Appendix II).

Statistically, two-way ANOVA on chloride content of water as a function of variation between seasons (F=30.08, $p<0.01$) and between sites (F=54.01, $p<0.01$) is significant (Table 5.21).

Table 5.21: Two-way Anova for Chloride as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	2800.754	2	1400.377	30.07691	0.003888	6.944272
Between Sites	5029.351	2	2514.675	54.00951	0.001275	6.944272
Error variance	186.2394	4	46.55986			
Total	8016.344	8				

n. Nitrate-N

A positive and significant correlation of Nitrate-N was established with Temperature ($r=0.912$, $p<0.05$), EC ($r=0.952$, $p<0.01$), BOD ($r=0.947$, $p<0.01$), TA ($r=0.956$, $p<0.01$), Turbidity($r=0.956$, $p<0.01$), TSS ($r=0.942$, 0.01), TDS ($r=0.946$, $p<0.01$) , Phosphate-P($r=0.952$, $p<0.01$) and Sulphate($r=0.938$, $p<0.01$). On the contrary, a negative and significant correlation of Nitrate-N was established with pH (-0.893, $p<0.05$) and DO ($r=-0.909$, $p<0.05$) (Appendix II).

Statistically, two-way ANOVA on Nitrate-N content of water as a function of variation between seasons ($F=10.06$, $p<0.05$) and between sites ($F=23.01$, $p<0.01$) is significant (Table 5.22).

Table 5.22: Two-way Anova for Nitrate-N as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	0.031089	2	0.015544	10.06475	0.02748	6.944272
Between Sites	0.071089	2	0.035544	23.01439	0.006393	6.944272
Error variance	0.006178	4	0.001544			
Total	0.108356	8				

o. Phosphate-P

A positive and significant correlation of Phosphate-P was established with Temperature ($r=0.922$, $p<0.01$), EC ($r=0.906$, $p<0.05$), BOD ($r=0.976$, $p<0.01$), TA ($r=0.939$, $p<0.01$), Turbidity ($r=0.972$, $p<0.01$), TDS ($r=0.945$, $p<0.01$), Nitrate-N ($r=0.952$, $p<0.01$) and Sulphate ($r=0.922$, $p<0.01$). On the contrary, a negative and significant correlation of Phosphate-P was established with pH ($r=-0.977$, $p<0.01$) and DO ($r=-0.985$, $p<0.01$) (Appendix II).

Statistically, two-way ANOVA on Phosphate-P content of water as a function of variation between seasons is not significant and between sites (F= 17.14, $p<0.05$) is significant (Table 5.23).

Table 5.23: Two-way Anova for Phosphate-P as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	0.006396	2	0.003198	5.155773	0.078117	6.944272
Between Sites	0.021269	2	0.010634	17.14409	0.010914	6.944272
Error variance	0.002481	4	0.00062			
Total	0.030146	8				

p. Sulphate

A positive and significant correlation of Sulphate was established with temperature (r=0.942, $p<0.01$), BOD (r=o.865, $p<0.05$), TA (r=0.868, $p<0.05$), Turbidity (r=0.940, $p<0.01$), TDS (r=0.908, $p<0.01$), Phosphate-P (r=0.922, $p<0.01$) and Nitrate-N (r=0.938, $p<0.01$). On the contrary, a negative and significant correlation of Sulphate was established with pH (r=-0.916, $p<0.01$), DO (r=0.870, $p<0.05$) and Chloride (r=-0.870, $p<0.05$) (Appendix II).

Statistically, two-way ANOVA on sulphate content as a function of variation between seasons (F=20.98, $p<0.01$) and between sites (F=13.26, $p<0.05$) is significant (Table 5.24).

Table 5.24: Two-way Anova for Sulphate as a function of variation between different seasons Vs variation among different sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Seasons	13.21927	2	6.609633	20.98019	0.007574	6.944272
Between Sites	8.356217	2	4.178108	13.26208	0.017172	6.944272
Error variance	1.260167	4	0.315042			
Total	22.83565	8				

5.1.3.1 Correlation matrix of Site 1 (March 2015-February 2017)

The results reveal that at Site 1, the temperature is significantly correlated with pH ($r=-0.818$, $p<0.05$), BOD ($r=0.947$, $p<0.01$), TA ($r=0.943$, $p<0.05$), TS ($r=0.840$, $p<0.05$), TSS ($r=0.849$, $p<0.849$), Chloride ($r=-0.962$, $p<0.01$) and Sulphate ($r=0.911$, $p<0.05$). The pH is correlated with EC ($r=0.954$, $p<0.01$), DO ($r=0.945$, $p<0.01$), BOD ($r=0.830$, $p<0.05$), TA ($r=0.891$, $p<0.05$), Turbidity ($r=0.909$, $p<0.05$), TS ($r=-0.882$, $p<0.05$), TDS ($r=0.946$, $p<0.01$), Phosphate ($r=-0.961$, $p<0.01$), Sulphate ($r=-0.862$, $p<0.01$). EC is correlated with DO ($r=-0.984$, $p<0.01$), BOD ($r=0.854$, $p<0.05$), Acidity ($r=0.855$, $p<0.05$), TA ($r=0.820$, $p<0.05$), Turbidity ($r=0.985$, $p<0.01$), TS ($r=0.951$, $p<0.01$), TSS ($r=0.851$, $p<0.05$), TDS ($r=0.971$, $p<0.01$), Chloride ($r=0.831$, $p<0.05$), Nitrate ($r=0.890$, $p<0.05$), Phosphate ($r=0.984$, $p<0.01$), Sulphate ($r=0.912$, $p<0.05$). The DO is correlated with BOD ($r=-0.864$, $p<0.05$), Turbidity ($r=-0.959$, $p<0.01$), TS($r=-0.970$, $p<0.01$), TSS ($r=0.890$, $p<0.05$), TDS ($r=-0.959$, $p<0.01$), Chloride ($r=0.857$, $p<0.05$), Nitrate ($r=-0.912$, $p<0.05$), Phosphate ($r=0.985$, $p<0.01$), Sulphate ($r=-0.927$, $p<0.01$). The BOD is correlated with TA ($r=0.926$, $p<0.01$), Turbidity($r=0.842$, $p<0.05$), $p<0.05$), TS ($r=0.912$, $p<0.05$), TSS ($r=0.937$, $p<0.01$), Chloride ($r=0.962$, $p<0.01$), Nitrate ($r=0.950$, $p<0.01$), Phosphate ($r=0.857$, $p<0.05$), Sulphate ($r=0.946$, $p<0.01$). The TH is correlated with Acidity ($r=0.924$, $p<0.01$). Acidity is correlated with Turbidity ($r=0.855$, $p<0.05$), TDS($r=0.906$, $p<0.05$). Alkalinity is correlated with Chloride ($r=-0.867$, $p<0.05$), Phosphate ($r=0.834$, $p<0.05$), Sulphate($r=0.841$, $p<0.05$).Turbidity is correlated with TS ($r=0.960$, $p<0.01$), TSS ($r=0.868$, $p<0.05$), TDS ($r=0.967$, $p<0.01$), Chloride ($r=-0.845$, $p<0.05$), Nitrate ($r=0.876$, $p<0.05$), Phosphate ($r=0.940$, $p<0.01$), Sulphate ($r=0.930$, $p<0.01$). TS is correlated with TSS ($r=0.964$, $p<0.01$), TDS ($r=0.920$, $p<0.01$), Chloride($r=-0.936$, $p<0.01$), Nitrate ($r=0.936$, $p<0.01$), Phosphate ($r=0.927$, $p<0.01$), Sulphate ($r=0.984$, $p<0.01$). TSS is correlated with Chloride ($r=--0.955$, $p<0.01$), Nitrate ($r=0.962$, $p<0.01$), Phosphate ($r=0.836$, $p<0.05$), Sulphate ($r=0.969$, p<0.01).TDS is correlated with Phosphate (r=0.938, p<0.01), Sulphate (r=0.876, p<0.05). Chloride is correlated with Nitrate (r=-0.896, p<0.05), Sulphate (r=-0.980, p<0.01). Nitrate is correlated with Phosphate(r=0.901, p<0.05), Sulphate (r=0.925, p<0.01). Phosphate is correlated with Sulphate(r=0.880, p<0.05) (Appendix III).

5.1.3.2 Correlation matrix of Site 2 (March 2015-February 2017)

The results reveal that at Site 2, the temperature is significantly correlated with pH (r=-0.878, p<0.05), EC (r=0.928, p<0.01), BOD (r=0.961, p<0.01), TA (r=0.961, p<0.01), Turbidity (r=0.941, p<0.01), Chloride (r=-0.852, p<0.05) Nitrate (r=0.850, p<0.05), Phosphate (r=0.954, p<0.01) and Sulphate (r=0.866, p<0.05). The pH is correlated with EC (r=-0.894, p<0.05), DO (r=0.916, p<0.05), BOD (r=-0.915, p<0.05), Acidity (r=-0.883, p<0.05), TA (r=-0.847, p<0.05), Turbidity (r=-0.931, p<0.01), TS (r=-0.880, p<0.05), TDS (r=-0.917, p<0.01), Nitrate (r=-0.960, p,0.01), Phosphate (r=-0.970, p<0.01), Sulphate (r=-0.971, p<0.01). The EC is correlated with BOD (r=0.871, p<0.05), TA (r=0.936, p<0.01), Turbidity (r=0.847, p<0.05), TS (r=0.880, p<0.05), TSS (r=0.814, p<0.05), TDS (r=0.856, p<0.05), Nitrate (r=0.915, p<0.05), Phosphate (r=0.893, p<0.05), Sulphate (r=0.826, p<0.05). The DO is correlated with BOD (r=-0.821, p<0.05), Acidity (r=-0.852, p<0.05), Turbidity (r=-0.890, p<0.05), Nitrate (r=-0.825, p<0.05), Phosphate (r=-0.895, p<0.05), Sulphate (r=-0.948, p<0.01). BOD is correlated with TA (r=0.954, p<0.01), Turbidity(r=0.934, p<0.01), Chloride (r=-0.895, p<0.05), Nitrate(r=0.837, p<0.05), Phosphate (r=0.979, p<0.01), Sulphate (r=0.890, p<0.05). TH is correlated with Acidity (r=0.824, p<0.05). Acidity is correlated with TS (r=0.888, p<0.05), TDS(r=0.934, p<0.01), Nitrate (r=0.911, p<0.05), Sulphate (r=0.884, p<0.05). Alkalinity is correlated with Turbidity (r=0.853, p<0.05), Nitrate (r=0.815, p<0.05), Phosphate (r=0.912, p<0.05). Turbidity is correlated with Chloride (r=-0.839, p<0.05), Nitrate (r=0.908, p<0.05), Phosphate (r=0.972, p<0.01), Sulphate (r=0.972, p<0.01). TS is correlated with TSS (r=0.866, p<0.05), TDS (r=0.990, p<0.01), Nitrate (r=0.961, p<0.01), Sulphate (r=0.845, p<0.05). TDS is correlated with Nitrate (r=0.970, p<0.01), Phosphate (r=0.828, p<0.05), Sulphate (r=0.886, p<0.05). Chloride is correlated with Phosphate (r=-0.850, p<0.05). Nitrate is correlated with Phosphate(r=0.909, p<0.05), Sulphate (r=0.950, p<0.01). Phosphate is correlated with Sulphate(r=0.958, p<0.01) (Appendix IV).

5.1.3.3 Correlation matrix of Site 3 (March 2015-February 2017)

The results reveal that at Site 3, the temperature is significantly correlated with pH (r=-0.887, p<0.05), TA (r=0.904, p<0.05), Turbidity (r=0.834, p<0.05), TDS (r=0.874, p<0.05), Chloride (r=-0.906, p<0.05), Nitrate (r=0.952, p<0.01), Phosphate (r=0.908, p<0.05) and Sulphate (r=0.980, p<0.01). pH is correlated with Turbidity (r=-0.890, p<0.05), TS (r=-0.858, p<0.05), TDS (r=-0.912, p<0.05), Phosphate (r=-0.936, p<0.01), Sulphate (r=-0.832, p<0.05). EC is correlated with DO (r=-0.884, p<0.05), BOD (r=0.913, p<0.05), Acidity (r=0.888, p<0.05), TSS (r=0.955, p<0.01), Nitrate (r=0.816, p<0.05). DO is correlated with BOD (r=-0.993, p<0.01), TA (r=-0.845, p<0.05), Turbidity (r=-0.855, p<0.05), TSS (r=-0.886, p<0.05), Nitrate (r=-0.814, p<0.05), Phosphate (r=-0.920, p<0.01). BOD is correlated with TA (r=0.862, p<0.05), Turbidity(r=0.886, p<0.05), TSS (r=0.918, p<0.01), TDS (r=0.812, p<0.05), Nitrate(r=0.818, p<0.05), Phosphate (r=0.923, p<0.01). TH is correlated with Acidity (r=0.873, p<0.05). Acidity is correlated with Turbidity (r=0.945, p<0.01), TS (r=0.865, p<0.05), TDS (r=0.937, p<0.01), Phosphate (r=0.829, p<0.05). Alkalinity is correlated with Turbidity (r=0.835, p<0.05), TSS (r=0.960, p<0.01), TDS (r=0.825, p<0.05), Nitrate (r=0.977, p<0.01), Phosphate (r=0.905, p<0.05), Sulphate(r=0.865, p<0.05). Turbidity is correlated with TS (r=0.848, p<0.05), TSS (r=0.853, p<0.05), TDS (r=0.987, p<0.01), Phosphate (r=0.958, p<0.01). TSS is correlated with TDS (r=0.814, $p<0.05$), Nitrate (r=0.887, $p<0.05$), Phosphate (r=0.875, $p<0.05$). TDS is correlated with Phosphate (r=0.942, $p<0.01$), Sulphate (r=0.860, $p<0.05$). Chloride is correlated with Nitrate (r=-0.833, $p<0.05$), Sulphate (r=-0.897, $p<0.05$). Nitrate is correlated with Phosphate(r=0.909, $p<0.05$), Sulphate (r=0.902, $p<0.05$). Phosphate is correlated with Sulphate (r=0.837, $p<0.05$) (Appendix V).

6.1.3.4 Linear regression

The linear regression equations were derived for the parameters having moderate to strong correlation coefficient at all the selected study sites. The regression graph was plotted for the pairs of parameters having highly significant correlation coefficient (Figure: 5.17-5.19).

Figure: 5.17(a-i) Plots of water quality parameters as a linear regression model at Site 1

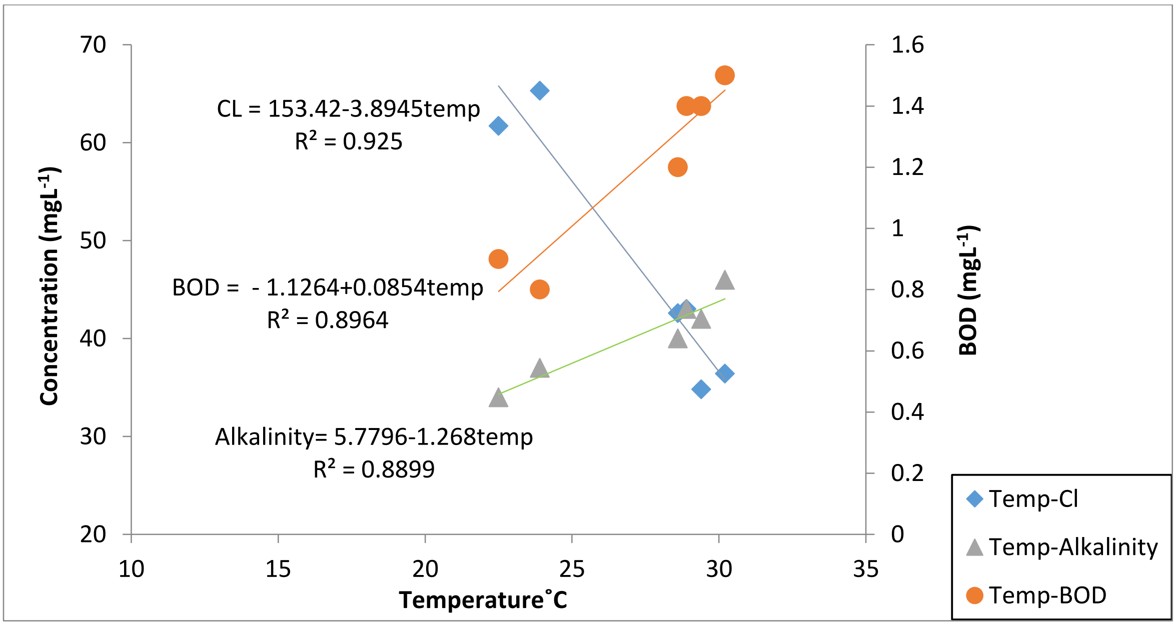


Fig: 5.17(a)

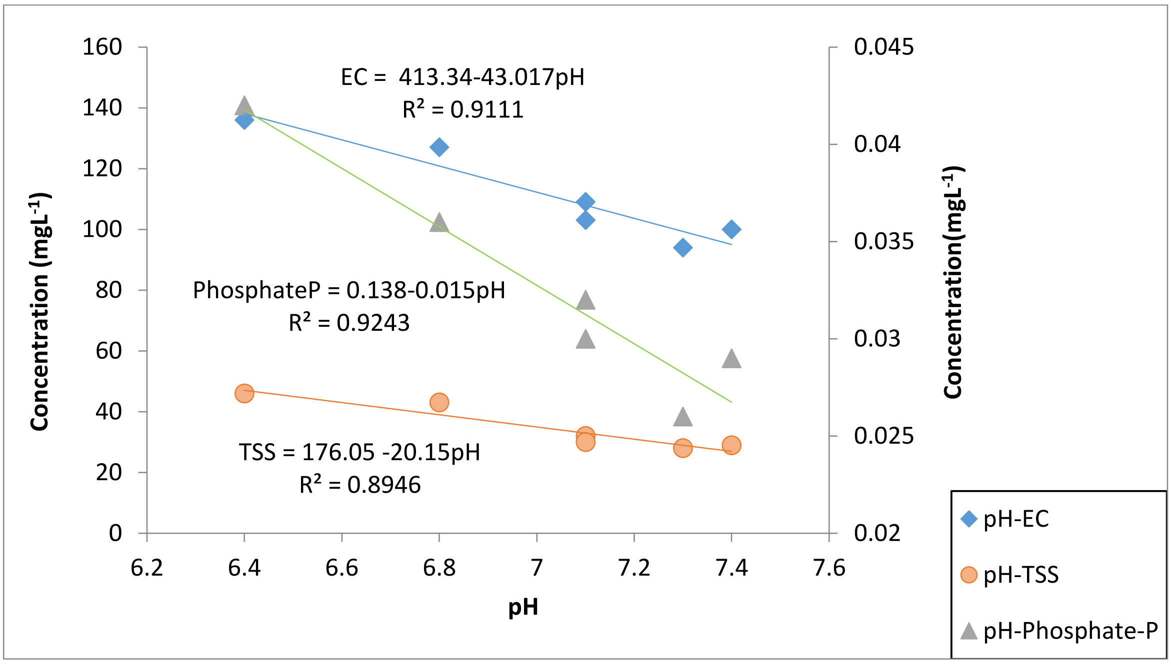


Fig: 5.17(b)

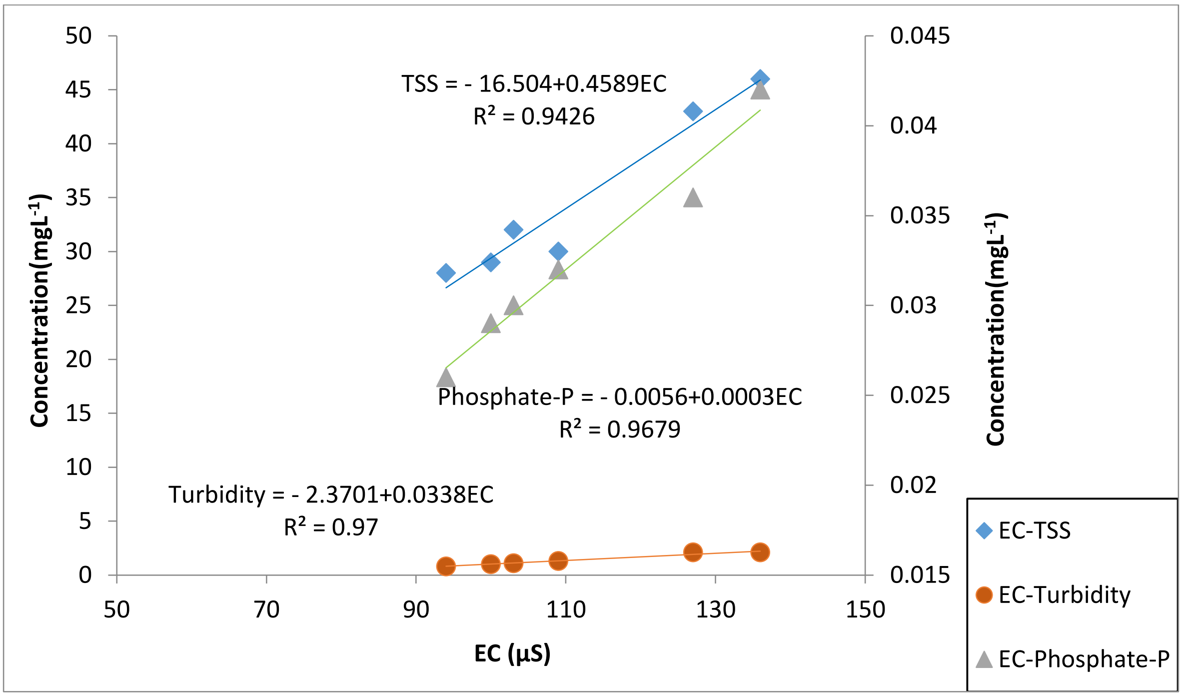


Fig: 5.17(c)

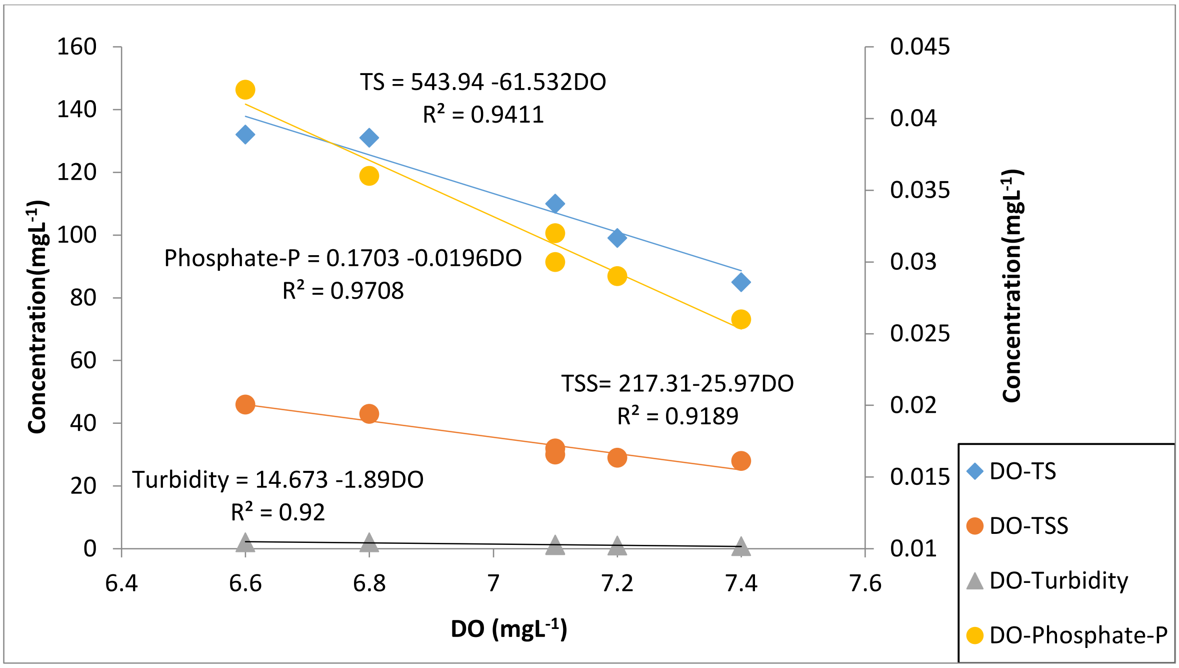


Fig: 5.17(d)

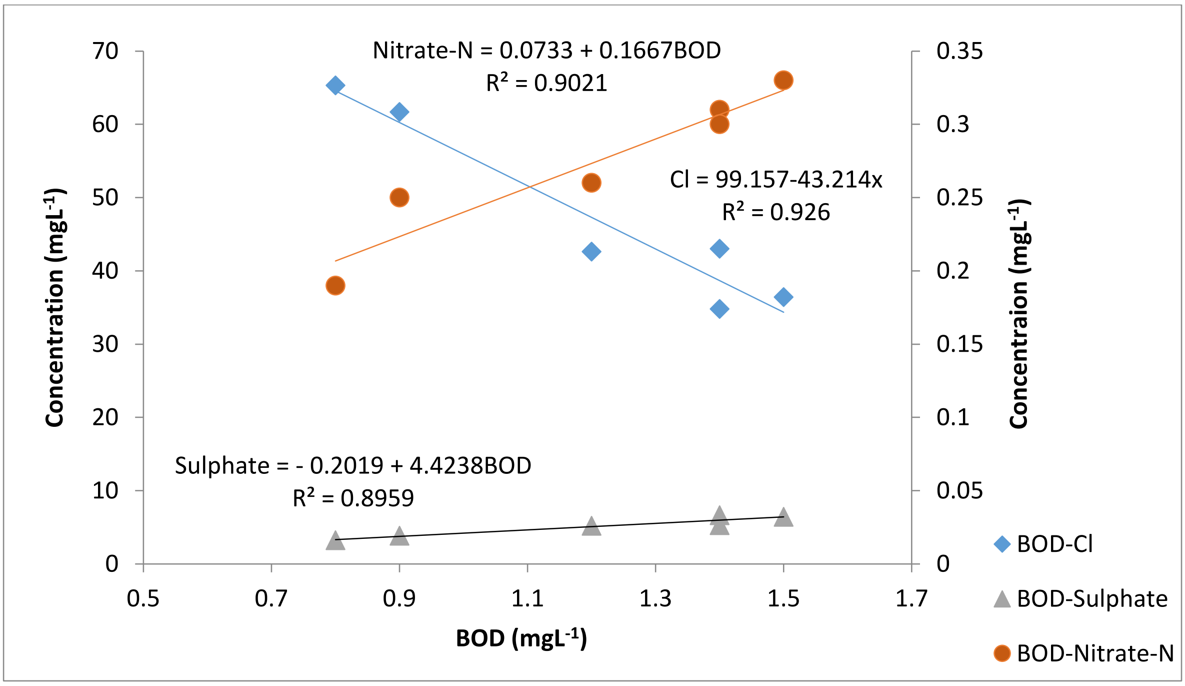
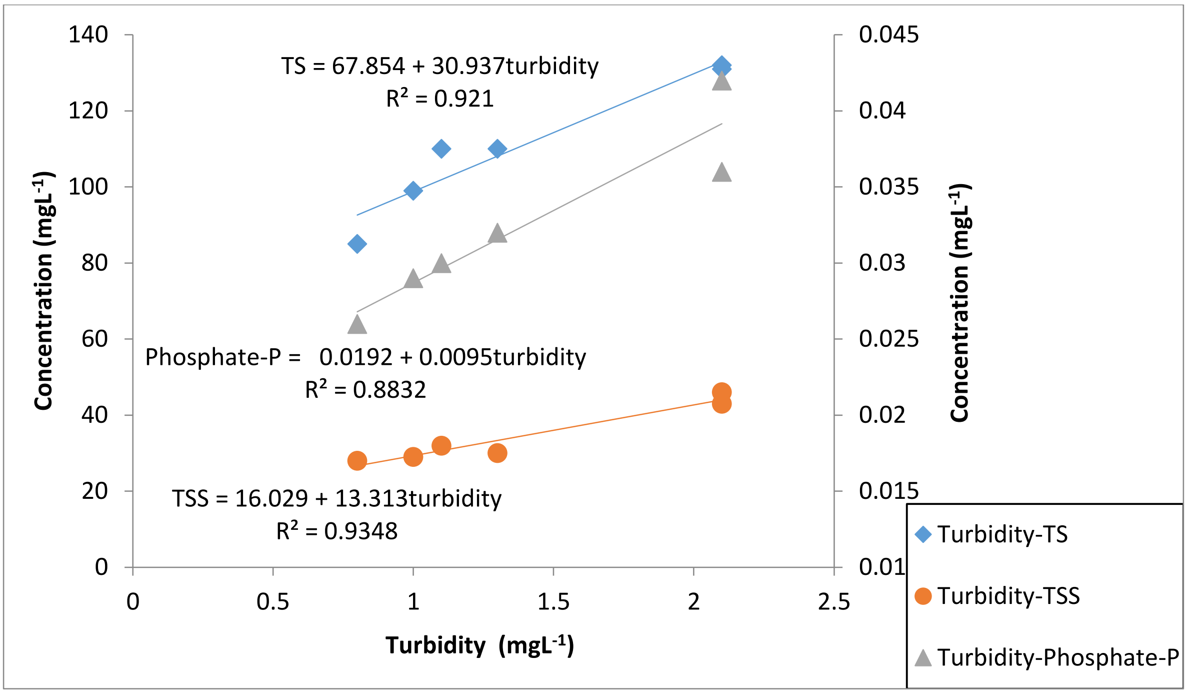


