ANALYSIS OF SELECT ECOSYSTEMS WITH SPECIAL REFERENCE TO BIODIVERSITY AND TOLERANCE CHARACTERISTICS

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"ANALYSIS OF SELECT ECOSYSTEMS WITH SPECIAL REFERENCE TO BIODIVERSITY AND TOLERANCE CHARACTERISTICS"** in fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY**, submitted in the Department of Biosciences and Biotechnology of the University is an authentic record of my work carried out during a period from February, 1994 to June, 1996 under the supervision of Professor (Dr.) C.B. Sharma, (Retd.) Professor and Head, Department of Biosciences and Biotechnology, University of Roorkee, Roorkee and Dr. J.S. Pandey, Scientist, Land Environment Management Division, NEERI, Nagpur.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other university.

DATE : 20/07/96

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

The present state of environmental decision-making is often based on short-term analysis of an individual component of the system, and interpretation made on the basis of some set of general evaluation criteria, which ignore site and pollutant-specificity. The ecosystem health analysis, therefore, requires identification of a systematic set of relationships which provide the basis for ecosystem health assessment. Moreover, the issues of biodiversity have multifarious dimensions which need to be analysed appropriately in the context of several environmental parameters such that meaningful assessment and interpretation of cause-effect relationships emerge facilitating pragmatic planning of terrestrial ecosystems.

The present study, therefore, aims at development of suitable methodologies for appropriate analysis of the select ecosystems with reference to vegetation and their tolerance characteristics, in order to evaluate the impacts, and offer measures for biodiversity conservation and management.

As evident, biotic community plays a vital role in ecological sanitation by assimilating various pollutants through tissue uptake, accumulation, metabolism and physiological biodegradation. Moreover, green plants not only serve as sinks/air purifiers/assimilators of the air pollutants, but are also the primary producers, because of their photosynthetic capacity, and form the first baseline

organisms for the attack, deposition and assimilation of the pollution. Though plant-environment interactions have been explored, and the mechanisms responsible for the impacts have been well investigated/documented, very little is known about the effects of various interacting stresses due to pollutant impacts, and the management strategies in combination.

A substantial body of research is directed towards understanding the impacts of gaseous pollutants on the vegetation. As a primary pathway for the exchange of gases between internal leaf surfaces and the atmosphere, stomates play an important regulatory role in the leaf physiological processes. It has always been assumed that adsorption into the leaves through the outer layer and the stomata of the leaves play the sole role in the elimination of the pollutants by the plants. The environmental alterations due to the population explosion since the past century have imposed physiological stresses, which make stomatal action a potentially important mechanism for protection against damage due to the pollutants, and thus an important criteria to be incorporated in studies related to ecosystem health assessment.

In the present study species diversity has been used in order to identify the most important species representing different ecosystem communities investigated. Ecosystem Health Analysis has been carried out on the basis of various diversity indices and their incorporation in the ecosystem-process-based Assimilative Capacity Model (ACM).

Assimilative Capacity Model as a modified version of the earlier developed Ecosystem-Health-Exposure-Risk Model has been applied for quantifying assimilative capacities of the studied ecosystems. This has enabled delineation of pragmatic and ecosystem-specific biodiversity management plans.

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LIST OF PUBLICATIONS

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2. Pandey, J.S., Khan, S., Gupta, A.K., and Khanna, P. Sink Potentials and Assimilative Capacities of Some Select Indian Tree Species with Special Reference to Air Pollution. Vanshobha. A Journal of Friends of Trees on Environmental Conservation. 1995, 33-38.

3. Pandey, J.S.; Khan, S., Gupta, A.K., and Khanna, P. Modified Sink Potential Index : A Case Study of Doon Valley. Paper Presented at "Group Discussion on Sustainable Development in the Doon Valley : Constraints of Geo-environment", at Wadia Institute Of Himalayan Geology, Dehradun, India, during June 15-16, 1995.

4. Pandey, J.S., S. Khan, A.K. Gupta and P. Khanna. Quantification of Air Pollution Assimilative Capacities for Forest Areas : Methodology and Case Study. Environ. Pollut. (Communicated), March, 1996.

LIST OF CONTENTS

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CHAPTER I
INTRODUCTION

1.0 INTRODUCTION

The environment with its biotic and the abiotic components provides the basic resources that support production-consumption activities and assimilate the residues produced therefrom. Environmental Impact Assessment, therefore, is a major instrument in decision-making and for measurement of sustainability in the context of the cumulative assessment of developmental policies, plans, projects on a regional basis [155]. The concept of sustainable development is closely linked to that of the carrying capacity of the ecosystem [266], and the assimilative capacity of the region is closely linked with its supportive capacity (**Figure 1.1**).

Biological Diversity, is a central component of the stock of natural capital on which all the economic development of a country is based. Biological resources provide food, fibre, housing material, medicines, and such other essential commodities for the very existence of man on this earth. The current decline in the biodiversity, due to various factors poses a serious threat to mankind (**Figure 1.2**). Loss of biodiversity implies loss of developmental potential, and its conservation through sustainable use or outright protection implies the protection of that potential [239]. One of the characteristics of biodiversity loss of special importance is that ~~biodiversity loss~~, more than any other current environmental problems, it is associated with the ecological threshold effects.

Increasing levels of environmental pollution are expected to alter forest productivity and species composition by bringing about significant changes in the spatial and temporal distribution of key climatic parameters [90, 174, 230]. Growth responses due to increasing carbon dioxide concentration and reduction in stomatal conductance have also been hypothesized [64, 91, 237 and 273]. It is quite likely that even biological diversity undergoes significant changes. Species may move and migrate at different rates. This, in turn, may alter their distribution patterns. Some might even undergo genetic and ecotypic changes [37]. It is also possible that some species will be left in areas climatically unsuitable for them leading finally to their gradual disappearance.

Terrestrial ecosystems are the sources as well as sinks of air pollutants. Their large scale degradation is a combined result of overuse, misuse and under-utilization. The resulting ecological, environmental, economic, and political problems are acute and formidable, and immediately felt at local level. Their long-term effects reach beyond regional national and international levels.

