Chapter - I
INTRODUCTION

1.1 An Overview on Wetlands

Wetlands are considered as naturally water logged and marshy areas which serve as regulators of hydrologic regimes, conservation of environmental quality and reservoirs of diverse biotic natural resources. Wetlands are habitats for fish and wildlife and they are ruined for recreation by human. Despite these benefits, wetlands are the first target of human interference and are among the most threatened of all natural resources. Around 50% of the earth's wetland area is estimated to already have disappeared over the last hundred years through conversion to industrial, agricultural and residential developments.

Generally, wetlands are shallow seasonally or permanently water logged or flooded areas, which normally support hydrophytic (water tolerant) vegetation. Many definitions of wetland have been proposed and utilised over time from different perspectives. As defined in terms of physical geography, a wetland is an environment "at the interface between truly terrestrial ecosystems and aquatic systems making them inherently different from each other yet highly dependent on both"[1]. The World Conservation Union (WCN) defines wetland as "all submerged or water saturated lands, natural or manmade, inland or coastal, permanent or temporary, static or dynamic, vegetated or non-vegetated which necessarily have a land-water interface'. In 1971 RAMSAR Convention defines wetland as areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or saline, including areas of marine water, the depth of which at low tide does not exceed six metre. Among the most widely accepted definitions is that of Cowardin et al., which was adopted by Fish and Wildlife Service [2]. He defined wetland as a landscape where an excess of water is the dominant factor determining the nature of soil and the types of animal and plant communities living at the soil surface. It spans a continuum of environments where terrestrial and aquatic systems intergraded. This definition comprises three aspects – water, soil and organisms, which are accepted by wetland scientists as the basis for recognizing and describing wetland environments.

Wetlands were regarded as wastelands for long time, but now these are recognized as important features in the landscape that provide numerous beneficial services for people and for fish and wildlife. So, the interest and importance of the study of wetlands are increasing day by day. Though the study of wetlands began in 1930 on the Paraguayan Swamps, the systematic study of wetlands started just after the International Convention for Wetlands held in Ramsar of Iran in 1971 known as Ramsar Convention.

In RAMSAR Conference, the first listing of wetlands of internationally importance was made and the contracting parties agreed to take necessary steps to safeguard these wetlands. India is one of the original signatories who have made important efforts in initiating work for conservation and management of wetlands. The list of wetlands of International importance included 2,231 RAMSAR sites covering over 2.1 million square kilometres. However, India has 26 RAMSAR sites and two of them namely Deepar Beel and Loktak Lake belong to Northeast India.

Wetlands are vital for human survival. They are now recognized as important features in a landscape that provide numerous beneficial services to people, fish and wildlife. They are among the world’s most productive natural resources, roots of biological diversity that provide food and water upon which countless group of aquatic and terrestrial plants and animals depend for their survival. The ability of wetlands to perform various functions such as - recycling of nutrients, purification of water, attenuation of floods by storing floodwater, maintenance of stream flow, recharging of ground water, etc. make them one of the important ecosystem in a landscape.

1.1.1 Formation of Wetlands

The Millennium Ecosystem Assessment estimates conservatively that wetlands cover 7% of the earth's surface and deliver 45% of the world's natural productivity and ecosystem services [3]. The birth of the wetlands can be in different forms and ways. Earthquake is one of the major factors that can give birth to a wetland. In many cases, earthquake causes depression in an area leading to the formation of wetland. Generally lake/pond category belongs to this type of formation. Changing of a river course may also form a wetland. Most of the time, a river may change its direction due to deposition of silt and sediment or due to disasters like earthquake, landslides or building of dams etc. Artificially formed wetlands have also created a niche worldwide. Different activities like digging of land for building of roads, houses, industries etc. can also form wetlands that basically belong to the waterlogged category or artificial fishery. Those wetlands are considered as artificial as they are created by anthropogenic activities of human beings. They can be both perennial and seasonal.

Wetlands may be classified on the basis of their formation. The National Wetlands Inventory and Assessment (NWIA) [3] classified the wetlands in different categories as presented in ***Table 1.1***. Broadly, there are two categories of wetlands – Inland wetlands and coastal wetlands, which may be further subdivided into natural and manmade. There are ten types of Inland wetlands, out of which five are natural and five are manmade. Natural coastal wetlands are of twelve types, while the manmade coastal wetlands are of two types.