Fig: 5.17(e)



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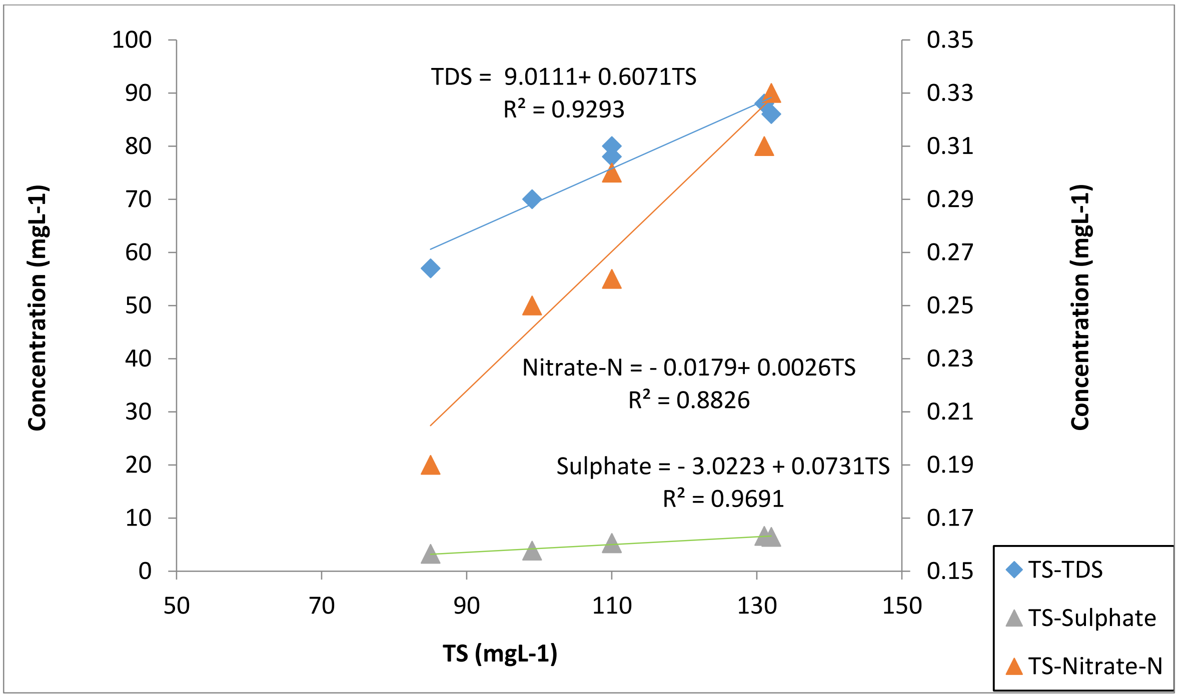

Fig: 5.17(g)

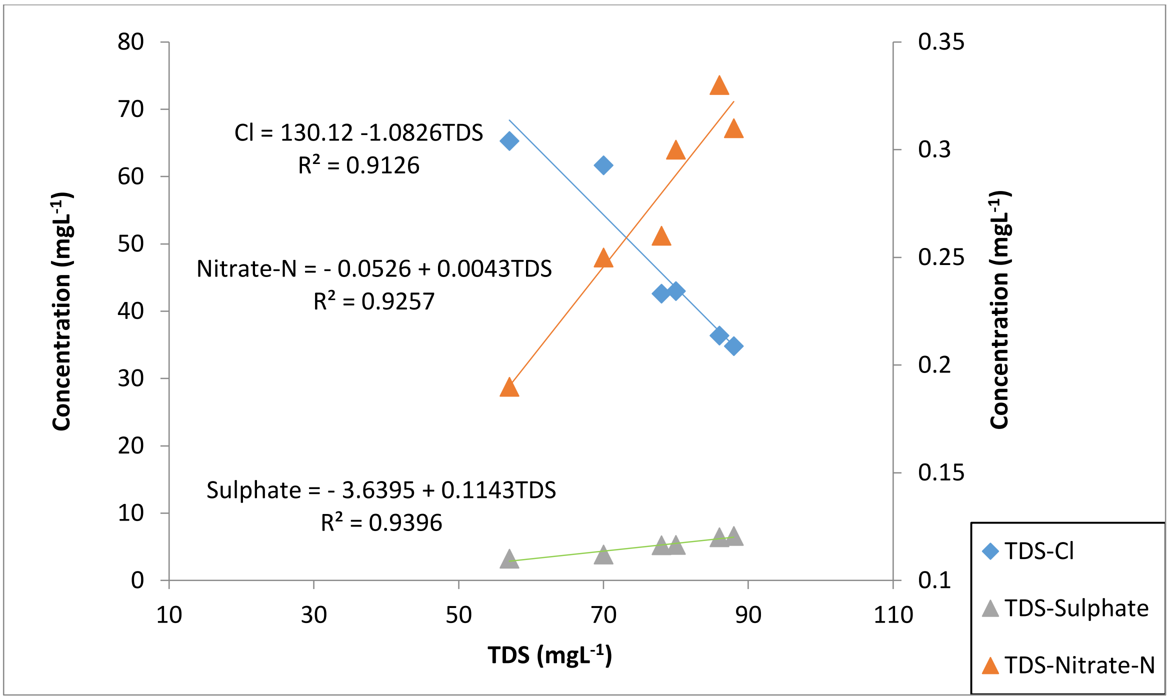

Fig: 5.17(h)

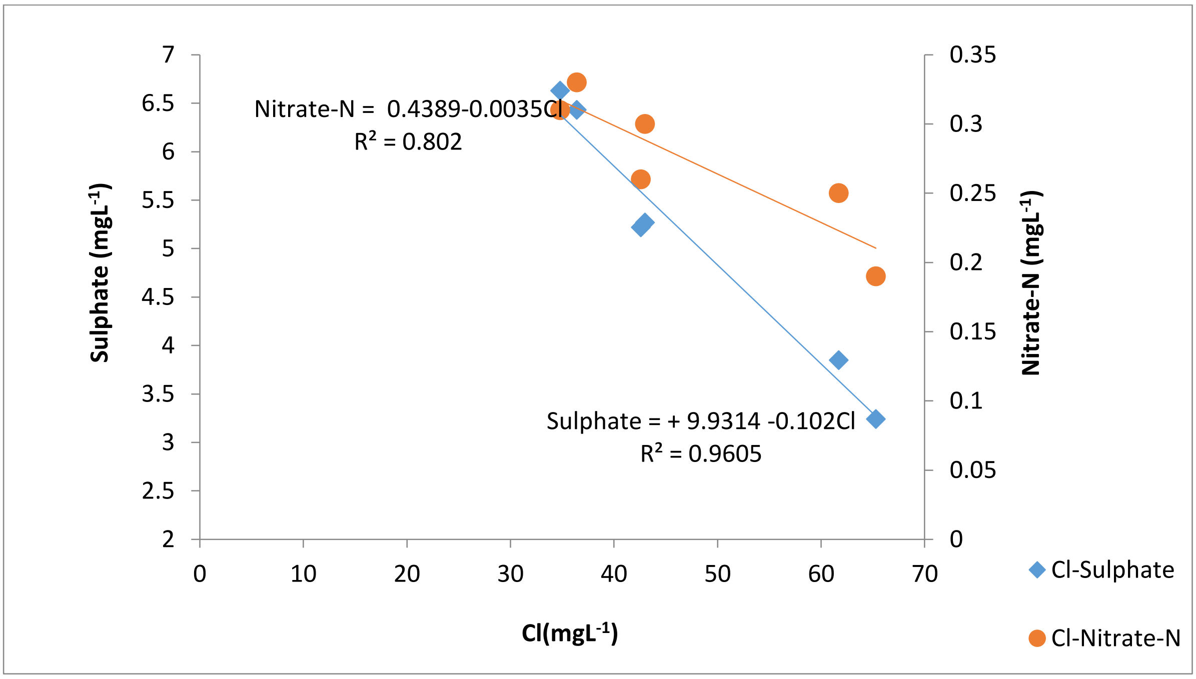

Fig: 5.17(i)

Figure: 5.18(a-e) Plots of water quality parameters as a linear regression model at Site 2

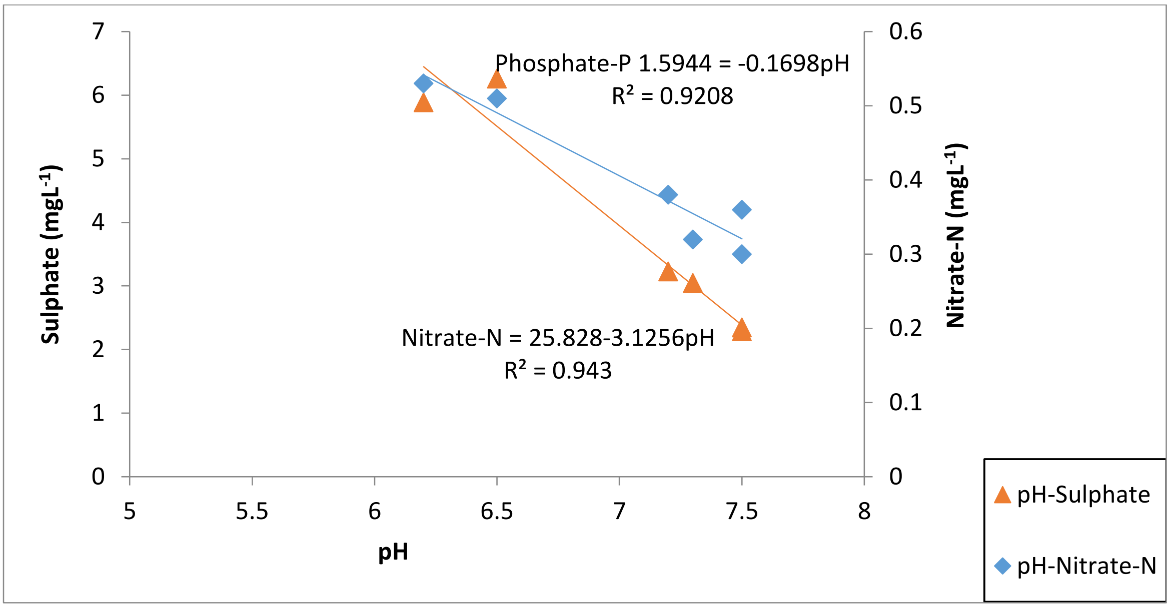

Fig: 5.18(a)

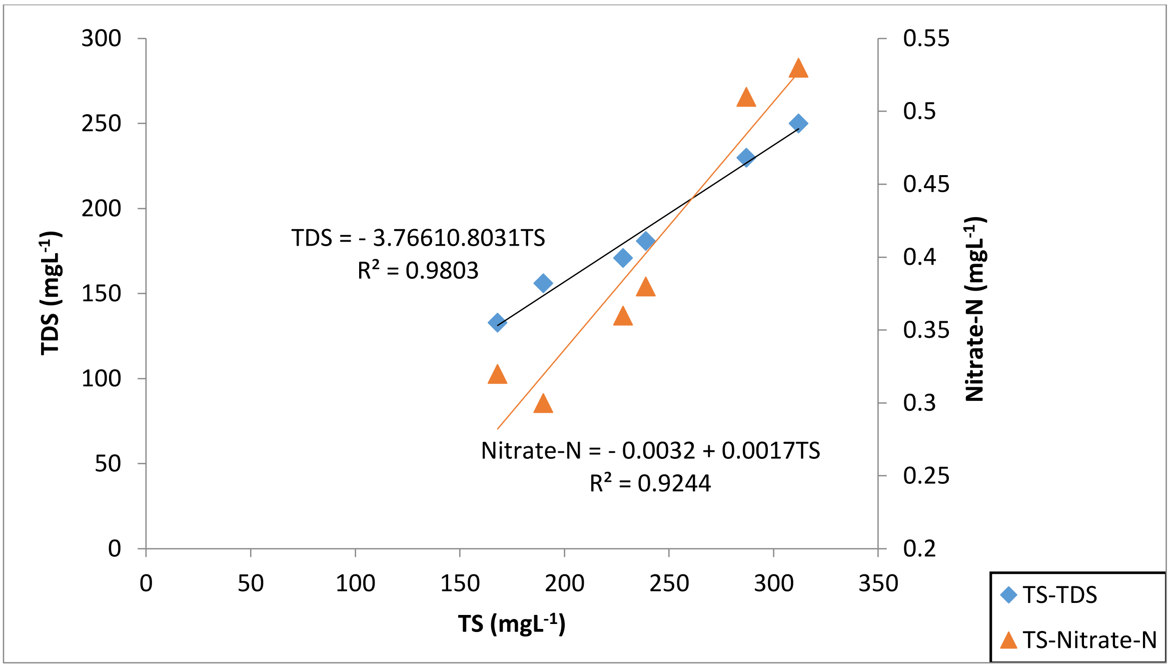

Fig: 5.18(b)

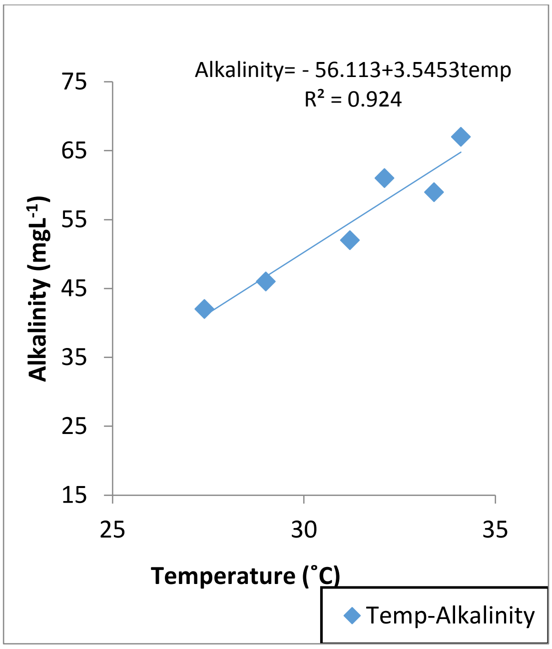

Fig: 5.18(c)

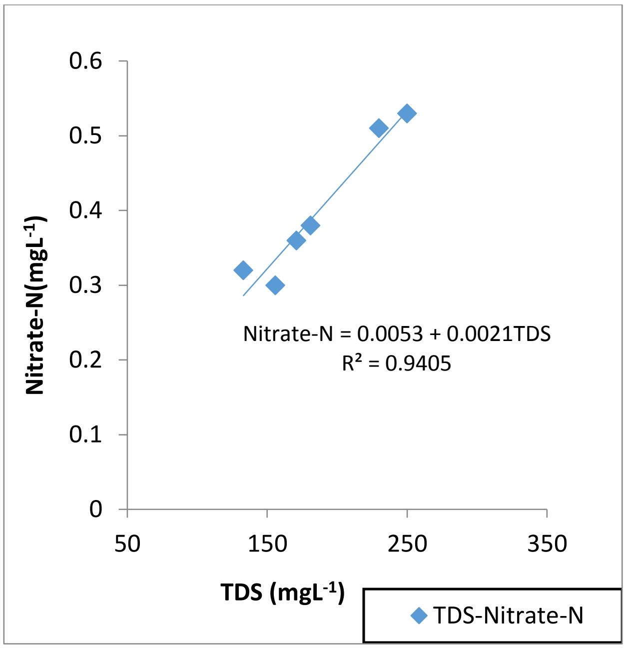

Fig: 5.18(d)

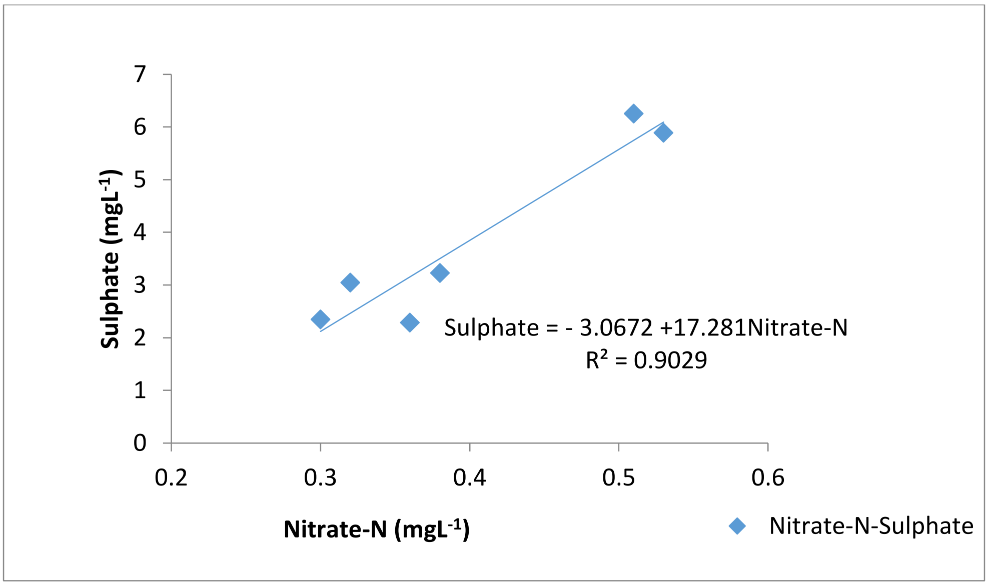

Fig: 5.18(e)

Figure: 5.19(a-e) Plots of water quality parameters as a linear regression model at Site 3

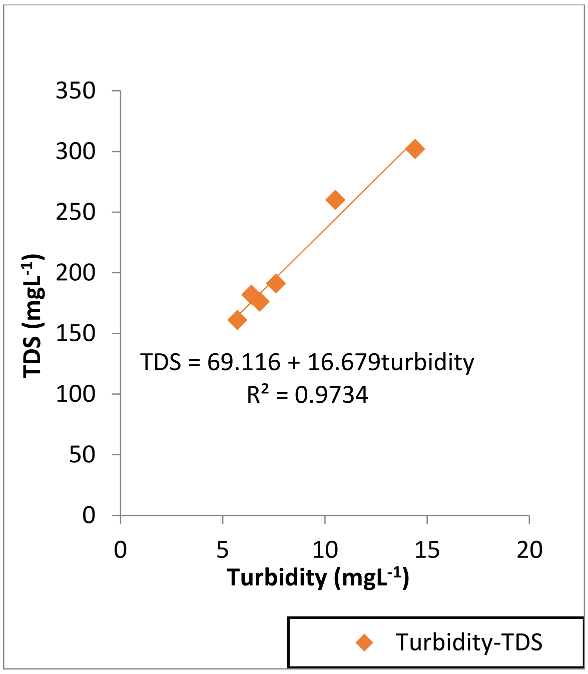

Fig: 5.19(a)

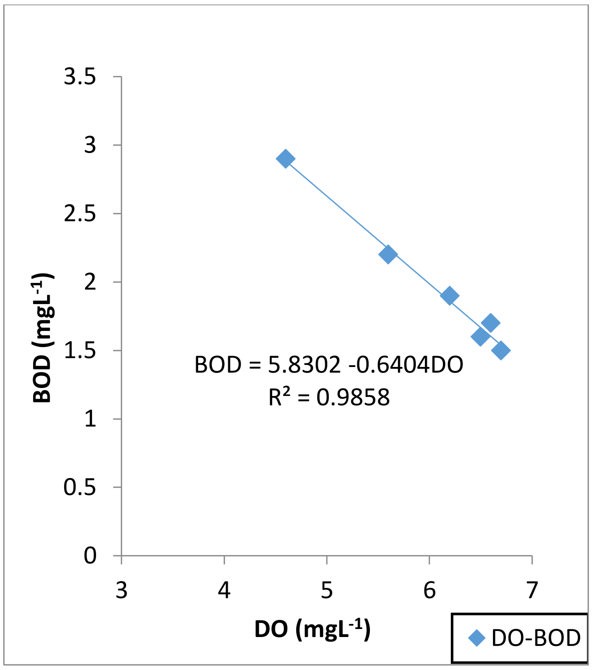

Fig: 5.19(b)

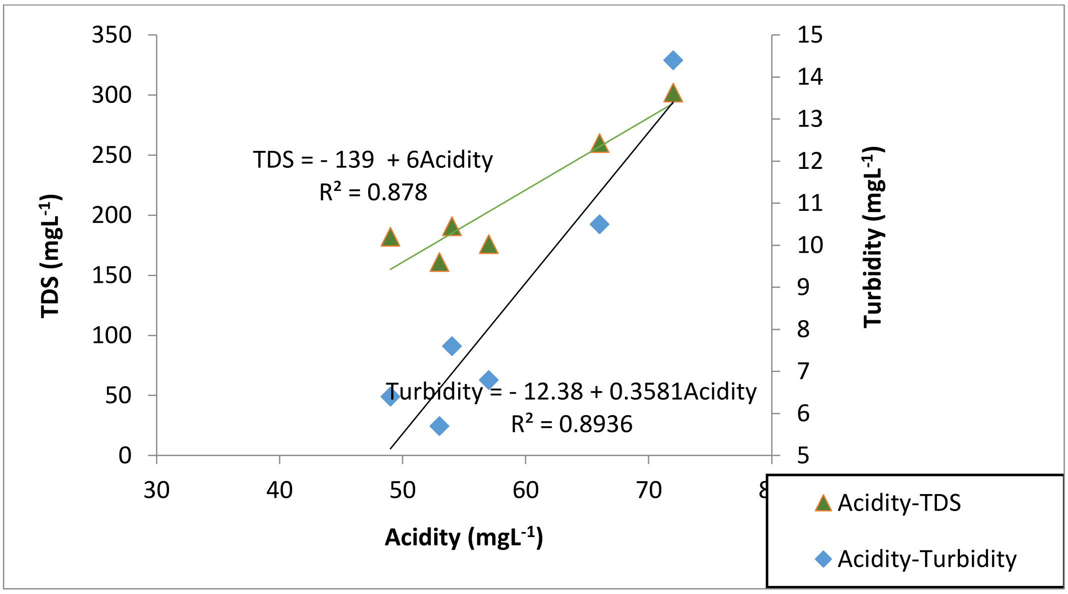

Fig: 5.19(c)

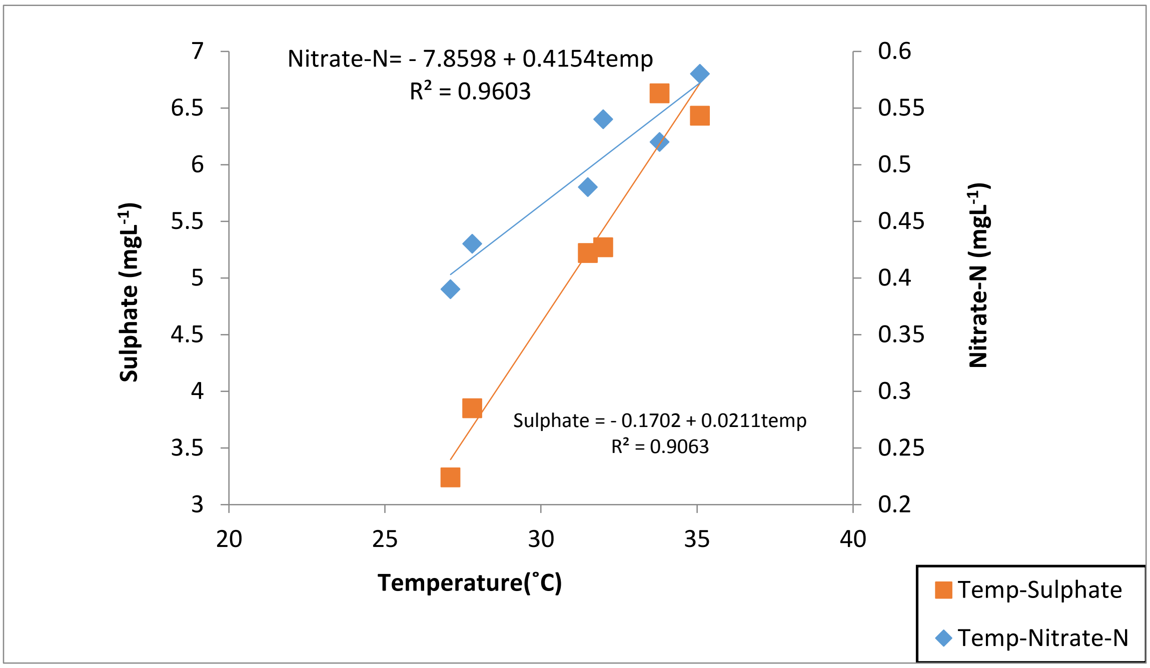

Fig: 5.19(d)

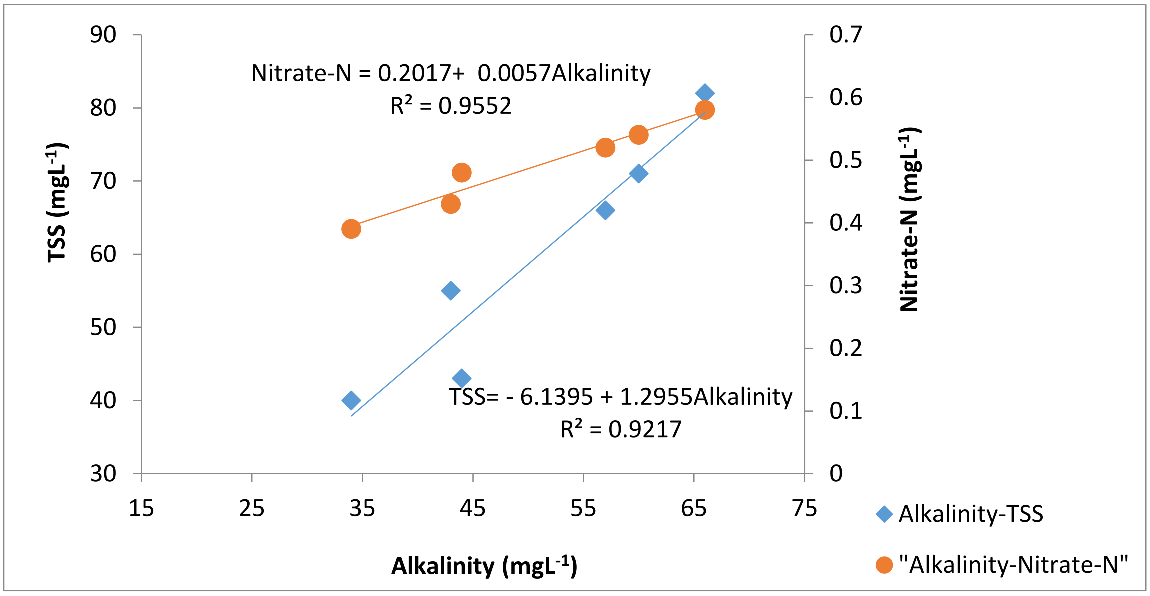

Fig: 5.19(e)

5.2 Aquatic Macophytes

5.2.1 Floristic Diversity of Macrophytes

The macrophytic composition of the study area has been presented in Table 5.25. A total of 28 aquatic macrophytes (16, 19 and 17 species at Site 1, Site 2 and Site 3 respectively) belonging to 24 genera and 13 families were recorded during the study period. Maximum number of species were shown by Poaceae and Commelinaceae (4 species), each contributing to 14.29%, followed by Cyperaceae, Onagraceae and Polygonaceae (3 species), each contributing to 10.71%, Amaranthaceae, Araceae and Pontideraceae (2 species) constituting 7.15% each, and Convolvulaceae, Fabaceae, Hydrocharitaceae, Juncaceae and Menyanthaceae were monospecific, each contributing to 3.57% (Fig: 5.20). The aquatic macrophytes found in the Serlui river were categorized into 4 groups i.e., (a) Emergent (b) Rooted with floating leaves (c) Free floating (d) Submerged. The maximum number of 22 species (78%) were recorded in the emergent group, and followed by rooted floating leaves consisting of 3 species (10.71%), free floating group 2 species (7.14%), submerged group only 1 species (3.57%) (Fig-5.21).

