# STUDIES ON RIPARIAN VEGETATION DIVERSITY AND ITS RELATIONSHIP WITH SOIL AND WATER CHARACTERISTICS OF DOYANG RIVER, WOKHA, NAGALAND.

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OF
**DOCTOR OF PHILOSOPHY IN BOTANY**

By
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## CERTIFICATE

This is to certify that the thesis entitled "Studies on riparian vegetation diversity and its relationship with soil and water characteristics of Doyang river, Wokha, Nagaland" is a record of original research work carried out by Mr. Akumtoshi Lkr under our supervision. He is a registered research scholar bearing the registration no. 719/2016 of the Department of Botany and has fulfilled all the requirements of Ph.D. regulations of Nagaland University for submission of thesis. The work is original and neither the thesis nor any part of it has been submitted elsewhere for the award of any degree or distinctions. The thesis is therefore, forwarded for adjudication and consideration for the award of degree of Doctor of Philosophy in Botany under Nagaland University

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## DECLARATION

I, Mr. **Akumtoshi Lkr**, bearing Ph.D. registration no. 719/2016 dated 6th August, 2015 hereby declare that the subject matter of this thesis is the record of work done by me, and that the contents of this thesis did not form the basis for the award of any previous degree to me or to anybody else to the best of my knowledge, and that the thesis has not been submitted by me for any research degree in any other University/Institution.

This is further certified that the Ph.D. thesis is submitted in compliance with the UGC Regulation 2016 dated May 05, 2016 (Minimum Standard and Procedure for the Award of Ph.D. Degree). Further, it is certified that the content of the thesis is checked for 'Plagiarism' with the licensed software 'iThenticate' and satisfies with the norms of 'University Grants Commission', Govt. of India. This thesis is being submitted to Nagaland University for the degree of Doctor of Philosophy in Botany.

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**(Mr. Akumtoshi Lkr)**

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# CHAPTER – 1

# INTRODUCTION AND REVIEW OF LITERATURE

Most early humans settled on the banks of rivers to avail the supplies of fresh water, fertile soil for cultivation, and other benefits. To mention, the presence of irrigated agricultural practices, urbanization, and industrial build-up along the catchment areas of the river itself indicates the inseparable dependence of human races on the riverine ecosystem. Rivers are important for the reason that they provide vital resources for drinking, irrigation, fish production, industrial cooling, generation of power, habitat, transports water, and other important nutrients necessary for living organisms including humans, plants, and fishes. Rivers not only sustain mankind but also the life of other flora and fauna that dwells within its ecosystem and they play a major role in integrating, organizing, and molding the ecological setting of the riverine landscape. The term "riparian areas" which is associated with the areas adjacent to surface freshwater bodies, first appeared in the scientific literature in the early 1970s (Johnson and McCormick, 1978). Subsequently, it has been officially accepted by the scientific community with numerous articles and dozens of books being published, that discussed various issues related to this ecosystem. However, in early 1800, the term 'riparian' was initially used as a legal term in the United States that describes a property of land adjacent to a stream or river (Ortega Kleet, 2002). Over the decades, the importance and definition of this ecosystem have evolved and incorporated in nearly all aspects of integrated watershed management approaches (Naiman, 1992; Doppelt *et al*., 1993; Naiman and Bilby, 1998; García de Jalón and Vizcaíno, 2004; European declaration for a new water centre cultura, 2005). Due to its beneficiary role, the conservation and restoration agenda of the riparian ecosystem has become a crucial requirement in all water resource planning and ecosystem sustainability.

Ecosystems that are located next to streams, rivers, lakes, and wetlands are referred to as riparian ecosystems and they have a direct influence on aquatic and wildlife habitat. They are of critical importance to the function, protection, and management of a river (Naiman *et al*.,1993). Riparian ecosystem typically occupies an insignificant portion of a landscape, but they often play a disproportionately important role in controlling the exchange of water and chemical between surrounding lands and stream systems (NRC, 2002; Burt and Pinay, 2005). Riparian zone act as a sink of sediments by temporarily storing the fluvial transport sediments. The presence of healthy vegetation cover in riparian zones is considered beneficial as it helps in reducing sediment, nutrient, and pesticide runoff into creeks and streams (Jones *et al*., 2000). Qureshi and Harrison (2001) observed that those riparian areas that have poor vegetation cover, are more prone to erosion, slumping of banks, invasion by weeds, and pests. These instances adversely affect the water quality and riparian biota leading to increased downstream flooding and sedimentation. Riparian zone is considered to be an important ecosystem component that helps in maintaining the stream water quality. (Lowrance *et al*.,1984). Both the direct and indirect influences of riparian vegetation such as nutrient uptake, organic matter supply, and soil stabilization role have a strong relation to structural and phytosociological characteristics of the vegetation (Fausch *et al*., 2010). Soils of riparian forests are potentially more heterogeneous in the mineral character compared to their upland counterparts. Multiple factors like the availability of water, geomorphic processes, coarse woody debris, litterfall, decomposition, and cycling of nutrients (C, N, P) significantly contribute towards the heterogeneity of soil (Mikkelsen and Vesho, 2000).

The floodplain habitats of India are under threat due to the pressure from various anthropogenic activities like overgrazing, deforestation, and reclamation of lands (Gopal, 1988). The Ganga river has also lost almost 80% of its original forest cover in its basin (Smakhtin *et al*., 2007) as a result of anthropogenic happenings. It is indeed disheartening to observe riparian forests adjoining stream and river banks being virtually extinguished outside the protected areas (Madhav, 2004). Likewise, the changing land-use practices, deforestation in the catchment and river banks, shifting cultivation, and pollution were also observed along the riparian zones of the Doyang river, Nagaland. All these activities conjointly threaten the riparian habitats as never before and pose serious challenges to the various important ecological function of the riparian ecosystem. These occurrences have therefore compelled the urgent need to assess and formulate conservation strategies that can help protect riparian areas.

## 1.2 LITERATURE REVIEW

### 1.2.1 Definition of riparian ecosystem

The word '*riparian*' originated from the Latin word "*rípariu*s" which pertains to the bank of a river (Dunne and McGinnis, 2002). This includes the geographic concept that classifies lands adjacent to streams as well as the hydrologic, geomorphic, and ecological concept that identifies sites that are hydrologically and geomorphologically influenced by the flow of rivers and streams. Riparian ecosystem possesses a set of characteristics that is distinctly separated by space, time, and strengths of interactions between the adjacent ecological systems (Risser, 1993; Naiman *et al*., 1998). Riparian zones are therefore three-dimensional areas directly linked with the aquatic and terrestrial ecosystem and are described as an ecotone or transitional zone (Naiman *et al*., 2005). There are multiple definitions for the term riparian, which were given by both the academician and regulatory agencies for use in a legal, regulatory, and ecological context. However, defining riparian areas may typically reflect the projected application of the intending parties for use in research or management purposes. The following are some of the definitions of riparian areas laid down by various workers and international agencies. Gregory *et al*. (1991) defined riparian areas as "The interfaces between terrestrial and aquatic ecosystems. Comprised of mosaics of landforms, communities, and environments within the larger landscapes." According to the American Society of Fisheries (2000) "Riparian ecosystems are the complex assemblages of organisms and their environment existing adjacent to and near flowing water." Canadian Council of Forest Ministers (2000) defined riparian areas as "A strip of land of variable width adjacent to and influenced by a body of freshwater." Ilhardt *et al*. (2000; p. 29) proposed a more functional definition of riparian zones. According to them, riparian zones are, "three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the watercourse at a variable width."

The National Research Council (2002) defined riparian areas as a "transitional between terrestrial and aquatic ecosystems distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine–marine shorelines." Among the many existing definitions, one of the most comprehensive ones was given by the American National Research Council, which states: "Riparian areas are ecosystems that occur along watercourses and water bodies. They are distinctly different from the surrounding lands because of the unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Riparian ecosystems occupy the transitional area between the terrestrial and aquatic ecosystems. Typical examples would include floodplains, streambanks, and lakeshores." Nonetheless, to define a riparian ecosystem, we must understand the main characteristics that differentiate it, its uniqueness, and most importantly the intent of our research application.

### 1.2.2 Ecological roles of riparian ecosystem

Riparian buffers are vital elements of watersheds, primarily due to the various ecological function tied to their well-being. Riparian buffers with native forested vegetation can effectively improve the stability of riverbank, regulate the alteration of vegetation structure and moderate the in-stream litter substrate, light, temperature, and water quality (Chellaiah and Yule, 2017). Riparian areas that have a wider and larger area, offer additional prospects to perform various functions and provide valuable floodplain habitats to many species. Spackman and Hughes (1995) study in the mid-order streams of Vermont (USA) reported that smaller riparian width (between 10 and 30 m) is necessary to sustain 90 % of the vegetation species, while a much wider area (between 75 m-175 m) is vital to support 90 % of the bird species. The geomorphic, biogeochemical, and biological characteristics of riparian areas are heavily influenced by events of regular flooding (Bowden, 1987; Pinay *et al*., 2002; Arscott *et al*., 2003) and this differentiates the riparian areas from the wetland and non-wetland types of ecosystem. They form an integral part of the biological system and have a direct influence on the aquatic and wildlife habitat. They are inherently rare habitats, covering just a mere one-thousandth of the earth's surface (Hynes, 1970). They are one of the biosphere's most complex ecological systems and is regarded as one of the important components necessary for maintaining the vitality of the landscape and its rivers (Naiman and Decamps, 1990, 1997). The reason being high productivity and inherent connections with the rest of the watershed, riparian areas offer important habitat diversity at the landscape level. Due to the role it plays in providing many ecosystem services, the riparian forest has gained plentiful attention and has attracted much international concern (Scott *et al*., 2009). Riparian forests are recognized as a “key-stone ecosystem” as they harbor certain unique habitats that are highly influenced by water (Goebel *et al*., 2003). When compared to adjacent uplands, riparian areas have typically shallow water tables with a distinct vegetation type found in both the perennial and many ephemeral streams (Carsey *et al*., 2003). They create a mosaic of microhabitats with the co-existence of numerous plant species (Gregory *et al*., 1991) and exhibits particularly high diversity due to the sharp environmental gradient and diverse ecological processes (Ricklefs, 1989). They provide important ecological functions through the complex interaction of their soils, hydrology, animals, and plant life. Ecological functions include providing shade to the stream and migratory fish, control of nutrient export, filtration of materials from the surrounding areas, retention of organic and inorganic material, regulating the types and quantity of organic input, stabilization of streambank, maintenance of moisture in the riparian soils, improving water quality, flood control and biodiversity (Gregory *et al*., 1991; Gillilan and Brown, 1997; Wenger, 1999; Castelli *et al*., 2000; Bicalho *et al*., 2010; Salo and Theobald, 2016; Sutfin *et al*., 2016; Xiang *et al*., 2016).

Riparian areas support rich plant species due to the diversity of microhabitats created by their linear structure, events of regular flooding, competitive interactions, periodic stages of succession, and the everchanging mosaic of landforms (Kalliola and Puhakka, 1988; Wissmar and Swanson, 1990; Gregory *et al*., 1991; Décamps and Tabacchi, 1994; Pollock *et al*., 1998). The coexistence of many wildlife species is also supported by the availability of their diverse foraging and breeding sites (Tucker and Wayne, 1990). The root systems of riparian vegetation and the microbes associated with it actively takes part in intercepting and detaining agricultural runoff from adjacent upland areas. This helps in maintaining the quality of the river water (Jones *et al*., 1999), and plays a significant role in nutrient cycling (Johnes, 1996) and nutrient dynamics (Cummins, 1992). The inherent capacity of riparian vegetation to proactively act as a natural filter, trapping of chemical elements from fertilizers (nitrogen and phosphorus) and breaking them down into usable nutrients substantially contribute towards the improvement and maintenance of water quality (Stevens *et al*., 1995). The riparian forest along the riverbanks stabilizes the soil by their strong rooting system (Cordes *et al*., 1997). The presence of herbs and shrubs firmly stabilizes the banks by holding them together with the soil, rock, and organic material. This vigorously reduces the erosion of soil and further prevents the entry of sediments into the water system. The decomposed litter from riparian vegetation also acts as a primary food source for many aquatic invertebrates. This in turn nourishes the fish and other organisms that are inhabiting the riparian zone. Majority of river organism depends largely on such organic litter inputs and coarse woody debris and this helps in maintaining healthy food chains and food webs system (Wootton *et al*., 1996). The shade provided by the above-ground vegetation controls the water temperature and in-stream photosynthetic productivity, making the habitat more suitable for fishes and other aquatic organisms to sustain (Gregory *et al*., 1991).

Ecologists have acknowledged riparian forests as habitats for many animals and have well recognized them as a promising area for the conservation of terrestrial mammals (Darveau *et al*., 2001), and birds (Saab, 1999; Woinarski *et al*., 2000). Naiman and Rogers (1997) did recognize riparian areas as an important contributor to regional biota. Riparian forests are vital for the global biodiversity (Sala *et al*., 2000). They are important since they protect the key resources such as water sources, quality of stream environment (Trimble, 1999), and harbors diverse flora and physical structure (Kokou *et al*., 2002). They also potentially store large quantities of carbon which is attributed to their relatively higher rates of productivity and/or saturated conditions that favor belowground carbon storage (Thuille *et al*., 2000). Riparian landscapes are some of the most diversified and dynamic ecosystems on earth yet they are also highly threatened. Under normal circumstances, riparian ecosystem supports the prevalence of vegetation types that are typically adapted to saturated soil conditions (Gosselink *et al*., 1981). It also observed to exist a strong positive link between the composition of species and elevation above the channel bed (Hupp and Osterkamp, 1985), and this is related to the soil texture (Aruga *et al*., 1996) and soil moisture (Adams and Anderson, 1980). It is also observed that the distribution of species in the riparian areas is significantly affected by light (Menges and Waller, 1983), downstream variation (Nilsson *et al*., 1989), land-use history (Hermy and Stieperaere, 1981), and regulation in the natural flow of the river (Meentemeyer, 2006).

### 1.2.3 Factors responsible for the high diversity of riparian vegetation

'Riparian vegetation' generally refers to those plants that are found growing along the river margins. They are generally much denser, taller, and have a more diverse species composition than the adjacent upland terrestrial ecosystems. Riparian vegetations are generally diverse in species composition, structure, and regeneration processes (Maingi and

Marsh, 2006). Much of this is attributed to the elevated water tables, flooding, ability of soils to retain water, and other environmental factors that are unique to its ecosystem. Along the river, the distribution of the riparian plant community is determined by the frequency and duration of floods (Manci, 1989). This led to the creation of mosaics of plant assemblages containing patches that are distinctly wetland vegetation types mixed with elements of upland types of vegetation (Oliver and Hinckley, 1987). Another major reason for the high species richness in riparian areas is due to the spatial heterogeneity caused by geomorphological processes (Hupp, 1988; Gould and Walker, 1997; Ferreira and Stohlgren, 1999). The riparian forest extends laterally from the active channel of the river to the uplands; includes both the active floodplains and the immediate adjacent corridors. In most cases, the vegetation in the riparian zones has year-round access to water because of the high water table (Ward, 1989; Amoros and Bornette, 2002). This greater and longer period of water availability supports more plant species than the other landscape and enables them to grow faster and to larger dimensions.

The differences in the condition of climate and geomorphological valley, gradients in the ecology of river continuum, dynamics of the network have a profound effect on the composition and structure of riparian vegetation along a river corridor (Montgomery, 1999; Benda *et al*., 2004). Edaphic factors have a significant influence on the distribution and composition of riparian vegetation. Several workers did embrace this relationship by having recorded mutual interaction between the two. Fagundes *et al*. (2019) in their study recorded a rich composition of 751 individuals belonging to 35 botanical families. They believed that soil attributes and ecotonal character may have influenced the composition, patterns of richness, structure, dominance, and the establishment of different species. A study by Moreno-Jiménez *et al*. (2019) observed that the edaphic variables were found to positively correlated with the tree height, being evident the beneficial effect of plant-soil interactions. Sunil *et al*. (2016) did observe a significant difference in the number of individuals found, species, and family richness between the forest and agroecosystem landscape with the agro-ecosystem showing a much lesser diversity compared to that of the forest landscape. Riparian vegetation also responds positively with continuous species turnover to availability of light, the input of dissolved constituents' (such as carbon or nitrogen), soil moisture, magnitude of flood and duration, erosion and accumulation rates (Naiman *et al*., 1987, 2005; Gregory *et al*., 1991; Nadeau and Rains, 2007; Huang *et al*., 2013). Thus, considering the multiple environmental gradients that are operating within the riparian landscape would give us a better explanation for the species richness and the potential mechanism responsible for enhancing the plant diversity in the riparian vegetation (Meragiaw *et al*., 2018). Adel *et al*. (2018) have indicated the Hydro-geomorphic process, flooding, elevation gradient, distance from the river, and soil properties as the most important factors influencing the distribution of plant community along the river. However, we have to understand that ecological conditions like the biogeographic region, altitudinal range, or geological condition specific to each river, acts differently on the riparian vegetation development. As mentioned above, the flow regime occupies an important position in influencing the distribution pattern of riparian vegetation. This factor leads towards the maximum variability of vegetation characteristics in riparian areas and generates a significant influence on the confluences of tributaries or climatic boundaries and their longitudinal zonation (Tabacchi *et al*., 1990). Even along a single river line, variations of riparian vegetation could be observed due to altitude gradients and/or level of anthropogenic effects (Lovett and Price, 2010; Dibaba *et al*., 2014; Sunil *et al*., 2017). Workers like Meragiaw *et al*. (2018) in the study of Walga river, Southwestern Ethiopia indicated that about 42% of the variation in species richness per plot could be explained by altitude gradient.

Riparian vegetation potentially acts as a sink and/or source of matter and energy and comprises an inseparable entity in the river nutrient dynamics. As a sink, they dissipate the energy of the flowing water by retaining and absorbing the movement of particles from upland areas (Turner, 1989; Fisher *et al*. 1998; Kindler, 1998). As a source, the woody debris of riparian vegetation contributes to structure and the leaf litter production adds matter to the stream ecosystem (Hawkins *et al*., 1993; Tabacchi *et al*., 1998). The benefit of shading provided by the riparian vegetation in alleviating water pollution has gained immense recognition (Ghermandi *et al*., 2009; Warren *et al*., 2017). On the matter of this mediatory role, Hutchins *et al*. (2010) found that establishing riparian shading did perform better at suppressing the phytoplankton growth than the reduction of nutrient pollution. Similarly, Bowes *et al*. (2012) also observed a significant reduction in the periphyton accrual rate (50%) of River Thames through shading. Riparian vegetation also enhances the infiltration capacity of riparian soil. These attributes positively decrease the transport of fine particles and soluble nutrients by decreasing runoff (Lee *et al*., 2000). Larger infiltration rates further reduce soil compaction, crusting, and soil water evaporation in the riparian zone (Radke and Berry, 1993). Along with the nutrient uptake, improved infiltration, and trapping of sediments, the dense root network system of riparian vegetation sturdily binds to the streamside soil, providing resistance to erosion (Brookes *et al*., 2000). Riparian vegetations are being increasingly recognized as an important component due to the significant role they play in influencing the hydrology and morphology of fluvial systems (Tooth and Nanson, 1999). They play a disproportionately significant role in controlling the exchange of water and chemical between the surrounding lands and stream systems (NRC, 2002). Despite their important ecological function, they are the first to display deterioration by the processes associated with changing land-use practices (Burton *et al*., 2005).

### 1.2.4 Role of riparian vegetation in improving water quality

The declining trends in the water quality of rivers due to disturbances incurred from both natural and anthropogenic actions along the catchment areas irrefutably threaten their sustainability. The quality of water usually reflects its composition as affected by both the natural processes and humans' cultural activities, which are often expressed in terms of its measurable quantities intended for usage (Novotny and Chesters, 1981). Roopshah (2016) stated that water bodies are the mirror of the environment and they reflect the kind of society that exists around the surface water bodies. Polluted water has been a major concern worldwide due to its ability to act as an important vehicle for spreading diseases. WHO (2004) reported that about 1.8 million people in developing countries, mostly children, die every due to water-related diseases. The state of well-being of surface water bodies is necessary for biological life to function and required for most human activities. Its pollution can cause disturbances to the natural ecosystem and can affect the food chain, degrading the population of aquatic life and wildlife (Thorne *et al*., 2008). Thus, it remains a crucial responsibility to keep the health of the river in check. During the last few decades, the pursuit of development has sustained immense stress on our freshwater resources. They are being continuously contaminated and deteriorated to an inconceivable stage. The increasing urbanization, industrialization, and overpopulation along the river banks are some of the main factors responsible for increasing pollution.

An important function of riparian forests is protecting the quality of water by reducing the entry of sediment, nutrients, and other pollutants. Riparian zones and river are intimately linked together, characterized by the ability to interchange resources across the land and water system. The presence of vegetation in the riparian zones moderates nutrient input, base flows, air/water temperature, erosion, and inputs of terrestrial litter into the stream system. Accordingly, these attributes considerably characterize the water quality of the rivers and streams. Any disturbance in the riparian zones can damage this positive interaction across the landscape and can lead to deterioration of water quality. The presence of healthy riparian buffer strips advocates physical processes like infiltration, sediment deposition, or adsorption, while the biochemical mechanisms include nutrient uptake or denitrification (Lowrance, 1992; Daniels and Gilliam, 1996; Schoonover *et al*., 2006). Efforts being made in increasing landscape diversity can positively contribute to the improvement of water quality (Huang *et al*., 2013). Souza *et al*. (2013) in the study of 15 streams along a gradient of forest cover had noticed that gradient in the tree size versus density influenced P concentrations in the streams, having found lower concentrations in streams with higher tree density in the riparian forest due to the increase in uptake of P. The riparian forest receives and processes water, sediments, and nutrients transport from upslope; effectively function as sinks for nutrients and sediments, and regulates the loading of nutrient to the aquatic system (Luke *et al*., 2007; Mayer *et al*., 2007). Brogna *et al*. (2017) showed the presence of forest cover explaining one-third of the variability of water quality and found a positive correlation with high water quality. Fernandes *et al*. (2014) also indicated that the presence of riparian forest remnants in the rural landscape can improve the stream water quality by mitigating the non-point effects of agricultural activities. Their study suggests consideration of forest remnants while trying to manage the stream water quality at larger spatial scales. A study by Ranalli and Macalady (2010) observed that undisturbed headwater watersheds significantly helps in retaining nitrogen. Such observation further confirms the positive role of a healthy riparian vegetative buffer in mitigating the runoff of nutrients and other pollutants into the water system.

Landscape features like the topography, land cover, geochemical reactivity, climate, inhabitation, and watershed area play a significant role in regulating the stream water chemistry (Chuman *et al*., 2013). Studies have shown that properties of stream water respond directly to changes made in the land cover of the catchment areas (Storey and Cowley, 1997; Park *et al*., 2011). So, any alterations in the catchment area forest cover can convincingly exert immense pressure on the natural hydrological and ecological processes of the aquatic environment (Allan and Castillo, 2007). Consequently, the presence of healthy watersheds is crucial for their role in the cycling of nutrients, purification of water, protection of habitats, erosion/sedimentation control, flood control, and regulation of climate (Hazbavi *et al*., 2018). Mori *et al*. (2015) provided critical information on how degraded and highly fragmented forests not being able to effectively contribute towards the protection of aquatic ecosystems. Bahar *et al*. (2008) in the study of the O-Hori river basin observed that despite recording higher concentrations of major ions in areas where human activities are present, forested areas showed considerably lower levels of inorganic ions and positively contributed towards the maintenance of water quality. To efficiently control the inputs of nutrients into the water system, it is essential to have more trees in the riparian zone which can effectively reduce the speed of the overland flow and effectively intercept the particulate material (Dosskey *et al*., 2010).

### 1.2.5 Attributes of riparian soil

Soil plays an indispensable role in many of the ecosystem processes like decomposition, water filtering capacity, and are considered as the main drivers of community assembly (Wardle, 2002). Vegetation dynamics of an area are strongly influenced by the condition of the soil (Caylor *et al*., 2005), likewise the plant productivity and diversity (Naiman *et al*., 2005). Riparian soil act as a source or sinks of different nutrient elements and is regarded as a biogeochemical 'hotspot' of nutrient cycling (Zhu *et al*., 2013). In the riparian ecosystem, nutrient redistribution and export are significantly influenced by the sedimentation process and are therefore potentially more heterogeneous in their mineral character. Processes related to hillslopes like the solution transport, litterfall, surface erosion, debris avalanches, slump, and earthflow coherently facilitate the delivery of soil in the riparian ecosystems. Because of the presence of abundant water and movement of groundwater into the rooting zone, soils in the riparian area also retains higher soil moisture content (Bilby, 1988; Lewis *et al*., 2003; Zaimes *et al*., 2007; Daniel *et al*., 2017) which in turn promotes higher decomposition rate (Bilby, 1988). Compared to other adjacent non-riparian areas, soils of the riparian zone have higher microbial biomass (Naiman *et al*., 2010), they also have higher organic carbon contents (Figueiredo *et al*., 2016; Graf-Rosenfellner, 2016), greater amounts of nutrients, and fine-grained sediments (Lee *et al*., 2000; Mayer *et al*., 2007). Jiang *et al*. (2017) recognized riparian zones as the hot spot of soil C and N dynamics. According to their findings, soil moisture constituted the driving force for the spatial and seasonal distributions of soil labile C and N pools. Similarly, changes in soil aeration condition and flooding also affect the soil N dynamics in the riparian zone (Gergel *et al*., 2005; Hernandez and Mitsch, 2007).

The nexus between the riparian soil-plant-microorganism yields vital physical, chemical, and biological functions that perform the role of filtering, infiltration, absorption, retention, and deposition (McDowell *et al*., 2001; Sharpley *et al*., 2001). They conjointly act together to remove non-point source pollutants from surface runoff entering the receiving water bodies thereby controlling pollution; purify and protect the water bodies (Ranjith and Peter, 2006; Soltani *et al*., 2015; Yang *et al*., 2016; Ogunbanjo *et al*., 2016). However, the riparian zone of reservoirs has an independent water regime from that of streams and rivers system. This results in a distinct impact on the soil characteristics that are often very perceptible. In these zones, the direct effects at the local scale by the fluctuating water level constitute the main controlling factor affecting the riparian soil properties and ultimately regulates the nutrient cycling in the process. For instance, the pH of the soil, dissolved oxygen, and redox potential are very sensitive to soil moisture (Devêvre and Horwáth, 2000; Fearnside and Pueyo, 2012), and varies according to the availability and content of soil moisture. Similarly, the nutrient sorption–desorption dynamics (Zhang *et al.*, 2012) and microbial communities are also considerably impacted after the flooding phase (Barros *et al.*, 1995; Wang *et al.*, 2016). The anaerobic environmental condition under flooding also possibly induces the transformation of nitrate ($NO_3^-$) into dinitrogen ($N_2$), nitrous oxide ($N_2O$), or ammonium ($NH_4^+$) (Forshay and Stanley, 2005).

### 1.2.6 Heterogenous condition of riparian soil

By nature of its position within the landscape, soils in the riparian zones receive sediments and other materials from the uplands and watershed. Riparian soils perform many important regulatory functions and aid in the transformation of energy and materials between the terrestrial and aquatic ecosystems (Naiman and Decamps, 1997; Hill and Cardaci, 2004). They too share many similar characteristics with their upland terrestrial counterparts, yet differ in several ways. Processes and events like erosion/sedimentation, flood dynamics, the activity of soil microbes, or pedogenesis significantly influence the soil morphology. The combined role of physical, chemical, or biological processes at different scales, often validate the spatial heterogeneity of soil (Goovaerts, 1998; Fennessy and Mitsch, 2001; Bruland and Richardson, 2005). It is therefore observed that the spatial dependence of soil properties especially in floodplains is generally high. (Daniel *et al.*, 2017). Factors such as parent material, topography, vegetation composition, climatic and biological conditions, land-use changes, and agriculture also affect the spatial heterogeneity of soil properties (Liu *et al.*, 2013). Xia *et al.* (2018) attributed the spatial heterogeneity of soil properties in the riparian zone to the trivial difference in topography, vegetation composition, and floods. Gallardo, (2003) believed microtopography, vegetation, and the directional effect of environmental gradients due to the flooding is behind the spatial heterogeneity of riparian soil.

Factors such as water, geomorphic processes, coarse woody debris, litterfall, decomposition, and cycling of C, N, and P contribute immensely towards the heterogeneity of soil and plant in the riparian zones (Mikkelsen and Vesho, 2000). Riparian areas, because of their proximity to the water bodies, flood induced processes such as frequent erosion and depositional disturbances create complex mosaics of soil conditions that can fundamentally stimulate vegetation colonization and establishment (Oliver and Larson, 1996). The outcome of such events in the floodplain areas results in well-drained patches of soil or deposits of mineral-rich alluvium next to poorly drained organic soils in abandoned high-flow channels or hillslope seeps. It further increases the heterogeneous nature of riparian soils by producing bare soil surface in some areas and creating hospitable microenvironments for those seed species that require bare soil surface for germination (Bilby, 1988). The occurrence of such heterogeneous soil conditions comprised a major factor in influencing and maintaining high plant diversity in the riparian areas. Subsequently, the abundance of vegetation further influences the soil properties of riparian zones by releasing organic matter content (Quideau *et al*., 2001) and other necessary nutrients necessary for the growth of plants.

## 1.3 MAJOR THREATS TO RIPARIAN ECOSYSTEM ADDRESSED IN THE LITERATURE

### 1.3.1 Disturbances to riparian vegetation

Factors like nutrient enrichment, alteration of temperature, the addition of suspended solids, and acid precipitation can cause a profound impact on the river environments. Other disruption like the removal of vegetation, increasing urbanization, changes in the inputs of organic and hydrologic regimes due to forest and agricultural related activities can potentially amplify soil erosion, algal production, changes in temperature, and reduction in the concentrations of dissolved oxygen (Welch *et al*., 1998). All these observations suggestively indicate that biodiversity in streams and rivers is determined by a large number of factors which, when altered could produce a profound impact on the species' composition, abundance, and richness. Additional disturbances such as agricultural activities along the riparian zones and uncontrolled tourism can also exert significant pressure on the riparian forests, leading to the decline of typical riparian plant species (Sunil *et al*., 2016). A study by Méndez-Toribio *et al*. (2014) showed convincing evidence on how the presence of land-use types near the riverbank can potentially modify the attributes of the riparian plant community, particularly the richness and density of plant species. Similarly, Leishangthem and Singh (2018) have also observed anthropogenic activities prevailing in the lower zone (collection of fodder for animals, fuelwood, construction purposes, and logging) which were posing a serious threat to the survival and population structure of the species. Degradation of riparian trees can have great impacts on water quality, causing increased water turbidity and a negative correlation with water pH (Semiun *et al*., 2013). Compositional gradients and spatial assemblages of riparian vegetation communities respond negatively to environmental variables caused by human-induced disturbances (Mligo, 2017).

Likewise, the occurrence of other multiple disturbances such as hydrological alterations from the construction of Dam or regulation of river channel, clearing of vegetation for agriculture, logging, livestock grazing, human settlements and infrastructure development, pollution, mining, water extraction or recreation (Tockner and Stanford, 2002; Naiman *et al*., 2005; Richardson *et al*., 2007) collectively pose a serious threat to the distribution and assemblages of plants community in the riparian habitats. The presence of hydroelectric facilities is one pressing factor that can either cause an increased or decreased in the downstream vegetation cover (Turner and Karpiscak, 1980; Nagel and Dart, 1980). Such alteration to the natural flow of the river reduces the meandering of the channel and can possibly lead to loss of spatial heterogeneity along the riparian corridor (Johansson *et al*., 1996). The effects of the dam can have an irreversible change on the diversity and floristic composition across the strata and the entire topography of the downstream (Rocha *et al*., 2019). With the emerging threat to riparian vegetation, a sensible management solution must be urgently needed. Heartsill-Scalley and Aide (2003) suggested that land cover should not just restrict to the riparian areas only, but also the drainage or sub-watershed areas as well. Therefore, for the management of streams and freshwater communities, it is imperative that woody species and vegetative cover surrounding the stream channels should also be considered. It is observed that land-use at the local scale remains an imposing factor of plant assemblages compared to land-use at the broader scale; such observation must also be taken into account in future land management programs to effectively mitigate the effects of urbanization on riparian ecosystems (Kuglerová *et al*., 2019).

### 1.3.2 Impacts of land use and anthropogenic activities on water quality

In recent years, the assessment of water quality of rivers has gained many scientific interests for its human consumption and aquatic health. The water quality of the system provides substantial information about the resources available to support life (Thirupathaiah *et al*., 2012; Pandit and Solanki, 2004), and it depends largely on a number of physicochemical parameters and biological characteristics. The enrichment of nutrients (nitrate and phosphorus) and suspended particles have the capacity to deteriorate the overall water quality of the river and can create unfavorable conditions for aquatic life (Abdollahi *et al*., 2019). A study by Wu *et al*. (2019) showed an increase in nutrient fluxes in the

Yangtze River annually from 1963 to 2012. A similar consistent trend was also observed by them from the Jiulong River where the nutrient fluxes increase from 1998 to 2007 but then decrease afterward. Draining of nutrient-rich water can trigger algae blooms in the Great Lakes, reduce the water quality, and ultimately damage the life of fishes and plants. In surface water, the presence of phosphorus (P), and nitrogen (N) (Carpenter *et al*., 1998) are of major concern as they play an important role in controlling eutrophication (Lewis and Wurtsbaugh, 2008; Conley *et al*., 2009). Rather *et al*. (2016) in the study observed nitrate enrichment and an increase in sediment load, indicating a clear human footprint in the catchment of the river. According to them, the large-scale urbanization along the banks of the river has incurred negative impacts on water chemistry. The physicochemical properties of water also have seasonal influence and are affected by the presence of anthropogenic activities in the catchment area (Shetty *et al*., 2012). Rainfall, which is a natural seasonal phenomenon largely influenced by the climate within the basin causes substantial surface water runoff (Karbasi *et al*., 2008; Najafpour *et al*., 2008) causing changes in the water chemistry. The spatio-temporal variations in precipitation, surface runoff, and base flow sturdily influence the river discharge affecting the concentration of pollutants in the river (Twesigye *et al*., 2011; Zhang *et al*., 2012). Other factors such as precipitation, weathering of crustal materials, urban development and expansion, effluent discharges from industries, agricultural practices and use of chemicals, erosion of soils, and land-use practices can also significantly affect the surface water quality of a river (Carpenter *et al*., 1998; Muangthong and Shrestha, 2015).

Within the watershed, any changes in the land cover patterns as a result of an increase in human activities may relentlessly degrade the water quality of rivers (Sliva and Williams, 2001; Ngoye and Machiwa, 2004). The key influencing factors behind the modification of the hydrological system is related to changes in the land cover and land management practices, which leads to alteration in the runoff as well as the water quality (Yong and Chen, 2002; Bai *et al*., 2010). The presence of chemical components in the water sample is closely tied to the land use pattern in the watershed (Jang and An, 2016). De Souza Pereira *et al*. (2019) recognized that land use and occupation, population density, and lack of sanitation as major agents of water pollution. Since the biogeochemical processes in the watershed directly affect the quality of river water, it, therefore, pressed the need to scale the effects of land use by assessing the water quality status. Effendi *et al*. (2018) in their study of Pesanggrahan River concluded that although the land cover influences water quality, domestic wastes are generally the main cause of river water pollution in almost developing countries. Urban development in the watershed can cause substantial modifications of flood runoff and water quality (Tong, 1990). Martinez-Tavera *et al*. (2017) indicated that sites that encounter a high degree of contamination are those that pass through the urban sector or are directly affected by the raw settled sewage. A study by Kumari *et al*. (2013) illustrated the spatial variations in river water quality and demonstrated the presence of heavy metals which are a result of industrial effluents. Mohammadi *et al*. (2019) in the study of Talar river, Iran indicated a positive correlation between heavy metals and land uses which varies with the level of agricultural and urbanization development at the sub-watershed. Deterioration of water quality from industrial use of water and discharge into the river without any pre-treatment (Vaishali and Punita, 2013) continue to pose a serious threat to all the other existing challenges. Rashid *et al*. (2017a, b) witnessed significant changes in land use and land cover in and around the vicinity of Dal Lake due to unplanned urbanization, high population growth, intensive agricultural practices, and tourism. All these factors were found to concordantly act together in changing the chemistry of the Lake. Such variation in water quality caused by different land-use conditions was also reported by Yilma *et al*. (2019). Bahar *et al*. (2008) established that land-use types have the greatest influence on water quality in the O-Hori river basin. Their study reported the highest concentrations of major ions in areas where human activities were most prevalent, while forested areas showed lower levels of inorganic ions, contributing positively to maintaining the water quality. Kilic and Yucel (2019) also found that mineral pollution, nutrient pollution, and organic pollution as the major latent factors influencing the water quality of Asi River, and the fundamental causes of water pollution in the study area was found to link with erosion, agricultural activities, domestic and industrial discharges.

Several studies did indicate the deleterious effect of land use and land cover change (LULC) on water quality and quantity (Duan *et al*., 2012; Nagy *et al*., 2012; Groffman *et al*., 2003; Raney and Eimers, 2014). The varying land use and land management practices have been regarded as one of the main key drivers altering the hydrological system as well as the quality of receiving water (Changnon and Demissie, 1996). It is therefore imperative that the recommended remediation measures such as reforestation and other management steps should be implemented proactively to achieve load reduction in close conjunction with social needs (Tzoraki *et al*., 2014). A study by Pissarra *et al*. (2019) in eight catchments of the Uberaba River Basin Environmental Protection Area (Minas Gerais State, Brazil) revealed a combined positive influence of landscape composition and buffer strip widths (L) on stream water quality. Thus, confirming the positive role of riparian vegetation in improving water quality. Bellingham (2012) emphasized the importance of implementing comprehensive monitoring regimes to mitigate the impact of human societies on natural waters. He further highlighted that, identifying the impairments in water quality and helping policymakers to make a prudent decision concerning land use policy will considerably help in preserving the natural areas and improve the quality of life. For effective management of river ecosystems, identifying the source of pollution is a prerequisite condition (Bednarova *et al*., 2013). Karlsen *et al*. (2019) suggested that for an effective riparian zone, the catchment area of any specific stream must at least contain an area with a minimum of 20–30% without agriculture or urban areas to obtain good ecological status; when focusing only on the riparian zone (10 m on each side of the stream), a minimum of 40–55% is needed to create a good ecological status. The intensification of land use pattern is not the only pressing factor to affect the health of the watershed but also the role of climate change which can cause an increase in the hydrologic extremes and contaminant loads both from urban and agricultural runoffs (Hoque *et al*., 2014; Mehdi *et al*., 2015).

### 1.3.3 Disturbances to riparian soils

Mismanagement of land resources, excessive livestock grazing in the protected forest areas, and intensive agricultural production in nearby farmland can cause substantial deterioration to the quality of soil (Moges *et al*., 2013). In particular, excessive removal of stabilizing vegetation due to grazing of livestock on riparian soils has incurred a significant impact on soil compaction, breakdown of undercut stream banks, and increase the loss of sediment. Timber harvest can also potentially increase soil erosion and soil temperatures (Hall, 1988). Indiscriminate pollution as a result of nonpoint agricultural sources and increased domestic waste from adjacent riparian areas have become a serious public-safety issue (Zhang and Lou, 2011). Pollution from such human persuaded activities plays a major role in affecting the soil properties (Jiang *et al*., 2015). However, the human disturbances from adjacent uplands remain an inevitable force affecting the riparian soil nutrients spatial autocorrelations (Xia *et al*., 2018). The study by Saint-Laurent *et al*. (2017) observed that the hydrological conditions (e.g., more frequent floods) have collectively led to the depletion of soil organic carbon (SOC) resulting in a decrease of soil quality and fertility. Undoubtedly, vegetation structure act as a good proxy to monitor the soil ecosystem services (i.e. regulation of water flow, erosion control, and life-supporting). Degrading the structure of riparian vegetation can produce deleterious effects on riparian soils. Supporting this notion, Celentano *et al*. (2017) reported that degradation of riparian forests can significantly reduce the content of soil carbon, phosphorus, cation exchange capacity, silt proportion, total porosity, the content of water, and infiltration rate of water. According to them, the successful application of management strategy across broader spatial scales may enhance the monitoring and modeling of riparian forest ecosystem services.

Following land-use changes in riparian areas, soil aggregation and soil C sequestration can change (Qian *et al*., 2018). This can alter the composition and holding capacity of the riparian soil. Deterioration in the riparian soil can shift the soil conditions from immobilizing environments with low quantities of mineral N. Degraded hydrological condition can probably lead to loss of nearly half of soil organic carbon (SOC) and Total Nitrogen (TN) stored in properly functioning meadows (Norton *et al*., 2011). Such negative observation underscored the need to properly maintain the functioning riparian meadows and restoring the degraded ones. A study by Matano *et al*. (2015) confirmed that land use types affected land degradation differently along the Mara River, while adjacent land degradation has some effect on water physicochemical properties. Concordance to their result, they suggested the need to have a focused policy on integrated land and water resource management strategies along the riparian zones. Research conducted in the Three Gorges Reservoir riparian zone of China by Ye *et al*. (2019) reported that soil properties in the riparian zone were jointly affected by both local and regional factors. To counter these advances, they conclusively proposed a threshold of 167.5 m that divides the riparian zone into two different response zones of soil reaction in relation to local and regional factors. A study by Hale *et al*. (2018) provided an invaluable insight into the likely short-term responses of soil properties to riparian management. They recognized that continued monitoring effort would allow to assess if the predicted longer-term responses (e.g. increased soil carbon) occur. To assess or track the effectiveness of management interventions in removing P from riparian areas, Satchithanantham *et al*. (2018) asserted that testing of soil might be a good tool to aid in the siting of new buffers. While undertaking a stream and riparian restoration program, it is important that extreme climatic events like floods and droughts must also be considered (Reich and Lake, 2015). Not only that, reforestation initiatives followed by a broader approach in planting aquatic plants would act as an effective method in preventing the loss of valuable nutrients elements from riparian ecosystems. Considering all the other options, to effectively assess and evaluate the riparian ecosystem, it is imperative that long-term and well-designed monitoring programs are highly encouraged.

## 1.4 WORK DONE OVER THE LAST DECADE IN INDIA

Over the last decade, significant research progress had been made in areas related to the riparian ecosystem. Workers like Alam and Pathak (2010), Kumar *et al*. (2011), Sharma and Kansal (2011), Tyagi *et al*. (2013), Kumari *et al*. (2013), Singh and Kamal (2014), Bhat and Pandit (2014), Kumar *et al*. (2015), Shah and Joshi (2017), Gupta *et al*. (2017), Mohanty and Nayak (2017), Acharya *et al*. (2018), Maji and Chaudhary (2019), Mir and Gani (2019), Tripathi and Singal (2019) have worked rigorously in assessing and generating the overall water quality status of different rivers. Concerning the effect of land use on water quality workers like Khare *et al*. (2017) have worked along Narmada River, Rather *et al*. (2016) along Jhelum River in Kashmir, Himalaya. Romshoo and Rashid (2014) in Hokersar wetland, while Mir and Jeelani (2015) and Mir *et al*. (2016) have both worked in Jhelum river. Srivastava *et al*. (2010) and Srivastava and Singh (2012) had studied the role of riparian herbs in soil and water conservation.

Several quantitative studies on riparian forest plant diversity inventories have been conducted by authors like Tapati *et al*. (2010) along Dikong river, Arunachal Pradesh, Sunil *et al*. (2010) in Cauvery river of Tamil Nadu, Iqbal *et al*. (2012) along Khoh river of Garhwal Himalayas, Manoj *et al*. (2012) in Alakyam stream, Kerela, Varghese (2015) in Meenachil river basin of Kerela, Aziem *et al*. (2016) in Bhilangana Valley of Garhwal Himalaya, Sunil *et al*. (2016) in Cauvery river of southern India and Haq *et al*. (2019) in the protected forest of Kashmir. To date, a couple of studies from the North-eastern part of India has been done, mainly confined to Assam and Manipur. Workers like Singh *et al*. (2016), Bora and Goswami (2017), Singh *et al*. (2017) have worked on the water quality assessment of rivers. Other workers like Dutta *et al*. (2011), Barman and Gupta (2015), Debnath *et al*. (2017) have also contributed substantial information related to riparian studies. Recently, Leishangthem and Singh (2018) from Nagaland, have studied the riparian forest from certain zones along the Dikhu river. Geomorphology and seasonal variation of physicochemical parameters of Doyang River had already been worked out by Imnatoshi and Ahmed (2012), however, there has been no scientific investigation on water quality assessment of Doyang River to date.

## 1.5 ORIGIN OF THE RESEARCH PROBLEM

Human activities have severely altered landscapes, mainly through the conversion of large forested areas into agricultural and residential lands. These changes at the watershed scale, including deforestation of riparian areas, have seriously impacted the watercourses through sedimentation and degradation of water quality (chemical, physical, and biological characteristics) and depletion of species diversity (Quinn *et al*., 1997; Allan, 2004). Riparian zones being the interface between the terrestrial and aquatic ecosystems, deforestation of these zones can have disproportional effects on water quality (Naiman *et al*., 2005; Fausch *et al*., 2010). The same phenomenon has been increasingly noticed along the riparian zone of the Doyang river. The high prevalence of shifting cultivation, also known as Jhum, forms the major land-use system practices along the riparian zones of the Doyang river, which is leading to cutting down of large riparian areas for such a cause. With the rapid increase in population, the jhum cycle has now been reduced and the previously uncultivated and steep land is being taken into the jhum system. This results in accelerating both on-site and off-site degradation due to erosion, runoff, nutrient losses, siltation, loss of biodiversity, and disruption in watershed hydrology. The riparian zone of the Doyang river supports diverse flora and fauna, thereby maintaining the biodiversity of this region. Besides the existence of jhum practices, other anthropogenic activities like the increasing deforestation in the catchment and river banks, increasing population, extensive teak plantation for timber, and developmental activities threaten the riparian habitats as never before. The current emergent threat has therefore called for an urgent need to protect the riparian ecosystem, assess and formulate conservation strategies. Apart from the biodiversity and ecological values, the conservation of these habitats is very much directly linked to the livelihood and security of the people in this region. In recognition of this, the research work entitled **"*Studies on riparian vegetation diversity and its relationship with soil and water characteristics of Doyang river, Wokha, Nagaland*"** was taken up.

For the present study, three research questions were raised to effectively justify the entitled research work.

1. Do land-use systems have any specific effects on the water quality parameters?
2. Do land-use practices have any effects on riparian vegetation diversity?
3. Is there any relationship between the riparian vegetation diversity and soil?

The following hypotheses were made to help understand the relationship between the riparian vegetation diversity, soil and water characteristics of the Doyang river.

(a) Land-use activities have some effect on water quality.

(b) Land-use practices affects the riparian vegetation diversity.

(c) There is a positive relationship between the riparian vegetation and soil.

## 1.6 SCOPE OF THE STUDY

The study will provide a preliminary assessment of the riparian vegetation of the Doyang river against which the course of future monitoring can be taken up and assist in formulating conservation strategies. Similarly, the spatio-temporal variability of physicochemical properties of water and the impact of different land uses on water quality will help in the protection and management plan of the Doyang river. The outcome of the study will raise awareness among peoples by providing information on the benefits of having vegetation in the watershed as a way to promote water quality improvement; the necessity to protect the riparian zones and improvement in ground cover. The Water Quality Index (WQI) generated from the physicochemical parameters of water will also help us in assessing the suitability of water for human use. This study would ultimately pave ways for future management and action plans to protect those riparian zones that face pressure from different land-use practices; facilitate the improvement of the water quality. A lot of information is currently available about the aboveground processes in riparian zones but very little information exists at the time regarding the riparian soil characteristics. Hence the outcome of the study will also provide information on the relationship between the vegetation composition and edaphic factors from different zones of the Doyang river.

## OBJECTIVES OF THE STUDY

1. To determine the physicochemical characteristics of water quality.
2. To calculate the Water Quality Index (WQI).
3. To study the riparian vegetation diversity along the Doyang river.
4. To determine the soil physicochemical characteristics of the riparian zones.

Accordingly, the thesis is organized as follows:

Chapter 1: Introduction and review of literature

Chapter 2: Materials and methods

Chapter 3: Spatio-temporal variation on water quality parameters of the Doyang river

Chapter 4: Water Quality Index (WQI) of the Doyang River

Chapter 5: Phytodiversity of the Doyang riparian forest

Chapter 6: Physicochemical properties of the riparian soil

Chapter 7: Summary

References

Appendices

# CHAPTER – 2

# MATERIALS AND METHODS

## 2.1 DESCRIPTION OF THE STUDY SITES

The state of Nagaland is largely a mountainous region with altitude rising to an elevation of 3840 meters at Mount Saramati, has a total geographical area of 16,579 sq. km and extends from 25°6′ N to 27°4′ N Latitude and 93°20′ E to 95°15′ E Longitude. The state is bounded by Assam in the north and west, by Myanmar and Arunachal Pradesh in the east, and by Manipur in the south. The state is dissected by several seasonal and perennial rivers and rivulets. Major rivers that flow westward into the Brahmaputra River of Assam are Dhansiri, Doyang, and Dikhu. The Doyang river is one of the major rivers in Nagaland and runs along the southern boundary of the state. It originates from the Japfü Hill near the southern slope of Mao in Manipur and moves in a southwest direction passing through Kohima district and flows northward into Zunheboto and Wokha. The Doyang River passes through a great part of the Wokha district of Nagaland and is called 'POFU' by the local inhabitants (Lothas) which simply means 'encircle' because the river flows right through the middle of the district touching all three ranges encircling the whole district. It further flows southwest into the Dhansiri river in the Sibsagar district of Assam and finally joins the mighty Brahmaputra River of Assam. The main tributaries of Doyang are Tsui, Tullo, and Tishi. The river has a length of 167 km (from Gariphema/Ghathashi area to Liphi) and a catchment area of 3283 $km^2$ (Laishram and Yumnam 2016). The Doyang Hydro- Electric Project (DHEP) is located in this river and the large reservoir is more than 20 $km^2$. The present study was conducted within a stretch of 40-45 km of Doyang River under Wokha district, Nagaland, and the Dam area also comes under the preview on the study. The Dam area of Doyang River is an important eco-tourism spot for bird-watchers as it is a roosting place of a migratory bird Amur falcon (*Falco amurensis*). The falcons travel almost 22,000 km every year (October-November) from south-eastern Siberia and Northern China in millions and spend nearly a month around the vicinity of the Dam. The river also has a strong economic and traditional attachment to the local people (Lothas) because of its sufficient fertile plains and slopes for cultivation. The location of the study area along with their sampling stations is shown in **Fig. 2.1.**

The increasing land-use practices along the riparian zones of the Doyang river incessantly threaten the riparian habitats as never before. Currently, this has drawn much attention in preserving the riparian vegetation along the river and in other sensitive areas to protect the water quality and habitat value of these areas. **Table 2.1** shows the characteristics features of the eight selected sampling stations, their coordinates, and elevation along the Doyang River. Upstream of the river consists of one sampling station (S1), midstream consists of four sampling stations (S2, S3, S4, and S5), while the downstream of the river constitute three sampling stations (S6, S7, and S8). For the analysis of water physicochemical parameters, surface water samples were collected from all the sampling stations. However, for the analysis of soil physicochemical parameters and phytosociology, sampling stations of S1 (Upstream forested site), S2 (Midstream forested site), and S8 (Downstream forested site) were only taken into account.

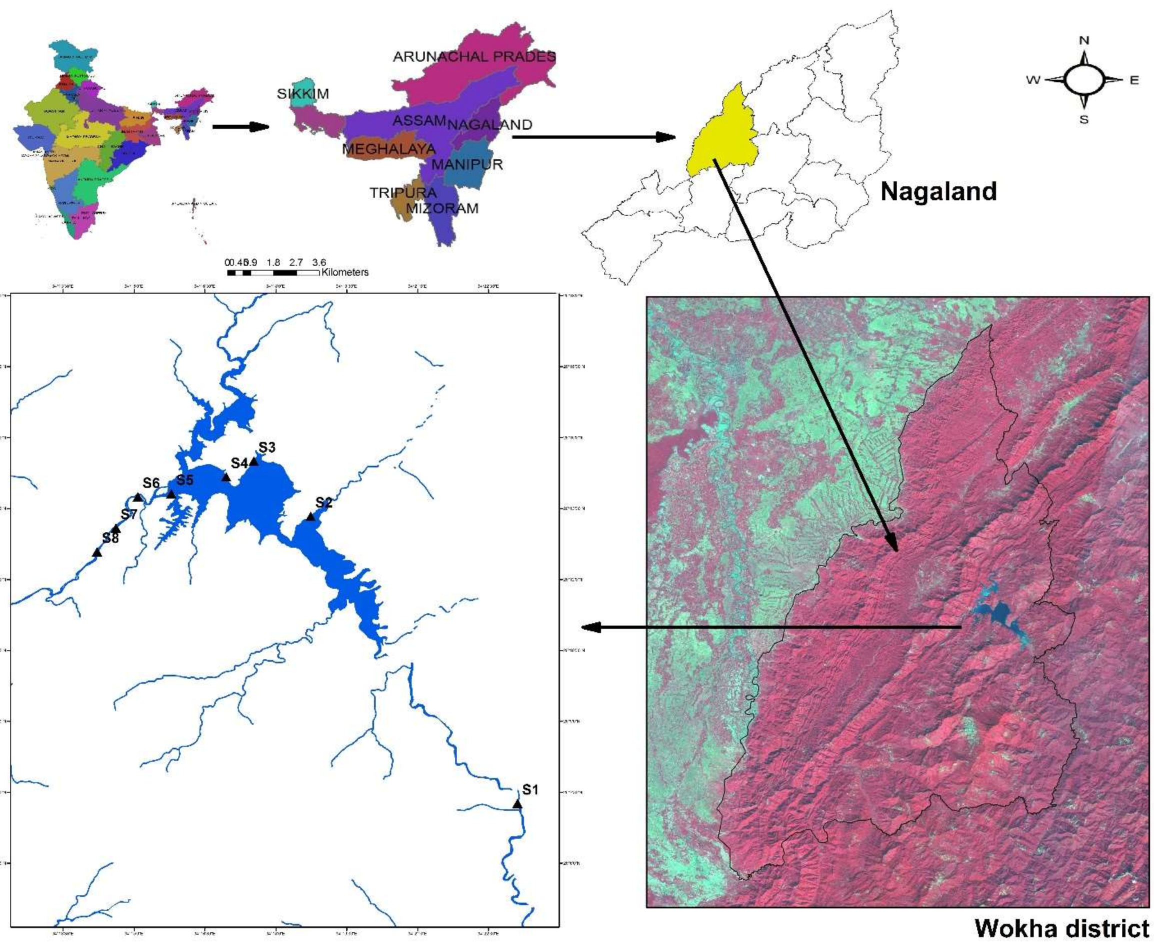



**Fig. 2.1:** Map showing the sampling stations located along the Doyang river, Wokha, Nagaland (Source: Remote Sensing Centre, Nagaland Science and Technology Council, Department of Science and Technology)

**Table 2.1:** Characteristics features of the sampling station and their coordinates along the Doyang River

| Sampling station | Station code | Characteristics of sampling station | Coordinates | Elevation (above msl) |
|---|---|---|---|---|
| Upstream site | S1 | Upstream forested area inhabited by some residential families and ongoing construction of National Highway bridge (NH 2). | $26^{0}$07.298′ N<br>$094^{0}$23.099′ E | 348m |
| Midstream site | S2 | Midstream forested area located around the vicinity of Hydro Electric Dam along the river. | $26^{0}$13.331′ N<br>$094^{0}$18.747′ E | 314m |
| Jhum Cultivated site at midstream | S3 | Jhum cultivate site located around the vicinity of Hydro Electric Dam. | $26^{0}$14.542′ N<br>$094^{0}$17.529′ E | 335m |
| Teak Plantation site at Midstream | S4 | Teak plantation site located around the vicinity of Hydro Electric Dam. | $26^{0}$14.214' N<br>$094^{0}$16.933′ E | 332m |
| Dam site at midstream | S5 | Point of Dam construction. | $26^{0}$13.811′ N<br>$094^{0}$15.779′ E | 325m |
| Residential site at downstream | S6 | Residential area located downstream of the river. | $26^{0}$13.752′ N<br>$094^{0}$15.068′ E | 266m |
| Abandoned Jhum site at downstream | S7 | Abandoned Jhum land located downstream of the river | $26^{0}$13.078′ N<br>$094^{0}$14.661′ E | 257m |
| Downstream site | S8 | Downstream forested area. | $26^{0}$12.622′ N<br>$094^{0}$14.211′ E | 243m |

## 2.2 CLIMATIC FEATURES OF THE STUDY AREA

The state enjoys a tropical monsoon type with a hot wet summer and a cool dry winter. Nagaland experiences heavy rainfall and the annual rainfall varies from 100 to 300 cm. The monsoon seasons last for a period of five months from May to September with June, July, and August experiencing the highest rainfall. **Fig. 2.2** and **Fig. 2.3** shows the Ombrothermic diagram of the study area (Wokha district) during the study period from 2016 and 2017.