Over the last three decades there has been a dramatic increase in the forest decline [33]. Although it is well established that air pollution, especially O_3 and SO_2 [99], is one of the most important factors behind forest decline, replication of many damage symptoms has not been possible. Suggestions indicating synergistic interactions between air pollutants and several other environmental stresses are

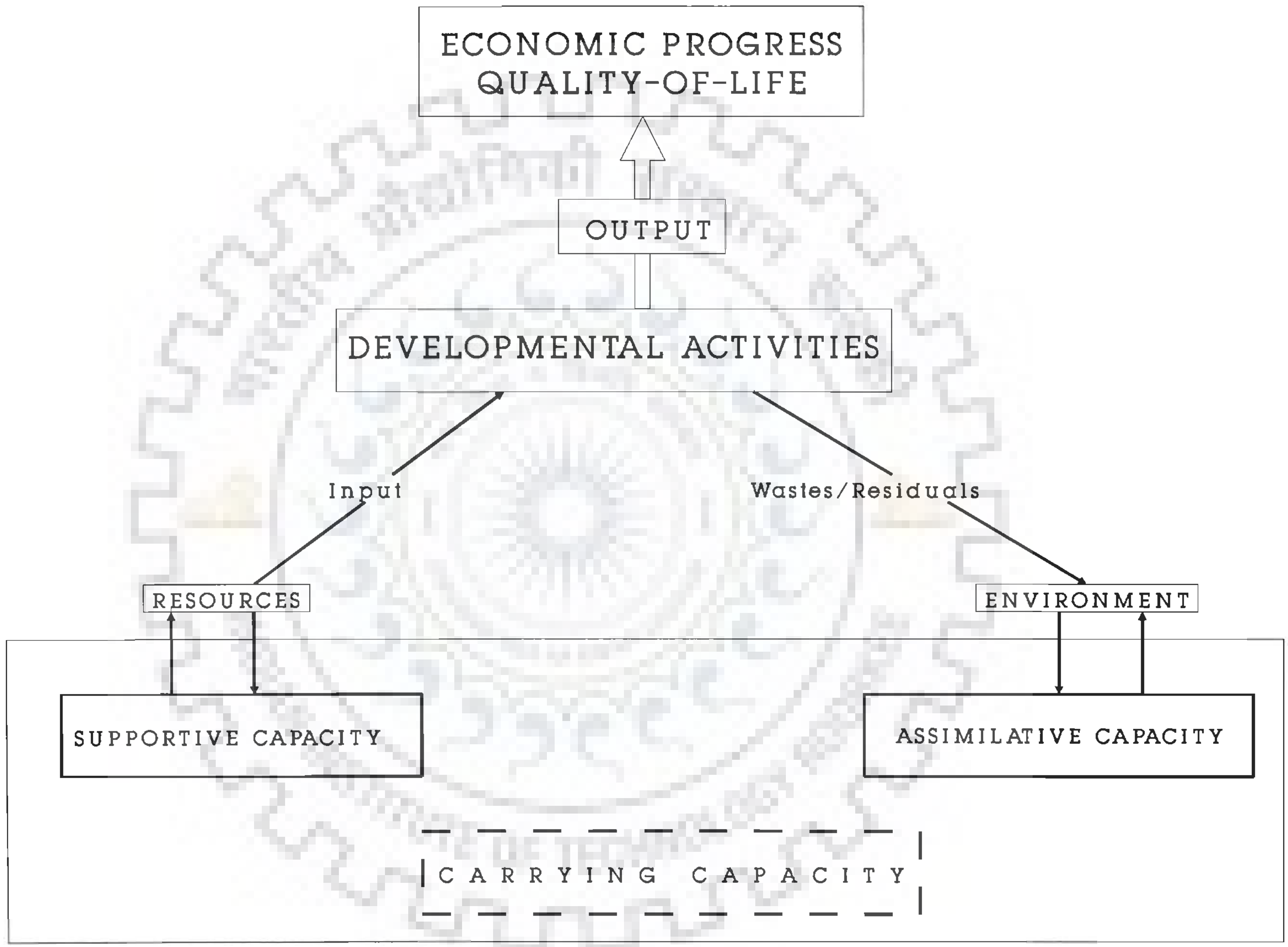


Fig.1.1 Concept of Regional Carrying Capacity (Khanna et al., 1991)

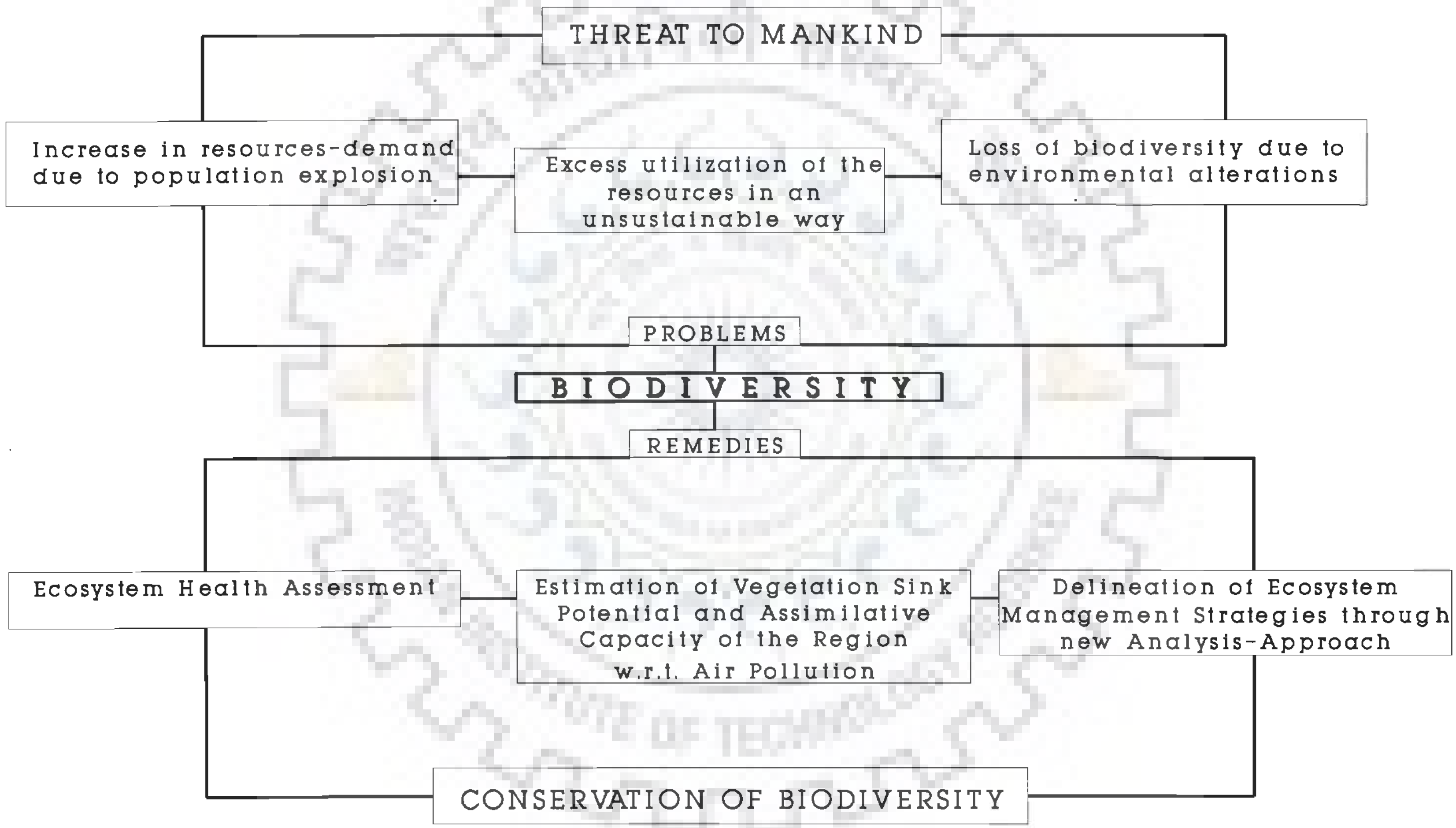

THREAT TO MANKIND
Increase in resources-demand due to population explosion
Excess utilization of the resources in an unsustainable way
Loss of biodiversity due to environmental alterations
PROBLEMS
BIODIVERSITY
REMEDIES
Ecosystem Health Assessment
Estimation of Vegetation Sink Potential and Assimilative Capacity of the Region w.r.t. Air Pollution
Delineation of Ecosystem Management Strategies through new Analysis-Approach
CONSERVATION OF BIODIVERSITY