1.1.2 Wetland Ecology

Wetlands are areas where water is the primary factor controlling the surroundings and the allied plants and animals life. Wetlands like marshes or swamps are familiar to most of the people, however some wetlands like bottomland forests, bogs, or wet meadows are not so easily recognized as they remain dry during half of the year and do not look very wet [4]. Wetland’s hydrology refers to the presence of water above the soil surface or within the soil, so that it has an impact on the types of soil and plants found in this area. The water that makes wetlands may come from different sources, like - tidal or non-tidal sources. Examples of non-tidal sources are rain, streams, groundwater etc. They have unique hydric soil that is different from the quality of terrestrial soils and support unique vegetation that is adapted to the wet conditions. Hence the soil is anaerobic and turns black due to the chemical changes take place in the soil.

Table 1.1: Different kinds of wetlands as classified in the National Wetlands Inventory and Assessment (NWIA, 2011).

Inland Wetlands	Natural	1. Lakes/Ponds
		2. Ox-bow lakes/cut-off meanders
		3. Waterlogged (seasonal)
		4. Playas
		5. Swamp/Marsh
	Manmade	1. Reservoirs
		2. Tanks
		3. Waterlogged
		4. Abandoned quarries
		5. Ash pond/ cooling pond
Coastal Wetlands	Natural	1. Estuary
		2. Lagoon
		3. Creek
		4. Backwater (Kayal)
		5. Bay
		6. Tidal fat/mud feet
		7. Sand/Beach/Spit/Bar
		8. Coral reef
		9. Rocky coast
		10. Mangrove forest
		11. Salt marsh/Marsh vegetation
		12. Other vegetation
	Man-made	1. Salt Pans
		2. Aquaculture ponds.

Plants grown in wetlands are referred as hydrophytes, which mean water loving. Hydrophytes are morphologically, reproductively or physiologically adapted to life in water. These plants use solar energy to convert inorganic minerals to organic plant tissues. These plant species which are common to the wetlands have higher levels of primary production, which is the first phase of production and is accomplished only by those microorganisms that contain chlorophyll. The primary consumers directly feed on the wetlands vegetation and most of the plant materials become detritus, the partially decomposed plant materials. Different types of microorganisms feed on the detritus and populate increasing the quantity of the detritus as food for the crabs, fishes etc. The higher levels of consumers are those that feed on the detrital consumers, such as shore birds, finfish, mammal including human, etc. Moreover, the wetlands vegetation slows water velocity, causing sediments and sorted chemicals to filter out from the water column before reaching on to the wetlands. Again, increase in the productivity of wetlands may lead to higher intake of nutrient uptake and subsequent burial when the plants die.

Wetlands are home to varieties of plants and animals that are adapted to the complex wetland conditions and varieties of microhabitats. Microhabitats are small areas within the same habitat having different sets of living environment and include open water zone, emergent zone and the zone where the place is sometimes dry and sometimes wet. The wetland's ecology consists of plants and animals that may be abundant in one of those areas but may perhaps find difficulty in surviving in the adjacent zone. Inspite of being abundance of water and soil, it may be a challenging place to survive. One of the biggest challenges of the aquatic flora is to survive in an air deprived environment. However, the wetland plants have adapted themselves to deal with this particular set of challenges by developing air space throughout their structures to move oxygen from the parts above water to their roots. Moreover, wetland's bacteria have also unique way of dealing by using sulphate for respiration rather than oxygen. Variety of birds, fishes, mammals and invertebrates use wetlands for foraging, shelter, nesting, spawning and nursery areas. Meanwhile, some of the species use wetlands as a temporary residence for food or refuge.

Wetlands provide numerous products and services to humans use directly or indirectly. Many agricultural benefits, like using high nutritional wetland vegetation for grazing or haying, trapping of sediments and runoff from ploughed ground before it can enter local water supply are also associated with wetland values. In a nutshell wetlands play a major role in the natural and physical world.

1.1.3 Indicators of Wetland Ecology

Wetlands are unique habitats which sustain consequential biodiversity. A large number of animal and plant species are restrained to only wetlands and hence the survival of this flora and fauna totally depends on the existence of these habitats. The dynamic and complex hydrological settings of a wetland body may have taken centuries to become naturally established and its continuous process is interrupted by human intervention or other natural calamities. Hence, indicators are mainly used to assess the environmental status of a wetland as an early warning signal of environmental degradation and ecological problems.