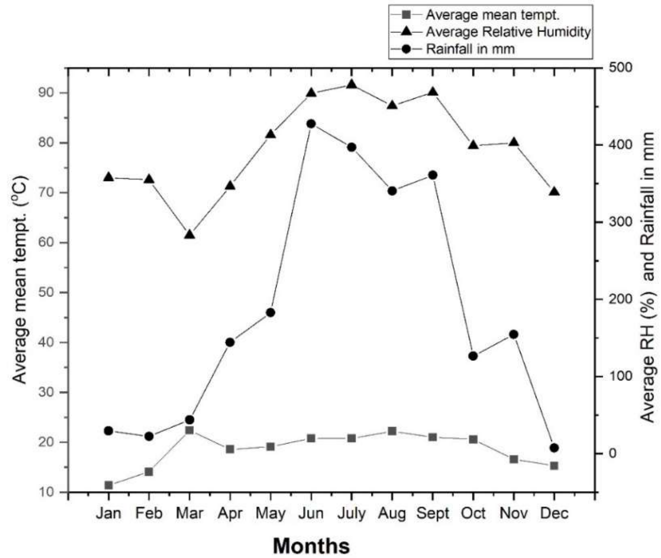



**Fig. 2.2:** Ombrothermic diagram of Wohka district for the period of 2016 (Source: Soil and Water Conservation Department, Govt. of Nagaland)

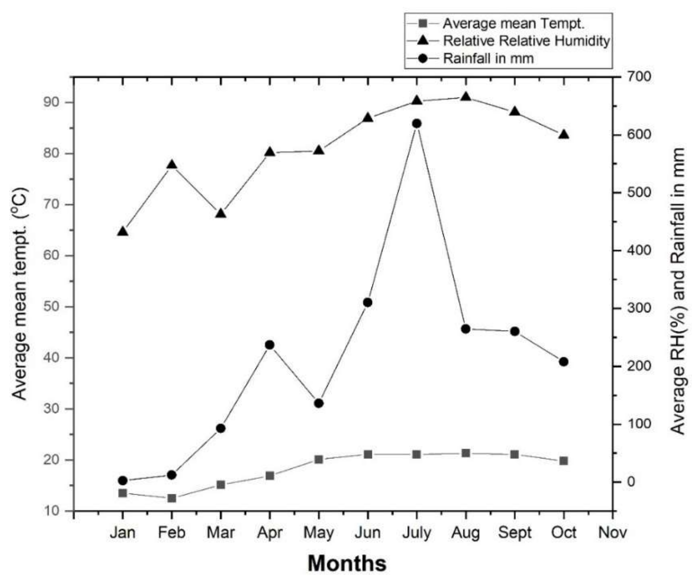



**Fig. 2.3:** Ombrothermic diagram of Wohka district for the period of 2017 (Source: Soil and Water Conservation Department, Govt. of Nagaland)

## A. Analysis of physicochemical parameters of surface water

From the eight selected sampling stations, surface water samples were collected once every month during the period from February 2016 to January 2017 within 25-30 days' time interval. The months were later categorized into three different seasons, *viz*., pre-monsoon (February, March, April, May), monsoon (June, July, August, September), and post-monsoon (October, November, December, January) and only the average values of each season were used for the data analysis. Pre-monsoon season experiences a moderate rainfall while monsoon experiences heavy showers and post-monsoon season meager to almost no rainfall at all. Water samples were collected from the first 20 cm of the water column using a bottom-weighted polyethylene flask, previously washed in the laboratory with lapoline,10% HCl and then with water from each site. Sixteen physicochemical parameters of water quality were chosen for the present study based on the permissibility limits of drinking water and their potential risk to human health (ICMR, 1975; BIS, 2009; WHO, 1995, 1998, 2011). Parameters like pH, water temperature (WT), and TDS (Total Dissolved Solids) were measured on the spot with the help of a digital portable pH meter, Thermometer, and TDS meter. Electrical conductivity (EC) was measured in the laboratory with the help of a conductivity meter. Free carbon dioxide ($CO_2$) was also estimated on the spot. For Dissolved Oxygen (DO) fixatives were added on the spot and analyzed thereafter in the laboratory. A separate sample for Biological Oxygen Demand (BOD) was also collected in BOD bottles, incubated in the dark at $20^0$C for 5 days, and then estimated. Parameters like Total alkalinity (TA), Total hardness (TH), Calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$), and chloride ($Cl^{-}$) were analyzed in the laboratory within 28hrs after filtration. Nutrient parameters like Nitrate ($NO_3^{-}$), Sulphate ($SO_4^{2-}$), Inorganic phosphorus ($PO_4^{3-}$), and Potassium (K) were analyzed in the next 48 hrs. from the samples that were previously filtered and refrigerated at 4°C. All the parameters were estimated using standards methods prescribed by the APHA (2012) and Trivedy and Goel (1986).

### 1. Chloride

On addition of silver nitrate, it reacts with the chloride to form a slightly soluble white precipitate of AgCl. At the endpoint when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate of reddish-brown color.

50 ml of the water sample is taken in a conical flask and in it, added 2 ml of 5% $K_2CrO_4$ solution and titrated with 0.02N $AgNO_3$ until a persistent red tinge appears.

Calculation;

$$Cl^{-}\ (mg/l) = \frac{Volume\ of\ \text{AgNO3 used} \times 1000 \times 35.5}{Volume\ of\ water\ sample\ used}$$

2. **Total Hardness**

The hardness of a water sample is generally measured as its concentration of calcium and magnesium (as calcium carbonate). Calcium and magnesium, both form a complex of wine-red color on the addition of Eriochrome Black T at pH 10 ± 0.1. The EDTA has got stronger affinity towards $Ca^{++}$ and $Mg^{++}$ and therefore by the addition of EDTA, the former complex is broken down and a new complex of blue color is formed.

50 ml of the water sample is taken in a conical flask and added 1 ml of buffer solution (a mixture of $NH_4Cl$ and EDTA). A pinch of Eriochrome Black T is further put into the sample solution until the solution turns wine red and is titrated with EDTA solution (0.01M). The endpoint color changes to blue.

Calculation;

$$\text{Hardness as } CaCO_3\ (mg/l) = \frac{ml\ of\ EDTA\ used \times 1000}{ml\ of\ water\ sample\ used}$$

3. **Total alkalinity**

Total alkalinity can be estimated by titrating the water sample with a strong acid (HCl or $H_2SO_4$). But first, the pH of the sample must be adjusted to around 8 by using a phenolphthalein indicator.

100 ml of the water sample is taken in a conical flask and in it, 2 drops of Phenolphthalein indicator are added. With this, the color of the sample changes to pink and is then titrated against 0.1N HCl until the endpoint the color changes to colorless.

Calculation;

$$\text{Total alkalinity as } CaCO_3\ (mg/l) = \frac{ml\ of\ HCl\ used \times 1000 \times 50}{ml\ of\ water\ sample\ used}$$

4. **Calcium**

Indicators such as ammonium purpurate form a complex compound with only calcium but not with magnesium at higher pH. EDTA has a higher affinity towards calcium; the former complex is broken down and a new complex is formed. However, EDTA has a property to combine with both $Ca^{++}$ and $Mg^{++}$, therefore magnesium is largely precipitated as its hydroxide at sufficiently higher pH.

In a 50 ml of the water sample, 2 ml of 1N NaOH solution and a pinch of murexide indicator is added. At this point, the color of the solution develops into a pink and is then titrated against 0.01M EDTA solution until the pink color changes to purple.

Calculation;

$$Ca^{2+} \text{ (mg/l)} = \frac{volume\ of\ EDTA\ used \times 400.8}{ml\ of\ water\ sample\ used}$$

5. **Magnesium**

Calcium and magnesium form a complex of wine-red color with Eriochrome Black T at pH 10. However, EDTA has got a stronger affinity for $Ca^{++}$ and $Mg^{++}$; the former complex is broken down and a new complex of blue color is formed. The value of $Mg^{++}$ can then be obtained by subtracting the value of calcium ion from the total of $Ca^{++}$ and $Mg^{++}$. Calculation;

$$Mg^{2+} \text{ (mg/l)} = \frac{Y - X \times 400.8}{Volume\ of\ water\ sample\ used \times 1.645}$$

Where, Y = EDTA used in hardness determination for the same volume of the water sample.

X = EDTA used in calcium determination for the same volume of the water sample.

6. **Free $CO_2$**

Free carbon dioxide is determined by titrating the water sample on the spot using a strong alkali (Sodium hydroxide) of pH 8.3. At this pH range (pH 8.3), all the free $CO_2$ present in the water sample is converted into bicarbonates.

100 ml of the sample is taken on a conical flask and adds a few drops of phenolphthalein indicator. The solution is then titrated with 0.05N NaOH solution until the endpoint turns pink.

Calculation;

$$\text{Free } CO_2 \text{ (mg/l)} = \frac{ml\ of\ NaOH\ used \times 44 \times 100}{volume\ of\ sample\ taken}$$

**7. Dissolved Oxygen (DO)**

The oxygen present in the water sample oxidizes the iodide ion ($I^-$) to iodine ($I_2$) quantitatively. Upon reaction, the amount of iodine generated is then determined by titration with the help of a standard sodium thiosulfate solution. The endpoint is determined by using starch as an indicator.

Water samples are collected in 125 ml of BOD bottles and immediately adds 1 ml each of manganous sulfate and alkali iodide solution. On addition of these solutions, brown precipitates are formed indicating the presence of oxygen. Once this is confirmed, 2 ml of $H_2SO_4$ is added to the surface of the BOD bottles and mixed thoroughly till the brown precipitates are dissolved. From it, 50 ml of the sample is removed and then titrated with 0.025N sodium thiosulphate till a straw yellow color appears. Few drops of starch solution are added to the sample and titrate further until the blue color disappears to a colorless state.

Calculation;

$$\text{DO (mg/l)} = \frac{ml\ of\ sodium\ thiosulpha\quad used \times 8 \times 1000}{volume\ of\ the\ sample}$$

**8. Biological Oxygen Demand (BOD)**

BOD is the measure of degradable organic matter present in the water sample and can be defined as the amount of oxygen required by the microorganism to stabilized the biologically degradable organic matter under aerobic conditions. BOD measures the difference in the oxygen concentration of the water sample after incubating it for 5 days at 20ºC.

Calculation;

BOD (mg/l) = ($DO_0$-$DO_5$)

Where, $DO_0$ = initial dissolved oxygen value

$DO_5$ = final dissolved oxygen value after 5 days

**9. Nitrate (Brucine method)**

On addition of brucine, nitrate present in the water sample reacts to produce a yellow color. The intensity of the yellow color is then measured at 410 nm. The reaction is highly dependent upon the heat generated during the test. However, it can be controlled by carrying out the reaction for a fixed time at a constant fixed temperature.

In a 50 ml test tube, 10 ml of the water sample that was earlier adjusted to pH 7 is taken and in it, 10 ml of $H_2SO_4$ is added and mix thoroughly. Another 0.5 ml of brucine reagent is added and place the tubes in a hot water bath for about 20 minutes. After this, the contents are then allowed to cool in a cold-water bath, and readings are taken at 410 nm. For blank and standard solutions similar procedure is followed.

**10. Inorganic phosphorus:**

Phosphate in water reacts with ammonium molybdate and form a complex heteropoly acid (molybdophosphoric acid), which eventually gets reduced to a complex of blue color in the presence of $SnCl_2$. The absorption of light by this blue color is then measured at 690 nm to estimate the concentration of phosphates.

In a conical flask, 100 ml of the water sample is taken. 2 ml of Ammonium molybdate and 5 drops of stannous chloride solution are added to the sample and mix thoroughly. A blue color appears on the addition of all the above reagents and the readings are taken at 690 nm. For the reading of blank and standard solution, a similar amount of chemicals and other procedures are followed.

**11. Sulfate (Turbidimetric method)**

Measurement of sulfate ion is based on the logic that on the addition of barium sulfates, it tends to precipitate into a colloidal form of uniform size. This tendency is further enhanced in the presence of sodium chloride, hydrochloric acid, and glycerol. The absorbance of barium sulfates formed is measured by spectrophotometer at 420 nm and the sulfates ion concentration is determined by comparison of the reading with a standard curve.

In a 100 ml standard volumetric flask, 25 ml of the water sample is added. In it, 5 ml of the conditioning reagents is poured in and makes up the volume to 100 ml mark using distilled water. The solution is mix thoroughly and then adds a pinch of Barium chloride. The sample readings are taken at 420 nm exactly after 4 mints.

**12. Potassium**

Potassium present in the water sample was determined using a flame photometer. The characteristic radiation for potassium is 768 nm and the intensity of the emitted flame is read on a scale by using a filter for this wavelength. The characteristic flame produced in the process is due to the excitation of electrons when the sample with potassium is sprayed into the flame. The intensity of this characteristic radiation is directly proportional to the concentration of potassium in the water sample analyzed.

The water samples are diluted in a 100 ml volumetric flask and observed the reading using potassium filter at 768 nm. To calibrate the flame photometer, a standard calibration curve is prepared from the standard potassium solution in the range of 0-10 mg/l against which the concentration of potassium in the water sample is calculated.

Calculation;

K (mg/l) = (mg/l of K in diluted aliquot) + dilution factor

**Water Quality Index (WQI)**

To generate the overall water quality index (WQI) of the Doyang River, out of the sixteen physicochemical parameters, only twelve were selected *viz*., pH, Electrical conductivity (EC), Total dissolved solids (TDS), Total Alkalinity (TA), Total hardness (TH), Calcium($Ca^{2+}$), Magnesium ($Mg^{2+}$), Chloride ($Cl^{-}$), Nitrate ($NO_3^{-}$), Sulphate ($SO_4^{2-}$), dissolved oxygen (DO) and Biological Oxygen demand (BOD). These water quality variables were chosen based on the evidence of high organic pollution from various land use activities, ongoing developmental works, and discharges from residential homes. Dunette (1975) recommended that the variables chosen to determine the water quality must have a major impact on the water. For the calculation of WQI, the values used for each parameter are the mean of respective sampling stations and seasons. All the variables selected for the WQI calculation was based on the standards of drinking water quality recommended by the Bureau of Indian Standards (BIS, 2003) and Indian Council of Medical Research (ICMR, 1975). In the formulation of WQI, water quality parameters are studied from the point of suitability for various human usage. The WQI of the present study was calculated by employing the Weighted Arithmetic Index method developed by Brown *et al*. (1970) which is given in the following equation:

$$WQI = \sum QiWi / \sum Wi$$

The quality rating scale (Qi) for each parameter was calculated by using the expression:

$Q_i = 100[(V_i\text{-}V_o/S_i\text{-}V_o)]$

Where,

**$V_i$** = concentration of $i^{th}$ parameter in the water sample analyzed.

**$V_o$** = ideal value of parameter in pure water i.e., Vo = 0 (except $p^H$ = 7.0 and DO = 14.6 mg/l)

**$S_i$** = recommended standard value of $i^{th}$ parameter.

The unit weight (***$W_i$***) for each water quality parameter is calculated by using the following formula:

***$W_i = K/S_i$***

Where,

**K** = proportionality constant calculated by using the equation

$$\mathbf{K} = \frac{1}{\sum(1/Si)}$$

The water quality index (WQI) range, it's status and possible usage (Brown *et al*., 1972) is shown in **Table 2.2**

**Table 2.2:** Water quality index (WQI) range, status and possible usage of water sample (Brown *et al*., 1972)

| WQI range | Water quality status (WQS) | Probable usage |
|---|---|---|
| 0-25 | Excellent water quality | Drinking, irrigation and industrial purpose |
| 26-50 | Good water quality | Drinking, irrigation and industrial purpose |
| 51-75 | Poor water quality | Irrigation and industrial purpose |
| 76-100 | Very poor water quality | For irrigation purpose |
| Above 100 | Unsuitable for drinking purpose | Proper treatment required for any kind of usage |

## B. Plant diversity analysis

For the phytosociological analysis, the plant survey was carried out at the beginning and end of rainy seasons (March-May and September-November 2017). For the present study, well-preserved patches of riparian forest each separated by approximately 15-20 km were selected in the upstream (S1), midstream (S2), and downstream zone (S8) of the river. In each zone of the gallery forest, two-hectare area, one hectare on both the side of the river were established. On both sides, within that 100×100 $m^2$ area, five transects, each separated by 10 m perpendicular to the water flow of the river were laid (**Fig. 2.4**). Quadrats size of 10 m x10 m for trees was laid along the line transect each separated by 10 m. For shrubs, 5 m x 5 m were nested within the quadrats laid for trees. Accordingly, a total of 50 quadrates for trees and 100 quadrates for shrubs were laid in each zone of the river. All trees with cbh (circumference at breast height i.e. 1.37 m above the ground) ≥10cm were measured individually and converted to DBH (diameter at breast height). For herbs sampling, on both sides of the river, three 20 x 20 m plot sizes each separated by 10 m was established in the ecotonal region parallel to the flow of the river (**Fig. 2.5**). Within each of that plot, 1 x 1m size plot of 20 numbers were laid randomly for the assessment of herbs. A total of 120 plots were taken into account in each zone of the Doyang river for the assessment of the herbaceous plant community. In general, a total of 810 quadrats (150 for tress, 300 for shrubs, and 360 for herbs) were laid along the riparian zones of the Doyang river covering an area of 6 hectares. Quadrat size and number were determined following Misra (1968). Each species collected were mounted, labeled, and systematically arranged in a herbarium (Jain and Rao, 1976). Identification of plant species was carried out with the help of standard literature (Kanjilal *et al*., 1934-40; Jain and Rao, 1976; Hooker, 1872-1897), BSI Shillong and Herbarium of the Department of Botany, Nagaland University.

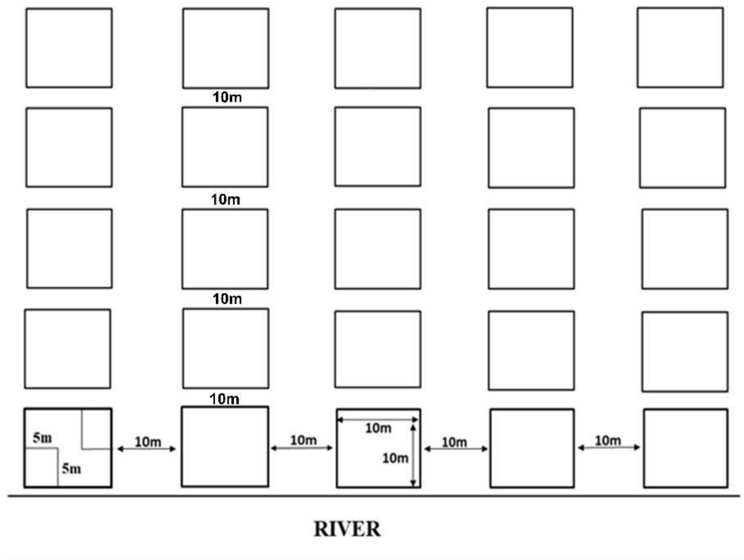



**Fig. 2.4:** Quadrat design for trees and shrubs

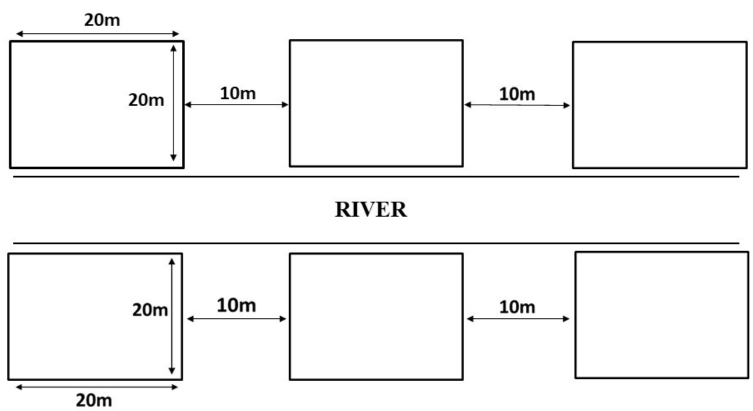



**Fig. 2.5:** Quadrat design for herbs

## 1. Quantitative analysis

Phytosociological characters like Frequency, Density, Abundance, Dominance, and Important Value Index were quantitatively analyzed following Curtis and Mclintosh (1950) and Muller-Dombois and Ellenberg, (1974). Density and the total basal cover values were converted to per hectare ($ha^{-1}$) for extrapolation of the result. Basal area ($m^2$ $ha^{-1}$) was used to determine the relative dominance of each tree, shrub, and herb species.

**Density**

$$Density = \frac{Total\ number\ of\ individuals\ of\ a\ species}{Total\ number\ of\ quadrates\ studied}$$

**Relative density (R.DEN)**

It is the study of the numerical strength of a species in a community to the total number of individuals of all the species. It is expressed as,

$$Relative\ density(\%) = \frac{Density\ of\ a\ species}{Sum\ of\ density\ of\ all\ species} \times 100$$

**Frequency (%)**

It denotes the degree of dispersion or distribution of individual species in an area and is usually expressed in terms of percentage.

$$Frequency\ (\%) = \frac{Total\ number\ of\ quadrates\ in\ which\ the\ species\ occur}{Total\ number\ of\ quadrates\ studied} \times 100$$

**Relative frequency (R.FEQ)**

Degree of dispersion of individual species in an area in relation to the number of all the species that occurred.

$$Relative\ frequency\ (\%) = \frac{frequency\ of\ a\ species}{Sum\ of\ frequency\ of\ all\ the\ species} \times 100$$

**Relative dominance (R.DOM)**

Dominance is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area. It is given by,

$$Relative\ dominance\ (\%) = \frac{Total\ Basal\ area\ of\ a\ species}{Total\ Basal\ area\ of\ all\ the\ species} \times 100$$

Finally, the Basal area of trees was calculated by using the formula:

$$Basal\ area = \frac{c^2}{4\pi}$$

Where C= Girth at breast height.

## 2. Importance Value Index (IVI)

The importance of each species in the community structure was calculated with the help of this index. The IVI of each species was calculated by summing up the Relative dominance (R.DOM), Relative density (R.DEN), and Relative frequency (R.FEQ) values following Curtis (1959) as IVI = R.DOM+ R.DEN+ R.FEQ. Species that record higher IVI values indicates that the species has a higher basal area, frequency, and density at a site or when one or two of these parameters are significantly higher than the other species (Felfili and Silva, 1993).

The abundance to frequency ratio (A/F) was calculated to determine the population distribution pattern in the study area (Curtis and Cottam, 1956). This ratio was categorized into regular, when (<0.025), random (0.025 - 0.05), and contagious (>0.05). The population structure of trees species across seven girth classes (0-5cm, 5.1-10cm, 10.1-15cm, 15.1-20cm, 20.1-25cm, 25.1-30cm, and 30.1-35cm) was also analyzed from all the three zones of the Doyang river.

## 3. Biological spectrum

Based on the plant habits (trees, shrubs, and herbs), the biological spectrum and their percentage in each community were prepared following Raunkiaer (1934) system of classification. The major classes were: (a) Phanerophytes (Ph): Tree and shrub species in which the buds are borne 0.25cm-2.00cm above ground surface; (b) Chamaephytes (Cha): Their perennating buds are situated 25 cm above ground surface; (c) Hemicryphotophytes (He): Herbaceous perennials whose aerial portion die at the end of the growing season leaving perennating bud at or just beneath the ground surface; (d) Cryptophytes (Cr): Plant buds are situated below ground surface as bulb; tuber; rhizome etc. and (e) Therophytes (Th), seed-producing plants who complete their life cycle in one year. The biological spectrum was worked out and for the categorization of species in their various life-forms, the following formula was applied.

$$Biological\ spectra = \frac{No.of\ species\ in\ a\ life\ form\ classes}{Total\ no.of\ all\ the\ species\ in\ a\ community}\ x\ 100$$

## 4. Species diversity measurement

Riparian plant species diversity from each zone of the river was determined by using the following diversity indices. Diversity indices would give a better understanding of the plant community structure and composition.

Shannon-Wiener Index (Shannon and Weiner, 1963), to analyze the species diversity. This index assumes all species in a sample are represented and are very susceptible to abundance. The abundance of certain species in a sample significantly affects the index. It typically takes values between 1 and 4.5 and values above 3 are typically interpreted as diverse (Barajas-Gea, 2005). It is expressed as,

$$H' = -\sum P_i \log(P_i)$$

Where, $P_i = n_i / N$ ($n_i$ = number of individuals of a species. N = total number of individuals of all species).

Simpson index of diversity (Simpson, 1949). It is a probability measurement that two randomly selected individuals from a sample will belong to different species and its value is directly affected by the abundance of species in a community (Whittaker, 1972). It gives relatively less weightage to rare species and more weightage to common species. A higher Simpson's value indicates a higher diversity. Its value ranges between 0-1 and the greater the value, the greater is the sample diversity.

$$D = 1 - \sum (P_i)^2$$

Where, $P_i = n_i / N$ ($n_i$ = number of individuals of a species. N = total number of individuals of a species).

The evenness index was calculated as given by Pielou (1969). Evenness measures the relative abundance of the different species that make up the richness of an area. Its value ranges between 0 and 1, with 1 indicating a complete evenness of species distribution.

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

Where S = number of species in the community.

The mean number of species present in a community is measured using Margalef's richness index (1958).

$$R = S - 1/\ln N$$

Where, N = Total number of all the individuals in the community.

The similarity between the community species composition was measured using the Sorenson Similarity Index (Sorensen, 1948). Its value also ranged between 0 and 1, the closer the value to 1, the more does the communities have in common and have low β-diversity (Magurran, 2004).

$$\text{Similarity Index} = 2C/A + B$$

Where A is the number of species in one community, B is the number of species in the other community, and C is the number of common species to both the community.

### C. Analysis of soil physicochemical parameters

Soil sampling was done from June to September 2017, when the soil moisture was almost similar across the landscape, and the soil temperature has obtained an optimum range for any microbial activity and other chemical processes. In each zone of the riparian forest i.e. upstream (S1), midstream (S2) and downstream (S8), one hectare on both the side of the river were established. Within that 100×100 $m^2$ area, after removing the plant litter, topsoil samples (0-20 cm depth) were randomly collected following a composite sampling system, with each sampling point separated by 15 m. From each zone of the riparian forest, a total of ten sub-samples (five on each side of the river) of 300 gm of the topsoil were collected and mixed to form one composite sample. The collected soil samples were then air-dried at room temperature, crushed, sieved through a 2mm sieve, and stored at room temperature in a zip lock polybag to avoid any contamination. All the physicochemical parameters of soil were analyzed using the air-dried soil samples collected from the topsoil (0-20 cm depth). Soil temperature was measured on the spot at each site with the help of a digital soil thermometer. Soil moisture content (Gravimetric method) was estimated from the collected composite sample. Soil pH was analyzed in the ratio of 1:5 (V/V) using a pH glass electrode, soil texture was mechanically analyzed using pipette method, organic carbon following Walkley and Black (1934), and soil bulk density by Core method. Total nitrogen was estimated through sulphuric acid digestion, followed by distillation and then titration

(Kjeldahal method). Available nitrogen was also estimated through distillation and titration (Anderson and Ingram, 1993). Available phosphorous was estimated using Sodium bicarbonate solution of pH 8.5 that act as an extracting agent (Olsen *et al.*, 1954) and potassium concentration using ammonium acetate (pH 7.0) as extracting solution (Jackson, 1973). A brief analysis of the various physicochemical parameters of the riparian soil is described below.

Soil temperature at each site was measured on the spot from the depth of 0-20 cm. Soil pH was measured by taking10 gm of the air-dried soil sample and then diluting it with 50 ml of distilled water. It was then continuously shaken for 30 minutes and the supernatant is finally noted using a pH meter (Systronics). For estimating the soil moisture, 50 gm of the freshly collected soil sample were weighted and kept in the oven at 105°C for 24 hrs. The moisture content of the riparian soil sample is then calculated as,

$$\text{Soil moisture content (\%)} = \frac{Weigh\quad of\ the\ oven\ dried\ soil}{Wei\qquad of\ fresh\ soil\ taken} \times 100$$

**Bulk density**: Soil bulk density was measured with the help of a soil core sampler measuring 10 x10 cm (Diameter × Height) from the depth of 0-10 cm, 10-20 cm, 20-30 cm. The soil samples from each layer were dried in the oven for 24 hrs at 105°C and then calculated by the following formula:

$$\text{Bulk density (gm/cm}^3\text{)} = \frac{Mass\ of\ the\ oven\ dry\ soil}{Volume\ ofthe\ soil\ core\ sampler}$$

**Porosity:** 25 gm of the oven-dried soil sample is taken from each layer of the soil (0-10, 10-20, 20-30 cm) and added to a half fill 100ml measuring cylinder, kept it for few seconds, and measured the rise in the volume of water after the addition of the soil particle. A similar protocol was followed for other layers and zones as well. From the values obtained, the soil particle density and porosity were calculated.

$$\text{Particle density (gm/cm}^3\text{)} = \frac{Mass\ of\ the\ dried\ soil}{Volume\ of\ soil\ solids}$$

$$\text{Soil porosity (\%)} = 1 - \frac{Bulk\ density}{Particle\ density} \text{ x } 100$$

**Soil texture**: From each layer of the oven-dried soil sample, 20 gm of the soil sample is transferred to a 500 ml graduated cylinder. A certain volume (10 ml) of distilled water is added along with 50 ml of sodium hexametaphosphate (dispersing reagent). It is then stirred continuously for 5 minutes and make up the volume to 500 ml, inverted several times to further resuspend the soil particles. After shaking, at 48 sec, 25 ml of the aliquot from the upper 10 cm is removed with the help of a pipette marked 10 cm from the tip to an evaporating dish. After about 40 min, the second 25 ml of aliquot is removed from the upper 5 cm of the suspension to an evaporating dish. All the transferred aliquot is weighed, labeled, and put in the oven at 105°C for 24 hrs. After drying, the evaporating dishes again recorded their weight and finally obtained the net difference of each aliquot. The percentage composition of clay, silt, and sand after the oven drying are calculated as follows.

Clay (%) = (20 x dry mass of the second aliquot / total mass of the soil taken) x 100

Silt (%) = (20 x [dry mass of the first aliquot – dry mass of the second aliquot] / total mass of the soil taken) x 100

Sand (%) = 100 - (silt % + clay %)

**Soil organic carbon:** 1 gm of the air-dried soil is weighted from each zone of the composite soil sample. 10 ml of $K_2Cr_2O_7$ solution and 20 ml of conc. $H_2SO_4$ was added to the soil sample and allow to react for 30 minutes. After which it is diluted with 200 ml of distilled water and 10 ml of phosphoric acid. Further, 1 ml of diphenylamine indicator (solution turns dark blue on the addition of this indicator) is added. On titration against 1N ferrous ammonium sulfate (FAS) the color changes to green (endpoint).

Calculation:

$$\text{Organic carbon (\%)} = \frac{3.951}{g} \times \left(1 - \frac{T}{S}\right)$$

Where,

g = weight of the soil sample taken

S = ml of FAS used in the blank titration

T = ml of FAS used in the sample titration

**Available phosphorus:** 5 gm of the air-dried soil sample was taken and mixed it with 50 ml of 0.5N sodium bicarbonate solution and a pinch of activated charcoal (Darco D-60). It is then continuously jiggled for 30 minutes on a mechanical shaker and filtered through Whatman No. 1 filter paper. Now, transfer 5 ml of the extracted solution into a 25 ml volumetric flask and added 5 ml of ammonium molybdate solution. After gently shaking the flask for some time, add 4 ml of freshly prepared ascorbic acid and make up the volume to 25 ml by adding distilled water. After 10 min, the aliquot is measured for their absorbance at 882 nm. For preparing the standard curve, corresponding P concentrations of 0, 0.2, 0.4, 0.6, 0.8, and 1 ppm were prepared and similar procedures were followed. The value of available phosphorus (in kg $ha^{-1}$) can be obtained from the following formula.

$$\text{P (ppm)} = \frac{GR \times 50 \times 5}{Corrected\ Ht.of\ soil}$$

Where,

GR – Concentration of P in the analyzed sample (read from std. curve)

**P (kg/ha) = P (ppm) x 2.24**

**Potassium:** 5 gm of the air-dried soil is placed in a 150 ml Erlenmeyer flask and in it, 25 ml of ammonium acetate (pH 7.0) solution is added. It is then placed in a mechanical shaker for 5 min and filtered through Whitman No. 1 filter paper. With the help of a flame photometer, each extracted sample solution is recorded after adjusting to zero with the blank. For the standard curve, 0, 0.5, 1, 2, 4, 6, 8, and 10 ppm of the working K standard solution were prepared and recorded each of the readings. The concentration of each sample was calculated by plotting against the standard curve.

$$\text{Available K (kg/ha)} = \frac{R \times volume\ of\ extract \times 2.24}{weigh\ \ of\ the\ soil\ taken}$$

Or

Available K (kg/ha) = R x 5 x 2.24 x Dilution factor (Df)

Where R is the ppm of K in the extract (obtained from the standard curve)

**Total nitrogen:** In the Kelplus – KES 20LR AL digestion System**,** 1 gm of the soil sample is digested by adding 10 ml of conc. $H_2SO_4$ and 3-4 gm of catalyst mixture (5: 1 potassium sulfate and copper sulfate). The temperature of the system is permitted to gradually surge to 420°C and allow the digestion to take place for 1 to ½ hours. After the digestion process, which is usually indicated by the development of green color, it is allowed to cool and adds 40-50 ml distilled water to undergo further distillation process.

For the distillation process, the sample tube is loaded in the distillation unit. At the receiving end, a conical flask mixed with 25 ml Boric acid and indicator is placed to collect the liquid ammonia. The color of the Boric acid changes according to the indicators used. During this process, 40% of Alkali is added to the sample tube until a dark brown color appears. The process takes place for about 9 minutes. After the completion of the process, the conical flask from the receiving end is titrated against 0.1N HCL.

Calculation:

$$\text{Nitrogen (\%)} = \frac{14.01 \times 0.1 \times (TV - B\ \ ) \times 100}{W \times 1000}$$

Where,

14.01 = Molecular weight of ammonia.

0.1N = Normality of titrating solution.

TV = titration value of soil sample.

BV = titration value of blank sample.

W = weight of the soil sample taken.

**Available nitrogen:** To estimate the percentage of available Nitrogen, the soil sample without any acid digestion undergoes a distillation process only. 5 gm of the air-dried soil sample, 20 ml of distilled water, and 25 ml of 0.32% $KMNO_4$ are added to the digestion tube, shake thoroughly, and fitted in the distillation unit. In this process, 2.5% NaOH solution is added to the sample tube until it turns dark brown. At the receiving end, 25 ml of 2.5% boric acid mixed with an indicator is placed at the recovery pipe to collect the liquid ammonia released from the distillation process. The collected distillate solution is then titrated with 0.02N $H_2SO_4$.

Calculation:

Available nitrogen (kg/ha) = $\frac{14 \times (Normality\ of\ the\ acid) \times (Titrant\ value\ of\ the\ sample) \times 2.24 \times 106}{wei \quad of t \quad soil\ sample \times 1000}$

**D. Statistical analysis**

To analyze the data of the large water quality variables obtained from the eight selected sampling stations and translation them into spatio-temporal variation, two multivariate techniques were applied: principal component analysis (PCA) and cluster analysis (CA). For this purpose, the average seasonal values of the aggregated monthly data were taken into account for each sampling station. This avoids misclassification and misinterpretation arising from different orders of magnitude of parameters that were assessed monthly. PCA was carried out by R package factoextra and FactoMiner and CA were performed using XLSTAT 2015. 5.01. 22537. To meet the PCA assumption, the data were first normalized using the scale function.

PCA was applied to identify the pattern of seasonal variation of water quality variables based on different sampling stations. PCA reduces the dimensionality of large data set into a new orthogonal, uncorrelated variable called principal components (PCs) without losing much information contained in the original data (Shaw 2003; Kowalkowski *et al*., 2006; Kumari *et al*., 2013). Each PC's generated significantly correlates to specific variables representing a different dimension of the water quality (Zhao *et al*., 2011). The first principal component (PC1) obtained in a PCA explains the most significant variation present in the original data; successive principal components (PCs) generated are ordered in a manner of decreasing percentage of variance (Vieira *et al*., 2012). The PCs with an eigenvalue equal or greater than 1 were only considered (Shrestha and Kazama, 2007) in the present study for the interpretation of the datasheet, and accordingly, the values of the factor loading were categorized into 'strong' (>0.75), 'moderate' (0.75−0.50) and 'weak' (0.50−0.30) respectively (Liu *et al*., 2003). The suitability of data for PCA was confirmed using the Kaiser-Meyer-Olkin (KMO) test (Barakat *et al*., 2016). KMO test confirms whether the data could be factorized efficiently. When the KMO index is close to 1, the PCA of the variable is suitable however if it is close to 0, the PCA is not relevant. Generally, the KMO index of greater than 0.5 is considered satisfactory for the analysis of PCA. In our analysis, the KMO had a value of 0.681 for pre-monsoon, 0.609 for the monsoon, and 0.553 for post-monsoon.

To examine the similarity and dissimilarity of composition between sampling stations (seasonally), agglomerative hierarchical clustering (AHC) analysis was employed on the normalized set of data using Ward's method, using Euclidean distances as a measure of similarity. Cluster analysis (CA) follows an unsupervised pattern of recognition aggregating a similar group of entities that describes a strong internal (within-class) homogeneity and strong external (between classes) heterogeneity (Al-Odaini *et al*., 2012). It performs in a way that objects with similar properties or characteristics are group together in a cluster. The results of CA are illustrated in the form of a dendrogram that presents each cluster and their proximity of the original reduced data (Forina *et al*., 2002). CA of water quality variables obtained from all the seasons and sampling stations was carried out to identify patterns or groups of similar stations within the studied variables (Kiani *et al*., 2016).

To quantify the plant species in each riparian zone, the species accumulation curve was performed in R with the help of Vegan package. The species accumulation curve will help in determining the adequacy of the plant survey in representing the Phyto diversity of the present study area. It will also provide information on the comparative diversity across populations and sampling sites and also the need for additional quadrat samplings. Similarly, to determine the variation of the soil variables (dependent) between the sampling sites (independent), Analysis of Variances (ANOVA/Kruskal-Wallis) (Zar, 1996) was employed. The Kruskal-Wallis test (also sometimes called one-way ANOVA) which is a rank-based nonparametric test is used when the data does not follow the normal distribution. Since the present soil data did not follow a normal distribution and had many outliers (indicated in Box plot), the ANOVA Kruskal-Wallis test was used. To study the correlation between the vegetation and the environmental variables (soil), PCA was performed in R using the R package, factoextra, and FactoMiner. For this analysis, the data were first normalized using the scale function to meet the necessary PCA assumption. The PCA biplot is then obtained for the physicochemical parameters of soil (pH, Temperature, Soil moisture-SM, Clay, Silt, Sand, Total nitrogen-TN, Available nitrogen-AN, Phosphorus-P, Potassium-K, Organic carbon-OC), and vegetation (Richness and Density) at upstream, midstream and downstream zone of the Doyang river.

# CHAPTER – 3

# SPATIO-TEMPORAL VARIATION ON PHYSICOCHEMICAL PROPERTIES OF DOYANG RIVER

## 3.1 INTRODUCTION

Out of the total water available on earth, the availability of freshwater to man is hardly 0.3-0.5% hence becomes an important commodity to use judiciously (Hedge and Kale, 1995). Preserving the quality of aquatic environments both for the benefits of human health and aquatic organisms has indeed become a major concern worldwide (Golterman *et al*., 1983; Kumar and Maiti, 2015; Banerjee *et al*., 2016). Rivers are an important source of freshwater yet its chemistry is constantly influenced by the combination of both the natural (e.g., precipitation, temperature, geology) and anthropogenic factors (e.g., agricultural practices, indiscriminate discharge of untreated sewage, industrial waste, land-use practices) (Nasehi *et al*., 2013) happening within its watershed. Human-induced activities such as effluent discharges, use of agricultural chemicals, soil erosions, and various land-use practices comprise a major factor in determining the surface water quality of rivers (Niemi *et al*., 1990). Likewise, the surface runoff during seasonal rainfall, largely affected by the climatic condition of the basin (Karbasi *et al*., 2008; Najafpour *et al*., 2008) also contributes towards the variability in the surface water of the river. The most important water quality parameters inducing water quality changes can be different from one river to another due to different environmental conditions and human activities around the river (Zeinalzadeh and Rezaei, 2017). Noticeable changes in the water quality variables may be found associated with changes in different land-use patterns along the watershed areas (Bolstad and Swank, 1997) and therefore, may be viewed as one of the main constituents altering the hydrological system and the quality of the water bodies (Changnon and Demissie, 1996).

Watershed areas that have high interspersion of various land-use types may likely degrade the water quality (Lee *et al*., 2009). The difference in variation of nutrient parameters especially Total Nitrogen and water pH were found to be associated with different land-use activities (Njue *et al*., 2016). Agriculture and build-up land use in the river basin tend to have worse water quality than the other areas (Bu *et al*., 2014; Li *et al*., 2012). The catchment area with a greater percentage of agricultural fields (Hassan *et al*., 2015) and anthropogenic activities was found to initiate deterioration of water quality. Many studies have also specified the effects of river water quality due to the presence of land use patterns in the drainage basin (Sliva and Williams, 2001; Tufford *et al*., 2003; Woli *et al*., 2004). All these suggest that is a positive relationship between the land-use practices and the water quality indicators which can then be used for the purpose of environmental protection and land use planning (Gyawali *et al*., 2013).

The changes in the uplands land-use pattern due to rapid urbanization can have a direct effect on the degradation of water quality of rivers and streams. Rapid urbanization corresponds to the rapid degradation of water quality and has a positive correlation with the declination in water quality (Ren *et al*., 2003; Hua, 2017). In contrast to other land use types, agriculture and urban lands have a strong relationship with the water quality variables (Yu *et al*., 2016), and that the size, density, aggregation, and diversity of landscape patterns were an important factor affecting the river water quality (Shi *et al*., 2017). For an effective assessment of water quality especially in an agricultural watershed, it is more reasonable to opt for a seasonal time scale rather than a larger time scale (Zhong *et al*., 2018). This avoids the weakening effect and potential risk of nutrient elements on water quality. Anthropogenic activities like logging (Ling *et al*., 2017), discharges from recreational centers, rural and agriculture (Zeinalzadeh and Rezaei, 2017) too contribute substantially to influencing the water quality. Accordingly, the variation in concentration of the water quality variables is related to the natural processes (weathering of soil and rocks), point (domestic and industrial waste-water), and non-point (agricultural activities) source of contamination (Barakat *et al*., 2016).

Along the riparian zones of the Doyang river, Wokha, Nagaland, several anthropogenic disturbances like extensive Jhum cultivation, teak plantations, urbanization, developmental activities, picnicking, use of explosives for fishing and logging and were significantly observed. This development has drawn much attention to measuring the extent of its effect on the river water quality. Besides, the presence of a Hydro-Electric Dam has also exerted much pressure on the microclimate of the area. Multivariate statistical techniques like PCA (principal component analysis) and CA (cluster analysis) were used to assess the spatial and temporal variations of the surface water quality of the Doyang river in varying seasons across the 8 sampling stations. These multivariate statistical techniques are widely accepted and have been used constantly as an effective tool to evaluate spatial and temporal variations of surface water (Phung *et al*., 2015; Kilic and Yucel, 2018; Stefanidis *et al.,* 2019; Abdollahi *et al*., 2019; Maji and Chaudhary, 2019; Yilma *et al*., 2019; Rezaali *et al*., 2019; De Souza Pereira *et al*., 2019; Mir and Gani, 2019). Imnatoshi and Ahmed (2012) worked on the geomorphology and seasonal variations of water quality in the Doyang river. Later, Lkr *et al*. (2020), worked on the Water Quality Index (WQI) of the river. However, those studies lack to provide appropriate information on the spatio-temporal variations of the water quality variables and site-specific management plans to tackle the sources of pollutants. Thus, the present study aims at identifying those water quality variables that are behind the spatial and temporal variation and to evaluate the possible sources of these water quality variables along the Doyang river.

## 3.2 RESULTS

Monthly values of all the physicochemical parameters of water quality recorded from the eight sampling stations are shown in **Appendix I**

### 3.2.1 Seasonal variation in physicochemical parameters of water

The descriptive statistics concerning the sixteen physicochemical parameters of water samples from all 8 sampling stations are presented in **Table 3.1**. All the sixteen physicochemical parameters of water quality parameters analyzed from the eight sampling stations were within the permissible limits of drinking water as given by BIS (2009), WHO (1995, 1998, 2011), and ICMR (1975), indicating it is suitable for different human purposes. **Table 3.2-3.9** shows the detailed estimated values of all the water quality parameters from the eight selected sampling stations during pre-monsoon, monsoon, and post-monsoon.

The surface water temperature (WT) of the Doyang river was recorded the highest during the monsoon season in all the stations with the maximum at S2 (29.75±0.26). During the post-monsoon, the temperature of the surface water sample was recorded the least at S1 (18.67±0.33). Interestingly, DO in the present study area was found to be considerably high in all the sampling stations all through the season. DO at S8 (11.38±0.14) recorded the maximum during pre-monsoon and the lowest was observed at S7 (7.75±0.12) during the monsoon. BOD levels showed significant variation across sampling stations and seasons. The lowest level of BOD was seen at S6 (0.88±0.10) during pre-monsoon and the highest was observed at S4 (3.34±0.08) during the monsoon. The pH of the water sample was recorded as almost neutral to alkaline. The most alkaline sample was observed at S4 (8.29±0.09) during the monsoon, while, the lowest pH value was recorded at S6 (6.75±0.05) during the post-monsoon. The concentration of free $CO_2$ had recorded almost a similar range throughout the stations and seasons. S1 (8.72±0.53) recorded the maximum concentration of free $CO_2$ during the monsoon while S3 (5.96±0.44) recorded the least during pre-monsoon. The concentration of $Cl^-$ in the present study area was recorded maximum at S1 throughout the season with the highest of 24.61 mg/l during the pre-monsoon. $Cl^-$ at S4 (14.55±0.68) recorded the least during the monsoon. The maximum electrical conductivity value was observed at S1 (271.49±0.47) during the pre-monsoon and the least was recorded during monsoon at S5 (134.28±0.27).

TDS at S1 (134.42±0.67) recorded the maximum during the pre-monsoon, while, S5 (64±0.46) recorded the lowest during monsoon. Comparatively during the pre-monsoon, TA values were found to be significantly higher in all the sampling stations with the highest value at S1 (141.25±1.67). Similarly, TH was also recorded the highest during the pre-monsoon in all the stations had recorded the maximum at S1 (111.33±0.79). The concentration of $Ca^{2+}$ at S1 (23.11±0.37) during the pre-monsoon recorded the maximum and at S4 (11.09±0.38) during monsoon noted the least. The concentration of $Mg^{2+}$ in the present study recorded moderately less in all the stations. During the pre-monsoon, $Mg^{2+}$ at S1 (13.03±0.20) recorded the maximum and at S2 (7.80±0.15) it recorded the least during the post-monsoon. The concentration of $NO_3^-$ was recorded much less in the present study. No substantial difference in the concentration of $NO_3^-$ was observed among the sampling stations. At S1 (0.84±0.02) during the post-monsoon, it recorded the highest. The concentration of $SO_4^{2-}$ remains rather consistent throughout the season across sampling stations. S1 (21.63±0.10) recorded the highest value during the pre-monsoon. $PO_4^{3-}$ in the present study was also observed to occurred comparatively less and no significant difference in its values was observed across seasons and stations. The highest $PO_4^{3-}$ concentration was reported from S6 (0.47±0.01) during monsoon and lowest from S2 (0.21±0.01) during the pre-monsoon. The presence of K in the present water sample indicated much seasonal variation having recorded the highest K concentration during the monsoon season. Its maximum value was observed during the monsoon at S8 (17.05±0.12) and lowest during the post-monsoon at S2 (4.14±0.08).