Figure 1.2

widely gaining ground. Studies on transfer of airborne pollutants to terrestrial surfaces have been mainly concerned with plant receptors that possess photosynthetically active foliage [228]. Vegetation, on the other hand, represents an important sink for air pollution emanating from several anthropogenic and natural sources [127, 133, 215, and 312] and the effects of air pollutants on forests have been the objectives of the studies carried out during past few decades [198].

Quantitative estimation of damage contributions from primary and secondary air pollutants and exposure-risk of vegetative canopy are important issues which need incorporation in environmental management plans with respect to air-pollution-control strategies [228]. An important task under atmosphere-vegetation exchange processes is to develop better methods for quantifying flux contributions and exposure-risks to the terrestrial environment in a given region.

Prediction of species-responses to air pollutants are generally extrapolated from relatively short-term seedling studies, carried out under controlled environmental conditions. In view of the uncertainties associated with inferring the growth responses of mature trees from the seedlings, and the responses of individual tree to different pollutants is highly variable [308], development of region-specific models help in more precise quantification of sink potential with reference to specific bio-environmental parameters and industries of that region. In the present study, a model has been developed and analysed for quantifying the assimilative capacity of the regions under study based on the dominant/representative species of the region, which is a modification of the earlier model on ecosystem-health exposure-risk developed by [228].

1.1 SCOPE OF THE PRESENT STUDY

The present state of environmental decision-making is often based on short-term analysis on an individual component of the system [291], and interpretation made on the basis of some set of general evaluation criteria, which ignore site and pollutant-specificity. The ecosystem health analysis, therefore, requires identification of a systematic set of relationships which provide the basis for ecosystem health assessment. Moreover, the issues of biodiversity have multifarious dimensions which need to be analysed appropriately in the context of several environmental parameters such that meaningful assessment and interpretation of cause-effect relationships emerge facilitating pragmatic planning of terrestrial ecosystems.

The present study aims at development of suitable methodologies for appropriate analysis of the select ecosystems with reference to vegetation and tolerance characteristics, in order to evaluate the impacts, and offer measures for ecosystem conservation and management. Stomatal density has been observed to be different under different environmental conditions [294]. The differential changes in the stomatal densities of various dominant species collected from the various sampled zones, therefore, serve as an appropriate measure for quantifying the species-specific-sink-potential of these zones with respect to gaseous air pollutants. The dominant species of these regions, have been identified on the basis of importance value indices [93 and 264] estimated for various regions falling in the study area.

The model [228], which was developed for quantifying Ecosystem-Health [291] Exposure-Risk (EHER) has been suitably modified for computing assimilative capacities of various zones under study. Differential changes in stomatal densities observed in dominant species (of various forest zones) have been included in the computer-code used for modelling and quantification.

The Assimilative Capacity Model (ACM), combines functionalities which, among other things, are dependent on species-specific stomatal features, photosynthetically active radiation and sulphur dioxide concentrations. The differences in stomatal features observed along the pollution gradient have been suitably incorporated in the computer program developed for quantification purpose.

Region-specific, species-specific studies as the present one, help in establishing a knowledge-base in regard to better air quality management, by making proper choice of the species with high sink potential/assimilative capacity. It can also be used in delineation of green belts based on ecological suitability and appropriateness of the desired species. Hence, it offers effective forest management and eco-restoration strategies.

1.2 PRESENTATION OF THE THESIS

The research reported herein deals with the ecosystem health analysis through development of alternative assessment techniques. The analysis has been carried out for three regions viz. Doon Valley, National Capital Region, and Jamshedpur.

Chapter I as introduction, dwells upon the issues of biodiversity, and the associated problems in ecosystem health analysis. Moreover, it highlights the need for taking such study as the present one in terms of its usefulness in forest management and eco-restoration strategies.

Chapter II presents the state-of-the-art on the research undertaken for the last several years i.e. in regard to the impact of gaseous pollutants on the vegetation.

Chapter III explains and presents the methodologies for the three selected ecosystems.

Chapter IV analyses and discusses the experimental and the modelling results. It also highlights the salient conclusions drawn from the present research work, and suggests its application.

The thesis concludes with a list of references relevant to the research. References are arranged in the alphabatical order with the name(s) of the author(s) and their initials; the title of the paper; name of the journal, book, or report; volume number; page numbers and year of the publication.

CHAPTER II
REVIEW OF LITERATURE

2.0 REVIEW OF LITERATURE

2.1 BIODIVERSITY AND ECOSYSTEM HEALTH ANALYSIS

From Linnaeus to Darwin, to the present era of cladograms and molecular evolution, a central theme of biology has always been the diversity of life [68]. A new urgency now implies the study of the subject for its own sake, just as the importance of all life forms for human welfare becomes most clear, the extinction of wild species and ecosystem is seen to be accelerating through human actions [94, 273 & 362]

Biodiversity refers to the variety and the variability of and within the living world. It is commonly used to describe the number, variety and variability of living organisms [94, 201, 333]. According to the article 2, of the International Convention on Biodiversity formulated during the Earth Summit of United Nations Conference on Environment and Development (UNCED), 1992 [218], . the Biodiversity is defined as, "*the variability among the living organisms from all sources including,* inter alia, *terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are the part; this includes diversity within species, between species and of the ecosystems*".

This very broad usage, embracing many different parameters, is essentially a synonym of 'Life on Earth'. Management requires measurements, and measurement of biodiversity is feasible only when some quantitative values can be ascribed to them and compared. It is, therefore, essential to critically examine different elements of the biodiversity for its management [94].

It has become a widespread practice to define biodiversity in terms of - genes, species, and the ecosystems, corresponding to three fundamental and hierarchically - related levels of biological organisations.

2.1.1 Genetic Diversity

It represents the heritable variation within and between populations of organisms. Ultimately, this resides in variations in the sequence of the four base-pairs which, as components of the nucleic acids, constitute the genetic code.