Assessments of environmental status of a wetland are based on indicators, such as - physical/chemical characteristics of soil and water, nutrient cycling, ecosystem processes, aquatic flora and fauna. Water velocity represents one of the most important environmental factors affecting the ecology of wetlands. On one hand water delivers food materials and oxygen and removes waste materials, on the other hand flow is a direct force on organisms. Quantifying flow regime indicates how a wetland responds to precipitation events, determines whether water is being over utilized etc. When too much water is removed or if flows are restricted, fish and other organisms living in the wetland can be affected.

Chemical attributes of soil and water also help to determine the number and diversity of organisms that it can support. The type of soil of a wetland also plays an equally large role in determining the hydrological aspects. Also, by looking at the aquatic bugs and different aquatic vegetations and environs in rivers, streams, lakes or pond, we can assess the health of that water body. Moreover, examination of the benthic organisms inhabiting in a wetland can provide valuable information about the ongoing health. Traditionally, quality or health assessments of a wetland were based on analyzing water and soil quality. The problem was that these measures reflect only the conditions at the moment of sample collection and only a defined set of parameters. Ecological indicators have widespread appeal to scientific persons and the general public. Biological monitoring techniques represent a departure from more standard physical and chemical monitoring systems, as it measures directly biological components, such as - community and functional structure. Many researchers and scientists have considered this to be advantageous as biota accommodate quality over time and space and are directly linked to ecosystem’s function and integrity. Biological indicators can indicate finite and comprehensive features of wetland ecology and hence effective bioindicators has to be identified that aid in wetland management and conservation. However fish, algae, protozoan and other groups of organisms are being used in water quality assessment. Diatoms are sensitive to many environmental variables and they are considered as powerful indicators of environmental changes including acidification, eutrophication, change of carbon and organic nitrogen contents, pH and phosphorus contents [5]. Macroinvertebrates which largely consist of insect are more frequently used as bioindicators [6]. When a large number of different macroinvertebrates acclimatize a water body or when those macroinvertebrates that dwell in a wetland are particularly pollution-intolerant or oxygen-demanding, the water body is generally considered to be healthy. Macroinvertebrates (e.g. anmay flies, caddis flies, true flies, snails, etc.) possess a life cycle of at least a year or more, do not move great distances, and are more or less confined to the area of the water body being sampled. The macroinvertebrates community of a water body lives with the stresses and changes that occur in the aquatic environment, whatever their cause, including those that are due to human activities, such as nutrient enrichment from diffuse and point source discharges as well as natural events, such as floods and droughts. They are fairly domiciliary and therefore, cannot escape occasional pollution. Presence or absence of certain species indicates good or poor water quality.

1.1.3.1 Macroinvertebrates as Bioindicators

Aquatic vegetation forms an important element of the aquatic environment in freshwater ecosystem. Diverse types of aquatic animal life, especially of macroinvertebrate fauna inhabit the vegetation of wetlands and provide significant support to the complex food chain. Vegetation of wetlands provide suitable surface area for shelter, a site for oviposition, development, resting and nesting ground and hiding places for macroinvertebrates and other aquatic life. During daytime, the macrophytic vegetation contributes to induce the dissolved oxygen content of water and harbours a wide variety of macroinvertebrate [7]. These macroinvertebrate communities function as a food for fish, prawns and birds. Empirical studies indicate that the total abundance of benthic macroinvertebrates is correlated with the biomass of macrophytes [7].

Few limnological studies have been done on macrobenthos in different types of wetlands. Although several works have been made by the scientists abroad, very little information is known about the macroinvertebrate faunal community associated with macrophytes inhabiting the Indian fresh water wetlands. In India, freshwater wetlands have undergone critical changes in recent years, largely due to rising pressure on land and lack of awareness about their benefits and functions. Hence a study is expected to provide interesting insights into interactions between macrophytes and associated macroinvertebrate fauna.

