Forests are one of the most important natural resources on earth providing the earth with a green cover. The forests offer several environmental services which are essential for sustenance of life. Forests provide shelter and protection, as well as many essential products such as food, timber, medicine, fuel and tools. Forests provide many other benefits such as control of erosion and flooding and reduction of wind erosion. In addition to many utilitarian aspects, the forests provide many aesthetic features to which quantitative values are difficult to assign. The amenities include forest wildlife such as colorful birds, wild flora and fauna, flowing springs and falls and beautiful landscapes.

Our country has forest cover about 733,424 km^2 and this constitutes 21.02 percent of the geographic area of the country, of this, 83,510 km^2 area (2.54 %) is categorized as very dense forest and 319,012 km^2 (9.71 %) as moderately dense forest, while 289,377 km^2 (8.77 %) in the form of open forest cover and 41,525 km^2 (1.26 %) as scrubland forest. There are various types of forests such as coniferous, deciduous, evergreen, temperate and tropical rain forest, tropical seasonal forest and sub-tropical rain forest in India. Broadly, about 34 % of the country's forests fall in the tropical moist deciduous category, 30 % in the tropical dry deciduous, 11 % in Himalayan temperate, 9 % in the tropical wet evergreen category, 6 % in subtropical pine and about 5 % in the tropical thorn category. Deciduous forests in India are of two types viz. The Tropical dry deciduous forests and Tropical monsoon deciduous forests as they form natural cover in almost all regions of India. These type of forests account for about more than half of total forest area in India and they are mainly found in Western and Northern India and in South Deccan Plateau. The dry deciduous forests are mainly situated in the areas, where annual rainfall ranges from 500 - 1,500 mm, climate is warm, round the year and every species in the forest has its own time of leaf casting. Sal and teak are the most significant trees found in the dry deciduous forests. Several studies have revealed that the dry deciduous forests are gradually replacing the moist deciduous forests in India. The Indian dry deciduous forests have generally a three-storied structure, with an upper canopy at 15-25 meters, an understorey at 10-15 meters, and undergrowth at 3-5 meters. The vegetation in these forests is characterised by *Anogeissus latifolia*, *Dalbergia latifolia*, *Pterocarpus marsupium*, *Stereospermum suaveolens*, *Spondia spinnata*, *Cleistanthus collinus*, *Acacia lenticularis*, *Anona squamosa*, *Acacia nilotica*, *Acacia leucophoea*, *Eucalyptus* *grandis, Flacourtia indica, Boswellia serrata, Butea monosperma, Tectona grandis, Acacia catechu, Terminalia tomentosa, Terminalia chebula, Terminalia belerica, Chloroxylon swietenia, Albizzia lebbeck, Cassia fistula* etc. They shed their leaves for about six to eight weeks during the dry season, generally during the months from March to May, in order to prevent the loss of water in the form of moisture through the process of transpiration.

1.1 Forest Ecosystem Structure and Function

The forest is a biological community of flora and fauna existing in a complex interaction with the abiotic environment which includes factors such as the soil, climate, and physiography. A continuous canopy of large trees usually distinguishes forests from other types of communities. Forests are widespread representing almost 29% of the earth's land surface, and typically have a predominant species composition. The rest of the earth surface is occupied by desert (30 %), grasslands (21 %), polar ice caps and wasteland (11 %), and croplands (9 %) .There are thousands, perhaps millions of different types of plants and animals in the forest. Trees, Shrubs, herbs, ferns, mosses, lichens and fungi are present beneath the forest canopy and in the gaps of the forest cover. Large animals such as deer and bears co-exist with smaller birds, insects and tiny microorganisms. Each component makes a contribution to the flow of energy and materials through the system. Although trees are the predominant woody vegetation in terms of biomass, trees represent only a small proportion of the total number of species present in the forest. The forest is thus a dynamic ecosystem dominated by trees that is continually changing its structure and composition. Disturbances such as fire, windfall and harvesting produce are sites, where new communities of trees, plants and animals can exist and differ from the original forest. Fallen leaves and woody material that reach the forest floor slowly gets decayed and continue the cycling of energy and nutrients through the system **(Odum, 1959).**

Green plants (i.e. trees, grasses) are called the "Primary producers" since virtually all the energy available to all organisms originates in plants. The "Primary Consumers" are herbivores (i.e. a moose, insects, deer, elephant etc.) who obtain their energy by consuming plants or plant products. Carnivores (i.e. birds or wolves) eat herbivores and are called "Secondary Consumers". Detritivores (i.e. scavengers, crows and ultimately bacteria and fungi) consume the droppings and the carcasses and are called "Decomposers".