New genetic variation arises in individuals by genes and the chromosome mutations, and in organisms with sexual reproduction can be spread through the population by recombination. It has been estimated that in humans and fruit flies alike, the number of possible combinations of different forms of each gene sequence exceeds the number of atoms in the universe. Other kinds of genetic diversity can be identified at all levels of organisations, including the amount of DNA per cell, and chromosome structure and number.

This pool of genetic variation present within an inter-breeding population is acted upon by selection. Differential survival results in changes of the frequency of genes within this pool, and this is equivalent to population evolution. The significance of genetic variations is thus clear: (a) it enables both natural evolutionary change and (b) artificial breeding to occur.

Each of the estimated 10^9 different genes distributed across the worlds' biota does not make an identical contribution to overall genetic diversity [94]. In particular, those genes which control fundamental biochemical processes are strongly conserved across different taxa and generally show little variation, although such variation that does exist may exert a strong effect on the viability of the organism; the converse is true of other genes.

2.1.2 Species Diversity

Perhaps, because the living world is most widely considered in terms of species, biodiversity is very commonly used as a synonym of species diversity, in particular of 'Species Richness', which is the number of species in site or habitat. An estimated 1.7 million species have been described to date; the total number of species on the earth, at present vary from 5 million to nearly 100 million [94].

The species level is generally regarded as the most natural one, which considers whole-organism diversity. Species are also the primary focus of evolutionary mechanisms, and the origin and extinction of species are the principal agents in governing biological diversity in most senses in which the latter is defined.

Terrestrial ecosystems have lower taxonomic diversity and higher species diversity as compared to marine habitats, which have higher taxonomic diversity and lower species diversity.

The ecological importance of a species can have a direct effect on the community structure, and thus on overall biological diversity. For. e.g. a species of tropical rain forest tree which supports an endemic invertebrate fauna of a hundred species evidently makes a greater contribution to the maintenance of global biological diversity than a European Alpine Plant which may have no other species wholly dependent on it.

2.1.3 Ecosystem Diversity

The quantitative assessment of diversity at the ecosystem, habitat or community level remains problematic. Whilst it is possible to define what is in principle meant by genetic and species diversity, and to produce various measures thereof, there is no unique definition and classification of ecosystems at the global level, and, it is, thus, difficult in practice to assess ecosystems diversity, eventhough it can be assessed on a local or regional basis, and in terms of vegetation. Ecosystems further differ from genes and species in that they explicitly include abiotic components, being partly determined by edaphic, climatic and other geographical features. Ecosystem diversity is often evaluated through measures of the diversity of the component species. This may involve assessment of the relative abundance of different species as well as consideration of the types of species. In the first instance, the more equally abundant different species are, more diverse that particular area/habitat is considered. In the second instance, weightage is given to the number of species in different sizes, classes, at different trophic levels, or in different taxonomic groups. Thus, a hypothetical ecosystem, which consisted only of several species of plants, would be less diverse than the one with same number of plants alongwith herbivores and predators. Thus, different weightages can be given to these factors, while estimating the diversity of particular areas, there is no single authoritative index for measuring diversity [94].

Management intended to maintain one facet of biodiversity will not necessarily maintain another. For example, a timber extraction programme designated to conserve biodiversity in the sense of site-species-richness, may well reduce the genetic biodiversity, within the tree species harvested. Hence, maintenance of different facets of biodiversity require different management strategies and resources to meet human needs.

2.2 INDICES FOR DETERMINING THE VEGETATION CHARACTERISTICS

Vegetation as any other living beings is adapted to their physical setting viz. climate, soil, etc. They are organised into natural groupings (communities) with mutual dependencies among their members, and they show various levels of responses, in terms of sensitivity/tolerance to their external environment. Retention or removal of natural communities and their replacement with domestic forms have numerous implications that must be considered both ecologically and economically.

Vegetation represents a resultant network of individual plants with different tolerance and physiological characteristics. While the production and the general growth are mainly driven by average climatic conditions (means); survival (presence/absence) of the species is determined mostly by extremes. There are, thus, various issues related to pollution induced changes in the vegetation and its distribution.

Assessment of the biological component of the environment must include; what is present, its value and its response to impacts. Various methods are available to describe the natural community and its components. The assessment should provide a description of the vegetation structure and its representative/dominant species and also an evaluation of the rare and endangered species.

The plants and animals population in an area form recognizable associations called "Natural Communities". These are characterised by a few species called "dominants". Natural communities have structure based on the life forms (eg. a grass) of the species that make them up. A hardwood forest has a given structure by virtue of the tree species and shrubs that compose it. 'Species' is the technical word used to describe all of the members of a population that can reproduce freely with each other, and the 'Species Composition' refers to the kinds of species, making up the community. The variety of species and their relative numbers are referred to as 'species diversity'. A community composed of few species is called 'simple' or one of "low diversity", whereas a 'complex' community is referred to as "high diversity". The greater the biotic diversity, the greater the number and kind of habitats for the inhabitants of the community. Conversely, a reduction in structural or species diversity results in a loss of habitats, with a further loss of species.

There are no universally acceptable procedures for conducting impact assessment studies for the biological environment [264 and 338]. In order to assess the impact on the biological components, it is essential to understand the structural and functional attributes of the vegetational characteristics.

Community structure has been defined as the complex of individuals belonging to different species in a biotic community [222]. The distribution patterns of individuals and species is one of the interesting and unexplained properties of ecological systems [224], because a relatively small percentage of the species may contain a large number of individuals and vice-versa. The distribution of individuals by species has been described by several graphical, empirical, and mathematical expressions, since last several decades [75, 85, 106, 189, 224, 226, 236, 255, 278, 358 and 367]. Mathematical expressions which express the ratio between species and individuals in a biotic community are called diversity indices [222]. Species diversity is a function of the number of species present (species richness or abundance) and the evenness with which the individuals are distributed amongst these species [172, 190, 244, 226, 255, 278 & 306].

Ever since the diversity index alpha (α) and other indices based on the information theory were proposed [75, 176 & 190], community ecologists have put much efforts in the mathematical and statistical refinement of these indices, in devising new indices, in describing and analyzing species diversity [255], in the comparison of diversity for various collections of organisms, and correlation of diversity with other variables [135]. The concept of diversity is particularly important because it is commonly considered as an attribute of a natural or organised community [107] or is related to important ecological processes [135 & 258]. A number of quantitative indices of diversity have been proposed since 1940 [75, 177, 190, 224, 244, 293 & 302] and particular attention has been given to the distribution of number of individuals among the species of a community [106, 107, 158, 172, 178, 179, 190, 203, 224, 251, 252, 253 & 321]. According to Hairston [106], numerical abundance and spatial distribution of all species must be taken into account before understanding the community organisation.

2.2.1 Shannon-Wiener Diversity Index (SWDI)

Although many indices for describing and analysing species diversity have been introduced during the last several decades, no single index has been commonly accepted because of various shortcomings [238, 344 & 352]. Of all the diversity indices devised ~~since~~ in the last several decades, Shannon-Wiener Diversity Index (SWDI) has been widely applied [255 & 352] in measuring diversity at different ecosystem levels, viz. at community level to species level [49 & 159]; at community level to species functional groups [323]; at landscape level to communities [327]; and at landscape level to landscape units [169].