**Table 3.1:** Descriptive statistics of the observed water quality parameters with respect to eight sampling stations

| Parameters | Pre-monsoon | | | Monsoon | | | Post-monsoon | | | ICMR/ BIS/ WHO |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum | Maximum | Mean ± SD | Minimum | Maximum | Mean ± SD | Minimum | Maximum | Mean ± SD | |
| pH | 7.92 | 8.64 | 8.34 ±0.24 | 7.15 | 7.99 | 7.61 ±0.35 | 6.68 | 7.24 | 6.92 ±0.22 | 8.5 |
| WT ($^0$C) | 24.08 | 28.09 | 25.94 ±1.679 | 25.09 | 29.50 | 27.20 ±1.93 | 17.17 | 22.91 | 21.29 ±1.79 | 32 |
| Free $CO_2$ | 5.780 | 8.080 | 6.99 ±0.69 | 6.53 | 8.25 | 7.54 ±0.66 | 6.51 | 7.52 | 6.91 ±0.32 | 22 |
| $Cl^-$ | 15.98 | 24.88 | 18.58 ±2.74 | 16.57 | 19.17 | 18.16 ±1.08 | 17.40 | 20.83 | 18.74 ±1.18 | 250 |
| EC | 176.54 | 249.73 | 189.78 ±24.66 | 119.77 | 176.26 | 143.04 ±16.11 | 147.85 | 231.48 | 162.39 ±28.16 | 750 |
| TDS | 85.08 | 121.42 | 92.10 ±11.90 | 57.00 | 81.25 | 65.99 ±7.09 | 76.33 | 123.33 | 84.48 ±15.84 | 500 |
| TA | 103.34 | 128.34 | 108.60 ±8.12 | 70.00 | 100.84 | 78.86 ±9.43 | 93.34 | 144.59 | 102.83 ±17.16 | 200 |
| TH | 77.75 | 103.00 | 83.45 ±8.16 | 61.83 | 75.33 | 68.52 ±4.99 | 68.67 | 113.33 | 78.41 ±14.70 | 200 |
| $Ca^{2+}$ | 15.70 | 21.240 | 16.89 ±1.80 | 9.69 | 16.03 | 12.24 ±2.03 | 13.16 | 24.39 | 15.06 ±3.79 | 75 |
| $Mg^{2+}$ | 9.34 | 12.14 | 10.11 ±0.88 | 8.00 | 9.99 | 9.18 ±0.66 | 7.79 | 11.12 | 8.67 ±1.06 | 30 |
| DO | 9.65 | 10.44 | 9.99 ±0.34 | 8.27 | 10.41 | 9.12 ±0.80 | 8.61 | 10.59 | 9.59 ±0.84 | 5 |
| BOD | 0.93 | 3.39 | 1.84 ±0.81 | 1.40 | 3.07 | 2.10 ±0.68 | 1.57 | 2.80 | 2.20 ±0.43 | 5 |
| $NO_3^-$ | 0.54 | 0.93 | 0.68 ±0.12 | 0.40 | 0.63 | 0.51 ±0.08 | 0.74 | 0.89 | 0.82 ±0.05 | 50 |
| $SO_4^{2-}$ | 14.75 | 20.80 | 16.32 ±1.93 | 11.10 | 16.37 | 13.32 ±2.02 | 12.83 | 18.53 | 13.79 ±1.93 | 200 |
| $PO_4^{3-}$ | 0.22 | 0.39 | 0.29 ±0.06 | 0.25 | 0.47 | 0.36 ±0.10 | 0.21 | 0.26 | 0.23 ±0.01 | 0.5 |
| K | 7.59 | 14.74 | 9.63 ±2.35 | 8.97 | 14.99 | 11.84 ±2.45 | 2.88 | 5.10 | 4.14 ±0.80 | 200 |

All the parameters are in milligrams per litre except for *p*H, WT($^0$C), and EC (µS/cm)

**Table 3.2:** Estimated water quality parameters during different seasons at sampling station 1 (S1)

| Parameters | Pre-monsoon | Monsoon | Post-monsoon | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| pH | 8.21 ±0.12 | 7.74 ±0.07 | 7.14 ±0.08 | 8.5 |
| WT ($^0$C) | 22.50 ±0.39 | 25.83 ±0.32 | 18.67 ±0.33 | 32 |
| Free $CO_2$ | 7.43 ±0.51 | 8.72 ±0.53 | 7.24 ±0.57 | 22 |
| $Cl^-$ | 24.61 ±0.75 | 17.43 ±0.46 | 22.72 ±0.80 | 250 |
| EC | 271.49 ±0.47 | 171.23 ±0.21 | 214.74 ±0.40 | 750 |
| TDS | 134.42 ±0.67 | 80.09 ±0.47 | 111.50 ±0.70 | 500 |
| TA | 141.25 ±1.67 | 100.84 ±1.67 | 131.67 ±1.67 | 200 |
| TH | 111.33 ±0.79 | 76 ±0.91 | 97.50 ±0.91 | 200 |
| $Ca^{2+}$ | 23.11 ±0.37 | 16.10 ±0.38 | 22.45 ±0.43 | 75 |
| $Mg^{2+}$ | 13.03 ±0.20 | 8.66 ±0.19 | 10.13 ±0.17 | 30 |
| DO | 10.39 ±0.15 | 9.33 ±0.16 | 9.68 ±0.12 | 5 |
| BOD | 1.91 ±0.05 | 1.66 ±0.07 | 2.40 ±0.09 | 5 |
| $NO_3^-$ | 0.81 ±0.02 | 0.71 ±0.03 | 0.84 ±0.02 | 50 |
| $SO_4^{2-}$ | 21.63 ±0.10 | 16.03 ±0.05 | 18.05 ±0.07 | 200 |
| $PO_4^{3-}$ | 0.24 ±0.01 | 0.46 ±0.01 | 0.29 ±0.24 | 0.5 |
| K | 9.94 ±0.15 | 13.26 ±0.31 | 4.63 ±0.09 | 200 |

All the parameters are in milligrams per litre except for pH, WT ($^0$C), and EC (µS/cm)

**Table 3.3:** Estimated water quality parameters during different seasons at sampling station 2 (S2)

| Parameters | Pre-monsoon Mean ± SD | Monsoon Mean ± SD | Post-monsoon Mean ± SD | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| pH | 7.86 ±0.09 | 7.83 ±0.09 | 7.12 ±0.05 | 8.5 |
| WT ($^0C$) | 23.92 ±0.39 | 28.59 ±0.26 | 22.93 ±0.39 | 32 |
| Free $CO_2$ | 6.88 ±0.44 | 6.97 ±0.95 | 7.70 ±0.64 | 22 |
| $Cl^-$ | 19.88 ±0.65 | 17.51 ±0.68 | 18.58 ±0.65 | 250 |
| EC | 194.26 ±0.40 | 148.37 ±0.24 | 145.71 ±0.27 | 750 |
| TDS | 97.92 ±0.80 | 69 ±0.42 | 74.67 ±0.52 | 500 |
| TA | 110.42 ±1.67 | 78.75 ±1.67 | 89.17 ±1.67 | 200 |
| TH | 86.33 ±0.79 | 72.34 ±0.79 | 66.17 ±0.79 | 200 |
| $Ca^{2+}$ | 17.17 ±0.32 | 12.69 ±0.27 | 13.63 ±0.27 | 75 |
| $Mg^{2+}$ | 10.52 ±0.12 | 9.99 ±0.19 | 7.80 ±0.15 | 30 |
| DO | 10.05 ±0.33 | 9.78 ±0.14 | 8.79 ±0.10 | 5 |
| BOD | 2.96 ±0.10 | 3.24 ±0.10 | 3.02 ±0.10 | 5 |
| $NO_3^-$ | 0.61 ±0.02 | 0.73 ±0.02 | 0.79 ±0.02 | 50 |
| $SO_4^{2-}$ | 16.94 ±0.10 | 13.53 ±0.05 | 11.27 ±0.07 | 200 |
| $PO_4^{3-}$ | 0.21 ±0.01 | 0.31 ±0.02 | 0.23 ±0.21 | 0.5 |
| K | 7.05 ±0.08 | 11.07 ±0.07 | 4.14 ±0.08 | 200 |

All the parameters are in milligrams per litre except for pH, WT ($^0C$), and EC (µS/cm)

**Table 3.4:** Estimated water quality parameters during different seasons at sampling station 3 (S3)

| Parameters | Pre-monsoon Mean ± SD | Monsoon Mean ± SD | Post-monsoon Mean ± SD | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| pH | 8.10 ±0.07 | 8.11 ±0.04 | 6.87 ±0.05 | 8.5 |
| WT ($^0$C) | 25.50 ±0.46 | 29.59 ±0.33 | 23.83 ±0.33 | 32 |
| Free $CO_2$ | 5.96 ±0.44 | 7.52 ±0.57 | 7.06 ±0.46 | 22 |
| $Cl^-$ | 18.68 ±0.73 | 15.98 ±0.65 | 18.46 ±0.56 | 250 |
| EC | 176.53 ±0.45 | 153.01 ±0.20 | 143.97 ±0.23 | 750 |
| TDS | 89.25 ±0.82 | 70.42 ±0.33 | 72 ±0.39 | 500 |
| TA | 107.59 ±1.67 | 77.50 ±1.67 | 92.92 ±1.67 | 200 |
| TH | 79 ±1.24 | 71.17 ±0.96 | 65.17 ±0.84 | 200 |
| $Ca^{2+}$ | 15.98 ±0.46 | 12.52 ±0.40 | 13.03 ±0.45 | 75 |
| $Mg^{2+}$ | 9.50 ±0.26 | 9.66 ±0.16 | 7.92 ±0.19 | 30 |
| DO | 10.09 ±0.12 | 9.38 ±0.19 | 8.79 ±0.10 | 5 |
| BOD | 2.07 ±0.07 | 2.84 ±0.09 | 2.18 ±0.07 | 5 |
| $NO_3^-$ | 0.59 ±0.01 | 0.59 ±0.02 | 0.70 ±0.02 | 50 |
| $SO_4^{2-}$ | 15.98 ±0.06 | 12.92 ±0.04 | 10.89 ±0.04 | 200 |
| $PO_4^{3-}$ | 0.22 ±0.01 | 0.27 ±0.01 | 0.23 ±0.22 | 0.5 |
| K | 6.37 ±0.09 | 10.92 ±0.11 | 5.14 ±0.08 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0$C), and EC (µS/cm)

**Table 3.5:** Estimated water quality parameters during different seasons at sampling station 4 (S4)

| Parameters | Pre-monsoon Mean ± SD | Monsoon Mean ± SD | Post-monsoon Mean ± SD | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| pH | 8.08 ±0.06 | 8.29 ±0.09 | 6.86 ±0.05 | 8.5 |
| WT ($^0$C) | 25.17 ±0.50 | 29.75 ±0.26 | 23.91 ±0.33 | 32 |
| Free $CO_2$ | 6.05 ±0.44 | 7.08 ±0.55 | 7.15 ±0.37 | 22 |
| $Cl^-$ | 19.41 ±0.65 | 14.55 ±0.68 | 19.17 ±0.65 | 250 |
| EC | 175.91 ±0.43 | 144.03 ±0.22 | 140.23 ±0.23 | 750 |
| TDS | 86.75 ±0.56 | 67 ±0.68 | 71.50 ±0.33 | 500 |
| TA | 107.50 ±1.67 | 83.75 ±1.67 | 87.09 ±1.67 | 200 |
| TH | 77.67 ±0.91 | 70.33 ±0.83 | 63.50 ±0.79 | 200 |
| $Ca^{2+}$ | 15.57 ±0.39 | 11.09 ±0.38 | 12.43 ±0.40 | 75 |
| $Mg^{2+}$ | 9.54 ±0.16 | 10.08 ±0.32 | 7.92 ±0.27 | 30 |
| DO | 10.20 ±0.10 | 10.61 ±0.13 | 8.64 ±0.10 | 5 |
| BOD | 1.38 ±0.10 | 3.34 ±0.08 | 1.72 ±0.07 | 5 |
| $NO_3^-$ | 0.56 ±0.01 | 0.49 ±0.02 | 0.63 ±0.02 | 50 |
| $SO_4^{2-}$ | 15.66 ±0.04 | 12.80 ±0.04 | 10.75 ±0.04 | 200 |
| $PO_4^{3-}$ | 0.23 ±0.01 | 0.25 ±0.01 | 0.22 ±0.23 | 0.5 |
| K | 6.10 ±0.09 | 9.47 ±0.12 | 5.07 ±0.08 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0$C), and EC (µS/cm)

**Table 3.6:** Estimated water quality parameters during different seasons at sampling station 5 (S5)

| Parameters | Pre-monsoon Mean ± SD | Monsoon Mean ± SD | Post-monsoon Mean ± SD | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| pH | 8.13 ±0.06 | 8.22 ±0.08 | 6.85 ±0.06 | 8.5 |
| WT ($^0$C) | 25.92 ±0.46 | 29.59 ±0.26 | 24.01 ±0.33 | 32 |
| Free $CO_2$ | 6.24 ±0.44 | 7.33 ±0.62 | 6.69 ±0.44 | 22 |
| $Cl^-$ | 18.23 ±0.71 | 16.80 ±0.80 | 18.70 ±0.59 | 250 |
| EC | 171.32 ±0.35 | 134.28 ±0.27 | 139.42 ±0.31 | 750 |
| TDS | 86.42 ±0.59 | 64 ±0.46 | 70.84 ±0.33 | 500 |
| TA | 104.17 ±1.67 | 79.59 ±1.67 | 87.92 ±1.67 | 200 |
| TH | 76.67 ±0.91 | 67.17 ±0.67 | 63.84 ±0.91 | 200 |
| $Ca^{2+}$ | 15.70 ±0.48 | 11.15 ±0.27 | 12.49 ±0.34 | 75 |
| $Mg^{2+}$ | 9.30 ±0.20 | 9.58 ±0.19 | 7.88 ±0.25 | 30 |
| DO | 10.02 ±0.12 | 10.12 ±0.13 | 8.26 ±0.11 | 5 |
| BOD | 1.39 ±0.07 | 2.63 ±0.13 | 1.78 ±0.10 | 5 |
| $NO_3^-$ | 0.66 ±0.02 | 0.60 ±0.01 | 0.63 ±0.02 | 50 |
| $SO_4^{2-}$ | 15.56 ±0.04 | 12.42 ±0.03 | 10.72 ±0.04 | 200 |
| $PO_4^{3-}$ | 0.24 ±0.01 | 0.29 ±0.01 | 0.25 ±0.24 | 0.5 |
| K | 6.48 ±0.12 | 11.11 ±0.12 | 5.89 ±0.08 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0$C), and EC (µS/cm)

**Table 3.7:** Estimated water quality parameters during different seasons at sampling station 6 (S6)

| Parameters | Pre-monsoon | Monsoon | Post-monsoon | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| pH | 8.17 ±0.07 | 7.56 ±0.06 | 6.75 ±0.05 | 8.5 |
| WT ($^0$C) | 22.50 ±0.52 | 26 ±0.26 | 22.58 ±0.39 | 32 |
| Free $CO_2$ | 7.15 ±0.44 | 7.89 ±0.52 | 7.33 ±0.44 | 22 |
| $Cl^-$ | 17.28 ±0.68 | 15.74 ±0.47 | 19.76 ±0.89 | 250 |
| EC | 172.77 ±0.41 | 153.76 ±0.22 | 154.56 ±0.26 | 750 |
| TDS | 84 ±0.46 | 70.31 ±0.47 | 78.25 ±0.48 | 500 |
| TA | 107.5 ±1.67 | 77.92 ±1.67 | 91.25 ±1.98 | 200 |
| TH | 77 ±0.91 | 68.67 ±0.67 | 68.67 ±0.79 | 200 |
| $Ca^{2+}$ | 15.36 ±0.38 | 13.23 ±0.32 | 13.50 ±0.38 | 75 |
| $Mg^{2+}$ | 9.44 ±0.21 | 8.73 ±0.33 | 8.53 ±0.12 | 30 |
| DO | 11.32 ±0.15 | 7.85 ±0.11 | 9.24 ±0.12 | 5 |
| BOD | 0.88 ±0.10 | 1.22 ±0.10 | 2.67 ±0.07 | 5 |
| $NO_3^-$ | 0.72 ±0.01 | 0.83 ±0.02 | 0.71 ±0.01 | 50 |
| $SO_4^{2-}$ | 16.03 ±0.03 | 16.94 ±0.03 | 12.04 ±0.04 | 200 |
| $PO_4^{3-}$ | 0.26 ±0.01 | 0.47 ±0.01 | 0.29 ±0.26 | 0.5 |
| K | 6.17 ±0.12 | 16.82 ±0.11 | 6.72 ±0.08 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0$C), and EC (µS/cm)

**Table 3.8:** Estimated water quality parameters during different seasons at sampling station 7 (S7)

| Parameters | Pre-monsoon | Monsoon | Post-monsoon | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| pH | 8.06 ±0.06 | 7.41 ±0.04 | 6.99 ±0.05 | 8.5 |
| WT ($^0C$) | 23.83 ±0.46 | 26.17 ±0.39 | 23.74 ±0.33 | 32 |
| Free $CO_2$ | 6.42 ±0.51 | 8.44 ±0.66 | 7.33 ±0.44 | 22 |
| $Cl^-$ | 16.69 ±0.47 | 16.21 ±0.67 | 20.95 ±0.77 | 250 |
| EC | 173.43 ±0.32 | 154.14 ±0.27 | 151.09 ±0.28 | 750 |
| TDS | 87.17 ±0.56 | 70.83 ±0.53 | 77.58 ±0.46 | 500 |
| TA | 104.58 ±1.25 | 81.25 ±1.67 | 92.5 ±1.67 | 200 |
| TH | 74.92 ±0.79 | 79.34 ±0.67 | 67.67 ±0.79 | 200 |
| $Ca^{2+}$ | 15.50 ±0.34 | 13.76 ±0.32 | 13.63 ±0.43 | 75 |
| $Mg^{2+}$ | 8.97 ±0.26 | 10.88 ±0.16 | 8.24 ±0.22 | 30 |
| DO | 10.99 ±0.11 | 7.75 ±0.12 | 9.40 ±0.10 | 5 |
| BOD | 1.29 ±0.08 | 1.28 ±0.05 | 2.20 ±0.08 | 5 |
| $NO_3^-$ | 0.63 ±0.01 | 0.60 ±0.02 | 0.76 ±0.01 | 50 |
| $SO_4^{2-}$ | 16.02 ±0.05 | 16.25 ±0.03 | 11.86 ±0.07 | 200 |
| $PO_4^{3-}$ | 0.35 ±0.01 | 0.44 ±0.01 | 0.28 ±0.35 | 0.5 |
| K | 6.65 ±0.09 | 16.93 ±0.15 | 5.47 ±0.09 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0C$), and EC (µS/cm)

**Table 3.9:** Estimated water quality parameters during different seasons at sampling station 8 (S8)

| Parameters | Pre-monsoon | Monsoon | Post-monsoon | ICMR/ BIS/ WHO |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | Mean ± SD | |
| pH | 8.14 ±0.08 | 7.57 ±0.04 | 6.89 ±0.05 | 8.5 |
| WT ($^0$C) | 23 ±0.39 | 25.59 ±0.26 | 22.34 ±0.46 | 32 |
| Free $CO_2$ | 6.33 ±0.44 | 7.88 ±0.53 | 6.78 ±0.53 | 22 |
| $Cl^-$ | 17.75 ±0.47 | 17.04 ±0.47 | 21.77 ±0.56 | 250 |
| EC | 173.64 ±0.35 | 153.16 ±0.28 | 150.65 ±0.24 | 750 |
| TDS | 85.67 ±0.52 | 71.17 ±0.33 | 77 ±0.39 | 500 |
| TA | 105.42 ±1.67 | 83.34 ±1.67 | 98.34 ±1.67 | 200 |
| TH | 76.17 ±0.79 | 75.17 ±0.91 | 69.50 ±0.67 | 200 |
| $Ca^{2+}$ | 15.90 ±0.25 | 13.36 ±0.32 | 14.17 ±0.34 | 75 |
| $Mg^{2+}$ | 8.89 ±0.35 | 10.15 ±0.12 | 8.36 ±0.20 | 30 |
| DO | 11.38 ±0.14 | 8.14 ±0.17 | 9.40 ±0.13 | 5 |
| BOD | 1.58 ±0.07 | 1.22 ±0.12 | 2.36 ±0.09 | 5 |
| $NO_3^-$ | 0.62 ±0.01 | 0.57 ±0.02 | 0.69 ±0.02 | 50 |
| $SO_4^{2-}$ | 15.45 ±0.04 | 15.90 ±0.04 | 11.79 ±0.04 | 200 |
| $PO_4^{3-}$ | 0.34 ±0.01 | 0.44 ±0.01 | 0.30 ±0.34 | 0.5 |
| K | 7.25 ±0.49 | 17.05 ±0.12 | 5.30 ±0.09 | 200 |

All the parameters are in milligrams per litre except for $p^H$, WT ($^0$C), and EC (µS/cm)

### 3.2.2 Principal component analysis (PCA) of water quality variables

To identify the relationship between the water quality variables and the monitoring stations, PCA was executed on the 16 parameters of water quality from eight selected sampling stations corresponding to different sampling seasons viz., pre-monsoon, monsoon, and post-monsoon. **Table 3. 10** shows the result of PCA loading for the three seasons. The present study ascertains 3 PCs each for pre-monsoon, monsoon, and post-monsoon that explains 94.75%, 93.63%, and 93.91% of the total variance of information contained in the original data set. The rest of the factors accounted for only small percentages of the total variance and had very low correlation coefficients therefore sidelined. PC1 of pre-monsoon accounted for 63.13%, monsoon 63.05%, and post-monsoon 62.53% of the overall data variability. **Fig. 3.1** shows the comprehensive expression of **Table 3.10** indicating the correlation between variables and their relative significance towards eight sampling stations in three different seasons. According to the statistical loading and score of each water variables (**Table 3.10**), the first factor (PC1) of pre-monsoon accounts for 63.13% of the total variance, which showed a strong positive score of $CO_2$, $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$ and K as well as a moderate negative score of DO. The second factor (PC2) with over 22.86% total variance provided a strong positive score of WT and a moderate positive score of pH, DO, and BOD; a strong and moderate negative score of $PO_4^{3-}$ and $CO_2$. The third factor (PC3) showed a moderate positive score towards pH accounting for 8.75% of the total variance. In monsoon, PC1 presented strong positive loading of $CO_2$, TDS, EC, TH, $Ca^{2+}$, $NO_3^-$, $SO_4^{2-}$, and $PO_4^{3-}$ as well as moderate positive loading of $Cl^-$, TA, and K contributing 63.05% of the total variance. It also recorded a strongly negative score of pH, WT, BOD, and a moderate negative score of DO. Next, PC2 got two variables, namely pH and DO that showed a moderate positive score contributing 19.21 % of the total variance while in PC3 a strong and moderate positive score was noted in $Mg^{2+}$, and $Cl^-$. Finally, in post-monsoon PC1 accounted for over 62.53% of the total variance with a strong positive loading of pH, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, and $SO_4^{2-}$ while moderate loading of $Cl^-$, DO, and BOD. It also observed a strong and moderate negative score of WT and K. The second factor (PC2) explaining 19.14% of the total variance obtained a strong positive and negative score of $PO_4^{3-}$ and $CO_2$ while a moderate positive score of K. PC3 had 12.24% of the total variance showing a strong positive loading of $NO_3^-$.

**Table 3.10:** Principal component loading of the whole data sets for pre-monsoon, monsoon and post monsoon

| Parameters | Pre-monsoon | | | Monsoon | | | Post-monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 |
| pH | -0.281 | 0.597 | 0.741 | -0.802 | 0.558 | -0.110 | 0.760 | 0.437 | 0.341 |
| WT | -0.449 | 0.798 | -0.082 | -0.955 | 0.177 | -0.097 | -0.938 | 0.212 | 0.027 |
| $CO_2$ | 0.752 | -0.546 | 0.092 | 0.886 | -0.159 | -0.097 | 0.205 | -0.903 | 0.285 |
| $Cl^-$ | 0.925 | 0.294 | -0.045 | 0.619 | 0.301 | 0.635 | 0.696 | 0.317 | -0.540 |
| TDS | 0.951 | 0.273 | -0.044 | 0.823 | 0.553 | -0.104 | 0.987 | -0.001 | -0.113 |
| EC | 0.970 | 0.222 | 0.012 | 0.835 | 0.518 | -0.112 | 0.982 | 0.001 | -0.124 |
| TA | 0.937 | 0.305 | 0.148 | 0.664 | 0.679 | -0.112 | 0.964 | 0.077 | -0.230 |
| TH | 0.933 | 0.340 | 0.034 | 0.757 | 0.427 | 0.476 | 0.957 | -0.223 | 0.019 |
| $Ca^{2+}$ | 0.951 | 0.257 | 0.015 | 0.931 | 0.345 | -0.052 | 0.979 | -0.044 | -0.170 |
| $Mg^{2+}$ | 0.884 | 0.411 | 0.122 | -0.330 | 0.157 | 0.922 | 0.983 | 0.071 | 0.113 |
| DO | -0.614 | 0.626 | 0.376 | -0.694 | 0.633 | -0.109 | 0.628 | 0.686 | 0.211 |
| BOD | -0.036 | 0.610 | -0.784 | -0.851 | 0.402 | 0.001 | 0.732 | 0.013 | 0.593 |
| $NO_3^-$ | 0.922 | -0.080 | -0.060 | 0.794 | 0.107 | -0.466 | 0.045 | 0.131 | 0.963 |
| $SO_4^{2-}$ | 0.985 | -0.086 | 0.052 | 0.981 | -0.004 | -0.081 | 0.986 | -0.052 | -0.096 |
| $PO_4^{3-}$ | 0.193 | -0.921 | 0.168 | 0.943 | -0.230 | 0.037 | -0.008 | 0.937 | 0.068 |
| K | 0.942 | -0.296 | 0.059 | 0.559 | -0.793 | 0.175 | -0.639 | 0.692 | -0.095 |
| Eigenvalue | 10.101 | 3.658 | 1.401 | 10.089 | 3.074 | 1.817 | 10.005 | 3.062 | 1.958 |
| Variability (%) | 63.133 | 22.863 | 8.754 | 63.054 | 19.214 | 11.357 | 62.533 | 19.135 | 12.239 |
| Cumulative % | 63.133 | 85.996 | 94.750 | 63.054 | 82.269 | 93.625 | 62.533 | 81.669 | 93.908 |

### 3.2.3 Cluster analysis (CA) of the eight sampling stations

CA was employed to determine the correspondence of sampling stations of the monitored study area. The dendrogram showed monitoring stations grouped into four distinct clusters during pre-monsoon and post-monsoon while into three clusters in monsoon. **Fig. 3.2** shows the result of the cluster analysis of the eight sampling stations based on 16 water quality variables throughout different seasons. The result of cluster analysis identified the spatial and temporal similarities between the sampling stations during pre-monsoon, monsoon, and post-monsoon. The stations in each group or cluster represent similar water characteristics and composition of contamination types. Throughout the seasons, cluster 1 comprised of the only S1. This parallel observation depicts that the upstream station (S1) has a discrete characteristic of water quality compared to that of other sampling stations.

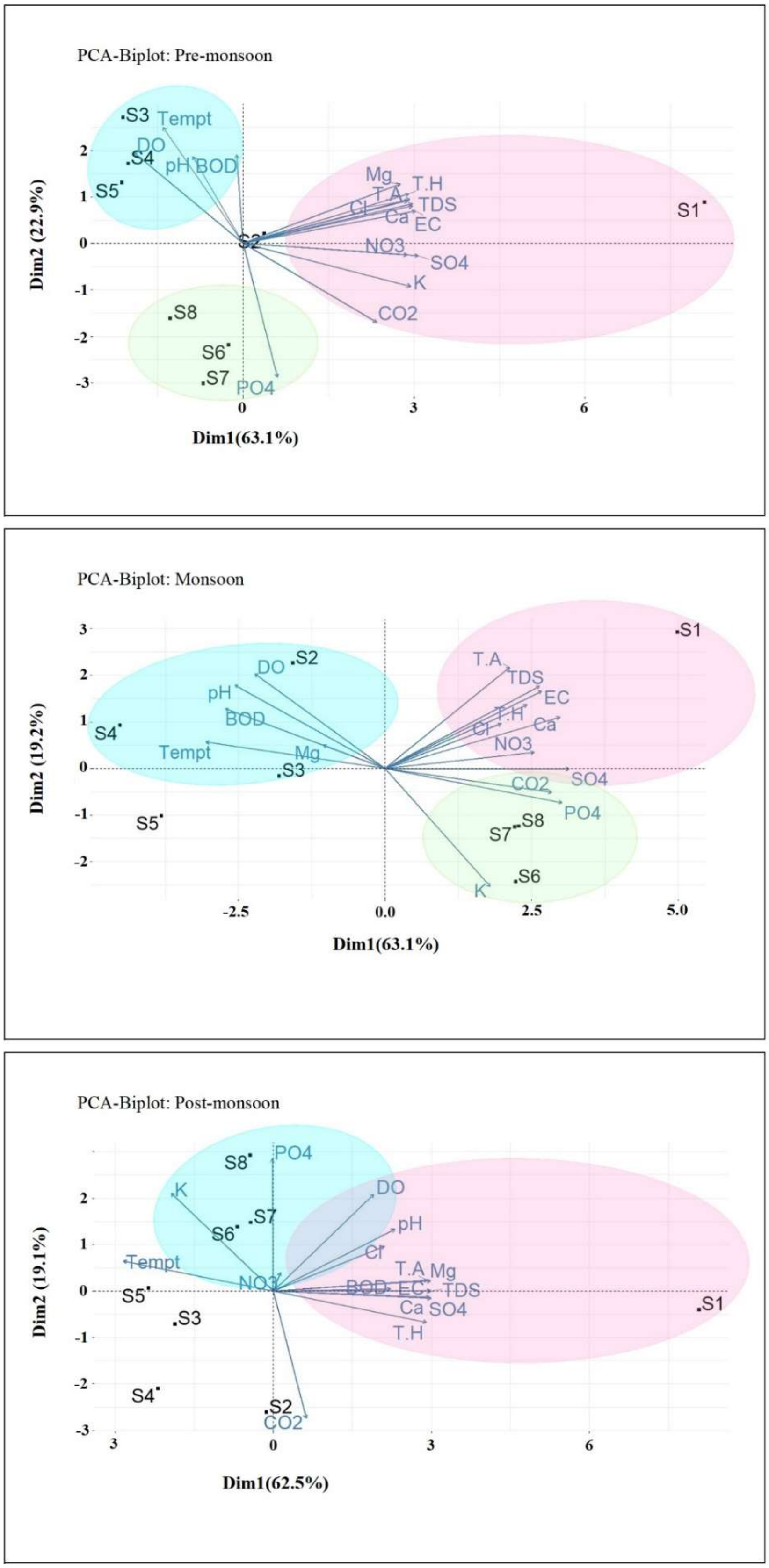
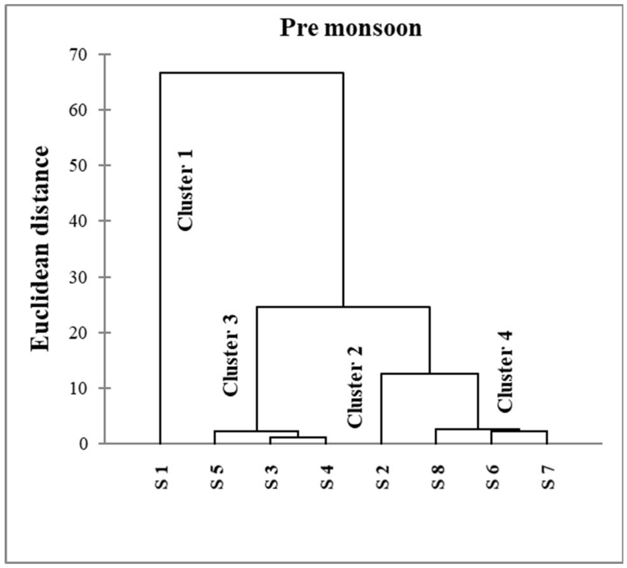
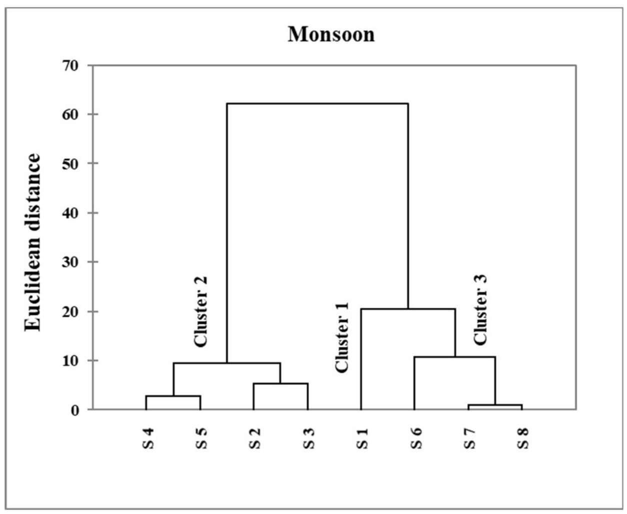


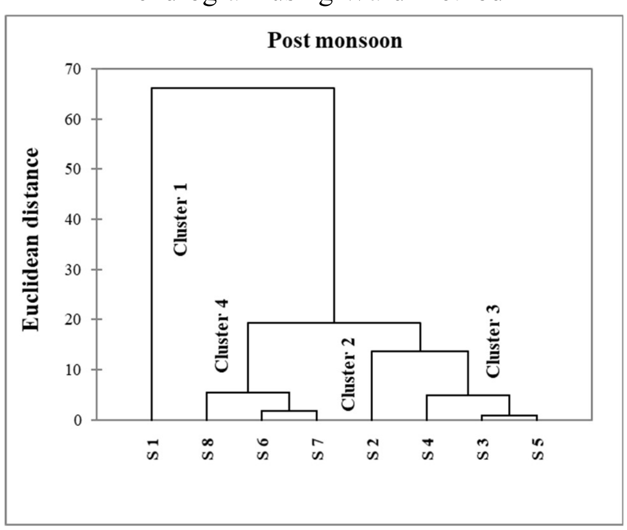

**Fig. 3.1:** Principal component analysis (PCA) of 16 water quality parameters related to 8 different sampling stations during pre-monsoon, monsoon and post-monsoon in Doyang River




Dendrogram using Ward Method A




Dendrogram using Ward Method B




Dendrogram using Ward Method C

**Fig. 3.2:** Dendrogram showing clustering of sampling stations based on 16 water quality variables during pre-monsoon (A), monsoon (B), and post monsoon (C)

## 3.3 DISCUSSION

### 3.3.1 pH

The pH of water measures whether it is acidic or alkaline in nature. The pH of water serves as an important index of water quality and accordingly determines the suitability of water for various purposes. The common range of pH in natural water lies within 6-8 (Thakre *et al*., 2010). In the present experimental water body, a similar range of pH values was also observed as it recorded approximately neutral or alkaline (Bouslah *et al*., 2017). The higher values of pH recorded during the pre-monsoon in all the stations may be attributed to the increase in photosynthetic activity of dissolved inorganic carbon by planktons (Iqbal *et al*., 2004). Another reason for the high value of pH during the monsoon especially at the midstream stations (S2, S3, S4, and S5) possibly have resulted from the runoff from the surrounding areas during rainfall (Singh *et al*., 2013).

### 3.3.2 Water temperature

Factors such as the condition of the weather, time of sampling, and location of the sampling stations can have a profound impact on the water temperature, and accordingly, it affects the dissolved oxygen percentage, biological activities, and other water quality parameters (Shuhaimi-Othman *et al*., 2007). In the present study, the potential difference in surface water temperature among the sampling stations may be due to differences in the timing of measurement on the spot. However, the higher values recorded at S2, S3, S4, and S5 throughout the season may be due to the presence of Hydro Electric Dam which has ultimately altered the climatic condition of the area. It is important to note that temperature can exert a strong influence on many of the physical and chemical properties of water including the solubility of oxygen and other gases, microbial activity, and remarkably the rate of chemical reaction and toxicity (Duffus, 1980).

### 3.3.3 Free $CO_2$

The presence of carbon dioxide in a water body may have resulted from atmospheric deposition, biotic respiration, and bacterial decomposition of organic matter. It may also be derived from within the water body in combination with other substances mainly calcium, magnesium, etc. The degradation of organic carbon in almost all aquatic environments has resulted in carbon dioxide as the end product and its variation is often viewed as a measure of net ecosystem metabolism (Wetzel, 2006). In the present study, no considerable difference in the $CO_2$ values was observed between the sampling stations and seasons. However, the higher mean values (7.54±0.66 mg/l) recorded during the monsoon could be related to the high rate of decomposition in the warmer seasons.

### 3.3.4 Chloride ($Cl^-$)

In all types of water, chloride occurs naturally due to its high solubility, yet, its main sources are the run-off of inorganic fertilizers from agricultural fields, sewage, etc. Chloride content in the present water sample was well within the permissible levels of 250 mg/l. At S1 (upstream), the concentration of $Cl^-$ continues to report higher throughout the season. This may be attributed to sewage discharge and runoff from developmental activities. In natural freshwaters, its concentration usually remains quite low and is generally less than that of sulfates and bicarbonates. Therefore, the chloride concentration serves as an indicator of pollution. Hasalam (1991) also reported that the discharge of sewage water and industrial effluent rich in $Cl^-$ could potentially result in high chloride levels in freshwater.

### 3.3.5 Electrical conductivity (EC)

EC gives an indirect measurement of total dissolved salts present in the water sample. Higher EC values indicate a higher amount of dissolved inorganic substances in their ionized form. The presence of these salts in the water sample greatly affects the taste and acceptance of the water as potable to the users (Pradeep, 1998). S1 experienced the maximum EC irrespective of seasons. This may be due to maximum disturbances in the riparian zones of S1 leading to maximum dissolving of inorganic substances. Conductivity of most freshwater ranges from 10 to 1000 $\mu$S/cm, but it can exceed well above 1000 $\mu$S/cm where pollution is present (Harun *et al*., 2010). The present study's EC values were all found to be within the permissible limits (750 $\mu$S/cm).

### 3.3.6 Total dissolved solids (TDS)

TDS measures the dissolved particle present in the water sample and it designates the general nature of water quality or saltiness. It represents the combined content of all inorganic and organic substances in a water sample. Factors such as the geological character of the watershed, rainfall, and amount of surface runoffs greatly determine the TDS and eventually indicate the degree of dissolved substances (Driche *et al*., 2008; Siebert, 2010). Maximum TDS observed at S1 in all the seasons also points to the maximum disturbances leading to the greater dissolution of organic and inorganic substances in the water sample. The lesser mean value observed during the monsoon in all the stations is due to the dilution caused by rainfall. However, the values recorded were all under the desirable limits of 500 mg/l (BIS). Normally, soil erosion is considered the source of suspended solids caused by human activities from the surrounding areas. Higher TDS in the water system can drastically increase the demand for chemical and biological oxygen, and result in the depletion of dissolved oxygen in the water.

### 3.3.7 Total alkalinity (TA)

Total Alkalinity is the measure of the capacity of water to neutralize acids and they increase as the dissolved carbonates and bicarbonates also increase (Smitha *et al*., 2007). In the present study, a significant decrease in TA values was observed during the monsoon in all the sampling stations. This may be attributed to the influx of fresh water during the rainy season into the river system causing dilution (Chatterjee and Raziuddin, 2002). The TA values recorded from all the stations irrespective of the season were well within the permissible limits (200 mg/l).

### 3.3.8 Total hardness (TH)

TH in natural water occurs mainly due to the dissolved calcium and magnesium ions (Ikomi and Emuh, 2000); other divalent cations from the surrounding rocks of the water body also contribute towards its concentration. The higher values recorded during the pre-monsoon may be related to the runoff of dissolved particles from the soil. S1 recorded the maximum value throughout the season. This may be related to the disturbances due to developmental activities at S1. According to some sources, water having hardness up to 75 mg/l is classified as soft, 76-150 mg/l as moderately soft, 151-300 mg/l as hard, and more than 300 mg/l as very hard (Saravanakumar and Kumar, 2011). Based on this, the surface water sample of the Doyang river may be classified as moderately soft.

### 3.3.9 Calcium ($Ca^{2+}$)

The basic source of calcium in natural water comes from carbonate rocks (limestone and dolomites) that are broken down by carbonic acid present in water. No substantial difference in the concentration of calcium was observed among the sampling stations. However, the maximum concentration at S1 throughout the season may be related to domestic waste (Devi *et al*., 2015). During the monsoon (12.24±2.03 mg/l), however, the average mean of calcium was found to be comparatively less, probably due to dilution.

### 3.3.10 Magnesium ($Mg^{2+}$)

In the natural water, the presence of magnesium may be credited to the chemistry of the river bed-rock geological composition. The concentration of magnesium was recorded comparatively lesser than that of calcium and observed no substantial difference among the sampling stations and seasons studied. Nevertheless, the higher value recorded at S1 may be due to the greater dissolution processes as a result of disturbances in the riparian areas due to developmental activities.

### 3.3.11 Dissolved Oxygen (DO)

The amount of oxygen dissolved in a water sample indicates the DO measurement of the given water sample. The measurement of DO is a direct indicator of water quality and is considered as one of the best indicators to assess the health of a water body (Edmondson, 1965). In a healthy water body that ensures good water quality, DO must be > 4 mg/l (Prasad and Bose, 2001). In a system where rates of respiration and organic decomposition are high, DO are recorded usually low than those where the rate of photosynthesis is high (Mishra *et al*., 2009). In the present study, DO was recorded significantly high in all the sampling stations throughout the study period. This may be related to the turbulent nature of the water bodies and photosynthesis (Bouslah *et al*., 2017). Despite the higher values of DO in all the stations, the comparatively lesser values noted at S6, S7, S8 during the monsoon is related to the higher input of organic matter during rainfall. This causes more dissolved oxygen to be rapidly consumed in the biological aerobic decay thereby affecting the water quality. This decreased in the level of dissolved oxygen in water ultimately affects aquatic lives (Chhatwal, 2011).

### 3.3.12 Biological Oxygen Demand (BOD)

BOD indicates organic loads in the water bodies and is taken as a pollution index especially for water bodies that are receiving organic effluent (Ndimele, 2012). Higher the BOD value, the higher is the level of organic pollution (Patel *et al*., 1983). Low BOD level indicates lesser organic pollution and good quality water status. There exists a nexus between the BOD and DO i.e. when the BOD level increases, the DO level automatically decreases due to the consumption of available oxygen in the water by the bacteria (Agarwal and Rajwar, 2010). BOD in the present study showed much fluctuation between sites and season. This may be due to the difference in the inputs of organic matter from site-specific disturbance. The higher values of BOD recorded at S2 and S4 during the monsoon could be due to the high inputs of organic matter from surrounding land-use practices. However, the low level of BOD recorded in the present study area indicates a comparatively lesser organic matter content in the water sample to be oxidized by the microorganisms (Singh *et al*., 2016) and also higher algal productivity (Clair, 2003).

### 3.3.13 Nitrate ($NO_3^-$)

Nitrate exist in surface waters as a result of sewage, runoff of fertilizer from agricultural lands, etc. Surplus of nitrate in the water bodies can cause eutrophication (WHO, 1998) which may result in the death of aquatic animals and cause serious health hazards. In the present study, the concentration of nitrate was found to be relatively low with values ranging from 0.40-0.84 mg/l. This indicates that there are no major inputs of $NO_3^-$ and apparent sources except for some residential homes present at S1 and downstream stations (S6, S7, and S8). The higher mean value of $NO_3^-$ during the post-monsoon may be related to the low flow of the river (Gunawardhana *et al*., 2016). River water that has a high level of nitrate can potentially harm human and animal health. Nevertheless, nitrate is much lesser toxic than ammonia and nitrite (Romano and Zeng, 2007).

### 3.3.14 Sulfate ($SO_4^{2-}$)

Sulfate occurs naturally in surface water as a result of the weathering of igneous and sedimentary rocks. Other sources include leachate from abandoned mines, industrial wastewater, and air deposition due to the combustion of fossil fuels. Nonetheless, its main source in water is from various sedimentary rocks which include gypsum and anhydride. Hem

(1985) recognized the major sources of sulfate in rivers as mostly from weathering of rocks, volcanoes, mining, discharges of waste, and combustion of fossil fuels. Sulfate concentrations in the present study were all within the tolerable limits of 200 mg/l and they occurred fairly consistently in all the stations and seasons. This is mostly related to natural sources. However, the higher values recorded at S1 throughout the season may be attributed to various human activities (domestic waste and developmental activities).

### 3.3.15 Phosphorus ($PO_4^{3-}$)

In natural waters, phosphorus exists as soluble phosphates and organic phosphates. Phosphorus enters the surface waters as a result of man-generated wastes and run-off. In freshwater bodies, phosphorus is considered as one of the limiting nutrients vital for floral growth. They regulate the production of phytoplankton (Sharma *et al*., 2004) are often considered as a limiting element in the water ecosystem (Hecky and Kilhan, 1988). The concentration of phosphorus in the present study was fairly low with values ranging from 0.21-0.46 mg/l. A possible reason for the low values of phosphorus may be due to precipitation of soluble phosphate into its insoluble form at slightly alkaline pH beyond 7.8 (Dhage *et al*., 2006).

### 3.3.16 Potassium (K)

The presence of potassium in natural water is essential since it is considered a crucial element required for the well-being of the plants. In surface water, they usually occur in low concentration as it has a weak migratory ability and more so, due to active absorption by living plants and micro-organism. The concentration of potassium in the present study was also observed to be relatively low yet, the relatively higher values recorded at S6, S7, and S8 during monsoon may be attributed to the runoff of domestics wastewater during rainfall. Kumar *et al*. (2010) also recognized the major source of potassium in natural freshwater as weathering of rocks and that its quantity increases as a result of the disposal of wastewater.

### 3.3.17 Similarities among the sampling stations

From the result of cluster analysis, minor variation in the grouping of sampling stations during monsoon was observed. Monsoon is characterized by heavy rainfall and high flow of water system while pre and post-monsoon experiences comparatively lesser rainfall and low flow. This could be the possible reason for the homogenous character of water causing dilution during this period, thereby reducing the grouping from 4 clusters into 3 clusters only. In all the seasons, cluster 1 comprised of the only S1. Cluster 2 of pre-monsoon and post-monsoon comprised of the only S2, while during monsoon it comprised of S2, S3, S4, and S5. All these stations are located around the vicinity of Hydro-Electric Dam in the midstream of the river, therefore have positioned themselves together in the same cluster (cluster 2), suggesting an associated influence on the water chemistry.

Accordingly, stations S6, S7, and S8 constituted cluster 3 of monsoon; concordant stations also constituted cluster 4 of both pre-monsoon and post-monsoon respectively. These sampling stations are all located downstream of the river and therefore shared similar composition and character of water quality. Thus, our result indicates the presence of three different clusters or groups of sampling stations based on the similar characteristics of water qualities they possess. The first group composed of only upstream station (S1), the second group composed of midstream stations (S2, S3, S4, and S5), and finally, downstream stations (S6, S7, and S8) constituted the third group. According to the CA result, the upstream station (S1) seems to possess a distinct characteristic of water quality having many of the water quality variables adequately loaded. This suggests the need to accordingly prioritized the sampling stations for a future monitoring plan.

In recent years, the approach made using CA in categorizing sampling station for long term monitoring programs have been widely accepted (Xiaoyun *et al*., 2012; Al-Badaii *et al*., 2013; Barakat *et al*., 2016; Zhong *et al*., 2018), providing a methodological framework in classifying catchment areas (Mena-Rivera *et al*., 2017). CA usually provide prospects for future monitoring of the experimental water bodies by optimizing the choice of sampling points (Fan *et al*., 2010). The present result of CA has also efficiently classified the sampling stations into certain groups and have categorized them according to their need for management. This classification, in turn, will assist in priority management and monitoring efforts. Subsequently, the number of sampling stations can be reduced by designing an optimal spatial sampling strategy (Bu *et al*., 2010).

### 3.3.18 Principal component analysis of the water quality variables

PCA generated three PCs each for the entire season and found a positive relationship between water quality variables, sampling stations, and season (**Fig. 3.1**). During pre-monsoon, clustering of $CO_2$, $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K with S1 was noted.

A similar grouping of variables in monsoon was also acknowledged showing a strong affiliation towards S1 (upstream). $NO_3^-$ and $PO_4^{3-}$ point to the presence of anthropogenic pollutants (Bhat *et al*., 2014), while, the hardness of water ($Ca^{2+}$, $Mg^{2+}$) reveals the effects of soil leaching and seasonal erosion (Mir and Gani, 2019). TDS and EC also indicate soil erosion during seasonal storms (Kowalkowskia *et al*., 2006) and $Cl^-$ mainly from untreated domestic waste and natural sources. The majority of these water quality parameters are linked to both natural and anthropogenic sources. Evidently, in the upstream zone, there observed a major ongoing developmental work (construction of national highway bridge: NH-02) just 300m above the sampling point. This activity has led to the runoff of massive construction materials (concrete, asphalt, etc.) directly into the river system. Also, the cutting down of the riparian hillslope for the same purpose has led to the dissolution of many of the mineral ions from the soil into the river system. Besides, some residential homes were also present around S1 and were found directly discharging their domestic waste and sewage into the river system. Other anthropogenic activities like logging and picnicking were also observed causing serious disturbance to the riparian areas and water quality. Therefore, the significant presence of many of the water quality variables at S1 suggestively points to all those anthropogenic disturbances upstream. Chen *et al*. (2005) and Zhang *et al*. (2011) also reported agricultural and road construction activities as agents accelerating the mechanical erosion and chemical weathering process which further enhances the presence of many of the water quality parameters reported from S1. Sulfate showed a fairly high range and has recorded a strong positive loading (PC1) throughout the season at S1 (upstream). Disturbances in the riparian soil due to developmental activities, logging, and domestic discharges may have all contributed fairly towards the consistent occurrence of sulfate in the present study. These disturbances eventually cause leaching of the natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt) (Davis and David, 2008; Davis, 2010) and get dissolved in the water. Mayer *et al*. (2010) from their study at Sleepers River watershed (Vermont, USA), reported that the potential source of $SO_4^{2-}$ was from the soil, bedrock weathering, and from the oxidation of secondary sulfides in C-horizons.

Free $CO_2$ observed during pre-monsoon and monsoon at S1 relates to deoxygenation associated with higher temperatures (Talling, 1957; Singh *et al*., 2010), which eventually leads to significantly higher values. A similar phenomenon can also be seen at S6, S7, and S8 during monsoon, however, during post-monsoon, it was observed to be closely associated with S2 (midstream). This may be due to the reason that the midstream of the river experiences comparatively higher atmospheric temperature and relative humidity throughout the year due to the presence of Hydroelectric Dam and thus temperature continues to play a major role. In the present study, water quality variables like pH, DO and BOD showed significant response towards seasonal changes. Positive loading of pH and weak $NO_3^-$ loading in post-monsoon at S1 reflects the role of denitrification during the dry season which is controlled by pH and dissolved matter (Zilberbran *et al*., 2001; De Souza Pereira *et al*., 2019).

During the pre-monsoon and monsoon (**Fig. 3.1**), pH, WT, DO and BOD was found to be associated with S2, S3, S4, and S5. The strong correlation of WT and pH observed in these sites suggest their regulatory effects on mineral, hardness, organic, and nutrient pollution during the rainy season (Bu *et al*., 2014). It is to be noted that the sampling stations S2, S3, S4, and S5 are all located in the midstream around the vicinity of the Hydro-Electric Dam, and are surrounded by various land-use practices like Jhum cultivation and teak plantation. The large surface and catchment area created by the Dam have made it vulnerable to multiple non-point source pollution. Especially, during rainfall, the surface runoff from areas of poor vegetation cover owing to intensive jhum practices, a vast area of teak plantations, and from disturbed logging areas. This has led to the influx of a substantial amount of organic matter into the water bodies. These disturbances have a massive effect on the BOD levels of midstream stations. The moderately high positive loading of BOD in PC2 of pre-monsoon, positive loading in PC2 of monsoon, and fairly high positive loading in PC2 of post-monsoon relate to all the addition of a high amount of waste along with rainwater from the surrounding areas and addition of organic waste from various human disturbance (Solanki, 2007; Qureshimatva *et al*., 2015). BOD perhaps indicated a wide range of values in the present study. This is due to the differential site-specific disturbance with a disparity in the inputs of organic matter. As temperature declines during winter, the activity of microbes is inhibited leading to a decrease in the BOD level (Shiddamallayya and Pratima, 2008). The higher pH values in these sites (midstream) also relate to the weathering of existing parent rocks rich in carbonates and bicarbonates (Isiyaka and Juahir, 2015) that ultimately seeps in during rainfall.

DO usually declines during summer due to the increase in temperature and microbial activity and increases during winter (Kataria, 1996; Shrestha and Kazama, 2007; Kelic and Yucel, 2019; Mir and Gani, 2019). Despite warmer seasons (pre-monsoon and monsoon), DO was observed to be positively related to S2, S3, S4, and S5. This may be due to the reason that the increase in temperature and longer duration of bright sunlight during summer had positively influenced the percentage of soluble gases ($O^2$ and $CO^2$). The long days and intense sunlight seem to have accelerated the photosynthesis activities of phytoplankton, thereby utilizing more $CO_2$ and giving off more oxygen. A similar situation has also been encountered by Krishnamurthy (1990). Other convincing reasons may also be related to seasonal flooding which causing turbulence in the water bodies leading to rapid aeration and photosynthesis of submerged plants. A similar phenomenon was also acknowledged by both Ling *et al*. (2017) and Bouslah *et al*. (2017). Likewise, during post-monsoon, DO records a positive relationship with upstream (positive loading in PC1) and downstream (positive loading in PC2) stations. This is probably due to the higher rate of dissolution of ambient oxygen in the water and a lower rate of microbial degradation. Nevertheless, DO was observed to remain consistently high (**Table 3.1**) throughout the seasons. No significant relationship between the DO and BOD was observed and was found to coexist mutually.

Throughout the season, $PO_4^{3-}$ and K occurred consistently at S6, S7, and S8 of downstream stations. Downstream of the river is characterized by the presence of Hydro Dam residential complexes, urbanization, and multiple hotels where all the domestics' and urban waste directly drain into the river system. Accordingly, the significant load of $NO_3^-$, K, and $PO_4^{3-}$ at downstream stations may be related to all these factors. Von Sperling (2014) indicated that the main source of pollution in urban areas is waste-water and rainwater. The concentration of $NO_3^-$ and $PO_4^{3-}$ during the post-monsoon (dry periods) relates to the low flow of the river (Gunawardhana *et al*., 2016; Mir and Gani, 2019). Downstream stations rather represent a 'nutrient' factor and this is attributed to the various point source pollution from residential homes and hotels. Bahar *et al*. (2008) in the study of the O-Hori river basin have also indicated a similar positive correlation of parameters like K, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $HCO_3^-$, EC, and TMI (total major ions) with the residential area. Likewise, in the study of Zanjanrud River, Iran, the influence of nitrogen and phosphorus inputs was directed to the residential and industrial areas (Abdollahi *et al*., 2019). Thus, the result of the present study found the water quality parameters of the Doyang River exhibiting the spatio-temporal variation. Much of these variations were observed at midstream stations (S2, S3, S4, and S5) with parameters like WT, $CO_2$, pH, DO and BOD positively responding to the seasonal cycle. Workers like Bhat *et al*. (2014) and Abdollahi *et al*. (2019) have also reported similar findings where WT, pH, and DO were found conforming to the seasonal changes.

### 3.3.19 Pollution load

**Table 3.10** of PCA result shows PC1 displaying a strong relationship towards the upstream station (S1) largely contributed by $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K. This factor (PC1) has a major concentration of mineral elements (TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$) and they continue to exhibit throughout the season. Thus, it may be term as a mineral factor. These variables originated mainly due to various anthropogenic disturbances like developmental activities, logging, inputs of domestic waste, and picnicking events present upstream. PC2 of pre-monsoon and monsoon exhibited positive loading of pH, WT, DO and BOD showing a strong influence from the midstream stations (S2, S3, S4, and S5). This factor (PC2) experiences seasonal influence. The main drivers of water quality in PC2 advocate organic matter and therefore may be as called an organic factor. This is related to the runoff of organic loads from areas of extensive jhum cultivation, teak plantation, and disturbed logging areas during rainfall. Subsequently, PC3 of post-monsoon represents a nutrient factor which is indicated by the strong positive loading of $NO_3^-$ showing an inclination towards the downstream stations (S6, S7, and S8). Downstream sampling stations (S6, S7, and S8) witnessed a noticeable effect on $CO_2$, $PO_4^{3-}$, $NO_3^-$, and K (**Fig. 3.1**). This indicates that the presence of residential complexes and hotels downstream has led to the presence of major nutrient elements ($PO_4^{3-}$, $NO_3^-$, and K). Despite observing positive nutrient loading downstream, it all existed under the permissible limits. Other water quality parameters also did not show any increase downstream of the river. This result perhaps indicates that some recovery process has been made as the river again flows through patches of riparian forest. Although various land-use activities had some negative impact on the water quality, the result from the present study positively confirms the mitigatory role of riparian vegetation in improving the water quality of the river.

From the result, a comprehensive source of pollution occurring along the Doyang river could be confirmed. The nature of pollution in the present study area may then be attributed to both anthropogenic and natural, accordingly, the Doyang river is segregated into three different zones based on the nature of pollution load. The upstream station represented more of mineral load, midstream stations represented more of organic load and downstream stations represented more of nutrient loading. The study clearly defined each zone of the river according to its exclusive characteristics of water chemistry and provided crucial information on the kinds of pollution taking place at each sampling station of the Doyang river. Developmental activities and discharges from residential homes at upstream had a major effect on the $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K, while jhum practices, teak plantation, and logging activities at midstream were found to significantly affect the pH, WT, DO and BOD. Lastly, the presence of several residential homes and hotels downstream were found to positively affect the $CO_2$, $PO_4^{3-}$, $NO_3^-$, and K. Likewise, the results from CA also categorized sampling stations into three distinct groups based on the similar characteristics of water quality they possess. This observation thus provides a significant finding which will be essential in designing a site-specific management plan and future assessment program for the implementing agency. To summarized, the use of PCA and CA have succinctly identified site-specific pollution sources and types of contaminants affecting the surface water chemistry of the Doyang river. Authors like Nie *et al*. (2015) and Kelic and Yucel (2019) have also conversed the same in their findings.

### 3.4 SUMMARY AND CONCLUSION

The present study was conducted to evaluate the temporal and spatial variation in surface water quality of Doyang River using multivariate statistical techniques like PCA and CA. All the sixteen physicochemical parameters of water quality analyzed from the eight selected sampling stations were all found to be within the permissible limits of drinking water. The 3 PCs obtained for pre-monsoon, monsoon, and post-monsoon explained 94.75%, 93.63%, and 93.91% of the total variance and in each of the seasons, PC1 produced the maximum explanatory variance with over 60%. The dendrogram of CA segregates the study area into three different clusters or groups based on the similar characteristics of water qualities they possess. The result of CA found upstream station (S1) possessing a distinct characteristic of water quality having many of the water quality variables adequately loaded.

The spatio-temporal variation of the water quality parameters obtained through PCA provided a comprehensive source and nature of pollution happening along the Doyang river. The results indicated upstream station (S1) largely affected by $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K. While midstream stations (S2, S3, S4, and S5) showed positive relation towards pH, WT, DO and BOD. Downstream stations of S6, S7, and S8 were found to be positively affected by $NO_3^-$, K, and $PO_4^{3-}$. The study found midstream stations (S2, S3, S4, and S5) facing much of the seasonal influence (rainfall) and parameters like WT, $CO_2$, pH, DO and BOD was found to accord to the seasonal cycle. The Doyang river was segregated into three different zones based on the nature of the pollution load. The upstream station represents mineral loading, midstream stations represent organic loading and the downstream stations represent nutrient loading. The study clearly defined each zone of the river according to its exclusive characteristics of water chemistry and provided crucial information on the kinds of pollution taking place at each sampling station of the Doyang river. Developmental activities and discharges from residential homes at upstream affected the $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K, while jhum practices and teak plantation at midstream were found to significantly affect the pH, WT, DO and BOD. Lastly, the presence of several residential homes and hotels downstream positively affected the $CO_2$, $PO_4^{3-}$, $NO_3^-$, and K.

Anthropogenic disturbances due to developmental activities, extensive Jhum cultivation, teak cultivation, picnicking, logging, and rapid urbanization were all found to adversely affect the water parameters of the Doyang river. The present study thus provides evidence on how different anthropogenic activities along the river can influence the water quality differently. It also provides crucial information on the nature and source of pollution which will positively assist in designing a site-specific management plan. Despite the negative impact of various land-use activities on the water quality, the result from the present study positively confirms the mitigatory role of riparian vegetation in improving the water quality of the river. This observation eventually underlines the need to adopt sustainable land-use practices and landscape planning at multiple scales and implement management guidelines to prevent further deterioration of water quality. Finally, the study advocates the necessity to maintain healthy riparian forests and measures to protect them. With better usage, planning, and proper management of catchment areas, the current water quality status of the Doyang river may be further optimized effectively.

# CHAPTER – 4

# WATER QUALITY INDEX (WQI) OF THE DOYANG RIVER

## 4.1 INTRODUCTION

Activities related to extensive urbanization, agricultural practices, industrialization, and population expansion have all led to water quality deterioration in many parts of the world. The adjacent landscapes (riparian zones) that act as an interface between the aquatic and terrestrial ecosystem play an important role in controlling water and chemical exchange between surrounding land and stream systems (Burt and Pinay, 2005). Disturbances in this landscape have the potential to deteriorate the water quality as they influence the flows of energy and material between the terrestrial and aquatic (Fausch *et al*., 2010) interface. Riparian zones form a unique ecosystem and act as 'buffer zones' between upland and streams (Hill, 1996; Lowrance, 1998) and are vital to the health of the watershed. The riparian forest along the river receives and processes water, sediments, and nutrients transport from upslope areas and effectively functions as sinks for sediment and nutrients, thus regulating the nutrient loading to the aquatic system (Luke *et al*., 2007; Mayer *et al*., 2007). Thus, the water quality of the river or stream has both direct or indirect influence from the various processes and disturbances occurring in the riparian zone. Water quality of any specific area or source may be assessed using physical, chemical, and biological parameters and is considered harmful and unfit for different human usage and other agricultural activities once it occurs more than the well-defined limits (ICMR, 1975; BIS, 2003).

To reliably assess the impairments in the water quality, site-specific evaluation of the chemical constituent is important. Water quality assessment guesstimates the impairment that is occurring, or could potentially occur, due to the presence of a certain chemical beyond its standard limits or other possible constituents. Accordingly, the suitability of the experimental water body for various usage may be categorized or described in terms of water quality index (WQI), which is one of the most effective ways to describe the status of water quality. It is calculated from the point of the aptness of surface water for human consumption (Atulegwu and Njoku, 2004). Water quality index (WQI) is a single number that expresses the water quality status of a studied component by aggregating the measurements of water quality parameters (such as dissolved oxygen, pH, nitrate, total hardness, etc.). It reduces the bulk of information from the several water quality parameters into a single value and expresses the data in a simplified and logical form (Semiromi *et al*., 2011). Assessment of water quality could provide us the overall information on the quality of the water bodies and their potential threat to various uses. The application of WQI is a useful method in assessing the water quality of the river. It helps to understand the overall water quality status of individual sampling stations at a certain time (Yogendra and Puttaiah, 2008) and its suitability for various beneficial uses.