Energy transformation and biogeochemical cycling are the main processes of ecosystems. They link the living or biotic components to the non-living or abiotic components. The transformation of energy in an ecosystem such as a forest ecosystem starts with the input of energy from the sun. Energy from the sun is captured by the process of photosynthesis by primary producers and flows from one trophic level to another through a series of living organisms.

The manifold significance of trees is due to their major role as the "Primary producers" in the forest ecosystem. The internal processes of forest ecosystems are dynamic and complicated since they occur at different levels i.e. individual, population and community level. There are numerous "Individuals" (i.e. trees, other plants, animals, fungi etc.) that each have their own physiology, reproduction and developmental traits. The second level is the "Population" of each "Individual" species that includes their habitat, resource needs and population growth. At third community level populations of many species interact with one another, even populations of different tree species can compete for space and nutrients. Energy flows and elements cycle are the key phrases of ecology.

During decomposition or mineralization, elements such as carbon, nitrogen, phosphorus, sulphur, sodium, potassium, calcium, magnesium (which have entered living organisms in a variety of ways) are not destroyed or lost. These elements are cycled endlessly among the trophic levels. The energy entering this biological system is ultimately converted to heat energy and lost. It cannot be recycled. Without the continued input of solar energy, biological systems would quickly shut down.

The principal energy input does not come from green plants but from dead organic matter (i.e. dead wood or leaves on the forest floor). This is called the "detritus food chain". Nutrients are the elements whose supply tends to limit biological activity. The amount and availability of nutrients, water and solar radiation varies greatly from place to place, and causes large differences in the amount of primary production. This variation is particularly seen in the primary production that forests represent.

Biotic components

The living or biotic components of the forest ecosystem are Trees, Shrubs, Herbs and Grasses. Herbivores and carnivores comprise of a wide variety of fauna that range from large mammals to small insects. In the living layers of soil, one can find mushrooms, beetles, worms and microscopic organisms. (Figure 1).

Abiotic components

The non-living or abiotic components of the forest ecosystem consist of : solar or radiation energy, macro and microclimates, the water cycle, nutrients and other particles found in the soil and soil parent materials (i.e. bedrock). The energy that is needed to support the biological production and hydrological cycle of forest ecosystems is obtained from solar radiation **(Figure 1.1.1)**.