Furthermore, SWDI has some other useful properties viz. it uses data containing both species number and their abundance, the two important parameters of a plant community [255 & 371]. SWDI has been selected for use in the International Co-operative Program on Integrated Monitoring, which involves 21 Countries' national monitoring programs [160]. However, SWDI has some serious shortcomings which do not satisfy many ecologists [62, 135 & 255]. The index is insensitive to the changes in relative abundance within the other trophic levels of the community [62]. For example, in a disturbed stream, benthic community studies revealed that the species richness was rarely affected but evenness was affected by the imposed disturbance [272]. The Diversity Monitoring (DIMO) model introduced by Quinghong [255], takes into account species richness and species evenness alongwith the SWDI, and helps monitoring biodiversity at community level (alpha biodiversity). The model and the index has been tested on vegetation data collected by the Swedish National Environmental Monitoring Program [255].

2.2.2 Importance Value Index

Natural communities are mixtures of species which are unequally successful. In a given community one or a few species, are the dominants, and overshadow all others in their mass and biological activity, and this strongly affects/influence the conditions of environment for other species. But, the community also includes other species which are of intermediate abundance or are rare.

In terrestrial ecosystems/communities, relations of species numbers to the sample area are complex. It is not feasible in most cases to obtain all the species from the community, and therefore, comparing number of species in sample quadrats of equal area is the most convenient way to compare diversities in different communities [355]. It is difficult to apply some of these measures to plant communities, because of the uncertainty associated with the individual of plants in some vegetation [92, 93 & 358]. It also seems inappropriate to compare on the same scale, individuals as disparate in size as trees and herbs. Terrestrial plant species are best ranked by scales of productivity, biomass, or coverage; which are independent of the concept of "individual" and more directly expressive of importance, than are numbers of individuals. The best measure of a species' importance in the community is its productivity [135 & 357], which expresses the species' biological activity and indicates its share of the communitys' environmental resources viz. water and nutrients. The importance of a species has also been defined as the sum over all species, including the species that were removed, and also those species that invaded subsequently, but were not initially present [135]. This index, though important, is time-consuming and has to be done over a time period of a decade or half.

Importance Value Index [93 & 264] takes into account three parameters viz. density, dominance and frequency of a species in a given system. Density measurement reflects the number of individual, dominance denotes the species largest in presence, and the frequency measurements indicate distribution of a particular species amongst sample plots. Hence, while density measurements may over-emphazise the importance of a species that consists of many small individuals; dominance measurements may, on the other hand, over-emphasize the importance of species that consist of a very few large individuals; and frequency measurements may over-emphasize the importance of distribution of individuals belonging to a particular species in the vegetation sampled, regardless of the size or number of individuals. Importance Value Index as a combination of all the above three indices is accordingly, considered an appropriate measure for assessing the overall significance of a species in the sampled system.

2.3. INDICES FOR DETERMINING AIR POLLUTION IMPACT ON VEGETATION

Studies on impact of air pollutants on the vegetation, has been the subject of research since last several decades [2, 29, 31, 113, 198, 215, 309, 312 336, 337, etc.]. Deleterious effects of atmospheric pollution have been studied for many years, since foliar damage and growth retardation is of extreme economic and aesthetic concern. In recent years, there has also been interest in the effect of vegetation on air quality.

Air pollution can influence forest ecosystems in diverse ways and at many levels of biological organisations [198, 309, 311 & 329]. Over the past several years, research efforts have been directed towards identifying, quantifying, and predicting these effects mainly on the crops and to some extent on the forests. Research in the area of air pollutants and its mixtures is rapidly increasing with the realization that particularly sulphur dioxide and ozone, occur as mixtures [139, 181, 204 & 331]. Effects of pollutant mixtures are complex because of species-specificity and region-specificity and the amount of pollutants [22 & 308]. The response may be additive, greater-than additive (Synergistic), or less-than-additive (antagonistic) [129 & 204]. The pollutant responses range from initial cytological reactions to changes in growth of forest trees and the productivity of forest communities, a consequence of complex interactions which may involve multiple species of multiple age classes. According to

Smith [308], the influence of air pollutants on the forest ecosystems can be categorised into three classes. Class I comprises the vegetation and soils of forest ecosystems which presumably function as a very important sink for air contaminants. When exposed to intermediate dosage - class II relationship; the individual tree species or individual members of a given species may be subtly but adversely affected by nutrient stress, reduced photosynthesis or reproductive rate, predisposition to entomological or microbial stress, or direct disease induction. Exposure to high dosage - class III relationship; may induce acute morbidity or mortality of specific trees. The ecosystem impact of these relationships are very complex and highly variable, and could include reduced productivity or biomass, shifts in species composition, increased secondary effects viz. insects outbreaks or disease epidemics, or increased mortality and reduced vigour [308 & 310].

While these numerous ecosystem impacts, resulting from air pollution, have been identified, few have been quantified in the field, especially for class I and II relationships. It is important to assess the impact of air pollution on the vegetative components of forest ecosystems and which can be justified when one considers their role as primary producers, their dominant influence on the forest ecosystem and, moreover, vegetation covers almost 90 percent of the land area [308]. And, it is a widely accepted fact that trees function efficiently in removal of air pollutants from the atmosphere [123 & 306], and ultimately maintain the microclimate of the region. Trees are also more effective filters than agricultural crops [150]. Vegetal sorption has been proposed as a means for reducing concentrations of toxic air pollutants [105, 127, 165, 314, 316 & 351]. Little has been reported, however, about the relative ability of various plants species to serve as air purifiers [329].

Specific and quantified estimates of the extent of the various relationships between air pollutants and forests are very difficult, beacuse the inherent response of the individual tree within a single species and the response of various species to individual pollutant is highly variable [122, 311 & 281], and the response of plants to air contaminants is largely regulated by environmental condition [113, 114, 122 & 281]. Plants are known to represent characteristics of the environments which they occupy differentially [337]. The distribution and relative performance of the vegetation is greatly/ strongly influenced by the temperature, moisture, solar radiation, elevation and soil quality [166 & 308]. Most of the research data regarding air pollution and trees have resulted from studies of small trees under highly controlled and artificial conditions. Little has been documented concerning the reaction of large trees in their natural habitat [308].