Macroinvertebrates may be small and spineless, but when it comes to the cycling of wetland nutrients, they always occupy a unique function. These benthic aquatic insects include small worms, molluscs, leeches, crustacean’s insects and insect larvae. They are ideal candidates for biotic (rather than physical and chemical) measures of wetland health as they are affected by the ongoing process and conditions of the wetland including pollution. Benthic macroinvertebrates as bioindicators give a definite picture to monitor the health of aquatic ecosystem and learn about aquatic habitat water quality. If we examine what types of bugs and how many of each kind are present in the water, we can interpret the quality of that particular water body. These aquatic little bugs are indicators of the health of the aquatic ecosystem for several reasons. Different bugs have different tolerances to water contamination. So, the types of bugs that present in a wetland gauge the quality of water of the wetland. They are a potential indicator, because they represent a diverse group of long living sedentary species that react strongly and often predictably to human influences on aquatic systems [8]. However, the overall condition or the health of aquatic ecosystems is determined by the interaction of all its physical, chemical and biological components.

Macroinvertebrates exhibit a wide range of response to pollutants, and have been extensively studied with a holistic approach to evaluate water quality and complement physico-chemical surveys. However, the ecology and distribution of these macroinvertebrates are yet less understood. Many aquatic invertebrates have specific habitat requirement, while others can survive over a wide range of habitat types [9]. Macroinvertebrates are large enough to be seen with naked eyes, yet are generally small. They lack a backbone and can inhibit all types of water bodies. From the logistic point of view, they make good study specimens, because, they are abundant, readily surveyed, and taxonomically rich [10]. Presence and absence of the dominant and diverse group and the extent of community assemblages reflect the pollution levels making macro-invertebrates good bioindicators [11].

1.1.4 Environmental Significance of Wetlands

Wetlands are a critical part of our natural environment. They offer an important range of environmental, social and economic services. They help check floods, prevent coastal erosion, mitigate the effects of natural disasters like cyclones and tidal waves and can also store water for long periods. Wetlands have been observed to provide multiple important functions in a storm water management system. It can reduce flood peak as it can change high storm runoff peaks to slower discharges over longer periods of time and thus, it gain potentiality to reduce flood damage. Ability of wetlands to control flood depends on - topography, size and shape of the wetlands, roughness of wetland surface, location in the catchment, water regime and permeability of the wetlands etc. Wetlands can also purify water through trapping of pollutants such as suspended sediments, silt and clay, excess nutrients like nitrogen/phosphate, toxicants like pesticides/heavy metals and viruses/bacteria. They have the competence to do this by reducing the velocity of water flow, filtering out suspended solids, long contact between water and sediments, anaerobic and aerobic processes taking place in the water and microbial decomposition.

Wetlands also provide habitat for a large number of animal and plants, and consist of wide diversity of eccentric aquatic plants and animals that are found nowhere else. Many plants grown in wetlands have specific environmental needs and are extremely vulnerable to change. Some of the endangered plant species depend totally on wetlands. Wetlands are also contemplated as areas of great natural beauty where the indigenous people have occupied the wetlands for their benefits. Their diverse resources can be directly exploited for fishing, agriculture, wildlife products, wood products and water supply [12]. The ability of wetlands to recycle nutrients makes them unfavourable in the overall functioning of earth. Wetlands also act as storehouses for carbon dioxide and other greenhouse gases, especially if their vegetation is protected and their natural processes are maintained. Wetland's microbe, plants and wildlife are part of the global cycles for water, nitrogen and sulphur. Scientists have appraised that atmospheric maintenance may perhaps be additional functions of wetlands. Wetlands also store carbon within their plant communities and soil instead of releasing it to the atmosphere as carbon dioxide. Thus, wetlands help to restrain global climate conditions [13]. In view of this multidimensional importance in maintaining the overall balance of nature as well as occupying vital position as natural resources in a region, wetlands assume much significant role and thus draw attention of the natural scientist in general. Moreover, understanding the structure and functions of the wetlands, their importance is realized in the recent years. The wetlands are areas with rich biodiversity and they serve as a spawning and cradles for fishes, birds etc. and hence can be used as an excellent area for conservation of rare and endangered species.

1.1.5 Socioeconomic Importance of Wetlands

Wetlands provide tangible and intangible benefits on sustainable basis to the rural society dwelling around the wetlands. They constitute an essential component of human civilization, meeting crucial needs to sustain life on earth, such as - water (agriculture, drinking, etc.), food (protein production, fodder, etc.), biodiversity (diverse flora and fauna), energy (fuel wood, etc.), recreation (tourism), transport, water purification, flood control, pollutant sink and climate stabilisers. The values of wetlands though overlapping (like cultural, economic and ecological factors) are inseparable.