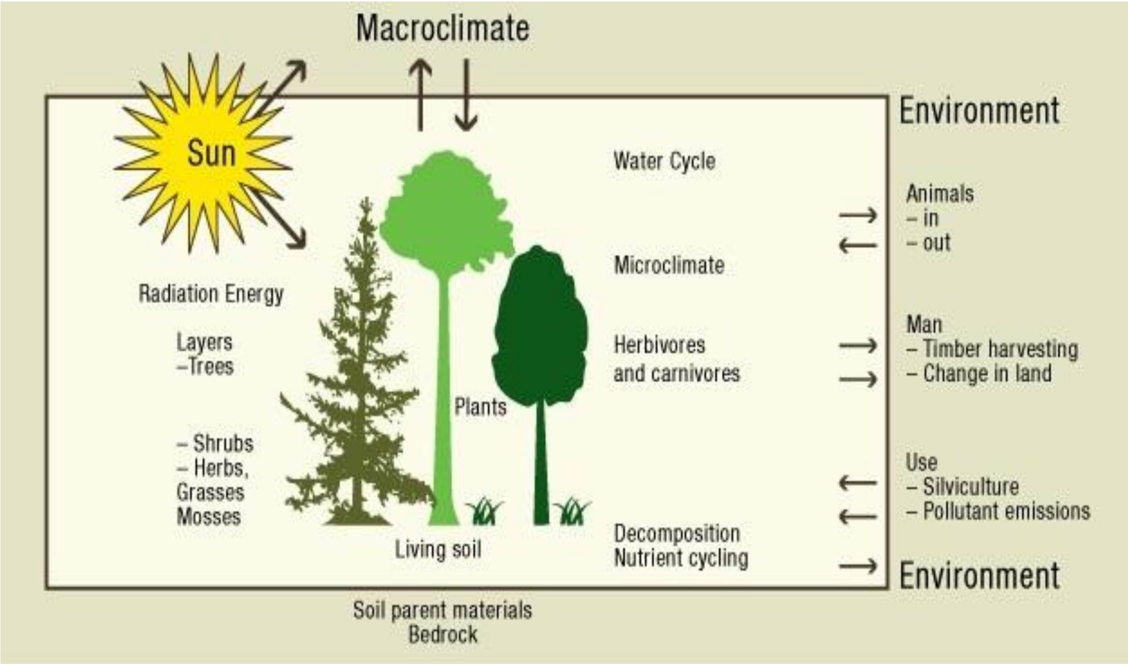

Figure 1.1.1 The Forest ecosystem; components and the environmental factors affecting the ecosystem **(Hannelius & Kuusela, 1995).**

The elements such as Carbon, Nitrogen, Phosphorus, Sulphur, Sodium, Potassium, Calcium and Magnesium are among the nutrients captured by trees and other minor "Primary producer" plants in the forest ecosystem. These elements are needed for growth and are used by various organisms. In photosynthesis carbon dioxide is combined with hydrogen (derived from the splitting of water molecules) to produce carbohydrates.

Forests influence the micro-climate, wind, soil, stream flow and wildlife populations. They serve as a critical source of biological diversity on which mankind depends and will increasingly depend on for a variety of purposes (including food production, timber, herbal drugs). In other words, the industrial timber that is used for making paper and wood products, the local wood used for farming and construction, and the use of wood for energy will provide a multiplicity of human benefits (including environmental services and natural beauty) that will continue to grow in number and importance.

Forest ecosystems, as a science called forest ecology can provide us with a basic understanding of forests which can be applied to many purposes such as understanding the protective structure and functions of forests and the issues related to forest biodiversity, biomass, net primary productivity, nutrient dynamics, energy production and carbon sequestration.

1.2 Biodiversity

Biodiversity is the variation of life forms within a given ecosystem, biome or for the entire Earth. Biodiversity is often used as a measure of the health of biological systems. Biodiversity found on Earth today consists of many millions of distinct biological species, the product of four billion years of evolution. Biodiversity literally means "variation of life at all levels of biological organization". It is a measure of the relative diversity among organisms present in different ecosystems. "Diversity" here, includes diversity within a species and among species and comparative diversity among ecosystems. India is one of the 12 mega biodiversity countries of the world. From about 70% of the total geographical regions surveyed so far, 46,000 plant species and 81,000 animal species have been described. India has become a part of the International Conservation on Biological Diversity Program in May 1994.

Biodiversity can be categorized as:

- **Genetic diversity** - diversity of genes within a species. There is a genetic variability among the populations and the individuals of the same species.
- **Species diversity** - diversity among species in an ecosystem. "Biodiversity hotspots" are excellent examples of species diversity.
- **Ecosystem diversity** - diversity of a place at the level of ecosystems. The term differs from biodiversity, which refers to variation in species rather than ecosystems. Ecosystem diversity can also refer to the variety of ecosystems

present in a biosphere, the variety of species and ecological processes that occur in different physical settings.

1.2.1 Community and Ecosystem Diversity

Ecosystem diversity describes the number of niches, trophic levels and various ecological processes that sustain energy flow, food webs and the recycling of nutrients. It has a focus on various biotic interactions and the role and function of keystone species. Studies in temperate grasslands have shown that diverse communities are functionally more productive and stable even under environmental stresses such as prolonged dry conditions.