The injuries of vegetation, as an air pollution criterion was evaluated by Treshow [336]. Accurate diagnosis and evaluation of air pollutant symptoms and their variations on different plant species under a range of environmental conditions form the basis for evaluation of air pollution levels based on vegetation injury. Measurements of the amount of injury incurred may also provide a sound basis for determining the economic effects of the pollution. Foliar markings on the vegetation have been proven to be highly sensitive indicators for the presence of many air pollutants, and proper evaluation of such effects serve as a valuable and inexpensive tool for delineating air pollution status of a given region. The feasibility of using field vegetation survey and plant damage to estimate presence, distribution and level of pollution on a state-wide basis using native plants as well as the agricultural crops was demonstrated by Middleton [206] and Middleton et al. [207]. The baseline data on the susceptibility of hundreds of crops varieties, widely occurring weed species, to six major air pollutants was established by Benedict [27]. Quantification of effects on the vegetation was reported by Juhren et al. [147], Middleton et al. [207] and Noble and Lylod [221], by using specific sensitive species growing under different environmental conditions. However, standardisation of highly sensitive plant species for bioassay has the disadvantage of providing no information as to the actual effects of air pollutants on more tolerant agricultural or ornamental species in an area [336]. The usefulness of plants to monitor and identify air pollutants was reported as early as in 1960 [58]. Despite the recognised advantages and continued necessity for crop survey, particularly where agronomic species are involved, in recent years, more reliance has been placed on improved instrumentation to detect levels of pollutants. Foliar injury studies are descriptive in nature and time-consuming [2] and moreover foliar levels of pollutants can also be obtained in some cases, but again fails to provide an index of possible effects to vegetation [336]. However, air-pollution-induced effects were evaluated by estimation of visible injury symptoms and supplementing it by biochemical and physiological studies as reported by a number of workers [4, 132, 144, 161, 166, 182, 303, etc.]

Air pollution is an important environmental variable that may adversely affect the plant health and ultimately the health of the ecosystem. The differential effect it has on specific plants has been used as a measure of environmental quality [187]. Plants are seriously affected by pollutants such as SO_2, O_3, CO, CO_2, Oxidants, peroxylacetate nitrate, nitrogen oxides, halogen derivatives, ammonia, ethylene, mercury, fluorides, particulate matters and several heavy metals [28, 30, 145, 149, 157, 275 & 318].

SO_2 is the most widespread phytotoxic air pollutant in India [163 & 256]. Its effects on vegetation have been well reviewed in terms of foliar injury [138] and physiological and biochemical alterations [104 & 185]. Response of plants to SO_2 varies from species to species [72], depending on the genetic make-up and phenological stages of the plants on one hand, and the concentration of pollutants and the prevailing ecological conditions on the other [11]. SO_2, can penetrate plant foliage through stomata and can cause metabolic or physical injury, and inhibition of net photosynthesis in crop species [40 & 326] and forest vegetation [185]. Most studies with SO_2 in India have been focussed on lichens, bryophytes and crops of agricultural importance either as monitors of air pollution or for economic reasons, but little information exists on studies on Indian tree species of economic and ecological relevance [73].

Some plants are so adapted to their surroundings, by developing resistance to the pollution hazards through various mechanisms viz. degradation of the pollutants, development of the resistant enzymes, excretion of the pollutants by anatomical modifications. All these features are under genetic control [31], and the resistant genotype survive [188, 299 & 335].

Thus, plants, grown in a particular environment are products of that environment and can provide important information regarding air pollutant effects [160]. According to Posthumus [250], plants express the biological effects of the dose of the air pollutant, integrating climatological, cultural, biological and other environmental factors into a response. This may allow direct interpretation of the effect of air pollution on the environment, whereas physical monitoring methods provide only a measure of pollution occurrence [160]. On the other hand, bioindicators (plants) can provide a direct method for estimating the risk that pollution presents to the biological components of the affected environment [90]. Plants and their parts have long been used as indicators of environmental pollution/alterations. Atmospheric pollutants bring about various changes in plants and many reports are available [15, 24, 42, 56, 141, 206 & 294]. For this reason, there is a renewed interest in biological methods to determine air pollution effects on vegetation [187]. Some plant species and varieties are so sensitive to pollutants that they can conveniently be employed as biological indicators or monitors, indicative of certain kind of pollutants, this helps in identification and/or selection of the species, thus enabling proper landuse planning of the region [31 & 182]. The susceptibility of plants to air pollutants is species-specific. The identification and categorization of plants into sensitive and tolerant groups is important because the former can serve as indicators and the latter as sinks for the abatement of air pollution in urban and industrial habitats [303]. To screen plants for their sensitivity/tolerance level of air pollutants, proper selection of the representative plant is of vital importance. A large number of plant parameters have been used for this purpose, including visible foliar injury [59], leaf conductance [364], membrane permeability [72], ascorbic acid [151], relative water content, chlorophyll content [26], leaf extract pH [45], and peroxidase activity [67]. By monitoring the growth of the trees against various pollutants and in pollution free area, data can be generated on the relative effectiveness of the various trees in reducing air pollution [305]. Trees that can absorb harmful gases and particles have been planted on large scale around many factories in China to purify the air and reduce environmental pollution [353].

To indicate the susceptibility level of a plant, pollution-induced changes in individual parameters are usually quantified and correlated with the level of plant response (through various indices studies). Several indices have been formulated in order to study the impact of major air pollutants on the vegetation.

2.3.1 Additional Indices

The Air Pollution Tolerance Index (APTI) [303], takes into account the parameters viz., ascorbic acid, chlorophyll, relative water contents, and leaf-extract pH (to pollution tolerance in plants). These parameters are computed together in a formulation in order to obtain an empirical value signifying the air pollution tolerance index (APTI). The Sulphur Dioxide Tolerance Index (STI) [265] uses four parameters as an empirical value signifying the tolerance of a plant to the SO_2 pollutant.

Some researchers have proposed empirical formulae so as to use it as a scale for evaluating atmospheric purity (IAP). The Index by Inserentant and Margot in Ferry et al. [74] can be calculated from phytocoenotic surveys revealing the species diversity in the community.

2.3.2 Sink Potential Index

Vegetation of a region, an assemblage of plant species consisting of a number of communities, represent an important sink of air pollutants. Assimilation in plants occur through adsorption or absorption, mainly through the stomatal pores, hence, it is dependent on the plant-specific and industry-specific parameters.

Plants leaves function as efficient gas exchange systems, having large surface area bearing stomatal pores and an internal structure which allows rapid diffusion of water and soluble gases. Stomata play a central role in regulating photosynthetic rate and the water loss in the plant system [364]. Therefore, they are significantly important in studies related to impact of air pollutants on the vegetation. Moreover, stomatal density has been observed to be different under different environmental conditions [294].

While the damaging effects of air pollution on the foliar characteristics have been known for long time [59 & 127], foliar epidermal features were first quantified through Salisburys' Stomatal Index [369]. Measurement/estimates of the gas exchange capacity of leaves are interlinked with the spatial distribution of various species belonging to the experimental vegetation structure. Hence, incorporation of diversity indices alongwith indices based on stomatal features helps in arriving at more precise and realistic estimates for species specific sink ptential and region specific assimilative capacity. Differences in frequency and size of stomata play an important role in determining the assimilative capacity of a particular vegetation structure of a region.