Table 5.25: List of Aquatic Macrophytes recorded from the Serlui river during the study period

Sl. No.	Scientific names	Family	Common name	Life form (Group)
1	*Alternanthera philoxeroides* (Mart) Griseb	Amaranthaceae	Aligator weed	Emergent
2	*Alternanthera sessilis* (L.)	Amaranthaceae	Sessile joyweed	Emergent
3	*Brachiaria mutica* (Forsk). Stapf.	Poaceae	Water grass	Emergent
4	*Carex camosa* Boott	Cyperaceae	Bottlebrush sedge	Emergent
5	*Colocasia affinis* Schott.	Araceae	Dwarf elephant ear	Emergent
6	*Commelina benghalensis* Linn.	Commelinaceae	Bengal day flower	Emergent
7	*Commelina maculata* Edgew.	Commelinaceae	Spotted day flower	Emergent
8	*Cyperus corymbosus* Rottb.	Cyperaceae	Not known	Emergent
10	*Echinochloa stagnina* (Retz.) P.Beauv.	Poaceae	Hippo grass	Emergent
9	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Water hyacinth	Free floating
11	*Epilobium parviflorum* (Schreb.)	Onagraceae	Hoary willow herb	Emergent
12	*Floscopa scandens* Lour.	Commelinaceae	Climbing flower cup	Emergent
13	*Hydrilla verticillata* (Linn F.) Royle	Nymphaeaceae	Not known	Submerged
14	*Hymenachne pseudointerrupta* C. Muell.	Poaceae	Water straw grass	Emergent
15	*Ipomoea aquatica* Forssk.	Convolvulaceae	Water spinach	Emergent
16	*Juncus effusus* L.	Juncaceae	Soft rush	Emergent
17	*Ludwigia adscendens* (L.) H. Hara	Onagraceae	Water primrose	Rooted floating leaves
18	*Monochoria hastifolia* C. Presl	Pontederiaceae	Arrow leaved monochoria	Emergent
19	*Murdannia nudiflora* (L.) Brenan	Commelinaceae	Doveweed	Emergent
20	*Neptunia aquatica* (Pers.)	Fabaceae	Water mimosa	Rooted floating leaves
21	*Nymphoides indica* (L.) Kuntze	Menyanthaceae	Water snowflake	Rooted floating leaves
22	*Oenothera rosea* Soland	Onagraceae	Rose evening primrose	Emergent
23	*Pistia stratiotes* Linn.	Araceae	Watter lettuce	Free floating
24	*Polygonum barbatum* L.	Polygonaceae	Knotweed	Emergent
25	*Polygonum glabrum* Willd	Polygonaceae	Dense flower knotweed	Emergent
26	*Polygonum hydropiper* L.	Polygonaceae	Water pepper	Emergent
27	*Saccharum procerum* Roxb.	Poaceae	Not known	Emergent
28	*Scirpus atrovirens* Willd.	Cyperaceae	Darkgreen bulrush	Emergent

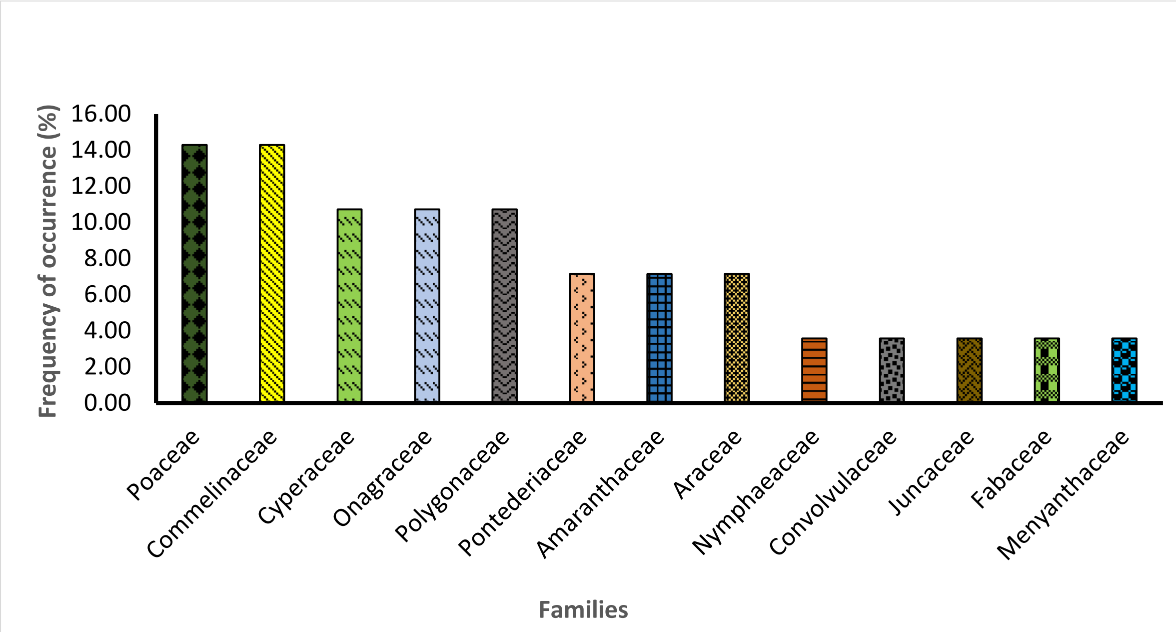

Fig 5.20: Family-wise per cent distribution of Species.

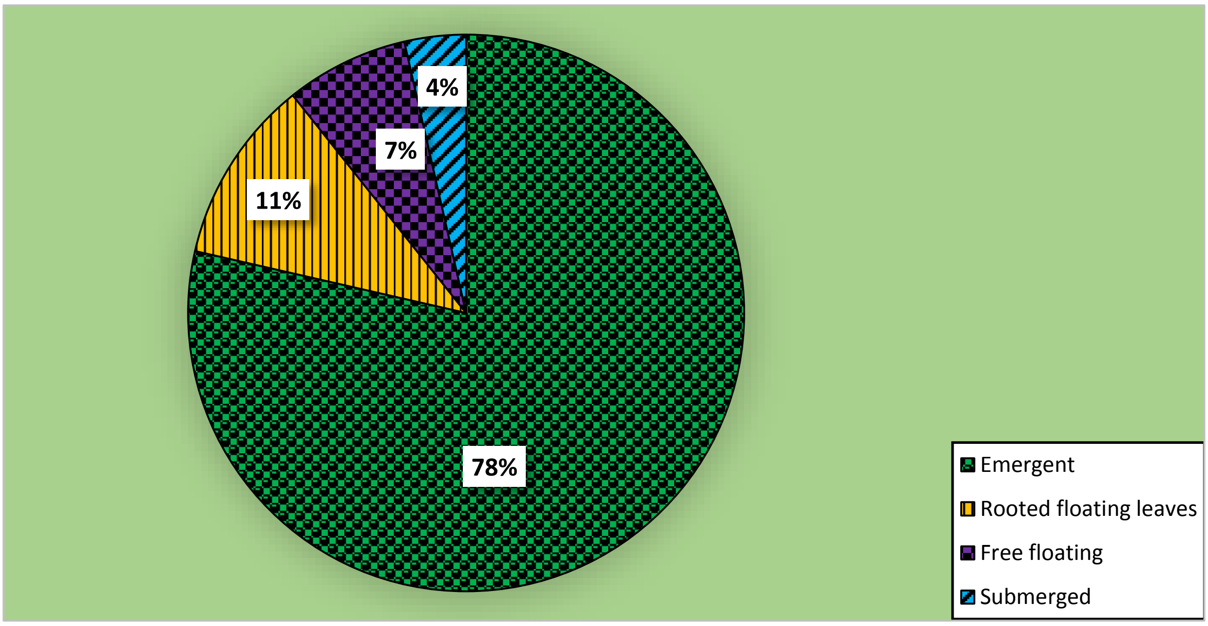

Fig 5.21: Per cent life form (Group) contribution

The species encountered during the study period from the selected study sites are listed in Table 5.26. A total of 16, 19 and 17 species were recorded from Site1, Site 2 and Site 3, respectively. A marked variation in the species composition was observed with regards to Sites. The species like *Commelina bengalensis*, *Commelina maculata*, *Epilobium parviflorum*, *Floscopa scandens*, *Juncus effuses* and *Oenothera rosea* were present only at Site 1, whereas species like *Hydrilla verticillata*, *Ipomoea aquatica*, *Ludwigia adscendens*, *Nymphoides indica* and *Pistia stratiotes* were confined only to Site 2. On the other hand, *Alternanthera sessilis* was sole species present only at Site 3. Species such as *Murdannia nudiflora* and *Saccharum arundinaceum* were found only at Site 1 and Site 3, whereas species like *Alternanthera philoxeroides*, *Eichinochloa stagnina*, *Eichhornia crassipes*, *Hymenachne pseudointerrupta*, *Monochoria hastifolia* and *Polygonum glabrum* were present only at Site 2 and Site 3. The number of species common at all the study sites was amounting to 8.

Similarly, a marked seasonal variation in the species composition was also observed during the study period (Table 5.26). During the summer season, the total number of species of recorded was 15, 15 and 17, whereas during the rainy season the number of species recorded was 16, 19 and 16 at Site 1, Site 2 and Site3, respectively. Similarly, during winter season the number of species counted was 11, 13 and 15 at Site 1, Site 2 and Site 3, respectively. At Site 1, species namely *Floscopa scandens* was found only during the rainy season, whereas species such as *Commelina bengalensis*, *Commelina maculata*, *Epilobium parviflorum* and *Oenothera rosea* were absent during the winter season. Similarly, at Site 2, species such as *Nymphoides indica*, *Pistia stratiotes* and *Polygonum glabrum* were present only during the rainy season, whereas species such as *Brachiaria mutica*, *Ipomoea aquatica*, *Ludwigia adscendens*, were absent during the winter season. At Site 3, *Brachiaria mutica* was found only during the summer season, and during the winter season, *Polygonum glabrum* was absent.

5.2.2 Phytosociological characteristics of Aquatic Macrophytes

1. **Community structure:** The phytosociological attributes namely, frequency, relative frequency, density, relative density, abundance, relative abundance and Importance Value Index (IVI) were computed and presented in Table 5.27 to 5.35.

a. **Frequency**

It was observed that the maximum frequency value during the summer season was exhibited by *Murdannia nudiflora* (80%), *Alternanthera philoxeroides* (93%) and *Alternanthera sessilis* (90%) at Site 1, Site 2 and Site 3, respectively. However, the minimum value was reported for *Oenothera rosea* (27%), *Polygonum hydropiper* (17%) and *Polygonum glabrum* (30%) at Site 1, Site 2 and Site 3, respectively.

In rainy season, the maximum value was shown by *Polygonum hydropiper* (87%), *Pistia stratiotes* (97%) and *Colocasia affinis* (93%) at Site 1, Site 2 and Site 3, respectively. On the other hand, the minimum value during said season was recorded for *Oenothera rosea* (30%) at Site 1, *Polygonum barbatum* (13%) at Site 2, *Cyperus corymbosus* and *Saccharum procerum* (27% each) at Site 3.

In winter season, the maximum value was exhibited by *Cyperus corymbosus* (80%), *Eichhornia crassipes* (100%) and *Monochoria hastifolia* (87%) and the minimum for *Polygonum barbatum* (37%), *Polygonum barbatum* (13%) and *Saccharum procerum* (27%) at Site 1, Site 2 and Site 3, respectively.

b. Density

The summer season showed maximum value for *Polygonum hydropiper* (4.7plantm^{-2}), *Hymenachne pseudointerrupta* (11.3 plantm^{-2}) and *Alternanthera sessilis* (4.2 plantm^{-2}) at Site 1, Site 2 and Site 3, respectively. On other hand, the minimum value was reported for *Oenothera rosea* (0.7 plantm^{-2}) at Site 1, *Polygonum hydropiper* (0.3 plantm^{-2}) at Site 2, and *Polygonum glabrum* and *Polygonum barbatum* (0.9 plantm^{-2} each) at Site 3.

During rainy season, the maximum value was exhibited by *Murdannia nudiflora* (5.8 plantm^{-2}), *Pistia stratiotes* (6.5 plantm^{-2}) and *Colocasia affinis* (5.4 plantm^{-2}) at Site 1, Site 2 and Site 3, respectively. On the other hand, the minimum value was recorded for *Oenothera rosea* (1.0 plantm^{-2}) at Site 1, *Polygonum barbatum (*0.3 plantm^{-2}) at Site 2, *Cyperus corymbosus* (0.8 plantm^{-2}) at Site 3.

In winter season, the maximum value was exhibited by *Murdannia nudiflora* (4.8 plantm^{-2}), *Eichhornia crassipes* (8.5 plantm^{-2}) and *Hymenachne pseudointerrupta* (5.8 plantm^{-2}), and minimum for *Polygonum barbatum* (1.3 plantm^{-2}), *Polygonum barbatum* (0.4 plantm^{-2}) and *Saccharum procerum* (0.9 plantm^{-2}*)* at Site 1, Site 2 and Site 3, respectively.

c. Abundance

During the summer season, the maximum value was shown by *Polygonum hydropiper* (6.1 plantm^{-2}), *Hymenachne pseudointerrupta* (13 plantm^{-2}) and *Echinochloa stagnina* (6.2 plantm^{-2}) at Site 1, Site 2 and Site 3, respectively. The minimum value during the season was reported for *Oenothera rosea* (2.5 plantm^{-2}) and *Epilobium parviflorum* (2.5 plantm^{-2}) at Site 1, *Polygonum hydropiper* (1.8 plantm^{-2}) at Site 2 and *Polygonum barbatum* (2.4 plantm^{-2}) at Site 3.

In rainy season, the maximum value was exhibited by *Murdannia nudiflora* (7.3 plantm^{-2}), *Hymenachne pseudointerrupta* (8.9 plantm^{-2}) and *Hymenachne pseudointerrupta*

(7.3 plantm^{-2}) at Site 1, Site 2 and Site 3, respectively. On the other hand, the minimum value was recorded for *Epilobium parviflorum* (2.2 plantm^{-2}) at Site 1, *Polygonum barbatum (*2.2 plantm^{-2}) at Site 2, *Monochoria hastifolia* (2.8 plantm^{-2}) at Site 3.

In winter season, the maximum value was exhibited by *Murdannia nudiflora* (5.6 plantm^{-2}), *Hymenachne pseudointerrupta* (9 plantm^{-2}) and *Hymenachne pseudointerrupta* (7 plantm^{-2}) and minimum value was recorded for *Neptunia aquatica* (2.9 plantm^{-2}), *Polygonum barbatum* (2.8 plantm^{-2}) and *Neptunia aquatica* (2.6 plantm^{-2}) at Site 1, Site 2 and Site 3, respectively.

d. Importance Value Index (IVI)

During the summer season, the maximum IVI was recorded for *Polygonum hydropiper* (35.2), *Hymenachne pseudointerrupta* (56.2) and *Alternanthera sessilis* (28.1) at Site 1, Site 2 and Site 3, respectively. However, the minimum value was reported for *Oenothera rosea* (9.8), *Polygonum hydropiper (5.4) and Polygonum barbatum* (9.8) at Site 1, Site 2 and Site 3, respectively.

In rainy season, the maximum value was exhibited by *Murdannia nudiflora* (34), *Pistia stratiotes* (32.1) and *Colocasia affinis* (32.2) at Site 1, Site 2 and Site 3, respectively. On the other hand, the minimum value was recorded for *Oenothera rosea* (10.6) at Site 1, *Polygonum barbatum (*5.2) and *Polygonum glabrum (*5.2) at Site 2, *Cyperus cormybosus* (9.3) at Site 3.

In winter season, the maximum value was exhibited by *Murdannia nudiflora* (39.8), *Eichhornia crassipes* (48.1) and *Hymenachne pseudointerrupta* (41.3), and minimum value was recorded for *Polygonum barbatum* (16.7) and *Polygonum barbatum* (7.1) and *Saccharum procerum* (11.7) at Site 1, Site 2 and Site 3, respectively.

The species rank of the macrophytic species based on the IVI for the selected study sites in different seasons is presented in Table 6.36-6.38. In terms of species rank, during the summer seasons, *Polygonum hydropiper* was the most dominant species at Site 1, *Hymenachne pseudointerrupta* at Site 2 and *Alternanthera sessilis* at Site 3 marking a shift in the species position. During the rainy seasons, the emergent form (*Murdannia nudiflora*) at Site 1 was succeeded by free floating form at Site 2, whereas during the winter season the co-dominant species at Site 2 (*Hymenachne pseudointerrupta)* was reported as the dominant species at Site 3.

Table 5.26: Seasonal variation in diversity of aquatic macrophytes at the selected study sites

Sl No.	Name of the Species	Site 1			Site 2			Site 3		
		Summer	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter
1	*Alternanthera philoxeroides*	–	–	–	+	+	+	+	+	+
2	*Alternanthera sessilis*	–	–	–	–	–	–	+	+	+
3	*Brachiaria mutica*	+	+	+	+	+	-	+	–	–
4	*Carex camosa*	+	+	+	+	+	+	+	+	+
5	*Colocasia esculenta*	+	+	+	+	+	+	+	+	+
6	*Commelina benghalensis*	+	+	–	–	–	–	–	–	–
7	*Commelina maculata*	+	+	–	–	–	–	–	–	–
8	*Cyperus corymbosus*	+	+	+	+	+	+	+	+	+
10	*Echinochloa stagnina*	–	–	–	+	+	+	+	+	+
9	*Eichhornia crassipes*	–	–	–	+	+	+	+	+	+
11	*Epilobium parviflorum*	+	+	–	–	–	–	–	–	–
12	*Floscopa scandens*	–	+	–	–	–	–	–	–	–
13	*Hydrilla verticillata*	–	–	–	+	+	+	–	–	–
14	*Hymenachne pseudointerrupta*	–	–	–	+	+	+	+	+	+
15	*Ipomoea aquatica*	–	–	–	+	+	–	–	–	–
16	*Juncus effusus*	+	+	+	–	–	–	–	–	–
17	*Ludwigia adscendens*	–	–	–	+	+	–	–	–	–
18	*Monochoria hastifolia*	–	–	–	+	+	+	+	+	+

Continued Table 5.26

Sl. No.	Name of the Species	Site 1			Site 2			Site 3		
		Summer	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**	**Summer**	**Rainy**	**Winter**
19	*Murdannia nudiflora*	+	+	+	-	-	-	+	+	+
20	*Neptunia aquatica*	+	+	+	+	+	+	+	+	+
21	*Nymphoides indica*	_	_	_	_	+	_	_	_	_
22	*Oenothera rosea*	+	+	_	_	_	_	_	_	_
23	*Pistia stratiotes*	_	_	_	_	+	_	_	_	_
24	*Polygonum barbatum*	+	+	+	_	+	+	+	+	_
25	*Polygonum glabrum*	_	_	_	_	+	_	+	+	+
26	*Polygonum hydropiper*	+	+	+	+	+	+	+	+	+
27	*Saccharum procerum.*	+	+	+	_	_	_	+	+	+
28	*Scirpus atrovirens*	+	+	+	+	+	+	+	+	+
	TOTAL	**15**	**16**	**11**	**15**	**19**	**13**	**17**	**16**	**15**

Abbreviation: +, Present; -, Absent

Table 5.27: Phytosociological characteristics of aquatic macrophytes at Site 1 during summer season

Sl. No.	Name of the Species	Frequency (%)	Relative frequency	Density (plants/m^2)	Relative density	Abundance	Relative abundance	IVI	A/F Ratio
1	*Brachiaria mutica*	53	7.1	2.1	6.8	4.0	6.7	20.6	0.08
2	*Carex camosa*	40	5.3	1.7	5.3	4.2	7.0	17.6	0.10
3	*Colocasia affinis*	43	5.8	1.4	4.4	3.2	5.3	15.4	0.07
4	*Commelina benghalensis*	47	6.2	1.7	5.4	3.6	6.1	17.7	0.08
5	*Commelina maculata*	53	7.1	1.8	5.7	3.4	5.6	18.5	0.06
6	*Cyperus corymbosus*	60	8.0	2.8	9.0	4.7	7.9	24.9	0.08
7	*Epilobium parviflorum*	37	4.9	0.9	2.9	2.5	4.1	11.8	0.07
8	*Juncus effusus*	30	4.0	1.6	5.1	5.3	8.9	18.0	0.18
9	*Murdannia nudiflora*	80	10.6	4.5	14.3	5.6	9.4	34.4	0.07
10	*Neptunia aquatica*	67	8.9	1.8	5.8	2.8	4.6	19.3	0.04
11	*Oenothera rosea*	27	3.5	0.7	2.1	2.5	4.2	9.8	0.09
12	*Polygonum barbatum*	57	7.5	2.6	8.2	4.5	7.6	23.3	0.08
13	*Polygonum hydropiper*	77	10.2	4.7	14.9	6.1	10.2	35.2	0.08
14	*Saccharum procerum*	33	4.4	1.1	3.5	3.3	5.5	13.5	0.10
15	*Scirpus atrovirens*	50	6.6	2.1	6.6	4.1	6.9	20.1	0.08
	TOTAL	**753**	**100**	**31.4**	**100**	**59.78**	**100**	**300**	

Table 5.28: Phytosociological characteristics of aquatic macrophytes at Site 1 during rainy season

Sl. No.	Scientific names	Frequency (%)	Relative Frequency	Density (plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Brachiaria mutica*	36.67	4.10	1.67	4.1	4.55	6.5	14.7	0.12
2	*Carex camosa*	50.00	5.60	2.47	6.1	4.93	7.0	18.8	0.10
3	*Colocasia affinis*	60.00	6.72	1.70	4.2	2.83	4.0	15.0	0.05
4	*Commelina benghalensis*	40.00	4.48	1.60	4.0	4.00	5.7	14.2	0.10
5	*Commelina maculata*	46.67	5.22	1.70	4.2	3.64	5.2	14.6	0.08
6	*Cyperus corymbosus*	73.33	8.21	4.37	10.8	5.95	8.5	27.5	0.08
7	*Epilobium parviflorum*	50.00	5.60	1.10	2.7	2.20	3.1	11.5	0.04
8	*Floscopa scandens*	60.00	6.72	2.27	5.6	3.78	5.4	17.7	0.06
9	*Juncus effusus*	50.00	5.60	2.73	6.8	5.47	7.8	20.2	0.11
10	*Murdannia nudiflora*	80.00	8.96	5.87	14.5	7.33	10.5	34.0	0.09
11	*Neptunia aquatica*	70.00	7.84	2.07	5.1	2.95	4.2	17.2	0.04
12	*Oenothera rosea*	30.00	3.36	1.00	2.5	3.33	4.8	10.6	0.11
13	*Polygonum barbatum*	56.67	6.34	3.23	8.0	5.71	8.2	22.5	0.10
14	*Polygonum hydropiper*	86.67	9.70	4.20	10.4	4.85	6.9	27.0	0.06
15	*Saccharum procerum*	46.67	5.22	1.70	4.2	3.64	5.2	14.6	0.08
16	*Scirpus atrovirens*	56.67	6.34	2.73	6.8	4.82	6.9	20.0	0.09
	TOTAL	**893.33**	**100**	**40.40**	**100**	**69.99**	**100**	**300**	

Table 5.29: Phytosociological characteristics of aquatic macrophytes at Site 1 during winter season

Sl. No.	Names of the species	Frequency (%)	Relative Frequency	Density (plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Brachiaria mutica*	53.33	8.6	2.87	9.3	5.38	10.0	27.9	0.10
2	*Carex camosa*	46.67	7.5	2.47	8.0	5.29	9.9	25.4	0.11
3	*Colocasia affinis*	53.33	8.6	2.63	8.6	4.94	9.2	26.3	0.09
4	*Cyperus corymbosus*	80.00	12.8	4.13	13.4	5.17	9.7	35.9	0.06
5	*Juncus effusus*	40.00	6.4	1.93	6.3	4.83	9.0	21.7	0.12
6	*Murdannia nudiflora*	73.33	11.8	4.83	15.7	6.59	12.3	39.8	0.09
7	*Neptunia aquatica*	63.33	10.2	1.83	6.0	2.89	5.4	21.5	0.05
8	*Polygonum barbatum*	36.67	5.9	1.30	4.2	3.55	6.6	16.7	0.10
9	*Polygonum hydropiper*	66.67	10.7	3.37	10.9	5.05	9.4	31.1	0.08
10	*Saccharum procerum*	50.00	8.0	2.47	8.0	4.93	9.2	25.3	0.10
11	*Scirpus atrovirens*	60.00	9.6	2.93	9.5	4.89	9.1	28.3	0.08
	TOTAL	**623.33**	**100**	**30.77**	**100**	**53.50**	**100**	**300**	

Table 5.30: Phytosociological characteristics of aquatic macrophytes at Site 2 during summer season

Sl. No.	Name of the species	Frequency (%)	Relative Frequency	Density (Plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	93	12.0	10.83	25.0	11.6	16.9	53.9	0.12
2	*Brachiaria mutica*	43	5.6	1.67	3.8	3.8	5.6	15.0	0.09
3	*Carex camosa*	33	4.3	1.07	2.5	3.2	4.7	11.4	0.10
4	*Colocasia affinis*	57	7.3	2.43	5.6	4.3	6.2	19.1	0.08
5	*Cyperus corymbosus*	50	6.4	1.90	4.4	3.8	5.5	16.3	0.08
6	*Echinochloa stagnina*	27	3.4	1.17	2.7	4.4	6.4	12.5	0.16
7	*Eichhornia crassipes*	67	8.5	2.53	5.9	3.8	5.5	19.9	0.06
8	*Hydrilla verticillata*	50	6.4	2.50	5.8	5.0	7.3	19.5	0.10
9	*Hymenachne pseudointerrupta*	87	11.1	11.30	26.1	13.0	19.0	56.2	0.15
10	*Ipomoea aquatica*	57	7.3	1.47	3.4	2.6	3.8	14.2	0.05
11	*Ludwigia adscendens*	80	10.3	3.13	7.2	3.9	5.7	23.2	0.05
12	*Monochoria hastifolia*	70	9.0	1.73	4.0	2.5	3.6	16.6	0.04
13	*Neptunia aquatica*	23	3.0	0.60	1.4	2.6	3.7	8.1	0.11
14	*Polygonum hydropiper*	17	2.1	0.30	0.7	1.8	2.6	5.4	0.11
15	*Scirpus atrovirens*	27	3.4	0.67	1.5	2.5	3.6	8.6	0.09
	TOTAL	**780**	**100**	**43.3**	**100**	**68.8**	**100**	**300**	

Table 5.31: Phytosociological characteristics of aquatic macrophytes at Site 2 during rainy season

Sl. No.	Name of the Species	Frequency (%)	Relative Frequency	Density (plants/m2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	63	6.3	3.9	8.3	6.1	7.8	22.3	0.10
2	*Brachiaria mutica*	57	5.6	1.9	4.2	3.4	4.3	14.1	0.06
3	*Carex camosa*	50	5.0	2.3	4.9	4.5	5.8	15.6	0.09
4	*Colocasia affinis*	37	3.6	1.5	3.2	4.1	5.2	12.1	0.11
5	*Cyperus corymbosus*	40	4.0	1.4	3.1	3.6	4.6	11.6	0.09
6	*Echinochloa stagnina*	23	2.3	0.8	1.6	3.3	4.2	8.1	0.14
7	*Eichhornia crassipes*	93	9.2	5.3	11.3	5.6	7.2	27.7	0.06
8	*Hydrilla verticillata*	80	7.9	3.0	6.4	3.7	4.7	19.0	0.05
9	*Hymenachne pseudointerrupta*	67	6.6	5.9	12.8	8.9	11.3	30.7	0.13
10	*Ipomoea aquatica*	43	4.3	1.1	2.3	2.5	3.1	9.7	0.06
11	*Ludwigia adscendens*	70	6.9	3.5	7.5	5.0	6.3	20.7	0.07
12	*Monochoria hastifolia*	73	7.3	2.4	5.1	3.2	4.1	16.5	0.04
13	*Neptunia aquatica*	50	5.0	1.2	2.7	2.5	3.1	10.7	0.05
14	*Nymphoides indica*	70	6.9	3.0	6.5	4.3	5.5	19.0	0.06
15	*Pistia stratiotes*	97	9.6	6.5	14.0	6.7	8.5	32.1	0.07
16	*Polygonum barbatum*	13	1.3	0.3	0.7	2.5	3.2	5.2	0.19
17	*Polygonum glabrum*	17	1.7	0.4	0.8	2.2	2.8	5.2	0.13
18	*Polygonum hydropiper*	33	3.3	1.1	2.4	3.4	4.3	10.1	0.10
19	*Scirpus atrovirens*	33	3.3	1.1	2.3	3.2	4.1	9.7	0.10
	TOTAL	**1010**	**100**	**47**	**100**	**79**	**100**	**300**	