Diversity at the level of community and ecosystem has three perspectives. These are:-

a. **Alpha diversity** - This refers to the diversity of organisms sharing the same community/habitat (within-community diversity).
b. **Beta diversity -** Species frequently change when habitat or community changes. The rate of replacement of species along a gradient of habitats or communities is called **beta diversity** (diversity between-community). There are differences in species composition of communities along environmental gradients, e.g. altitudinal gradient, moisture gradient, etc. Higher the heterogeneity in the habitats in a region or greater the dissimilarity between communities, higher is the beta diversity.
c. **Gamma diversity: -** Diversity of the habitats over the total landscape or geographical area is called **gamma diversity.** The number of habitats or ecosystems can vary within a geographical area. Savannas, rain forests, deserts, lakes and wetlands and oceans are major ecosystems, where species live and evolve. The number of habitats/ecosystems present in a region is also a measure of biodiversity.

There are three common metrics used to measure species-level biodiversity, these are: -

- Species richness
- Simpson index
- Shannon index

Species richness is the number of species in a given area. It is the least sophisticated of the indices available. Species richness is used in conservation studies to determine the sensitivity of ecosystems and their resident species. The actual number of species calculated alone is largely an arbitrary number. There is a strong inverse correlation in many groups between species richness and latitude - the farther from the equator, the fewer species can be found, even when compensating for the reduced surface area in higher latitudes due to the spherical geometry of the earth. As altitude increases, the species richness decreases.

Simpson's diversity index (also known as Species diversity index) is a measure of diversity. In ecology, it is often used to quantify the biodiversity of a habitat. It takes into account the number of species present as well as the relative abundance of each species. The Simpson index represents the probability that two randomly selected individuals in the habitat belong to the same species

Shannon index is one of several diversity indices used to measure diversity in categorical data. It is simply the information entropy of the distribution, treating species as symbols and their relative population sizes as the probability.

The advantage of this index is that it takes into account the number of species and the evenness of the species. The index is increased either by having additional unique species or by having greater species evenness.

1.3 Dry Matter Dynamics

Vegetation biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a larger global store of carbon than the atmosphere and changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon and having the potential either to sequester carbon in the future or to become an even larger source. Depending upon the quantity of biomass, the vegetation cover can have a direct influence on local, regional and even global climate; particularly on air temperature and humidity. Therefore, a global assessment of biomass and its dynamics is an essential input to climate change forecasting models and mitigation and adaptation strategies. In addition, there are two other emerging issues which contribute to the increasing importance of the biomass role as an essential climate variable: (i) the growing use of biomass for energy production, so the increasing percentage of global greenhouse gases (GHGs) emitted from biomass consumption, and (ii) the increasing concern on the possibility to significantly reduce global GHG emissions by avoiding biomass losses from deforestation, forest degradation and accounting for the effects of natural disturbances.

The present study mainly addresses living terrestrial above-ground vegetation biomass, in particular woody biomass. Biomass is defined as mass of organic matter. The changes in time of vegetation biomass per unit area (biomass density) can be used as an essential climate variable, because they are a direct measure of sequestration or release of carbon between terrestrial ecosystems and the atmosphere. In present study the term "biomass" is referred to as the vegetation biomass density i.e. mass per unit area of live or dead plant material expressed as unit of measure (g/m^2). The carbon pools of terrestrial ecosystems involving biomass are conceptually divided into above-ground biomass, below-ground biomass, dead mass and litter.

Biomass productivity is one of the most apparent and economically important ecosystem functions. Biomass accumulation begins at the cellular level via photosynthesis. The global patterns of annual biomass production are correlated with annual precipitation. Amounts of productivity are also dependent on the overall capacity of plants to capture sunlight which is directly correlated with plant leaf area and N content. Net primary productivity (NPP) is the primary measure of biomass accumulation within an ecosystem. Net primary productivity can be calculated by a simple formula where the total amount of productivity is adjusted for total productivity losses through maintenance of biological processes.