The concept of WQI was initially developed in 1848 in Germany that used microorganisms as an indicator to mention the quality and potential use of water. This system of classification was based on the amount of pollution and the presence of the micro and macroscopic organisms. However, the major drawback of this classification was that it was only qualitative and lacks a numerical representation. To achieve this deficiency, Horton (1965) developed a concept of indices which was based upon a numerical scale commonly known as the Horton's index. His method emphasized that the variables considered in the index should be restricted to numbers only and that the chosen variables ought to be the most important. To represent the gradation in water quality, he selected 6 most commonly used water quality variables like dissolved oxygen, pH, total coliforms, specific conductance, alkalinity, and chloride. Subsequently, numerous methods of WQI have been developed to evaluate the overall water quality status (Brown *et al*., 1970; Miller *et al*., 1986; Bordalo *et al*., 2001; Cude, 2001; Qian *et al*., 2007; Simoes *et al*., 2008; Alam and Pathak, 2010; Bharti and Katyal, 2011; Akoteyon, 2013; Damo and Icka, 2013). Based on the aggregation functions and varying number and types of water quality parameters as compared with the respective standards of a particular region, various water quality indices *viz*., Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI), etc. have been formulated by several national and international organizations that can easily evaluate the overall water quality of an area promptly and efficiently. For the present study, the general WQI developed by Brown *et al*. (1970), which is based on the weights of individual parameters has been employed. This method was chosen for the present study as it is one of the most commonly used methods by researchers and agencies in multiple countries. Over the decades, this index has undergone much-improved modification suitable for different purposes and several researchers have widely used this method effectively (Chauhan and Singh, 2010; Rao *et al*., 2010; Chowdhury *et al*., 2012; Balan *et al*., 2012). Around the world, several workers like Debels *et al*. (2005), Yisa and Jimoh (2010), Akoteyon *et al*. (2011), Othman *et al*. (2012), Naubi *et al*. (2016), Ewaid (2017), Bouslah *et al*. (2017), Ewaid and Abed (2017), Abdel-Satar *et al*. (2017), García-Ávila *et al*. (2018) have carried out studies using water quality index. Similarly, in India, workers like Yogendra and Puttaiah (2008), Kumar *et al*. (2011), Sharma and Kansal (2011), Singh and Kamal (2014), Shah and Joshi (2017), Gupta *et al*. (2017), Acharya *et al*. (2018) have also worked on WQI of different rivers. So far only a few studies on WQI from the Northeastern part of India, mainly confined to Assam and Manipur (Singh *et al*., 2016; Bora and Goswami, 2017) have been reported.

The increasing land-use practices (shifting cultivation, timber monoculture, growing settlements) and other anthropogenic activities incessantly threaten the riparian habitats of the Doyang river thereby posing a serious threat to the water quality status of the Doyang river. All these circumstances have irrefutably pressed the necessity to assess and determine the status of the surface water quality of the Doyang river. Therefore, the application of WQI in the present study would ultimately give us a comprehensive result on the water quality status of the Doyang river at different sampling stations and in varying seasons. This information will eventually be useful for regulatory policy and also to answer the community and different stalk holders on the overall status of the water quality of the Doyang river. Last but not the least, the calculation of WQI in the present study would finally pave ways for future management and monitoring plans of targeted sites that require priority attention.

## 4.2 RESULTS

Based on the evidence of high organic pollution from various land use activities, ongoing developmental works, and discharges from residential homes, 12 parameters were selected for the WQI. **Table 4.1** shows the standards of the various water quality parameters and the unit weights assigned to each parameter used for the calculation of WQI. A maximum weightage of 0.366 was assigned to both DO and BOD followed by 0.192 for pH. **Tables 4.2-4.9** presents the values observed for the 12 selected physicochemical parameters of water quality and their corresponding WQI values from the eight selected sampling stations during pre-monsoon, monsoon, and post-monsoon. From the result, it was observed that pH, DO and BOD were the most important parameters contributing to the overall WQI scores. The maximum WiQi score at S1 during the pre-monsoon (15.4512) was contributed by pH, and during the monsoon (17.8755) and post-monsoon (16.6883), it was DO. At S2, BOD recorded the maximum WiQi score during the pre-monsoon (19.2770) and monsoon (21.1005), while DO during the post-monsoon (19.7071). At S3, the highest WiQi was contributed by DO during the pre-monsoon (15.2976) and post-monsoon (19.7071) and BOD during the monsoon (18.4955). A similar pattern of WiQi score was also observed at S4 and S5, where, DO contributes the maximum score during the pre-monsoon and post-monsoon while the BOD during the monsoon. At S6, the maximum WiQi score was contributed by pH during the pre-monsoon (14.9405) and DO during the monsoon (22.8955), post-monsoon (18.1808). Corresponding WiQi score was also observed at S7 and S8, where the maximum was contributed by pH during the pre-monsoon and DO during the monsoon and post-monsoon.

The maximum WQI value (47.86) was observed at S1 during the pre-monsoon and at S2 (51.76), S3 (53.10), S4 (55.45), S5 (51.45), S6 (41.51), S7 (40.77), S8 (40.97), the maximum WQI values were recorded during the monsoon. Summary of WQI from all the eight sampling stations for pre-monsoon, monsoon, and post-monsoon are shown in **Table 4.10**. During the pre-monsoon, sampling station S2 (50.14) recorded the highest value indicating a poor water quality status. Subsequently, during monsoon, sampling stations of S2 (51.76), S3 (53.10), S4 (55.45), and S5 (51.45) recorded the highest WQI all indicating poor water quality status. However, during the post-monsoon, WQI values of all the sampling stations were observed to be in good water quality status. Nevertheless, the overall average WQI values of the Doyang river for pre-monsoon, monsoon, and post-monsoon recorded 42.95, 47.13, and 36.66 respectively (**Table 4.11)** indicating a good water quality status.

**Table 4.1:** Relative weights ($W_i$) of selected water quality parameters and their standards ($S_i$) used for WQI determination

| **Parameters** | **ICMR/BIS standards ($S_i$)** | **Unit weight ($W_i$)** |
|---|---|---|
| $p^H$ | 6.5-8.5 | 0.192 |
| EC | 300 | 0.005 |
| TDS | 500 | 0.003 |
| T H | 300 | 0.005 |
| T A | 120 | 0.014 |
| $Ca^{2+}$ | 75 | 0.022 |
| $Mg^{2+}$ | 30 | 0.054 |
| $Cl^{-}$ | 250 | 0.007 |
| $NO_3^{-}$ | 45 | 0.036 |
| $SO_4^{2-}$ | 150 | 0.011 |
| DO | 5 | 0.326 |
| BOD | 5 | 0.326 |
| $\sum W_i$=1.000 | | |

**Table 4.2:** Calculation of WQI at station 1 (S 1)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.21 | 80.6667 | 15.4512 | 7.74 | 49.3333 | 9.4495 | 7.14 | 9.3333 | 1.7877 |
| EC | 271.49 | 90.4967 | 0.4911 | 171.23 | 57.0767 | 0.3098 | 214.74 | 71.5800 | 0.3885 |
| TDS | 134.42 | 26.8840 | 0.0875 | 80.09 | 16.0180 | 0.0522 | 111.5 | 22.3000 | 0.0726 |
| T H | 111.33 | 37.1100 | 0.2014 | 76 | 25.3333 | 0.1375 | 97.5 | 32.5000 | 0.1764 |
| T A | 141.25 | 117.7083 | 1.5970 | 100.84 | 84.0333 | 1.1401 | 131.67 | 109.7250 | 1.4887 |
| $Ca^{2+}$ | 23.11 | 30.8133 | 0.6689 | 16.1 | 21.4667 | 0.4660 | 22.45 | 29.9333 | 0.6498 |
| $Mg^{2+}$ | 13.03 | 43.4333 | 2.3572 | 8.66 | 28.8667 | 1.5666 | 10.13 | 33.7667 | 1.8325 |
| $Cl^{-}$ | 24.61 | 9.8440 | 0.0641 | 17.43 | 6.9720 | 0.0454 | 22.72 | 9.0880 | 0.0592 |
| $NO_3^{-}$ | 0.81 | 1.8000 | 0.0651 | 0.71 | 1.5778 | 0.0571 | 0.84 | 1.8667 | 0.0675 |
| $SO_4^{2-}$ | 21.63 | 14.4200 | 0.1565 | 16.03 | 10.6867 | 0.1160 | 18.05 | 12.0333 | 0.1306 |
| DO | 10.39 | 43.8542 | 14.2800 | 9.33 | 54.8958 | 17.8755 | 9.68 | 51.2500 | 16.6883 |
| BOD | 1.91 | 38.2000 | 12.4389 | 1.66 | 33.2000 | 10.8108 | 2.4 | 48.0000 | 15.6300 |
| | | | $\sum W_iQ_i$=47.8591 WQI=47.86 | | | $\sum W_iQ_i$=42.0264 WQI=42.03 | | | $\sum W_iQ_i$=38.9719 WQI=38.97 |

**Table 4.3:** Calculation of WQI at station 2 (S 2)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 7.86 | 57.3333 | 10.9819 | 7.83 | 55.3333 | 10.5988 | 7.12 | 8.0000 | 1.5324 |
| EC | 194.26 | 64.7533 | 0.3514 | 148.37 | 49.4567 | 0.2684 | 145.71 | 48.5700 | 0.2636 |
| TDS | 97.92 | 19.5840 | 0.0638 | 69 | 13.8000 | 0.0449 | 74.67 | 14.9340 | 0.0486 |
| T H | 86.33 | 28.7767 | 0.1562 | 72.34 | 24.1133 | 0.1309 | 66.17 | 22.0567 | 0.1197 |
| T A | 110.42 | 92.0167 | 1.2485 | 78.75 | 65.6250 | 0.8904 | 89.17 | 74.3083 | 1.0082 |
| $Ca^{2+}$ | 17.17 | 22.8933 | 0.4970 | 12.69 | 16.9200 | 0.3673 | 13.63 | 18.1733 | 0.3945 |
| $Mg^{2+}$ | 10.52 | 35.0667 | 1.9031 | 9.99 | 33.3000 | 1.8072 | 7.8 | 26.0000 | 1.4110 |
| $Cl^{-}$ | 19.88 | 7.9520 | 0.0518 | 17.51 | 7.0040 | 0.0456 | 18.58 | 7.4320 | 0.0484 |
| $NO_3^{-}$ | 0.61 | 1.3556 | 0.0490 | 0.73 | 1.6222 | 0.0587 | 0.79 | 1.7556 | 0.0635 |
| $SO_4^{2-}$ | 16.94 | 11.2933 | 0.1226 | 13.53 | 9.0200 | 0.0979 | 11.27 | 7.5133 | 0.0816 |
| DO | 10.05 | 47.3958 | 15.4333 | 9.78 | 50.2083 | 16.3491 | 8.79 | 60.5208 | 19.7071 |
| BOD | 2.96 | 59.2000 | 19.2770 | 3.24 | 64.8000 | 21.1005 | 3.02 | 60.4000 | 19.6678 |
| | | | $\sum W_iQ_i$=50.1355 WQI=50.14 | | | $\sum W_iQ_i$=51.7598 WQI=51.76 | | | $\sum W_iQ_i$=44.3464 WQI=44.35 |

**Table 4.4:** Calculation of WQI at station 3 (S 3)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.1 | 73.3333 | 14.0466 | 8.11 | 74.0000 | 14.1743 | 6.87 | -8.6667 | -1.6601 |
| EC | 176.53 | 58.8433 | 0.3193 | 153.01 | 51.0033 | 0.2768 | 143.97 | 47.9900 | 0.2604 |
| TDS | 89.25 | 17.8500 | 0.0581 | 70.42 | 14.0840 | 0.0459 | 72 | 14.4000 | 0.0469 |
| T H | 79 | 26.3333 | 0.1429 | 71.17 | 23.7233 | 0.1287 | 65.17 | 21.7233 | 0.1179 |
| T A | 107.59 | 89.6583 | 1.2165 | 77.5 | 64.5833 | 0.8762 | 92.92 | 77.4333 | 1.0506 |
| $Ca^{2+}$ | 15.98 | 21.3067 | 0.4625 | 12.52 | 16.6933 | 0.3624 | 13.03 | 17.3733 | 0.3771 |
| $Mg^{2+}$ | 9.5 | 31.6667 | 1.7186 | 9.66 | 32.2000 | 1.7475 | 7.92 | 26.4000 | 1.4328 |
| $Cl^-$ | 18.68 | 7.4720 | 0.0487 | 15.98 | 6.3920 | 0.0416 | 18.46 | 7.3840 | 0.0481 |
| $NO_3^-$ | 0.59 | 1.3111 | 0.0474 | 0.59 | 1.3111 | 0.0474 | 0.7 | 1.5556 | 0.0563 |
| $SO_4^{2-}$ | 15.98 | 10.6533 | 0.1156 | 12.92 | 8.6133 | 0.0935 | 10.89 | 7.2600 | 0.0788 |
| DO | 10.09 | 46.9792 | 15.2976 | 9.38 | 54.3750 | 17.7059 | 8.79 | 60.5208 | 19.7071 |
| BOD | 2.07 | 41.4000 | 13.4809 | 2.84 | 56.8000 | 18.4955 | 2.18 | 43.6000 | 14.1973 |
| | | | $\sum W_iQ_i$=46.9548<br>WQI=46.95 | | | $\sum W_iQ_i$=53.9958<br>WQI=53.10 | | | $\sum W_iQ_i$=35.7132<br>WQI=35.71 |



**Table 4.5:** Calculation of WQI at station 4 (S 4)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.08 | 72.0000 | 13.7912 | 8.29 | 86.0000 | 16.4728 | 6.86 | -9.3333 | -1.7877 |
| EC | 175.91 | 58.6367 | 0.3182 | 144.03 | 48.0100 | 0.2606 | 140.23 | 46.7433 | 0.2537 |
| TDS | 86.75 | 17.3500 | 0.0565 | 67 | 13.4000 | 0.0436 | 71.5 | 14.3000 | 0.0466 |
| T H | 77.67 | 25.8900 | 0.1405 | 70.33 | 23.4433 | 0.1272 | 63.5 | 21.1667 | 0.1149 |
| T A | 107.5 | 89.5833 | 1.2154 | 83.75 | 69.7917 | 0.9469 | 87.09 | 72.5750 | 0.9847 |
| $Ca^{2+}$ | 15.57 | 20.7600 | 0.4507 | 11.09 | 14.7867 | 0.3210 | 12.43 | 16.5733 | 0.3598 |
| $Mg^{2+}$ | 9.54 | 31.8000 | 1.7258 | 10.08 | 33.6000 | 1.8235 | 7.92 | 26.4000 | 1.4328 |
| $Cl^-$ | 19.41 | 7.7640 | 0.0506 | 14.55 | 5.8200 | 0.0379 | 19.17 | 7.6680 | 0.0499 |
| $NO_3^-$ | 0.56 | 1.2444 | 0.0450 | 0.49 | 1.0889 | 0.0394 | 0.63 | 1.4000 | 0.0507 |
| $SO_4^{2-}$ | 15.66 | 10.4400 | 0.1133 | 12.8 | 8.5333 | 0.0926 | 10.75 | 7.1667 | 0.0778 |
| DO | 10.2 | 45.8333 | 14.9245 | 10.61 | 41.5625 | 13.5338 | 8.64 | 62.0833 | 20.2159 |
| BOD | 1.38 | 27.6000 | 8.9873 | 3.34 | 66.8000 | 21.7518 | 1.72 | 34.4000 | 11.2015 |
| | | | $\sum W_iQ_i$=41.8190<br>WQI=41.82 | | | $\sum W_iQ_i$=55.4512<br>WQI=55.45 | | | $\sum W_iQ_i$=33.0004<br>WQI=33.00 |

**Table 4.6:** Calculation of WQI at station 5 (S 5)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.13 | 75.3333 | 14.4297 | 8.22 | 81.3333 | 15.5789 | 6.85 | -10.0000 | -1.9154 |
| EC | 171.32 | 57.1067 | 0.3099 | 134.28 | 44.7600 | 0.2429 | 139.42 | 46.4733 | 0.2522 |
| TDS | 86.42 | 17.2840 | 0.0563 | 64 | 12.8000 | 0.0417 | 70.84 | 14.1680 | 0.0461 |
| T H | 76.67 | 25.5567 | 0.1387 | 67.17 | 22.3900 | 0.1215 | 63.84 | 21.2800 | 0.1155 |
| T A | 104.17 | 86.8083 | 1.1778 | 79.59 | 66.3250 | 0.8999 | 87.92 | 73.2667 | 0.9941 |
| $Ca^{2+}$ | 15.7 | 20.9333 | 0.4544 | 11.15 | 14.8667 | 0.3227 | 12.49 | 16.6533 | 0.3615 |
| $Mg^{2+}$ | 9.3 | 31.0000 | 1.6824 | 9.58 | 31.9333 | 1.7331 | 7.88 | 26.2667 | 1.4255 |
| $Cl^-$ | 18.23 | 7.2920 | 0.0475 | 16.8 | 6.7200 | 0.0438 | 18.7 | 7.4800 | 0.0487 |
| $NO_3^-$ | 0.66 | 1.4667 | 0.0531 | 0.6 | 1.3333 | 0.0482 | 0.63 | 1.4000 | 0.0507 |
| $SO_4^{2-}$ | 15.56 | 10.3733 | 0.1126 | 12.42 | 8.2800 | 0.0899 | 10.72 | 7.1467 | 0.0776 |
| DO | 10.02 | 47.7083 | 15.5350 | 10.12 | 46.6667 | 15.1959 | 8.26 | 66.0417 | 21.5048 |
| BOD | 1.39 | 27.8000 | 9.0524 | 2.63 | 52.6000 | 17.1279 | 1.78 | 35.6000 | 11.5923 |
| | | | $\sum W_iQ_i$=43.0498<br>WQI=43.05 | | | $\sum W_iQ_i$=51.4463<br>WQI=51.45 | | | $\sum W_iQ_i$=34.5535<br>WQI=34.55 |

**Table 4.7:** Calculation of WQI at station 6 (S 6)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.17 | 78.0000 | 14.9405 | 7.56 | 37.3333 | 7.1510 | 6.75 | -16.6667 | -3.1924 |
| EC | 172.77 | 57.5900 | 0.3125 | 153.76 | 51.2533 | 0.2782 | 154.56 | 51.5200 | 0.2796 |
| TDS | 84 | 16.8000 | 0.0547 | 70.31 | 14.0620 | 0.0458 | 78.25 | 15.6500 | 0.0510 |
| T H | 77 | 25.6667 | 0.1393 | 68.67 | 22.8900 | 0.1242 | 68.67 | 22.8900 | 0.1242 |
| T A | 107.5 | 89.5833 | 1.2154 | 77.92 | 64.9333 | 0.8810 | 91.25 | 76.0417 | 1.0317 |
| $Ca^{2+}$ | 15.36 | 20.4800 | 0.4446 | 13.23 | 17.6400 | 0.3829 | 13.5 | 18.0000 | 0.3908 |
| $Mg^{2+}$ | 9.44 | 31.4667 | 1.7077 | 8.73 | 29.1000 | 1.5793 | 8.53 | 28.4333 | 1.5431 |
| $Cl^-$ | 17.28 | 6.9120 | 0.0450 | 15.74 | 6.2960 | 0.0410 | 19.76 | 7.9040 | 0.0515 |
| $NO_3^-$ | 0.72 | 1.6000 | 0.0579 | 0.83 | 1.8444 | 0.0667 | 0.71 | 1.5778 | 0.0571 |
| $SO_4^{2-}$ | 16.03 | 10.6867 | 0.1160 | 16.94 | 11.2933 | 0.1226 | 12.04 | 8.0267 | 0.0871 |
| DO | 11.32 | 34.1667 | 11.1255 | 7.85 | 70.3125 | 22.8955 | 9.24 | 55.8333 | 18.1808 |
| BOD | 0.88 | 17.6000 | 5.7310 | 1.22 | 24.4000 | 7.9453 | 2.67 | 53.4000 | 17.3884 |
| | | | $\sum W_iQ_i$=35.8902<br>WQI=35.89 | | | $\sum W_iQ_i$=41.5135<br>WQI=41.51 | | | $\sum W_iQ_i$=35.9928<br>WQI=35.99 |

**Table 4.8:** Calculation of WQI at station 7 (S 7)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.06 | 70.6667 | 13.5358 | 7.41 | 27.3333 | 5.2355 | 6.99 | -0.6667 | -0.1277 |
| EC | 173.43 | 57.8100 | 0.3137 | 154.14 | 51.3800 | 0.2788 | 151.09 | 50.3633 | 0.2733 |
| TDS | 87.17 | 17.4340 | 0.0568 | 70.83 | 14.1660 | 0.0461 | 77.58 | 15.5160 | 0.0505 |
| T H | 74.92 | 24.9733 | 0.1355 | 79.34 | 26.4467 | 0.1435 | 67.67 | 22.5567 | 0.1224 |
| T A | 104.58 | 87.1500 | 1.1824 | 81.25 | 67.7083 | 0.9186 | 92.5 | 77.0833 | 1.0458 |
| $Ca^{2+}$ | 15.5 | 20.6667 | 0.4486 | 13.76 | 18.3467 | 0.3983 | 13.63 | 18.1733 | 0.3945 |
| $Mg^{2+}$ | 8.97 | 29.9000 | 1.6227 | 10.88 | 36.2667 | 1.9682 | 8.24 | 27.4667 | 1.4906 |
| $Cl^{-}$ | 16.69 | 6.6760 | 0.0435 | 16.21 | 6.4840 | 0.0422 | 20.95 | 8.3800 | 0.0546 |
| $NO_3^{-}$ | 0.63 | 1.4000 | 0.0507 | 0.6 | 1.3333 | 0.0482 | 0.76 | 1.6889 | 0.0611 |
| $SO_4^{2-}$ | 16.02 | 10.6800 | 0.1159 | 16.25 | 10.8333 | 0.1176 | 11.86 | 7.9067 | 0.0858 |
| DO | 10.99 | 37.6042 | 12.2449 | 7.75 | 71.3542 | 23.2347 | 9.4 | 54.1667 | 17.6380 |
| BOD | 1.29 | 25.8000 | 8.4011 | 1.28 | 25.6000 | 8.3360 | 2.2 | 44.0000 | 14.3275 |
| | | | $\sum W_iQ_i$=38.1517<br>WQI=38.15 | | | $\sum W_iQ_i$=40.7680<br>WQI=40.77 | | | $\sum W_iQ_i$=35.4166<br>WQI=35.42 |

**Table 4.9:** Calculation of WQI at station 8 (S 8)

| Parameters | Pre monsoon | | | Monsoon | | | Post monsoon | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ | $V_i$ | $Q_i$ | $W_i*Q_i$ |
| $p^H$ | 8.14 | 76.0000 | 14.5574 | 7.57 | 38.0000 | 7.2787 | 6.89 | -7.3333 | -1.4047 |
| EC | 173.64 | 57.8800 | 0.3141 | 153.16 | 51.0533 | 0.2771 | 150.65 | 50.2167 | 0.2725 |
| TDS | 85.67 | 17.1340 | 0.0558 | 71.17 | 14.2340 | 0.0463 | 77 | 15.4000 | 0.0501 |
| T H | 76.17 | 25.3900 | 0.1378 | 75.17 | 25.0567 | 0.1360 | 69.5 | 23.1667 | 0.1257 |
| T A | 105.42 | 87.8500 | 1.1919 | 83.34 | 69.4500 | 0.9423 | 98.34 | 81.9500 | 1.1119 |
| $Ca^{2+}$ | 15.9 | 21.2000 | 0.4602 | 13.36 | 17.8133 | 0.3867 | 14.17 | 18.8933 | 0.4101 |
| $Mg^{2+}$ | 8.89 | 29.6333 | 1.6082 | 10.15 | 33.8333 | 1.8362 | 8.36 | 27.8667 | 1.5123 |
| $Cl^{-}$ | 17.75 | 7.1000 | 0.0462 | 17.04 | 6.8160 | 0.0444 | 21.77 | 8.7080 | 0.0567 |
| $NO_3^{-}$ | 0.62 | 1.3778 | 0.0498 | 0.57 | 1.2667 | 0.0458 | 0.69 | 1.5333 | 0.0555 |
| $SO_4^{2-}$ | 15.45 | 10.3000 | 0.1118 | 15.9 | 10.6000 | 0.1151 | 11.79 | 7.8600 | 0.0853 |
| DO | 11.38 | 33.5417 | 10.9220 | 8.14 | 67.2917 | 21.9119 | 9.4 | 54.1667 | 17.6380 |
| BOD | 1.58 | 31.6000 | 10.2898 | 1.22 | 24.4000 | 7.9453 | 2.36 | 47.2000 | 15.3695 |
| | | | $\sum W_iQ_i$=39.7451<br>WQI=39.75 | | | $\sum W_iQ_i$=40.9656<br>WQI=40.97 | | | $\sum W_iQ_i$=35.2832<br>WQI=35.28 |

**Table 4.10:** Summary of WQI of Doyang River along with its water quality status (WQS)

| Sampling station | Pre monsoon | | Monsoon | | Post monsoon | |
|---|---|---|---|---|---|---|
| | WQI | WQS | WQI | WQS | WQI | WQS |
| S 1 | 47.86 | Good | 42.03 | Good | 38.97 | Good |
| S 2 | 50.14 | Poor | 51.76 | Poor | 44.35 | Good |
| S 3 | 46.95 | Good | 53.10 | Poor | 35.71 | Good |
| S 4 | 41.82 | Good | 55.45 | Poor | 33.00 | Good |
| S 5 | 43.05 | Good | 51.45 | Poor | 34.55 | Good |
| S 6 | 35.89 | Good | 41.51 | Good | 35.99 | Good |
| S 7 | 38.15 | Good | 40.77 | Good | 35.42 | Good |
| S 8 | 39.75 | Good | 40.97 | Good | 35.28 | Good |

**Table 4.11:** Seasonal WQI of Doyang River with its water quality status (WQI)

| **Seasons** | **WQI** | **WQS** |
|---|---|---|
| Pre monsoon | 42.95 | Good |
| Monsoon | 47.13 | Good |
| Post monsoon | 36.66 | Good |

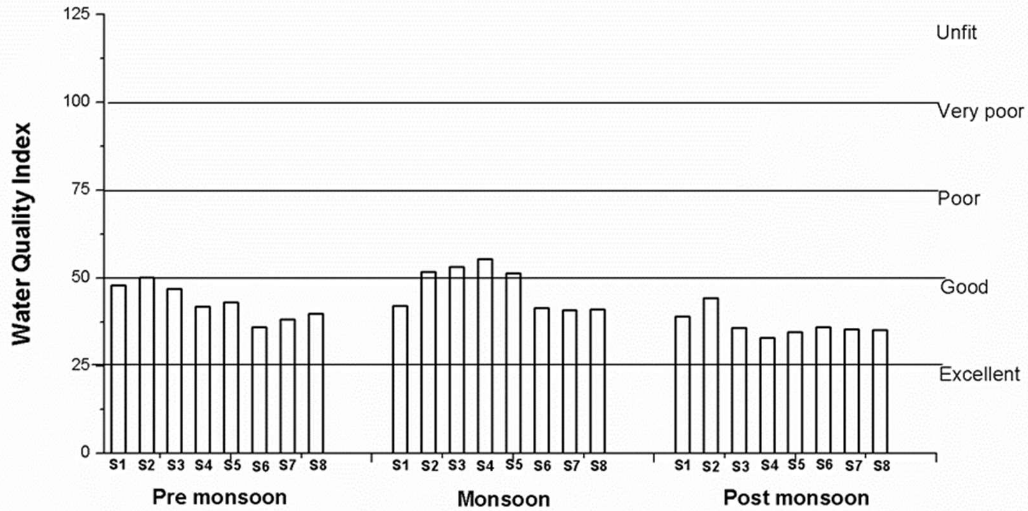



**Fig. 4.1:** WQI value of various sampling stations showing a varied pattern of change across seasons

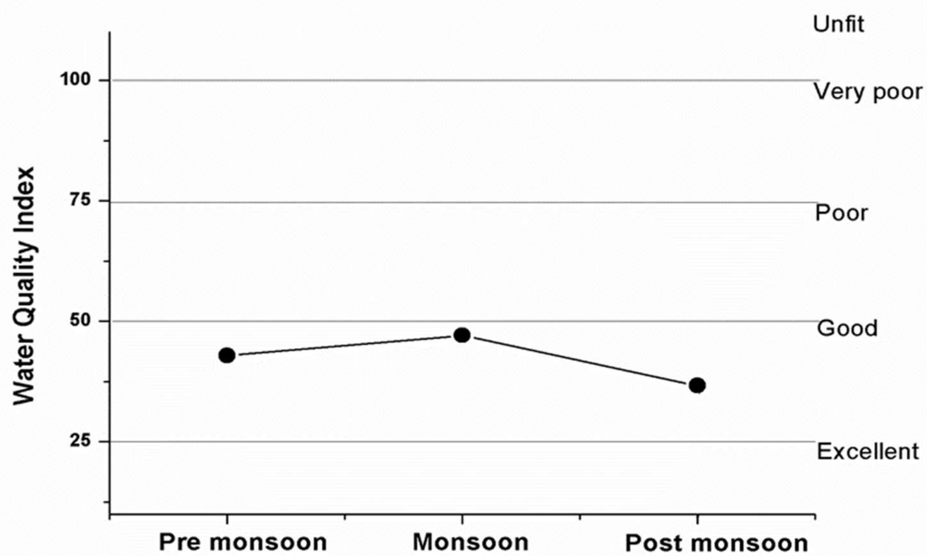



**Fig. 4.2:** Overall WQI rating of Doyang river

## 4.3 DISCUSSION

The calculation of WQI using 'weighted arithmetic index involves the estimation of 'unit weight' assigned to each physicochemical parameter selected. The different units and dimensions of the selected parameters are transformed into a common scale using the assigning units. Considering the significance of water quality assessment and their impact on the value of WQI, a maximum weightage of 0.366 is assigned to both DO and BOD, followed by pH having weighted 0.192. This indicates that DO, BOD, and pH have a major effect on the water quality in the present study area. Water quality indexes (WQI) were observed to have a positive relationship with the seasonal changes. Maximum WQI values were recorded during monsoon from all the eight stations followed by pre-monsoon and post-monsoon. A similar finding has also been reported by researchers like Singh and Kamal (2014), Bora and Goswami (2017) in their studies of assessment of surface water quality status. Despite observing some distortion during the monsoon, the overall average value (**Table 4.11**) indicates that the water quality of the Doyang river falls under the class of good water quality (25 < WQI < 50), which is suitable for drinking, irrigation, and industrial purpose (**Fig. 4**.**2**). In all the stations, both pre-monsoon and post-monsoon showed good water quality status. However, during monsoon, it indicated a poor water quality status at stations 2, 3, 4, and 5 which are all located midstream around the vicinity of the Hydro-Electric Dam.

The WQI values showed a mixed pattern of changes in all the seasons (**Fig. 4.1**). WQI of the upstream stations (S1), and midstream stations (S2-S5) were recorded higher than the downstream stations (S6-S8), showing a decrease in pollution level while moving downstream of the river. A similar observation was also made by a worker like Bora and Goswami (2017) in their studies of water quality assessment of Kolong River, Assam where the water samples showed a decrease in pollution as it further moves downstream of the river. Ewaid (2017) did observe a better water quality status upstream than downstream due to the decrease in water and accumulation of contaminants downstream of the river. However, this was not the case in the present study as better water quality status was observed downstream of the river. This could be due to the mitigatory role played by the riparian vegetation as water flows downstream of the river. Despite witnessing several land-use practices along the riparian zones of the Doyang river, the abundance of healthy riparian vegetation might have positively mitigated in controlling the pollution level of the river. Workers like Othman *et al*. (2012) and Naubi *et al*. (2016) have also shown encouraging results in the improvement of water quality due to proper management policy and remedial measures.

The present study found that sampling stations 2, 3, 4, and 5 experiencing an abrupt rise in pollution level. This perhaps might be because all these sampling stations are located around the vicinity of the Hydro-electric Dam. This circumstance has eventually allowed the water body to remain stagnant without any free movement and also made it vulnerable to multiple non-point source pollution due to the large surface and catchment area created by the Dam. Besides, during rainfall, the surface runoff from areas of poor vegetation cover and disturbed areas owing to intensive jhum agricultural practices and logging has led to the influx of a substantial amount of organic matter. All these factors could have played a crucial role in deteriorating the water quality in these stations. Particularly at station 1, the runoff of construction materials (concrete, asphalt, etc.) from the ongoing bridge construction of national highway (NH-02) across the river and cutting down of riparian hill slope for the same have significantly contributed towards the increased concentration of many of the water quality parameters analyzed. Moreover, the presence of some residential homes in the adjoining areas of station 1 has also played a significant role in influencing the physicochemical parameters of the water sample. Different land-use activities in the midstream stations (S2-S5) of the river like the extensive jhum cultivation and Teak plantation (monoculture) have all imposed a serious threat to the water quality. Besides, the burning of riparian forests annually for shifting cultivation, felling, and logging of trees for timber, picnic activities, tourism, and use of poison and explosives for fishing have all exerted considerable pressure in influencing the water quality of the Doyang river. Other anthropogenic activities like the sewage disposal from the residential communities that are residing along the riparian areas, agricultural runoff, unprotected river sites (Yisa and Jimoh, 2010; Bouslah *et al*., 2017; Shah and Joshi, 2017), and developmental activities continue to pose a major threat in deteriorating of water quality status of the Doyang river.

## 4.4 SUMMARY AND CONCLUSION

The study provides us with valuable information on the overall water quality status of the Doyang River by calculating the WQI values. Variables like the DO, BOD, and pH were found to have a major effect on the water quality in the present study but nutrient parameters had no such significant roles. WQI was found to positively respond to seasonal changes and the maximum WQI values were recorded during monsoon from all the eight stations followed by pre-monsoon and post-monsoon. As per the observation, recorded WQI values fall in good water quality status during pre and post-monsoon in all the sampling stations, while, poor water quality status during monsoon at sampling stations that are located upstream and midstream of the river. No considerable changes in WQI were observed throughout the study period except in few sites, where a modest increase in WQI was observed during monsoon. Nevertheless, the overall average WQI pre-monsoon-42.95, monsoon-47.13, and post-monsoon-36.66) indicated good water quality status. This indicates that the presence of riparian vegetation has positively mitigated the pollution level of the river. However, the disturbances like Jhum cultivation, extensive Teak plantation (monoculture), and increased settlements in the catchment area, the annual burning of the riparian forest for shifting cultivation, logging of trees for timber, picnic activities, tourism, poisoning of the river and use of explosives for fishing continue to impose a serious threat to the water quality of the Doyang. If these activities are not checked, it could lead to further deterioration of water quality in the near future. To further improve the water quality, proper management policy must be adopted on disposal of sewage by the communities residing in the catchment areas, agricultural runoff, unmanaged land-use practices, and unprotected riparian areas. A special focus on community participation in conservation efforts could be helpful. Remedial measures and management of riparian zones could play a positive role in future monitoring and improvement of Doyang river water quality.

# CHAPTER – 5

# PHYTODIVERSITY OF THE DOYANG RIPARIAN FOREST

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## 5.1 INTRODUCTION

'*Riparian forest*' refers to the vegetation that is present directly adjacent to the river. The riparian forest extends laterally from the active channel to the uplands, includes both the active floodplains and the immediate adjacent corridors. Riparian forests are recognized as a "key-stone ecosystem" as they harbor certain unique habitats that are highly influenced by water (Goebel *et al*., 2003). Olson *et al*. (2000) define a riparian forest as an ecosystem that lies immediately on both sides of riverbanks, including flood terraces, which interact with the river in flooding periods. Riparian vegetations are diverse in species composition, structure, and regeneration processes (Maingi and Marsh, 2006). The soil properties and topography in riparian areas vary significantly and this may lead to a high degree of structural and compositional diversity of riparian plant communities (Gregory *et al*., 1991). Riparian forests are important areas for global biodiversity (Sala *et al*., 2000) because they protect key resources for mankind, such as water sources, quality, and stream environment (Trimble, 1999). They also harbor diversified flora and physical structure (Kokou *et al*., 2002). Ecologists have recognized riparian forests as habitats for many animals and recognized them as a priority area for conservation of terrestrial mammals (Darveau *et al*., 2001), as well as birdlife (Saab, 1999; Woinarski *et al*., 2000).

Streamside forests, also sometimes referred to as 'riverine forests' are mostly controlled by the streamflow regime. Streamside forests are much more diverse, as they grow along channels that have changing environmental conditions from small mountain headwaters to a large river (Pielech, 2015). The availability of light, dissolved constituents' input (such as carbon or nitrogen), soil moisture, the magnitude of flood and duration, erosion and accumulation rates all constitute the longitudinal environmental gradient (Naiman *et al*., 1987, 2005; Gregory *et al*., 1991; Nadeau and Rains, 2007; Huang *et al*., 2013). Riparian vegetation in this system, respond positively to these changes with a continuous species turnover. Several authors have indicated the vegetation formation in these areas as botanically more diverse, higher tree density and basal area, luxuriant and presence of endemic species (Urban *et al*., 2006; Sunil *et al*., 2010; Sambaré *et al*., 2011; Iqbal, 2012; Aziem *et al*., 2016). In riparian areas, events of flooding constitute the major natural phenomenon controlling the biological community structure. Any changes in the flood regime have the potential to modify the indicative species even after their establishment (Crawford, 1996). In areas that are prone to flooding, the important determinant aspects of plant community composition are elevation and hydrogeomorphic processes (Goebel *et al*., 2006).

The natural channel, where the flow of water is either controlled or obstructed by manmade activities, may lead to the disappearance of the natural riparian vegetation (Taylor, 1983). Construction of Dam has altered the flow pattern of the river thereby limiting downstream movement of sediment and also the upstream and downstream movement of biological materials (Williams and Wolman, 1984; Jones and Stokes Associates, 1989; Johnson, 1992). Such alterations to the natural flow of the river reduce the meandering of the channel and eventually result in the loss of spatial heterogeneity in the riparian corridor (Johansson *et al*., 1996). Disturbances in streams or rivers due to hydroelectric facilities cause increased or decreased downstream vegetation cover (Pelzman, 1973; Turner, 1974; Turner and Karpiscak, 1980; Nagel and Dart, 1980). Other activities like clearing of vegetation for agriculture, livestock grazing, rise in human settlements and infrastructure, mining, and pollution continue to pose a serious threat to riparian ecosystems. (Tockner and Stanford, 2002; Naiman *et al*., 2005). Besides these, uncontrolled tourism activities also seem to exert immense pressure on the riparian forest, leading to a decline in typical riparian species composition (Sunil *et al*., 2016). Variations of riparian vegetation are not restricted from region to region only, but also shows variations along a single river line with altitude gradients and/or level of anthropogenic effects (Lovett and Price, 2010; Dibaba *et al*., 2014; Sunil *et al*., 2017). A study carried out by Meragiaw *et al*. (2018) along the Walga river, Southwestern Ethiopia indicated that about 42% of the variation in species richness per plot was explained by altitude gradient. Adel *et al*. (2018) have also indicated that the distribution of plant community along the river positively respond to factors such as Hydro-geomorphic process, flooding, gradients in elevation, distances from the river, and soil properties.

Land use types continue to pose a major threat to the riparian vegetation community. A study by Méndez-Toribio *et al*. (2014) showed convincing evidence on how the presence of various land-use types adjacent to the riverbank can potentially alter the community attributes, especially the species richness and density of riparian vegetation. Equivalent implication of land use practices on the community attributes of riparian vegetation was also indicated by Burton *et al*. (2005). Riparian vegetations are particularly vulnerable to any changes in the environment (Malanson, 1993) and they certainly display deterioration in its functions caused by the processes associated with changing land-use practices in any given landscape (Burton *et al*., 2005). Because of the fragile nature of the riparian system, some species are more vulnerable than others, and hence better land-use planning is the need of the hour (Mligo, 2017).

In the present study area, the different land-use practices have been found to have a negative impact on the assemblages of riparian vegetation. Vast areas of riparian vegetation in these areas are cut down successively each year for Jhum cultivation and tree plantation (monoculture) for timber. These activities disturbed the riparian vegetation along the river affecting the vegetation composition and other functional attributes like the loss of biodiversity and disruption in water hydrology. It has also led to the fragmentation of the riparian forest. Several quantitative studies on riparian forest plant diversity inventories have been conducted in India. Authors like Sunil *et al*. (2010) have worked in the Cauvery river of Tamil Nadu, Vargashe (2014) in Meenachil river basin of Kerela, Aziem *et al*. (2016) in Bhilangana Valley of Garhwal Himalaya, Sunil *et al*. (2016) in Cauvery river of southern India and Haq *et al*. (2019) in the protected forest of Kashmir. There is not much work or reports on the riparian forest of Nagaland except studies in certain zones along the Dikhu river, Nagaland, India by Leishangthem and Singh (2018). The present research work would eventually add more information on the status of riparian vegetation diversity and composition of the Doyang river, Wokha, Nagaland. This research will serve as a preliminary assessment of riparian vegetation along the Doyang river and would aid in formulating future conservation strategies. The main purpose of the present phytosociology analysis is to examine the species composition and diversity along the different zones (upstream, midstream, and downstream zone) of the Doyang river. The study would also look into the effects of anthropogenic disturbances on the plant species composition and major threats to riparian vegetation diversity.

## 5.2 RESULTS

**Table 5.1** shows the comprehensive quantitative analysis of riparian forest in the upstream, midstream, and downstream zone of the Doyang river. A total of 810 quadrats (150 quadrats for trees, 300 for shrubs and, 360 quadrats for herbs) were laid for the present study. A total of 174 plant species were recorded (68 trees, 54 shrubs and 52 herbs) along the different zones of the Doyang river represented by over 61 families. Rubiaceae comprised the maximum with 13 species followed by Moraceae with 11 species, Lamiaceae 10 species, Fabaceae and Euphorbiaceae 9 species each, Phyllanthaceae and Malvaceae 8 species each followed by other families as shown in **Table 5.2**. Total tree density upstream recorded the highest with 784 individuals $ha^{-1}$. Shrubs recorded the highest in the upstream with over 2664 individuals $ha^{-1}$. While in the case of herbs, midstream recorded the highest density with 197000 individuals $ha^{-1}$. The highest basal area for trees (63.47 $m^2$ $ha^{-1}$) and shrubs (22.60 $m^2$ $ha^{-1}$) was observed in the downstream zone of the river.

### 5.2.1 Vegetation composition and distribution pattern of the upstream zone

The upstream zone of the river recorded 92 species of plants (**Table 5.3, 5.4, 5.5**). A total of 392 individuals of trees represented by 32 species belonging to 19 families were identified within the 2 $ha^{-1}$ area (**Table 5.1**). A total of 666 individuals of shrubs belonging to 35 species represented by 22 families were recorded. A total of 1061 individuals of herbaceous plant that belong to 25 species and represented by 16 families were identified in the upstream zone of the river. Among the tree species in the upstream zone, *Sumbaviopsis albicans* recorded the maximum density (58 individuals $ha^{-1}$) and frequency (22 %) while *Bombax ceiba* (8 individuals $ha^{-1}$) and *Syzygium reticulatum* (8 individuals $ha^{-1}$) recorded the lowest density. *Syzygium reticulatum* was also found to exhibit the least frequency (4%). Amongst shrubs, *Chromolaena odorata* (244 individuals $ha^{-1}$) recorded the maximum density while the highest frequency was observed in *Capparis acutifolia* (11%). *Murraya paniculata* was recognized as the sparsely populated (20 indi. $ha^{-1}$) species among shrubs of the upstream zone and also the least frequent (2%). Amongst herbs, *Digitaria setigera*

(25416.67 individuals ha$^{-1}$) reported the maximum density, and *Dianella ensifolia* was observed as the most frequent (10.83%) species. *Solanum americanum* was observed as the least dense (24 individuals ha$^{-1}$) and least frequent (2%) herbaceous plant in the upstream zone. **Figure 5.1-5.3** shows the dominant trees, shrubs and herbs species based on their IVI recorded in the upstream zone of Doyang river. The highest IVI among the trees was observed in *Sumbaviopsis albicans* (15.95), *Wallichia oblongifolia* (88.38) among the shrubs and *Musa cheesmanii* (50.012) among the herbs of the upstream zone. The A/F ratio of all the riparian plants in the upstream zone recorded values >0.05 thus, indicating a contagious pattern of distribution. The distribution pattern of girth size in upstream zone were characterized as >10.1-15>5.1-10>15.1-20 >20.1-25 > 25.1-30 cm (**Fig. 5.4**).

**Table 5.1:** Comprehensive quantitative analysis of riparian forest in upstream, midstream, and downstream of the study area.

| Sites and vegetation type | | Number of plots | Number of individuals | Number of species | Number of families | Density (indi.ha$^{-1}$) | Basal area (m$^2$ ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| **Upstream** | a. Trees | 50 | 392 | 32 | 19 | 784 | 52.53 |
| | b. Shrub | 100 | 666 | 35 | 22 | 2664 | 16.19 |
| | c. Herb | 120 | 1061 | 25 | 16 | 87940.67 | 203.54 |
| **Midstream** | a. Trees | 50 | 325 | 22 | 14 | 650 | 25.89 |
| | b. Shrub | 100 | 448 | 20 | 13 | 1792 | 2.09 |
| | c. Herb | 120 | 2364 | 29 | 18 | 197000 | 138.32 |
| **Downstream** | a. Trees | 50 | 346 | 31 | 17 | 692 | 63.47 |
| | b. Shrub | 100 | 531 | 32 | 21 | 2124 | 22.60 |
| | c. Herb | 120 | 1911 | 24 | 15 | 159250 | 19.07 |
| Total | | 810 | 8043 | | | | |

Upstream: 48 families
Midstream: 37 families
Downstream: 43 families
Total plant species: 174 species (68 trees, 54 shrubs, and 52 herbs)

**Table 5.2:** Summary of families, genera and species composition recorded along Doyang river

| Sl.No | Family | Genera | Species |
|---|---|---|---|
| 1 | Rubiaceae | 12 | 13 |
| 2 | Moraceae | 3 | 11 |
| 3 | Lamiaceae | 8 | 10 |
| 4 | Fabaceae | 9 | 9 |
| 5 | Euphorbiaceae | 8 | 9 |
| 6 | Phyllanthaceae | 6 | 8 |
| 7 | Malvaceae | 8 | 8 |
| 8 | Asteraceae | 7 | 7 |

| | | | |
|---|---|---|---|
| 9 | Urticaceae | 4 | 5 |
| 10 | Commelinaceae | 4 | 5 |
| 11 | Zingiberaceae | 4 | 5 |
| 12 | Poaceae | 5 | 5 |
| 13 | Mrytaceae | 1 | 4 |
| 14 | Meliaceae | 4 | 4 |
| 15 | Lauraceae | 2 | 4 |
| 16 | Acanthaceae | 2 | 4 |
| 17 | Lythraceae | 3 | 3 |
| 18 | Primulaceae | 3 | 3 |
| 19 | Rutaceae | 3 | 3 |
| 20 | Bignoniaceae | 2 | 2 |
| 21 | Magnoliaceae | 1 | 2 |
| 22 | Araliaceae | 2 | 2 |
| 23 | Combretaceae | 2 | 2 |
| 24 | Ebenaceae | 1 | 2 |
| 25 | Anacardiaceae | 2 | 2 |
| 26 | Vitaceae | 1 | 2 |
| 27 | Annonaceae | 2 | 2 |
| 28 | Solanaceae | 2 | 2 |
| 29 | Asparagaceae | 2 | 2 |
| 30 | Musaceae | 1 | 2 |
| 31 | Polygonaceae | 2 | 2 |
| 32 | Cornaceae | 1 | 1 |
| 33 | Iteaceae | 1 | 1 |
| 34 | Rhizophoraceae | 1 | 1 |
| 35 | Apocynaceae | 1 | 1 |
| 36 | Capparaceae | 1 | 1 |
| 37 | Chloranthaceae | 1 | 1 |
| 38 | Gnetaceae | 1 | 1 |
| 39 | Piperaceae | 1 | 1 |
| 40 | Arecaceae | 1 | 1 |
| 41 | Malpighiaceae | 1 | 1 |
| 42 | Sapindaceae | 1 | 1 |
| 43 | Pentaphylacaceae | 1 | 1 |
| 44 | Opiliaceae | 1 | 1 |
| 45 | Melastomataceae | 1 | 1 |
| 46 | Amaryllidaceae | 1 | 1 |
| 47 | Marantaceae | 1 | 1 |
| 48 | Costaceae | 1 | 1 |
| 49 | Xanthorrhoeaceae | 1 | 1 |
| 50 | Boraginaceae | 1 | 1 |
| 51 | Amaranthaceae | 1 | 1 |
| 52 | Compositae | 1 | 1 |
| 53 | Cyperaceae | 1 | 1 |
| 54 | Gentianaceae | 1 | 1 |
| 55 | Oxalidaceae | 1 | 1 |
| 56 | Ranunculaceae | 1 | 1 |
| 57 | Leguminosae | 1 | 1 |
| 58 | Linderniaceae | 1 | 1 |
| 59 | Brassicaceae | 1 | 1 |
| 60 | Ulmaceae | 1 | 1 |
| 61 | Resedaceae | 1 | 1 |

**Table 5.3:** Quantitative analysis of trees at upstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind. ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Sumbaviopsis albicans* (Blume) J.J.Sm. | 22 | 58 | 1.207 | 2.298 | 7.398 | 6.250 | 15.95 | 2.64 | 0.12 | Contagious |
| *Syzygium megacarpum* (Craib) Rathakr. & N.C.Nair | 12 | 42 | 1.814 | 3.452 | 5.357 | 3.409 | 12.22 | 3.50 | 0.29 | Contagious |
| *Bombax ceiba* L. | 6 | 8 | 4.635 | 8.824 | 1.020 | 1.705 | 11.55 | 1.33 | 0.22 | Contagious |
| *Duabanga grandiflora* (DC.) Walp. | 10 | 28 | 2.432 | 4.629 | 3.571 | 2.841 | 11.04 | 2.80 | 0.28 | Contagious |
| *Callicarpa arborea* Roxb. | 18 | 34 | 0.833 | 1.585 | 4.337 | 5.114 | 11.04 | 1.89 | 0.10 | Contagious |
| *Brassaiopsis mitis* C.B.Clarke | 18 | 34 | 0.833 | 1.585 | 4.337 | 5.114 | 11.04 | 1.89 | 0.10 | Contagious |
| *Bischofia javanica* Blume | 14 | 26 | 1.960 | 3.730 | 3.316 | 3.977 | 11.02 | 1.86 | 0.13 | Contagious |
| *Colona floribunda* (Kurz) Craib | 16 | 30 | 1.368 | 2.604 | 3.827 | 4.545 | 10.98 | 1.88 | 0.12 | Contagious |
| *Neolamarckia cadamba* (Roxb.) Bosser | 10 | 16 | 3.109 | 5.918 | 2.041 | 2.841 | 10.80 | 1.60 | 0.16 | Contagious |
| *Melia azedarach* L. | 14 | 26 | 1.696 | 3.229 | 3.316 | 3.977 | 10.52 | 1.86 | 0.13 | Contagious |
| *Ficus auriculata* Lour. | 8 | 18 | 2.985 | 5.682 | 2.296 | 2.273 | 10.25 | 2.25 | 0.28 | Contagious |
| *Chukrasia tabularis* A. Juss. | 6 | 14 | 3.528 | 6.716 | 1.786 | 1.705 | 10.21 | 2.33 | 0.39 | Contagious |
| *Ficus obscura* Blume | 16 | 38 | 0.363 | 0.691 | 4.847 | 4.545 | 10.08 | 2.38 | 0.15 | Contagious |
| *Trevesia palmata* (Roxb. ex Lindl.) Vis. | 16 | 32 | 0.754 | 1.435 | 4.082 | 4.545 | 10.06 | 2.00 | 0.13 | Contagious |
| *Carallia brachiata* (Lour.) Merr. | 12 | 32 | 1.306 | 2.487 | 4.082 | 3.409 | 9.98 | 2.67 | 0.22 | Contagious |
| *Grewia abutilifolia* Vent. ex Juss. | 14 | 36 | 0.723 | 1.377 | 4.592 | 3.977 | 9.95 | 2.57 | 0.18 | Contagious |
| *Triadica cochinchinensis* Lour. | 6 | 14 | 3.267 | 6.219 | 1.786 | 1.705 | 9.71 | 2.33 | 0.39 | Contagious |
| *Ocotea lancifolia* (Schott) Mez | 14 | 30 | 0.985 | 1.874 | 3.827 | 3.977 | 9.68 | 2.14 | 0.15 | Contagious |
| *Magnolia hodgsonii* (Hook. f. & Thomson) H. Keng | 10 | 28 | 1.673 | 3.185 | 3.571 | 2.841 | 9.60 | 2.80 | 0.28 | Contagious |
| *Terminalia myriocarpa* Van Heurck & Müll. Arg. | 8 | 16 | 2.745 | 5.225 | 2.041 | 2.273 | 9.54 | 2.00 | 0.25 | Contagious |
| *Stereospermum tetragonum* DC. | 8 | 18 | 2.459 | 4.681 | 2.296 | 2.273 | 9.25 | 2.25 | 0.28 | Contagious |
| *Alangium chinense* (Lour.) Harms | 12 | 30 | 0.865 | 1.647 | 3.827 | 3.409 | 8.88 | 2.50 | 0.21 | Contagious |
| *Glochidion ellipticum* Wight | 14 | 26 | 0.465 | 0.886 | 3.316 | 3.977 | 8.18 | 1.86 | 0.13 | Contagious |
| *Dysoxylum excelsum* Blume | 12 | 20 | 1.149 | 2.188 | 2.551 | 3.409 | 8.15 | 1.67 | 0.14 | Contagious |
| *Albizia chinensis* (Osbeck) Merr. | 6 | 12 | 2.242 | 4.268 | 1.531 | 1.705 | 7.50 | 2.00 | 0.33 | Contagious |
| *Pterospermum acerifolium* (L.) Willd. | 6 | 14 | 1.960 | 3.730 | 1.786 | 1.705 | 7.22 | 2.33 | 0.39 | Contagious |
| *Itea macrophylla* Wall. | 10 | 26 | 0.430 | 0.818 | 3.316 | 2.841 | 6.98 | 2.60 | 0.26 | Contagious |
| *Litsea monopetala* (Roxb.) Pers. | 8 | 20 | 1.020 | 1.942 | 2.551 | 2.273 | 6.77 | 2.50 | 0.31 | Contagious |
| *Oreocnide integrifolia* (Gaudich.) Miq. | 8 | 14 | 1.410 | 2.683 | 1.786 | 2.273 | 6.74 | 1.75 | 0.22 | Contagious |
| *Sterculia coccinea* Jack. | 8 | 18 | 0.679 | 1.292 | 2.296 | 2.273 | 5.86 | 2.25 | 0.28 | Contagious |
| *Syzygium reticulatum* (Wight) Walp. | 4 | 8 | 1.410 | 2.683 | 1.020 | 1.136 | 4.84 | 2.00 | 0.50 | Contiguous |
| *Ficus concinna* (Miq.) Miq. | 6 | 18 | 0.229 | 0.436 | 2.296 | 1.705 | 4.44 | 3.00 | 0.50 | Contiguous |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.4:** Quantitative analysis of shrub at upstream riparian forested zone of Doyang River