Table 5.32: Phytosociological characteristics of aquatic macrophytes at Site 2 during winter season

Sl. No.	Name of the Species	Frequency (%)	Relative Frequency	Density (plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	93	12.6	6.4	15.6	6.8	11.0	39.2	0.07
2	*Carex camosa*	33	4.5	1.5	3.7	4.5	7.3	15.4	0.14
3	*Colocasia affinis*	73	9.9	3.1	7.7	4.3	6.9	24.5	0.06
4	*Cyperus corymbosus*	43	5.9	1.7	4.2	3.9	6.3	16.3	0.09
5	*Echinochloa stagnina*	47	6.3	1.6	3.8	3.4	5.4	15.6	0.07
6	*Eichhornia crassipes*	100	13.5	8.5	20.9	8.5	13.8	48.1	0.09
7	*Hydrilla verticillata*	67	9.0	3.2	7.9	4.9	7.8	24.7	0.07
8	*Hymenachne pseudointerrupta*	90	12.2	8.1	19.9	9.0	14.6	46.6	0.10
9	*Monochoria hastifolia*	73	9.9	2.9	7.0	3.9	6.3	23.2	0.05
10	*Neptunia aquatica*	43	5.9	1.3	3.1	2.9	4.7	13.7	0.07
11	*Polygonum barbatum*	13	1.8	0.4	0.9	2.8	4.4	7.1	0.21
12	*Polygonum hydropiper*	37	5.0	1.2	2.9	3.3	5.3	13.2	0.09
13	*Scirpus atrovirens*	27	3.6	1.0	2.5	3.9	6.3	12.4	0.15
	TOTAL	**740**	**100**	**40.9**	**100**	**62.0**	**100**	**300**	

Table 5.33: Phytosociological characteristics of aquatic macrophytes at Site 3 during summer season

Sl. No.	Name of the Species	Frequency (%)	Relative Frequency	Density (plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	83.3	9.3	4.1	10.9	4.9	7.0	27.1	0.06
2	*Alternanthera sessilis*	90.0	10.0	4.2	11.3	4.7	6.7	28.1	0.05
3	*Brachiaria mutica*	40.0	4.5	1.7	4.5	4.2	5.9	14.9	0.10
4	*Carex camosa*	36.7	4.1	1.4	3.7	3.8	5.4	13.3	0.10
5	*Colocasia affinis*	76.7	8.5	3.3	8.9	4.3	6.2	23.7	0.06
6	*Cyperus corymbosus*	43.3	4.8	1.9	5.0	4.3	6.1	16.0	0.10
7	*Echinochloa stagnina*	46.7	5.2	2.9	7.8	6.2	8.9	21.8	0.13
8	*Eichhornia crassipes*	53.3	5.9	1.8	4.8	3.4	4.8	15.6	0.06
9	*Hymenachne pseudointerrupta*	36.7	4.1	2.2	6.0	6.1	8.7	18.7	0.17
10	*Monochoria hastifolia*	70.0	7.8	2.5	6.7	3.6	5.1	19.6	0.05
11	*Murdannia nudiflora*	46.7	5.2	2.6	7.0	5.6	7.9	20.1	0.12
12	*Neptunia aquatica*	60.0	6.7	2.0	5.3	3.3	4.7	16.6	0.05
13	*Polygonum barbatum*	36.7	4.1	0.9	2.3	2.4	3.4	9.8	0.06
14	*Polygonum glabrum*	30.0	3.3	0.9	2.5	3.1	4.4	10.3	0.10
15	*Polygonum hydropiper*	63.3	7.1	2.1	5.6	3.3	4.7	17.4	0.05
16	*Saccharum procerum*	43.3	4.8	1.4	3.8	3.3	4.7	13.4	0.08
17	*Scirpus atrovirens*	40.0	4.5	1.5	4.0	3.8	5.3	13.8	0.09
	TOTAL	**896.7**	**100**	**37.4**	**100**	**70.2**	**100**	**300**	

Table 5.34: Phytosociological characteristics of aquatic macrophytes at Site 3 during rainy season

Sl. No.	Name of the Species	Frequency (%)	Relative Frequency	Density (plants/m^2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	57	6.5	3.9	9.5	6.9	9.7	25.8	0.12
2	*Alternanthera sessilis*	83	9.6	5.0	12.1	6.0	8.4	30.1	0.07
3	*Carex camosa*	40	4.6	1.4	3.5	3.6	5.1	13.2	0.09
4	*Colocasia affinis*	93	10.8	5.4	13.2	5.8	8.2	32.2	0.06
5	*Cyperus corymbosus*	27	3.1	0.8	1.9	3.0	4.2	9.3	0.11
6	*Echinochloa stagnina*	70	8.1	3.4	8.3	4.9	6.9	23.2	0.07
7	*Eichhornia crassipes*	57	6.5	2.3	5.5	4.0	5.7	17.7	0.07
8	*Hymenachne pseudointerrupta*	60	6.9	4.4	10.6	7.3	10.3	27.8	0.12
9	*Monochoria hastifolia*	67	7.7	1.9	4.5	2.8	4.0	16.2	0.04
10	*Murdannia nudiflora*	77	8.8	4.5	10.9	5.8	8.2	28.0	0.08
11	*Neptunia aquatica*	53	6.2	1.6	4.0	3.1	4.3	14.5	0.06
12	*Polygonum barbatum*	30	3.5	1.0	2.4	3.3	4.7	10.6	0.11
13	*Polygonum glabrum*	40	4.6	1.6	3.9	4.0	5.7	14.2	0.10
14	*Polygonum hydropiper*	50	5.8	2.0	4.8	3.9	5.6	16.1	0.08
15	*Saccharum procerum*	27	3.1	0.9	2.1	3.3	4.6	9.8	0.12
16	*Scirpus atrovirens*	37	4.2	1.1	2.8	3.1	4.4	11.4	0.08
	TOTAL	**867**	**100**	**41.1**	**100**	**70.7**	**100**	**300**	

Table 5.35: Phytosociological characteristics of aquatic macrophytes at Site 3 during winter season

Sl. No.	Name of the Species	Frequency (%)	Relative Frequency	Density (plants/m2)	Relative Density	Abundance	Relative Abundance	IVI	A/F Ratio
1	*Alternanthera philoxeroides*	43	5.6	2.0	6.4	4.6	7.8	19.8	0.11
2	*Alternanthera sessilis*	47	6.0	2.1	6.6	4.4	7.5	20.2	0.09
3	*Carex camosa*	40	5.2	1.3	4.3	3.3	5.6	15.1	0.08
4	*Colocasia affinis*	67	8.6	2.7	8.5	4.0	6.8	24.0	0.06
5	*Cyperus corymbosus*	37	4.7	1.1	3.6	3.1	5.2	13.6	0.08
6	*Echinochloa stagnina*	37	4.7	1.5	4.9	4.2	7.1	16.7	0.11
7	*Eichhornia crassipes*	53	6.9	1.9	6.1	3.6	6.0	19.0	0.07
8	*Hymenachne pseudointerrupta*	83	10.8	5.8	18.7	7.0	11.9	41.3	0.08
9	*Monochoria hastifolia*	87	11.2	2.8	9.1	3.3	5.5	25.8	0.04
10	*Murdannia nudiflora*	50	6.5	2.5	7.9	4.9	8.4	22.7	0.10
11	*Neptunia aquatic*	57	7.3	1.5	4.8	2.6	4.5	16.6	0.05
12	*Polygonum barbatum*	47	6.0	1.6	5.0	3.4	5.7	16.7	0.07
13	*Polygonum hydropiper*	50	6.5	2.1	6.6	4.1	7.0	20.1	0.08
14	*Saccharum procerum*	27	3.4	0.9	2.8	3.3	5.5	11.7	0.12
15	*Scirpus atrovirens*	50	6.5	1.5	4.9	3.1	5.2	16.6	0.06
	TOTAL	**773**	**100**	**31**	**100**	**59**	**100**	**300**	

Table 5.36: Species dominance (based on IVI) at selected study sites during summer season

Site 1			Site 2			Site 3		
Species rank	**Species**	**IVI**	**Species rank**	**Species**	**IVI**	**Species rank**	**Species**	**IVI**
1	*P. hydropiper*	35.2	1	*H.pseudointerrupta*	56.2	1	*A. sessilis*	28.1
2	*M. nudiflora*	34.4	2	*A. philoxeroides*	53.9	2	*A. philoxeroides*	27.1
3	*C. corymbosus*	24.9	3	*L. adscendens*	23.2	3	*C. esculenta*	23.7
4	*P. barbatum*	23.3	4	*E. crassipes*	19.9	4	*E. stagnina*	21.8
5	*B. mutica*	20.6	5	*H. verticillata*	19.5	5	*M. nudiflora*	20.1
6	*S. atrovirens*	20.1	6	*C. esculenta*	19.1	6	*M. hastifolia*	19.6
7	*N. aquatica*	19.3	7	*M. hastifolia*	16.6	7	*H.pseudointerrupta*	18.7
8	*C. maculata*	18.5	8	*C.corymbosus*	16.3	8	*N. aquatica*	16.6
9	*J. effusus*	18	9	*B. mutica*	15	9	*C. corymbosus*	16
10	*C. benghalensis*	17.7	10	*I. aquatica*	14.4	10	*P. hydropiper*	17.4
11	*C. camosa*	17.6	11	*E. stagnina*	12.5	11	*E. crassipes*	15.6
12	*C. esculenta*	15.4	12	*C. camosa*	11.4	12	*B. mutica*	14.9
13	*S.arundinaceum*	13.5	13	*S. atrovirens*	8.6	13	*S. atrovirens*	13.8
14	*E. parviflorum*	11.8	14	*N. aquatica*	8.1	14	*S. arundinaceum*	13.4
15	*O. rosea*	9.8	15	*P.hydropiper*	5.4	15	*C. camosa*	13.3
						16	*P. glabrum*	10.3
						17	*P. barbatum*	9.8

Table 5.37: Species dominance (based on IVI) at selected study sites during rainy season

Site 1			Site 2			Site 3		
Species rank	**Species**	**IVI**	**Species rank**	**Species**	**IVI**	**Species rank**	**Species**	**IVI**
1	*M. nudiflora*	34	1	*P. stratiotes*	32.1	1	*C. esculenta*	32.2
2	*C. corymbosus*	27.5	2	*H. pseudointerrupta*	30.7	2	*A. sessilis*	30.1
3	*P. hydropiper*	27	3	*E. crassipes*	27.7	3	*M. nudiflora*	28
4	*P. barbatum*	22.5	4	*A. philoxeroides*	22.3	4	*H.pseudointerrupta*	27.8
5	*J. effusus*	20.2	5	*L. adscendens*	20.7	5	*A. philoxeroides*	25.8
6	*S. atrovirens*	20	6	*N. indica*	19.3	6	*E. stagnina*	23.2
7	*C. camosa*	18.8	7	*H. verticillata*	19	7	*E. crassipes*	17.7
8	*F. scandens*	17.7	8	*M. hastifolia*	16.5	8	*M. hastifolia*	16.2
9	*N.aquatica*	17.2	9	*C. camosa*	15.6	9	*P. hydropiper*	16.1
10	*C. esculenta*	15	10	*B. mutica*	14.1	10	*N. aquatica*	14.5
11	*B. mutica*	14.7	11	*C. esculenta*	12.1	11	*P. glabrum*	14.2
12	*C. maculata*	14.8	12	*C. corymbosus*	11.6	12	*C. camosa*	13.2
13	*S.arundinaceum*	14.6	13	*N. aquatica*	10.7	13	*S. atrovirens*	11.4
14	*C. benghalensis*	14.2	14	*P. hydropiper*	10.1	14	*P. barbatum*	10.6
15	*E. parviflorum*	11.5	15	*S. atrovirens*	9.8	15	*S. arundinaceum*	9.8
16	*O. rosea*	10.6	16	*I. aquatica*	9.7	16	*C. corymbosus*	9.3
			17	*E. stagnina*	8.1			
			18	*P. barbatum*	5.2			
			19	*P. glabrum*	5.1			

Table 5.38: Species dominance (based on IVI) at selected study sites during winter season

Site 1			Site 2			Site 3		
Species rank	**Species**	**IVI**	**Species rank**	**Species**	**IVI**	**Species rank**	**Species**	**IVI**
1	*M. nudiflora*	39.8	1	*E. crassipes*	48.1	1	*H. pseudointerrupta*	41.3
2	*C.corymbosus*	35.9	2	*H.pseudointerrupta*	46.6	2	*M. hastifolia*	25.8
3	*P. hydropiper*	31.1	3	*A. philoxeroides*	39.2	3	*C. esculenta*	24
4	*S. atrovirens*	28.3	4	*H. verticillata*	24.7	4	*M. nudiflora*	22.7
5	*B. mutica*	27.9	5	*C. esculenta*	24.5	5	*A. sessilis*	20.2
6	*C. esculenta*	26.3	6	*M. hastifolia*	23.2	6	*P. hydropiper*	20.1
7	*C. camosa*	25.4	7	*C. corymbosus*	16.3	7	*A. philoxeroides*	19.8
8	*S.arundinaceum*	25.3	8	*E. stagnina*	15.6	8	*E. crassipes*	19
9	*J. effusus*	21.7	9	*C. camosa*	15.4	9	*P. barbatum*	16.7
10	*N. aquatica*	21.5	10	*N. aquatica*	13.7	10	*E. stagnina*	16.6
11	*P. barbatum*	16.7	11	*P. hydropiper*	13.2	11	*N. aquatica*	16.5
			12	*S. atrovirens*	12.4	12	*S. atrovirens*	16.2
			13	*P. barbatum*	7.1	13	*C. camosa*	15.1
						14	*C. corymbosus*	13.6
						15	*S. arundinaceum*	11.7

5.2.3 Diversity Indices

The Shannon-Weiner diversity index (H'), Menhinick index (D_{mn}) and Species richness index (d) were maximum (H'=2.82; D_{mn}=0.51; d=2.49) at Site 2 during the rainy season, and minimum (H'=2.37; D_{mn}=0.3.36; d=1.47) at Site 1 during winter season, whereas Simpson index of dominance (D) was highest (D=0.102) at Site 2 during summer season (Fig: 6.22).The findings reveal that maximum value of the diversity index was recorded during rainy season at all the study sites. Majority of species possessed contagious distribution at all study sites, as it is prevalent in natural ecosystem. The species were more evenly distributed at control site (Site 1). The polluted sites (Site 2 & 3) were more similar (Similarity Index- 78%) in terms of species composition, and Similarity Index was accounted for 78%. However, Site 1 (control site) and Site 2 are least similar (Similarity Index- 46%). The dominance-distribution curves for Site 1, Site 2 and Site 3 are given in Fig: 5.23 to 5.25.

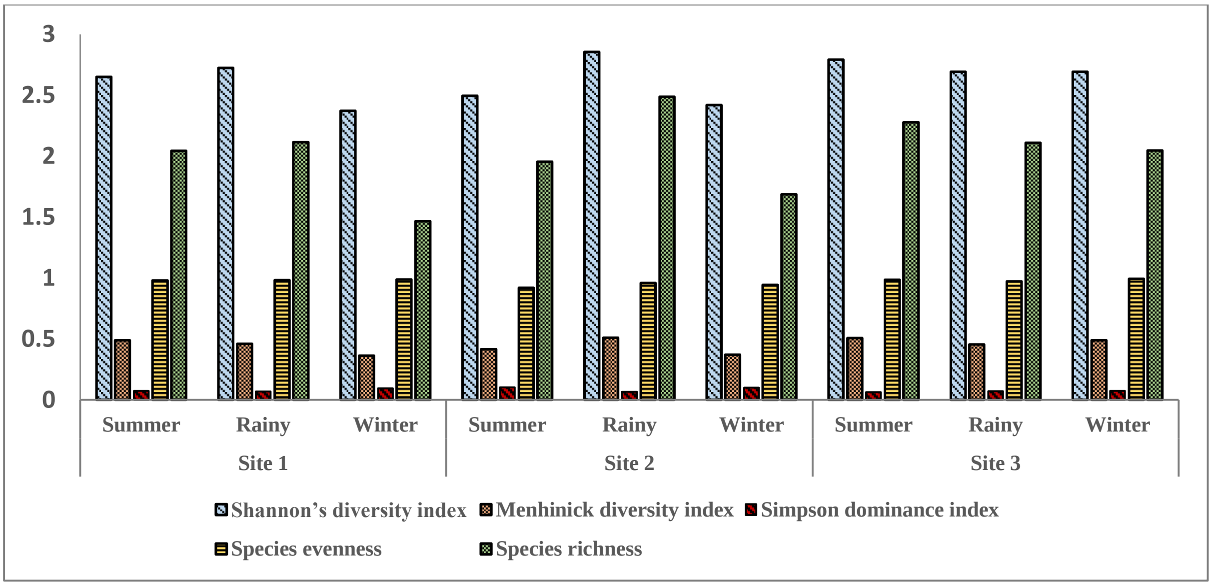

Fig 5.22: Seasonal variation in diversity-dominance indices of aquatic macrophytes at selected study sites

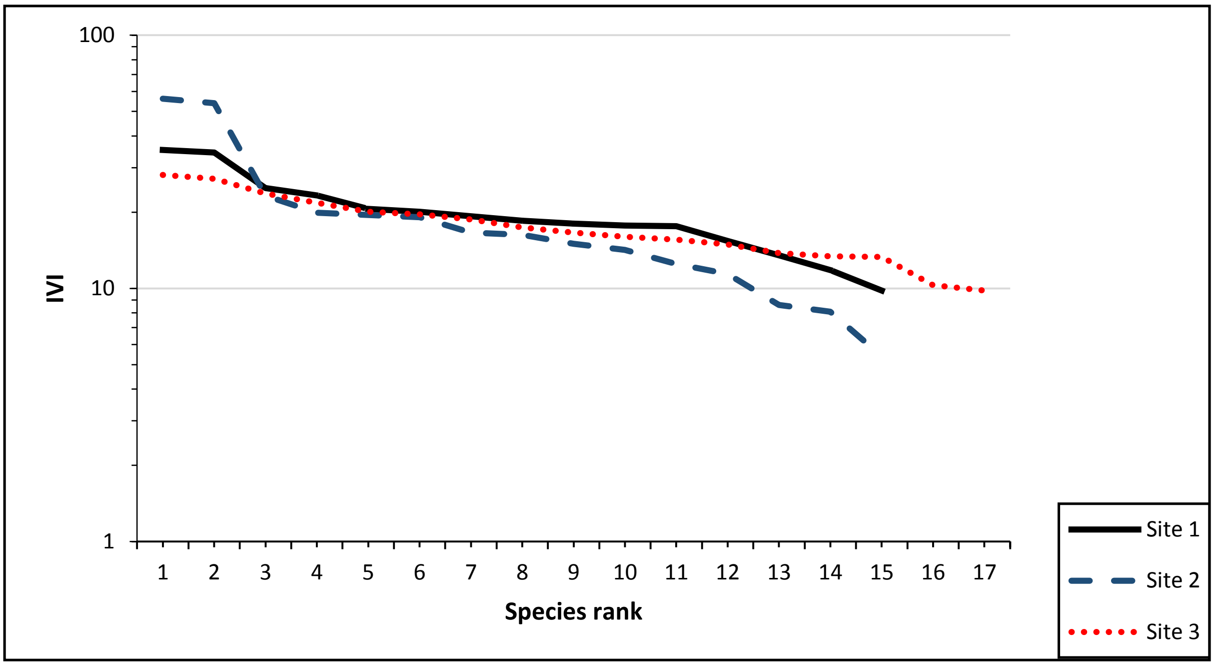

Fig 5.23: Dominance-distribution pattern of the species at selected study sites during summer season

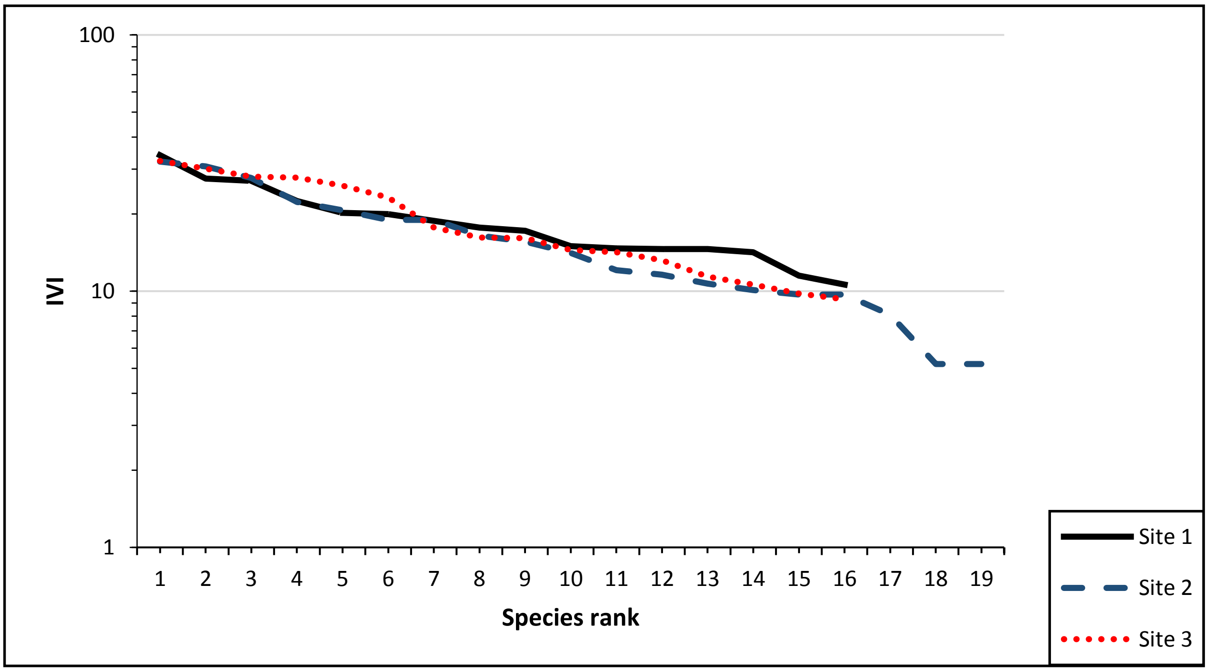

Fig 5.24: Dominance-distribution pattern of the species at selected study sites during rainy season

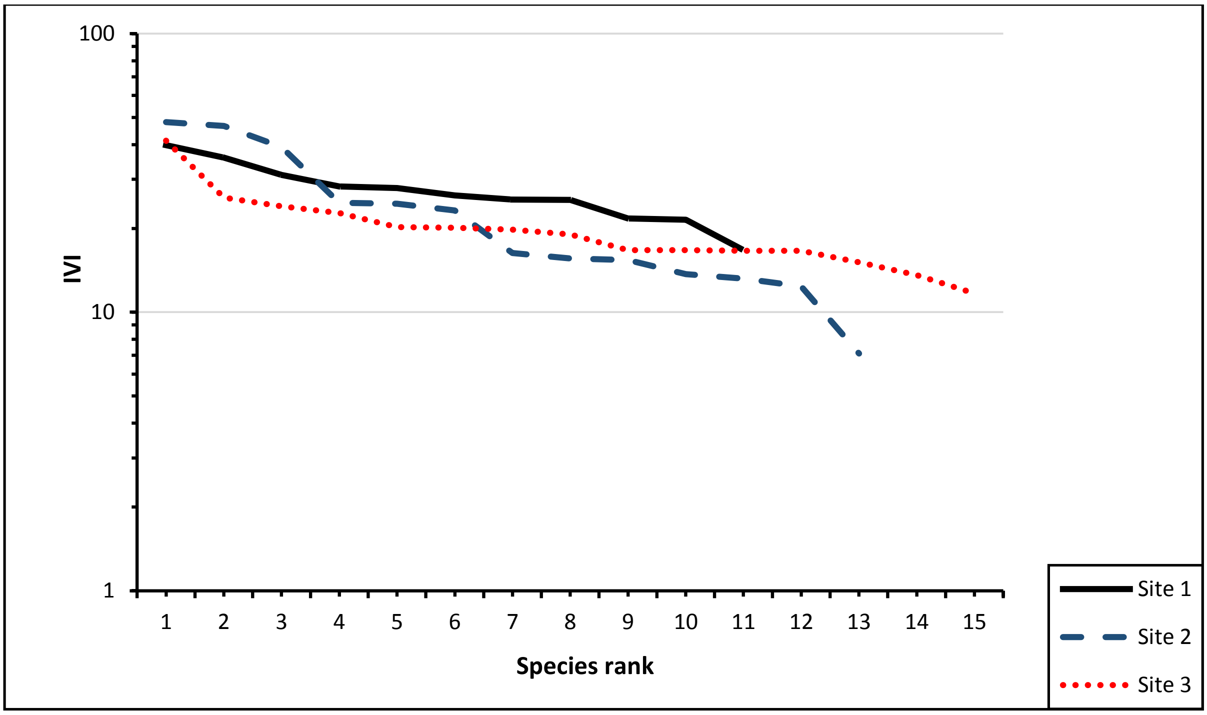

Fig 5.25: Dominance-distribution pattern of the species at selected study sites during winter season

a. ***Eichhornia crassipes***

b. ***Nymphoides indica***

c. ***Ludwigia adscendens***

d. ***Pistia stratiotes***

e. ***Monochoria hastifolia***

f. ***Hymenachne pseudointerrupta***

Photo Plate 5.1: Some important aquatic macrophytes

5.3 Floristic Diversity in the Catchment Area

The floristic diversity of the study area along with medicinal/economic uses of plants have been presented in Table 5.39-5.40. A total of 140 species i.e., 55 woody species, 62 herb species, 16 climbers and 7 bamboo and cane species belonging to 120 genera and 59 families were recorded from the undisturbed (UD) and disturbed (D) stands. The overall habit-wise distribution of plants indicates dominance of herbs (44.3%), and was followed by woody plants (39.3%), climbers (11.4%), cane and bamboo species (5%), respectively (Fig 5.26). Maximum number of species were represented by Asteraceae (19 species), followed by Poaceae (14 species), Rubiaceae (8 species), Fabaceae (6 species), Mimosaceae and Solanaceae (5 species each), Amaranthaceae, Euphorbiaceae, Malvaceae and Verbenaceae (4 species each), Arecaceae, , Polygonaceae, Urticaceae and Vitaceae (3 species each), Anacardiaceae, Araceae, Begoniaceae, Caesalpiniceae, Cucurbitaceae, Fagaceae, Lamiaceae, Passifloraceae, Rosaceae, and Zingiberaceae (2 species each) and remaining 35 families were mono-specific. (Fig: 5.27).

In the undisturbed stand, a total of 118 species belonging to 104 genera and 56 families were recorded. Maximum number of species were recorded from Asteraceae (15 species) followed by Poaceae (10 species), Rubiaceae (6 species), Mimosaceae (5 species), Euphobiaceae and Fabaceae (4 species each), Amaranthaceae, Arecaceae, Malvaceae, Polygonaceae, Verbenaceae and Vitaceae (3 species each), Anacardiaceae, Araceae, Begoniaceae, Caesalpiniaceae, Cucurbitaceae, Fagaceae, Lamiaceae, Passifloraceae, Rosaceae, Solanaceae, Urticaceae and Zingiberaceae (2 species each) and remaining 32 families were mono-specific. Species such as *Anthocephalus cadamba, Boehmeria platyphylla, Begonia rex, Paederia foetida, Phaseolus sublobatus, Rhus semialata, Tadehagi triquetrum, Unona longiflora*, were recorded only from the undisturbed stand (Table 5.39 and 5.40). Habit-wise distribution of plants indicates dominance of woody species (40.7%), and was followed by herbs (39.8%), climbers (13.6%) and cane and bamboo species (5.9%) in the undisturbed stand (Fig 5.28).