1.4 Nutrient Dynamics

Nutrients are elements or compounds that are essential for the growth and survival of plants. Plants require large amounts of nutrients such as nitrogen (N), phosphorus (P), carbon (C), hydrogen (H), oxygen (O), potassium (K), sodium (Na), sulphur (S), calcium (Ca) and magnesium (Mg) as macronutrients but only small amounts of others such as boron (B), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and chlorine (Cl) called as micronutrients. Forest nutrient cycling is an exchange of elements between the living and nonliving components of an ecosystem **(Van Cleve et al., 1991).** The processes of the forest nutrient cycle include nutrient uptake and storage in vegetation perennial tissues, litter production, litter decomposition, nutrient transformations by soil fauna and flora, nutrient inputs from the atmosphere and the weathering of primary minerals and nutrient export from the soil by leaching and gaseous transfers.

Each nutrient element is characterized by a unique biogeochemical cycle. Some of the key features of the major nutrients are shown in **Table 1.4.1.** Forest trees make less demand on the soil for nutrients than annual crops because a large proportion of absorbed nutrients are returned annually to the soil in term of leaf and fine root litter and are reabsorbed after biological breakdown of litter materials. Also, large portions of nutrient requirement of trees are met through internal cycling as compared with agricultural crops.

Table 1.4.1 Features of the major nutrient cycles

Element	**Uptake by the trees**	**Major sources for tree uptake**	**Limiting situation**
Carbon	Atmosphere	Atmosphere	Atmospheric concentration may limit growth
Oxygen	Atmosphere	Atmosphere	Waterlogged soils
Hydrogen	Atmosphere	Atmosphere	Extremely acidic and alkaline conditions
Nitrogen	Soluble NO_3 and NH_4; N_2 for nitrogen fixing species	Soil organic matter atmospheric N_2 for nitrogen fixing species	Most temperate forests, many boreal forests and some tropical forests
Phosphorus	Soluble phosphorus	Soil organic matter; absorbed phosphate and mineral phosphorus	Old soils high in iron and aluminum, common in subtropical and tropical environment
Potassium, sodium, calcium, magnesium,	Soluble K^+/soluble Na^+/ soluble Ca^+/ soluble Mg^{2+}	Soil organic matter; exchange complex and minerals	Miscellaneous situations and some old soils

Nutrient cycling in forest ecosystems is controlled primarily by three key factors: climate, abiotic properties (topography, parent material) and biotic communities. The importance of ecosystem disturbance to nutrient cycling is examined briefly, since some nutrients are added or lost from forest ecosystems through natural (e.g., fire, erosion, leaching) or human activity (harvesting, fertilization).

Photosynthesis is the chemical process by which plants use sunlight to convert nutrients into sugars and carbohydrates. Carbon dioxide (CO_2) is one of the nutrients essential to building the organic chemicals that comprise leaves, roots, and stems. All parts of a plant — the stem, branches, leaves, and roots — contain carbon, but the proportion in each part varies enormously, depending on the plant species and the individual specimen's age and growth pattern. Nonetheless, as more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering (storing) it in plant tissue (vegetation) above and below ground. Plants also respire, using oxygen to maintain life and emitting CO_2 in the process. At times (e.g., at night and during winter seasons in non-tropical climates), living, growing forests are net emitters of CO_2, although they are generally net carbon sinks over the life of the forest. When vegetation dies, carbon is released to the atmosphere. This can occur quickly, as in a fire, or slowly, as fallen trees, leaves, and other detritus decompose.

1.5 Litter decomposition

Plant litter produced during senescence processes and plant residues left on site after harvest operations are the primary substrate for heterotrophic respiration in plant-soil ecosystems. They constitute both of above ground and below ground plant parts. The substrate quality together with the physico-chemical environment and the decomposer community is one of the three interacting factors regulating decomposition rates **(Swift et al., 1979b)**. Thus, the quantity and quality of plant litter are key factors controlling carbon (C) loss in the plant-soil ecosystem.