The socioeconomic value of the resources and services provided by freshwater natural resources are yet to be documented well. However, these wetlands play a very significant role in socioeconomic lives of the local people. Since time immemorial, people had been utilizing the resources of the wetlands for their personal benefits. Wetlands provide numerous benefits and services on which people can find out varieties of ways to generate their sources of income. They are among the most productive ecosystem and directly or indirectly support millions of people and alleged as an asset that aid in providing resources and services to them. The direct benefits of wetlands are in the form of products, such as - fish, livestock resources, medicinal plants, recreation and water supply etc. They use the water both for irrigation and drinking purposes also. Their indirect benefits are the functions performed by the wetlands such as flood control, ground water recharge and storm water reservoir. They sustain all life and perform some useful functions in the maintenance of overall balance of nature [14].

Assam, well-known as the land of rivers, has rich aquatic assets and the numerous *beels*, swamps, rivers and ponds clearly reveal the richness in aquatic wealth [15].

Besides using the wetlands as a source for collecting various resources and satisfying their domestic utilities, it is a source for providing easily accessible nutrition by fulfilling the domestic demand for fish. The fish production can also be used to generate the economy of the region as selling and exporting the fish to other places can be source of income for the local folks. However, this kind of practices encourages the local community not only in the exertion of resources from the wetlands as well as conservation for the same. Due to various environmental degradation like siltation, weed infestation, water quality changes etc, the resource potential of the aquatic wealth has been exhausting in the recent times, affecting the livelihood of a large number of people living in peripheral villages. Apart from various physical changes occurring in the inland water bodies, changes in the nature of the locals to use the floodplains and the water in the wetland have also exposed into limelight.

1.1.6 Human Impact on Wetlands

Wetlands represent one of the vital natural resources which the planet is endowed with. The interaction of man with wetlands during the last few decades has been a concern largely due to the rapid population growth accompanied by intensified industrial, commercial, and residential developments. Wetlands are being polluting due to domestic and industrial sewages, and agricultural runoffs, such as - fertilizers, insecticides, and feedlot wastes.

Sustainability of many wetlands are becoming a problem because of increasing impact from a wide range of pressures on arable lands and ballooning of population. The impact of these activities is still poorly understood. The importance and values of the wetlands have been ignored by the rural and urban society since recent times. In fact, failure to restore these resources may result in extinction of species or ecosystem types and cause permanent ecological damage. Commercialization of the wetlands inspite of being a valuable resource to the rural dwellers has become content for threat. Major degrading factors include excessive eutrophication due to nutrient and organic matter loading, siltation due to inadequate erosion control in agriculture, etc. In addition, physical changes at the land-lake interface (for example, draining of riparian wetlands) and hydrologic manipulations such as damming outlets to stabilise water levels have major impacts on the structure and functioning of these ecosystems. However, the valuable functions contributed by the wetlands cannot be left unspoken.

Improper uses of wetlands, especially by human beings deteriorates water quality, enhances siltation rate and disturb inflow and outflow leading to overall degradation of wetlands and thereby reduce their productivity. The existence of these exclusive resources is under threat due to developmental activities and excessive human usage. With ballooning population and increasing pressure on arable lands, sustainability of many wetland ecosystems around the world is becoming problematic. This calls for a long term planning for preservation and conservation of these resources. So, considerable attention has to be paid and major strategies have to be introduced for proper management of wetlands that will aid in sustainable conservation of the wetlands. Decision makers must understand that impacts on wetland functions can eliminate or diminish the values of wetlands [13].

1.1.7. Wetlands of Lower Subansiri Basin

The Subansiri River is the major tributary of the mighty Brahmaputra and originates in the great Himalayan range in the Tibet, which is the source of many rivers at an altitude of about 5000 m above the mean sea level. It contributes about 10% of the flow of the river Brahmaputra. The topography of the Basin consists of plain and mountainous terrain, where the hill ranges varies approximately from 1000 to 1600 metres above sea level. Hence the river can provide favourable geo-ecological conditions for the development and growth of wetlands. These wetlands are locally known as ‘*beel*’s in Assam. The *beels* in Assam represent water bodies of different shape and sizes, and are generally connected to rivers.