| Species | FQ (%) | Density (ind./ ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Wallichia oblongifolia* Griff. | 9 | 44 | 13.325 | 82.296 | 1.654 | 4.433 | 88.38 | 1.22 | 0.14 | Contagious |
| *Chloranthus elatior* Link | 7 | 224 | 0.020 | 0.124 | 8.421 | 3.448 | 11.993 | 8.00 | 1.14 | Contagious |
| *Chromolaena odorata* (L.) R.M.King & H.Rob. | 5 | 244 | 0.020 | 0.124 | 9.173 | 2.463 | 11.760 | 12.20 | 2.44 | Contagious |
| *Ficus squamosa* Roxb. | 8 | 148 | 0.181 | 1.117 | 5.564 | 3.941 | 10.622 | 4.63 | 0.58 | Contagious |
| *Maesa indica* (Roxb.) A. DC. | 10 | 92 | 0.020 | 0.124 | 3.459 | 4.926 | 8.509 | 2.30 | 0.23 | Contagious |
| *Homonoia riparia* Lour. | 5 | 136 | 0.138 | 0.855 | 5.113 | 2.463 | 8.431 | 6.80 | 1.36 | Contagious |
| *Capparis acutifolia* Sweet | 11 | 68 | 0.062 | 0.380 | 2.556 | 5.419 | 8.355 | 1.55 | 0.14 | Contagious |
| *Pseuderanthemum crenulatum* (Wall. ex Lindl.) Radlk. | 9 | 92 | 0.008 | 0.048 | 3.459 | 4.433 | 7.941 | 2.56 | 0.28 | Contagious |
| *Mycetia longifolia* (Wall.) Kuntze | 9 | 84 | 0.053 | 0.328 | 3.158 | 4.433 | 7.919 | 2.33 | 0.26 | Contagious |
| *Piper lonchites* Schult. | 6 | 124 | 0.020 | 0.124 | 4.662 | 2.956 | 7.741 | 5.17 | 0.86 | Contagious |
| *Benkara griffithii* (Hook.f.) Ridsdale | 8 | 68 | 0.045 | 0.279 | 2.556 | 3.941 | 6.777 | 2.13 | 0.27 | Contagious |
| *Breynia retusa* (Dennst.) Alston | 7 | 60 | 0.166 | 1.026 | 2.256 | 3.448 | 6.730 | 2.14 | 0.31 | Contagious |
| *Eranthemum palatiferum* (Wall. ex Nees) Nees | 7 | 84 | 0.011 | 0.070 | 3.158 | 3.448 | 6.676 | 3.00 | 0.43 | Contagious |
| *Eranthemum pulchellum* Andrews | 7 | 76 | 0.011 | 0.070 | 2.857 | 3.448 | 6.375 | 2.71 | 0.39 | Contagious |
| *Glycosmis pentaphylla* (Retz.) DC. | 7 | 68 | 0.053 | 0.328 | 2.556 | 3.448 | 6.332 | 2.43 | 0.35 | Contagious |
| *Hiptage acuminata* Wall. ex A. Juss. | 5 | 84 | 0.113 | 0.700 | 3.158 | 2.463 | 6.321 | 4.20 | 0.84 | Contagious |
| *Premna pinguis* C.B.Clarke | 7 | 68 | 0.045 | 0.279 | 2.556 | 3.448 | 6.284 | 2.43 | 0.35 | Contagious |
| *Boehmeria glomerulifera* Miq. | 4 | 108 | 0.031 | 0.194 | 4.060 | 1.970 | 6.225 | 6.75 | 1.69 | Contagious |
| *Leea alata* Edgew. | 6 | 68 | 0.062 | 0.380 | 2.556 | 2.956 | 5.892 | 2.83 | 0.47 | Contagious |
| *Stixis suaveolens* (Roxburgh) Pierre | 6 | 52 | 0.138 | 0.855 | 1.955 | 2.956 | 5.766 | 2.17 | 0.36 | Contagious |
| *Clerodendrum infortunatum* L. | 6 | 60 | 0.080 | 0.496 | 2.256 | 2.956 | 5.708 | 2.50 | 0.42 | Contagious |
| *Ixora thwaitesii* Hook.f. | 5 | 48 | 0.212 | 1.311 | 1.805 | 2.463 | 5.579 | 2.40 | 0.48 | Contagious |
| *Callicarpa macrophylla* Vahl | 6 | 52 | 0.071 | 0.436 | 1.955 | 2.956 | 5.347 | 2.17 | 0.36 | Contagious |
| *Ardisia involucrata* Kurz | 5 | 44 | 0.126 | 0.776 | 1.654 | 2.463 | 4.893 | 2.20 | 0.44 | Contagious |
| *Flemingia strobilifera* (L.) W.T.Aiton | 3 | 72 | 0.113 | 0.700 | 2.707 | 1.478 | 4.885 | 6.00 | 2.00 | Contagious |
| *Clerodendrum robustum* Klotzsch | 5 | 48 | 0.091 | 0.560 | 1.805 | 2.463 | 4.828 | 2.40 | 0.48 | Contagious |
| *Mallotus leucocarpus* (Kurz) Airy Shaw | 4 | 52 | 0.113 | 0.700 | 1.955 | 1.970 | 4.625 | 3.25 | 0.81 | Contagious |
| *Gnetum acutum* Markgr. | 4 | 56 | 0.062 | 0.380 | 2.105 | 1.970 | 4.456 | 3.50 | 0.88 | Contagious |
| *Mussaenda roxburghii* Hook.f. | 4 | 56 | 0.045 | 0.279 | 2.105 | 1.970 | 4.355 | 3.50 | 0.88 | Contagious |
| *Allophylus chartaceus* (Kurz) Radlk. | 4 | 44 | 0.102 | 0.628 | 1.654 | 1.970 | 4.253 | 2.75 | 0.69 | Contagious |
| *Glochidion zeylanicum* (Gaertn.) A.Juss. | 3 | 28 | 0.264 | 1.631 | 1.053 | 1.478 | 4.161 | 2.33 | 0.78 | Contagious |
| *Leea indica* (Burm. f.) Merr. | 3 | 28 | 0.196 | 1.212 | 1.053 | 1.478 | 3.743 | 2.33 | 0.78 | Contagious |
| *Goniothalamus sesquipedalis* (Wall.) Hook.f. & Thomson | 4 | 36 | 0.045 | 0.279 | 1.353 | 1.970 | 3.603 | 2.25 | 0.56 | Contagious |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Embelia ribes* Burm.f. | 2 | 24 | 0.102 | 0.628 | 0.902 | 0.985 | 2.516 | 3.00 | 1.50 | Contagious |
| *Murraya paniculata* (L.) Jack | 2 | 20 | 0.045 | 0.279 | 0.752 | 0.985 | 2.016 | 2.50 | 1.25 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.5:** Quantitative analysis of herbs at upstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA $m^2$/ha | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Musa cheesmanii* N.W. Simmonds | 2.50 | 500.00 | 96.720 | 47.520 | 0.566 | 1.931 | 50.016 | 2.00 | 0.80 | Contagious |
| *Musa balbisiana* Colla | 3.33 | 583.33 | 83.281 | 40.917 | 0.660 | 2.574 | 44.151 | 1.75 | 0.53 | Contagious |
| *Digitaria setigera* Roth | 3.33 | 25416.67 | 0.126 | 0.062 | 28.746 | 2.574 | 31.382 | 76.25 | 22.88 | Contagious |
| *Oldenlandia tenelliflora* (Blume) Kuntze | 7.50 | 6333.33 | 0.126 | 0.062 | 7.163 | 5.792 | 13.016 | 8.44 | 1.13 | Contagious |
| *Ageratum conyzoides* (L.) L. | 5.00 | 6583.33 | 0.196 | 0.096 | 7.446 | 3.861 | 11.403 | 13.17 | 2.63 | Contagious |
| *Dianella ensifolia* (L.) DC. | 10.83 | 2250.00 | 0.950 | 0.467 | 2.545 | 8.366 | 11.377 | 2.08 | 0.19 | Contagious |
| *Amischotolype hookeri* (Hassk.) H.Hara | 6.67 | 4083.33 | 0.385 | 0.189 | 4.618 | 5.148 | 9.955 | 6.13 | 0.92 | Contagious |
| *Pollia subumbellata* C.B.Clarke | 9.17 | 2333.33 | 0.385 | 0.189 | 2.639 | 7.079 | 9.907 | 2.55 | 0.28 | Contagious |
| *Commelina benghalensis* L. | 6.67 | 3583.33 | 0.385 | 0.189 | 4.053 | 5.148 | 9.390 | 5.38 | 0.81 | Contagious |
| *Zingiber rubens* Roxb. | 7.50 | 1250.00 | 3.799 | 1.867 | 1.414 | 5.792 | 9.072 | 1.67 | 0.22 | Contagious |
| *Elatostema rupestre* (Buch.-Ham. ex D.Don) Wedd. | 5.00 | 4416.67 | 0.196 | 0.096 | 4.995 | 3.861 | 8.953 | 8.83 | 1.77 | Contagious |
| *Torenia cordifolia* Roxb. | 4.17 | 4916.67 | 0.126 | 0.062 | 5.561 | 3.218 | 8.840 | 11.80 | 2.83 | Contagious |
| *Rumex nepalensis* Spreng. | 5.83 | 3000.00 | 0.283 | 0.139 | 3.393 | 4.505 | 8.036 | 5.14 | 0.88 | Contagious |
| *Arundo donax* L. | 3.33 | 3416.67 | 2.834 | 1.392 | 3.864 | 2.574 | 7.831 | 10.25 | 3.08 | Contagious |
| *Elatostema monandrum* (Buch.-Ham. ex D.Don) H.Hara | 5.00 | 3083.33 | 0.385 | 0.189 | 3.487 | 3.861 | 7.537 | 6.17 | 1.23 | Contagious |
| *Cheilocostus speciosus* (J.Koenig) C.D.Specht | 5.83 | 1333.33 | 2.543 | 1.250 | 1.508 | 4.505 | 7.262 | 2.29 | 0.39 | Contagious |
| *Gomphostemma parviflorum* Wall. ex Benth. | 5.83 | 1416.67 | 2.010 | 0.987 | 1.602 | 4.505 | 7.094 | 2.43 | 0.42 | Contagious |
| *Floscopa scandens* Lour. | 4.17 | 3083.33 | 0.502 | 0.247 | 3.487 | 3.218 | 6.952 | 7.40 | 1.78 | Contagious |
| *Crinum amoenum* Ker Gawl. ex Roxb. | 5.00 | 1083.33 | 3.462 | 1.701 | 1.225 | 3.861 | 6.787 | 2.17 | 0.43 | Contagious |
| *Rorippa indica* (L.) Hiern | 5.00 | 2250.00 | 0.283 | 0.139 | 2.545 | 3.861 | 6.545 | 4.50 | 0.90 | Contagious |
| *Amomum subulatum* Roxb. | 5.00 | 1083.33 | 2.834 | 1.392 | 1.225 | 3.861 | 6.479 | 2.17 | 0.43 | Contagious |
| *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda | 2.50 | 3166.67 | 0.785 | 0.386 | 3.582 | 1.931 | 5.898 | 12.67 | 5.07 | Contagious |
| *Phrynium pubinerve* Blume | 5.00 | 1416.67 | 0.636 | 0.312 | 1.602 | 3.861 | 5.776 | 2.83 | 0.57 | Contagious |
| *Crassocephalum crepidioides* (Benth.) S.Moore | 3.33 | 1333.33 | 0.283 | 0.139 | 1.508 | 2.574 | 4.221 | 4.00 | 1.20 | Contagious |
| *Solanum americanum* Mill. | 2.00 | 24.00 | 0.025 | 0.012 | 0.566 | 1.544 | 2.122 | 3.00 | 1.50 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

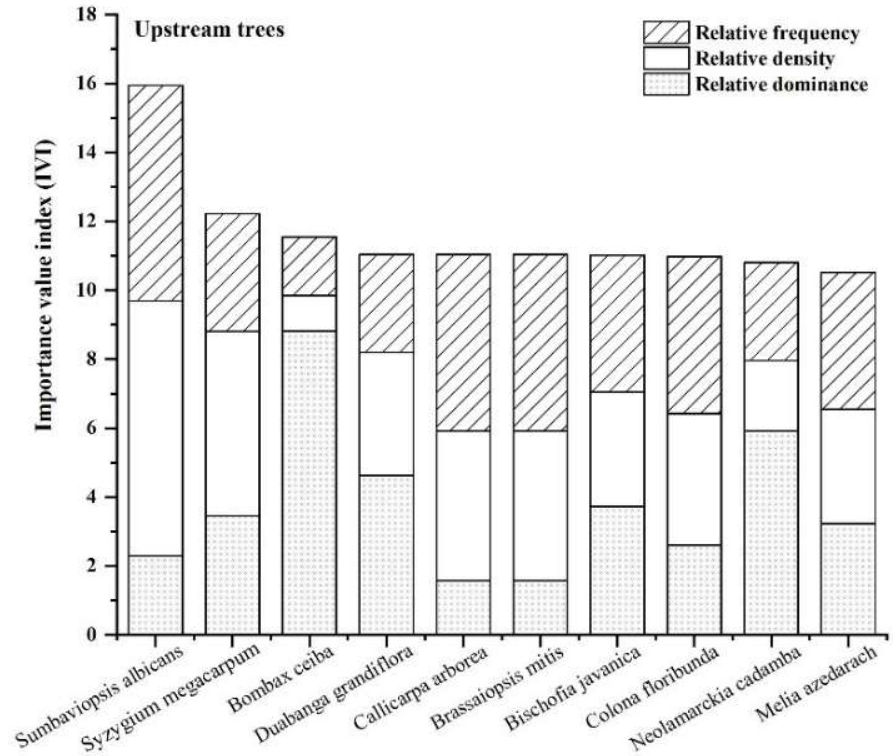


**Fig. 5.1:** Dominant tree species based on IVI in the upstream zone

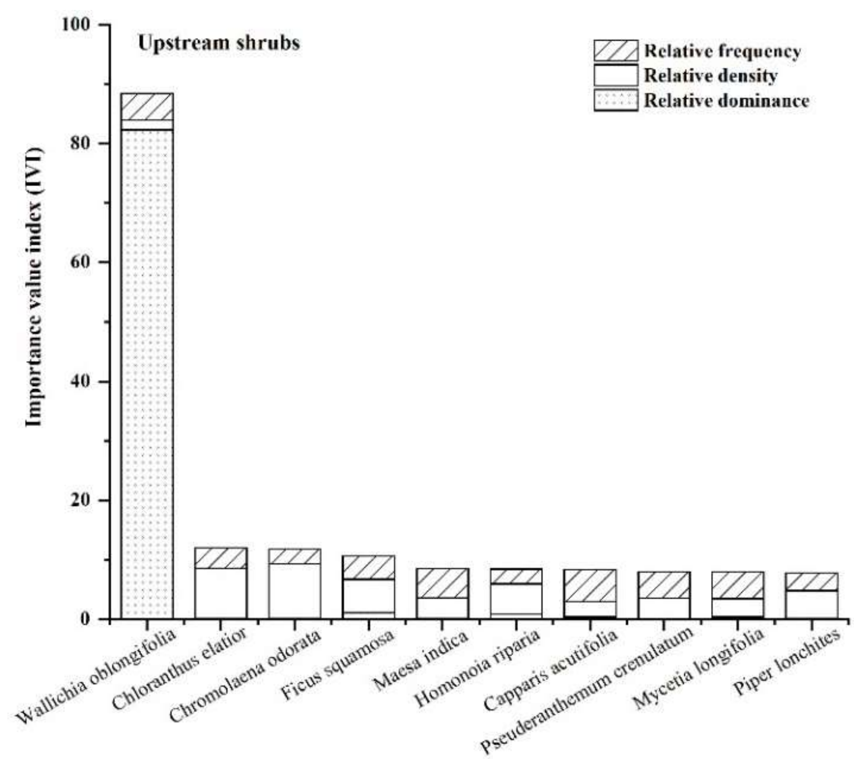


**Fig. 5.2:** Dominant shrub species based on IVI in the upstream zone

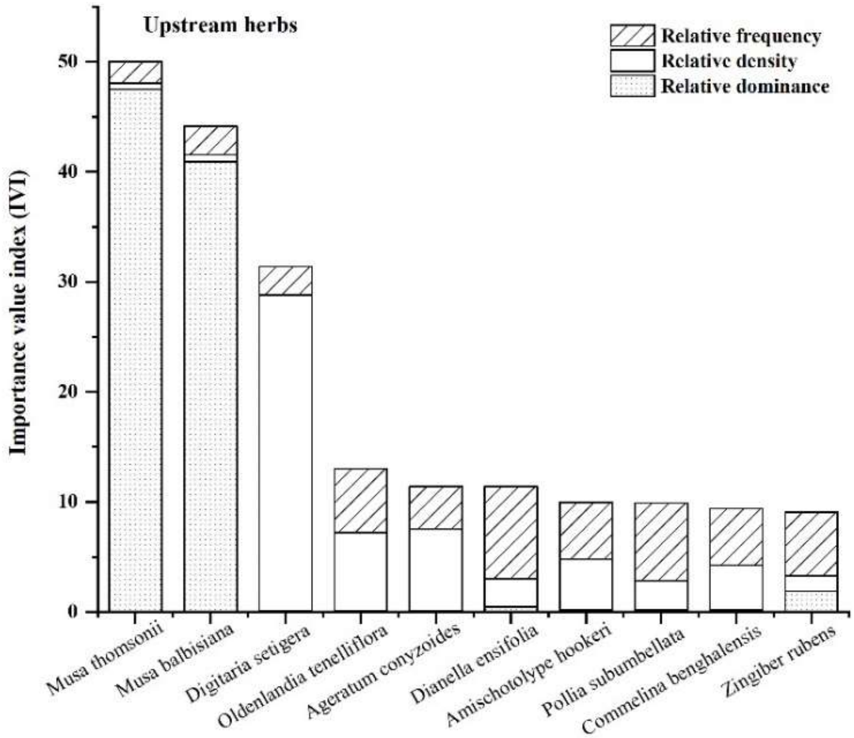


**Fig. 5.3:** Dominant herb species based on IVI in the upstream zone

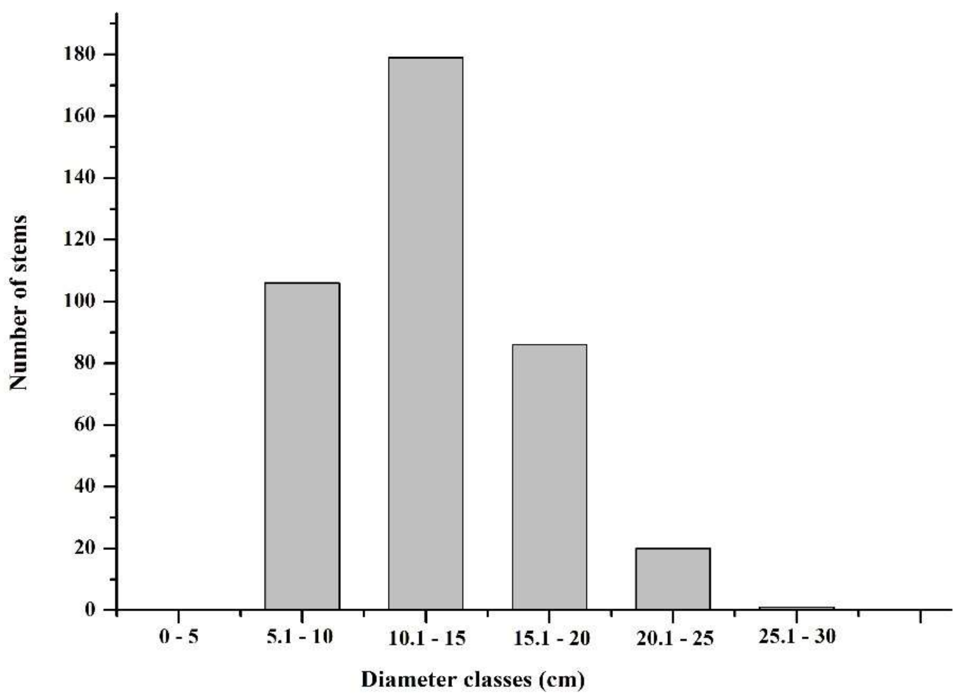


**Fig. 5.4:** Diameter class distribution of trees in upstream riparian zone

### 5.2.2 Vegetation composition and distribution pattern of the midstream zone

In the midstream zone, altogether 71 species of plants were documented (**Table 5.6, 5.7, 5.8**). A total of 325 tree individuals represented by 22 species belonging to 14 families were identified within the 2 $ha^{-1}$ areas of the plot (**Table 5.1**). Likewise, a total of 448 individuals of shrub belonging to 20 species represented by 13 families were recorded. Also, a total of 2364 individuals of herb represented by 29 species belonging to 18 families were identified. *Wrightia arborea* recorded the highest density (78 individuals $ha^{-1}$) and frequency (26 %) amongst the trees, while, *Stereospermum tetragonum* (10 individuals $ha^{-1}$) and *Syzygium syzygioides* (10 individuals $ha^{-1}$) observed the lowest density. *Toona ciliata* (6%) and *Syzygium syzygioides* (6%) recorded the lowest frequency amongst the tree species of the midstream zone. Among shrubs, *Chromolaena odorata* (508 individuals $ha^{-1}$) recorded the highest density. The highest frequency of shrub was observed in *Capparis acutifolia* (13%). *Combretum yunnanense* was recognized as the least dense (12 individuals $ha^{-1}$) and the least frequent (1%) shrub species. Amongst herbs, *Digitaria setigera* (37333.33 individuals $ha^{-1}$) recorded the highest density and *Carex baccans* were observed as the most frequent (12.50%). The least density among the herbaceous plant of the midstream zone was observed in *Alpinia roxburghii* (750 individuals $ha^{-1}$) and species like *Heliotropium indicum, Cuphea carthagenensis, Alpinia roxburghii, Crotalaria pallida, Solanum americanum, Thysanolaena latifolia* and *Musa balbisiana* were reported as the least frequent (3.33%) herbaceous plants in the midstream zone of the river. **Figure 5.5-5.7** shows the dominant trees, shrubs, and herbs species based on their IVI recorded in the midstream zone of the Doyang river. *Wrightia arborea* (22.59) reported the highest IVI among trees, *Chromolaena odorata* (36.66) among shrubs, and *Musa balbisiana* (87.04) recorded the highest IVI among the herbs. The values of A/F ratio of all the riparian plants in the midstream zone observed >0.05, indicating species distribution pattern in the midstream zone as contagious. The distribution pattern of girth size in midstream zone were characterized as >10.1-15>5.1-10>15.1-20 >0-5>20.1-25 cm (**Fig. 5.8**).

**Table 5.6:** Quantitative analysis of trees at midstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Wrightia arborea* (Dennst.) Mabb. | 26 | 78 | 0.528 | 2.038 | 12.000 | 8.553 | 22.591 | 3.00 | 0.12 | Contagious |
| *Bauhinia variegata* L. | 20 | 62 | 0.882 | 3.406 | 9.538 | 6.579 | 19.524 | 3.10 | 0.16 | Contagious |
| *Lagerstroemia speciosa* (L.) Pers. | 16 | 54 | 1.168 | 4.512 | 8.308 | 5.263 | 18.083 | 3.38 | 0.21 | Contagious |
| *Toona ciliata* M.Roem. | 6 | 14 | 3.528 | 13.625 | 2.154 | 1.974 | 17.753 | 2.33 | 0.39 | Contagious |
| *Lannea coromandelica* (Houtt.) Merr. | 12 | 16 | 2.432 | 9.391 | 2.462 | 3.947 | 15.800 | 1.33 | 0.11 | Contagious |
| *Albizia chinensis* (Osbeck) Merr. | 14 | 24 | 1.935 | 7.473 | 3.692 | 4.605 | 15.770 | 1.71 | 0.12 | Contagious |
| *Colona floribunda* (Kurz) Craib | 22 | 34 | 0.849 | 3.279 | 5.231 | 7.237 | 15.747 | 1.55 | 0.07 | Contagious |
| *Melia azedarach* L. | 18 | 30 | 1.266 | 4.890 | 4.615 | 5.921 | 15.426 | 1.67 | 0.09 | Contagious |
| *Morus macroura* Miq. | 18 | 34 | 1.002 | 3.871 | 5.231 | 5.921 | 15.023 | 1.89 | 0.10 | Contagious |
| *Mitragyna rotundifolia* (Roxb.) kuntze | 16 | 36 | 0.967 | 3.735 | 5.538 | 5.263 | 14.537 | 2.25 | 0.14 | Contagious |
| *Derris robusta* (DC.) Benth. | 18 | 26 | 0.754 | 2.912 | 4.000 | 5.921 | 12.833 | 1.44 | 0.08 | Contagious |
| *Litsea cubeba* (Lour.) Pers. | 14 | 34 | 0.739 | 2.852 | 5.231 | 4.605 | 12.688 | 2.43 | 0.17 | Contagious |
| *Oroxylum indicum* (L.) Kurz | 10 | 14 | 1.628 | 6.286 | 2.154 | 3.289 | 11.730 | 1.40 | 0.14 | Contagious |
| *Artocarpus heterophyllus* Lam. | 8 | 18 | 1.605 | 6.199 | 2.769 | 2.632 | 11.600 | 2.25 | 0.28 | Contagious |
| *Kydia calycina* Roxb. | 12 | 22 | 1.075 | 4.150 | 3.385 | 3.947 | 11.482 | 1.83 | 0.15 | Contagious |
| *Stereospermum tetragonum* DC. | 8 | 10 | 1.814 | 7.004 | 1.538 | 2.632 | 11.174 | 1.25 | 0.16 | Contagious |
| *Ficus hispida* L.f. | 12 | 26 | 0.833 | 3.216 | 4.000 | 3.947 | 11.164 | 2.17 | 0.18 | Contagious |
| *Macaranga denticulata* (Blume) Müll. Arg. | 10 | 28 | 0.916 | 3.536 | 4.308 | 3.289 | 11.133 | 2.80 | 0.28 | Contagious |
| *Phyllanthus emblica* L. | 16 | 30 | 0.173 | 0.670 | 4.615 | 5.263 | 10.548 | 1.88 | 0.12 | Contagious |
| *Baliospermum solanifolium* (Burm.) Suresh | 12 | 22 | 0.769 | 2.971 | 3.385 | 3.947 | 10.303 | 1.83 | 0.15 | Contagious |
| *Ocotea lancifolia* (Schott) Mez | 10 | 28 | 0.246 | 0.951 | 4.308 | 3.289 | 8.548 | 2.80 | 0.28 | Contagious |
| *Syzygium syzygioides* (Miq.) Merr. & L.M.Perry | 6 | 10 | 0.785 | 3.032 | 1.538 | 1.974 | 6.544 | 1.67 | 0.28 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.7:** Quantitative analysis of shrubs at midstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Chromolaena odorata* (L.) R.M.King & H.Rob. | 10 | 508 | 0.015 | 0.736 | 28.348 | 7.576 | 36.660 | 12.70 | 1.27 | Contagious |
| *Combretum yunnanense* Exell | 1 | 12 | 0.453 | 21.688 | 0.670 | 0.758 | 23.115 | 3.00 | 3.00 | Contagious |
| *Breynia retusa* (Dennst.) Alston | 7 | 68 | 0.246 | 11.775 | 3.795 | 5.303 | 20.873 | 2.43 | 0.35 | Contagious |
| *Capparis acutifolia* Sweet | 13 | 108 | 0.071 | 3.379 | 6.027 | 9.848 | 19.255 | 2.08 | 0.16 | Contagious |
| *Croton caudatus* Geiseler | 6 | 92 | 0.152 | 7.269 | 5.134 | 4.545 | 16.949 | 3.83 | 0.64 | Contagious |
| *Morinda angustifolia* Roxb. | 9 | 84 | 0.091 | 4.341 | 4.688 | 6.818 | 15.846 | 2.33 | 0.26 | Contagious |
| *Dracaena angustifolia* (Medik.) Roxb. | 3 | 36 | 0.229 | 10.949 | 2.009 | 2.273 | 15.231 | 3.00 | 1.00 | Contagious |
| *Benkara griffithii* (Hook.f.) Ridsdale | 12 | 76 | 0.038 | 1.817 | 4.241 | 9.091 | 15.149 | 1.58 | 0.13 | Contagious |
| *Maesa indica* (Roxb.) A.DC. | 9 | 116 | 0.031 | 1.502 | 6.473 | 6.818 | 14.793 | 3.22 | 0.36 | Contagious |
| *Clerodendrum infortunatum* L. | 8 | 60 | 0.102 | 4.866 | 3.348 | 6.061 | 14.275 | 1.88 | 0.23 | Contagious |
| *Melastoma malabathricum* L. | 8 | 84 | 0.062 | 2.944 | 4.688 | 6.061 | 13.692 | 2.63 | 0.33 | Contagious |
| *Holmskioldia sanguinea* Retz. | 4 | 68 | 0.138 | 6.624 | 3.795 | 3.030 | 13.449 | 4.25 | 1.06 | Contagious |
| *Clerodendrum robustum* Klotzsch | 7 | 72 | 0.071 | 3.379 | 4.018 | 5.303 | 12.700 | 2.57 | 0.37 | Contagious |
| *Flueggea virosa* (Roxb. ex Willd.) Royle | 5 | 52 | 0.113 | 5.422 | 2.902 | 3.788 | 12.112 | 2.60 | 0.52 | Contagious |
| *Eurya acuminata* DC. | 7 | 84 | 0.025 | 1.217 | 4.688 | 5.303 | 11.207 | 3.00 | 0.43 | Contagious |
| *Mussaenda glabra* Vahl | 6 | 68 | 0.031 | 1.502 | 3.795 | 4.545 | 9.842 | 2.83 | 0.47 | Contagious |
| *Dalbergia stipulacea* Roxb. | 3 | 44 | 0.102 | 4.866 | 2.455 | 2.273 | 9.594 | 3.67 | 1.22 | Contagious |
| *Uraria crinita* (L.) DC. | 5 | 80 | 0.020 | 0.961 | 4.464 | 3.788 | 9.213 | 4.00 | 0.80 | Contagious |
| *Mussaenda roxburghii* Hook. f. | 5 | 48 | 0.038 | 1.817 | 2.679 | 3.788 | 8.284 | 2.40 | 0.48 | Contagious |
| *Leea indica* (Burm. f.) Merr. | 4 | 32 | 0.062 | 2.944 | 1.786 | 3.030 | 7.760 | 2.00 | 0.50 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.8:** Quantitative analysis of Herbs at Midstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Musa balbisiana* Colla | 3.33 | 1166.67 | 116.839 | 84.467 | 0.592 | 1.980 | 87.040 | 3.50 | 1.05 | Contagious |
| *Digitaria setigera* Roth | 9.17 | 37333.33 | 0.196 | 0.142 | 18.951 | 5.446 | 24.538 | 40.73 | 4.44 | Contagious |
| *Imperata cylindrica* (L.) Raeusch | 4.17 | 28916.67 | 0.283 | 0.204 | 14.679 | 2.475 | 17.358 | 69.40 | 16.66 | Contagious |
| *Carex baccans* Nees | 12.50 | 4083.33 | 0.950 | 0.687 | 2.073 | 7.426 | 10.185 | 3.27 | 0.26 | Contagious |
| *Spermacoce articularis* L.f. | 5.83 | 11166.67 | 0.283 | 0.204 | 5.668 | 3.465 | 9.338 | 19.14 | 3.28 | Contagious |
| *Crassocephalum crepidioides* (Benth.) S.Moore | 7.50 | 8416.67 | 0.283 | 0.204 | 4.272 | 4.455 | 8.932 | 11.22 | 1.50 | Contagious |
| *Setaria viridis* (L.) P.Beauv. | 5.83 | 9916.67 | 0.126 | 0.091 | 5.034 | 3.465 | 8.590 | 17.00 | 2.91 | Contagious |
| *Sonchus arvensis* L. | 10.83 | 3000.00 | 0.283 | 0.204 | 1.523 | 6.436 | 8.163 | 2.77 | 0.26 | Contagious |
| *Ranunculus sceleratus* L. | 6.67 | 7333.33 | 0.385 | 0.278 | 3.723 | 3.960 | 7.961 | 11.00 | 1.65 | Contagious |
| *Ageratum conyzoides* (L.) L. | 4.17 | 10583.33 | 0.126 | 0.091 | 5.372 | 2.475 | 7.938 | 25.40 | 6.10 | Contagious |
| *Curcuma angustifolia* Roxb. | 9.17 | 1583.33 | 2.010 | 1.453 | 0.804 | 5.446 | 7.702 | 1.73 | 0.19 | Contagious |
| *Zingiber rubens* Roxb. | 8.33 | 1416.67 | 2.543 | 1.839 | 0.719 | 4.950 | 7.508 | 1.70 | 0.20 | Contagious |
| *Canscora andrographioides* Griff. ex C.B.Clarke | 5.83 | 7583.33 | 0.196 | 0.142 | 3.849 | 3.465 | 7.457 | 13.00 | 2.23 | Contagious |
| *Pouzolzia zeylanica* (L.) Benn. | 5.83 | 7250.00 | 0.196 | 0.142 | 3.680 | 3.465 | 7.287 | 12.43 | 2.13 | Contagious |
| *Alternanthera sessilis* (L.) R.Br. ex DC. | 5.00 | 6583.33 | 0.385 | 0.278 | 3.342 | 2.970 | 6.590 | 13.17 | 2.63 | Contagious |
| *Oxalis corniculata* L. | 5.00 | 7000.00 | 0.071 | 0.051 | 3.553 | 2.970 | 6.575 | 14.00 | 2.80 | Contagious |
| *Bidens bipinnata* L. | 5.00 | 6500.00 | 0.283 | 0.204 | 3.299 | 2.970 | 6.474 | 13.00 | 2.60 | Contagious |
| *Persicaria decipiens* (R.Br.) K.L.Wilson | 5.00 | 6083.33 | 0.385 | 0.278 | 3.088 | 2.970 | 6.336 | 12.17 | 2.43 | Contagious |
| *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda | 3.33 | 6500.00 | 1.130 | 0.817 | 3.299 | 1.980 | 6.097 | 19.50 | 5.85 | Contagious |
| *Amomum subulatum* Roxb. | 6.67 | 1333.33 | 2.010 | 1.453 | 0.677 | 3.960 | 6.090 | 2.00 | 0.30 | Contagious |
| *Dianella ensifolia* (L.) DC. | 6.67 | 1916.67 | 1.327 | 0.959 | 0.973 | 3.960 | 5.892 | 2.88 | 0.43 | Contagious |
| *Xanthium strumarium* L. | 4.17 | 4750.00 | 1.130 | 0.817 | 2.411 | 2.475 | 5.704 | 11.40 | 2.74 | Contagious |
| *Cheilocostus speciosus* (J.Koenig) C.D.Specht | 5.83 | 1083.33 | 2.010 | 1.453 | 0.550 | 3.465 | 5.468 | 1.86 | 0.32 | Contagious |
| *Physalis minima* L. | 5.83 | 2833.33 | 0.636 | 0.460 | 1.438 | 3.465 | 5.363 | 4.86 | 0.83 | Contagious |
| *Heliotropium indicum* L. | 3.33 | 5500.00 | 0.636 | 0.460 | 2.792 | 1.980 | 5.232 | 16.50 | 4.95 | Contagious |
| *Cuphea carthagenensis* (Jacq.) J.F. Macbr. | 3.33 | 3583.33 | 0.126 | 0.091 | 1.819 | 1.980 | 3.890 | 10.75 | 3.23 | Contagious |
| *Alpinia roxburghii* Sweet | 3.33 | 750.00 | 1.766 | 1.277 | 0.381 | 1.980 | 3.638 | 2.25 | 0.68 | Contagious |
| *Crotalaria pallida* Aiton | 3.33 | 1583.33 | 0.950 | 0.687 | 0.804 | 1.980 | 3.471 | 4.75 | 1.43 | Contagious |
| *Solanum americanum* Mill. | 3.33 | 1250.00 | 0.785 | 0.568 | 0.635 | 1.980 | 3.182 | 3.75 | 1.13 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

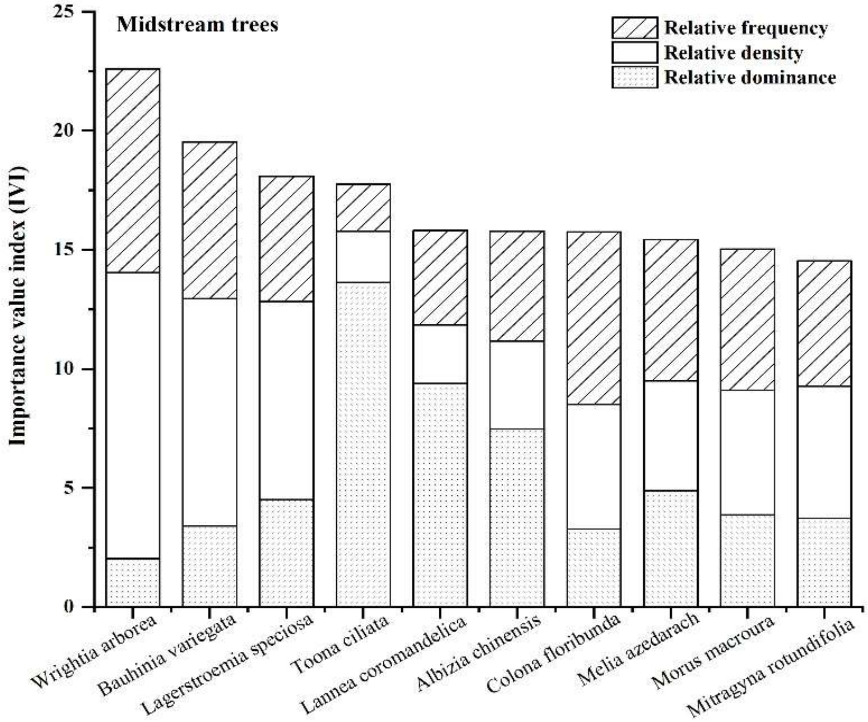


**Fig. 5.5:** Dominant tree species based on IVI in the midstream zone

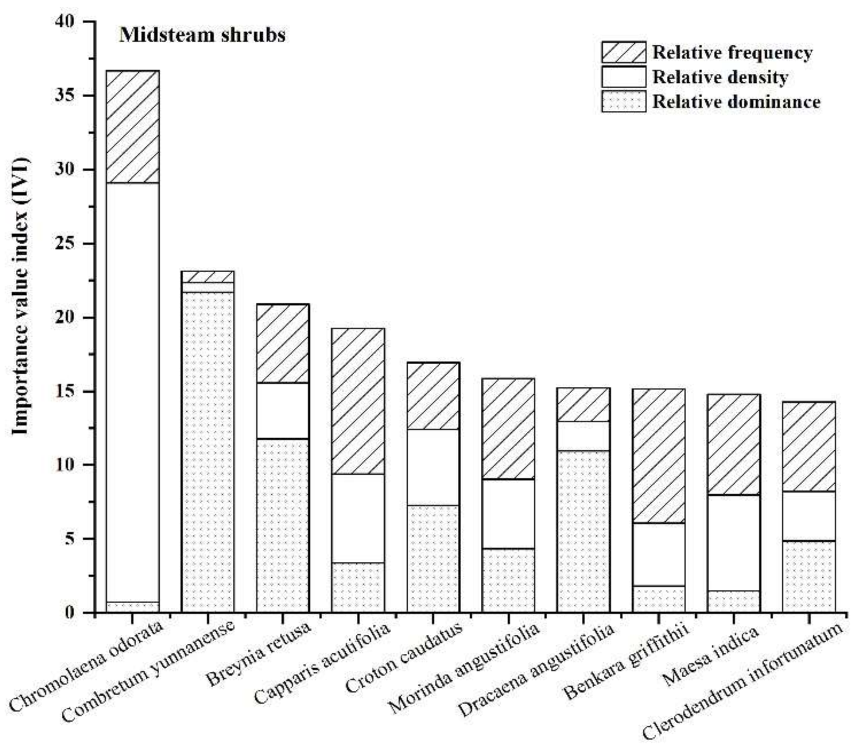


**Fig. 5.6:** Dominant shrub species based on IVI in the midstream zone

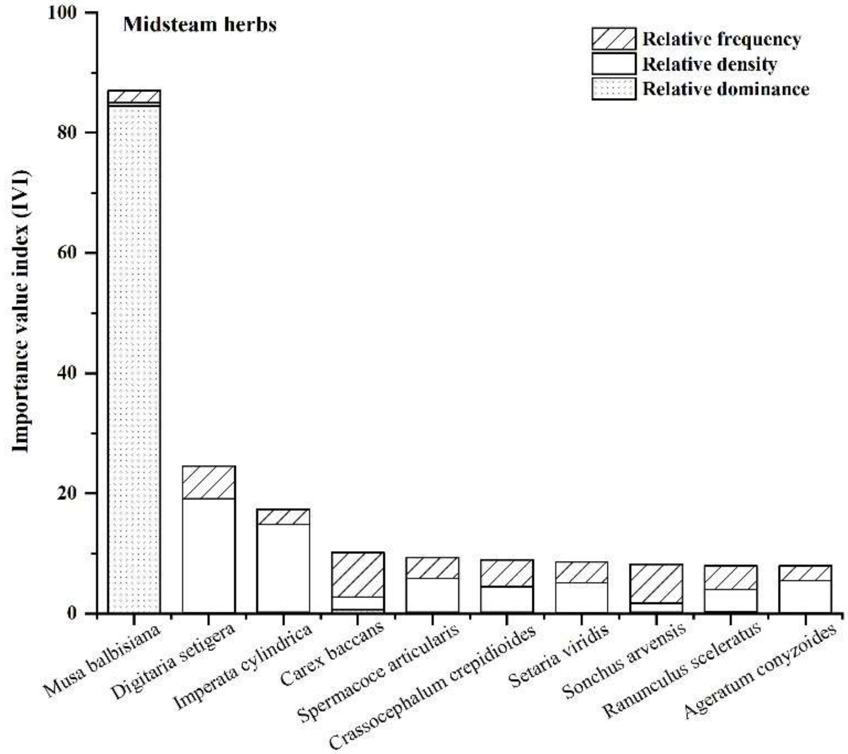


**Fig. 5.7:** Dominant herb species based on IVI in the midstream zone

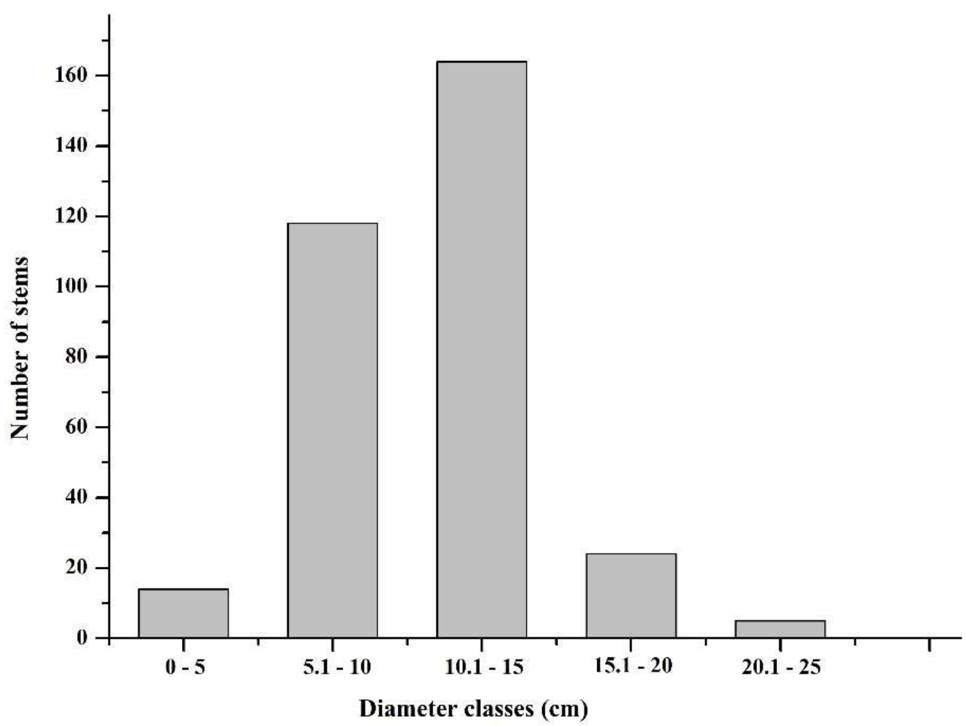


**Fig. 5.8:** Diameter class distribution of trees in midstream riparian zone

### 5.2.3 Vegetation composition and distribution pattern of the downstream zone

The downstream zone of the river recorded a total of 87 species of plants (**Table 5.9, 5.10, 5.11**). Trees comprised of 346 individuals represented by over 31 species belonging to 17 families were noted within the 2 $ha^{-1}$ areas of the plot (**Table 5.1**). Similarly, 531 individuals of shrubs that belong to 32 species and represented by over 21 families were recorded. A total of 1911 individuals of herbs belonging to 24 species represented by 15 families were also identified in the downstream zone. Amongst the tree species, *Aporosa octandra* reported the maximum density (54 individuals $ha^{-1}$) while, *Ulmus lanceifolia* observed the least density (4 individuals $ha^{-1}$). Species like *Diospyros stricta* and *Carallia brachiata* recorded the maximum frequency (14 %) and *Ulmus lanceifolia* reported the least (2%). *Chromolaena odorata* (292 individuals $ha^{-1}$) recorded the highest density, while, *Wallichia oblongifolia*, *Miliusa roxburghiana*, and *Leea indica* recorded the lowest density (16 individuals $ha^{-1}$) among the shrubs of the downstream zone. The highest shrub frequency was observed in *Maesa indica* (10%). *Digitaria setigera* (69083.33 individuals $ha^{-1}$) was observed as the most densely populated herbaceous plant while *Amomum subulatum* (500 individuals $ha^{-1}$) was observed the least. The highest frequency among herbs in downstream was also observed in *Digitaria setigera* (10.83%) while the lowest frequency (2.50%) was observed in *Alpinia roxburghii* and *Ophiorrhiza oppositiflora*. **Figure 5.9-5.11** shows the dominant trees, shrubs, and herbs species of downstream zone based on their observed IVI. The tree with the highest IVI in the downstream zone was observed in *Ficus benjamina* (17.36), *Wallichia oblongifolia* (85.50) among shrubs, and *Digitaria setigera* (52.85) among herbaceous plants. The A/F ratio of riparian plants in the downstream zone also recorded values that were >0.05. This suggests an equivalent pattern of contagious species distribution to upstream and midstream zone. The distribution pattern of girth size in downstream zone were characterized as >10.1-15>5.1-10>15.1-20 >0-5>20.1-25 > 25.1-30>30.1-35 cm (**Fig. 5.12**).

**Table 5.9:** Quantitative analysis of trees at downstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA $m^2/ha$ | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Ficus benjamina* L. | 4 | 6 | 9.452 | 14.892 | 0.867 | 1.600 | 17.359 | 1.50 | 0.38 | Contagious |
| *Magnolia champaca* (L.) Baill. ex Pierre | 8 | 46 | 3.462 | 5.454 | 6.647 | 3.200 | 15.302 | 5.75 | 0.72 | Contagious |
| *Carallia brachiata* (Lour.) Merr. | 14 | 34 | 2.060 | 3.246 | 4.913 | 5.600 | 13.759 | 2.43 | 0.17 | Contagious |
| *Gmelina arborea* Roxb. | 12 | 34 | 2.377 | 3.744 | 4.913 | 4.800 | 13.458 | 2.83 | 0.24 | Contagious |
| *Bombax ceiba* L. | 6 | 8 | 5.980 | 9.421 | 1.156 | 2.400 | 12.977 | 1.33 | 0.22 | Contagious |
| *Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery | 10 | 54 | 0.145 | 0.229 | 7.803 | 4.000 | 12.032 | 5.40 | 0.54 | Contagious |
| *Balakata baccata* (Roxb.) Esser | 10 | 18 | 3.299 | 5.198 | 2.601 | 4.000 | 11.799 | 1.80 | 0.18 | Contagious |
| *Tectona grandis* L.f. | 10 | 30 | 2.189 | 3.449 | 4.335 | 4.000 | 11.784 | 3.00 | 0.30 | Contagious |
| *Mitragyna rotundifolia* (Roxb.) kuntze | 12 | 34 | 1.306 | 2.058 | 4.913 | 4.800 | 11.771 | 2.83 | 0.24 | Contagious |
| *Stereospermum tetragonum* DC. | 4 | 10 | 5.513 | 8.685 | 1.445 | 1.600 | 11.730 | 2.50 | 0.63 | Contagious |
| *Triadica cochinchinensis* Lour. | 4 | 10 | 5.225 | 8.232 | 1.445 | 1.600 | 11.278 | 2.50 | 0.63 | Contagious |
| *Croton persimilis* Müll. Arg. | 10 | 38 | 1.056 | 1.664 | 5.491 | 4.000 | 11.156 | 3.80 | 0.38 | Contagious |
| *Macaranga denticulata* (Blume) Müll. Arg. | 10 | 34 | 1.227 | 1.932 | 4.913 | 4.000 | 10.846 | 3.40 | 0.34 | Contagious |
| *Ocotea lancifolia* (Schott) Mez | 12 | 36 | 0.166 | 0.262 | 5.202 | 4.800 | 10.264 | 3.00 | 0.25 | Contagious |
| *Diospyros stricta* Roxb. | 14 | 30 | 0.204 | 0.322 | 4.335 | 5.600 | 10.257 | 2.14 | 0.15 | Contagious |
| *Artocarpus chama* Buch.-Ham. | 8 | 18 | 2.322 | 3.659 | 2.601 | 3.200 | 9.460 | 2.25 | 0.28 | Contagious |
| *Itea macrophylla* Wall. | 10 | 30 | 0.679 | 1.070 | 4.335 | 4.000 | 9.405 | 3.00 | 0.30 | Contagious |
| *Wendlandia tinctoria* (Roxb.) DC. | 8 | 28 | 1.347 | 2.122 | 4.046 | 3.200 | 9.369 | 3.50 | 0.44 | Contagious |
| *Diospyros variegata* Kurz | 12 | 26 | 0.322 | 0.507 | 3.757 | 4.800 | 9.064 | 2.17 | 0.18 | Contagious |
| *Archidendron clypearia* (Jack) I.C.Nielsen | 10 | 28 | 0.622 | 0.980 | 4.046 | 4.000 | 9.026 | 2.80 | 0.28 | Contagious |
| *Ulmus lanceifolia* Roxb. ex Wall. | 2 | 4 | 4.789 | 7.545 | 0.578 | 0.800 | 8.923 | 2.00 | 1.00 | Contagious |
| *Artocarpus lacucha* Buch.-Ham. | 6 | 14 | 1.985 | 3.127 | 2.023 | 2.400 | 7.550 | 2.33 | 0.39 | Contagious |
| *Litsea cubeba* (Lour.) Pers. | 8 | 18 | 0.833 | 1.312 | 2.601 | 3.200 | 7.113 | 2.25 | 0.28 | Contagious |
| *Hibiscus macrophyllus* Roxb. Ex Hornem. | 6 | 8 | 2.010 | 3.166 | 1.156 | 2.400 | 6.722 | 1.33 | 0.22 | Contagious |
| *Rhus chinensis* Mill. | 6 | 12 | 1.188 | 1.871 | 1.734 | 2.400 | 6.005 | 2.00 | 0.33 | Contagious |
| *Glochidion ellipticum* Wight | 6 | 18 | 0.622 | 0.980 | 2.601 | 2.400 | 5.981 | 3.00 | 0.50 | Contagious |
| *Syzygium syzygioides* (Miq.) Merr. & L.M.Perry | 4 | 6 | 1.985 | 3.127 | 0.867 | 1.600 | 5.594 | 1.50 | 0.38 | Contagious |
| *Trevesia palmata* (Roxb. ex Lindl.) Vis. | 6 | 16 | 0.490 | 0.772 | 2.312 | 2.400 | 5.484 | 2.67 | 0.44 | Contagious |
| *Ficus nervosa* B.Heyne ex Roth | 6 | 16 | 0.145 | 0.229 | 2.312 | 2.400 | 4.941 | 2.67 | 0.44 | Contagious |
| *Litsea salicifolia* (J. Roxb. ex Nees) Hook. f. | 6 | 14 | 0.322 | 0.507 | 2.023 | 2.400 | 4.930 | 2.33 | 0.39 | Contagious |
| *Syzygium balsameum* (Wight) Wall. ex Walp. | 6 | 14 | 0.152 | 0.239 | 2.023 | 2.400 | 4.663 | 2.33 | 0.39 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.10:** Quantitative analysis of shrubs at downstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA $m^2$/ha | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Wallichia oblongifolia* Griff. | 2 | 16 | 18.848 | 83.378 | 0.753 | 1.370 | 85.502 | 2.00 | 1.00 | Contagious |
| *Chromolaena odorata* (L.) R.M.King & H.Rob. | 8 | 292 | 0.031 | 0.139 | 13.748 | 5.479 | 19.366 | 9.13 | 1.14 | Contagious |
| *Maesa indica* (Roxb.) A. DC. | 10 | 108 | 0.025 | 0.113 | 5.085 | 6.849 | 12.047 | 2.70 | 0.27 | Contagious |
| *Urena lobata* L. | 5 | 172 | 0.020 | 0.089 | 8.098 | 3.425 | 11.611 | 8.60 | 1.72 | Contagious |
| *Homonoia riparia* Lour. | 5 | 132 | 0.138 | 0.613 | 6.215 | 3.425 | 10.252 | 6.60 | 1.32 | Contagious |
| *Premna pinguis* C.B.Clarke | 6 | 88 | 0.038 | 0.168 | 4.143 | 4.110 | 8.421 | 3.67 | 0.61 | Contagious |
| *Clerodendrum infortunatum* L. | 7 | 64 | 0.102 | 0.450 | 3.013 | 4.795 | 8.258 | 2.29 | 0.33 | Contagious |
| *Eranthemum palatiferum* Hook.f. | 3 | 116 | 0.020 | 0.089 | 5.461 | 2.055 | 7.605 | 9.67 | 3.22 | Contagious |
| *Melastoma malabathricum* L. | 5 | 68 | 0.166 | 0.735 | 3.202 | 3.425 | 7.361 | 3.40 | 0.68 | Contagious |
| *Micromelum pubescens* Blume | 5 | 44 | 0.385 | 1.702 | 2.072 | 3.425 | 7.198 | 2.20 | 0.44 | Contagious |
| *Clerodendrum robustum* Klotzsch | 6 | 52 | 0.126 | 0.556 | 2.448 | 4.110 | 7.113 | 2.17 | 0.36 | Contagious |
| *Gnetum acutum* Markgr. | 6 | 52 | 0.102 | 0.450 | 2.448 | 4.110 | 7.008 | 2.17 | 0.36 | Contagious |
| *Mycetia longifolia* (Wall.) Kuntze | 5 | 68 | 0.071 | 0.313 | 3.202 | 3.425 | 6.939 | 3.40 | 0.68 | Contagious |
| *Boehmeria glomerulifera* Miq. | 4 | 84 | 0.038 | 0.168 | 3.955 | 2.740 | 6.863 | 5.25 | 1.31 | Contagious |
| *Callicarpa macrophylla* Vahl | 6 | 44 | 0.138 | 0.613 | 2.072 | 4.110 | 6.794 | 1.83 | 0.31 | Contagious |
| *Mussaenda glabra* Vahl | 6 | 52 | 0.045 | 0.200 | 2.448 | 4.110 | 6.758 | 2.17 | 0.36 | Contagious |
| *Stixis suaveolens* (Roxburgh) Pierre | 5 | 52 | 0.138 | 0.613 | 2.448 | 3.425 | 6.485 | 2.60 | 0.52 | Contagious |
| *Croton caudatus* Geiseler | 5 | 48 | 0.181 | 0.800 | 2.260 | 3.425 | 6.485 | 2.40 | 0.48 | Contagious |
| *Morinda angustifolia* Roxb. | 5 | 56 | 0.071 | 0.313 | 2.637 | 3.425 | 6.374 | 2.80 | 0.56 | Contagious |
| *Psychotria erratica* Hook.f. | 4 | 64 | 0.080 | 0.356 | 3.013 | 2.740 | 6.109 | 4.00 | 1.00 | Contagious |
| *Eranthemum indicum* (Nees) C.B.Clarke | 4 | 68 | 0.031 | 0.139 | 3.202 | 2.740 | 6.080 | 4.25 | 1.06 | Contagious |
| *Tadehagi triquetrum* (L.) H.Ohashi | 5 | 52 | 0.031 | 0.139 | 2.448 | 3.425 | 6.012 | 2.60 | 0.52 | Contagious |
| *Ixora thwaitesii* Hook.f. | 5 | 32 | 0.166 | 0.735 | 1.507 | 3.425 | 5.666 | 1.60 | 0.32 | Contagious |
| *Dracaena angustifolia* (Medik.) Roxb. | 3 | 52 | 0.246 | 1.089 | 2.448 | 2.055 | 5.592 | 4.33 | 1.44 | Contagious |
| *Phyllanthus leschenaultii* Müll.Arg. | 4 | 32 | 0.264 | 1.168 | 1.507 | 2.740 | 5.415 | 2.00 | 0.50 | Contagious |
| *Breynia retusa* (Dennst.) Alston | 3 | 36 | 0.212 | 0.939 | 1.695 | 2.055 | 4.689 | 3.00 | 1.00 | Contagious |
| *Allophylus chartaceus* (Kurz) Radlk. | 3 | 40 | 0.102 | 0.450 | 1.883 | 2.055 | 4.388 | 3.33 | 1.11 | Contagious |
| *Eurya acuminata* DC. | 2 | 60 | 0.020 | 0.089 | 2.825 | 1.370 | 4.284 | 7.50 | 3.75 | Contagious |
| *Lepionurus sylvestris* Blume | 3 | 20 | 0.264 | 1.168 | 0.942 | 2.055 | 4.165 | 1.67 | 0.56 | Contagious |
| *Miliusa roxburghiana* Hook.f. & Thomson | 2 | 16 | 0.246 | 1.089 | 0.753 | 1.370 | 3.212 | 2.00 | 1.00 | Contagious |
| *Leea indica* (Burm. f.) Merr. | 2 | 16 | 0.196 | 0.868 | 0.753 | 1.370 | 2.991 | 2.00 | 1.00 | Contiguous |
| *Leea alata* Edgew. | 2 | 28 | 0.062 | 0.272 | 1.318 | 1.370 | 2.960 | 3.50 | 1.75 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