In the disturbed stand, a total of 71 species belonging to 63 genera and 31 families were recorded. Maximum number of species were reported from Asteraceae (14 species), followed by Poaceae (12 species), Fabaceae (5 species), Amaranthaceae, Rubiaceae, Mimosaceae and Solanaceae (3 species each), Malvaceae, Polygonaceae, Verbenaceae and Rosaceae (2 species each) and remaining 20 families were mono-specific. Species such as *Abelmoschus moschatus, Amaranthus spinosus, Cadariocalyx gyroides, Cleome viscosa, Lantana camara, Mussaenda roxburghii, Physalis angulata, Spermacoce ocymoides, Ziziphus jujuba*, were confined only in the disturbed stand (Table 5.39 and 5.40). Habit-wise distribution of plants indicates dominance of herbs (57.7%), and was followed by woody plants (35.2%), climbers (4.2%) and cane and bamboo species (2.8%) in the disturbed stand Figure 5.29).

A total of 49 species belonging to 46 genera and 26 families were found common in both the stands. Important common species were *Arthocarpus heterophyllus, Bidens pilosa*, *Cassia alata*, *Chromolaena odorata*, *Cheilocostus speciosus*, *Leucas aspera*, *Melastoma malabathrium*, *Meloccana baccifera, Mikania micranta*, *Mimosa pudica*, *Saurauia napaulensis, Scoparia dulcis*, *Urena lobata*. (Table 5.39 and Table 5. 40). The species similarity index calculated was found to be 0.52 between the undisturbed and disturbed stand.

The documentation of ethno-medicinal plants depicts that out of the total 140 plant species recorded so far from the catchment area of Serlui river, 116 species belonging to 106 genera and 52 families are being used for the treatment of various ailments by the indigenous communities as enlisted in Table 5.39 and Table 5. 40. The data obtained showed that most of the species recorded were used for diseases such as gastrointestinal diseases, dermatitis, fever, respiratory problems, urinary problems, snake bite, diabetes, and dental problems, which are some of the major health problems encountered in most communities. The plants parts used ranged from leaves, roots, barks, seed, flowers, fruits and in some case the whole plant. Asteraceae comprises the maximum number of ethnomedicinal plants (18 species) followed by Poaceae (9species), Rubiaceae (7species), Fabaceae and Solanaceae (5species each), Amaranthaceae, Euphorbiaceae, Malvaceae and Mimosaceae (4 species each), Urticaceae and Verbenaceae (3 species each), Anacardiaceae, Araceae, Begoniaceae, Cucurbitaceae, Lamiaceae, Passifloraceae, Polygonaceae, Rosaceae and Vitaceae (2 species each). Majority of the families (32) were monospecific. Anthropogenic activities have resulted in low species content of medicinal plants (58 species) in the disturbed stand, whereas, the undisturbed stand had high species richness of medicinal plants (98 species), 40 species were found common in both the stands. Although most of the species recorded were of medicinal importance, some were also used for other purposes such as vegetable, fruits, firewood. The percentage distribution of species used for various purposes present at the undisturbed and disturbed site is shown in Fig 5.30.

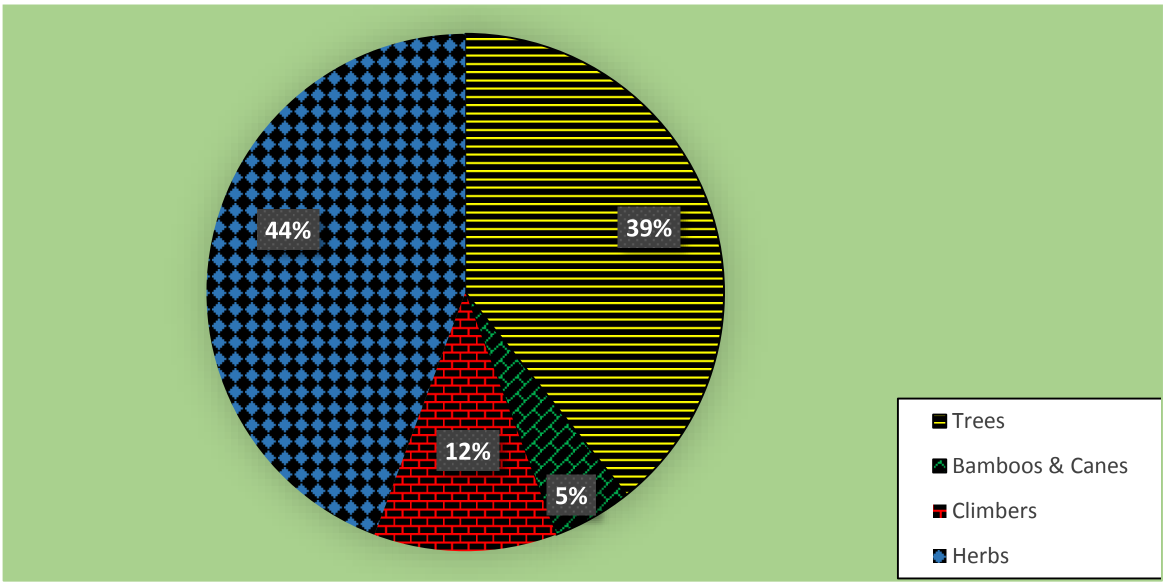

Fig 5.26: Overall habit-wise distribution of species

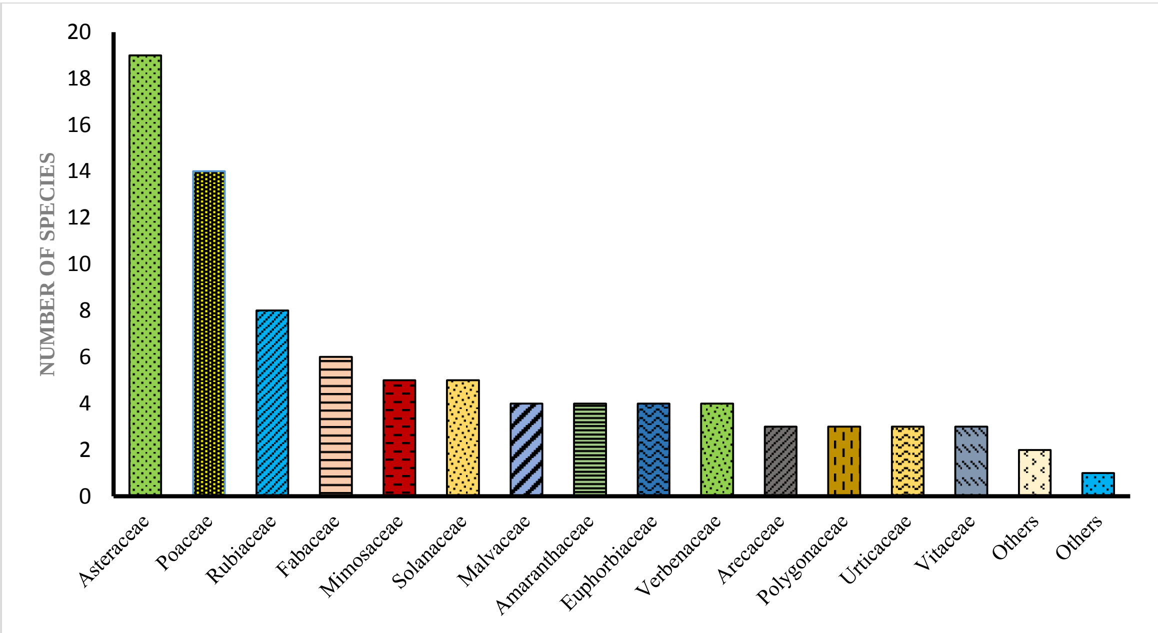

Fig 5. 27: Family-species distribution of plants in catchment area

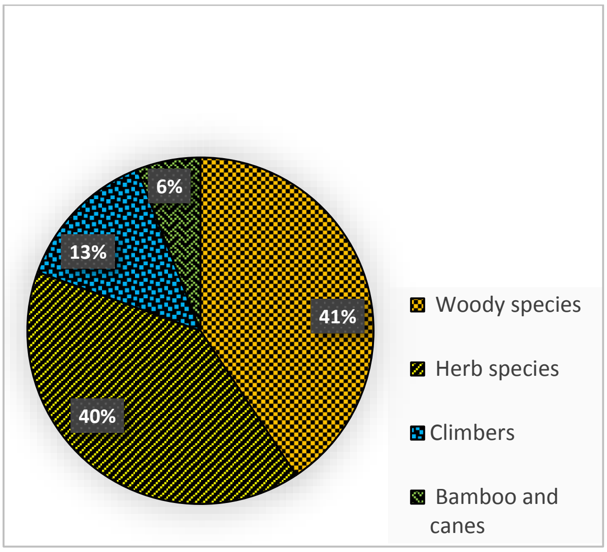

Fig 5.28: Habit-wise distribution of species in the undisturbed stand

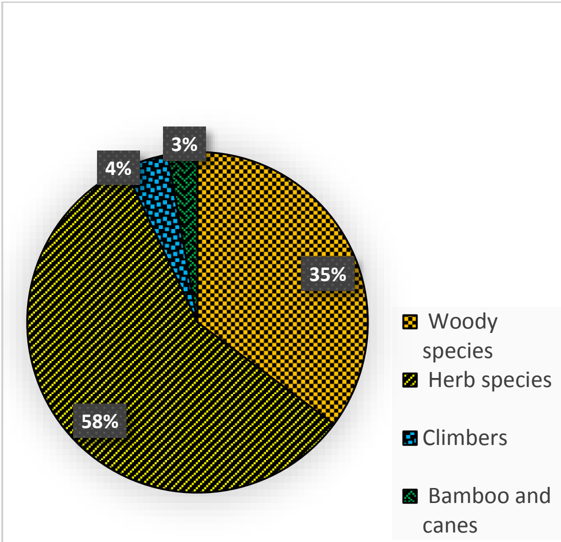

Fig 5.29: Habit-wise distribution of species in the disturbed stand

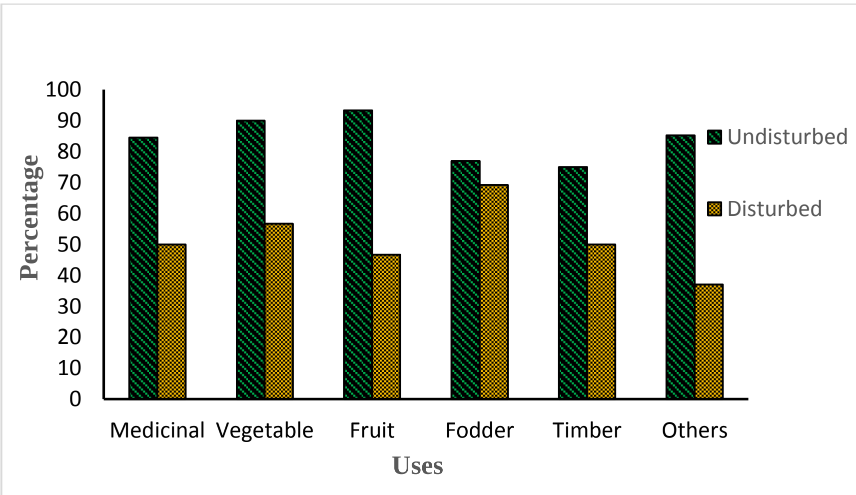

Fig 5.30: Percentage of plants used for medicinal and other purposes in the undisturbed and disturbed stands

Table 5.39- List of tree species and shrubs present in the undisturbed (UD) and disturbed (D) stands of the catchment area, and their economic values.

Sl. No.	Scientific Names	Family	Local Names	UD	D	Economic Values
1	*Acer laevigatum* Wall.	Aceraceae	Thing-khim	+	-	Wood is used for buildings, firewood etc.
2	*Albizzia chinensis* (Osb.) Merr.	Mimosaceae	Vang	+	-	Gum in headache; bark for skin burn and scabies; leaves used as fodder
3	*Anthocephalus cadamba* (Roxb.) Miq	Rubiaceae	Banphar	+	-	Wood used as timber; leaves are used for curing diabetes
4	*Antidesma bunius* (L.) Spreng	Euphorbiaceae	Tuai-tit	+	+	Leaves in snake-bites and whooping cough; wood used for firewood; bark for making ropes
5	*Aphananthe cuspidate* (Blume) Planch.	Cannabaceae	Thei-she-ret	+	-	Fruits are edible; leaves used as fodder; wood used for planking, firewood and charcoal
6	*Artocarpus heterophyllus* Lam.	Moraceae	Lam-khuang	+	+	Root in fever, diarrhoea, asthma and sterility in women; leaves for fever, skin diseases, wounds and boils; young fruit and seeds is used as vegetable; wood used for furniture
7	*Bauhinia variegata* L.	Caesalpiniaceae	Vaube	+	-	Root in dyspepsia; bark/leaves in menstrual disorder, intestinal worms, piles, diabetes, diarrhoea and dysentery
8	*Blumea balsamifera* (L.) DC.	Asteraceae	Buarthau	+	+	Leaves in asthma, cough, diuretic and oedema; stem and root in common cold
9	*Blumea lanceolaria* (Roxb.) Druce	Asteraceae	Buarze	-	+	Leaves in stomach ulcer, indigestion, asthma, chronic dysentery, scabies, skin diseases, sores, dandruff and animal sores and ulcers
10	*Boehmeria platyphylla* D.Don	Urticaceae	Not known	+	-	Whole plant in boils and dermatitis

11	*Breynia retusa* (Dennst.) Alston	Phyllanthaceae	Pi- beng-beh	+	+	The root, leaves and fruits are medicinal
12	*Callicarpa arborea* Roxb.	Verbenaceae	Hnahkiah	+	-	Leaves and bark in diabetics; cholera, dysentery, diarrhoea, internal bleeding, colic and stomach ulcer; wood used as firewood and charcoal
13	*Canarium strictum* Roxb.	Burseraceae	Berawthing	+	-	Bark and fruits medicinal
14	*Cassia alata* L.	Fabaceae	Tuihlo	+	+	Leaves in skin diseases
15	*Castanopsis indica* (Roxb.ex Lindl) A.DC.	Fagaceae	Se-hawr	+	-	Nuts are edible, wood is used as timber, firewood etc
16	*Castanopsis tribuloides* (Sm.) A.DC.	Fagaceae	Thing-sia	+	-	Juice of the stem is used as medicine; nuts edible
17	*Chromolaena odorata* L.	Asteraceae	Tlangsam	+	+	Leaves haemostatics
18	*Clerodendrum infortunatum* L	Lamiaceae	Phuihnamchhia	+	-	Roots and twigs in diarrhoea and dysentery; leaves in malaria, scorpion sting and snake-bite; roots and leaves in scabies and other skin diseases
19	*Codariocalyx gyroides* (Link.) Hassk.	Fabaceae	Hmei-thai-sa-rawh-tul	-	+	Root medicinal
0220	*Crotalaria pallida* Aiton	Fabaceae	Ram-tum-thang	+	+	Whole plant in urinary problems and fever; leaves/root medicinal
21	*Dendrocnide sinuate* (Blume) Chew.	Urticaceae	Thakpui	+	-	The roots are used for diarrhoea, dysentery and liver ailments
22	*Jatropha carcus* Linn.	Euphorbiaceae	Kangdamdawi	+	-	Juice of the stems is applied on burns
23	*Lantana camara* L.	Verbenaceae	Shilong flangsam	-	+	Whole plant for malaria
24	*Leucaena leucocephala* (Lam.) de Wit	Mimosaceae	Japan-zawng-tah	+	+	Wood is used for fencing, firewood and charcoal; leaves and pods are eaten as vegetables

25	*Lyonia ovalifolia* (Wall). Drude.	Ericaceae	Tlangham	+	-	Young leaves and buds are used as medicine
26	*Mangifera indica* Linn.	Anacardiaceae	Thei-hai	+	+	Leaves in diabetics and diarrhoea; root, bark, leaves, fruit, seeds medicinal
27	*Melastoma malabathricum* L.	Melastomaceae	Builukhampa	+	+	Leaves used for cuts, diarrhoea, and dysentery; whole plant is used for high blood pressure
28	*Mesua ferrea* Linn.	Clusiaceae	Herhse	+	+	The flowers are chewed as stomachic
29	*Mimosa pudica* L.	Mimosaceae	Hlonuar	+	+	Root used for the removal of kidney/gall-bladder stones
30	*Mitragyna rotundifolia* (Roxb). O.Kthe.	Rubiaceae	Thinglung	+	-	Leaves and bark used to lower blood pressure
31	*Morinda angustifolia* Roxb.	Rubiaceae	Lum	+	+	Bark and roots in urinary problems; leaves medicinal
32	*Mussaenda roxburghii* Hook. f	Rubiaceae	Vakep	-	+	Leaves are eaten as vegetables
33	*Phyllanthus emblica* Linn.	Euphorbiaceae	Sunhlu	+	-	Bark in diarrhoea and dysentery; fruit for liver cirrhosis
34	*Pithecellobium monadelphum* (Roxb). Kosterm.	Mimosaceae	Ardahte	+	-	Seeds in diabetes; leaves used in leprosy
35	*Psychotria calicarpa* Kurz.	Rubiaceae	Kawr-pelh	+	-	Leaves, bark and stem used for skin problems
36	*Pterospermum acerefolium* Willd.	Sterculiaceae	Siksilthing	+	-	Flowers to cure blood disorders, inflammation, ulcers, tumors, and leprosy and also used as insect repellent and disinfectant
37	*Rhus semialata* Murray	Anacardiaceae	Khawm-hma	+	-	Leaves in colic, diarrhoea and dysentery, measles and rashes
38	*Rhynchotechum ellipticum* (Wall. exD. Dietr.) A.D.	Gesneraceae	Tiar-rep	+	-	Leaves is used in treatment of cancer; fruit and leaves edible; leaves used as pig fed

39	*Rubus alceifolius* Poir.	Rosaceae	Siali-nu-theihmu	+	+	The plant is used as a medicine; leaves and fruits edible
40	*Saurauia napaulensis* DC.	Actinidiaceae	Tiar-pui	+	+	Bark is used as anesthesia and antiseptic
41	*Schima wallichii* Choisy	Theaceae	Khiang	+	+	Fruit in scorpion-sting, bites of centipede, and large black spider; bark used for chronic ulcer and fresh cuts; leaves edible; wood used for construction, firewood etc.
42	*Sida acuta* Burm. f.	Malvaceae	Khing-khih	+	-	Roots in nervous and urinary diseases, fever and common stomach ailment
43	*Sida rhombifolia* L.	Malvaceae	Kel-chawngi-mai	+	-	Root and leaves in urinary complaints ,fever, heart diseases
44	*Smilax lanceifolia* Roxb.	Smilacaceae	Kaiha	+	-	Root in rheumatism
45	*Solanum indicum* L.	Solanaceae	Tawkte	+	-	Root and fruits in asthma, dropsy, dysuria, fever and colic; fruits for scabies, burns, boils, bites of snakes, centipede, and scorpion
46	*Solanum khasianum* C.B. Clarke	Solanaceae	At-hlo	-	+	The fruit or seeds are used for toothache
47	*Solanum nigrum* L.	Solanaceae	Anhling	+	-	Whole plant for liver problems and dropsy; leaves and tender shoot edible
48	*Stachytarpheta jamaicensis* (L.) Vahl	Verbenaceae	Not known	+	+	Not known
49	*Tadehagi triquetrum* (L.) H. Ohashi	Fabaceae	Ui-fawm-a-ring	+	-	Leaves in dysentery also used as tea leaves
50	*Tithonia diversifolia* (Hemsl.) A. Gray	Asteraceae	Bawng-pu-pang-par	-	+	Whole plant for malaria, hepatitis, liver problems, intestinal parasites, sore throat etc.; flower for wounds and bruises
51	*Toona ciliata* Roem.	Meliaceae	Teipui	+	-	Bark in diarrhoea and dysentery

52	*Unona longiflora* Roxb.	Annonaceae	Se-zang	+	-	Leaves and flowers in diarrhoea, dysentery and cholera
53	*Urena lobata* L.	Malvaceae	Se-hnao	+	+	Root used for rheumatism; bark stomachic and analgesic
54	*Vitex peduncularis* Wall. ex Schauer	Verbenaceae	Thingkhawi-hlu	+	-	Bark/leaves in malarial fever, jaundice, typhoid, stomach ulcer, and kidney stone; wood is used for firewood, charcoal, etc.
55	*Ziziphus jujuba* Mill	Rhamnaceae	Bo-rai	-	+	Wood used as timber, firewood, and charcoal; leaves used as fodder; fruits edible

Abbreviation: +, Present; -, Absent.

Table 5.40- List of bamboos, herbs and climbers in the undisturbed (UD) and disturbed (D) stands of catchment area, and their ecomonic values

Sl No.	Scientific Names	Family	Local Names	UD	D	Medicinal/Economic Values
1	*Abelmoschus moschatus* Medic.	Malvaceae	Uichhuhlo	-	+	Root and leaves in syphilis; root in wounds/ulcers; seed in throat pain
2	*Achyranthes aspera* Linn.	Amaranthaceae	Ui-hlo	+	+	Leaves in boils and piles, infusion of the plant in dysentery and colic; leaves in skin ulcers
3	*Achyranthes bidentata* Blume	Amaranthaceae	Vang-vat-tur	+	-	Whole plant in urination, suppressed menstruation and leech bite; leaves are eaten as vegetable
4	*Acmella oleracea* (L.) R.K.Jansen	Asteraceae	Ansapui	+	+	Leaves in stomach problem; whole plant in headache, throat and gums infection, toothache; leaves and stem are eaten as vegetable
5	*Acmella paniculata* (Wall. Ex DC.) R.K.Jansen	Asteraceae	Ankasakirlo	+	+	The leaves with stem are used as vegetable. Whole plant used as medicine; flowers in toothache, gum and throat infection
6	*Acmella uliginosa* (Sw.) Cass	Asteraceae	An-sa-te	+	+	It is used as a vegetable and for pig feed
7	*Ageratum conyzoides* L.	Asteraceae	Vailen-hlo	+	+	Roots in tuberculosis, leaves used as haemostatic
8	*Amaranthus spinosus* L.	Amaranthaceae	Len-hling	-	+	Juice of plant is used as antidote in snake bite, roots for hemorrhage, leaves for difficult urination;tender leaves eaten cooked as vegetable and also for pig feed
9	*Amaranthus viridis* Linn.	Amaranthaceae	Zamzo	+	+	Leaves emollient, eaten as vegetable
10	*Amomum dealbatum* Roxb.	Zingiberaceae	Aidu	+	-	Fruits are edible, young shoots and buds are eaten cooked or fried, whole plant used as medicine

11	*Bambusa tulda* Roxb.	Poaceae	Raw-thing	+	-	Roots used as medicine, young shoots eaten as vegetables; used for manufacturing paper, baskets, mats and building
12	*Bambusa vulgaris* Schrad.	Poaceae	Raw-eng	+	+	Use for fencing, and paper making.
13	*Begonia inflata* (Clarke)	Begoniaceae	Sekhupthur	+	-	Whole plant for piles disorder, dysentery; roots in genito-urinary problems
14	*Begonia rex* Putzeys.	Begoniaceae	Lalruanga-dar-nawhna	+	-	The juice of the plant is poisonous to leeches
15	*Bidens pilosa* L.	Asteraceae	Vawkpuithal	+	+	Plant in diarrhoea and dysentery; leaves in eyes, ear and skin infections
16	*Caesalpinia cucullata* Roxb.	Caesalpiniaceae	Hling-vawn	+	-	Not known
17	*Calamus erectus* Roxb.	Arecaceae	Thil-thek	+	-	Leaves used for thatching; shoots and fruits edible
18	*Calamus latifolius* Roxb.	Arecaceae	Hnah-bawr	+	-	The cane is used for making baskets, furniture etc. The ripe fruits and tender shoots are edible
19	*Calamus nambariensis* Becc.	Arecaceae	Hnah-bawr	+	-	The cane is used in furniture making.
20	*Cayratia japonica* (Thunb.) Gagnep	Vitaceae	Rem-te	+	-	Plant used to relieve swelling and heat
21	*Centella asiatica* (L) Urban.	Apiaceae	Lambak	+	-	Leaves in diarrhoea; root in dysentery, ulcers, hypertension
22	*Cheilocostus speciosus* (J. Koenig) C. Specht	Costaceae	Sumbul	+	+	Rhizome in kidney problems and leprosy, root in stomatitis, seed in malaria
23	*Cissus repens* Lam.	Vitaceae	Hruipawl	+	-	Root in tumors; roots, stem and leaves for inflamed kidneys, leaves used as vegetable

24	*Cleome viscosa* L.	Capparaceae	Not known	-	+	Whole plant in dermatitis, blood diseases and cough; leaves in earache and headache; seeds in malarial fevers and diarrhoea; roots used as cardiac stimulants
25	*Colocasia esculenta* (Linn.) Schott.	Araceae	Dawl or Bal	+	+	The corm, stem and young leaves are eaten as vegetables; the acrid juice is applied to wounds and bee-sting.
26	*Commelina benghalensis* Linn.	Commelinaceae	Not known	+	+	Whole plant in oedema and leprosy
27	*Conyza bonariensis* (L.) Cronquist	Asteraceae	Buar-zen	+	-	Leaves rheumatic; tender leaves eaten as vegetable
28	*Crassocephalum crepidioides* (Benth.) S.Moore	Asteraceae	Buar-thau	-	+	Whole plant used as medicine
29	*Crotalaria linifolia* Linn.	Fabaceae	Not known	+	+	Not known
30	*Cyclosorus extensa* Naud.	Thelypteridaceae	Limbirsi	+	-	Leaves used as medicine
31	*Cynodon dactylon* (L.) Pers	Poaceae	Phaitual hnim	+	+	Whole plant in piles, painful urination, vomiting with blood, blood dysentery, failure of pregnancy, minor cuts, liver cirrhosis, indigestion, body swelling, uterus infection etc.
32	*Dendrocalamus longispathus* (Kurz) Kurz	Poaceae	Raw-nal	+	-	Culms used for making papers pulp, buildings, baskets etc.; culm for wound or cut; young shoots used as vegetable
33	*Desmodium trifolium* (L.) D.C	Fabaceae	Bawngek-hlo(Lalrem)	-	+	Leaves in wounds; whole plants in kidney trouble and urinal problems
34	*Dichrocephala integrifolia* (L.f) Kuntze	Asteraceae	vawk-ek-a-tum-tual	-	+	Whole plant used in dyspepsia, indigestion; shoots for insect bites and stings

35	*Dicranopteris linearis* (Burm.f) Underw	Gleicheniaceae	Ar-thla-dawn	+	-	Whole plant in boils, ulcers, wounds and to expel intestinal worm; leaves are woven into mats; rhizomes edible
36	*Diplazium esculentum* (Retz) Sw.	Athyriaceae	Cha-kawk	+	-	Whole plant in skin disease; young fronds used as vegetable
37	*Duchesnea indica* (Andrews) Focke	Rosaceae	Vai-thei-hmu	+	+	Whole plant medicinal; fruits edible
38	*Eleusine indica* (L.) Gaertn	Poaceae	Not known	+	+	Roots in liver complaints, wounds and boils
39	*Entada phaseoloides* (L.) Merr.	Mimosaceae	Kawi-hrui	+	+	Seeds, young shoots and leaves are used as medicine
40	*Eupatorium perfoliatum* L.	Asteraceae	Not known	+	-	Whole plant used in dengue fever
41	*Euphorbia hirta* L.	Euphorbiaceae	Zawhte-hlo	+	-	Whole plant used for asthma, cough, stomach-ache, diarrhoea, dysentery, kidney stones; the milky juice is applied on wounds and sores
42	*Fagopyrum acutatum* (Lehm.) Mansf. exK Hammer	Polygonaceae	An-bawng	+	+	Grains in colic, cholera, diarrhoea, and abdominal problems; leaves used as vegetable; whole plant used as pig feed
43	*Galinsoga parviflora* Cav.	Asteraceae	Sazu(Pui) chaw	+	+	Leaves in fever, diarrhoea, vomiting, snake-bite; juice of the plant for wounds
44	*Galinsoga quadriradiata* Ruiz & Pavon	Asteraceae	Not known	+	-	The herb for nettle stings and as an antidote to snake bite; leaves to stop bleeding
45	*Globba racemosa* Smith	Zingiberaceae	Ai-chhia	+	-	Not known
46	*Gnaphalium luteo-album* L.	Asteraceae	Not known	+	-	Leaves haemostatic

47	*Gynura conyza* Cass.	Asteraceae	Buarzo	+	+	Leaves in tuberculosis, cancer, dysentery, stomach ulcer, asthma, jaundice, scabies, fresh wounds, and skin diseases
48	*Homalomena aromatica* Schott.	Araceae	Anchiri	+	-	Whole plant in skin diseases; burnt smoke of dried rhizome is used as mosquito repellent; petiole is taken as vegetable
49	*Ichnanthus pallens* (Sw.) Munro ex Benth	Poaceae	Not known	+	+	Leaves are used as fodder.
50	*Impatiens chinensis* Linn	Balsaminaceae	Hawilo	+	+	Plant used for burns and internal gonorrhea
51	*Imperata cylindrica* (L.) Raeusch.	Poaceae	Di	-	+	Roots for wounds, diarrhoea, dysentery, expelling worms from the body; leaves used for thatching
52	*Ipomoea hederifolia* L.	Convolvulaceae	Ni-pui-par	+	-	Root medicinal
53	*Kyllinga brevifolia* Rottb.	Cyperaceae	Pisum-bur	-	+	Used as fodder
54	*Laportea bulbifera* (Siebold & Zucc.) Wedd.	Urticaceae	Zo-kang-thai	-	+	Young shoots is used for high blood pressure
55	*Lepidagathis incurva* Buch Ham. ex D.Don	Acanthaceae	Vangvathlo	+	-	Leaves for leech bite
56	*Leucas aspera* (Willd.) Link	Lamiaceae	Not known	+	+	Leaves in scabies, skin disease; flowers in cold
57	*Lygodium scandens* (L.) Sw.	Lygodiaceae	Dawnzem	+	-	Not known
58	*Meloccana baccifera* (Roxb.) Kurz	Poaceae	Mautak	+	+	Outer skin haemostatics; Young shoot edible
59	*Mikania micrantha* Kunth	Asteraceae	Japan-hlo	+	+	Leaves haemostatics used in diarrhoea and dysentery associate with fever
60	*Mirabilis jalapa* L.	Nyctaginaceae	Ar-tuk-khuan	+	-	Roots in fever and diabetes; leaves for itching
61	*Molineria capitulata* (Lour.)	Hypoxidaceae	Phaiphek	+	-	Roots for stomachache and headache; stem haemostatics

62	*Oxalis corniulata* (L.)	Oxalidaceae	Siak-thur	+	+	Whole plant in fever, diarrhoea and dysentery; digestion; stalks and leaves used for fodder
63	*Paederia foetida* L.	Rubiaceae	Vawih-uih-hrui	+	-	Leaves in diarrhoea and dysentery; stem and leaves in toothache and gum boils
64	*Panicum brevifolium* L.	Poaceae	Not known	+	+	Not known
65	*Paspalum conjugatum* P.J. Bergius	Poaceae	Not known	+	+	Not known
66	*Paspalum distichum* L.	Poaceae	Not known	-	+	Plant use in scorpion bite
67	*Passiflora edulis* Sims.	Passifloraceae	Sap-thei	+	-	Fruit in jaundice
68	*Passiflora nepalensis* Wallich	Passifloraceae	Nauawimuhrui	+	-	Leaves in malaria, dysentery; fruit edible, young leaves used as vegetable
69	*Phaseolus sublobatus* Roxb.	Leguminosae	Not known	+	-	Not known
70	*Physalis angulata* L.	Solanaceae	Kel-a-sai-raw-phit	-	+	The plant is useful in inflammations and abdominal troubles; leaves and fruits in diabetes and toothache
71	*Physalis maxima* (Mill)	Solanaceae	Not known	-	+	Leaves for snakebite; fruits in spleen disorders
72	*Polygonum persicaria* L	Polygonaceae	Not known	+	+	It is used against diarrhoea and infections; leaves and young shoots are eaten as vegetable; used as dye
73	*Polygonum punctatum* Elliott	Polygonaceae	Not known	+	-	Not known
74	*Pteridium aquilinum* (L.) Kuhn.	Polypodiaceae	Katchat	+	-	Rhizomes and fruits are used as medicine
75	*Rubia cordifolia* L.	Rubiaceae	Rawngsen	+	-	Roots used for ulcers and skin diseases; leaves and stem medicinal
76	*Saccharum procerum* Roxb.	Poaceae	Rai-ruang	-	+	Buds edible; silkily panicles used for making mattress; roots medicinal
77	*Saccharum ravennae* L.	Poaceae	Not known	-	+	Young leaves used for as fodder.