The lower part of the Subansiri basin comprising the plain area of the basin covers an area of 10929.05 sq. km, out of which 4227.64 sq. km (38%) belongs to Assam part. It is a composite of two sub-basins – Ranganadi and Dikrong sub-basins [16]. The area is very fertile and supports quite a good density of rural population. The Subansiri River is the lifeline of the region. It provides diverse habitat, especially in the lower part of its basin, for natural aquatic resources such as - stream, riparian zones, wetlands etc. A few wetlands have feeding channels with the river. The riparian wetlands have the most ecological and economic importance. The riparian zone of the river was widely varied - from waste barren land to woody forested area. The width of the river is also highly variable and has more sand bars from upstream to downstream. Moreover, human habitation near the bank side is rather found to be sparse.

Subansiri river maintains a stable course while flowing though the hilly region of Arunachal Pradesh, but becomes almost unstable as soon as it enters the alluvial plains of Assam. The major geological event believed to be responsible for bringing about a change in the hydrologic aspects of the river is the devastating earthquake of 1950, which caused large scale landslides in Arunachal Pradesh and blocked the river temporarily for about three days [17]. It has been noticed that the river is experiencing floods more frequently after that event causing large scale devastation in terms of geomorphologic changes and socioeconomic losses. The major geomorphologic changes are bank side erosion, deposition of sands and changes of the river course, sometimes leading to the formation of wetlands in its lower catchment. Besides the changing of river course, wetlands were also formed due to the deposition by the overflowing of river banks which leaves waterlogged areas behind. There might be some wetlands formed by other geological processes also. Some wetlands are also formed due to the development of roads and railways that formed waterlogged areas. Thus, the basin contains a good number of wetlands of different sizes and limnological characteristics. Most of the wetlands, locally known as '*beel*', of the basin are formed as the oxbow or abandoned stream segments spread over the floodplains of the rivers. A few of these water bodies, however, owe their origin to depressions caused as a result of earthquake.

A *beel* is a complex natural system whose origin and development depends on the variety of interactive natural as well as biotic factors. Any attempt to understand such a system will require consideration of several aspects related to various geological, hydrological, biological and socioeconomic parameters. Basically, attention towards the wetlands is required due to growing human interference, which has been degrading the wetland and is posing serious threat to the natural resource.

Researchers working on the Subansiri River have also expressed the fear that the 2000 MW Lower Subansiri Hydroelectric Project (LSHP) may cause death to this major north bank tributary of the Brahmaputra. It is reported that several environmental activist groups and student organisations have been opposing the proposal to construct the LHSP dam without the expert committee clearance on the downstream impact of the project. The downstream impact may perhaps affect the interconnecting wetlands by trapping the nutrients content, sedimentation, etc.

1.2. Statement of the Problem

The Subansiri River has many interconnecting wetlands in the lower part of its basin. The nearby indigenous villagers are socioeconomically attached with these wetlands which provide support to them for their sustenance. The people of the region get benefitted from the wetlands by using their resources. The resources collected from the wetlands are mainly food, fodder, medicinal plants, thatch grasses, raw materials, etc. The wetlands are the storehouse of a huge number of aquatic flora and fauna. These are also chief habitats of migratory birds, aquatic plants, amphibian species, and habitats of many deep water rice varieties.

The local people are more likely to use the river and its floodplain wetlands for various purposes. Rice and vegetables are cultivated during the post-monsoon period. Wetland water is used for irrigation, bathing and other purposes. Large verities of fishes available in the wetlands are the only source of fish for the nearby villagers and fishing is considered as their main economic activity. The demand for these local varieties of fishes is very high in the market.

Over dependence for fishing and using of various types of fishing gears to catch fishes of different sizes is causing depletion in fish fauna in the wetlands (*beels*). Moreover, some of the *beels* are given on lease by the Government. As the lease period is fixed, the lease-leaders catch the entire stock of fish from the wetland at a stretch to augment their income. To achieve this, they reduce the water level of the *beels* by pumping out water to the nearby areas. For these reason the total fish production in the *beels* are declining in recent years which have resulted in loss of various direct and indirect loss to the livelihoods of the villagers. Besides fishing, other human activities, such as - buffalo and cattle rearing, agricultural activities, etc. have resulted in continuous siltation and accumulation of petrified matters, heavy weed infestation and damages to the microflora and water quality deterioration in the *beels*. The wetlands are also shrinking due to encroachment for residential and commercial developments, construction of roads and buildings etc. Moreover, most of the natural wetlands have been converted to commercial fisheries in recent years, where local fish species are replaced by commercially beneficial new species. Thus, in recent years, it has been observed and reported by the local people of the region that the wetlands are degrading and shrinking day by day due to human intervention, indiscriminate overexploitation, siltation, encroachment, bad land use practices and construction of roads and embankments etc.