**Table 5.11:** Quantitative analysis of herbs at downstream riparian forested zone of Doyang River

| **Species** | FQ (%) | Density (ind./ ha) | BA ($m^2$/ha) | R.DOM (%) | R.DEN (%) | R.FEQ (%) | IVI | Abundance | A/F ratio | Distribution pattern |
|---|---|---|---|---|---|---|---|---|---|---|
| *Digitaria setigera* Roth | 10.83 | 69083.33 | 0.196 | 1.029 | 43.380 | 8.442 | 52.851 | 63.77 | 5.89 | Contagious |
| *Ageratina riparia* (Regel) R.M.King & H.Rob. | 5.83 | 24916.67 | 0.385 | 2.017 | 15.646 | 4.545 | 22.209 | 42.71 | 7.32 | Contagious |
| *Cheilocostus speciosus* (J.Koenig) C.D.Specht | 4.17 | 916.67 | 2.543 | 13.339 | 0.576 | 3.247 | 17.161 | 2.20 | 0.53 | Contagious |
| *Amomum subulatum* Roxb. | 3.33 | 500.00 | 2.543 | 13.339 | 0.314 | 2.597 | 16.250 | 1.50 | 0.45 | Contagious |
| *Amomum koenigii* J.F.Gmel. | 5.00 | 1500.00 | 2.010 | 10.539 | 0.942 | 3.896 | 15.377 | 3.00 | 0.60 | Contagious |
| *Spermacoce articularis* L.f. | 6.67 | 11083.33 | 0.283 | 1.482 | 6.960 | 5.195 | 13.637 | 16.63 | 2.49 | Contagious |
| *Curcuma angustifolia* Roxb. | 3.33 | 750.00 | 2.010 | 10.539 | 0.471 | 2.597 | 13.608 | 2.25 | 0.68 | Contagious |
| *Dianella ensifolia* (L.) DC. | 5.83 | 1500.00 | 1.327 | 6.958 | 0.942 | 4.545 | 12.445 | 2.57 | 0.44 | Contagious |
| *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda | 5.83 | 4416.67 | 0.950 | 4.981 | 2.773 | 4.545 | 12.300 | 7.57 | 1.30 | Contagious |
| *Carex baccans* Nees | 6.67 | 1833.33 | 0.950 | 4.981 | 1.151 | 5.195 | 11.328 | 2.75 | 0.41 | Contagious |
| *Commelina benghalensis* L. | 9.17 | 2166.67 | 0.385 | 2.017 | 1.361 | 7.143 | 10.521 | 2.36 | 0.26 | Contagious |
| *Pollia subumbellata* C.B.Clarke | 7.50 | 1833.33 | 0.636 | 3.335 | 1.151 | 5.844 | 10.330 | 2.44 | 0.33 | Contagious |
| *Ageratum conyzoides* (L.) L. | 5.83 | 7083.33 | 0.196 | 1.029 | 4.448 | 4.545 | 10.023 | 12.14 | 2.08 | Contagious |
| *Acmella paniculata* (Wall. ex DC.) R.K.Jansen | 5.00 | 5916.67 | 0.283 | 1.482 | 3.715 | 3.896 | 9.094 | 11.83 | 2.37 | Contagious |
| *Canscora andrographioides* Griff. ex C.B.Clarke | 5.83 | 5250.00 | 0.196 | 1.029 | 3.297 | 4.545 | 8.871 | 9.00 | 1.54 | Contagious |
| *Pollia secundiflora* (Blume) Bakh.f. | 6.67 | 1583.33 | 0.502 | 2.635 | 0.994 | 5.195 | 8.824 | 2.38 | 0.36 | Contagious |
| *Alpinia roxburghii* Sweet | 2.50 | 500.00 | 1.130 | 5.928 | 0.314 | 1.948 | 8.190 | 2.00 | 0.80 | Contagious |
| *Peliosanthes teta* Andrews | 5.00 | 2333.33 | 0.502 | 2.635 | 1.465 | 3.896 | 7.996 | 4.67 | 0.93 | Contagious |
| *Elatostema rupestre* (Buch.-Ham. ex D.Don) Wedd. | 5.00 | 3750.00 | 0.283 | 1.482 | 2.355 | 3.896 | 7.733 | 7.50 | 1.50 | Contagious |
| *Setaria viridis* (L.) P.Beauv. | 5.00 | 4583.33 | 0.126 | 0.659 | 2.878 | 3.896 | 7.433 | 9.17 | 1.83 | Contagious |
| *Rumex nepalensis* Spreng. | 4.17 | 3833.33 | 0.283 | 1.482 | 2.407 | 3.247 | 7.136 | 9.20 | 2.21 | Contagious |
| *Ophiorrhiza oppositiflora* Hook.f. | 2.50 | 583.33 | 0.785 | 4.117 | 0.366 | 1.948 | 6.431 | 2.33 | 0.93 | Contagious |
| *Scutellaria discolor* Colebr. | 3.33 | 1916.67 | 0.283 | 1.482 | 1.204 | 2.597 | 5.283 | 5.75 | 1.73 | Contagious |
| *Mimosa pudica* L. | 3.33 | 1416.67 | 0.283 | 1.482 | 0.890 | 2.597 | 4.969 | 4.25 | 1.28 | Contagious |

Note: FQ: Frequency, BA: Basal area, R.DOM: Relative dominance, R.DEN: Relative density, R.FEQ: Relative frequency, IVI: Importance value index, A/F: Abundance/Frequency

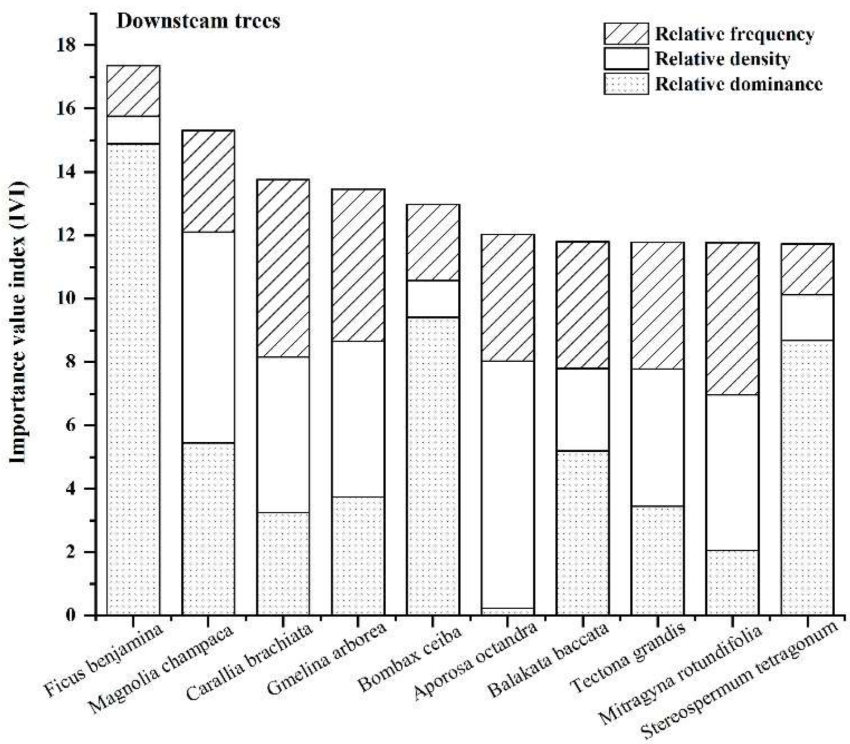


**Fig. 5.9:** Dominant tree species based on IVI in the downstream zone

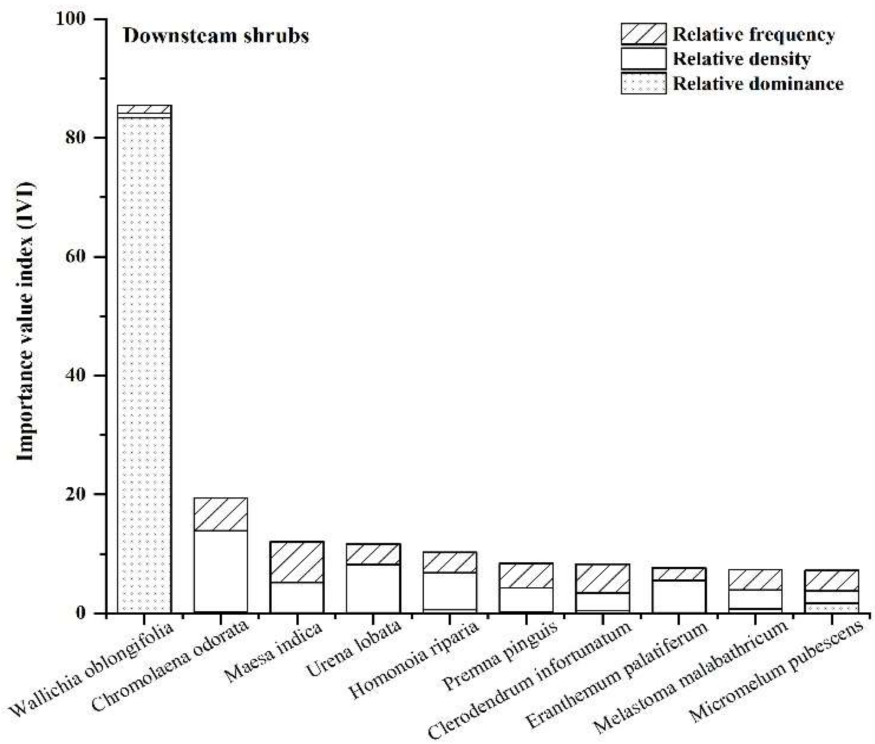


**Fig. 5.10:** Dominant shrub species based on IVI in the downstream zone

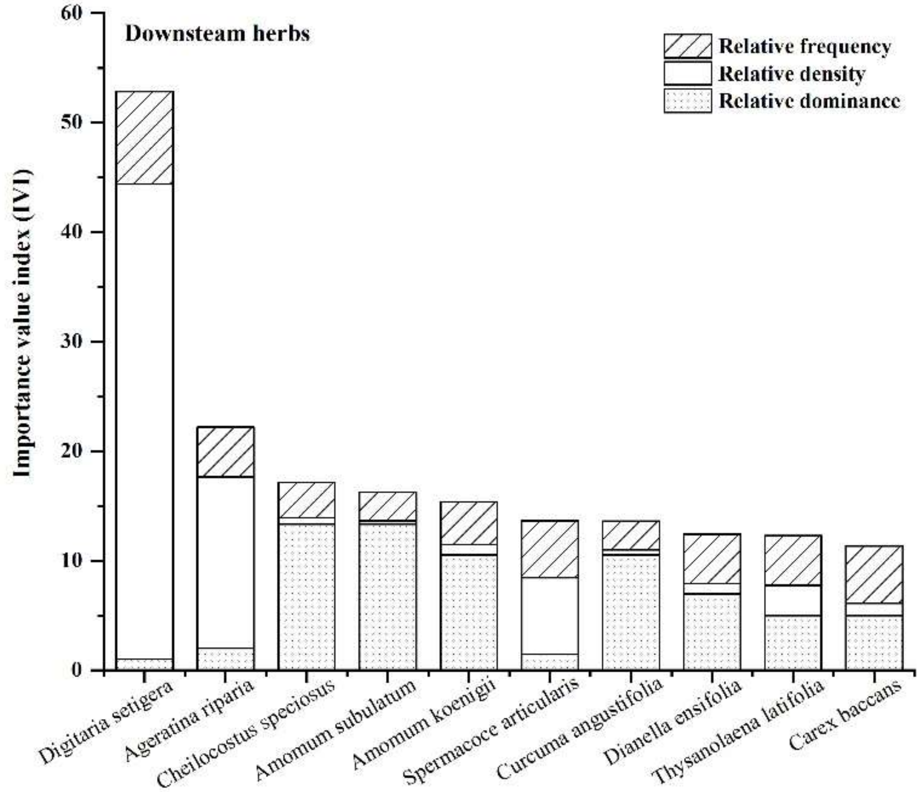


**Fig. 5.11:** Dominant herb species based on IVI in the downstream zone

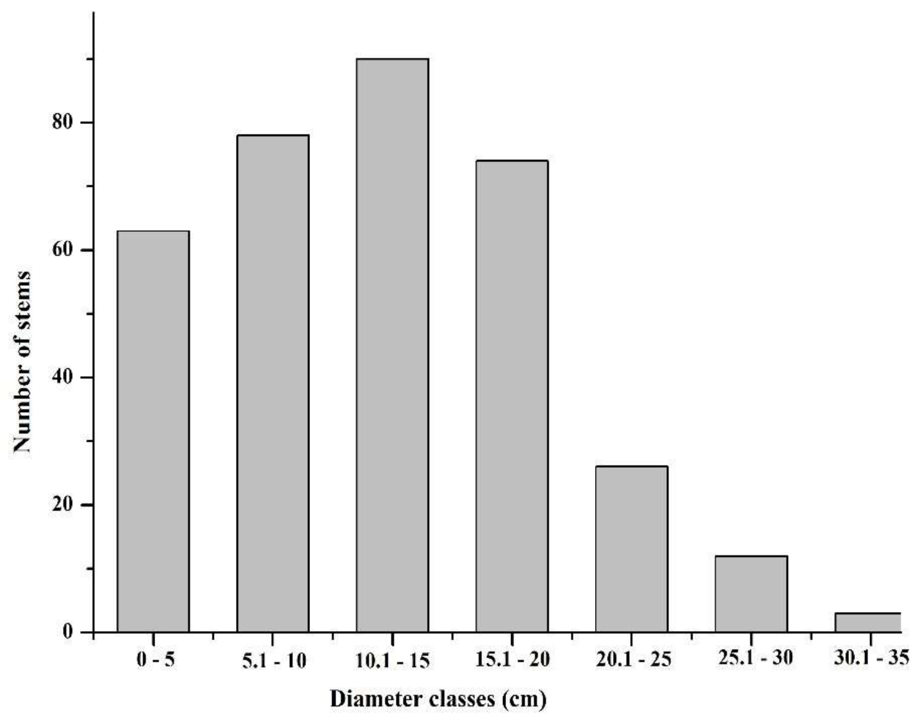


**Fig. 5.12:** Diameter class distribution of trees in downstream riparian zone

### 5.2.4 Diversity indices and life forms in different zone of the Doyang river

**Table 5.12** shows the diversity indices of riparian plant communities at the upstream, midstream, and downstream zone of the Doyang river. The trees and shrubs of upstream (trees-3.373 and shrubs-3.387) and downstream zones (trees-3.274 and shrubs-3.230) recorded the maximum Shanon index (H′) whereas, the herbs of the midstream zone recorded the maximum Shanon index (2.154). Margalef richness index (R) absolute value was recorded in upstream shrubs (5.385) and the minimum was noted in downstream shrubs (3.176). The trees of the upstream zone recorded the maximum Simpson index of diversity (0.965) while the downstream herbs recorded the minimum Simpson index (0.774). Maximum evenness (J) was observed amongst the trees (0.973) of the upstream zone and the least evenly distributed species was noted in downstream herbs (0.669). In terms of similarity of species composition between the different zones of the Doyang river, the shrubs composition of the upstream and downstream zone (0.537) showed the maximum similarity. The tree species composition recorded the least similarity in the upstream and midstream zone as shown in **Table 5.13**.

**Table 5.12:** Diversity indices of riparian plants at upstream, midstream and downstream zone of Doyang river.

| Sites | | Shanon index (H′) | Margalef index (R) | Evenness (J) | Simpson index (1-D) |
|---|---|---|---|---|---|
| **Upstream** | a. Trees | 3.373 | 5.191 | 0.973 | 0.965 |
| | b. Shrub | 3.387 | 5.385 | 0.945 | 0.961 |
| | c. Herb | 2.718 | 3.445 | 0.844 | 0.888 |
| **Midstream** | a. Trees | 2.956 | 3.631 | 0.956 | 0.944 |
| | b. Shrub | 2.649 | 3.276 | 0.870 | 0.891 |
| | c. Herb | 2.908 | 3.476 | 0.873 | 0.920 |
| **Downstream** | a. Trees | 3.274 | 5.131 | 0.953 | 0.960 |
| | b. Shrub | 3.230 | 4.940 | 0.932 | 0.951 |
| | c. Herb | 2.154 | 3.176 | 0.669 | 0.774 |

**Table 5.13:** Similarity index between upstream, midstream and downstream zone of Doyang river

| Similarity indices | | Trees | Shrubs | Herbs |
|---|---|---|---|---|
| Sorenson's index | Upstream & midstream | 0.185 | 0.327 | 0.370 |
| | Midstream & downstream | 0.226 | 0.500 | 0.453 |
| | Upstream & downstream | 0.254 | 0.537 | 0.449 |

**Table 5.14** shows the habit classification and Life forms of plants recorded in all three zones of the study area. The comparison of different life-forms with the normal biological spectrum is represented in **Table 5.15**. The Phanerophytes comprised the major percentage of life form in the present study area with over 70.11% followed by Therophytes (10.92%), Cryptophytes (8.05%), Chamaephytes (7.47%), and Hemicryptophytes (3.45). **Figure 5.13-5.15** shows the species accumulation curve for upstream, midstream, and downstream. The accumulation curves of trees, shrubs, and herbs of upstream, midstream, and downstream riparian zone flatten as the number of plots increases, but for the herbs of midstream, it showed a steady increase.

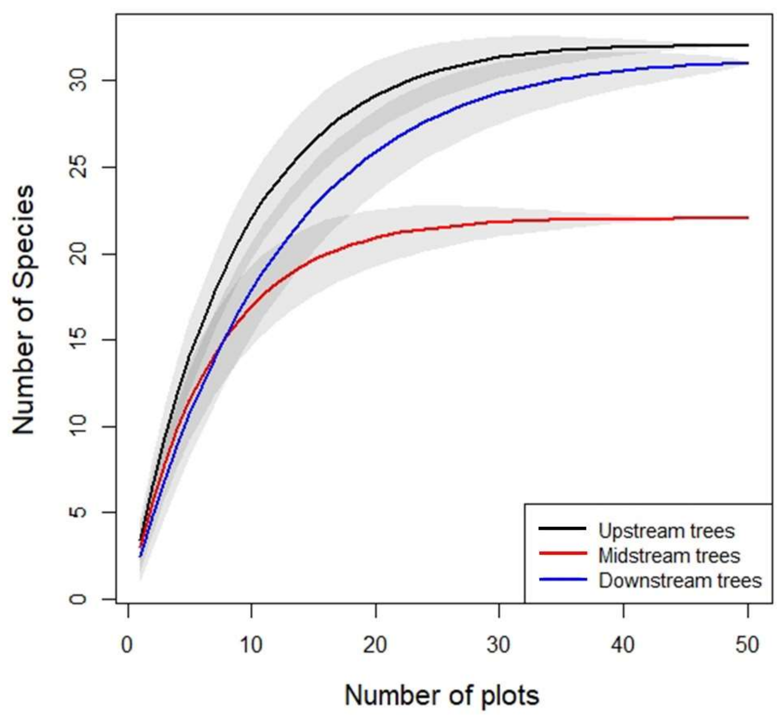


**Fig. 5.13:** Accumulation curve of tree species estimated for upstream, midstream and downstream riparian forest of Doyang river, Wokha

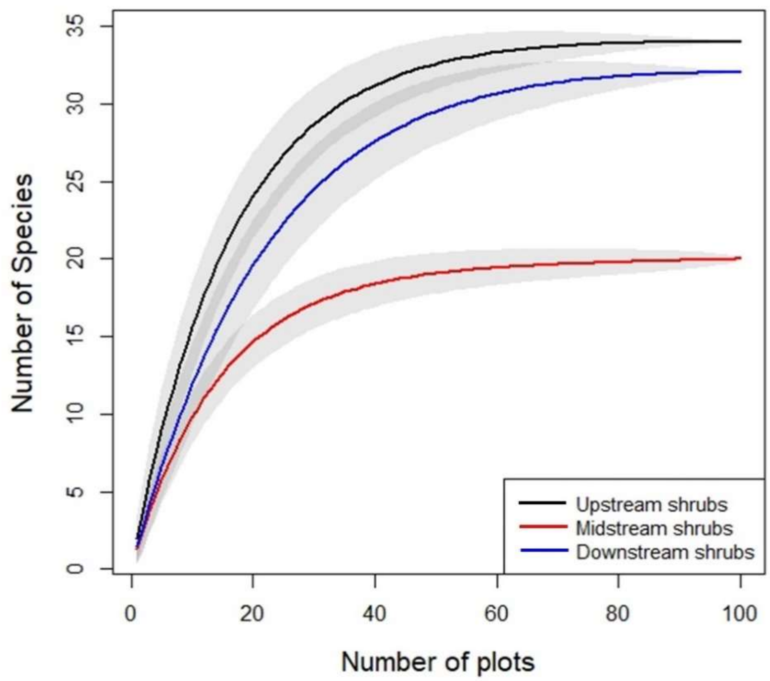


**Fig. 5.14:** Accumulation curve of shrub species estimated for upstream, midstream and downstream riparian forest of Doyang river, Wokha

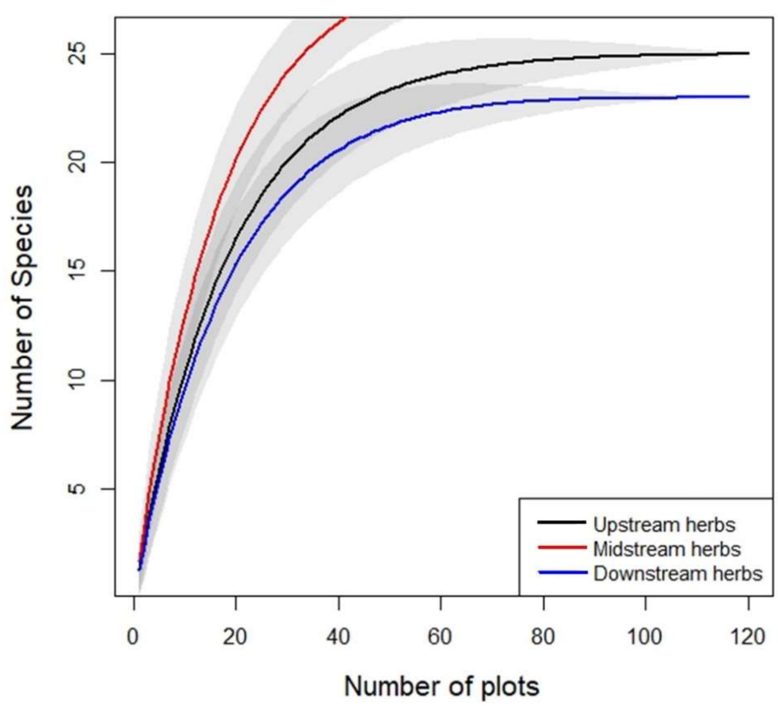


**Fig. 5.15:** Accumulation curve of herb species estimated for upstream, midstream and downstream riparian forest of Doyang river, Wokha

**Table 5.14:** Habit classification and life forms of plants recorded along the Doyang river

| Sl.No | Species | Family | Habit | Life-form | UPS | MDS | DWS |
|---|---|---|---|---|---|---|---|
| 1 | *Ficus auriculata* Lour. | Moraceae | Tree | Ph | + | - | - |
| 2 | *Syzygium megacarpum* (Craib) Rathakr. & N.C.Nair | Mrytaceae | Tree | Ph | + | - | - |
| 3 | *Albizia chinensis* (Osbeck) Merr. | Fabaceae | Tree | Ph | + | + | - |
| 4 | *Stereospermum tetragonum* DC. | Bignoniaceae | Tree | Ph | + | + | + |
| 5 | *Magnolia hodgsonii* (Hook. f. & Thomson) H. Keng | Magnoliaceae | Tree | Ph | + | - | - |
| 6 | *Alangium chinense* (Lour.) Harms | Cornaceae | Tree | Ph | + | - | - |
| 7 | *Bischofia javanica* Blume | Phyllanthaceae | Tree | Ph | + | - | - |
| 8 | *Chukrasia tabularis* A. Juss. | Meliaceae | Tree | Ph | + | - | - |
| 9 | *Grewia abutilifolia* Vent. ex Juss. | Malvaceae | Tree | Ph | + | - | - |
| 10 | *Callicarpa arborea* Roxb. | Lamiaceae | Tree | Ph | + | - | - |
| 11 | *Sterculia coccinea* Jack. | Malvaceae | Tree | Ph | + | - | - |
| 12 | *Triadica cochinchinensis* Lour. | Euphorbiaceae | Tree | Ph | + | - | - |
| 13 | *Duabanga grandiflora* (DC.) Walp. | Lythraceae | Tree | Ph | + | - | - |
| 14 | *Sumbaviopsis albicans* (Blume) J.J.Sm. | Euphorbiaceae | Tree | Ph | + | - | - |
| 15 | *Trevesia palmata* (Roxb. ex Lindl.) Vis. | Araliaceae | Tree | Ph | + | - | + |
| 16 | *Melia azedarach* L. | Meliaceae | Tree | Ph | + | + | - |
| 17 | *Terminalia myriocarpa* Van Heurck & Müll. Arg. | Combretaceae | Tree | Ph | + | - | - |
| 18 | *Pterospermum acerifolium* (L.) Willd. | Malvaceae | Tree | Ph | + | - | - |
| 19 | *Syzygium reticulatum* (Wight) Walp. | Mrytaceae | Tree | Ph | + | - | - |
| 20 | *Ficus obscura* Blume | Moraceae | Tree | Ph | + | - | - |
| 21 | *Itea macrophylla* Wall. | Iteaceae | Tree | Ph | + | - | + |
| 22 | *Ocotea lancifolia* (Schott) Mez | Lauraceae | Tree | Ph | + | + | + |
| 23 | *Litsea monopetala* (Roxb.) Pers. | Lauraceae | Tree | Ph | + | - | - |
| 24 | *Mitragyna rotundifolia* (Roxb.) kuntze | Rubiaceae | Tree | Ph | - | + | + |
| 25 | *Oreocnide integrifolia* (Gaudich.) Miq. | Urticaceae | Tree | Ph | + | - | - |
| 26 | *Ficus concinna* (Miq.) Miq. | Moraceae | Tree | Ph | + | - | - |
| 27 | *Brassaiopsis mitis* C.B.Clarke | Araliaceae | Tree | Ph | + | - | - |
| 28 | *Carallia brachiata* (Lour.) Merr. | Rhizophoraceae | Tree | Ph | + | - | + |
| 29 | *Bauhinia variegata* L. | Fabaceae | Tree | Ph | - | + | - |
| 30 | *Ficus hispida* L.f. | Moraceae | Tree | Ph | - | + | - |
| 31 | *Morus macroura* Miq. | Moraceae | Tree | Ph | - | + | - |
| 32 | *Artocarpus heterophyllus* Lam. | Moraceae | Tree | Ph | - | + | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 33 | *Wrightia arborea* (Dennst.) Mabb. | Apocynaceae | Tree | Ph | - | + | - |
| 34 | *Toona ciliata* M.Roem. | Meliaceae | Tree | Ph | - | + | - |
| 35 | *Syzygium syzygioides* (Miq.) Merr. & L.M.Perry | Mrytaceae | Tree | Ph | - | + | + |
| 36 | *Wendlandia tinctoria* (Roxb.) DC. | Rubiaceae | Tree | Ph | - | - | + |
| 37 | *Baliospermum solanifolium* (Burm.) Suresh | Euphorbiaceae | Tree | Ph | - | + | - |
| 38 | *Lagerstroemia speciosa* (L.) Pers. | Lythraceae | Tree | Ph | - | + | - |
| 39 | *Derris robusta* (DC.) Benth. | Fabaceae | Tree | Ph | - | + | - |
| 40 | *Oroxylum indicum* (L.) Kurz | Bignoniaceae | Tree | Ph | - | + | - |
| 41 | *Phyllanthus emblica* L. | Phyllanthaceae | Tree | Ph | - | + | - |
| 42 | *Lannea coromandelica* (Houtt.) Merr. | Anacardiaceae | Tree | Ph | - | + | - |
| 43 | *Macaranga denticulata* (Blume) Müll. Arg. | Euphorbiaceae | Tree | Ph | - | + | + |
| 44 | *Litsea cubeba* (Lour.) Pers. | Lauraceae | Tree | Ph | - | + | + |
| 45 | *Colona floribunda* (Kurz) Craib | Malvaceae | Tree | Ph | - | + | - |
| 46 | *Artocarpus chama* Buch.-Ham. | Moraceae | Tree | Ph | - | - | + |
| 47 | *Artocarpus lacucha* Buch.-Ham. | Moraceae | Tree | Ph | - | - | + |
| 48 | *Balakata baccata* (Roxb.) Esser | Euphorbiaceae | Tree | Ph | - | - | + |
| 49 | *Tectona grandis* L.f. | Lamiaceae | Tree | Ph | - | - | + |
| 59 | *Hibiscus macrophyllus* Roxb. ex Hornem. | Malvaceae | Tree | Ph | - | - | + |
| 51 | *Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery | Phyllanthaceae | Tree | Ph | - | - | + |
| 52 | *Diospyros stricta* Roxb. | Ebenaceae | Tree | Ph | - | - | + |
| 53 | *Diospyros variegata* Kurz | Ebenaceae | Tree | Ph | - | - | + |
| 54 | *Ficus nervosa* B.Heyne ex Roth | Moraceae | Tree | Ph | - | - | + |
| 55 | *Gmelina arborea* Roxb. | Lamiaceae | Tree | Ph | - | - | + |
| 56 | *Litsea salicifolia* (J. Roxb. ex Nees) Hook. f. | Lauraceae | Tree | Ph | - | - | + |
| 57 | *Magnolia champaca* (L.) Baill. ex Pierre | Magnoliaceae | Tree | Ph | - | - | + |
| 58 | *Croton persimilis* Müll. Arg. | Euphorbiaceae | Tree | Ph | - | - | + |
| 59 | *Ulmus lanceifolia* Roxb. ex Wall. | Ulmaceae | Tree | Ph | - | - | + |
| 60 | *Ficus benjamina* L. | Moraceae | Tree | Ph | - | - | + |
| 61 | *Glochidion ellipticum* Wight | Phyllanthaceae | Tree | Ph | + | - | + |
| 62 | *Syzygium balsameum* (Wight) Wall. ex Walp. | Mrytaceae | Tree | Ph | - | - | + |
| 63 | *Archidendron clypearia* (Jack) I.C.Nielsen | Fabaceae | Tree | Ph | - | - | + |
| 64 | *Rhus chinensis* Mill. | Anacardiaceae | Tree | Ph | - | - | + |
| 65 | *Kydia calycina* Roxb. | Malvaceae | Tree | Ph | - | + | - |
| 66 | *Bombax ceiba* L. | Malvaceae | Tree | Ph | + | - | + |
| 67 | *Neolamarckia cadamba* (Roxb.) Bosser | Rubiaceae | Tree | Ph | + | - | - |
| 68 | *Dysoxylum excelsum* Blume | Meliaceae | Tree | Ph | + | - | - |
| 69 | *Leea alata* Edgew. | Vitaceae | Shrub | Ph | + | - | + |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 70 | *Mycetia longifolia* (Wall.) Kuntze | Rubiaceae | Shrub | Ph | + | - | + |
| 71 | *Breynia retusa* (Dennst.) Alston | Phyllanthaceae | Shrub | Ph | + | + | + |
| 71 | *Capparis acutifolia* Sweet | Capparaceae | Shrub | Ph | + | + | - |
| 73 | *Chloranthus elatior* Link | Chloranthaceae | Shrub | Ph | + | - | - |
| 74 | *Ficus squamosa* Roxb. | Moraceae | Shrub | Ph | + | - | - |
| 75 | *Clerodendrum robustum* Klotzsch | Lamiaceae | Shrub | Ph | + | + | + |
| 76 | *Clerodendrum infortunatum* L. | Lamiaceae | Shrub | Ph | + | + | + |
| 77 | *Gnetum acutum* Markgr. | Gnetaceae | Shrub | Ph | + | - | + |
| 78 | *Chromolaena odorata* (L.) R.M.King & H.Rob. | Asteraceae | Shrub | Ph | + | + | + |
| 79 | *Mussaenda roxburghii* Hook.f. | Rubiaceae | Shrub | Ph | + | + | - |
| 80 | *Piper lonchites* Schult. | Piperaceae | Shrub | Ph | + | - | - |
| 81 | *Premna pinguis* C.B.Clarke | Lamiaceae | Shrub | Ph | + | - | + |
| 82 | *Maesa indica* (Roxb.) A. DC. | Primulaceae | Shrub | Ph | + | + | + |
| 83 | *Flemingia strobilifera* (L.) W.T.Aiton | Fabaceae | Shrub | Ph | + | - | - |
| 84 | *Ixora thwaitesii* Hook.f. | Rubiaceae | Shrub | Ph | + | - | + |
| 85 | *Homonoia riparia* Lour. | Euphorbiaceae | Shrub | Ph | + | - | + |
| 86 | *Mallotus leucocarpus* (Kurz) Airy Shaw | Euphorbiaceae | Shrub | Ph | + | - | - |
| 87 | *Ardisia involucrata* Kurz | Primulaceae | Shrub | Ph | + | - | - |
| 88 | *Benkara griffithii* (Hook.f.) Ridsdale | Rubiaceae | Shrub | Ph | + | + | - |
| 89 | *Wallichia oblongifolia* Griff. | Arecaceae | Shrub | Ph | + | - | + |
| 90 | *Glochidion zeylanicum* (Gaertn.) A.Juss. | Phyllanthaceae | Shrub | Ph | + | - | - |
| 91 | *Hiptage acuminata* Wall. ex A. Juss. | Malpighiaceae | Shrub | Ph | + | - | - |
| 92 | *Boehmeria glomerulifera* Miq. | Urticaceae | Shrub | Ph | + | - | + |
| 93 | *Embelia ribes* Burm.f. | Primulaceae | Shrub | Ph | + | - | - |
| 94 | *Allophylus chartaceus* (Kurz) Radlk. | Sapindaceae | Shrub | Ph | + | - | + |
| 95 | *Glycosmis pentaphylla* (Retz.) DC. | Rutaceae | Shrub | Ph | + | - | - |
| 96 | *Goniothalamus sesquipedalis* (Wall.) Hook.f. & Thomson | Annonaceae | Shrub | Ph | + | - | - |
| 97 | *Pseuderanthemum crenulatum* (Wall. ex Lindl.) Radlk. | Acanthaceae | Shrub | Ph | + | - | - |
| 98 | *Callicarpa macrophylla* Vahl | Lamiaceae | Shrub | Ph | + | - | + |
| 99 | *Dracaena angustifolia* (Medik.) Roxb. | Asparagaceae | Shrub | Ph | - | + | + |
| 100 | *Morinda angustifolia* Roxb. | Rubiaceae | Shrub | Ph | - | + | + |
| 101 | *Mussaenda glabra* Vahl | Rubiaceae | Shrub | Ph | - | + | - |
| 102 | *Uraria crinita* (L.) DC. | Fabaceae | Shrub | Ph | - | + | - |
| 103 | *Eurya acuminata* DC. | Pentaphylacaceae | Shrub | Ph | - | + | + |
| 104 | *Dalbergia stipulacea* Roxb. | Fabaceae | Shrub | Ph | - | + | - |
| 105 | *Croton caudatus* Geiseler | Euphorbiaceae | Shrub | Ph | - | + | - |
| 106 | *Flueggea virosa* (Roxb. ex Willd.) Royle | Phyllanthaceae | Shrub | Ph | - | + | - |

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|---|---|---|---|---|---|---|---|---|
| 107 | *Lepionurus sylvestris* Blume | Opiliaceae | Shrub | Ph | - | - | + |
| 108 | *Combretum yunnanense* Exell | Combretaceae | Shrub | Ph | - | + | - |
| 109 | *Melastoma malabathricum* L. | Melastomataceae | Shrub | Ph | - | + | + |
| 110 | *Holmskioldia sanguinea* Retz. | Lamiaceae | Shrub | Ph | - | + | - |
| 111 | *Urena lobata* L. | Malvaceae | Shrub | Ph | - | - | + |
| 112 | *Eranthemum indicum* (Nees) C.B.Clarke | Acanthaceae | Shrub | Ph | - | - | + |
| 113 | *Micromelum pubescens* Blume | Rutaceae | Shrub | Ph | - | - | + |
| 114 | *Phyllanthus leschenaultii* Müll.Arg. | Phyllanthaceae | Shrub | Ph | - | - | + |
| 115 | *Psychotria erratica* Hook.f. | Rubiaceae | Shrub | Ph | - | - | + |
| 116 | *Tadehagi triquetrum* (L.) H.Ohashi | Fabaceae | Shrub | Ph | - | - | + |
| 117 | *Eranthemum palatiferum* Hook.f. | Acanthaceae | Shrub | Ph | + | - | + |
| 118 | *Murraya paniculata* (L.) Jack | Rutaceae | Shrub | Ph | + | - | - |
| 119 | *Miliusa roxburghiana* Hook.f. & Thomson | Annonaceae | Shrub | Ph | - | - | + |
| 120 | *Leea indica* (Burm. f.) Merr. | Vitaceae | Shrub | Ph | + | + | + |
| 121 | *Eranthemum pulchellum* Andrews | Acanthaceae | Shrub | Ph | + | - | - |
| 122 | *Stixis suaveolens* (Roxburgh) Pierre | Resedaceae | Shrub | Ph | + | - | + |
| 123 | *Solanum americanum* Mill. | Solanaceae | Herb | Cha | + | + | - |
| 124 | *Arundo donax* L. | Poaceae | Herb | Cr | + | - | - |
| 125 | *Floscopa scandens* Lour. | Commelinaceae | Herb | He | + | - | - |
| 126 | *Rorippa indica* (L.) Hiern | Brassicaceae | Herb | Th | + | - | - |
| 127 | *Zingiber rubens* Roxb. | Zingiberaceae | Herb | Cr | + | + | - |
| 128 | *Ageratum conyzoides* (L.) L. | Asteraceae | Herb | Th | + | + | + |
| 129 | *Amischotolype hookeri* (Hassk.) H.Hara | Commelinaceae | Herb | Cr | + | - | - |
| 130 | *Digitaria setigera* Roth | Poaceae | Herb | Th | + | + | + |
| 131 | *Crassocephalum crepidioides* (Benth.) S.Moore | Asteraceae | Herb | Th | + | + | - |
| 132 | *Crinum amoenum* Ker Gawl. ex Roxb. | Amaryllidaceae | Herb | Cr | + | - | - |
| 133 | *Elatostema monandrum* (Buch.-Ham. ex D.Don) H.Hara | Urticaceae | Herb | Cha | + | - | - |
| 134 | *Musa cheesmanii* N.W. Simmonds | Musaceae | Herb | Cr | + | - | - |
| 135 | *Phrynium pubinerve* Blume | Marantaceae | Herb | Cr | + | - | - |
| 136 | *Cheilocostus speciosus* (J.Koenig) C.D.Specht | Costaceae | Herb | Cr | + | + | + |
| 137 | *Commelina benghalensis* L. | Commelinaceae | Herb | Th | + | - | + |
| 138 | *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda | Poaceae | Herb | Cha | + | + | + |
| 139 | *Oldenlandia tenelliflora* (Blume) Kuntze | Rubiaceae | Herb | Th | + | - | - |
| 140 | *Pollia subumbellata* C.B.Clarke | Commelinaceae | Herb | Cha | + | - | + |
| 141 | *Musa balbisiana* Colla | Musaceae | Herb | Cr | + | + | - |
| 142 | *Dianella ensifolia* (L.) DC. | Xanthorrhoeaceae | Herb | Cr | + | + | + |
| 143 | *Elatostema rupestre* (Buch.-Ham. ex D.Don) Wedd. | Urticaceae | Herb | Cha | + | - | + |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 144 | *Amomum koenigii* J.F.Gmel. | Zingiberaceae | Herb | Cr | - | - | + |
| 145 | *Rumex nepalensis* Spreng. | Polygonaceae | Herb | He | + | - | + |
| 146 | *Gomphostemma parviflorum* Wall. ex Benth. | Lamiaceae | Herb | Cha | + | - | - |
| 147 | *Heliotropium indicum* L. | Boraginaceae | Herb | Th | - | + | - |
| 148 | *Persicaria decipiens* (R.Br.) K.L.Wilson | Polygonaceae | Herb | He | - | + | - |
| 149 | *Pouzolzia zeylanica* (L.) Benn. | Urticaceae | Herb | Cha | - | + | - |
| 150 | *Alternanthera sessilis* (L.) R.Br. ex DC. | Amaranthaceae | Herb | Cha | - | + | - |
| 151 | *Ageratina riparia* (Regel) R.M.King & H.Rob. | Compositae | Herb | Cha | - | - | + |
| 152 | *Carex baccans* Nees | Cyperaceae | Herb | Cr | - | + | + |
| 153 | *Canscora andrographioides* Griff. ex C.B.Clarke | Gentianaceae | Herb | Th | - | + | + |
| 154 | *Curcuma angustifolia* Roxb. | Zingiberaceae | Herb | Cr | - | + | + |
| 155 | *Spermacoce articularis* L.f. | Rubiaceae | Herb | Th | - | + | + |
| 156 | *Bidens bipinnata* L. | Asteraceae | Herb | Th | - | + | - |
| 157 | *Amomum subulatum* Roxb. | Zingiberaceae | Herb | Cr | - | + | + |
| 158 | *Setaria viridis* (L.) P.Beauv. | Poaceae | Herb | Th | - | + | + |
| 156 | *Sonchus arvensis* L. | Asteraceae | Herb | Th | - | + | - |
| 160 | *Oxalis corniculata* L. | Oxalidaceae | Herb | He | + | + | - |
| 161 | *Physalis minima* L. | Solanaceae | Herb | Th | - | + | - |
| 162 | *Ranunculus sceleratus* L. | Ranunculaceae | Herb | Th | - | + | - |
| 163 | *Xanthium strumarium* L. | Asteraceae | Herb | Th | - | + | - |
| 164 | *Crotalaria pallida* Aiton | Fabaceae | Herb | Cha | - | + | - |
| 165 | *Imperata cylindrica* (L.) Raeusch | Poaceae | Herb | He | - | + | - |
| 166 | *Cuphea carthagenensis* (Jacq.) J.F. Macbr. | Lythraceae | Herb | Th | - | + | - |
| 167 | *Ophiorrhiza oppositiflora* Hook.f. | Rubiaceae | Herb | Cha | - | - | + |
| 168 | *Pollia secundiflora* (Blume) Bakh.f. | Commelinaceae | Herb | Cha | - | - | + |
| 169 | *Peliosanthes teta* Andrews | Asparagaceae | Herb | He | - | - | + |
| 170 | *Acmella paniculata* (Wall. ex DC.) R.K.Jansen | Asteraceae | Herb | Th | - | - | + |
| 171 | *Scutellaria discolor* Colebr. | Lamiaceae | Herb | Th | - | - | + |
| 172 | *Alpinia roxburghii* Sweet | Zingiberaceae | Herb | Cr | - | + | + |
| 173 | *Mimosa pudica* L. | Leguminosae | Herb | Cha | - | - | + |
| 174 | *Torenia cordifolia* Roxb. | Linderniaceae | Herb | Th | + | - | - |

Note: (+) = Present, (-) = Absent, Ph: Phanerophyte, Cha: Chamaephyte, He: Hemicryptophyte, Cr: Cryptophytes, Th: Therophytes, UPS: Upstream, MDS: Midstream, DWS: Downstream.

**Table 5.15:** Comparison of life-forms with the normal biological spectrum recorded in the study area

| Life –form classes | No. of species | Study area Life-form (%) | Raunkiaer Normal biological Spectrum (%) |
|---|---|---|---|
| Phanerophytes | 122 | 70.11 | 46 |
| Chamaephytes | 13 | 7.47 | 9 |
| Hemicryptophytes | 6 | 3.45 | 26 |
| Cryptophytes | 14 | 8.05 | 6 |
| Therophytes | 19 | 10.92 | 13 |
| Total | 174 | | |

## 5.3 DISCUSSION

The overall species documented a diverse community that comprised of 174 species of plants represented by 146 genera and 61 families. The species was found in the following order of Trees (68)>Shrubs (54)>Herbs (52). Equivalent findings of such remarkably rich and diverse community of plants in riparian areas were also reported by workers like Marimon *et al*. (2002); Urban *et al*. (2006); Sunil *et al*. (2010); Sambare *et al*. (2011); Iqbal *et al*. (2012); Mligo (2017); Coelho *et al*. (2018); Meragiaw *et al*. (2018). The reason for the high diversity in the present study area may be attributed to the magnitude and frequency of floods, changing environmental conditions along the upstream-downstream gradient, the minuscule difference in the topography and soil as a result of lateral migration of rivers' channel, disturbances regimes exerted on the riparian forest by the upland environment and from within and higher groundwater level (Naiman *et al*., 1993; Suzuki *et al*., 2002; Naiman *et al*., 2008; Pielech *et al*., 2015). Our study also reported a considerable number of typical riparian plant species abundantly thriving along the different zones of the Doyang river. Some of the species like the *Ficus auriculate, Oreocnide integrifolia, Syzygium megacarpum, Triadica cochinchinensis, Magnolia hodgsonii, Bischofia javanica, Ficus squamosa, Homonoia riparia, Arundo donax,* and *Ardisia involucrata* were observed in the upstream zone. *Lagerstroemia speciosa and Dracaena angustifolia* in midstream zone. Similarly, *Ficus nervosa, Triadica cochinchinensis, Syzygium balsameum and Homonoia riparia* were recorded in the downstream zone. Thus, the significantly rich and potential mechanisms responsible for dispensing plant diversity is related to multiple environmental gradients that are operating simultaneously. It is assumed that environmental heterogeneity, productivity, and resource diversity have a major effect on the richness of species (Solbrig, 1991; Menaut *et al*., 1995; Koponen *et al*., 2004). Therefore, all these factors may be taken into account to explain the relative importance of species, abundance of families, the species diversity indices (Shannon's Index, Margalef's Index, Simpson index, and Evenness), and β-diversity (Sorenson Index) of Doyang river, Wokha, Nagaland.

The upstream riparian forest was observed to be the most species rich and diverse zone (92 species represented by 48 families) followed by downstream riparian forest (87 species represented by 43 families) and midstream riparian forest (71 species represented by 37 families). This contrast difference in upstream, midstream and downstream species composition indicates a more dynamic system marked with anthropogenic influence. The occurrence of a greater number of typical riparian plant species at upstream and downstream sites and lesser at midstream site perhaps indicate a more dynamic condition that is unique to each site. These differences further indicate an alteration in hydrological site conditions, all the more due to the presence of Dam and other land-use practices especially at midstream zone allowing species to adopt variable life strategies. The variable flood regimes, geomorphic channel processes, the influence of upland on the fluvial corridor, land use types, and degree of anthropogenic disturbance (Naiman *et al*., 1993; Natta, 2003; Kozlowski, 2002; Damasceno-Junior *et al*., 2004; Maingi and Marsh, 2006; Méndez-Toribio *et al*., 2014; Singh *et al*., 2016) seem to have all equally contributed towards the heterogeneity of species composition along the different zones of Doyang river.

Evenness gives us an idea regarding the relative abundance of species in the area and when the species are equally distributed higher evenness is observed (Kent and Coker, 1992). The high evenness observed among the trees and shrubs (**Table 5.12**) of different zones perhaps points to site-specific disturbances on the vegetation types thereby allowing the plants to have equal distribution. Authors like Osborne (2000), Suzuki *et al*. (2002), and Tilman *et al*. (2006) have acknowledged that moderate disturbance can suppress competition among species and enhances species diversity. Tree composition recorded the least similarity (**Table. 5.13**) in the present study. This is obvious for the reason that trees in this area are fell regularly for selective cutting both for timber and firewood. Furthermore, the general dissimilarity observed between the different riparian zones may be attributed to contrast climatic conditions due to the presence of Dam and various land-use practices present adjacent to the river banks. Commonly targeted trees for timber are *Magnolia champaca, Terminalia myriocarpa, Duabanga grandiflora, Tectona grandis,* and *Gmelina arborea*. Some of these species are either cultivated or are naturally grown. The availability of water and other appropriate environmental condition, allow many of these tree species to grow healthier and faster eventually becoming a victim to most loggers. Nevertheless, despite the anthropogenic disturbances, the similarities observed among the shrubs and herbs of different zones could be due to their geographical proximity, similar altitude ranges (Meragiaw *et al*., 2018), and ecological succession (Osborne, 2000).

The most species rich families recorded were in the order of Rubiaceae (13) > Moraceae (11)> Lamiaceae (10)>Fabaceae and Euphorbiaceae (9)>Phyllanthaceae and Malvaceae (8)> Asteraceae (7). Studies conducted in riparian vegetation by workers like Sambare *et al*. (2011), De Melo *et al*. (2016), Aziem *et al*. (2016), Lucheta *et al*. (2018), and Leishangthem and Singh (2018) have all specified the dominance of these families in the riparian areas. The abundance of Rubiaceae is associated with the humidity of the area i.e. it increases with humidity (Ouédraogo, 2006; Bognounou *et al*., 2009) and flooding (Sambare *et al*., 2011). In the present study area, similar features of flooding and humidity may be accorded to the high abundance of Rubiaceae family. Families like Asteraceae (7), Poaceae (5), and Commelinaceae (5) also reported maximum species among herbs. The higher density and diversity of most herbaceous plant is linked to a vigorous recruitment process during floods. The annual flood disturbances create suitable bare ground and deposits rich alluvial soil. The combined effects of these factors together with humid climatic conditions generate a congenial environment for such types of plants to flourish. Annual species have the potential to originate from both seed banks and seed carried by flooding water (Naiman and Decamps, 1997; Washitani, 2001). The shrubs species also recorded reasonably high diversity and density. Authors like Villarin *et al*. (2009); Šálek *et al*. (2013), Adel *et al*. (2018) have also reported the abundance of shrubs cover more along the river and observed a decreasing pattern as it moves away from the river.

The highest IVI recorded from different zones showed their dominance both in terms of density and frequency. Yet, this same rule does not apply to shrubs and herbs. Despite scoring lower IVI, most of the shrubs and herbs reported higher frequency and density in their distribution. According to the individual IVI score, exclusive dominance by few species is rather curbed, providing more rooms to other underrepresented species to perform and contribute towards higher plant diversity. Perhaps, this may be due to moderate disturbances in the study area that eventually retards competition among species (Osborne, 2000; Suzuki *et al*., 2002; Tilman *et al*., 2006). Except for herbaceous plants, the present plant community was observed to have any clear dominant species (as represented by their IVI) but relatively a suite of more or less equally co-dominant taxa. We know that individuals that have higher frequency are ecologically more important in the community (Kent, 2012). However, in the present case, the frequency distribution of most of the species was low and had an almost similar frequency class. Thus, we can assume that all the reported plant species are equally important and responsible for the ecological functions of the study area.

### 5.3.1 Population structure and distribution pattern

Higher tree density was recorded at upstream zone (784 individual $ha^{-1}$), while, at midstream (650 individual $ha^{-1}$) and downstream zone it recorded lesser tree density (692 individual $ha^{-1}$) with a significant population of smaller DBH class. In the case of the basal area, downstream recorded the maximum (63.47 $m^2$ $ha^{-1}$), and this could be related to the presence of a certain fraction of trees in the bigger DHB class. The general pattern of DBH class distribution of trees at each zone showed an inverted J-shape with abundant smaller stems compared to that of a few larger ones. The highest density of trees was in the 10.1-15 cm classes while the lowest was in the 30.1-35 cm DBH class. Accordingly, the study area may be characterized as an uneven-aged forest structure having experienced some form of selective cutting and disturbance. Similar findings of a higher density of smaller individuals by Almeida Jr. and Zickel (2012) indicated the occurrence of austere disturbances in the past. Larger diameter trees generally occur in low density natural riparian areas resulting in a reverse J-shaped diameter distribution (Nebel *et al*., 2001). Meragiaw *et al*. (2018) acknowledge that such a reversed J-shaped distribution pattern depicts that the area is naturally on the verge of healthy regeneration and the recruitment process. Sambare *et al*. (2011) also suggest such a distribution pattern of a natural forest that is regenerating itself from seed. A good representation of typical riparian tree species suggests a natural regeneration and recovery process occurring in the present study area. Nonetheless, extraction of fuelwood for domestic usage and logging for timber remains a major threat.

The distribution pattern of any species at a given place and time depends on both the nature of the environment and the biological aspects of the entity itself. The contagious distribution pattern is the most recurrent (Odem, 1971), while, the random distribution occurs only in a uniform environment and regular distribution exists where there is severe competition between the individuals (Panchal and Pandey, 2004). The A/F ratio in the present study area was observed to be a contagious nature. In all three zones, the distribution pattern of the species irrespective of trees, shrubs, and herbs followed a parallel contagious pattern of distribution. Any variation in the distribution pattern across slopes and vegetation strata are associated with multiple factors, especially the micro-environments and biotic factor (Josh and Tiwari, 1990). Yet the major distressing factor influencing the distribution pattern of plants is the profound regular floods and pronounced drought (Nunes Da Cunha and Junk, 2001).

### 5.3.2 Influence of flooding and anthropogenic disturbances on riparian vegetation

The study observed upstream riparian forest to be least disturbed, while downstream riparian forest to be moderately disturbed and relatively maximal disturbances at midstream riparian forest. Huston (1979), Vannotte *et al*. (1980), and Tabacchi *et al*. (1990) reported the highest species richness and habitat diversity in the midcourse of the river attributing it to maximum environmental heterogeneity. However, this was not the case in the present study as lesser woody species diversity was reported in the midstream zone. These lower values of diversity (**Table 5.12**) in the midstream zone may be related to anthropogenic pressure existing in the area. Despite this observation, higher diversity and abundance of the herbaceous plant was observed in the midstream zone. This may be related to the presence of Dam, whereby they are exposed to a higher degree of recurring flooding events than upstream and downstream. As such, they are subjected to frequent erosion, submergence, and deposition of seeds propagules and alluvial soils. This intensity and frequency of floods is the major determinant for the higher diversity of annual invasive weeds in the midstream zone. Some of the common ones are *Alternanthera sessilis*, *Crassocephalum crepidioides, Crotalaria pallida, Cuphea carthagenensis*, *Heliotropium indicum, Xanthium strumarium, Oxalis corniculate, Ageratum conyzoides, Sonchus arvensis,* and *Ranunculus sceleratus*. It is important to note that Dam can change the timing, duration, frequency, and magnitude of floods, eventually altering the hydraulic regime of rivers (Johansson *et al*., 1996; Nilsson and Berggran, 2000; Nilsson and Svedmark, 2002). Besides, it also affects the microclimate of the area by increases the atmospheric temperature and humidity. This results in the loss of spatial heterogeneity in the riparian corridor (Johansson *et al*., 1996).

The presence of various land-use practices like Jhum cultivation and teak plantation appears to have incurred negative effects on the community attributes of midstream riparian vegetation. These activities have led to the cutting down of riparian forests annually, thereby affecting the species richness and diversity. The effect of all these disturbances is evident in the decline of woody species diversity (trees and shrubs) and the abundance of more herbaceous plants (*Chromolaena odorata, Carex baccans*, *Digitaria setigera, Imperata cylindrica*) at midstream. Variation induces due to various land-use practices on riparian plant diversity were indicated by workers like Makkay *et al*. (2008), Méndez-Toribio *et al*. (2014) and Mligo (2017). Another important environmental factor affecting the riparian vegetation diversity of midstream is the edge effects from surrounding agricultural practices (Murcia, 1995). The edge effect arises from the immediate transition between the agricultural fields or urban areas and the continuous vegetation of the habitats. This eventually affects the microclimate (e.g., atmospheric temperature, soil moisture, vapor pressure, and light intensity) and the continuous vegetation of the surrounding (Saunders *et al*., 1999). Authors like Heartsill-Scalley and Aide (2003); Moffatt *et al*. (2004); Aguiar and Ferreira (2005); Meek *et al*. (2010); and Méndez-Toribio *et al*. (2014) have all provided strong evidence on how remnant vegetation that were earlier let out to land use types and had experienced profound human influence (agriculture or urban development) tends to show changes in its physiognomy. Thus, the combination of the land-use system, edge effects, and Hydro Dam have caused a considerable effect on the physiognomy of the midstream riparian forest.