78	*Scoparia dulcis* L.	Scrophulariaceae	Perhpawng-chaw	+	+	Plant for jaundice, genito-urinary trouble, diarrhoea and dysentery; roots in fever, gall bladder stone; leaves haemostatics, used in burns, sores and ulcers
79	*Solena amplexicaulis* (Lam.) Gandhi	Cucurbitaceae	Nawh-Phuai	+	-	Root in malaria, diabetes; leaves, roots and fruits edible
80	*Spermacoce ocymoides* Burm.f.	Rubiaceae	Khuang-bai-bu	-	+	Whole plant in diarrhoea, dysentery and skin diseases
81	*Tetrastigma lanceolarium* (Roxb.) Planch	Vitaceae	Thur-pui	+	+	Fruits edible; leaves used as vegetables and also for pig fed
82	*Thysanolaena latifolia* (Roxb. Ex Hornem.) Honda	Poaceae	Hmun-phiah	+	+	Leaves medicinal
83	*Tinospora cordifolia* (Willd.) Miers	Menispermaceae	Theisawntlung	+	-	Leaves and stem medicinal
84	*Trichosanthes tricuspidata* Lour.	Cucurbitaceae	Cho-ak-a-um	+	-	Fruit in asthma, earache; root in inflammation, boils
85	*Vernonia cinerea* (L.) Less.	Asteraceae	Buar	+	-	Plant in diarrhoea, cough, stomachache, piles, malaria; flowers in conjunctivitis, fever, cough, and other chronic skin diseases

Abbreviation: +, Present; -, Absent

a. ***Melastoma malabathricum***

b. ***Unona longiflora***

c. ***Morinda angustifolia***

d. ***Cheilocostus speciosus***

e. ***Anthocephalus cadamba***

f. ***Saurauia napaulensis***

Photo plate 5.2: Some terrestrial flora in catchment area

CHAPTER 6

DISCUSSION

6.1 Water Quality

Water pollution is defined as the presence of excessive amount of unwanted substances in water in such a way that it is no longer suitable for specific purposes such as drinking, bathing, cooking, irrigation (Olaniran, 1995). Water quality is of paramount importance for an aquatic ecosystem as it maintains all the ecological processes which support biodiversity. The growth and productivity of the aquatic organisms depend on the physicochemical characteristics of the water body (Verma *et al.*, 2012). Increased anthropogenic activities have resulted into deterioration of aquatic environment, especially the surface water bodies in last few decades, leading to a drastic decline in the water quality thereby, causing a hindrance in the ecosystem functions and stability (Pradhan, 1998). The pollution of rivers, lakes and other reservoirs by various types of pollutants poses major threat for the world's fresh water resources (Vorosmarty *et al.*, 2010). High level of pollutants in river ecosystem leads to an increase in BOD, TDS, TSS, salts and nutrients, and hence makes the water unfit for domestic purposes and also leads to eutrophication which may results into the chocking of the water system. High concentration of nitrate and phosphate in a water body is usually an indicator of sewage pollution (Kamal *et al.*, 1999). The structural interventions in the natural water bodies through canalization or damming of rivers, diversion of water within or among drainage basins, construction of river front and over-pumping of aquifer, are usually undertaken with a beneficial objective in mind though the resulting into long term environmental degradation often outweighs these benefits (Chapman, 1996). The mode of operation of a reservoir, unnatural location and shape may result into an actual alteration of the basic limnological behavior of a river system (Straskraba *et al*., 1993). Balon and Coche (1974) studied water quality of Kariba reservoir in Zimbabwe, and they have reported that the release of organically-bound elements from flooded vegetation, excreta and soil could be resulted into an increase in the biological production of the reservoir.

The findings of the present study are interpreted as follows.

6.1.1 Physicochemical characteristics

a. Temperature

Water temperature is a measure of the concentration of heat energy in water. It represents one of the most imperative controlling factor of surface water quality as it affects the nutrient cycling, rate of chemical reactions, metabolic activities, productivity and mortality of the aquatic ecosystems (Poole and Berman, 2001), thus acting as an important indicator of environmental quality (Gu and Li, 2002). It varies from place to place and overtime within a river system, and influence based on the catchment physiognomies such as drainage area, elevation, lithology (Swanson *et al*., 1990; Hawkins *et al*., 1997). The variation in water temperature depends on season, geographical location, ambient air temperature and chemical reaction in water body (Ahipathi and Putlaiah, 2006). Anthropogenic disturbances such as river regulation and industrialization may also cause an alteration in the water temperature (Beschta *et al*., 1987). Regulated rivers tend to have warmer temperature than the unregulated rivers (Hatten and Conrad, 1995).

In the present study, it was found that there is an increase in the water temperature from Site 1 to 3. Lower temperature at Site 1 may be linked with vegetation cover that provides shade and insulate the water temperature by trapping the cool air around (Johnson and Jones, 2000) whereas, a sharp increase in water temperature towards the downstream maybe linked with the removal of riparian vegetation of the catchment area as a result of the construction of the dam leading into accelerated rate of surface runoff from the nearby area carrying more total solids and other organic pollutants into the river water and due to the release of treated water after power generation directly into the river from the power house outlet resulting into warmer temperature towards the downstream. The average temperature was found to be higher during rainy season and lower during winter. High temperature during rainy season maybe due to the discharge of organic matters through surface runoff and subsequently microbial decomposition which leads into the release of catabolic energy in the form of heat and resulting into an increase in water temperature. Downstream warming of water of a degraded river system has been reported by some scientists (Torgersen *et al*., 1999; Zwieniecki and Newton, 1999; Ravindra *et al*., 2003; Tepe *et al*., 2005; Begum and Harikrishna, 2008; Murthuzasab *et al*., 2010; Yuceer and Coskun, 2016 and Rios- Villamizar *et al*., 2017).

b. pH

The pH of water is an important parameter for determination of the water quality as many chemical reactions such as solubility and toxicity are highly influenced by pH. It is a limiting factor for most of the aquatic life and it works as an index of general environmental conditions (Welch, 1952). The measurement of pH of water is necessaty to determine the corrosiveness of the water. The pH scale runs from 0 to 14, and value of 7 is considered as neutral (pH less than 7 represents acidic and greater than 7 indicates basic or alkaline water). It has been reported that high pH is generally associated with a high rate of photosynthetic activity in water (Wani and Sulaba, 1990). The DO content of water, photosynthesis of aquatic plants and metabolic rate of aquatic organisms are highly affected by pH (FWPCA, 1968). Acidic pH can be attributed to the deposition of acid forming substances and high organic content which results into decrease in pH because of the carbonate chemistry (Fella *et al.*, 2013). Toxicity is greater in acidic water rather than in alkaline water (Singh *et al*., 1989).

In the present study, a decline in pH of water was observed from Site 1 to Site 3. Higher pH at Site 1 maybe linked with increased rate of photosynthesis, resulting into intake of more CO_2. The pH values were found to be slightly acidic during the rainy season at all the sites, this may be attributed due to the contamination of water through surface runoff, and the high rate of decomposition of organic matter present in water which results into the release of humic acid. In reservoir, the rousing consequence of the surface runoff during rainy season results into the mixing of the poorly alkaline or acidic bottom water with the alkaline surface water leading into a decline in pH (Araoye, 2009). Acidic nature of river water towards the downstream has also been reported by Bajracharya and Tamrakar (2007) and Rios-Villamizar *et al*. (2017). The findings of the present study are in conformity with the work of Khatoon *et al*. (2013), Ali *et al*. (2014) and Erick *et al*. (2016).

c. Electrical Conductivity (EC)

Electrical conductivity (EC) is a mathematical expression of the capacity of an aqueous solution to carry an electric current, and is a function of the quantity and types of dissolved substances in water. It is dependent on the concentration of ions and nutrients load such as chloride, nitrate, phosphate, sulphate. Higher the value of TDS in water, greater is the amount of ions (Bhatt *et al*., 1999). Increased level of conductivity and cations are the product of decomposition and mineralization of organic materials (Abida, 2008). An increase in EC content indicates the presence of high amount of dissolved inorganic substances in ionized form (Gupta *et al*, 2013), and is regarded as an indicator of pollution in water bodies (Das *et al*., 2006).

In the present study, an increase in EC was observed from Site 1 to Site 3. High value at Site 3 maybe due to the increased degree of ionic state which could be as a result of direct discharge of water from the power house outlet after power generation, addition of sewage, agricultural runoff and inorganic salts from other nutrients towards the downstream of the dam. Increased EC during rainy season maybe attributed to the high concentration of dissolved solids, decomposition and mineralization of organic matters. Lower EC content during winter season maybe linked with the presence of low inorganic material followed by low ionic state. The findings of the present study are in conformity with the work of Mishra and Tripathi (2000, 2001, 2003), Bajracharya and Tamrakar (2007), Bharali *et al*. (2008), Singh and Gupta (2010) and Zeb *et al*. (2011).

d. Dissolved Oxygen

The DO content is of outmost importance for the survival of aquatic organisms and maintenance of water bodies (Mishra and Tripathi, 2001). DO level in natural water and wastewater depends on the physical, chemical and biological activities in a water body. It is an important limnological parameter that indicates the water quality status and level of organic pollution in water (Wetzel and Likens, 2006) therefore, it is an imperative indicator of water purity and its capacity to sustain aquatic life. The DO content in water is altered due to numerous factors such as photosynthesis, chemical oxidation, exchange of oxygen between water and atmosphere, respiration of plants and bacteria (Rawson, 1937). A decline in DO maybe due to an increase in temperature, sewage influx (Mathuthu *et al*., 1993) and increased microbial activity (Kataria *et al*., 2006).

In the present study, a marked decrease in the DO content was observed from Site1 to Site 3, which maybe due to the consumption of DO in the decomposition of organic materials from the waste discharged at the downstream of the dam indicates a high pollution intensity in river water. Higher values of DO content during winter season maybe due to the decrease in temperature as dissolved oxygen shows an inverse relationship with water temperature therefore, solubility of oxygen increases in water with decrease in temperature. On the contrary, rainy season shows lower values of DO which could be due to the increased surface runoff carrying more sewage and domestic wastes and substantial process of microbial decomposition which accelerate the rate of oxygen consumption by oxidizable matters leading to the release of more CO_2. The findings are in conformity with the work of Mishra and Tripathi (2001, 2003), Chattopadhyay *et al*. (2005), Lalparmawii and Mishra (2012), Shivayogimath *et al.* (2012), Hasan *et al*. (2014), and Rios- Villamizar *et al*. (2017).

e. Biological Oxygen Demand (BOD)

The determination of BOD level in water gives a detail account of the amount of oxygen consumed by aerobic biological organisms for the degradation of organic matters and also the oxygen required for the oxidization of various chemical processes in water. The BOD measurement is used to determine the level of organic pollutants in water. The BOD level increases with an increase in the amount of readily metabolic organics in water (Rasool *et al*., 2003). An increase in BOD content during the monsoon season is due to the influx of organic waste and enhanced microbial activities (Prasannakumari *et al*., 2003).

The highest value of BOD in the rainy season at Site 3 maybe the result of high concentration of untreated organic waste discharge into the water from the power house outlet, leading to high rate of decomposition, and resulting into consumption of more oxygen by the microorganisms. Moreover, the higher values in rainy season might be due to addition of more organic matter from surface runoff, leading to acidification of water due to increase in microbial activities at elevated temperature. On the other hand, lower values during the winter season at Site 1 maybe the result of low amount of contaminants present at Site 1. In addition to this, the lower values during winter season maybe attributed to low rate of decomposition of organic material. The BOD showed a reverse trend in results in comparison with the DO content of water. A similar trends in results has been reported by Mishra and

Tripathi (2000, 2001); Ravindra *et al*. (2003), Ghavzan *et al*. (2006), Dulo (2008), Lalparmawii and Mishra (2012), Pathak *et al*. (2012) and Hasan *et al*. (2014).

f. Total Hardness

Water hardness is measure of the presence of calcium and magnesium salts mostly in combination with carbonates and bicarbonates with trace amount of sulphate, chloride and other anions of mineral acids. The hardness may be either temporary hardness (carbonate) or permanent hardness (non-carbonate). The principle cause of hardness in natural water is the concentration of multivalent metallic cations from sedimentary rocks, seepage and runoff from soils. Hardness of water is primarily of concern as hard water requires considerably more soap to produce lather, causes yellowing of fabrics, toughens vegetables cooked in the water and often produces a noticeable deposit of precipitate in boilers, pipes, water heaters, containers and cooking utensils (Kataria and Kumar, 2010). Excessively hard water that is not stabilized has a tendency to cause corrosion of metal surfaces and pipes, resulting in the presence of certain heavy metals such as cadmium, copper, lead and zinc in drinking water (National Research Council, 1977). Thomas and Sach (2000) reported that increase soap usage in hard water results in metal or soap salt residues on the skin or on clothes which are not easily rinsed off and lead to irritation.

Sawyer (1960) and Saravanakumar and Kumar (2011) have classified water on the basis of hardness values into four types as follows:

Water Quality	**Total hardness value (mgL^{-1} C_aCO_3)**
Soft	0 to <75
Moderately hard	75 to <150
Hard	150 to <300
Very hard	300 and above

In the present study, total hardness shwed a marked increase from Site 1 to Site 3. The relatively higher values at Site 3 may be due to sediments, washing clothes by the people in surroundings, and dumping of domestic sewage. Moreover, higher values during rainy season maybe due to the mixing of sewage effluents into the river containing carbonates and bicarbonates, chlorides and sulphates of Ca^{++} and Mg^{++}. On other hand, low values at Site 1 maybe due to least anthropogenic activities. Similar trends of results have also been reported by Unni *et al*. (1992), Sivasubramani (1999), Mishra and Tripathi (2000, 2001, 2003), Zafar and Sultana (2008) and Singh and Gupta (2010).

g. Acidity

Acidity in water is a measure of its aggregate property, and can be interpreted in terms of specific substances only when the chemical composition of sample is known. CO_2 is the main cause of acidity in water. Some other compounds such as SO_2 and NO_3 also cause acidity in water. The other factors responsible for acidity of water are uncombined carbon dioxide, organic acids and salts of strong and weak bases (Mishra *et al.,* 2009). The mineral acidity corresponds to pH<4 and CO_2 corresponds to pH > 8.5 due to dissolution of carbon dioxide in water and algal photosynthesis. Although, there is no particular limit for acidity in water, however, increase in acidity tends to contribute to corrosiveness and influences the rate of chemical reactions, chemical speciation, and biological activities and is also injurious for human health. Acidic water is less buffered and less productive because sufficient amount of bicarbonates are not dissolved to give CO_2 for a high rate of photosynthesis. Warren (1971) argued that lowering of pH in water is the result of decomposition of organic matter and finally releases excess of CO_2.

In the present study, higher values at Site 3 during the rainy season maybe due to influx of high organic load towards the downstream of the dam, supporting decomposition which leads to consumption of oxygen and release of CO_2 by the respiratory activity of the biological organisms, and resulting into carbonic acid. In addition, rain water is also slightly acidic in nature. A similar trend of results was reported by Mishra and Tripathi (2000, 2001, 2003), Shrivastava *et al.* (2010) and Singh *et al.* (2010).

h. Total Alkalinity

Alkalinity refers to the buffering capacity of water to neutralize acidic pollution and resist any change in pH of water. Alkaline compounds such as hydroxide, carbonates and bicarbonate are the main causes of alkalinity in water. Smitha *et al*. (2007) reported that alkalinity increases with an increase in the amount of dissolved carbonates and bicarbonates in water. In a lake, alkalinity maybe as a result of waste discharge and microbial decomposition of organic matter in the water body (Kumar *et al*., 2008). Unni *et al*. (1992) suggested that alkalinity value higher than 50mgL^{-1} indicates the entry of sewage in the water body in considerable amount. Trivedy and Goel (1986) reported that alkalinity is itself not harmful to human beings. According to Schaeperclaus (1990), aquatic systems have been categorized into three major categories based on alkalinity values.

Water Quality	**Total Alkalinity values (mgL^{-1}$CaCO_3$)**
Less Productive	0-15
Medium Productive	15-100
Highly Productive	100-250

In the present study, higher values of alkalinity were recorded at Site 2 in comparison to Site 3, and Site 1 had markedly low values. The maximum values at Site 2 could be attributed due to washing of clothes in reservoir (Site 2) and rocky nature of surrounding including bottom of reservoir having calcium rich sediment. Higher values during rainy season maybe attributed to surface runoff containing pesticides from agricultural field and sandstone from the surrounding. Similar trend of results was also reported by Mishra and Tripathi (2000, 2001, 2003), Zafar and Sultana (2008), Shaikh and Mandre (2009) and Awoyemi *et al*. (2014).

i. Turbidity

Turbidity is the measure of the relative clarity of water (Sadar, 1996). The clarity of water is an important parameter to determine its productivity and efficiency. Turbidity in water is mainly due to the presence of suspended solids, organic colloidal substances and coarse dispersion of sewage which causes cloudiness in water (Kataria, 1995). The degree of turbidness of stream water is an appropriate measure of pollution intensity (Siliem, 1995).

In the present study, higher turbidity value at Site 2 and 3 maybe linked with the presence of more suspended solids, organic matters and aquatic weeds. Higher value during rainy season maybe due to the flow of rainwater carrying significant amount of organic and inorganic material, suspended particles, sediments and other pollutants from the surroundings which contributes to turbidity in water. Turbidity values recorded were higher than the permissible limit as given by BIS. High turbidity towards the downstream may be the result of accelerated rate of soil erosion as an outcome of developmental activities for the dam construction. Similar trend of results was reported by Unni (1985), Solanki (2001), Giri and Singh (2013) and Rios- Villamizar *et al*. (2017).

j. Total solid, Total Suspended solid and Total Dissolved solid

The upsurge in the values of TS, TSS and TDS adversely affect the quality of running water and it is unsuitable for any other purposes such as drinking, irrigation and its deteriorates plumbing and appliances. The high level of TSS in a water body inhibits the penetration of sunlight through the water, thereby, hampers the photosynthesis activity of aquatic plants. Suspended solids containing much organic matters result into putrefaction and consequently the stream maybe devoid of DO (Manivasakam, 1980). Kataria *et al*. (1996) suggested that the increase in the value of TDS indicates pollution by unnecessary sources. The value of TDS in water varies from season to season and affects the density and quality of water (Imtiyaz *et al*., 2012). The high concentration of TDS leads to an increase in the nutrient status of water, and resulting into eutrophication of aquatic bodies (Singh and Mathur, 2005).

In the present study, higher values of TS, TSS and TDS during the rainy season maybe linked with the increase in inflow as well as surface runoff containing organic and inorganic impurities. Higher value of suspended matter at Site 3 maybe as a result of soil erosion caused by hydraulic engineering and also due to runoff from agricultural land thereby, indicating an increase in pollution towards the downstream of the dam. Similar trend of results was reported by Ravindra *et al*. (2003), Dulo (2008), Singh and Gupta (2010), Zeb *et al*. (2011), Khatoon *et al*. (2013), Giri and Singh (2013) and Pawar and Shendge (2016).

k. Chloride

The chloride is naturally occuring in fresh water in the form of sodium, potassium and calcium chloride. Concentration of chloride serves as an indicator of sewage pollution (Trivedy and Goel, 1986; Shrivastava *et al.*, 2012). High chloride content causes difficultly in irrigation and is also harmful to the aquatic life (Rajkumar *et al*., 2004). Munawar (1970) reported that the high chloride content in water serves as an index of pollution of animal origin and is an important parameter in assessing the water quality.

In present investigation, increase in the chloride content of water from Site 1 to Site 3 maybe due to the release of chloride rich effluent of sewage from the dam outlet. Higher values during winter season maybe due to the decrease in water level. On contrary, lower values during the rainy season may be due to dilution of water with rain water. A similar trend of results was reported by Mishra and Tripathi (2000, 2001, 2003), Singh and Gupta (2010) and Tewari *et al*. (2014).

l. Nitrate-N

The nitrate-N is an important factor in assessing the water quality status of surface water (Johns and Burt, 1993). The high content of nitrate-N in reservoirs and water bodies due to rigorous anthropogenic activities supports growth of algae and other organisms that may produce undesirable taste and odours in water and alters other ecological processes (Kataria and Kumar, 2010). The high accumulation of nitrate-N in water leads to eutrophication and supports luxuriant growth of aquatic macrophytes.

In the present study, higher value at Site 3 could be attributed to intensive human activities towards the downstream of the dam such as use of agricultural fertilizers and influx of human and animal waste into the river from the surrounding. Higher value during rainy season maybe due to discharge of waste through runoff containing organic matter that results into accelerated rate of organic matter decomposition and release of ammonia (NH_4^+) which is oxidized into nitrate (NO_3^-) and nitrite (NO_2^-) by the aerobic bacteria in a process called nitrification. Similar trend of results was also reported by Singh (1995), Das *et al*. (1997), Mishra and Tripathi (2000, 2001, 2003), Shrivastava *et al.* (2010), Banerjee and Gupta (2010), Ezzat *et al*. (2012), Khatoon *et al*. (2013) and Sridhar and Ramaneswari (2017).

m. Phosphate-P

The phosphate-P is present naturally in unpolluted water in trace. In surface water, an increase in phosphate-P content is a result of the influx of domestic sewage, detergents and agricultural effluents containing fertilizers. The phosphate is considered as a critical limiting nutrient, leading to eutrophication of fresh water bodies (Rabalais, 2002). Phosphate-P is an essential plant nutrient in low concentration, but in combination with nitrate-N, it leads to algal bloom (Singh *et al*., 2010).

In the present study, higher values of phosphate-P at Site 3 maybe due to the entry of contaminated waste water containing decayed organic matter and leaching of phosphate fertilizers. The higher values of phosphate-P during rainy season maybe due to the dissolution of P ions from the soil into the water body, as developmental activities pertaining to hydro power project lead to removal of top soil and weathered soil enters into river through wind and current. Phosphate-P values recorded were higher than the permissible limit as given by USPH. High phosphate-P content may be attributed to agricultural run-off containing phosphate fertilizers caused by heavy rain and sewage influx as waste water tends to increase phosphate-P concentration in water. A similar trend of results has been reported by Mishra (1992), Gowda *et al*. (2001), Shrivastava *et al.* (2010), Singh *et al*. (2010), Glinska-Lewczuk *et al*. (2016) and Sridhar and Ramaneswari (2017).

n. Sulphate

The sulphate is found in appreciable quantity in all natural water. It occurs naturally in combination with numerous minerals including Barite ($BaSO_4$), Epsomite ($MgSO_4.7\ H_2O$) and Gypsum ($CaSO_4.2H_2O$). Sulphate salts are mostly soluble in water and impart hardness. Water with high sulphate concentration imparts a bitter taste. Sulphate is of major concern as indirectly responsible for major problems associated with handling and treatment of waste water. In excess dose of 1000 to 2000 mgL^{-1} it produces certain diseases in human being including catharsis, dehydration and gastrointestinal irritation (McKee and Wolf, 1963).

In the present study, higher value at Site 3 during rainy season maybe due to surface runoff from agricultural land, influx of sewage water containing organic and inorganic materials and increased biological activities. A similar trend in results has been reported by Rizvi *et al*. (2015).

6.1.2 Water Quality Index

WQI gives a general account on quality of water considering various attributes that affect stream's ability to sustain life and whether the overall quality of the water bodies poses a potential threat to various uses of water (Akkaraboyina and Raju, 2012). The WQI calculated for Serlui river exhibits poor quality of water at Site 2 and Site 3 when compared to Site 1 indicating the negative impact of the Serlui-B hydroelectric power project on the water quality. The high value of WQI maybe linked with the increase in EC, BOD, TDS, hardness, turbidity, Chloride, Nitrate-N, Phosphate-P and Sulphate, and a decline in the DO content in the water towards the downstream of the river.

6.1.3 Correlation and linear regression model

If the range of the correlation coefficient is from +0.8 to 1.0 and -0.8 to -1.0 it is termed as strong, from +0.5 to 0.8 and -0.5 to -0.8 as moderate and weak when it is in the range of +0.0 to 0.5 and -0.0 to -0.5 (Achuthan *et al*., 2005). As DO exhibited negative correlation with most of the parameters, therefore, it can be considered as an useful pollution index of water quality as with the increase in the values of the other parameters there in a significant decrease in the DO content (Rawatkar *et al*., 2016). A negative correlation between DO and BOD indicates that the decrease in DO content is linked with the accelerated decomposition and oxidation of organic matter by aerobic bacteria which is usually accompanied by an increase in BOD level (Rawatkar *et al*., 2016). A positive correlation between Nitrate-N and temperature may be due to accelerated rate of nitrification process at higher temperature (Emerson *et al*., 1975). On the contrary, a negative correlation between DO content and turbidity maybe linked with turbid water which minimize the DO content in water to a great extent.