Therefore, it is the need of the hour to prepare proper management plans for the wetlands (*beels*) to take necessary steps for their maintenance and conservation, so that the wetlands remain sustainable. In this context, a detailed study on the wetlands of the basin with a holistic approach is very much essential.

1.3 Aims and Objectives

In view of the urgency of the matter, the present investigation on the wetlands of Lower Subansiri Basin was undertaken which would be very much useful in preparing proper management plans of the wetlands for their sustenance and sustainability, so that a major portion of the local people may continue their dependence on the wetlands for their day to day necessities and also for their livelihood. The following objectives were considered to fulfil the aims of the investigation.

1. To delineate the wetlands of Lower Subansiri Basin by using Remote Sensing and GIS technique.
2. To classify the wetlands on the basis of their formation and area coverage.
3. To investigate the environmental status and productivity of each category of wetlands on sample basis.
4. To access the socioeconomic importance of the wetlands.

1.4. Working Hypothesis

Human pressure on most of the wetlands of the Lower Subansiri basin has been increased in the last few decades due to growth of indigenous local population. Hence the demands of various wetland resources have been increasing where the wetland resources are overexploited to fulfil the demands. Indiscriminate use of wetland resources caused deterioration of water quality, loss of productivity, loss of diversity of aquatic flora and fauna, heavy weed infestation, siltation and accumulation of petrified matters. Shrinking of area coverage of most of the wetlands have been reported due to bad land use practices, encroachment of the peripheral areas of the wetlands for agricultural activities and construction of roads and embankments etc. Thus, most of the wetlands of the basin are degrading in terms of surface area, water quality, productivity and biodiversity in the recent years due to such kind of activities.

1.5. Methodology

The study was based on field observations, literature survey, laboratory analysis and standard protocols. Moreover, the study consisted of remote sensing data and Survey of India Topo-Sheets for mapping the Lower Subansiri Basin and delineating its wetlands.

Remote Sensing data includes IRS P4 LISS III satellite imagery of the year 2006 and ASTER and SRTM data with spatial resolution of 15m and 90m respectively [18]. The maps generated from the Brahmaputra Board and the Digital Maps of India were used as the reference data [19]. National Atlas of Assam prepared by ARSAC and ISRO was used as the reference [3]. Area was calculated for each wetland and classified according to their types and formation. As the Lower Subansiri basin covers an area of 10929.0549 sq. km comprising of numerous wetlands, it was not possible to study each wetland individually and therefore, the investigations were limited to one representative wetland from each of the classified four categories of wetlands - Oxbow, Waterlogged area, Lake/Pond and Riverine found in the study area.

The sampling for the physico-chemical and biological parameters consisted of four transition phase viz. - Pre-monsoon, Monsoon, Autumn/Retreating Monsoon, Post-monsoon. Water quality parameters were investigated for the years 2013-2014, whereas soil quality data were generated only for the year 2013, as the probability of yearly variation of soil quality is minimal. Eighteen sampling sites were selected from the four wetlands and continued for the said four seasons considering the variation in the macro-habitat and hydrological settings.

Water and soil samples were collected from each of the sampling sites and the composite of four to five samples based on the practicality of sampling in the wetlands were undertaken for analysis in the laboratory. Temperature was determined on the spot and the rest of the physicochemical and bacteriological parameters of water and soil were undertaken following the methods outlined in Trivedi and Goel [20], APHA [21], NEERI [22] and Central Pollution Control Board Guide manual [23]. The bacteriological parameters for the water samples were analysed following the standard methods in the laboratory within 24 hours from the time of sampling. After collection, the samples for physico-chemical parameters were immediately transported to the laboratory and store in refrigerator at 4°C prior to analysis. The soil samples were air dried, sealed and labelled prior to analysis.