### 5.3.3 Life forms

The comparison of life-forms recorded in the study area is shown in **Table 5.15**. The vegetation of the riparian forest showed a higher percentage of Phanerophytes (70.11%) followed by other groups of life forms like Therophytes (10.92%), Cryptophytes (8.05%), Chamaephytes (7.47%), and Hemicryptophytes (3.45). The riparian zone recorded a total of 52 species of herbaceous plants belonging to 27 families that comprise of Therophytes, Chamaephytes, Cryptophytes, and Hemicryptophytes. The diversity in families of plants growing in this region may be attributed to the peculiar environmental condition. The prevalence of Therophytic plants in the present study area points to the effects of regular flood disturbance and frequent modification of the terrain thereby enabling species recruitment and establishment of exotic species. Therophytic plants are adapted to occupy vacant spaces that have resulted from earlier disturbances (Pysek *et al*., 2005) and their life cycle is linked with the suitable season and usually survive as seeds when the availability of water is limited (Cain *et al*., 1959; Rooyen *et al*., 1990). A considerable percentage of Chamaephyte, Hemicryptophyte and Cryptophyte also belong to the invader group. They are mostly herbaceous plants that prefer flood plain and marshy areas for their establishment. This reflects the impact of floods that deposits fresh alluvial soil or has removed the vegetation from pre-existing surfaces (McBride and Strahan, 1984a, b; Auble and Scott, 1998) during floods creating an ideal condition for such seedling to established. This may also occur where floods remove organic litter, allowing colonization of species that can germinate on bare mineral soil (Yanosky, 1982) where the invaders and endures group of plants is only able to establish on such limited floodplains resources. The performance of

Chamaephytes affects other associated species through the competitive ability and their abundance is more in sites that encounter anthropogenic stress (Singh and Gupta, 2016).

The predominance of Phanerophytes (60%) indicates that this ecotone has a Phanerophytic climatic condition which is usually seen in the warm tropical regions (Raunkiaer, 1934; Cain, 1950) and was observed to show maximum divergence from the normal spectrum of Raunkier. Phanerophytes and Therophytes together constitute 80.03% of the total life forms, accordingly, the phytoclimate of the area may be termed as "*Phanero-therophytic type*". This reflects the bioclimatic condition of the area (Meher-Homji, 1964) as a humid and arid region. Similar phytoclimatic association of life forms have also been reported by authors like Thakur and Khare (2011), Thakur (2015), indicating dual extremes climatic conditions i.e. warm-moist and warm-dry climate. The Hemicryptophyte, despite its ability to withstand adverse climatic conditions and biotic pressure it occupies the least life form percentage (3.45%). In this case, the Hemicryptophytes seem to have much improvised themselves. This could be due to the above existing edaphic and phytoclimatic conditions. Parallel findings have also been reported by Bouri and Mukherjee (2011) and they attributed this to the xeric nature of habitat sprang from the removal of topsoil by erosion and poor water retention. Apart from the regular flood disturbances, other anthropogenic activities like Jhum cultivation, increased settlements in the catchment area, clearing of forest for plantation, and logging continues to exert immense pressure on the vegetation composition, consequently, modify the phytoclimatic condition of the area.

### 5.3.4 Conservation and management

Besides the adverse effects of Dam, the riparian areas of the Doyang river intrinsically come under the stress of extensive Jhum cultivation, teak plantation, increased settlements in the riverbanks, logging, and to some extend tourism. All these activities induce disruption or cutting down of natural riparian vegetation. These actions collectively endanger the existence of native riparian plant species and other related functional attributes of the riparian ecosystem. Riparian vegetations are particularly responsive to any minor changes in the environmental (Malanson, 1993) and they are the first component to exhibit deterioration in its functionality from processes associated with such a disproportionate land-use system (Burton *et al*., 2005). The present study documented many typical riparian plant species thriving all along the riparian zone. These species are crucial as their disappearance due to fragmentation could affect the composition, richness, and structure of native species in the riparian corridor (Ramakrishnan *et al*., 2000) more so, which may threaten the associated biological diversity of riparian areas (Nyelele *et al*., 2014). Assuredly, several studies did indicate the negative effects of the decline of native riparian species on the richness and diversity of avian species (Hinojosa-Huerta, 2006; Villasenor-Gomez, 2006; Arizmendi *et al*., 2008; Edward *et al*., 2008).

The present study also recorded *Ficus* Genera comprising the maximum species (*F. auriculate, F. obscura, F. concinna, F. hispida, F. nervosa, F. benjamina, F. squamosa*), followed by *Syzygium* (*megacarpum, reticulatum, syzygioides, balsameum*) and *Artocarpus* (*A. chama*, *A. lacucha, A. heterophyllus*). Particularly, *Ficus* spp. and *Artocarpus* spp. have been recognized as a major food resource and keystone species in the tropical forest. Keystone species are those species whose absence in an ecosystem can have an adverse effect on the overall food-chain of the community. The fruits of *Ficus* spp. constitute a large part of the diet for several important frugivores like hornbills, bats, squirrels, and primates (Borges, 1993; Dew and Wright, 1998; Shanahan *et al*., 2001; Muscarella and Fleming, 2007). In a study at Manu National Park, Peru, Terborgh (1983) also identified fig as keystone resources maintaining nearly 40% of the animal biomass in the ecosystem. *Ficus* spp. has also been recommended for use as an efficient forest restoration program maintaining the keystone resources in tropical forest ecosystems (Kuaraksa *et al*., 2012). A study conducted by Oliveira (2011) in the cacao-growing region of southern Bahia, Brazil, observed that the most dependent species for food by Lion tamarins was *Artocarpus heterophyllus*. The abundance of these species in the present study area certainly recognizes their ecological importance and the compelling need to prioritized the management and conservation efforts of these keystone species.

In the approaching decades, as anthropogenic activities in the riparian areas are expected to increase both in magnitude and complexity (Allan, 2004), urgent conservation awareness and an appropriate management plan are needed. Though the present condition of riparian vegetation along the Doyang river is in fairly good status, yet with the current trend of anthropogenic disturbances, it could sabotage the diversity, composition, and functional attributes of riparian areas in the near future. Therefore, a judicious management effort from every stakeholder is a must. The work of conservation and management should not be left only to the government agency but also the active participation of the community is crucial. Some of the important mitigation measures that both parties can emulate, includes, creating awareness among the local community, strict maintenance of riparian buffer zones, curbing of tourism activity, proper management, and restriction of land use practices close to riparian areas. Our study also suggests that the management action plan must not only focus on the maintenance of riparian areas but also protecting the native and keystone species from logging and other forms of selective cutting.

## 5.4 SUMMARY AND CONCLUSION

The present assessment of riparian vegetation diversity along the Doyang river observed a rich floristic community. The overall species documented 174 species of plants represented by 146 genera and 61 families. The species was found in the following order of Trees (68)>Shrubs (54)>Herbs (52). In terms of species richness and diversity, the upstream riparian zone was observed to be the richest and the most diverse zone. The upstream riparian forest reported 92 species represented by 48 families followed by the downstream riparian forest which described 87 species represented by 43 families and finally the midstream riparian forest, where 71 species of plants were reported belonging to 37 families. The high evenness observed among the trees and shrubs in the present study area points to the site-specific disturbance regime on the vegetation types allowing the plants to have equal distribution. The study also recorded a considerable number of typical riparian plant species adequately distributed all along the river. The composition of trees recorded the least similarity in the present study area. This is obvious for the reason that trees in this area are fell regularly as a result of selective cutting for timber, anthropogenic disturbances, contrast climatic conditions between the zones due to the presence of Dam and various land-use system. The general pattern of DBH class distribution of trees at each zone was observed to be inverted J-shape. The highest density of trees was in the 10.1-15 cm classes while the lowest was in the 30.1-35 cm DBH class. The study area is classified as an uneven-aged forest structure having experienced some form of selective cutting and disturbance. The highest species representation was recorded in the family Rubiaceae (13 species) and this is related to the high humidity and seasonal flooding which is a common phenomenon in the study area.

The high proportion of species in the lower frequency classes further contributed to the floristic heterogeneity of riparian vegetation. The study observed that land-use systems, edge effects, and the presence of Hydro Dam have a considerable impact on the community structure and diversity of midstream riparian forest. This has led to floristically less diverse than the upstream and downstream riparian forest. Despite this, the herbaceous plant in the midstream zone had higher diversity and abundance. This is attributed to the presence of Dam, whereby they are exposed to a higher degree of recurring floods. As such, they are subjected to frequent erosion, submergence, deposition of seeds propagules, and mineral soils. The life-form study reveals the biological spectrum of the given study area. The highest percentage was observed in Phanerophytes (70.11%) followed by Therophytes (10.92%), Cryptophytes (8.05%), Chamaephytes (7.47%), and Hemicryptophytes (3.45). Phanerophytes and Therophytes together constitute 80.03% of the total life forms and accordingly depicts a Phanero-therophytic type of phytoclimatic condition.

Besides documenting many typical riparian plant species thriving all along the riparian zone of Doyang, the study also recorded several *Ficus* spp. and *Artocarpus* spp. These species of plants are recognized as keystone species which constitute a major food source and habitat for birds, insects, and mammals in the tropical forest. The abundance of these species in the present study area certainly recognizes their ecological importance and the compelling need to prioritized the management and conservation efforts of these keystone species. Besides the Dam, the riparian areas of the Doyang river were found to be under the pressure of extensive Jhum cultivation, teak plantation (monoculture), increased settlements in the riverbanks, logging, and tourism. All these activities pose a serious threat to the riparian ecosystem and endanger the existence of native riparian plant species and other functional attributes of the riparian ecosystem. Judicious management efforts from every stakeholder both the government agency and the community are critical. Some of the suggested mitigation measures include creating awareness among the local community, strict maintenance of riparian buffer zones, proper management of tourism activity, and restriction of land use practices close to riparian areas. It also suggests for an effort to protect the important native and keystone species found in these areas both from logging and other forms of selective cutting.

# CHAPTER – 6

# PHYSICOCHEMICAL PROPERTIES OF RIPARIAN SOIL

## 6.1 INTRODUCTION

Riparian zones are among the most productive and biologically diverse areas in landscapes and play a positive role in preventing the loss of biodiversity (Naiman *et al*., 2005). They provide several vital ecosystem services like managing reservoirs, restoring degraded ecosystems, protecting water quality from non-point source pollution (Hale *et al*., 2014), carbon sequestration (Smukler *et al*., 2010; Smith *et al*.,2012), and most importantly, regulating the transfer of nutrients and sediments into the waterways (Likens *et al*., 1970). Riparian soils possess heterogeneous properties (Xia *et al*., 2018; Ye *et al*., 2019), and the spatial heterogeneity of soil properties in riparian zone relates to the trivial difference in topography, vegetation composition, and effects of floods thereby creating a directional effect of the environmental gradient (Xia *et al*., 2018). Multiple factors like water, geomorphic processes, coarse woody debris, litterfall, decomposition, and cycling of nutrients (C, N, and P) actively contribute towards the heterogeneity of riparian soil (Mikkelsen and Vesho, 2000). Riparian soil act as a source or sinks of different nutrient elements and is regarded as a biogeochemical ‘hotspot’ of nutrient cycling (Zhu *et al*., 2013).

Riparian soils also retain the highest soil moisture content owing to the presence and movement of groundwater into the rooting zone of riparian vegetation (Bilby, 1988; Lewis *et al*., 2003; Zaimes *et al*., 2007; Daniel *et al*., 2017). This, in turn, promotes a higher decomposition rate where organic matter is present (Bilby, 1988). Compared to other adjacent non-riparian areas, soils of the riparian zone also have higher microbial biomass (Naiman *et al*., 2010), higher organic Carbon contents (Figueiredo *et al*., 2016; Graf-Rosenfellner, 2016), and greater amounts of nutrients and fine-grained sediments (Lee *et al*., 2000; Mayer *et al*., 2007).

The various physical, chemical, and biological processes of soil are regulated by the soil organic carbon (SOC) content (Mikha and Rice, 2004), and in the riparian zone, SOC is strongly influenced by the aquatic plants' root depth, structure, properties, water retention capacity and biological diversity of soil (Capon *et al*., 2013; Feller and Beare, 1997; Thomson *et al*., 2012). The degree of soil aggregation and SOC are positively influenced by the riparian plant composition (Blazejewski *et al*., 2005; Kimura *et al*., 2017), and workers like Eisenhauer *et al*. (2012) and Materechera *et al*. (1992) have reported root exudates (e.g., polysaccharides and enzymes) of plants in the riparian zone directly affecting the soil physicochemical and microbiological properties, soil aggregation and soil organic carbon (SOC) content. Qian *et al*. (2018) have also documented effective prevention of loss of carbon from riparian ecosystems by planting aquatic plants. Nitrogen inputs in riparian landscape from groundwater discharge, precipitation, and surface runoff or flooding (Lowrance *et al*., 1984; Galloway *et al*., 2003) subsequently alter the C dynamics by increasing the decomposition rates and soil respiration (Valiela *et al*., 1976; Nadelhoffer, 2000; Wigand *et al*., 2009). The abundant C source from decomposing roots allows active N transformations by denitrifying bacteria in the riparian soil (Jacinthe *et al*., 1998). Nitrogen enrichment of riparian soils significantly increases the root biomass and over time it may increase Carbon pools in riparian soils (Paolucci and Stoly, 2018). The capacity of riparian soil to retain or release nutrient elements (nitrogen, phosphorous, and potassium) depends largely on the characteristics of the soil, its particle size (Cotovicz *et al*., 2014), and redox conditions (Meynendonckx *et al*., 2006).

The biogeochemical properties of riparian soil are significantly affected by the hydrological dynamics (e.g., frequency and timing of floods or drought) of the river (Baldwin and Mitchell, 2000). The fluctuation in water level remains the key controlling factor in determining the soil properties and regulating the nutrient cycling processes in riparian areas. For instance, soil pH, dissolved oxygen, and redox potential which are very sensitive to soil moisture (Devêvre and Horwáth, 2000; Fearnside and Pueyo, 2012) are significantly affected by this phenomenon. Periodic sediment deposits during floods actively contribute to soil nutrient dynamics through the process of sorption, desorption, and nutrient transport (Cook, 2007). In riparian ecosystems, sedimentation processes facilitate the redistribution and export of nutrients. Hillslope processes like the movement of the solution, litterfall, surface erosion, debris avalanches, and earthflow significantly contribute to the transfer of soil from the uplands to the riparian ecosystem. Nutrient deposition during floods is typically associated with fine sand particles accompanied by fine organic matter (Brovelli *et al*., 2012), and in certain riparian sites, organic litter is also flushed away thereby creating bare soils surface. This creates hospitable microenvironments for certain species that require bare soil surface for germination and ultimately increases the plant diversity in riparian zones (Bilby, 1988). Frequent flooding has the potential to reduce the soil's ability to retain P and promote losses of N via coupled nitrification-denitrification (Bai *et al*., 2007; Kerr *et al*., 2010).

The effect of natural and anthropogenic disturbances on riparian soils are variable and they both modify the riparian ecosystem according to its degree of impact. By removing the protective riparian vegetation, surface runoff tends to increase in the riparian system altering the flow of water (Manci, 1989). Livestock grazing on riparian soil induces soil compaction, increases the breakdown of undercut stream banks, and accelerates the loss of soil sediment due to the removal of stabilizing vegetation. The soil's total carbon, total nitrogen, and organic matter are mainly affected by anthropogenic disturbances while soil pH, ammonium, and nitrate had major influence from fluctuation in water level (Ye *et al*., 2019). The harvest of timber also increases soil erosion and modifies the soil microclimate by increasing the soil temperatures (Hall, 1988). Other anthropogenic disturbances such as agricultural and domestic pollutant input continue to play a major role in indirectly influencing the soil properties (Jiang *et al*., 2015), and these disturbances are increasingly becoming a serious public-safety issue (Zhang and Lou, 2011). The riparian zones of the Doyang river also relatively come under threat from vast unprotected agricultural practices (shifting cultivation), logging, deforestation, human interference from increased population, recreational activities, and movement of people. These activities have more so accelerated soil erosion and have led to an uncontrolled runoff of solution into the river system. Therefore, the assessment of soil physicochemical parameters from among the different forested riparian zones of the Doyang river would give us comparative information on the variation of various soil physicochemical parameters. This study would also provide an understanding of the impact of various disturbances on the physical and chemical properties of riparian soil. Finally, an association between the riparian plant community structures and varying edaphic gradients would be established, which would ultimately help us to understand the influence of the existence of riparian vegetation on the soil characteristics.

## 6.2 RESULTS

Monthly values for all the soil physicochemical parameters obtained from upstream, midstream and downstream riparian forest are shown in **Appendix II.** Similarly, ANOVA Post-hoc Test (Dunn Test) of p-values adjusted with the Bonferroni method for upstream, midstream and downstream site is shown in **Appendix III.**

### 6.2.1 Bulk density and porosity

**Table 6.1** shows the comparative mean value of bulk density and porosity between Upstream, Midstream, and Downstream forested riparian sites. Bulk density at the depth of 20-30 cm recorded the highest in all the three sites (upstream - 1.13±0.04, midstream - 1.19±0.05, downstream - 0.96±0.04). Compared to other sites, the midstream area observed the maximum density both at 10-20 cm (1.10±0.03) and 20-30 cm (1.19±0.05). However, the downstream site recorded the least bulk density in all the three layers (0-10 cm=0.88±0.05, 10-20 cm=0.83±0.07, 20-30 cm=0.96±0.04) of the soil (**Fig. 6.1**). Soil porosity also showed variation among the sites and layers of soil. The downstream site recorded the maximum porosity irrespective of layers when compared to other sites. A maximum mean of 49.59±1.76 was recorded in the first 0-10 cm depth of downstream, 52.52±4.66 in the second 20-30 cm depth, and 44.45±2.20 in the third layer 20-30 cm of downstream site. Soil porosity from all three sites showed a decreasing pattern as it moves further deep into the soil (**Fig. 6.2**).

**Table 6.1:** Comparison of bulk density and porosity between upstream, midstream and bownstream forested riparian areas

| Parameters | Layers (in cm) | Upstream site | Midstream site | Downstream site |
|---|---|---|---|---|
| Bulk density ($g/cm^3$) | 0-10 | 1.05 ±0.06 | 1.01 ±0.05 | 0.88 ±0.05 |
| | 10-20 | 1.03 ±0.10 | 1.10 ±0.03 | 0.83 ±0.07 |
| | 20-30 | 1.13 ±0.04 | 1.19 ±0.05 | 0.96 ±0.04 |
| Porosity (%) | 0-10 | 43.38 ±1.96 | 47.22 ±5.00 | 49.59 ±1.76 |
| | 10-20 | 43.86 ±4.95 | 45.77 ±2.50 | 52.52 ±4.66 |
| | 20-30 | 37.96 ±2.93 | 37.62 ±3.74 | 44.45 ±2.20 |

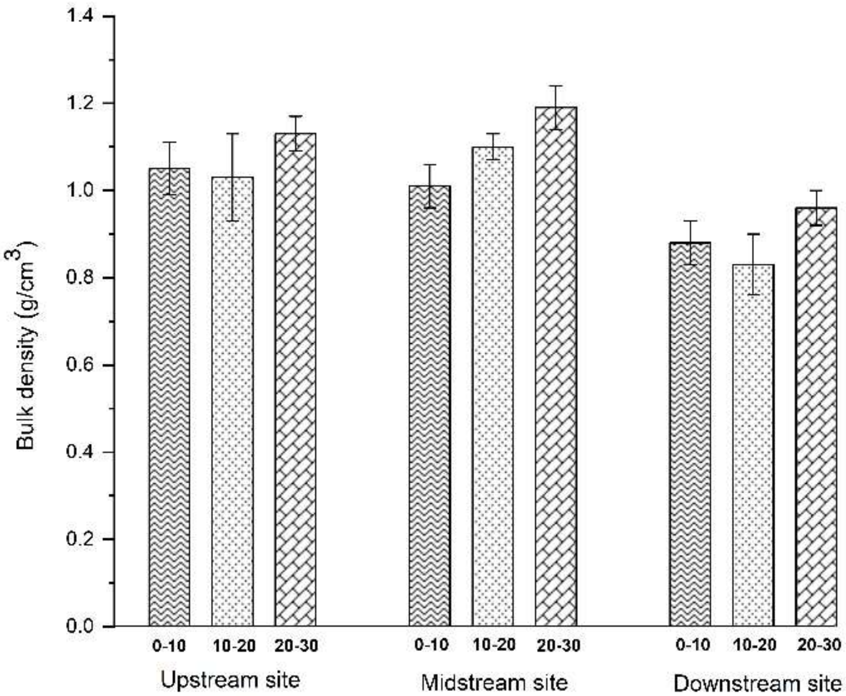



**Fig. 6.1:** Variation in bulk density (g/cm$^3$) across the vertical depth (0-10, 10-20 and 20-30 cm) in three different sites (upstream, midstream and downstream forested riparian site) along the Doyang river.

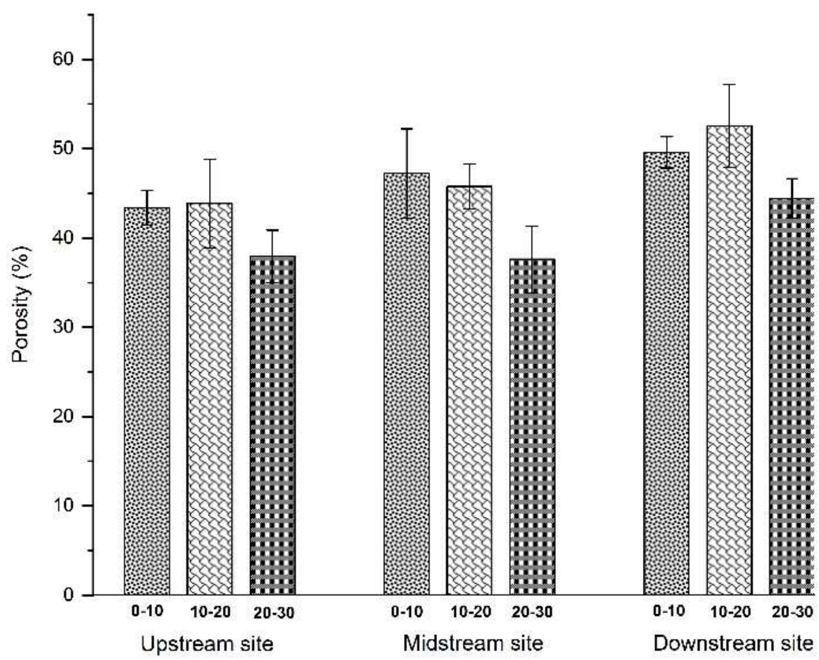



**Fig. 6.2:** Variation in soil porosity (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in three different sites (upstream, midstream and downstream forested riparian site) along the Doyang river.

**Table 6.2:** Comparison between soil attributes of upstream, midstream and downstream forested riparian areas along the Doyang river: Soil moisture (SM), Soil temperature (T), Organic carbon of soil (OC), Phosphorus (P), Potassium (K), Total Nitrogen (TN), Available Nitrogen (AN), pH of soil (pH), Clay, Silt and Sand. Considering P value ≤ 0.05

| **Parameters** | **Upstream** | **Midstream** | **Downstream** | **ANOVA/Kruskal-Wallis** |
|---|---|---|---|---|
| | Mean ±SE | Mean ±SE | Mean ±SE | P |
| SM (%) | 80.60 ±1.33 | 81.05 ±1.18 | 78.45 ±1.21 | 0.275 |
| T (°C) | 26.10 ±0.27 | 25.31 ±0.77 | 26.71 ±0.79 | 0.144 |
| OC (%) | 1.65 ±0.27 | 1.93 ±0.11 | 1.69 ±0.15 | 0.388 |
| P (kg/ha) | 7.88 ±0.42 | 8.41 ±0.72 | 8.06 ±0.37 | 0.869 |
| K (kg/ha) | 46.84 ±8.54 | 116.32 ±10.32 | 17.78 ±1.72 | **0.000** |
| TN (%) | 0.22 ±0.02 | 0.23 ±0.01 | 0.20 ±0.01 | 0.342 |
| AN (kg/ha) | 156.80 ±9.71 | 186.07 ±8.10 | 195.48 ±9.00 | **0.022** |
| pH | 6.57 ±0.09 | 6.59 ±0.05 | 5.85 ±0.09 | **0.000** |
| Clay (%) | 31.54 ±2.61 | 41.96 ±2.16 | 26.51 ±2.14 | **0.003** |
| Silt (%) | 40.94 ±1.63 | 42.08 ±1.64 | 39.40 ±1.00 | 0.578 |
| Sand (%) | 27.40 ±3.39 | 15.96 ±2.10 | 33.96 ±2.75 | **0.003** |

### 6.2.2 pH

The midstream site recorded the maximum mean pH of 6.59±0.05, followed by 6.57±0.09 upstream, and 5.85±0.09 downstream. Kruskal-Wallis's ANOVA test showed a significant difference ($p<0.05$) between the sites (**Table 6.2**). Box plot of pH shows the median of both the midstream and upstream sites in an almost similar position indicating that there is no significant difference between the two sites (**Fig.6.3**). However, upstream represented a difference in its pH value from among the sites. The distribution of data seems normal across the downstream site while it showed a positively skewed (mean>median) distributed data in midstream and slightly negatively skewed (mean<median) in the downstream site. The box plot also displays that the pH value downstream is more dispersed than the midstream and upstream sites.

### 6.2.3 Organic carbon (%)

The average mean organic carbon percentage was recorded highest at the midstream site (1.93±0.11) followed by downstream (1.69±0.15) and upstream (1.65±0.27). Kruskal-Wallis's ANOVA test noted an insignificant difference ($p>0.05$) between the sites (**Table 6.2**). According to the position of medians of the box plot, it indicates that there is not much difference in the percentage of organic carbon among the sites (**Fig.6.3**). The comparison of interquartile ranges (box lengths) and whisker of box plot showed much more dispersed data or variation in the observed value at the upstream site. Data recorded a normal distribution at a downstream site while it showed a slight negatively skewed (mean<median) distribution of data at midstream and downstream sites.

### 6.2.4 Temperature ($^o$C)

In the present study, no significant variation in the soil temperature was observed among the sites. The downstream site noted the maximum mean temperature of 26.71±0.79, while the upstream recorded 26.10±0.27. The minimum mean soil temperature of 25.31±0.77 was observed at the midstream site. Kruskal-Wallis's ANOVA test also showed an insignificant difference ($p>0.05$) between the sites (**Table 6.2**). As per the position of each respective medians, the data was observed to have no significant difference across the sites (**Fig.6.3**). Compared to the upstream, the values of recorded soil temperature presented much more dispersed in the midstream and downstream sites.

### 6.2.5 Soil moisture (%)

Soil moisture at midstream recorded the maximum mean of 81.05±1.18. The upstream site also observed a comparatively similar mean of 80.60±1.33 followed by the least percentage of 78.45±1.21 downstream. An insignificant difference ($p>0.05$) between the sites can be observed from the Kruskal-Wallis's ANOVA test (**Table 6.2**). The widespread interquartile range (that is, the box lengths) at upstream indicates more dispersed data (**Fig.6.3**). The outliers observed at the midstream site indicates that the particular data point does not fit into the data set and represent a statistically different data point. However, the distribution of data across different sites (upstream, midstream, and downstream) indicates a normal distribution.

### 6.2.6 Total nitrogen (%)

The percentage of total nitrogen was observed to be almost similar in all the sites. Only a meager difference was recorded among the sites. The upstream site recorded a mean value of 0.22±0.02, while the midstream recorded 0.23±0.01, and the downstream site recorded 0.20±0.01 (**Table 6.2**). The Kruskal-Wallis's ANOVA test showed an insignificant difference ($p>0.05$) in the percentage of total nitrogen between the sites. The whisker length and the interquartile ranges (box length) of the box plot at the upstream site observed to be much longer and wider (**Fig.6.3**). This indicates more dispersed data in the upstream site than the other sites. The outliers observed at the midstream site indicate that a particular data point does not fit and quite represent a statistically different data point. The distribution of data at downstream showed a normal distribution while in the case of upstream and midstream, it symbolizes a more positively skewed data (mean>median).

### 6.2.7 Available nitrogen (Kg/ha)

Considerable variation in the concentration of available nitrogen was recorded in the present study from among the sites. The downstream site reported the maximum mean of 195.48±9.00 followed by 186.07±8.10 at midstream. The upstream site recorded the minimum with an average mean of 156.80±9.71. Kruskal-Wallis's ANOVA test showed a significant difference ($p<0.05$) in the concentration of available nitrogen between the sites (**Table 6.2**). The box plot interquartile range of downstream site was observed much wider indicating more dispersed data (**Fig.6.3**). The whisker length at the upstream site was recorded much longer. This signifies that available nitrogen in this site also varies widely. Data downstream and midstream indicates a negatively skewed distribution (mean<median) while at the upstream site it is observed to be normally distributed.

### 6.2.8 Potassium (Kg/ha)

The concentration of potassium in the present study recorded a large variation among the sites. Midstream recorded a whooping mean value of 116.32±10.32 followed by an average mean value of 46.84±8.54 at upstream. The least was recorded at the downstream site having a mean value of 17.78±1.72 (**Table 6.2**). Kruskal-Wallis's ANOVA test showed a significant difference ($p<0.05$) between the different sites. By comparing the median of the box plot, it also indicates that there is a significant difference between the sites (**Fig.6.3**). The whisker length of the midstream site is much longer indicating that potassium in this site varies more widely. The spread of data in the midstream showed a positively skewed distribution (mean>median). The downstream site showed a much lesser variation in the concentration of potassium.

### 6.2.9 Phosphorus (Kg/ha)

The study recorded the maximum mean concentration of phosphorus at the midstream site, (8.41±0.72). This is followed by 8.06±0.37 at downstream and finally 7.88±0.42 at the upstream site (**Table 6.2**). An insignificant difference ($p>0.05$) between the sites was observed as shown by Kruskal-Wallis's ANOVA test. The comparison of medians in the box plot indicates that there is no significant difference in the concentration of phosphorus between the sites (**Fig.6.3**). The outliers observed from midstream and upstream site points that certain data point does not fit the data set and represent a statistically different data point. The distribution of data in midstream showed a normal distribution however upstream and downstream indicated a positive skewed (mean>median) distribution of data.

### 6.2.10 Clay (%)

The percentage of clay at midstream recorded the maximum with a mean value of 41.96±2.16, while the downstream site recorded the least with a mean value of 26.51±2.14. The percentage of clay at the upstream site also recorded a mean value of 31.54±2.61 (**Table 6.2**) The Kruskal-Wallis's ANOVA test indicated a significant difference ($p<0.05$) between the sites in the percentage of clay composition. The wide difference in the median of the box plot of Clay percentage indicates a substantial difference between the sites (**Fig.6.3**). Downstream and midstream sites indicated a normal distribution of data while the upstream site showed a negatively skewed (mean<median) distribution of data. The interquartile ranges (box lengths) and whisker of the box plot also indicate that the dispersion of data is almost equal in all the sites.

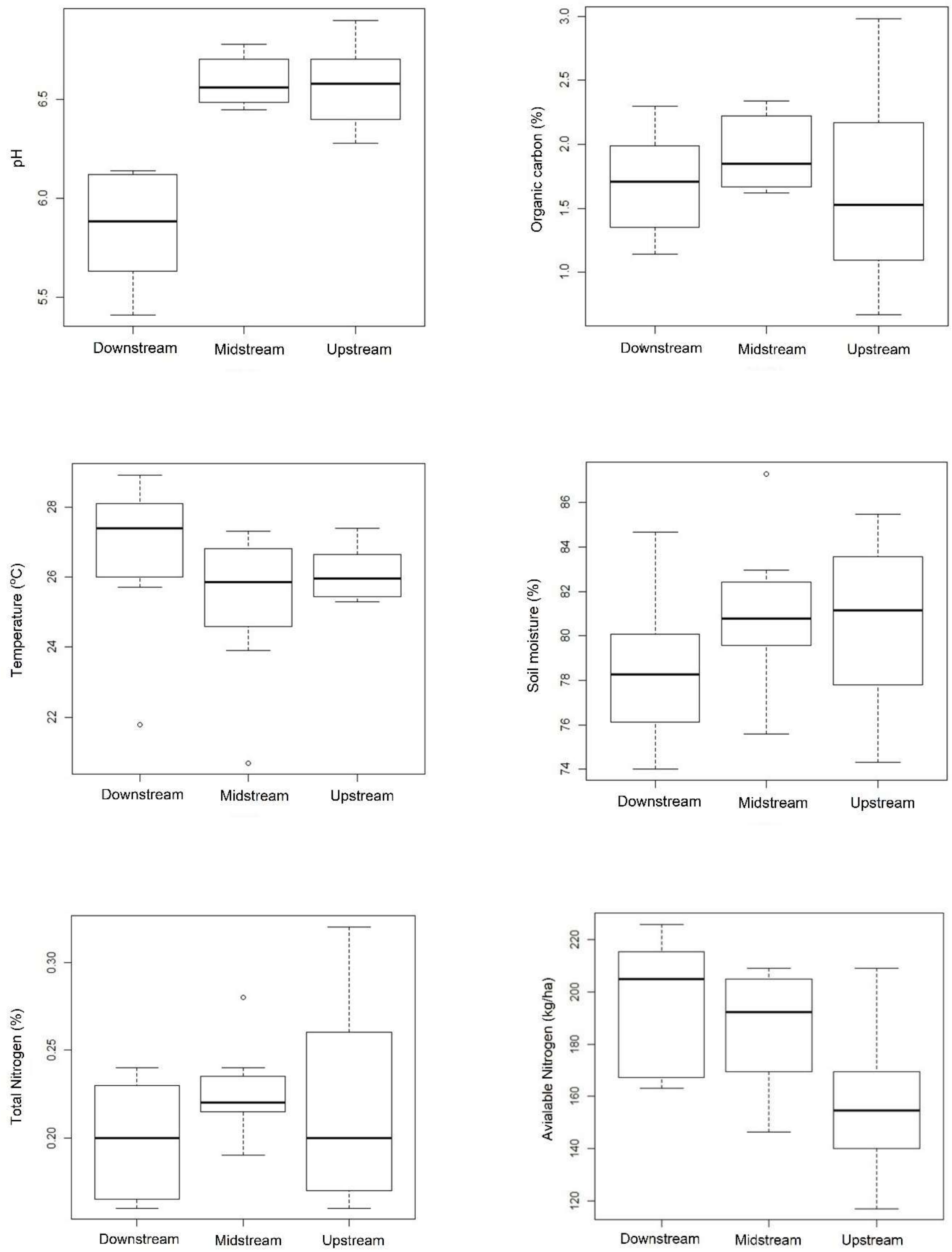
### 6.2.11 Silt (%)

The percentage of silt in the midstream site reported the highest mean value of 42.08±1.64 followed by 40.94±1.63 at upstream. The minimum was recorded downstream with a mean value of 39.40±1.00. Kruskal-Wallis's ANOVA test showed an insignificant difference ($p>0.05$) between the sites (**Table 6.2**). The comparison of the interquartile ranges (that is, the box lengths) shows that the data are more dispersed or varied in midstream and upstream (**Fig.6.3**). The distribution of data seems normal at downstream and midstream site, while it showed a positively skewed (mean>median) distribution of data at upstream.

### 6.2.12 Sand (%)

Among the sites, the highest percentage of sand was recorded downstream having a mean of 33.96±2.75 which is then followed by a mean value of 27.40±3.39 at the upstream site. Midstream site observed the least mean value of 15.96±2.10. Kruskal-Wallis's ANOVA test indicated a significant difference ($p<0.05$) in the percentage of sand between the sites (**Table 6.2**). The comparison of respective medians of each box plot indicates the difference between the sites (**Fig.6.3**). The interquartile ranges (that is, the box lengths) showed no significant difference, yet the midstream site was observed to have the least range. Downstream and midstream sites showed an almost normally distributed data, while the upstream site showed a negatively skewed (mean<median) distribution of data.

The principal component analysis (PCA) biplot (**Fig.6.4**) showed a significant relationship between the soil physicochemical parameters (pH, Soil moisture, Clay, Silt, Total nitrogen, Available nitrogen, Phosphorus, Potassium, Organic carbon) and herbaceous plant (richness and density) at Midstream zone of Doyang river.


pH
5.5
6.0
6.5
Downstream
Midstream
Upstream
Organic carbon (%)
1.0
1.5
2.0
2.5
3.0
Downstream
Midstream
Upstream
Temperature (°C)
22
24
26
28
Downstream
Midstream
Upstream
Soil moisture (%)
74
76
78
80
82
84
86
Downstream
Midstream
Upstream
Total Nitrogen (%)
0.20
0.25
0.30
Downstream
Midstream
Upstream
Avialable Nitrogen (kg/ha)
120
140
160
180
200
220
Downstream
Midstream
Upstream

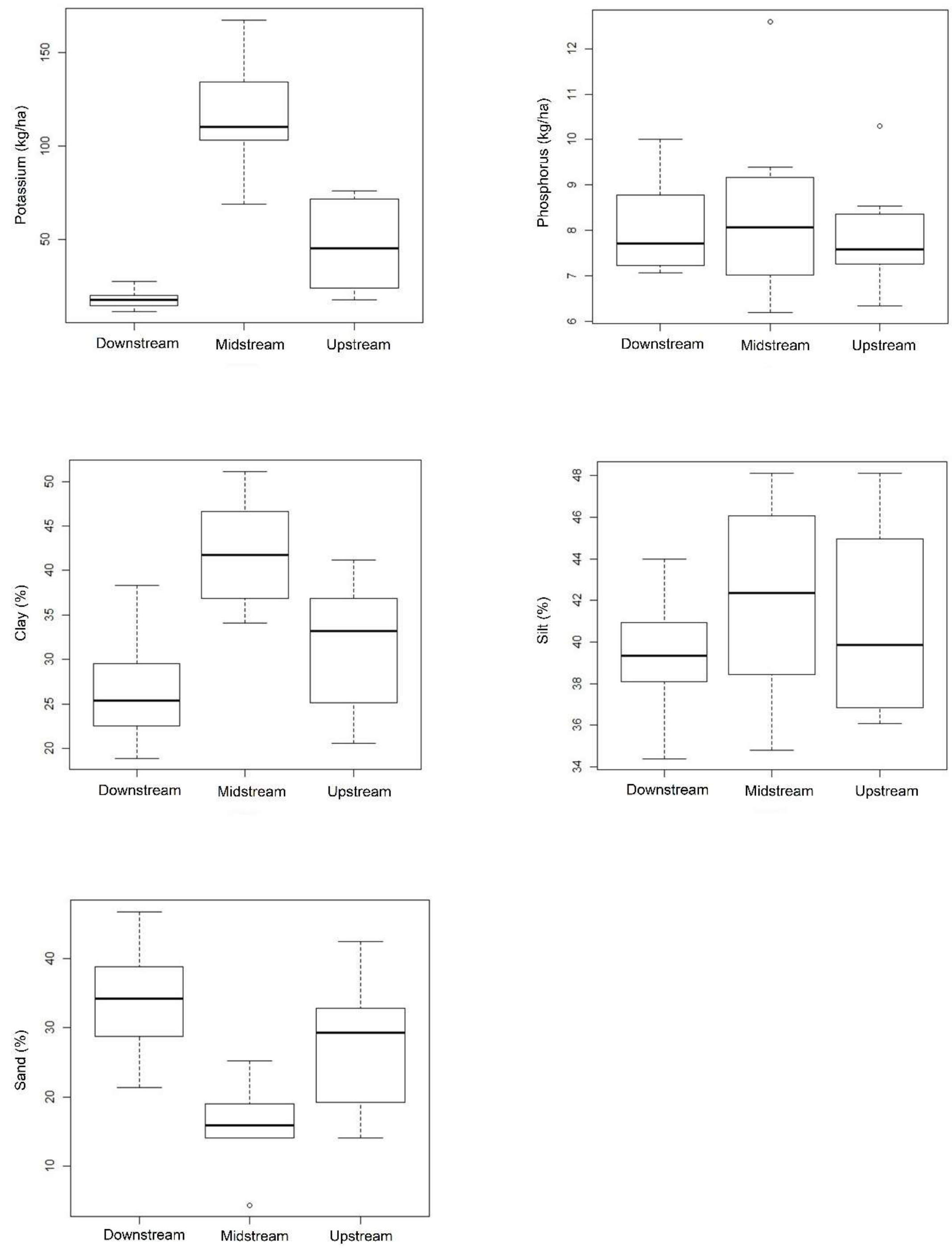



**Fig. 6.3:** Box plot displaying the distribution of various soil physicochemical parameters (pH, Organic carbon, Soil temperature, Soil moisture, Total Nitrogen, Available Nitrogen, Potassium, Phosphorus, Clay, Silt and Sand) across different sites (Upstream, midstream and downstream forested riparian zone).

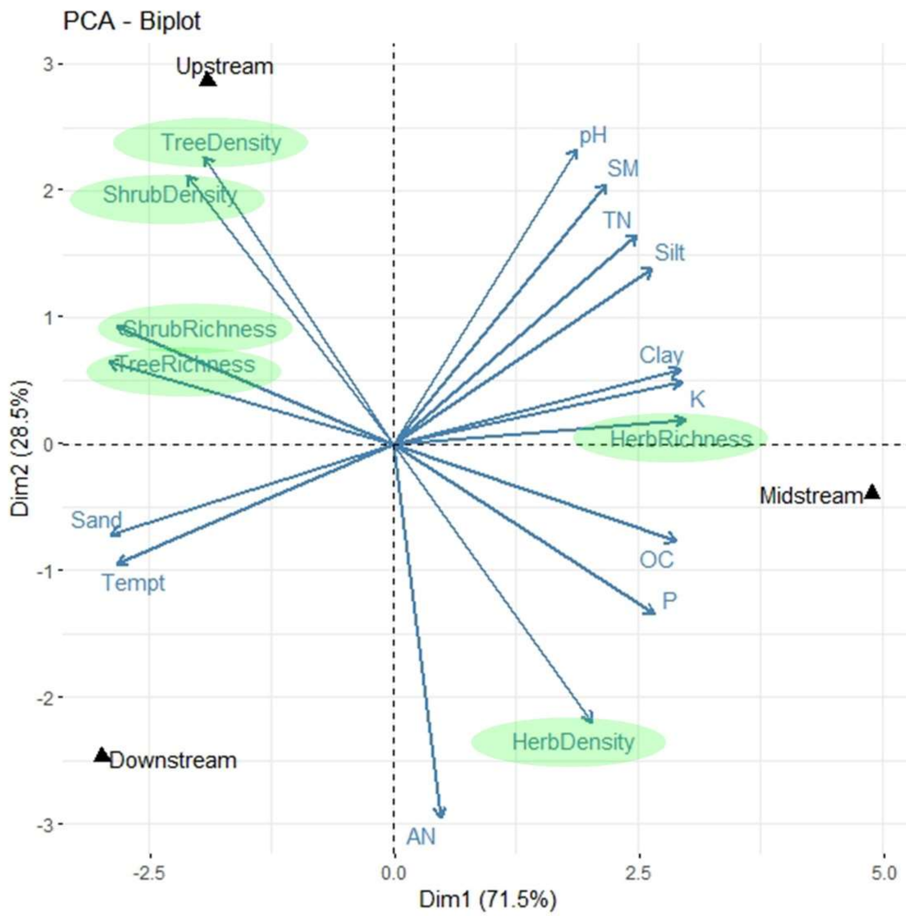



**Fig. 6.4:** Principal component analysis (PCA) biplot of soil physicochemical parameters (pH, Temperature, Soil moisture-SM, Clay, Silt, Sand, Total nitrogen-TN, Available nitrogen-AN, Phosphorus-P, Potassium-K, Organic carbon-OC) and vegetation (Richness and Density) at upstream, midstream and downstream zone of Doyang river.

## 6.3 DISCUSSION

In all three forested riparian sites, i.e. upstream, midstream, and downstream, the heterogeneous nature of the riparian soil can be explained along the line of topographic features. Other attributes like the difference in the rapidness of decomposition, the quantity of decomposition, and the chemical composition of the decomposition products could have also perhaps induced the variation or heterogeneity of the soil physicochemical properties (Qian *et al*., 2017). Workers like Kong *et al*. (2014) and Zhi *et al*. (2013) found that physicochemical properties of soil were mainly affected by the root exudates thus, underscoring the arbiter role of vegetation composition. A similar explanation may also be considered in the present study too. The present study found the concentration of nutrients parameters like total nitrogen, available phosphorus, potassium, and available nitrogen lesser at upstream and downstream riparian forested sites. This particular result could be linked to both erosional loss and higher levels of plant uptake (Fraser *et al*., 2004; Ye *et al*., 2019). Groffman *et al*. (1992) found the dominant sink for nitrate in riparian soil was mostly plant uptake, especially during the growing season. Moreover, in riparian zones, due to the presence of high-water tables, it also coherently creates an anoxic condition necessary for the denitrification process to take place (Hill, 1996; Bilby, 1998). In the present study area, specifically at upstream and downstream sites, due to the steeper slopes, the soil is more easily eroded, leading to loss of nutrients, organic matter, and P from soil to water system during the wave erosion and storm events (Bing *et al*., 2016; Sun *et al*., 2018; Ye *et al*., 2019).

### 6.3.1 Soil physical properties

The bulk density of soil represents its degree of compactness. Results have shown that with soil depth, the compactness of the soil also increases. This tendency of bulk density to increase with depth underlines the effects of the weight of the overlying soil and the corresponding decrease in the content of soil organic matter (Brady and Weil, 2002). Arshad and Martin, (2002) reported that bulk density tends to usually increase with compaction and increasing depth. Maurice *et al*. (2014) highlighted that human activities, like frequent farming, tend to usually increase soil compaction and, hereafter, increases bulk density. Events of regular inundation leading to fluvial deposits that are rich in organic matter also influence the bulk density. The combined impact of all these factors together with the regular movement of villagers along the riparian zones could have influenced the bulk densities of soil in the present study area. The occurrence of relatively lower bulk density in the topsoil layer may be related to the concentration of organic matter. Soil with a bulk density higher than 1.6 $g/cm^3$ usually restricts root growth and interferes with the ability of the plant to absorb water and nutrients (McKenzie *et al*., 1992). However, in the present study, we observed that the mean bulk densities in all the sites and layers range from 0.83 g/cm3 to 1.19 $g/cm^3$ indicating that there is an optimum movement of water and air (Hunt and Gilkes, 1992). Soil porosity showed an inversed relationship with the bulk density, that is, it decreases as the bulk density increases and vice versa. It displayed a decreasing pattern with an increase in depth of the soil layers. It was found that soil porosities in the downstream site were relatively higher which corresponds to lesser bulk density.

Soil texture constitutes an important parameter in agriculture due to its role in soil aeration, water supply, exchange of cations, and soil hydraulic conductivity (Faulkner and Richardson, 1989). The study observed a higher percentage of silt and clay soil texture at upstream and midstream, while silty soil texture at downstream. This could be related to both floodwaters and the movement of soil particles from uplands during rainfall. Clay percentage showed significant variation between the sites (P=0.003). The probable reason could be weathering processes that dually shears and pulverizes the soil particles. Budke *et al*. (2007) also reported that moisture, clay, and silt were higher in riverside and that the local environmental constraints and flooding play an important role in regulating these components. Another convincing reason for the higher percentage of clay and silt at midstream site could be linked to gentler slopes allowing lower water flow velocities facilitating rapid accumulation (Bao *et al*., 2015) and decisive trapping by the presence of dense herbaceous plant communities. These topographic advantages certainly account for the higher accumulation of nutrients in soils (Ye *et al*., 2019) and positively support the higher concentration of soil organic carbon, Total N, K, Available P, and K at midstream site (**Table 6.2**). The fine-grained particles have the absorption capacity for nutrients and as a result, contribute toward the higher accumulation of soil nutrients at the midstream site. The percentage of sand also showed a significant difference between the sites (P=0.003). Particularly at the downstream site, the steep topographic features and various land-use practices in the uplands have led to the transport of soil particles accompanied by flushing of the same during rainfall. This leads to the deposition of sandy particles from the upland disturbed soils. The co-dominance of silt and clay soil texture in the present study area may positively boost an ideal condition for the growth of plants. Nevertheless, there are possibilities that, pedogenesis processes such as erosion, deposition, eluviation's and weathering can also potentially change the soil texture over a long period (Foth, 1990; Brady and Weil, 2002).

Soil temperature controls many chemical and biological processes and they constitute an important property of the soil. Factors such as fluctuation of air temperature near the ground, soil depth, metabolic activities of the plant roots, and microbes influence the surface soil temperature (Kasper and Bland, 1992). No significant variation in soil surface temperature was observed between the sites (P=0.144). This could be due to the reason that riparian vegetation structure has positively aided in mitigating the soil temperature. The marginal difference in the soil temperature recorded between the sites may be attributed to the timing of data collection. Soil moisture also did not show any significant variation with sites (P=0.275). Being closely connected to the water bodies and having access to groundwater all year round, soils in the riparian zones have abundant moisture content.

### 6.3.2 Soil chemical properties

Soil organic carbon did not show any significant variation across sites (P=0.388) and was observed to have a higher percentage in all the riparian sites. This is attributed to the higher accumulation of organic matter due to high inputs from the root and above-ground biomass (Reicosky and Forcella, 1998; Yimer *et al*., 2007). The major source of soil carbon comes from plant litter which is the main source of organic matter. The abundance of soil organic matter undoubtedly contributes towards N and P supply, cation exchange capacity, and act as a good soil structure favoring plant growth (Ross, 1993). Corresponding to the richness of organic matter, soil pH was observed to range from moderate to slightly acid soil conditions but did show any significant variation across the different sites (P=0.000). This might be related to the presence of higher organic carbon content and regular deposits of organic matter during floods in all the riparian sites.

The higher AN, TN at midstream is associated with the relatively higher organic carbon content which is a product of plant and root biomass as well as residues being returned to the soil system (Moges *et al*., 2013). Most soil nitrogen is bound together with the organic carbon and therefore followed a similar distribution pattern to organic carbon (**Table 6.2**). Available nitrogen in the riparian soil showed significant variation with sites (P=0.022) and this could be related to the accumulation of varying organic carbon content and other sources such as groundwater inputs, atmospheric deposition, and surface runoff (Lowrance *et al*., 1984; Galloway *et al*., 2003). An increase in soil N may subsequently elevate the above and belowground productivity and also the microbial activity. This in turn affects other soil processes such as soil respiration driving the dynamics of soil properties such as C content.

Comparatively lower phosphorus content in all the sites might be due to the high fixation capacity of the soil (Yimer *et al*., 2006) and absorption by plants. Other possible reasons could be due to the inherently low-P status of the parent materials and erosional loss (Moges *et al*., 2013). Waken *et al*. (2001) noted that under acidic conditions, the presence of high levels of soluble Al and Mn can possibly lead to precipitation of insoluble phosphate compounds. Furthermore, hydrous oxides of Al and Fe, as well as silicate clays, can fixed phosphate, which can potentially reduce its availability. Other soil properties like the presence of organic matter, pH, Fe, and Al play a crucial role in the retention capacity of P in the riparian soil. However, these factors can vary across landscapes and accordingly they affect the composition of P (Lyons *et al*., 1998). However, the marginally higher content of phosphorus at the midstream site may be related to the role of phosphatase enzymes. The maximal activity of these enzymes is reported to occur at a pH range of 6.5 and 6.9 (Amador *et al*., 1997), and depends considerably on the content of soil organic matter, moisture, and increases with an increase in root mass. All these factors were favorably available at the midstream site for the activity of these enzymes to effectively function. Soil potassium showed significant variation with sites (P=0.000). This observation was obvious for the reason that the availability of potassium in the soil is largely dependent on the parent rock material and climatic condition of the area. Among the sites, midstream recorded the highest potassium concentration of 116.32 kg/ha. This is attributed to the higher decomposition rate of organic carbon and warmer climatic condition which in turn facilitate the availability of K. The higher potassium availability can also be explained by the relative pumping of potassium from the subsoil by the vegetation (Bohn *et al*., 2001).

### 6.3.3 Soil-vegetation relationship

The relationship between the vegetation and the soil characteristics differed among the types of vegetation formation (i.e. at upstream, midstream, and downstream zone). Our study observed a notable relationship between the riparian soil parameters and the quantitative characteristics of plants (richness and density). The PCA biplot indicated a positive correlation between the soil parameters (pH, SM, clay, silt, TN, AN, P, K, and OC) and the herbaceous plant of the midstream site. While the sand and temperature of soil were found to be correlated with the woody plants (richness and density) at upstream and downstream sites. In the present study, higher herbaceous diversity and density were observed in the midstream riparian forest. Whereas, higher woody plant diversity and density were observed at upstream and downstream riparian forest. This has led to greater uptake of nutrients at upstream and downstream sites by the woody plant communities and their associated soil biota through immobilization (Peterjohn and Correll, 1984; Hill, 1996; Lovell and Sullivan, 2006; Young-Mathews *et al*., 2010). Hence, most of the soil parameters did not show any positive relationship with the woody vegetations. The steeper slopes and absence of sufficient ground cover (herbaceous plants community) in these sites (upstream and downstream) have also facilitated the runoff of soil particles during rainfall, leading to erosion.

However, at the midstream site due to the presence of thick and densely populated herbaceous vegetation cover, the surface runoff is relatively barred, hence, maximizing the retention capacity of the soil. The vegetation intercepts the water droplets of rainfall and they formed a local hindrance to the free and fast movement of water, thus providing ample time for the soil to absorb and retain the nutrients and minerals from the runoff (Raju *et al*., 1992). The presence of herbaceous riparian vegetation can effectively inhibit slope runoff and sediment yield (Zhang *et al*., 2019). While, its absence can maximize intense interaction between the raindrops and the soil system thereby allowing greater desorption, dissolution, and subsequent deferment in run-off (Kumar *et al*., 1992). Apart from this, the selective cutting of trees for firewood in the midstream zone has also caused greater canopy openness. This allows higher levels of lights in the riparian forest stimulating the decomposition and release of nutrients; besides, flooding, periodic sedimentation, and poor drainage have also influenced the availability of nutrients at midstream (Everson and Boucher, 1998). A study by Nadeau and Sullivan (2015) found the structural richness of herbs to be positively correlated with the soil fertility index and P concentration. Their study provided crucial insight into the ecological relationships between plant biodiversity and soil chemical fertility in the primary tropical forest. Finally, it may be understood that the presence of an abundant herbaceous community in the riparian zone may positively play an important role in the conservation efficiencies and management of soil.

## 6.4 SUMMARY AND CONCLUSION

The outcome of the present study found that soil physicochemical parameters like potassium, available nitrogen, soil pH, clay, and sand reported a significant difference among the sites. Nutrient parameters like total nitrogen, available phosphorus, potassium, and available nitrogen were reported comparatively less at upstream and downstream riparian forested sites. This is mainly due to the erosional loss and higher levels of plant uptake. The steeper slopes observed at upstream and downstream sites have greatly facilitated the soil erosion, leading to loss of nutrients and organic matter from the soil during the wave erosion and storm events. The gentler topographic advantages are certainly one important factor to take into account for the higher accumulation of nutrients and other soil parameters at the midstream site. The mean bulk densities in all the sites and layers ranged from 0.83 g/cm3 to 1.19 g/$cm^3$ indicating the porous nature of the present study area. The silty soil texture dominated all the riparian sites in the present study and this is due to both floodwaters and the movement of soil particles from uplands during rainfall. No significant variation in soil surface temperature was observed between the sites indicating that the riparian vegetation structure had positively mitigated the soil temperature. Soil moisture also did not show any significant variation with sites and this is due to the close connection to the water bodies and access to groundwater all year round.

The study reported a high percentage of soil organic carbon in all the riparian sites. At the midstream site, available nitrogen (186.07±8.10 kg/ha) and total nitrogen (0.23±0.01 %) were reported higher. Throughout the sites, soil *p*H was observed to range from moderate to a slightly acid condition. This is due to the higher organic carbon content and regular deposits of organic matter during floods. The high fixation capacity of the soil and absorption by plants contributed towards low phosphorus content in the present study sites. Concerning potassium, the midstream site recorded the highest concentration and this is attributed to the higher rate of decomposition of organic carbon and warmer climatic condition which in due course facilitate the availability of K.

The relationship between the riparian vegetation and the soil properties have indicated a positive relationship. Most of the soil parameters showed a positive correlation with richness and density of herbaceous plant community. The midstream zone was dominated by herbaceous species where the soil parameters like pH, SM, clay, silt, TN, AN, P, K, and OC were found to be higher in concentration. Densely populated herbaceous vegetation seems to have considerably prevented the runoff, thereby, maximizing the retention capacity. This herbaceous vegetation at the midstream site acts as a local hindrance to the free and fast movement of water, allowing the soil to absorb and retain the nutrient minerals from runoff. However, the woody plants (density and richness) did not show any positive relationship with the soil parameters. The higher density and diversity of woody plants at upstream and downstream sites may suggest that they have a higher ability to absorb and compete for nutrient uptake. This has led to greater uptake of nutrients by the growing woody vegetation. The steeper slopes and absence of sufficient ground vegetation cover in these sites (upstream and downstream) have also facilitated the runoff of soil particles during rainfall, leading to erosion. The present study establishes the conservation efficiencies of soil by herbaceous vegetation which otherwise might be lost through runoff. Thus, the study highlights the importance of having a healthy herbaceous riparian plant community which would effectively mitigate the loss of soil nutrients.