As a differential change in the normal stomatal density of the dominant plants of the region, Sink Potential Index (SPI) [229], has been construed and quantified as an appropriate measure of site-specific, species-specific sink potential. A higher value of SPI indicates higher sink potential as it takes into consideration the differential count of the stomatal density of a reference species occurring in controlled as well as in polluted zone. Importance Value Index (IVI) [93, 264 & 278] is a reasonable measure which assesses the overall significance of a particular species, and higher the value of IVI of a species, higher is its importance/significance in the ecosystem. Therefore, the product of SPI and IVI would more appropriately quantify the Sink Potential of the species under study.

2.3.3 Assimilative Capacity Index (ACI)

The concept of carrying capacity is not new, and yet, efforts to extend the same to the developmental planning are meagerly reported [156].

Environment, with its biotic and abiotic components, while providing its basic resources that support production-consumption activities, assimilates the residues produced during the course of these activities. The limits to development are therefore, defined by supportive and assimilative capacity of a planning region.

According to Rees [267], carrying capacity for human society can be defined as the maximum rate of resource consumption and waste discharge that can be sustained indefinitely in a defined planning region without progressively impairing bioproductivity and ecological integrity.

Carrying Capacity of the biotic component of an ecosystem can be understood as the maximum resource (and development) demand that can be supported (directly or indirectly) by the surplus output of the biotic components with assimilating the wastes (and effluents) generated by mans' activities, on one hand and without altering the ecological homeostasis, on the other.

Most often, industrial and other developmental activities are synonym to waste generation and effluent discharge in the nature. Biological environment plays a vital role in ecological sanitation by assimilating various pollutants through tissue uptake, accumulation, metabolism and physiological biodegradation. Green plants are the primary producers [308] and the first baseline organisms for the deposition, and assimilation of the pollution.

Thus, Assimilative Capacity, can be defined as the maximum amount of pollution load that can be discharged in the environment without affecting the designated use. The phenomena governing the assimilative capacity include, dilution, dispersion, and removal due to physico-chemical and biological processes [155].

Vegetal absorption/assimilation of the pollutants has been proposed as a means for reducing concentrations of toxic air pollutants [105, 127, 165, 314, 316 & 351].

According to Hanson and Thorne [105], herbaceous species absorb more than woody species and actively growing woody tissues are much more efficient absorbers than dormant tissue. A strong positive correlation exists between absorption rate and transpirational water loss. It is an established fact that trees/plants serve as a sink for gaseous pollutants viz. HF, SO_2 and photochemical smog [38], Hg and Pb in some cases [170], and thus, help in air purification. Plants, may, therefore, serve the purpose of significant global sinks for various pollutants. Number of workers have made comparative studies relating to the accumulation of different pollutants from atmosphere and on the basis of the injuries caused, the plants have been grouped in different categories viz. sensitive, intermediate, resistant [30, 96, 162, 227, 285, 303, 325 & 356]. Singh et al. [303], have categorised the plants (Deciduous, evergreen trees, and shrubs) into sensitive, intermediate, tolerant & more tolerant tree species based on the Air Pollution Tolerance Index (APTI) of plants. The efficacy of trees to absorb harmful gases and particulates varies according to the kind of tree, the region, and the growing conditions [279]. In warm provinces, the trees that absorb SO_2 include rose-apple, almond, mulberry and some other species, whereas in the winter provinces also certain deciduous trees successfully absorb Cl_2, SO_2 or HF [152]. Trees like alpine, fig, beet-wood, oleander and mango are known to absorb Cl_2, whereas tree like *Ficus elastica*, absorb HF. When trees absorb harmful gases, they gradually turn these harmful pollutants into harmless metabolites through photosynthesis and other metabolic activities. The luxuriant leaves and branches serve to restrain the harmful particles in the air from spreading [31].

Although, the method of classifying trees as sensitive, intermediate, and resistant may not be very satisfactory, as different stages in the life-cycle of a plant are likely to differ in their sensitivity, or resistance to pollution [346], nevertheless, such a classification may form a basis for the determination and selection of certain resistant tree species suitable for plantations in order to reduce the impact of air pollution [249 & 263].

The most important method for reducing effects of air pollutants at the growing site can be derived from genetic and environmentally determined resistance characteristics of single plant species and varieties. If these characteristics are to be used optionally in practice for recommendation, cultivation and for diagnostic purposes, effects-criteria and concentrations of the given pollutant must also be considered in the determination and evaluation of the degree of resistance.

Single plant species, varieties, cultivars, and individuals of a species react differently to a given air pollutant. There is no absolute resistance to gaseous air pollutants. The degree of resistance, expressed as species and individual-specific reaction, depends on genetic factors, stage of development and environmental factors, and varies within a broad range.

The relationships between air pollutants and forests have been classified as belonging to one of the three types [307]. The most dramatic and well studied of these interactions, is the visible damage or death of forest trees by air pollution [215]. At lower concentrations of pollutants or more favourable conditions for forests, there may be damage which is less obvious. Decreases in photosynthesis and production are examples of the second type of interactions [30, 127 & 326]. At still lower concentrations, effects of air pollutants may not be damaging and under certain conditions may be beneficial to the growth of the forest trees. The fertilization by SO_2 of plants growing in sulphur deficient soil is a well-documented example of this level of interaction [215]. When air pollutants cause no damage to forests or are beneficial to forest growth, it may be possible to use the forest as a sink, or "living air filter", to remove the pollutants from the air [215]. If forests can remove appreciable amounts of a certain pollutant, it may even be reasonable to use the forests as sinks for that air pollutant, even if growth reduction and other forms of less obvious damage take place, based upon considerations of aesthetics, cost-benefit analysis, or other criterion for optimization of the use of the forest resources [215]. Number of workers have focused their work on utilization of plants as pollutant "filters" [30, 127, 192 & 314]. These studies illustrate the potential for use of 'Forests' as 'Filters' and provide the basic data necessary for an operational evaluation of forests management [215].

The amount of gaseous airborne pollutant that will be absorbed by a forest is related to the atmospheric processes viz. wind, heat flux, temperature, humidity, etc., and the sink-source configuration, because these variables effect the delivery of the pollutant gas to the forest vegetation. The absorption rate is also influenced by the interactions of physical and chemical processes between the gas and the forest sinks [215]. The physical and chemical interactions of SO_2 with the forest vegetation at low concentrations is largely the solution of the gas in the leaf water, followed by the metabolism of the dissolved substance. At high concentrations, 'S' metabolism may not keep up with uptake; however, at these concentrations damage is likely and the use of forests as sink is not attractive. A number of experiments [29, 192 & 279] present an evidence that the uptake of SO_2 by vegetation can be maintained at a steady state for some period of time.