Regular samplings were conducted for four seasons at each sampling sites throughout the sampling period (2013-2014) to measure macroinvertebrates assemblages. The aquatic insects were monitored and analyzed following the procedure recommended by Subramanian and Shivaramakrishnan [6]. The method contains four main steps – sieving, sorting, preservation in 4% formalin, and identification. The macro-invertebrates were indentified till the taxonomic level 'Family' with the help of various keys provided by Subramanian and Shivaramakrishnan [6] and Water Bug Detective Guide [24].

Socioeconomic study was carried out preparing a questionnaire and approaching household of the locals using the random sampling method. People collecting resources at the study sites were also interviewed

1.6. Significance of the Study

The findings of the present study will generate a baseline database for future study and monitoring programs on the environmental conditions of the wetlands to augment conservation measures. Regular monitoring during the study period gave us an insight about the condition of the wetlands which will help in preparing future conservation strategies that come coupled together. As the humans dependence and association with the wetlands were observed and reported to be high, carrying out a proper study and management plan for the wetlands will assist in providing solutions in a sustainable manner to local communities whose livelihood depend on the wetlands.

1.7. Organisation of the Work

The present thesis is organized in ten chapters. The existing chapter consists of a brief overview of the wetlands and their formation, explaining both the natural and anthropogenic processes. Wetland's classification on the basis of their formation and types as per NWIA was also discussed. Environmental significance of wetlands and the functions performed by the wetlands has also been drafted in connection to human and the environment. The importance and its valuable resources and human impacts on the wetlands were also briefed precisely. A discussion on the indicators of wetlands to assess the health of a wetland with special reference to macroinvertebrates and the socio-economic benefits that the locals can fetch from the wetlands has also been made. This chapter also discusses about the study area Lower Subansiri Basin and its wetlands and the genesis for which the research is conducted, the objectives behind the study, working hypothesis and significance of the study.

The second chapter consists of 'Review of Literature'. It highlights the works already done and published on wetlands in terms of environmental, hydrological, social and economic aspects which includes regional, national and global study. This chapter also presents the perspectives and opinions given by individuals.

The third chapter explains about the materials and methodologies adopted during the study. Its contains a brief background and description of the study area, the protocols and procedures adopted for mapping and delineation, water, soil, macroinvertebrates population study and the socio-economic importance. This chapter also discusses the methods used to formulate the statistical techniques and different abiotic and biotic indexes.

The fourth chapter documents the results generated from mapping and delineating the basin. The results consist of details of the wetlands in the basin and their distribution in the study area. The wetlands carried forward for further study is selected from the delineation and classification done in this chapter.

The analysis report on the water quality of the selected wetlands is discussed in the fifth chapter to assess the condition of the wetlands and a comparative study on the classified wetlands is also reviewed. Seasonal trend analysis on water quality of the wetlands is also recorded and graphical presentations of the variables are formulated to evaluate the periodic variation. Correlation matrix was also derived to correlate the relationship among the attributes.

The sixth chapter consists of the variation of soil texture and quality in lieu of the wetland types. Seasonal changes on the soil quality parameters encompassing four seasons has also been discussed and presented graphically to learn about the periodic impact of wetland ecology. Statistical analysis like correlation matrix was also derived in this chapter.

Investigation on the macroinvertebrates population on the selected wetlands is discussed in the seventh chapter. The density and diversity variation in context of the wetlands types and the intensity of fluctuations in response to the seasonal meteorology is also discussed to depict the seasonal influence of macroinvertebrates habitat quality.

Abiotic and Biotic Indexes are used to derive a cumulative value to make the voluminous scientific data understandable and presented in the eighth chapter. Relationship between NSF Water Quality Index and the Biotic Indexes are also framed to measure the Biotic Index that share the maximum compatibility with NSF Water Quality Index.

The association and dependence with the wetlands of the neighbouring people and the socioeconomic benefits derived from the wetlands are discussed in the ninth chapter. The views and perceptions towards the wetlands were also reviewed and the data generated are presented graphically to facilitate the data in percentage.

The last chapter summarises the findings generated during the study from which conclusions are drawn. Appropriate recommendations are proposed for restoration and conservation of the wetlands coupled with some management techniques. Suggestions to assess the value of wetland resources and counsel on sustainable usage of the wetland resources are also commended.

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