# CHAPTER 7

# SUMMARY

The present study was conducted along the riparian zone of the Doyang river, Wokha, Nagaland, India. The Doyang river is one of the major rivers in Nagaland and runs along the southern boundary of the state. It originates from the Japfü Hill near the southern slope of Mao in Manipur and moves in a southwest direction passing through Kohima district and flows northward into Zunheboto and Wokha. The Doyang River passes through a great part of the Wokha district of Nagaland; Tsui, Tullo and Tishi are the main tributaries of the river. The Doyang river has a strong economic and traditional attachment to the local people (Lothas) because of its sufficient fertile plains and slopes for cultivation. The Doyang Hydro-Electric Project (DHEP) is located in this river and the large reservoir is more than 20 $km^2$. The present study was conducted within a stretch of 40-45 km of the Doyang River under Wokha district, Nagaland.

The increasing land-use practices along the riparian zones of the Doyang river incessantly threaten the riparian habitats as never before. The high prevalence of shifting cultivation, also known as Jhum, forms the major land-use system practices along the riparian zones of the Doyang river. This practice leads to cutting down of large riparian areas. Besides the existence of jhum practice, other anthropogenic activities like the increasing deforestation in the catchment and river banks, increasing population, extensive teak plantation for timber, and developmental activities continue to threaten the riparian habitats. The current emergent threat has therefore called for an urgent need to protect the riparian ecosystem, assess and formulate conservation strategies. These habitats are directly linked to the livelihood and security of the people in this region. Therefore, this research work entitled **"*Studies on riparian vegetation diversity and its relationship with soil and water characteristics of Doyang river, Wokha, Nagaland*"** was taken up with the following objectives.

1. To determine the physicochemical characteristics of water quality.
2. To calculate the Water Quality Index (WQI).
3. To study the riparian vegetation diversity along the Doyang river.
4. To determine the soil physicochemical characteristics of the riparian zones.

The following hypotheses were made to help understand the relationship between the riparian vegetation diversity, soil and water characteristics of the Doyang river.

(a) Land-use activities have some effect on water quality.

(b) Land-use practices affects the riparian vegetation diversity.

(c) There is a positive relationship between the riparian vegetation and soil.

Chapter 3 of the thesis emphasized on the evaluation of the temporal and spatial variation in surface water quality of the Doyang river using multivariate statistical techniques like Principal Component Analysis (PCA) and Cluster Analysis (CA). All the studied physicochemical parameters of water quality from the eight selected sampling stations were found to be within the permissible limits of drinking water (BIS, ICMR, and WHO) and suitable for different human purposes. The result of the PCA provided a comprehensive source and nature of pollution happening along the Doyang river. It indicated upstream station (S1) largely affected by $Cl^-$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $SO_4^{2-}$, and K. While midstream stations (S2, S3, S4, and S5) showed positive relation towards pH, WT, DO and BOD. Downstream stations of S6, S7, and S8 were found to be positively affected by $NO_3^-$, K, and $PO_4^{3-}$. The study found midstream sampling stations (S2, S3, S4, and S5) facing much of the seasonal influence (rainfall) and parameters like WT, $CO_2$, pH, DO and BOD was found to accord to the seasonal cycle. The Doyang river was segregated into three different zones based on the nature of the pollution load. The upstream station represented more of mineral load, midstream stations represented more of organic load and downstream stations represented more of nutrient loading. The presence of ongoing developmental activities (construction of national highway bridge: NH-02) and residential homes at the upstream had a major effect on the water quality parameters like $Cl^{-}$, TDS, EC, TA, TH, $Ca^{2+}$, $Mg^{2+}$, $NO_3^{-}$, $SO_4^{2-}$, and K. Land-use practices like jhum cultivation, and teak plantation at the midstream was found to significantly affect the pH, WT, DO and BOD. While downstream, the presence of several residential homes and hotels were found to positively affect $CO_2$, $PO_4^{3-}$, $NO_3^{-}$, and K. The result clearly segregates each zone of the river according to its exclusive characteristics of water chemistry and provided a crucial information on the kinds of pollution taking place at each sampling station of the Doyang river. This observation, therefore, is in agreement with our first hypothesis that land-use activities do have a positive effect on the water quality of the Doyang river.

Despite recording positive loading of nutrient parameters downstream, it was found to be under the permissible limits. Other water quality parameters also did not show any considerable increase downstream of the river indicating that some recovery process may have been made as the river again flows through the patches of riparian forest. The dendrogram of cluster analysis (CA) segregated the study area into three different clusters or groups based on the similar characteristics of water qualities they possess. The result of CA also found upstream station (S1) possessing a distinct characteristic of water quality having many of the water quality variables adequately loaded.

The calculation of the Water Quality Index (WQI) in chapter 4 also provided valuable information on the overall water quality status of the Doyang River. Variables like the DO, BOD, and pH were found to have a major effect on the water quality in the present study. However, the nutrient parameters did not show any significant roles in the WQI values. WQI was found to positively respond to seasonal changes. The maximum WQI values was recorded during monsoon from all the eight stations (S1-42.03, S2-51.76, S3-53.10, S4-55.45, S5-51.45, S6-41.51, S7-40.77, S8-40.97) followed by pre-monsoon and post-monsoon. As per the observation, recorded WQI values fall in good water quality status during pre and post-monsoon in all the sampling stations, while, poor water quality status during monsoon at sampling stations located upstream (S1) and midstream (S2, S3, S4, and S5) of the river. No considerable changes in WQI were observed throughout the study period except in few stations (S2-51.76, S3-53.10, S4-55.45 and S5-51.45), where a modest increase in WQI was observed during monsoon. Despite observing some distortion during the monsoon, the overall average WQI values (pre-monsoon-42.95, monsoon-47.13, and post-monsoon-36.66) indicates that the water quality of the Doyang river falls under the class of good water quality (25 < WQI < 50), which is suitable for drinking, irrigation, and industrial purpose.

Chapter 5 of the thesis discussed on the assessment of riparian vegetation diversity along the Doyang river and the study recorded a rich floristic community. The total number of species documented were 174 species of plants represented by 146 genera and 61 families. The species was found in the following order of trees (68)>shrubs (54)>herbs (52). In terms of species richness and diversity, the upstream riparian zone was observed to be the richest and the most diverse zone (H´of trees-3.373 and H´of shrubs-3.387). The upstream riparian forest reported 92 species which is represented by 48 families followed by the downstream riparian forest which described 87 species represented by 43 families and finally the midstream riparian forest, where 71 species of plants were reported belonging to 37 families. The highest species representation was recorded in the family Rubiaceae (13 species). The high evenness observed among the trees and shrubs in the present study area points to the site-specific disturbances on the vegetation types allowing the plants to have equal distribution. The composition of the trees recorded the least similarity in the present study area (upstream and midstream–0.185, midstream and downstream–0.226, upstream and downstream–0.254). This is obvious for the reason that trees in this area are fell as a result of regular selective cutting for timber, anthropogenic disturbances, contrast climatic conditions between the zones due to the presence of Dam and various land-use system. The general pattern of DBH class distribution of trees at each zone was observed to be inverted J-shape. The highest density of trees was in the 10.1-15 cm DBH class while the lowest was in the 30.1-35 cm DBH class. The study area is classified as an uneven-aged forest structure because of selective cutting and disturbance. The higher proportion of species in the lower frequency class contribute towards the floristic heterogeneity of riparian vegetation.

The life-form studies showed highest percentage in Phanerophytes (70.11%) followed by Therophytes (10.92%), Cryptophytes (8.05%), Chamaephytes (7.47%), and Hemicryptophytes (3.45%). Phanerophytes and Therophytes together constitute 80.03% of the total life forms and accordingly, the study area depicts a "Phanero-therophytic" type of phytoclimatic condition. This finding reflects the bioclimatic condition of the area as a humid and arid region. While documenting many typical riparian plant species, the study also recorded several *Ficus* spp. (*F. auriculate, F. obscura, F. concinna, F. hispida, F. nervosa, F. benjamina, F. squamosa*) and *Artocarpus* spp. (*A. chama*, *A. lacucha, A.*

*heterophyllus*). These plants are recognized as a keystone species and they constitute a major food source and habitat for birds, insects, and mammals in the tropical forest. The abundance of these species in the present study area certainly recognizes their ecological importance and the compelling need to prioritize the management and conservation efforts of these keystone species.

It was observed that construction of Hydro Dam, extensive jhum cultivation, teak plantation and edge effect causes a considerable effect on the physiognomy of midstream riparian forest as compared to the other two sites. The present study reported lesser diversity of woody plant species, while, herbaceous plant community recorded higher diversity (29 species) and abundance (197000 individual $ha^{-1}$) in the midstream riparian forest. As the natural riparian forest is cut down annually, woody plant diversity (trees and shrubs) starts to decline giving more space to the herbaceous plant community to flourish (*Chromolaena odorata, Carex baccans*, *Digitaria setigera, Imperata cylindrica*). Due to recurring flood events, frequent erosion, and submergence was observed. The flood also brings along rich alluvial soil and deposition of seeds propagules. This has resulted in the higher diversity of annual invasive weeds at the midstream zone (*Alternanthera sessilis*, *Crassocephalum crepidioides, Crotalaria pallida, Cuphea carthagenensis*, *Heliotropium indicum, Xanthium strumarium, Oxalis corniculate, Ageratum conyzoides, Sonchus arvensis,* and *Ranunculus sceleratus*). Another important environmental factor affecting the composition of riparian vegetation at midstream is the edge effects from surrounding agricultural practices. Edge effect may alter the microclimate (e.g., air temperature, soil moisture, vapor pressure deficit, and light intensity) of the area which may eventually persuade the species to make changes in the community structure. The above observations, therefore, suggest that the riparian vegetation diversity does respond to land-use practices. This may correspond to the second that land-use practices affect the riparian vegetation diversity.

The physicochemical parameters of riparian soils studied from different zones of the Doyang river are given in chapter 6. Soil physicochemical parameters like potassium, available nitrogen, soil pH, clay, and sand reported a significant difference ($p<0.05$) between the sites. Nutrient parameters like total nitrogen, available phosphorus, potassium, and available nitrogen were reported comparatively less at upstream and downstream riparian forested sites. This is mainly due to the erosional loss and higher levels of plant uptake. The steeper slopes observed at upstream and downstream sites have greatly facilitated soil erosion, leading to loss of nutrients and organic matter from the soil during the wave erosion and storm events. The gentler topographic advantages are certainly one important factor to take into account for the higher accumulation of nutrients and other soil parameters at the midstream site. The mean bulk densities in all the sites and layers ranged from 0.83 $g/cm^3$ to 1.19 $g/cm^3$ indicating the porous nature of the present study area. The silty soil texture dominated all the riparian sites in the present study; due to both floodwaters and movement of soil particles from uplands during rainfall. No significant variation in soil surface temperature (P=0.144) was observed between the sites indicating that the riparian vegetation structure had positively mitigated the soil temperature. Soil moisture also did not show any significant variation between the sites (P=0.275), mainly due to the close connection to the water bodies and access to groundwater all year round.

The study reported a high percentage of soil organic carbon in all the riparian sites. At the midstream site, available nitrogen (186.07±8.10 kg/ha) and total nitrogen (0.23±0.01 %) were reported higher. Throughout the sites, soil pH was observed to range from moderate to slightly acid (5.41-6.9). The high fixation capacity of the soil and absorption by plants may have contributed towards the low phosphorus content in the present study sites. Concerning potassium, the midstream site recorded the highest concentration (116.32±10.32 kg/ha) which may be attributed to the higher rate of decomposition of organic carbon and warmer climatic condition which in due course facilitate the availability of K.

The relationship between the riparian vegetation and the soil properties have also indicated a positive association. Most of the soil parameters showed a positive correlation with the herbaceous plant (density and richness). The midstream zone was dominated by herbaceous species where the soil parameters like pH, SM, clay, silt, TN, AN, P, K, and OC were found to be higher in concentration. Densely populated herbaceous vegetation seems to have considerably prevented the runoff, thereby, maximizing the retention capacity. The presence of herbaceous vegetation at the midstream site acts as a local hindrance to the free and fast movement of water, allowing the soil to absorb and retain the nutrient minerals from runoff. However, the woody plants (density and richness) did not show much correlation with the soil parameters. The high density of woody plants at upstream and downstream sites may suggest that they have a higher ability to absorb and compete for nutrient uptake. This has led to greater uptake of nutrients by the growing woody vegetation. Soil erosion was also observed in these sites (upstream and downstream) because of the steeper slopes and absence of sufficient ground cover (herbaceous plants). The present study establishes the conservation efficiencies and management of soil by herbaceous vegetation which otherwise might have lost through runoff. This observation thus supports the final hypothesis which assumed that there is a positive relationship between the riparian vegetation and soil.

The outcome of the present study has successfully answered all the research questions raised at the beginning and has ultimately provided the much-needed information on the source and kinds of pollution occurring along the river, water quality status, riparian vegetation diversity and the characteristics of riparian soil of the Doyang river. The study has also provided vital information on the effect of land-use practices on water quality and vegetation diversity and also the positive role played by the herbaceous plant community in the conservation and management of riparian soil. The study encourages the need to adopt sustainable land-use practices and landscape planning at multiple scales and implement management guidelines to prevent further deterioration of water quality. It also pressed the need to effectively manage all the current activities in the riparian zone of the Doyang river. If not checked, it could lead to further deterioration of water quality and endanger the existence of the native riparian plant species and other functional attributes of the services provided by the riparian ecosystem. Proper management policy must be adopted on the disposal of sewage by the communities residing in the catchment areas, agricultural runoff, unmanaged land-use practices, and unprotected riparian areas. Judicious management efforts from every stakeholder both the government agency and the community are crucial. Some of the suggested mitigation measures include creating awareness among the local community, strict maintenance of riparian buffer zones, proper management of tourism activity, and restriction of land use practices close to riparian areas. It also suggests an effort to protect the important native and keystone species found in these areas both from logging and other forms of selective cutting. The present study strongly advocates the necessity to maintain healthy riparian forests and measures to protect them.

**Plate - I: An overview of the Doyang river**

**Doyang riparian forest**

**Doyang Hydro-Electric Dam**

**Plate - II: Various anthropogenic activities observed along the Doyang river**

**Residential homes**

**Developmental activities**

**Logging**

**Cutting down of riparian forest for Jhum**

**Jhum practices**

**Teak plantation**

**Selective cutting of trees for firewood**

**Waste left behind by picnickers**

**Plate - III: Some of the field activities carried out during the study period**

**Preparation of water sample for DO and BOD**

**Random collection of soil sample**

**Measurement of tree DBH**

**Testing of water sample on the spot**

**Collection of soil for Bulk density and Porosity using soil core sample**

**Measurement of soil temperature on the spot**

**Plate - IV: Some of the tree species found along the riparian zones of the Doyang river**

*Aporosa octandra* (Buch.-Ham. ex D.Don) Vickery

*Archidendron clypearia* (Jack) I.C.Nielsen

*Bauhinia variegata* L.

*Brassaiopsis mitis* C.B.Clarke

*Carallia brachiata* (Lour.) Merr.

*Diospyros stricta* Roxb.

*Ficus benjamina* L

*Ficus nervosa* B.Heyne ex Roth

*Glochidion ellipticum* Wight

*Magnolia champaca* (L.) Baill. ex Pierre

*Magnolia hodgsonii* (Hook. f. & Thomson) H. Keng

*Ficus auriculata* Lour

*Sumbaviopsis albicans* (Blume) J.J.Sm.

*Syzygium balsameum* (Wight) Wall. ex Walp.

*Syzygium megacarpum* (Craib) Rathakr. & N.C.Nair

*Syzygium reticulatum* (Wight) Walp.

*Ulmus lanceifolia* Roxb. ex Wall.

*Wrightia arborea* (Dennst.) Mabb.

**Plate - V: Some of the shrub species found along the riparian zones of the Doyang river**

*Benkara griffithii* (Hook.f.) Ridsdale

*Breynia retusa* (Dennst.) Alston

*Capparis acutifolia* Sweet

*Chloranthus elatior* Link

*Combretum yunnanense* Exell

*Croton caudatus* Geiseler

*Ficus squamosa* Roxb.

*Gnetum acutum* Markgr.

*Hiptage acuminata* Wall. ex A. Juss.

*Homonoia riparia* Lour.

*Leea alata* Edgew.

*Lepionurus sylvestris* Blume

*Miliusa roxburghiana* Hook.f. & Thomson

*Morinda angustifolia* Roxb.

*Piper lonchites* Schult

*Premna pinguis* C.B.Clarke

*Pseuderanthemum crenulatum* (Wall. ex Lindl.) Radlk.

*Stixis suaveolens* (Roxburgh) Pierre

**Plate - VI: Some of the herb species found along the riparian zones of the Doyang river**

*Acmella paniculata* (Wall. ex DC.) R.K.Jansen

*Alternanthera sessilis* (L.) R.Br. ex DC.

*Amomum koenigii* J.F.Gmel.

*Crotalaria pallida* Aiton

*Cuphea carthagenensis* (Jacq.) J.F. Macbr.

Floscopa scandens Lour.

*Heliotropium* indicum L. (1)

*Imperata cylindrica* (L.) Raeusch

*Oxalis corniculata* L.

*Phrynium pubinerve* Blume

*Physalis minima* L.

*Pollia subumbellata* C.B.Clarke

*Pouzolzia zeylanica* (L.) Benn.

*Rorippa indica* (L.) Hiern

*Scutellaria discolor* Colebr.

*Setaria viridis* (L.) P.Beauv.

*Xanthium strumarium* L

*Zingiber rubens* Roxb

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## Appendix I

**Monthly values of all the physicochemical parameters of water quality recorded from the eight sampling stations (February 2016 - January 2017).**

**Sampling station 1 (S1)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| pH | 7.43 | 8.73 | 8.53 | 8.13 | 7.9 | 7.97 | 7.93 | 7.17 | 7.03 | 7.13 | 7.3 | 7.08 |
| WT (ºC) | 17.33 | 21.33 | 24.67 | 26.67 | 26 | 26.67 | 26.33 | 24.33 | 23.33 | 18.7 | 16.33 | 16.33 |
| Free $CO_2$ | 4.77 | 6.6 | 9.17 | 9.17 | 7.36 | 6.6 | 10.63 | 10.27 | 5.5 | 9.17 | 7.7 | 6.6 |
| $Cl^-$ | 16.57 | 28.4 | 20.35 | 33.13 | 17.63 | 12.31 | 19.41 | 20.35 | 24.14 | 26.98 | 21.77 | 17.99 |
| EC | 254.1 | 305.53 | 256.67 | 269.67 | 167.03 | 167.2 | 177.27 | 173.43 | 187.13 | 198.73 | 232.2 | 240.9 |
| TDS | 132.67 | 162.67 | 122 | 120.33 | 80.67 | 80.67 | 79.67 | 79.33 | 85.33 | 108.33 | 121 | 131.33 |
| TA | 143.33 | 146.67 | 131.67 | 143.33 | 91.67 | 98.33 | 91.67 | 121.67 | 91.67 | 146.67 | 161.67 | 126.67 |
| TH | 113.33 | 130 | 100.67 | 101.33 | 80 | 76 | 89.33 | 58.67 | 77.33 | 86.67 | 98 | 128 |
| $Ca^{2+}$ | 22.17 | 26.18 | 21.64 | 22.43 | 14.7 | 16.83 | 18.71 | 14.16 | 14.43 | 22.44 | 21.91 | 31.03 |
| $Mg^{2+}$ | 14.13 | 15.59 | 11.53 | 10.88 | 10.55 | 8.18 | 10.39 | 5.52 | 10.14 | 7.31 | 10.55 | 12.5 |
| DO | 12.01 | 11.14 | 9.87 | 8.53 | 9.06 | 8.86 | 9.87 | 9.53 | 8.39 | 9.39 | 9.87 | 11.07 |
| BOD | 2.75 | 1.14 | 1.95 | 1.81 | 1.88 | 1.14 | 1.88 | 1.74 | 1.14 | 2.89 | 2.89 | 2.68 |
| $NO_3^-$ | 0.48 | 1.2 | 0.74 | 0.81 | 0.96 | 0.74 | 0.49 | 0.66 | 0.62 | 0.99 | 0.93 | 0.8 |
| $SO_4^{2-}$ | 21.56 | 25.31 | 20.41 | 19.23 | 18.26 | 16.75 | 15.72 | 13.38 | 19.63 | 14.46 | 16.65 | 21.44 |
| $PO_4^{3-}$ | 0.18 | 0.2 | 0.23 | 0.35 | 0.41 | 0.47 | 0.68 | 0.28 | 0.44 | 0.25 | 0.27 | 0.21 |
| K | 2.32 | 9.02 | 7.58 | 20.84 | 21.52 | 9.79 | 11.39 | 10.32 | 9.34 | 4.91 | 2.48 | 1.79 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

**Sampling station 2 (S2)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 6.8 | 7.97 | 8.77 | 7.9 | 7.03 | 7.63 | 8.6 | 8.07 | 7.6 | 6.83 | 7.13 | 6.93 |
| **WT (ºC)** | 18.67 | 22.33 | 27.33 | 27.33 | 28.67 | 29.67 | 29.33 | 26.67 | 27.33 | 23.7 | 21.67 | 19 |
| **Free $CO_2$** | 6.23 | 6.23 | 4.77 | 10.27 | 6.6 | 6.97 | 5.87 | 8.43 | 6.97 | 8.07 | 9.53 | 6.23 |
| **$Cl^-$** | 17.51 | 23.67 | 17.05 | 21.3 | 16.09 | 11.83 | 22.72 | 19.41 | 22.25 | 19.88 | 19.41 | 12.78 |
| **EC** | 163.2 | 179.67 | 213.5 | 220.67 | 151.77 | 146.53 | 156.37 | 138.8 | 138.87 | 138.4 | 147.4 | 158.17 |
| **TDS** | 85.33 | 96 | 102.33 | 108 | 74.67 | 67.33 | 68.33 | 65.67 | 67 | 74 | 75.67 | 82 |
| **TA** | 93.33 | 101.67 | 108.33 | 138.33 | 78.33 | 76.67 | 83.33 | 76.67 | 76.67 | 96.67 | 96.67 | 86.67 |
| **TH** | 82 | 83.33 | 85.33 | 94.67 | 70.67 | 69.33 | 84.67 | 64.67 | 66 | 61.33 | 64.67 | 72.67 |
| **$Ca^{2+}$** | 13.9 | 14.96 | 20.57 | 19.24 | 13.1 | 11.75 | 13.36 | 12.56 | 12.56 | 15.5 | 13.36 | 13.1 |
| **$Mg^{2+}$** | 11.37 | 11.21 | 8.12 | 11.36 | 9.09 | 9.91 | 12.67 | 8.28 | 8.28 | 5.52 | 7.63 | 9.75 |
| **DO** | 10 | 10.14 | 12.89 | 7.18 | 8.39 | 9.73 | 8.86 | 12.15 | 9.19 | 7.52 | 7.98 | 10.47 |
| **BOD** | 2.09 | 1.41 | 6.51 | 1.81 | 3.83 | 3.36 | 2.69 | 3.09 | 3.15 | 2.69 | 2.82 | 3.42 |
| **$NO_3^-$** | 0.72 | 0.47 | 0.5 | 0.73 | 1.18 | 0.87 | 0.42 | 0.44 | 0.36 | 0.63 | 1.13 | 1.03 |
| **$SO_4^{2-}$** | 19.17 | 12.19 | 18.42 | 17.98 | 16.13 | 14.91 | 14.54 | 8.53 | 10.92 | 9.51 | 10.07 | 14.58 |
| **$PO_4^{3-}$** | 0.2 | 0.18 | 0.21 | 0.25 | 0.36 | 0.26 | 0.38 | 0.24 | 0.26 | 0.2 | 0.25 | 0.22 |
| **K** | 4.38 | 5.98 | 9.41 | 8.42 | 13.52 | 9.41 | 12.15 | 9.18 | 8.42 | 4.31 | 1.11 | 2.71 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

**Sampling station 3 (S3)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 6.73 | 8.13 | 8.83 | 8.7 | 8.7 | 7.13 | 8.43 | 8.17 | 7.33 | 6.77 | 6.6 | 6.77 |
| **WT (ºC)** | 20.33 | 23 | 29.33 | 29.33 | 29.67 | 30.67 | 30.67 | 27.33 | 27.67 | 24.3 | 23 | 20.33 |
| **Free $CO_2$** | 5.5 | 6.97 | 5.13 | 6.23 | 4.77 | 8.8 | 7.7 | 8.8 | 6.23 | 9.53 | 8.43 | 4.03 |
| **$Cl^-$** | 18.46 | 19.8 | 18.46 | 17.99 | 12.78 | 10.41 | 19.41 | 21.3 | 20.83 | 20.83 | 18.46 | 13.73 |
| **EC** | 158.13 | 159.7 | 190.27 | 198 | 182.8 | 143.63 | 145.1 | 140.5 | 131.83 | 143.83 | 142.3 | 157.9 |
| **TDS** | 81.33 | 88 | 90.33 | 97.33 | 88.67 | 61.33 | 66.33 | 65.33 | 62.67 | 73 | 71.67 | 80.67 |
| **TA** | 98.67 | 96.67 | 103.33 | 131.67 | 96.67 | 68.33 | 78.33 | 66.67 | 81.67 | 93.33 | 103.33 | 93.33 |
| **TH** | 73.33 | 76.67 | 76 | 90 | 90.67 | 54 | 81.33 | 58.67 | 64.67 | 59.33 | 65.33 | 71.33 |
| **$Ca^{2+}$** | 14.16 | 14.76 | 17.1 | 17.9 | 16.67 | 11.49 | 11.75 | 10.15 | 11.22 | 14.96 | 13.1 | 12.83 |
| **$Mg^{2+}$** | 9.26 | 9.74 | 7.96 | 11.04 | 11.85 | 6.17 | 12.5 | 8.12 | 8.93 | 5.36 | 7.96 | 9.42 |
| **DO** | 9.73 | 10.07 | 11.55 | 8.99 | 11.14 | 6.24 | 8.12 | 12.01 | 8.86 | 7.72 | 7.65 | 10.94 |
| **BOD** | 1.54 | 1.08 | 4.7 | 0.94 | 3.49 | 3.1 | 2.09 | 2.69 | 2.55 | 1.14 | 1.34 | 3.69 |
| **$NO_3^-$** | 0.78 | 0.43 | 0.48 | 0.66 | 0.84 | 0.66 | 0.29 | 0.55 | 0.43 | 0.52 | 1.04 | 0.82 |
| **$SO_4^{2-}$** | 18.37 | 11.3 | 16.48 | 17.78 | 15.56 | 14.13 | 13.94 | 8.04 | 10.24 | 9.37 | 9.9 | 14.05 |
| **$PO_4^{3-}$** | 0.23 | 0.2 | 0.21 | 0.23 | 0.25 | 0.24 | 0.37 | 0.23 | 0.24 | 0.21 | 0.22 | 0.26 |
| **K** | 4.99 | 5.75 | 7.89 | 6.86 | 9.87 | 10.32 | 13.22 | 10.25 | 8.88 | 5.52 | 1.86 | 4.31 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

**Sampling station 4 (S4)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 6.77 | 8.2 | 8.6 | 8.73 | 8.67 | 8.33 | 8.6 | 7.57 | 7.47 | 6.73 | 6.63 | 6.6 |
| **WT (ºC)** | 20.67 | 22.67 | 29 | 28.33 | 29.33 | 31.33 | 30.67 | 27.67 | 28.33 | 23.3 | 22.67 | 21.33 |
| **Free $CO_2$** | 5.13 | 7.33 | 5.87 | 5.87 | 7.33 | 8.07 | 6.23 | 6.67 | 5.13 | 9.17 | 8.07 | 6.23 |
| **$Cl^-$** | 19.88 | 21.77 | 17.04 | 18.93 | 11.83 | 8.99 | 19.88 | 17.51 | 19.88 | 23.67 | 19.88 | 13.25 |
| **EC** | 156.37 | 161.37 | 189.73 | 196.17 | 179.73 | 125.7 | 136.87 | 133.83 | 125.87 | 134.53 | 141.43 | 159.07 |
| **TDS** | 80 | 84 | 88 | 95 | 87.33 | 56.67 | 64 | 60 | 60.67 | 69.33 | 73.67 | 82.33 |
| **TA** | 96.67 | 96.67 | 108.33 | 128.33 | 98.33 | 71.67 | 91.67 | 73.33 | 71.67 | 96.67 | 98.33 | 81.67 |
| **TH** | 69.33 | 76 | 80 | 85.33 | 84.67 | 55.33 | 80 | 61.33 | 62.67 | 63.33 | 59.33 | 68.67 |
| **$Ca^{2+}$** | 13.63 | 13.1 | 18.17 | 17.37 | 15.5 | 9.89 | 9.62 | 9.35 | 10.69 | 13.36 | 11.75 | 13.9 |
| **$Mg^{2+}$** | 8.44 | 10.55 | 8.61 | 10.55 | 11.2 | 6.88 | 13.15 | 9.09 | 8.93 | 6.82 | 7.31 | 8.6 |
| **DO** | 9.8 | 10.54 | 10.6 | 9.87 | 10.4 | 10.34 | 9.8 | 11.88 | 9.6 | 7.38 | 7.72 | 9.87 |
| **BOD** | 1.18 | 1.14 | 1.94 | 1.27 | 3.89 | 3.69 | 2.95 | 2.82 | 1.75 | 1.28 | 1.54 | 2.29 |
| **$NO_3^-$** | 0.75 | 0.4 | 0.52 | 0.57 | 0.65 | 0.61 | 0.29 | 0.41 | 0.29 | 0.48 | 1.02 | 0.72 |
| **$SO_4^{2-}$** | 18.04 | 11.23 | 16.29 | 17.07 | 16.06 | 13.42 | 13.77 | 7.95 | 9.73 | 9.37 | 10.03 | 13.88 |
| **$PO_4^{3-}$** | 0.22 | 0.21 | 0.24 | 0.25 | 0.23 | 0.23 | 0.31 | 0.21 | 0.25 | 0.21 | 0.21 | 0.21 |
| **K** | 4.38 | 5.6 | 7.81 | 6.59 | 10.63 | 7.58 | 10.09 | 9.56 | 8.65 | 6.59 | 1.64 | 3.39 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

## Sampling station 5 (S5)

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 6.87 | 8.33 | 8.4 | 8.93 | 8.9 | 7.87 | 8.2 | 7.9 | 7.57 | 6.93 | 6.5 | 6.4 |
| **WT (ºC)** | 21 | 26.33 | 27.67 | 28.67 | 29.67 | 30.33 | 29.67 | 28.67 | 27.33 | 24.7 | 23.33 | 20.67 |
| **Free $CO_2$** | 6.23 | 8.07 | 4.77 | 5.87 | 8.43 | 7.33 | 7.7 | 5.87 | 6.23 | 8.07 | 6.97 | 5.5 |
| **$Cl^-$** | 16.57 | 20.83 | 16.57 | 18.93 | 17.51 | 10.89 | 20.35 | 18.46 | 19.41 | 22.25 | 19.41 | 13.73 |
| **EC** | 155.87 | 157.57 | 181.17 | 190.67 | 176.73 | 120.9 | 130.17 | 109.3 | 118.7 | 138.93 | 139.6 | 160.43 |
| **TDS** | 81.67 | 87 | 85.33 | 91.67 | 85.67 | 54.67 | 61.67 | 54 | 57.67 | 72.33 | 70.67 | 82.67 |
| **TA** | 91.67 | 91.67 | 106.67 | 126.67 | 96.67 | 66.67 | 88.33 | 66.67 | 58.33 | 101.67 | 93.33 | 98.33 |
| **TH** | 73.33 | 79.33 | 74 | 80 | 83.33 | 54.67 | 79.33 | 51.33 | 62 | 60.67 | 60 | 72.67 |
| **$Ca^{2+}$** | 13.9 | 15.23 | 17.64 | 16.03 | 15.76 | 10.15 | 9.35 | 9.35 | 9.89 | 14.16 | 12.56 | 13.36 |
| **$Mg^{2+}$** | 9.42 | 10.39 | 7.47 | 9.9 | 10.71 | 7.15 | 13.48 | 6.98 | 9.09 | 5.85 | 6.82 | 9.74 |
| **DO** | 9.94 | 10.2 | 10.67 | 9.26 | 10.87 | 8.59 | 8.93 | 12.08 | 8.53 | 7.18 | 7.99 | 9.33 |
| **BOD** | 1.95 | 0.88 | 1.74 | 1 | 2.68 | 2.75 | 2.15 | 2.95 | 1.61 | 1.54 | 1.82 | 2.14 |
| **$NO_3^-$** | 0.97 | 0.48 | 0.54 | 0.65 | 0.87 | 0.69 | 0.46 | 0.38 | 0.32 | 0.52 | 0.84 | 0.85 |
| **$SO_4^{2-}$** | 18.38 | 10.92 | 15.54 | 17.39 | 15.14 | 13.36 | 13.52 | 7.66 | 9.84 | 9.68 | 9.69 | 13.68 |
| **$PO_4^{3-}$** | 0.25 | 0.2 | 0.22 | 0.29 | 0.26 | 0.3 | 0.36 | 0.23 | 0.28 | 0.23 | 0.24 | 0.24 |
| **K** | 5.22 | 6.21 | 7.28 | 7.2 | 10.32 | 10.41 | 12.15 | 11.54 | 10.02 | 5.91 | 3.01 | 4.61 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

**Sampling station 6 (S6)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 7.23 | 8.57 | 8.07 | 8.8 | 7.83 | 7.37 | 7.63 | 7.4 | 6.43 | 6.67 | 7.03 | 6.87 |
| **WT (°C)** | 20 | 22.33 | 23.67 | 24 | 26.33 | 25.33 | 26.67 | 25.67 | 25 | 23.3 | 22.33 | 19.67 |
| **Free $CO_2$** | 5.87 | 7.33 | 7.33 | 8.07 | 7.33 | 6.97 | 9.17 | 8.07 | 8.07 | 9.53 | 6.6 | 5.13 |
| **$Cl^-$** | 14.67 | 18.93 | 17.04 | 18.46 | 16.57 | 9.47 | 16.57 | 20.35 | 21.77 | 22.72 | 20.35 | 14.2 |
| **EC** | 161.17 | 160.73 | 184.27 | 184.9 | 181.7 | 148.43 | 137.4 | 147.5 | 142.63 | 154 | 158.7 | 162.9 |
| **TDS** | 82.33 | 84.33 | 83.33 | 86 | 86.67 | 66.67 | 62.23 | 65.67 | 67.67 | 78.67 | 82.67 | 84 |
| **TA** | 93.33 | 93.33 | 116.67 | 126.67 | 86.67 | 76.67 | 71.67 | 76.67 | 71.67 | 96.67 | 108.33 | 88.33 |
| **TH** | 72 | 73.33 | 76.67 | 86 | 81.33 | 64.67 | 85.33 | 43.33 | 67.33 | 64 | 68.67 | 74.67 |
| **$Ca^{2+}$** | 13.36 | 15.5 | 16.83 | 15.76 | 14.7 | 15.23 | 11.49 | 11.49 | 13.63 | 13.9 | 14.16 | 12.29 |
| **$Mg^{2+}$** | 9.26 | 8.44 | 8.44 | 11.63 | 11.04 | 6.49 | 13.31 | 4.06 | 8.12 | 7.15 | 8.12 | 10.71 |
| **DO** | 11.07 | 11.14 | 11.07 | 12.01 | 4.83 | 7.65 | 8.39 | 10.54 | 6.98 | 7.25 | 9.73 | 13 |
| **BOD** | 1.01 | 0.47 | 1.08 | 0.94 | 1.24 | 0.53 | 1.61 | 1.48 | 2.55 | 0.88 | 2.68 | 4.56 |
| **$NO_3^-$** | 1.08 | 0.53 | 0.48 | 0.79 | 1.18 | 0.92 | 0.78 | 0.42 | 0.37 | 0.92 | 0.94 | 0.6 |
| **$SO_4^{2-}$** | 18.65 | 11.39 | 15.7 | 18.36 | 20.39 | 18.83 | 16.81 | 11.72 | 12.86 | 11.12 | 10.59 | 13.59 |
| **$PO_4^{3-}$** | 0.22 | 0.19 | 0.25 | 0.37 | 0.47 | 0.51 | 0.53 | 0.35 | 0.4 | 0.28 | 0.26 | 0.2 |
| **K** | 4.52 | 6.36 | 7.51 | 6.29 | 18.32 | 17.41 | 18.25 | 13.29 | 11.01 | 6.89 | 3.92 | 5.06 |

All the parameters are in milligrams per litre except for pH, WT (°C), and EC (µS/cm)

## Sampling station 7 (S7)

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Jan |
| **pH** | 7.17 | 8.43 | 7.67 | 8.97 | 7.57 | 7.23 | 7.37 | 7.47 | 6.53 | 6.87 | 7.47 | 7.07 |
| **WT (ºC)** | 22 | 23.67 | 23.33 | 26.33 | 26.67 | 25.67 | 25.33 | 27 | 25.33 | 24.3 | 23.67 | 21.67 |
| **Free $CO_2$** | 5.13 | 6.6 | 6.97 | 6.97 | 9.17 | 7.7 | 9.9 | 6.97 | 7.7 | 10.63 | 6.23 | 4.77 |
| **$Cl^-$** | 16.09 | 17.99 | 15.15 | 17.51 | 13.25 | 11.83 | 17.51 | 22.25 | 25.09 | 19.88 | 24.14 | 14.67 |
| **EC** | 157.5 | 157.73 | 192.07 | 186.43 | 179.87 | 147.7 | 139.77 | 149.2 | 141.73 | 152.17 | 151.7 | 158.77 |
| **TDS** | 81.33 | 87.33 | 90 | 90 | 87 | 65.67 | 63.33 | 67.33 | 67.33 | 79.67 | 80 | 83.33 |
| **TA** | 95 | 88.33 | 103.33 | 131.67 | 93.33 | 83.33 | 66.67 | 81.67 | 73.33 | 103.33 | 106.67 | 86.67 |
| **TH** | 75.33 | 71.67 | 72.67 | 80 | 86.67 | 69.33 | 82.67 | 78.67 | 64.67 | 66 | 66.67 | 73.33 |
| **$Ca^{2+}$** | 13.9 | 13.9 | 17.9 | 16.3 | 16.3 | 13.63 | 12.56 | 12.56 | 12.56 | 15.23 | 13.9 | 12.83 |
| **$Mg^{2+}$** | 9.91 | 9.26 | 6.98 | 9.74 | 11.37 | 8.44 | 12.34 | 11.37 | 7.79 | 6.82 | 7.96 | 10.39 |
| **DO** | 10.8 | 10.94 | 10.8 | 11.41 | 5.44 | 7.25 | 8.12 | 10.2 | 7.52 | 8.05 | 9.87 | 12.15 |
| **BOD** | 2.21 | 1.14 | 1.07 | 0.74 | 1.28 | 0.61 | 1.88 | 1.34 | 2.34 | 1.07 | 1.75 | 3.62 |
| **$NO_3^-$** | 0.76 | 0.5 | 0.51 | 0.73 | 0.73 | 0.81 | 0.42 | 0.44 | 0.31 | 0.76 | 1.17 | 0.8 |
| **$SO_4^{2-}$** | 18.38 | 10.95 | 16.08 | 18.67 | 20.43 | 18.12 | 16.47 | 9.96 | 12.77 | 10.96 | 10.28 | 13.43 |
| **$PO_4^{3-}$** | 0.24 | 0.22 | 0.51 | 0.41 | 0.43 | 0.48 | 0.51 | 0.33 | 0.39 | 0.28 | 0.25 | 0.19 |
| **K** | 4.76 | 6.66 | 8.11 | 7.05 | 20.38 | 17.11 | 17.6 | 12.61 | 9.71 | 4.84 | 3.16 | 4.15 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

**Sampling station 8 (S8)**

| Parameters | Pre-monsoon | | | | Monsoon | | | | Post-monsoon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Feb** | **Mar** | **April** | **May** | **June** | **July** | **Aug** | **Sept** | **Oct** | **Nov** | **Dec** | **Jan** |
| **pH** | 7.27 | 8.47 | 8.13 | 8.67 | 7.63 | 7.63 | 7.47 | 7.53 | 6.67 | 6.9 | 7.2 | 6.8 |
| **WT (ºC)** | 21.33 | 21.67 | 24.67 | 24.33 | 25.67 | 24.67 | 25.67 | 26.33 | 23.67 | 23.7 | 22 | 20 |
| **Free $CO_2$** | 6.23 | 5.87 | 7.33 | 5.87 | 8.07 | 8.43 | 9.53 | 5.5 | 7.33 | 10.27 | 5.13 | 4.4 |
| **$Cl^-$** | 15.15 | 17.51 | 17.99 | 20.35 | 13.73 | 13.73 | 16.09 | 24.61 | 22.25 | 25.56 | 23.19 | 16.09 |
| **EC** | 156.97 | 158.27 | 190.6 | 188.7 | 179.17 | 147.07 | 141.83 | 144.57 | 141.33 | 153.27 | 150.77 | 157.23 |
| **TDS** | 82 | 83.33 | 88.33 | 89 | 85.67 | 66.67 | 65.67 | 66.67 | 68.33 | 78.33 | 78.33 | 83 |
| **TA** | 96.67 | 91.67 | 106.67 | 126.67 | 88.33 | 81.67 | 76.67 | 86.67 | 76.67 | 111.67 | 113.33 | 91.67 |
| **TH** | 68.67 | 72.67 | 76 | 87.33 | 84 | 73.33 | 76 | 67.33 | 68.67 | 67.33 | 69.33 | 72.67 |
| **$Ca^{2+}$** | 13.63 | 14.96 | 17.37 | 17.64 | 15.23 | 14.7 | 11.75 | 11.75 | 13.1 | 16.3 | 13.36 | 13.9 |
| **$Mg^{2+}$** | 8.6 | 8.61 | 7.8 | 10.55 | 11.2 | 8.93 | 11.37 | 9.09 | 8.61 | 6.49 | 8.92 | 9.42 |
| **DO** | 11 | 11.34 | 11.28 | 11.88 | 6.11 | 7.85 | 7.78 | 10.81 | 7.12 | 7.92 | 10.14 | 12.41 |
| **BOD** | 1.88 | 1.27 | 1.48 | 1.67 | 1.48 | 0.67 | 1.78 | 0.94 | 2.22 | 1 | 2.21 | 4.02 |
| **$NO_3^-$** | 0.79 | 0.48 | 0.49 | 0.7 | 0.78 | 0.6 | 0.45 | 0.45 | 0.4 | 0.73 | 0.87 | 0.74 |
| **$SO_4^{2-}$** | 17.87 | 10.86 | 16.15 | 16.91 | 17.58 | 19 | 16.91 | 10.12 | 12.61 | 10.72 | 10.15 | 13.69 |
| **$PO_4^{3-}$** | 0.28 | 0.19 | 0.49 | 0.38 | 0.33 | 0.49 | 0.56 | 0.37 | 0.44 | 0.29 | 0.27 | 0.19 |
| **K** | 6.65 | 6.36 | 9.18 | 6.82 | 16.88 | 18.55 | 18.71 | 14.06 | 8.04 | 4.99 | 3.69 | 4.46 |

All the parameters are in milligrams per litre except for pH, WT (ºC), and EC (µS/cm)

## Appendix II

**Monthly duplicate values of soil physicochemical parameters obtained from upstream, midstream and downstream riparian forest of the Doyang river (June – September 2017)**

| Soil parameters | Upstream | | | | Midstream | | | | Downstream | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June | July | Aug | Sept | June | July | Aug | Sept | June | July | Aug | Sept |
| SM (%) | 78.01 | 80.31 | 82.98 | 77.55 | 79.56 | 82.95 | 75.57 | 81.12 | 78.65 | 84.66 | 79.01 | 74.53 |
| | 84.18 | 74.32 | 81.96 | 85.48 | 79.56 | 80.46 | 87.28 | 81.89 | 74.02 | 77.74 | 77.88 | 81.14 |
| T (ºC) | 26.3 | 25.3 | 27 | 25.6 | 26.4 | 26.8 | 20.7 | 23.9 | 28.2 | 28.9 | 28 | 25.7 |
| | 25.9 | 26 | 25.3 | 27.4 | 27.3 | 26.8 | 25.3 | 25.3 | 27.2 | 27.6 | 21.8 | 26.3 |
| OC (%) | 0.67 | 1.23 | 0.96 | 1.51 | 1.75 | 1.63 | 2.15 | 1.94 | 1.14 | 2.3 | 1.74 | 2.21 |
| | 2.98 | 1.54 | 2.51 | 1.83 | 1.7 | 2.34 | 2.29 | 1.62 | 1.27 | 1.68 | 1.43 | 1.77 |
| P (kg/ha) | 10.3 | 8.18 | 8.53 | 7.41 | 7.82 | 8.94 | 12.59 | 6.2 | 7.06 | 7.32 | 7.91 | 8.94 |
| | 7.77 | 7.32 | 6.34 | 7.21 | 8.33 | 7.73 | 6.29 | 9.39 | 8.62 | 7.12 | 7.53 | 10.01 |
| K (kg/ha) | 20.03 | 17.36 | 75.9 | 49.47 | 102.66 | 103.66 | 112.7 | 139.12 | 11.37 | 14.01 | 27.39 | 20.7 |
| | 71.54 | 27.39 | 41.11 | 71.88 | 167.22 | 107.23 | 68.87 | 129.09 | 18.36 | 18.69 | 16.69 | 15.01 |
| TN (%) | 0.25 | 0.27 | 0.17 | 0.21 | 0.24 | 0.21 | 0.22 | 0.22 | 0.24 | 0.22 | 0.21 | 0.19 |
| | 0.32 | 0.17 | 0.16 | 0.19 | 0.19 | 0.23 | 0.28 | 0.22 | 0.24 | 0.17 | 0.16 | 0.16 |
| AN (kg/ha) | 175.62 | 154.71 | 142.17 | 154.71 | 204.88 | 183.98 | 204.88 | 163.07 | 213.25 | 163.07 | 204.89 | 167.25 |
| | 209.07 | 163.07 | 137.98 | 117.08 | 209.07 | 200.7 | 175.62 | 146.34 | 217.43 | 204.89 | 225.79 | 167.25 |
| pH | 6.9 | 6.6 | 6.28 | 6.52 | 6.66 | 6.78 | 6.75 | 6.59 | 5.95 | 6.14 | 5.82 | 5.41 |
| | 6.28 | 6.7 | 6.56 | 6.71 | 6.47 | 6.53 | 6.5 | 6.45 | 5.56 | 6.1 | 6.14 | 5.7 |
| Clay (%) | 36.00 | 21.90 | 41.20 | 34.00 | 49.60 | 37.80 | 42.30 | 35.90 | 26.20 | 24.50 | 27.90 | 22.40 |
| | 28.40 | 20.60 | 37.80 | 32.40 | 41.20 | 43.70 | 34.10 | 51.10 | 22.70 | 18.90 | 31.20 | 38.30 |
| Silt (%) | 40.80 | 46.40 | 43.50 | 38.90 | 46.00 | 48.10 | 41.20 | 38.90 | 39.20 | 41.60 | 44.00 | 38.50 |
| | 36.70 | 37.00 | 48.10 | 36.10 | 43.50 | 38.00 | 46.10 | 34.80 | 37.70 | 34.40 | 39.50 | 40.30 |
| Sand (%) | 23.20 | 31.70 | 15.30 | 27.10 | 4.40 | 14.10 | 16.50 | 25.20 | 34.60 | 33.90 | 28.10 | 39.10 |
| | 33.90 | 42.40 | 14.10 | 31.50 | 15.30 | 18.30 | 19.80 | 14.10 | 38.60 | 46.70 | 29.30 | 21.40 |

**Bulk density and Porosity**

| Soil parameters | Layers (in cm) | Upstream | | | | Midstream | | | | Downstream | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | June | July | Aug | Sept | June | July | Aug | Sept | June | July | Aug | Sept |
| Bulk density (g/cm$^3$) | 0-10 | 0.93 | 1.1 | 1.26 | 1.1 | 1.1 | 1.18 | 0.87 | 1 | 0.96 | 0.94 | 0.65 | 0.92 |
| | | 0.99 | 1.11 | 0.88 | 0.99 | 1 | 1.01 | 0.88 | 1.01 | 0.9 | 0.92 | 0.88 | 0.9 |
| | 10-20 | 0.92 | 1.24 | 1.02 | 0.92 | 1.07 | 1.04 | 1.13 | 1.04 | 1 | 0.94 | 0.65 | 0.81 |
| | | 0.6 | 1.21 | 1.18 | 1.21 | 1.07 | 1.04 | 1.22 | 1.22 | 0.81 | 1 | 0.58 | 0.94 |
| | 20-30 | 1.2 | 1.14 | 1.16 | 1.2 | 1.11 | 1.32 | 1.1 | 1.22 | 1.06 | 1.03 | 0.81 | 1.01 |
| | | 1.04 | 0.97 | 1.24 | 0.97 | 1.06 | 1.22 | 1.33 | 1.06 | 1.01 | 0.96 | 0.89 | 1.06 |
| Porosity (%) | 0-10 | 45.08 | 40.6 | 36.13 | 44.19 | 46.19 | 37.87 | 57.75 | 37.87 | 45.95 | 46.68 | 57.41 | 48.3 |
| | | 44.19 | 43.78 | 50.5 | 43.78 | 33.18 | 42.86 | 65.49 | 33.18 | 51.64 | 48.3 | 47.54 | 45.95 |
| | 10-20 | 45.85 | 29.79 | 48.01 | 34.87 | 42.69 | 42.69 | 45.88 | 42.69 | 40.78 | 49.4 | 65.2 | 51.57 |
| | | 64.41 | 34.87 | 40.22 | 40.22 | 41.25 | 44.23 | 57.85 | 44.23 | 51.57 | 41.08 | 67.1 | 41.08 |
| | 20-30 | 29.09 | 38.78 | 37.81 | 29.09 | 34.28 | 40.46 | 42.88 | 40.46 | 37.54 | 41.98 | 49.78 | 39.65 |
| | | 38.1 | 50.51 | 33.47 | 37.81 | 21.55 | 38.24 | 48.28 | 42.88 | 39.65 | 48.15 | 49.62 | 48.15 |

**Appendix III**

**ANOVA Post-hoc Test (Dunn Test) showing Kruskal-Wallis multiple comparison p-values adjusted with the Bonferroni method of Upstream, Midstream and Downstream site along the Doyang River.**

**Soil moisture (SM)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -1.4852472 | 0.1374784 | 0.4124351 |
| Downstream-Upstream | -1.2730690 | 0.2029936 | 0.6089807 |
| Midstream-Upstream | 0.2121782 | 0.8319680 | 1.0000000 |

**Soil temperature (T)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | 1.8610165 | 0.06274185 | 0.1882256 |
| Downstream-Upstream | 1.4888132 | 0.13653657 | 0.4096097 |
| Midstream-Upstream | -0.3722033 | 0.70974149 | 1.0000000 |

**Organic Carbon of soil (OC)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -1.0253048 | 0.3052194 | 0.9156581 |
| Downstream-Upstream | 0.2828427 | 0.7772974 | 1.0000000 |
| Midstream-Upstream | 1.3081475 | 0.1908233 | 0.5724698 |

**Phosphorus (P)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -0.2652804 | 0.7907935 | 1 |
| Downstream-Upstream | 0.2652804 | 0.7907935 | 1 |
| Midstream-Upstream | 0.5305608 | 0.5957232 | 1 |

**Potassium (K)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -4.190519 | 2.783174e-05 | 8.349522e-05 |
| Downstream-Upstream | -1.909603 | 5.618429e-02 | 1.685529e-01 |
| Midstream-Upstream | 2.280915 | 2.255346e-02 | 6.766038e-02 |

**Total Nitrogen (TN)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -1.4591161 | 0.1445332 | 0.4335995 |
| Downstream-Upstream | -0.6227935 | 0.5334203 | 1.0000000 |
| Midstream-Upstream | 0.8363226 | 0.4029734 | 1.0000000 |

**Available Nitrogen (AN)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | 0.9921086 | 0.321144551 | 0.96343365 |
| Downstream-Upstream | 2.7282987 | 0.006366194 | 0.01909858 |
| Midstream-Upstream | 1.7361901 | 0.082530236 | 0.24759071 |

**pH of soil (pH)**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -3.395589 | 0.0006848105 | 0.002054432 |
| Downstream-Upstream | -3.395589 | 0.0006848105 | 0.002054432 |
| Midstream-Upstream | 0.000000 | 1.0000000000 | 1.000000000 |

**Clay**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -3.324848 | 0.0008846682 | 0.002654005 |
| Downstream-Upstream | -1.025751 | 0.3050090113 | 0.915027034 |
| Midstream-Upstream | 2.299097 | 0.0214994396 | 0.064498319 |

**Silt**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | -1.0436634 | 0.2966412 | 0.8899235 |
| Downstream-Upstream | -0.4422302 | 0.6583226 | 1.0000000 |
| Midstream-Upstream | 0.6014331 | 0.5475515 | 1.0000000 |

**Sand**

| Comparison | Z | P. Unadjusted | P. adjusted |
|---|---|---|---|
| Downstream-Midstream | 3.398548 | 0.0006774449 | 0.002032335 |
| Downstream-Upstream | 1.327558 | 0.1843241862 | 0.552972559 |
| Midstream-Upstream | -2.070990 | 0.0383596941 | 0.115079082 |

# LIST OF ATTENDED CONFERENCES, TRAININGS AND PAPERS PUBLISHED

## 1. Conferences attended:

a. Presented an Oral presentation during the **International Conference on Natural Resources Management and Technology Trends (ICNRM-17),** held on 27th-29th March,2017 at Manipur University, Imphal, Manipur, India jointly organized by the Centre of Advanced Study, Department of life sciences, Manipur University, Imphal-795003, Manipur, India & SLNA Planning Dept. Manipur.

b. Presented an oral paper in the National Seminar on '**Advances in Biological Research'** held during February 28-march, 2017 in the Department of Botany, Nagaland University, Lumami-798627, Nagaland, India.

c. Participated in the National Seminar on **'Inventory, Sustainable Utilization & Conservation of Bioresources'** held at Nagaland University, Lumami-798627, Nagaland, India during February 26-27, 2016 jointly organized by Department of Botany, Nagaland University & Institutional Biotech Hub, Nagaland University.

d. Participated in the National Conference on **'Stakeholders on conservation, cultivation, resource development and sustainable utilization of medicinal plants of North-Eastern India'** held at Nagaland University, Lumami-798627, Nagaland, India from March 6-7, 2019 jointly organized by Department of Botany, Nagaland University & Society for conservation and resource development of medicinal plants (SMP), New Delhi.

e. Presented a poster in the **"Water Future Conference 2019"** held at Indian Institute of Science (IISc), Bangalore, India from 24-27$^{th}$ of September 2019.

f. Participated in the Online platform "Outreach Programme" organized by the Bio-NEST NIPER-Guwahati Incubation Centre, Supported by BIRAC, DBT, GOI on 3$^{rd}$ of July, 2020.

## 2. Trainings attended:

a. Attended two weeks training on basic course of **'Remote Sensing and Geographical Information System-Technology and Application'** at North Eastern Space Application Centre, Department of Space, Government of India during July 16-27, 2018.

b. Participated in the **'Training on Basics of Plant Identification and Nomenclature'** Organized by Eastern Regional Centre, Botanical Survey of India (Ministry of Environment, Forest and Climate Change), Shillong from $7^{th}$ to $9^{th}$ November 2016.

c. Attended one-day workshop on **"Importance of IPR in Academic Institutions"** Organized by IPR Cell of Nagaland University, held on $29^{th}$ May, 2019.

d. Attend the 2019 Summer Seminars on **Intelligent Design in the Natural sciences** hosted by **Discovery Institute, Centre for Science and Culture, Seattle, USA** from July 5-13, 2019. It was a program to prepare students to make research contribution advancing the growing science of Intelligent design (ID).

e. Attended the training on the **Advanced Fieldcourse in Ecology and Conservation** from 15th Oct-26th Nov 2019 at **Xishuangbanna Tropical Botanical Garden, under Chinese Academy of Sciences.** This was an intensive course in academic skills and field research methods.

## 3. Publications:

1. **Lkr, A.,** Singh, M.R. and Puro, N. (2017). Biological spectrum of riparian plant communities in and around Doyang Hydro Electric Dam, Wokha in Nagaland. *Nagaland University Research Journal.* 10: 129-137.
2. **Lkr, A.,** Singh, M.R. and Puro, N. (2020). Assessment of water quality status of Doyang River, Nagaland, India using Water Quality Index. *Applied water Science.* 10: 46. https://doi.org/10.1007/s13201-019-1133-3