The present investigation involves a new approach to evaluate the water quality parameters of Serlui river using correlation coefficient and linear regression method. Using correlation coefficient and linear regression tools, a significant relationship has been established between different pairs of water quality parameters to describe the realistic water quality status of Serlui river. The application of mathematical equation modeling to evaluate the water quality of Serlui river showed that most of the parameters are either positively or negatively correlated to each other. Most of the correlated variables are influenced by one or more other variables. DO content and pH are important parameter for determination of water quality as they are significantly correlated with most of the parameters. Implementing linear regression method can be a major approach to get an indication of the water quality by determining a few factors experimentally. The regression equation obtained from the study can be widely used to estimate the unknown values by substituting the known values in the equation and therefore it can be a helpful technique to predict the water quality status of Serlui river prior to the detailed monitoring as this technique is precisely more convenient to get an accurate idea of the water quality and for the proper planning and sustainable management of the river system throughout its length.

6.2 Aquatic Macrophytes

The findings of the present investigation are on the line of the trends reported by earlier workers. Any alteration in the vertical and horizontal distribution of macrophytes is one of the major tool to detect change in macrophyte vegetation composition (Partanen *et al*., 2009). Aquatic macrophytes are vulnerable to any alteration in the aquatic ecosystem (Arts, 2002). The change in structure and composition of aquatic macrophytes in a river may be a result of both nutrient enrichment (Tusseau-Vuillemin, 2001) and the presence of pollutants (Bernez *et al*., 2001). Anthropogenic activities leading into nutrient leaching and morphological alteration may result into a direct impact on the macrophytic vegetation. Water quality is widely known to be the primary determinant of macrophytic composition (Lacoul and Freedman, 2006). Alteration of the morphology of water courses by construction work mostly results into degraded habitats for macrophytes, this may be due to increased water turbidity through erosion (Baattrup-Pedersen and Riis, 1999). The diversity and distribution of aquatic macrophytes in flowing water are largely influenced by certain physical and chemical factors such as nutrient content of the bottom substrate (Baattrup-Pedersen and Riis, 1999), water current (Janauer *et al*., 2010; Grinberga, 2011), trophic level of the water body (Demars and Harper, 1998) and geochemistry of the catchment area (Baattrup-Pedersen *et al*., 2008; Akasaka *et al*., 2010).

Macrophytes are frequently used for biological assessment (Melzer, 1999; Penning, 2008; Geurts *et al*., 2009; O'Hare *et al*., 2010) due to their relative easy identification and immobility (Toivonen, 2000) and sensitiveness to any change in the environmental conditions such as pollution and eutrophication. The finding of Heegaard *et al.* (2001) indicates that macrophytic species and their community not only reflect the effects of human-induced disturbances but they can also be considered as indicator of various habitat conditions in water ecosystem. Ladislas *et al*. (2012) showed that *Juncus* spp and *Typha* spp reflected the cumulative effect of heavy metal pollutants from soil and water and therefore can be regarded as bioindicator of environmental pollution. *Zannichellietum pallustris* is often regarded as a bioindicator for eutrophic water, particularly rich in mineral salt as it is linked with high conductivity and high concentration of ammonia (Iberite *et al*., 1995; Whitton *et al*., 1998). Ceschin *et al*. (2010) reported that aquatic species such as *Fontinalis antipyretica*, *Elodea-Potametum crispi*, *Ranunculus trichophyllus* and *Nasturtium officinalis* showed affinity for fresh, oxygenized and meso-eutrophic water with fairly low level of conductivity, ammonia and nitrate, therefore, they are regarded as potential indicator of fairly good water condition on the other hand; species such as *Ceratophylletum demersi, Najadetum marinae, Myriophylletum verticillati, Callitrichetum stagnalis, Lemno-Azolletum filiculoidis, Potamogeton nodosus, Myriophylletum spicati* and *Potametum pectinate* were linked to warm, less richly oxygenated and slow moving water. Some of the species such as *Potametum colorati, Potamogeton coloratus, Chara hispida* and *Juncus subnodulosus* are very sensitive to eutrophication and mineralization (Robach *et al*., 1996; Thiebaut and Muller, 1999). *Lemna minor* is often regarded as a good bioindicator for mesotrophic water, particularly linked with high conductivity and high concentration of chlorine in the water body (Dawson *et al*., 1999). Macrophytic species such as *Lemna minor, Callitriche stagnalis, Potamogeton crispus, Potamogeton polygonifolius* and *Ranunculus pennicillatus* are good bioindicators of nutrient enrichment in a water body (Onaindia *et al*., 2005).

In the present study, luxuriant growth of the aquatic plants with maximum number of emergent group recorded which can be attributed to the high tolerance of emergent species to any fluctuation in the water level (Van der Valk and Davis, 1976). Emergent macrophytic species forms an interface between the surrounding land and the water, and can therefore act as a buffer against direct nutrient run-offs and reflect the land use change in the vicinity of the shoreline (Wetzel, 2001). The diversity and richness of emergent species increased with the trophic status of a lake (Nurminen, 2003; Pereira *et al*., 2012).

Upstream of the Dam showed maximum growth of emergent species, whereas Site 2 was dominated by the growth of aquatic weeds such as *P. stratiotes*, *E.crassipes* and *H. pseudointerrupta* which may be attributed due to their invasive nature and also primarily due to their affinity for eutrophic and stagnant water (Gopal and Sharma, 1990). During rainy season, *P. stratiotes* was found in abundance at Site 2 which was gradually succeeded by *E. crassipes* with the onset of winter indicating alteration in the water quality, and resulting into transformation in weed formation (Jafari and Gunale, 2006). A dense growth of aquatic weeds such as *A.philoxeroides*, *A.sessilis*, *E.crassipes*, *P.stratiotes,* and *H.psedointerupta* at Site 2 and Site 3 maybe the result of organic pollution due to the accumulation of sewage containing more organic load and surface runoff from the nearby agricultural areas leading to eutrophication causing deterioration of major communities and consequently cause a shift in the community structure (Duarte, 1995) thereby, favoring the establishment of aquatic weeds.

Species such as *Commelina bengalensis*, *Commelina maculata*, *Epilobium parviflorum*, *Floscopa scandens*, *Juncus effuses* and *Oenothera rosea* were restricted to the control site (Site 1) and maybe considered as pollution sensitive species whereas, species such as *Alternanthera philoxeroides*, *Alternanthera sessilis, Eichinochloa stagnina, Eichhornia crassipes*, *Hymenachne pseudointerrupta*, *Monochoria hastifolia* and *Polygonum glabrum* were present only at polluted sites (Site 2 and 3) showing high ecological amplitude. Species such as *Brachiaria mutica, Carex camosa, Colocasia esculenta, Cyperus corymbosus, Neptunia aquatica, Polygonum barbatum, Polygonum hydropiper and Scirpus atrovirens* were found common to all stands indicating high tolerance to stress.

Determination of the species diversity indices is a useful tool for the comparison of communities under the influence of any sort of anthropogenic disturbance or to perceive the state of succession and stability in the community. Higher diversity values during the rainy season at all the study sites maybe attributed due to the leaching of excess nutrients from the nearby areas into the river water, and availability of more water leading to the inundated growth of most of the aquatic macrophytes. On other hand, low diversity during the winter season maybe due to insufficient water. The high similarity between the polluted sites (Site 2 & 3) in terms of species composition, indicating high pollution tolerant potential of a species. A log-normal distribution pattern at Site 1 indicates stable and complex nature of the community, whereas a short hooked distribution pattern at other sites may be due to the luxuriant growth of certain species causing uneven distribution of IVI among the species therefore, indicating high degree of ecological nuisance.

6.3 Floristic diversity of Catchment area

The importance of biodiversity to the human society is enormous. Although, construction of dams benefits the society in many ways, but it leads to the removal and submergence of large areas of vegetation thereby, affecting the diversity and composition of plant communities and ultimately leading to biodiversity loss (Gaur, 2007), as well as altering the structural pattern and can increase the vulnerability of people and ecosystems to further changes. Loss of biodiversity at the downstream may be the result of changed seasonal stream flow regime, reduction of peak discharge, altered channel morphology and pattern, and the retention of suspended silt, sediment and nutrients behind the dam wall (Harris *et al*., 1987).

Diverse plant species of ecological importance were found in the undisturbed site. Majority of the plant species recorded during the present study were used for variety of purposes (ranging from food, fodder, medicinal, firewood etc) by the local villagers, as mentioned in previous chapter. Ethno-medicinal significance of plants is of utmost importance in terms of social and cultural life in Mizoram. The plant species recorded from the catchment area of Serlui river were used to relieve a vast array of ailments such as fever, gastrointestinal diseases, dermatitis, dental, respiratory, cardiac, cuts and wounds. A changing pattern in the structure of the plant community was observed in response to the disturbance due to construction of Serlui-B dam. With the increase in the intensity of disturbance, a decreasing trend in the diversity and distribution of species were observed. Construction of dam has led to removal of majority of the dominant tree species with secondary growth or weedy species. Similar trend of results was also reported by Jansen (1986), Tabarelli *et al*. (1999), Adhikari *et al*. (2009) and Dar *et al*. (2013).

The results also indicate that the species dominant at the disturbed site maybe tolerant to stress and able to survive under such harsh condition. On the other hand, species sensitive to the disturbance shows poor growth and some species were totally eliminated in disturbed site due to increased stress. A similar trend in results was also reported by some other ecologists (Connell, 1971; Chase, 2003; Mishra *et al*., 2003, 2004, 2005; Laloo *et al.*, 2006; Lopes *et al*., 2015).

The disturbed site showed replacement of woody species with herbs, resulting in dominance of woody plants in the undisturbed stand and herbaceous species in the disturbed stand. The shift of plant habit could be linked with disturbance at a large. Similar trend of results was also reported by some scientists (Mishra *et al.*, 2004; Graf, 1978; Kumar and Shahabuddin, 2005; Mehta *et al*., 2008). The species similarity was found to be 52% between the undisturbed and disturbed stands, indicating site specific elimination as well as introduction of a large number of species.

The comprehensive study indicates that species rich communities of the Serlui river catchment area has not only reduced but also has become less diverse and poor in species richness due to the construction of the dam. Disturbance may lead to the removal of certain species of medicinal importance before they are fully assessed and validated. Therefore, there is an urgent need to preserve these floras which may otherwise be lost due to the various developmental activities. There is an ample scope to re-vegetate abandoned area with suitable species to reclaim soil and to conserve biodiversity on sustained basis.

6.4 Management Strategies

Serlui river is the major source of potable water for the people in the district of Kolasib, Mizoram. From the agricultural outlook, it is the single most important water system in the district with an immense fluvial plain along its course providing a productive agricultural land. Despite great significance, the river is lacking proper management measure. The construction of dam has resulted into mass felling of vegetation from the catchment area thereby, increasing the vulnerability of the soil to erosion and influx of inorganic and organic pollutants and nutrient enrichment from the nearby agricultural areas directly into the river the outcome of which have led to poor water quality towards the downstream. An increased degree of deterioration of quality of river water from the upstream to downstream along dam was observed during the present investigation indicating marked influx of pollutants in the river. Although, most of the water quality parameters were found to be within the prescribed limit given by scientific agencies, however pH, turbidity and phosphate-P were beyond the permissible limit. The local indigenous people settled in vicinity are directly dependent on untreated river water even for drinking purpose as there is lack of proper public supply of treated water in the area. Long-term consumption of such polluted water may result into adverse effects on health. Therefore, to combat some of the negative impacts of the dam on the water quality, there is an urgent need to follow some proper management strategies to ensure restoration of habitat and also to make available pure and pollutants free water for various purposes.

On account of findings of the present investigation, the following management strategies may be suggested for implementation.

- The regular monitoring of river water is a mandatory recommendation to find out state of river.
- The environmental awareness campaign should be launched for rural indigenous people periodically.
- The adequate water flow should be maintained towards the downstream of river.
- The regular flushing of silt out from the dam base should be taken into consideration, to overcome from siltation problem.
- Aeration technique should be employed especially for reservoir to increase DO content of water for proper survival and growth of aquatic life that may lead to maintain intity of water body, to facilitate aerobic digestion of organic matter, and also to reduce anaerobic stagnation in reservoir.
- The direct disposal of domestic waste generated from nearby settlement into river water should be checked strictly.
- The hydro-electric power plant should be regulated and operated reasonably.
- The plants growing in water are the best indicator of water pollution especially pollution sensitive species. The pollution tolerant species can effectively be used for harvesting different types of pollutants from waste water desirably. The pollutants/ unwanted substances are accumulated in different parts of plants, and pollutants

removal tendency of a species depends on nature of substance, and it differs from species to species.

- The pollution tolerant species such as *Brachiaria mutica, Carex camosa, Colocasia esculenta, Cyperus corymbosus, Neptunia aquatica, Polygonum barbatum, Polygonum hydropiper and Scirpus atrovirens* are recommended for harvesting pollutants from polluted water.
- The rehabilitation of abandoned catchment area though plantation using suitable species be adopted, this may also lead to restoration of degraded land, soil erosion control and conservation of plant diversity desirably.
- The river receives huge amount of soil and unwanted substances from river basin and dam construction area, as river receives soil from such slopy areas through run-off. It is suggested to develop green belt comprised of herbaceous species having strong network for binding of soil.
- The abandoned devasted catchment area due to dam construction should be re-vegetated with suitable species for rehabilitation of vegetation and eco-restoration of degraded soil. The green belt comprised of bushy plants/ soil binder plants is strongly recommended on the slope of river bank that may lead to control soil erosion and subsequently water pollution.
- The species common to the undisturbed and disturbed sites having very high ecological amplitude, and native species are regarded as key stone species performing major role in sustainability of habitat. Therefore, such species should be selected for plantation only after standardization of nursery technology. Moreover, fast growing

and nitrogen fixing species be given priority for plantation, as weed infestation is very common in the area, and abandoned area is nutrient deficit.

- There is an ample scope of integrated management approach involving Government, NGOs and local community. This may be an effective for management of river water, conservation of biodiversity and restoration of land.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Surface water systems are one of the most important natural assets. During last few decades, there is tremendous increase in human population, leading to rapid industrialization, accelerated use of chemical fertilizers in agriculture fields and other human-induced developmental activities. The direct disposal of wastes from above activities into surface aquatic reservoirs has resulted in deterioration of water bodies, making water polluted to a great pace. The global extent of reservoir including hydroelectric power facilities is enormous. Dams provides many benefits to the society in terms of water supply for drinking and other domestic purposes, flood control, provide water for irrigation and power generation. However, the negative effects on the environment and river system could not be neglected. Dams disrupt the normal continuity of a river and therefore, alter water quality and possess threat to aquatic as well as terrestrial life.

Serlui river is impounded with a 12MW hydroelectric power project in the Kolasib district of Mizoram. It is one of most important rivers in the district as the local people settled in vicinity of the river are directly dependent on the river water for their day to day requirement of water for various uses including drinking purpose. Therefore, the present study was conducted with an objective to study the water quality of Serlui River in vicinity of Serlui- B hydro-electric power project, and diversity and distribution of aquatic macrophytes at selected sites. The floristic composition in disturbed and undisturbed catchment areas was also documented. The impact analysis may lead to formulation of appropriate management strategies.

Keeping in view cause-effect analysis of hydroelectric power project, three sampling points along the river especially, upstream of the dam with least anthropogenic activities and maintains its natural flow and regarded as control site (Site 1); Reservoir (Site 2); and downstream where confluence of diversion outlet, spillover and power house meets (Site 3) were selected for detailed investigation.

The water samples were collected from selected study sites on monthly interval for two consecutive years (i.e. March 2015- February 2017). The samples were then analyzed for various physico-chemical characteristics namely, Temperature, pH, Electrical Conductivity, Dissolved Oxygen, Biological Oxygen Demand, Total Hardness, Acidity, Total Alkalinity, Turbidity, Total Solids, Total Suspended Solids, Total Dissolved Solids, Chloride, Nitrate-N, Phosphate-P and Sulphate contents. The analytical methods as described in the 'Standard Methods for Examination of Water and Wastewater' (APHA, 2005) and 'Handbook of Methods in Environmental Studies, Water and Waste Water Analysis (Maiti, 2001) were adopted, and observations were computed and expressed seasonally i.e., summer (March-June), rainy (July-October) and winter (November- February) seasons. The findings were interpreted in light of available literature on the work carried out in the past, and standards given by as USPH, BIS, WHO and ICMR. To check the validity and significance of data, statistical analyses such as analysis of variance (ANOVA) and correlation coefficient were computed. The linear regression model was also developed for water quality attributes having highly significant correlation coefficient.

For the phytosociological study of the aquatic macrophytes, Quadrat Method (Curtis 1959 and Misra, 1968) was adopted. The specimen collected were identified with the help of experts from Botanical Survey of India, Eastern Circle, Shillong, and counter-checked with standard literature (Cook, 1996). The calculation for the Frequency, Density, and Abundance was done for each species individually (Misra, 1968 and Ambasht, 1969). The values of Relative Frequency, Relative Density, Relative Abundance and Importance Value Index were calculated as per Cottam and Curtis (1956), Misra (1968) and Ambasht (1969). The diversity indices were calculated following Shannon Weaver diversity index (1963), Menhinick diversity index (1964), Simpson diversity index (1949), Species Evenness (Pielou, 1966), Species Richness (Margalef, 1958), Similarity Index (Sorenson, 1948).

For documentation of flora in the catchment area, the specimen of each species was collected and identified taxonomically.

The major findings of the present study can be summarized as below.

I. Water Quality

1. The temperature ranged from 22.5 ˚C (Site 1) to 35.1 ˚C (Site 3). The average value was found to be lowest during winter season, and highest during the rainy season at all the study sites.

2. The pH ranged from 5.9 (Site 3) to 7.5 (Site 2). The average value was found to be lowest during rainy season and highest during the winter season at all the study sites.

3. The Electrical Conductivity value ranged from 94 µS (Site 1) to 186 µS (Site 3). The average value was found to be lowest during winter season and highest during the rainy season at all the study sites.

4. The Dissolved Oxygen content ranged from 4.6 mgL^{-1} (Site 3) to 8mgL^{-1} (Site 2). The average value was recorded to be lowest during rainy season and highest during the winter season at all the study sites.

5. The Biological Oxygen Demand content ranged from 0.7 mgL^{-1} (Site 2) to 2.9 mgL^{-1} (Site 3). The average value was recorded to be lower during the winter season and higher during the rainy season at all the study sites.

6. The total hardness ranged from 47 mgL^{-1} (Site 1) to 253 mgL^{-1} (Site 3). The average value was recorded to be lowest during the summer season and highest during the rainy season at all the study sites.

7. The acidity ranged from 36 mgL^{-1} (Site 1) to 72mgL^{-1} (Site 3). The average value was recorded to be lowest during the summer season and highest during the rainy season at all the study sites.

8. The total alkalinity content ranged from 34 mgL^{-1} (Site 1) to 67 mgL^{-1} (Site 2). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

9. The turbidity content ranged from 0.8 NTU (Site 1) to 14.4 NTU (Site 2). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

10. The total solid ranged from 85 mgL^{-1} (Site 1) to 384 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

11. The total suspended solid ranged from 28 mgL^{-1} (Site 1) to 82 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

12. The total dissolved solid ranged from 57 mgL^{-1} (Site 1) to 302 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

13. The chloride content ranged from 34.8 mgL^{-1} (Site 1) to 132.9 mgL^{-1} (Site 3). The average value was recorded to be lowest during the rainy season and highest during the winter season at all the study sites.

14. The nitrate-N content ranged from 0.19 mgL^{-1} (Site 1) to 0.58 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

15. The phosphate-P content ranged from 0.026 mgL^{-1} (Site 1) to 0.244 mgL^{-1} (Site 3). The average value content was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

16. The sulphate content ranged from 1.67 mgL^{-1} (Site 1) to 6.63 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

17. The WQI at Site 1 (Control site) was found to be **33** and falls within Grade B (26-50) of the water quality classification based on weighted arithmetic WQI method.

18. The WQI at Site 2 and Site 3 were found to be **111 and 142**, respectively, and fall within Grade E (>100) of the water quality classification (polluted) based on weighted arithmetic WQI method.

19. To check the significance and validity of data on water quality analysis, the statistical analyses namely, correlation coefficient, linear regression and ANOVA were computed between various water quality attributes and between study sites.

II. Aquatic Macrophytes

1. Altogether, a total of 28 aquatic macrophytes belonging to 24 genera and 13 families were recorded from the selected study sites during the study period

2. The dominant families were Poaceae and Commelinaceae with 4 species each.

3. The maximum number of 22 species (78%) was recorded from the emergent group.

4. In the summer season, *Polygonum hydropiper* (IVI 35.2), *Hymenachne pseudointerrupta* (IVI 56.2) and *Alternanthera sessilis* (IVI 28.1) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

5. In the rainy season, *Murdannia nudiflora* (IVI 34), *Pistia stratiotes* (IVI 32.1) and *Colocasia affinis* (IVI 32.2) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

6. In winter season, *Murdannia nudiflora* (IVI 39.8), *Eichhornia crassipes* (IVI 48.1) and *Hymenachne pseudointerrupta* (IVI 41.3) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

7. The Shannon-Weiner diversity index (H'), Menhinick index (D_{mn}) and Species richness (d) were maximum (H'=2.82; D_{mn}=0.51; d=2.49) at Site 2 during the rainy season, and minimum (H'=2.37; D_{mn}=0.3.36; d=1.47) at Site 1 during winter season.

8. Simpson index of dominance (D) was highest (D=0.102) at Site 2 during summer season.

9. Majority of species showed contagious distribution at all the study sites, as it is prevalent in natural ecosystem.

10. The polluted sites (Site 2 & 3) were more similar (Similarity Index- 78%) in terms of species composition.

11. The dominance-distribution curve followed a log-normal distribution pattern at Site 1.

III. Floristic diversity in the catchment area

1. Altogether, a total of 140 species (55 woody species, 62 herb species, 16 climbers and 7 bamboo and cane species) belonging to 120 genera and 59 families were recorded from both the undisturbed (UD) and disturbed (D) stands.

2. In the undisturbed stand, 118 species from 104 genera and 56 families were reported. The important species such as *Anthocephalus cadamba, Boehmeria platyphylla, Begonia rex, Paederia foetida, Phaseolus sublobatus, Rhus semialata, Tadehagi triquetrum, Unona longiflora*, were restricted to undisturbed stand.

3. In the disturbed stand, 71 species from 63 genera and 31 families were recorded. The important species such as *Abelmoschus moschatus*, *Amaranthus spinosus*, *Cadariocalyx gyroides*, *Cleome viscosa*, *Lantana camara*, *Mussaenda roxburghii*, *Physalis angulata*, *Spermacoce ocymoides*, *Ziziphus jujube,* were restricted to disturbed stand.

4. 49 species belonging to 46 genera and 26 families were found common in both the stands. The important species such as *Arthocarpus heterophyllus, Bidens pilosa*, *Cassia alata*, *Chromolaena odorata*, *Cheilocostus speciosus*, *Leucas aspera*, *Melastoma malabathrium*, *Meloccana baccifera*, *Mikania micranta*, *Mimosa pudica*, *Saurauia napaulensis, Scoparia dulcis, Urena lobata* were common in both the stands.

5. The species similarity index calculated was found to be **52%** between the undisturbed and disturbed stands.

IV. Impact of Serlui-B dam on Water Quality of Serlui river

The findings of the study show that there is a mark increase in the intensity of pollutants from Site 1(upstream-control site) to Site 3 (diversion outlet), therefore, leading to deterioration of river water quality. A marked seasonal variation was also observed in the physico-chemical characteristics. A decrease in water pH from upstream to downstream of the river reveals slightly acidic nature of the river water. A sharp increase in the value of Temperature, EC, BOD, Acidity, Total Alkalinity, Chloride, Phosphate-P, Nitrate-N and Phosphate was observed from Site 1 to Site 3 of the river. On the contrary, a mark decrease in the DO content was recorded from upstream to downstream of the river which may be due soil erosion, addition of sewage containing more organic load and discharge of water after power generation from the power house outlet directly into the river without any proper treatment. Increase in BOD content at Site 2 and 3 is an indicative of increasing pollution stress due to hydropower project, this may be the result of accelerated microbial activity due to the presence of more organic matter as an outcome of the submergence of large areas of productive forest due to the construction of the reservoir. The phosphate-P values recorded were higher than the permissible limit as given by USPH, which could be attributed due to agricultural run-off containing phosphatized fertilizers and sewage influx as waste water tends to increase phosphate-P concentration in water. Turbidity values recorded were higher than the permissible limit as given by BIS. High turbidity towards the downstream may be the result of accelerated rate of soil erosion as an outcome of the dam construction.

The comparison of the WQI index of the control site and dam sites depicts marked impact of hydro-electric power project. Low WQI at Site 1 indicates good quality of the water at the control site, whereas, higher index at Site 2 and Site 3 reflects the negative impact of the dam construction on the water quality of the Serlui river and indicates that the water quality of the river towards the downstream is unsuitable for drinking purpose.

It seems that the controlled runoff and a change in the natural channel pattern have resulted into modification in the river bed structure, which has reduced the self-purification capacity of the river, and badly affected the overall water quality of the river. Increase in intensity of pollutants towards the downstream of the dam maybe because of river regulation as caused due to construction of the Serlui-B dam, resulting into an alteration in the natural runoff pattern of the Serlui river. The increase in human activities in the catchment area of the reservoir has resulted into increase in pollutant stress in the reservoir and downstream of the dam. The rapid deterioration of the water quality during the rainy season may be the consequence of the construction of the dam as the soil in the catchment area is left bare thereby, more prone to erosion during heavy rainfall.

V. Impact of Serlui-B dam on ecology of Aquatic Macrophytes of Serlui river

The creation of reservoir makes river water stagnant, and leads to change in temperature, salts, nutrient concentration and oxygen content in water. This may results in introduction of new macrophytic species including luxuriant growth of some aquatic weeds such as *Eichhornia crassipes*, *Pistia stratiotes* and *Hymenachne pseudointerrupta.* The species such as *Commelina bengalensis*, *Commelina maculata*, *Epilobium parviflorum*, *Floscopa scandens*, *Juncus effuses* and *Oenothera rosea* were restricted to the control site and maybe considered as pollution sensitive species and regarded as bio-indicator of pollution due to their affinity for clear and highly oxygenated water. The inundated growth of invasive aquatic weeds in the reservoir maybe considered as a characteristic feature of a degraded aquatic ecosystem, this may be as a result of sedimentation and accumulation of organic load leading to eutrophication. The present study reveals that the intensity of pollutants impacted the diversity and distribution of species to a great extent. As a result, the dominant species no longer maintained their position with increase in degree of disturbance. The shift in position seems to be linked with the intensity of pollutants.

VI. Impact of Serlui-B dam on floristic diversity of the catchment area

Anthropogenic activities altered community organization and botanical composition to a great extent and have resulted in greater opportunity of herbaceous species turnover at disturbed site. The dominant growth form in the community varied with disturbance, as woody species were dominant at undisturbed site, and herbs were dominant at disturbed site. The shrubs present in undisturbed stand appeared to have greater ecological amplitude. The tree species absent in disturbed stand appear to be more vulnerable to disturbance. Disturbance led to increase in number of mono-specific families.

It can be concluded that the Serlui-B hydel project has impart a significant negative impact on the water quality, aquatic macrophytes and floristic diversity of the catchment area. During the study period, although, most of parameters showed the values within the prescribed limit except pH, turbidity and Phosphate-P in each season as given by various scientific agencies but, prior to its usage, its proper treatment is of outmost importance as long term use of such water may adversely affect the lives of human as well as aquatic lives. The comprehensive study indicates that species rich communities of the Serlui river catchment area has not only reduced land area but also has become less diverse and poor in species richness due to the construction of the dam. Hence, there is an urgent need of appropriate management measures for sustainable development. The findings of present study may be a base line for further studies on maintenance of water quality of river Serlui from the severity of the hydel project through formulating appropriate management strategies.