1.6 Carbon sequestration or carbon stock

The term "carbon sequestration" is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments) and geologic formations. For herbaceous plants, the above-ground biomass dies annually and begins to decompose right away, but for woody plants, some of the aboveground biomass continues to store carbon until the plant dies and decomposes. Trees, unlike annual plants that die and decompose yearly, are long-lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. Thus, a forest ecosystem can capture and retain large volumes of carbon over long periods. This is the essence of the carbon cycle in forests - net carbon accumulation (sequestration) with vegetative growth, and release of carbon when the vegetation dies. Thus, the amount of carbon sequestered in a forest is constantly changing with growth, death, and decomposition of vegetation.

In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of the soil, generally in the partially decomposed vegetation (humus) both on the surface and in the upper soil layers, in the organisms that decompose vegetation (decomposers), and in the fine roots. The amount of carbon in soils varies widely, depending on the environment and the history of the site. Soil carbon accumulates as dead vegetation is added to the surface and decomposers respond. Carbon is also "injected" into the soil as roots grow (root biomass increases). Soil carbon is also slowly released to the atmosphere as the vegetation decomposes. Scientific understanding of the rates of soil carbon accumulation and decomposition is currently not sufficient for predicting changes in the amount of carbon sequestered in forest soils.

Forests operate both as vehicles for capturing additional carbon and as carbon reservoirs. A young forest, when growing rapidly, can sequester relatively large volumes of additional carbon roughly proportional to the forest's growth in biomass. An old-growth forest acts as a reservoir, holding large volumes of carbon even if it is not experiencing net growth. Thus, a young forest holds less carbon, but it is sequestering additional carbon over time. An old forest may not be capturing any new carbon but can continue to hold large volumes of carbon as

biomass over long periods of time. Managed forests offer the opportunity for influencing forest growth rates and providing for full stocking, both of which allow for more carbon sequestration. Forest systems operate on a cycle of many decades and centuries, rather than annually or over a few years as would be the case with most crops and non-tree vegetation. As forest biomass expands, the amount of carbon contained increases. As the biomass contracts, the forest holds less carbon.

Forests are a source of energy through the conversion of woody biomass into convenient solid, liquid or gaseous fuels to provide energy for industrial, commercial or domestic use. Already forests provide about 14% of world primary energy supplies, and forests have the potential to meet up to 50% of world energy demands during this century. About 55% of the 4 billion m^3 of wood used annually by the world's population is used as fuel wood or charcoal directly to meet daily energy needs of heating and cooking, mainly in developing countries.

Energy and bio-energy are becoming increasingly interesting and important subjects for policy makers and decision-makers as a result of rises in the prices of fossil-derived energy, coupled with an aversion to the use of nuclear energy. Enhanced environmental concerns are encouraging alternative and renewable sources of energy, particularly in developing countries. The National governments have begun to respond to the United Nations Framework Convention on Climate Change (UNFCCC) that created the Kyoto Protocol. The Protocol stimulates policy directed towards the limitation of emissions and the trading of carbon credits to reduce the concentration of greenhouse gases, particularly carbon dioxide (CO2).

In the present study the following objectives have been carried out in three distinct forest area of dry deciduous forest

1. To determine the biodiversity of different landscape elements in various selected forest area (frequency, density, abundance, relative frequency, relative density of the tree species, composition, dominance and relative dominance and Important Value Index (IVI), Shannon's index, Simpson's index, Margaleef's index)
2. To find out the biomass and net primary productivity of above and below ground of trees, shrubs, herbs, forest floor, litter fall of different landscape elements.
3. To determine the nutrient concentration and content i.e. Ash, N, P, K, Na, Ca, Mg and S in the different components such as bole wood, bole bark, branch, foliage, reproductive parts, stump root, lateral roots, fine root, litter fall, forest floor biomass of the dominant (tree, shrub and herb) species in the selected study sites.
4. To investigate the physical and chemical parameters of soil at different depth like 0-10, 10-20 and 20-30 cm in the study sites.
5. To estimate various aspects of nutrient dynamics such as to determine the pattern of litter fall, nutrient return to the soil, nutrient retranslocation, nutrient uptake, turnover rate and time, nutrient use efficiency and pattern of leaf litter decomposition in the selected study sites.
6. To assess the carbon sequestration or carbon stock of different landscape elements.