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Appendix I: Findings of present investigation in relation to the water quality standards given by various scientific agencies

Parameter	USPH	BIS	WHO	ICMR	Range of water quality characteristics during the study period
Temperature (◦C)	-	-	-	-	22.2-35.1
pH (nano mole L^{-1})	6 - 8.5	6.5- 8.5	6.5-8.5	7- 8.5	5.9-7.5
EC (μS)	300	-	-	-	94-186
DO (mgL^{-1})	>4	>5	-	-	4.6-8
BOD (mgL^{-1})	-	<3	-	-	0.7-2.9
Total Hardness	500	-	-	300	47-253
Acidity(mgL^{-1} $CaCO_3$)	-	-	-	-	36 -72
Total Alkalinity (mgL^{-1} CaCO3)	-	200	-	120	34-67
Turbidity(NTU)	-	10	-	-	0.8-14.4
TS(mgL^{-1})	-	-	-	-	85-384
TSS(mgL^{-1})	-	-	500	-	28-82
TDS(mgL^{-1})	-	-	500	500 - 1500	57-302
Chloride(mgL^{-1} CaCO3)	250	250	200	200-1000	34.8-1-132.9
Nitrate-N (mgL^{-1})	10	45	10	20	0.19-0.58
Phosphate-P (mgL^{-1})	0.1	-	-	-	0.026-0.244
Sulphate	250	150	200	150	1.67-6.63

Appendix II: Correlation coefficient (r) between the water quality parameters for two year data (March 2015-February 2017)

Parameters	Temp	pH	EC	DO	BOD	TH	Acidity	TA	Turbidity	TS	TSS	TDS	Chloride	Nitrate-N	Phosphate-P	Sulphate
Temperature	1															
pH	-.877*	1														
EC	0.798	-.814*	1													
DO	-.848*	.984**	-.883*	1												
BOD	.917*	-.921**	.940**	-.953**	1											
TH	0.254	-0.537	0.689	-0.609	0.491	1										
Acidity	0.554	-.837*	0.72	-.839*	0.681	.868*	1									
TA	.935**	-.860*	.938**	-.889*	.983**	0.431	0.599	1								
Turbidity	.863*	-.965**	.892*	-.966**	.916*	0.682	.892*	.876*	1							
TS	0.695	-.926**	.840*	-.944**	.847*	0.786	.951**	0.776	.942**	1						
TSS	0.733	-0.776	.976**	-.839*	.880*	0.774	0.775	.887*	.881*	.863*	1					
TDS	0.804	-.941**	.898*	-.950**	.890*	0.761	.929**	.848*	.991**	.968**	.910*	1				
Chloride	-.956**	0.758	-0.591	0.691	-0.774	0.014	-0.358	-0.809	-0.707	-0.5	-0.514	-0.624	1			
Nitrate-N	.912*	-.893*	.952**	-.909*	.947**	0.611	0.765	.956**	.956**	.862*	.942**	.946**	-0.761	1		
Phosphate-P	.922**	-.977**	.906*	-.985**	.976**	0.547	0.785	.939**	.972**	.899*	.855*	.945**	-0.785	.952**	1	
Sulphate	.942**	-.916*	0.79	-.870*	.865*	0.459	0.753	.868*	.940**	.813*	0.784	.908*	-.870*	.938**	.922**	1

*, Correlation is Significant at the 0.05 level (2-tailed)
**, Correlation is Significant at the 0.01 level (2-tailed)

Appendix III: Correlation coefficient (r) between the water quality parameters at Site 1 for two year data

Parameters	Temp	pH	EC	DO	BOD	TH	Acidity	TA	Turbidity	TS	TSS	TDS	Chloride	Nitrate-N	Phosphate-P	Sulphate
Temp	1															
pH	-.818*	1														
EC	0.768	-.954**	1													
DO	-0.779	.945**	-.984**	1												
BOD	.947**	-.830*	.854*	-.864*	1											
TH	0.162	-0.649	0.734	-0.66	0.33	1										
Acidity	0.379	-0.794	.855*	-0.802	0.467	.924**	1									
TA	.943**	-.891*	.820*	-0.8	.926**	0.365	0.489	1								
Turbidity	0.76	-.909*	.985**	-.959**	.842*	0.705	.855*	0.777	1							
TS	.840*	-.882*	.951**	-.970**	.912*	0.525	0.711	0.794	.960**	1						
TSS	.849*	-0.76	.851*	-.890*	.937**	0.339	0.515	0.758	.868*	.964**	1					
TDS	0.713	-.946**	.971**	-.959**	0.753	0.729	.906*	0.741	.967**	.920**	0.783	1				
Chloride	-.962**	0.811	-.831*	.857*	-.962**	-0.237	-0.466	-.867*	-.845*	-.936**	-.955**	-0.783	1			
Nitrate-N	0.81	-0.8	.890*	-.912*	.950**	0.48	0.564	0.804	.876*	.939**	.962**	0.781	-.896*	1		
Phosphate-P	0.759	-.961**	.984**	-.985**	.857*	0.718	0.809	.834*	.940**	.927**	.836*	.938**	-0.808	.901*	1	
Sulphate	.911*	-.862*	.912*	-.927**	.946**	0.408	0.621	.841*	.930**	.984**	.969**	.876*	-.980**	.925**	.880*	1

*, Correlation is Significant at the 0.05 level (2-tailed)
**, Correlation is Significant at the 0.01 level (2-tailed)

Appendix IV: Correlation coefficient (r) between the water quality parameters at Site 2 for two year data

Parameters	Temperature	pH	EC	DO	BOD	TH	Acidity	TA	Turbidity	TS	TSS	TDS	Chloride	Nitrate-N	Phosphate-P	Sulphate
Temperature	1															
pH	-.878*	1														
EC	.928**	-.894*	1													
DO	-0.734	.916*	-0.654	1												
BOD	.961**	-.915*	.871*	-.821*	1											
TH	0.294	-0.598	0.578	-0.439	0.256	1										
Acidity	0.592	-.883*	0.698	-.852*	0.637	.824*	1									
TA	.961**	-.847*	.936**	-0.641	.954**	0.29	0.544	1								
Turbidity	.941**	-.931**	.847*	-.890*	.934**	0.379	0.756	.853*	1							
TS	0.742	-.880*	.880*	-0.686	0.736	0.779	.888*	0.767	0.78	1						
TSS	0.635	-0.597	.814*	-0.278	0.524	0.658	0.573	0.689	0.558	.866*	1					
TDS	0.736	-.917**	.856*	-0.768	0.76	0.775	.934**	0.752	0.805	.990**	0.787	1				
Chloride	-.852*	0.709	-0.617	0.745	-.895*	0.126	-0.359	-0.783	-.839*	-0.382	-0.16	-0.426	1			
NitrateN	.850*	-.960**	.915*	-.825*	.837*	0.71	.911*	.815*	.908*	.961**	0.769	.970**	-0.568	1		
PhosphateP	.954**	-.970**	.893*	-.895*	.979**	0.403	0.758	.912*	.972**	0.796	0.549	.828*	-.850*	.909*	1	
Sulphate	.866*	-.971**	.826*	-.948**	.890*	0.535	.884*	0.787	.972**	.845*	0.554	.886*	-0.738	.950**	.958**	1

*, Correlation is Significant at the 0.05 level (2-tailed)
**, Correlation is Significant at the 0.01 level (2-tailed)

Appendix V: Correlation coefficient (r) between the water quality parameters at Site 3 for two year data

Parameters	Temp	pH	EC	DO	BOD	TH	Acidity	TA	Turbidity	TS	TSS	TDS	Chloride	Nitrate-N	Phosphate-P	Sulphate
Temperature	1															
pH	-.887*	1														
EC	0.632	-0.515	1													
DO	-0.709	0.78	-.884*	1												
BOD	0.713	-0.763	.913*	-.993**	1											
TH	0.394	-0.393	0.733	-0.614	0.696	1										
Acidity	0.669	-0.764	0.652	-0.735	0.788	.873*	1									
TA	.904*	-0.754	.888*	-.845*	.862*	0.618	0.712	1								
Turbidity	.834*	-.890*	0.735	-.855*	.886*	0.741	.945**	.835*	1							
TS	0.587	-.858*	0.477	-0.763	0.759	0.601	.865*	0.566	.848*	1						
TSS	0.777	-0.678	.955**	-.886*	.918**	0.789	0.795	.960**	.853*	0.626	1					
TDS	.874*	-.912*	0.656	-0.781	.812*	0.697	.937**	.825*	.987**	.835*	.814*	1				
Chloride	-.906*	0.728	-0.369	0.445	-0.419	0.003	-0.308	-0.726	-0.531	-0.297	-0.508	-0.604	1			
Nitrate-N	.952**	-0.793	.816*	-.814*	.818*	0.466	0.629	.977**	0.808	0.517	.887*	0.808	-.833*	1		
Phosphate-P	.908*	-.936**	0.778	-.920**	.923**	0.589	.829*	.905*	.958**	0.806	.875*	.942**	-0.68	.909*	1	
Sulphate	.980**	-.832*	0.555	-0.59	0.607	0.414	0.67	.865*	0.796	0.533	0.734	.860*	-.897*	.902*	.837*	1

*, Correlation is Significant at the 0.05 level (2-tailed)
**, Correlation is Significant at the 0.01 level (2-tailed)

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- Presented a poster entitled "Assessing the impact of hydroelectric power project construction on the water quality of Serlui river in Kolasib district, Mizoram, North-East India" in International Conference on Global Biodiversity, Climate Change and Sustainable Development organized by Department of Life Science, Rajiv Gandhi University, Rono Hills, Doimukh, Arunachal Pradesh, India held from 15^{th}-18^{th} October, 2016.
- Presented a paper entitled "Impact of Serlui-B hydel project on the water quality of Serlui river in Kolasib district, Mizoram, North-East India" in International Conference on Natural Resources Management for Sustainable Development and Rural Livelihoods organized by Department of Geography, Mizoram University, Aizawl, Mizoram, India held from 26^{th}-28^{th} October, 2017.
- Presented a paper entitled "Impacts of Serlui-B dam on the diversity and distribution of Aquatic Macrophytes in Serlui river, Mizoram, India" in National Conference on Contemporary Research Perspectives in Geography" organized by International Benevolent Research Foundation, Kolkata in Collaboration with: Confederation of Indian Universities, New Delhi held from 17^{th}-18^{th} May, 2018.

PAPER PUBLICATIONS

- **Sunar, S.** and Mishra, B.P. (2016). Assessing the impact of Hydroelectric Power Project on the Water Quality of Serlui River in Kolasib District, Mizoram, North-East India. *Int. Res. J. Environment Sci.*, 5(9): 40-44.
- **Sunar, S.** and Mishra, B.P. (2017). Impact of Disturbance on Phytodiversity In Undisturbed and Disturbed Catchment Areas of Serlui River In Vicinity of Serlui-B Hydel Project, Mizoram, North-East India. *Asian Journal of Multidisciplinary Studies,* 5(5): 95-111.
- **Sunar, S.** and Mishra, B.P. (2017).Consistent status of soil along disturbance gradient in the sub-tropical forest of Aizawl, Mizoram, India. *Int. Res. J. Earth Sci.*, 5(4): 1-7.
- **Sunar, S.** and Mishra, B.P. (2018). Correlation and linear regression as a water quality monitoring tool for Serlui River in Kolasib district, Mizoram, India. *International Journal of Academic Research and Development,* 3(2): 676-680.

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I hereby declare that the above information is correct to the best of my knowledge.

(Sangeeta Sunar)

IMPACTS OF SERLUI-B HYDEL PROJECT ON WATER QUALITY AND ECOLOGY OF MACROPHYTES OF SERLUI RIVER IN KOLASIB DISTRICT, MIZORAM

(ABSTRACT)

THESIS

SUBMITTED TO MIZORAM UNIVERSITY IN PARTIAL FULFILMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

ENVIRONMENTAL SCIENCE

By

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ABSTRACT

Water is very important for the survival and sustainability of life on the earth. For most of our domestic purposes (including drinking, irrigation, power supply etc.), it is mostly available as surface water in the form of rivers, ponds, and lakes. But, the rapid urbanization and developmental activities such as agricultural expansion, damming, diversion, over-use and pollution have led to severe environmental stress and deterioration of these surface water systems.

The society is benefitted by the construction of dams in various ways such as hydroelectric power supply, water level regulation, water supply, flood control, navigation, recreation etc., but an alteration in the river ecosystem instigated by the dams is a potential threat to the environment. Constructions of dam transform landscapes creating a risk of irreversible impact on the environment. Hydropower dams involve the setting up of large infrastructure, which in turns obstruct river flow, transforming the physical and biological characteristics of river channels and floodplains, fragmenting the continuity of rivers, environmental degradation, biodiversity reduction, leads to deterioration of water quality resulting into nuisance in aquatic environment.

Despite the fact that, the northeastern region has been identified as the future power house of India, as it harbors colossal water assets, the ongoing efforts to harness this cosmic hydropower potential through a series of dams has posed an unparalled threat to the water, social and ecological security of the region.

The Serlui (Rukni) river originates from the Serkhan village in the southern part of Kolasib district of Mizoram, and flows in the northward direction till it confluence with the Tuirial river in the Cachar district of Assam and finally discharges into the Barak river. It is impounded by the Serlui-B dam (24˚20'18'' N latitude and 92˚46'48''E longitude), located at 12km from the Bilkhawthlir village in the kolasib district of Mizoram. It is a 293m (961 feet) long, 51m (167 feet) high, 8m narrow top and 394.2m wide bottomed earthfill embankment dam with a 135m pressure tunnel, 415m headrace tunnel and a semi-ground power house. The hydel project has 3 units with a capacity to generate 12MW power. The dam creates a reservoir catchment area of 53 square kilometers with life storage capacity of 453.59 cubic million. It is the major source of potable water for the people in the district of Kolasib, Mizoram. The local indigenous people settled in vicinity are directly dependent on untreated river water even for drinking purpose as there is lack of proper public supply of treated water in the area. So far no systematic study has been undertaken to critically analyze the water quality and status of aquatic macrophytes of Serlui river in relation to the hydel project. The impact analysis may lead to formulation of appropriate management strategies and conservation plans in such degraded ecosystems. The floristic composition in disturbed and undisturbed catchment areas was also documented.

Therefore, the present study was conducted with the following objectives:

1. To study the water quality of Serlui river in vicinity of Serlui B hydroelectric power project at selected sites.
2. To study diversity and distribution of aquatic macrophytes at selected sites.
3. To assess the impact of hydel project on water quality and ecology of aquatic macrophytes.
4. To formulate appropriate management strategies.

Keeping in view the components of the hydro-electric power project, following three sampling points along the river have been selected for detailed investigation.

1. **Site 1-** This is situated at the upstream of the dam with least anthropogenic activities and maintains its natural flow, and is demarcated as reference site (Control site) to compare the findings recorded at other sites, for impact analysis.
2. **Site 2-** The Reservoir where the flow of the water recedes with the development of the dam.
3. **Site 3-** The downstream of the river where **c**onfluence of diversion outlet, spillover and power house meets.

The information procured for the reservoir site and downstream of the dam was compared with the results of the control site to assess the impact of the hydel project on water quality and ecology of the aquatic macrophytes of Serlui river and on the floristic composition in the catchment area.

The water samples were collected from selected study sites on monthly interval for two consecutive years (i.e. March 2015- February 2017). The samples were then analyzed for various physico-chemical characteristics namely, Temperature, pH, Electrical Conductivity, Dissolved

Oxygen, Biological Oxygen Demand, Total Hardness, Acidity, Total Alkalinity, Turbidity, Total Solid, Total Suspended Solid, Total Dissolved Solid, Chloride, Nitrate-N, Phosphate-P and Sulphate contents. The analytical methods as described in the 'Standard Methods for Examination of Water and Wastewater' (APHA, 2005) and 'Handbook of Methods in Environmental Studies, Water and Waste Water Analysis (Maiti, 2001) were adopted, and observations were computed and expressed seasonally i.e., summer (March-June), rainy (July-October) and winter (November- February) seasons. The findings were interpreted in light of available literature on the work carried out in the past, and standards given by as USPH, BIS, WHO and ICMR. To check the validity and significance of data, statistical analyses such as analysis of variance (ANOVA) and correlation coefficient were computed. The linear regression model was also developed for water quality attributes having highly significant correlation coefficient.

For the phytosociological study of the aquatic macrophytes, Quadrat Method (Curtis 1959 and Misra, 1968) was adopted. The specimen collected were identified with the help of experts from Botanical Survey of India, Eastern Circle, Shillong, and counter-checked with standard literature (Cook, 1996). The calculation for the Frequency, Density, and Abundance was done for each species individually (Misra, 1968 and Ambasht, 1969). The values of Relative Frequency, Relative Density, Relative Abundance and Importance Value Index were calculated as per Cottam and Curtis (1956), Misra (1968) and Ambasht (1969). The diversity indices were calculated following Shannon Weaver diversity index (1963), Menhinick diversity index (1964), Simpson diversity index (1949), Species Evenness (Pielou, 1966), Species Richness (Margalef, 1958), Similarity Index (Sorenson, 1948).

For documentation of flora in the catchment area, the specimen of each species was collected and identified taxonomically.

The major findings of the present study can be summarized as below.

I. Water Quality

1. The temperature ranged from 22.5 ˚C (Site 1) to 35.1 ˚C (Site 3). The average value was found to be lowest during winter season, and highest during the rainy season at all the study sites.

2. The pH ranged from 5.9 (Site 3) to 7.5 (Site 2). The average value was found to be lowest during rainy season, and highest during the winter season at all the study sites.

3. The Electrical Conductivity value ranged from 94 µS (Site 1) to 186 µS (Site 3). The average value was found to be lowest during winter season, and highest during the rainy season at all the study sites.

4. The Dissolved Oxygen content ranged from 4.6 mgL^{-1} (Site 3) to 8mgL^{-1} (Site 2). The average value was recorded to be lowest during rainy season, and highest during the winter season at all the study sites.

5. The Biological Oxygen Demand content ranged from 0.7 mgL^{-1} (Site 2) to 2.9 mgL^{-1} (Site 3). The average value was recorded to be lower during the winter season, and higher during the rainy season at all the study sites.

6. The total hardness ranged from 47 mgL^{-1} (Site 1) to 253 mgL^{-1} (Site 3). The average value was recorded to be lowest during the summer season, and highest during the rainy season at all the study sites.

7. The acidity ranged from 36 mgL^{-1} (Site 1) to 72mgL^{-1} (Site 3). The average value was recorded to be lowest during the summer season, and highest during the rainy season at all the study sites.

8. The total alkalinity content ranged from 34 mgL^{-1} (Site 1) to 67 mgL^{-1} (Site 2). The average value was recorded to be lowest during the winter season and highest during the rainy season at all the study sites.

9. The turbidity content ranged from 0.8 NTU (Site 1) to 14.4 NTU (Site 2). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

10. The total solid ranged from 85 mgL^{-1} (Site 1) to 384 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

11. The total suspended solid ranged from 28 mgL^{-1} (Site 1) to 82 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

12. The total dissolved solid ranged from 57 mgL^{-1} (Site 1) to 302 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

13. The chloride content ranged from 34.8 mgL^{-1} (Site 1) to 132.9 mgL^{-1} (Site 3). The average value was recorded to be lowest during the rainy season, and highest during the winter season at all the study sites.

14. The nitrate-N content ranged from 0.19 mgL^{-1} (Site 1) to 0.58 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

15. The phosphate-P content ranged from 0.026 mgL^{-1} (Site 1) to 0.244 mgL^{-1} (Site 3). The average value content was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

16. The sulphate content ranged from 1.67 mgL^{-1} (Site 1) to 6.63 mgL^{-1} (Site 3). The average value was recorded to be lowest during the winter season, and highest during the rainy season at all the study sites.

17. The WQI at Site 1 (Control site) was found to be **33** and falls within Grade B (26-50) of the water quality classification based on weighted arithmetic WQI method.

18. The WQI at Site 2 and Site 3 were found to be **111 and 142**, respectively, and fall within Grade E (>100) of the water quality classification (polluted) based on weighted arithmetic WQI method.

19. To check the significance and validity of data on water quality analysis, the statistical analyses namely, correlation coefficient, linear regression and ANOVA were computed between various water quality attributes and between study sites.

II. Aquatic Macrophytes

1. Altogether, a total of 28 aquatic macrophytes belonging to 24 genera and 13 families were recorded from the selected study sites during the study period

2. The dominant families were Poaceae and Commelinaceae with 4 species each.

3. The maximum number of 22 species (78%) were recorded from the emergent group.

4. In the summer season, *Polygonum hydropiper* (IVI 35.2), *Hymenachne pseudointerrupta* (IVI 56.2) and *Alternanthera sessilis* (IVI 28.1) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

5. In the rainy season, *Murdannia nudiflora* (IVI 34), *Pistia stratiotes* (IVI 32.1) and *Colocasia affinis* (IVI 32.2) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

6. In winter season, *Murdannia nudiflora* (IVI 39.8), *Eichhornia crassipes* (IVI 48.1) and *Hymenachne pseudointerrupta* (IVI 41.3) were the most dominant species at Site 1, Site 2 and Site 3, respectively.

7. The Shannon-Weiner diversity index (H'), Menhinick index (D_{mn}) and Species richness (d) were maximum (H'=2.82; D_{mn}=0.51; d=2.49) at Site 2 during the rainy season, and minimum (H'=2.37; D_{mn}=0.3.36; d=1.47) at Site 1 during winter season.

8. Simpson index of dominance (D) was highest (D=0.102) at Site 2 during summer season.

9. Majority of species showed contagious distribution at all the study sites, as it is prevalent in natural ecosystem.

10. The polluted sites (Site 2 & 3) were more similar (Similarity Index- 78%) in terms of species composition.

11. The dominance-distribution curve followed a log-normal distribution pattern at Site 1.

III. Floristic diversity in the catchment area

1. Altogether, a total of 140 species (55 woody species, 62 herb species, 16 climbers and 7 bamboo and cane species) belonging to 120 genera and 59 families were recorded from both the undisturbed (UD) and disturbed (D) stands.

2. In the undisturbed stand, 118 species from 104 genera and 56 families were reported. The important species such as *Anthocephalus cadamba*, *Boehmeria platyphylla*, *Begonia rex, Paederia foetida, Phaseolus sublobatus, Rhus semialata*, *Tadehagi triquetrum, Unona longiflora*, were restricted to the undisturbed stand.

3. In the disturbed stand, 71 species from 63 genera and 31 families were recorded. The important species such as *Abelmoschus moschatus, Amaranthus spinosus, Cadariocalyx gyroides, Cleome viscosa, Lantana camara, Mussaenda roxburghii,Physalis angulata, Spermacoce ocymoides, Ziziphus jujube,* were restricted to disturbed stand.

4. 49 species belonging to 46 genera and 26 families were found common in both the stands. The important species such as *Arthocarpus heterophyllus, Bidens pilosa*, *Cassia alata, Chromolaena odorata*, *Cheilocostus speciosus*, *Leucas aspera, Melastoma malabathrium*, *Meloccana baccifera, Mikania micranta*, *Mimosa pudica*, *Saurauia napaulensis, Scoparia dulcis*, *Urena lobata* were common in both the stands.

5. The species similarity index calculated was found to be **52%** between the undisturbed and disturbed stands.

IV. Impact of Serlui-B dam on Water Quality of Serlui river

The findings of the study reveal a mark increase in the intensity of pollutants from Site 1(upstream-control site) to Site 3 (diversion outlet), therefore, leading to deterioration of river water quality. A marked seasonal variation was also observed in the physico-chemical characteristics. A decrease in water pH from upstream to downstream of the river indicates slightly acidic nature of the river water. A sharp increase in the value of Temperature, EC, BOD, Acidity, Total Alkalinity, Chloride, Phosphate-P, Nitrate-N and Phosphate was observed from Site 1 to Site 3 of the river. On the contrary, a mark decrease in the DO content was recorded from upstream to downstream of the river which may be due soil erosion, addition of sewage containing more organic load and discharge of water after power generation from the power house outlet directly into the river without any proper treatment. Increase in BOD content at Site 2 and 3 is an indicative of increasing pollution stress due to hydropower project, this may be the result of accelerated microbial activity due to the presence of more organic matter as an outcome of the submergence of large areas of productive forest due to the construction of the reservoir. The phosphate-P values recorded were higher than the permissible limit as given by USPH, which could be attributed due to agricultural run-off containing phosphatized fertilizers and sewage influx as waste water tends to increase phosphate-P concentration in water. Turbidity values recorded were higher than the permissible limit as given by BIS. High turbidity towards the downstream may be the result of accelerated rate of soil erosion as an outcome of the dam construction.

The comparison of the WQI index at the control site and dam sites depicts marked impact of hydro-electric power project. Low WQI at Site 1 indicates good quality of the water at the control site, whereas, higher index at Site 2 and Site 3 reflects the negative impact of the dam construction on the water quality of the Serlui river and indicates that the water quality of the river towards the downstream is unsuitable for drinking purpose.

V. Impact of Serlui-B dam on ecology of Aquatic Macrophytes of Serlui river

The creation of reservoir makes river water stagnant, and leads to change in temperature, salts, nutrient concentration and oxygen content in water. This may results in introduction of new macrophytic species including luxuriant growth of some aquatic weeds such as *Eichhornia crassipes*, *Pistia stratiotes* and *Hymenachne pseudointerrupta.* The species such as *Commelina bengalensis*, *Commelina maculata*, *Epilobium parviflorum*, *Floscopa scandens*, *Juncus effuses* and *Oenothera rosea* were restricted to the control site and maybe considered as pollution sensitive species and regarded as bio-indicator of pollution due to their affinity for clear and highly oxygenated water. The inundated growth of invasive aquatic weeds in the reservoir maybe considered as a characteristic feature of a degraded aquatic ecosystem, this may be as a result of sedimentation and accumulation of organic load leading to eutrophication. The present study reveal that the intensity of pollutants impacted the diversity and distribution of species to a great extent. As a result, the dominant species no longer maintained their position with increase in degree of disturbance. The shift in position seems to be linked with the intensity of pollutants.

VI. Impact of Serlui-B dam on floristic diversity of the catchment area

Anthropogenic activities altered community organization and botanical composition to a great extent, and have resulted in greater opportunity of herbaceous species turnover at disturbed site. The dominant growth form in the community varied with disturbance, as woody species were dominant at undisturbed site, and herbs were dominant at disturbed site. The shrubs present in undisturbed stand appeared to have greater ecological amplitude. The tree species absent in disturbed stand appear to be more vulnerable to disturbance. Disturbance led to increase in number of mono-specific families.

It can be concluded that the Serlui-B hydel project has impart a significant negative impact on the water quality, aquatic macrophytes and floristic diversity of the catchment area. During the study period, although, most of parameters showed the values within the prescribed limit except pH, turbidity and Phosphate-P in each season as given by various scientific agencies but, prior to its usage, its proper treatment is of outmost importance as long term use of such water may adversely affect the lives of human as well as aquatic lives. The comprehensive study indicates that species rich communities of the Serlui river catchment area has not only reduced land area but also has become less diverse and poor in species richness due to the construction of the dam. Hence, there is an urgent need of appropriate management measures for sustainable development. The findings of present study may be a base line for further studies on maintenance of water quality of river Serlui from the severity of the hydel project through formulating appropriate management strategies.

Management strategies

On account of findings of the present investigation, the following management strategies may be suggested for implementation.

- The regular monitoring of river water is a mandatory recommendation to find out state of river.
- The regular flushing of silt out from the dam base should be taken into consideration, to overcome from siltation problem.

- Aeration technique should be employed especially for reservoir to increase DO content of water for proper survival and growth of aquatic life that may lead to maintain entity of water body, to facilitate aerobic digestion of organic matter, and also to reduce anaerobic stagnation in reservoir.

- The direct disposal of domestic waste generated from nearby settlement into river water should be checked strictly.

- The plants growing in water are the best indicator of water pollution especially pollution sensitive species. The pollution tolerant species can effectively be used for harvesting different types of pollutants from waste water desirably. The pollutants/ unwanted substances are accumulated in different parts of plants, and pollutants removal tendency of a species depends on nature of substance, and it differs from species to species.

- The pollution tolerant species such as *Brachiaria mutica, Carex camosa, Colocasia esculenta, Cyperus corymbosus, Neptunia aquatica, Polygonum barbatum, Polygonum hydropiper and Scirpus atrovirens* are recommended for harvesting pollutants from polluted water.

- The river receives huge amount of soil and unwanted substances from river basin and dam construction area, as river receives soil from such slopy areas through run-off. It is suggested to develop green belt comprised of herbaceous species having strong network for binding of soil.

- The abandoned devasted catchment area due to dam construction should be re-vegetated with suitable species for rehabilitation of vegetation and eco-restoration of degraded soil. The green belt comprised of bushy plants/ soil binder plants is strongly recommended on the slope of river bank that may lead to control soil erosion and subsequently water pollution.

- The species common to the undisturbed and disturbed sites having very high ecological amplitude, and native species are regarded as key stone species performing major role in sustainability of habitat. Therefore, such species should be selected for plantation only after standardization of nursery technology. Moreover, fast growing and nitrogen fixing species be given priority for plantation, as weed infestation is very common in the area, and abandoned area is nutrient deficit.

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