The differences in the rate of absorption of different species to different pollutants can be quantified/measured, on the basis of information on stomatal opening/aperture, under recognised environmental conditions [134 & 329]. The Assimilative Capacity Model (ACM), a modified version of the Ecosystem-Health [291] Exposure-Risk Model, developed by Pandey and Khanna [228] combines the functionalities which, among other things, are dependent on species-specific stomatal features, photosynthetically active radiation and SO_2 Concentrations. The differences in the stomatal density and other stomatal features, observed along the pollution gradient have been suitably incorporated in the computer programme developed for quantification purpose. Dominant species of different study zones, selected on the basis of IVI values have been considered in the model which also incorporates dependence on Stomatal conductance [228] and SO_2 concentration [103].

2.4 SOME SPECIES-SPECIFIC INVESTIGATIONS

Since last decade there has been a great deal of research dedicated to answering pollutant-related questions on trees and forest ecosystems [240]. Much of these works have involved tree seedlings in some type of the exposure chambers. While seedling studies are very useful for understanding physiological processes (viz. photosynthesis, carbon allocation, nutrient uptake, gas exchange and water relations), which, if affected under various air pollutant scenarios, might affect the growth of the plant and ultimately the bioproductivity of the ecosystem. The inferences from the seedling to larger spatial scales of mature trees are not well defined. But, because seedlings represent the future forests, studies on seedlings are useful as a direct contribution to risk assessment for seedling population and for regeneration, and also because they provide criteria to assist policy-makers under conditions of uncertainty. Seedling studies have also been employed to screen species [130], and screen families within a species [199], to study their relative sensitivities to pollutant exposures, to build exposure-response models, or to identify mechanisms of physiological response for subsequent studies of mature tree [240].

2.4.1 Exposure Chamber Studies

Plants (crops, ornamental, native vegetation) are sensitive to many air pollutants. The actual response of plants to an air pollutant is markedly influenced by environmental factors viz. light [66], relative humidity [217], temperature [111] and wind velocity, during the exposure to the pollutant, and the response of the plants to the pollutant gases vary with different concentrations and exposure time, with climatic and soil variable and also with the biological variables [134].

In studying the effects of air pollutants on plants, therefore, it is sometimes desirable to expose the plants to the pollutants under carefully controlled environmental conditions [2, 134 & 240], in order to study the injury-symptoms, mechanism of injury development, establishment of dose-response relationship and actual growth performance of the species under investigation. It is evident that plant responses can vary greatly depending on the species, environment and the method of exposure.

There are number of studies carried out in this field to study the impact of different pollutants on different plants in defined steady-state environmental conditions through controlled environmental chamber studies. Such chambers/fumigating systems are designed to apply precise treatments while reducing or controlling the variation in response due to fluctuations in ambient conditions. They offer advantages of providing reproducible experimental conditions and later on validation of the results on the fields. However, the design of fumigation systems is of great importance, if, realistic assessments of air pollutants effects on the vegetation are to be made [14]. The choice of chamber type usually involve trade-offs in experimental design, precision in the application of treatments and approximating an ambient environment [97].

A number of chambers with controlled environmental conditions viz. Phytotrons [2]; Growth Chambers [115]; Continuously Stirred Tank Reactors (CSTR) [119]; Hemispherical Glasshouses [14]; Open-Top Chamber (OTC) [108 & 186]; Free-Air-CO_2-Enrichment (FACE) Technology [317] have been designed and used since last several years to study the effect of pollutants like SO_2, NO_2, O_3, PAN, and CO_2. Apparatus have also been successfully designed for exposing plants under controlled condition [280], and for comparisons of growth in polluted and clean air [57]. These systems have their own advantages and disadvantages, which must be appreciated by the researcher, and make a proper choice of the system ~~which~~ to meet his objectives [14]. Most of the results obtained out of such studies by different workers have lot of discrepancies [341]. This is because of the facts; like differences in sensitivity at different growing conditions, at different times of the year [341]. There are further complications because of the evolution of SO_2 resistant strains [26] and the impact of other pollutants in the field which is not considered in artificial conditions [13]. Apart from these factors, one important factor is the design of the chambers [341]. It is an established fact that the sensitivity of plants is greatly dependent on the air movement which effects the aerodynamics resistance, the transfer of the pollutant molecules between the atmosphere and the surface of the leaf, and on the sensitivity to a given concentration of SO_2 or any other pollutants in the surrounding air [11, 108, 127 & 343].

Valuable tools to obtain an understanding of the effect of air pollutants on vegetation are physiological-based simulation models [134], which are based on existing crop ecological models, comprising the environmental variables and their effects on photosynthesis and other physiological processes like stomatal opening [134]. In modelling plant responses to air pollutants, a better understanding of the uptake of gases by the leaves is essential. The results thus obtained may also contribute to a better understanding of the (dry) deposition of pollutants gases on the vegetation and the physiological processes induced by the atmospheric pollutants. Such studies need to be carried out in a steady-state environmental conditions.

Stomata forms the chief means of entry of SO_2 to the interior of the leaves, and also play a central role in regulating photosynthetic rate and water loss as they are the primary pathways for water and CO_2. Hence rate of photosynthesis is strongly dependent on the length of the stomata, size and the density.

Stomatal movements are directly and indirectly affected by the light quality and the quantity, water availability (Plant-Soil-Water Status), water vapour pressure deficit (atmospheric humidity), CO_2 concentration, temperature, and wind velocity. Hence, stomatal aperture is a resultant/function of all these factors and the environmental pollutants. The behaviour of the stomata is, thus, likely to be important in determining the sensitivity of the plants to the pollutants [183]. The direct effect of simulated SO_2 (0.25 and 1.0 ppm) in a controlled environment (20^{o}C temperature, 50-55 percent relative humidity, and 12 h photoperiod of 10,000 lux) was studied by Majernik and Mansfield [183], in order to evaluate the effect of pollutants on the degree of stomatal opening in broad beans (*Vicia faba*). There has been general agreement that the effects of SO_2 are more damaging when the stomata are open [147 & 183]. They observed that no major alterations were found in the timing of the diurnal cycle of the opening and the closing of the stomata, but the stimulatory effects of SO_2 on the tendency to open were reversible after 6 hrs and irreversible after 3 days of exposure, and it was concluded that stomates of those varieties of crops with smaller openings such as the wild grasses [183] might be more resistant to SO_2. It is known that increase in the atmospheric CO_2 concentration suppress the stomatal opening in light [110 & 202], and this reaction could be important in determining resistance to pollution [183].

The effects of 1-50 pphm of SO_2 on stomatal diffusive resistance of beans (*Vicia faba*) and maize (*Zea mays*) was studied by Unsworth et al. [342], in a polythene chamber, consisting of fluorescnet tubes with an irradiance (0.3-3μm) of 60 Wm^{-2}, temperature of $20^{o}C \pm 1^{o}C$; and relative humidity of 50-60 percent in the chamber. Their results suggested that the stomata of the leaves remained partially opened in the night and within 2 minutes of transferring of the plants to 10 pphm SO_2, stomatal resistance decreased from 70 s cm^{-1} to about 30 s cm^{-1}.

The stomatal opening of the leaves of many crops in Britain is increased due to the ambient SO_2 levels, which could lead to two undesirable consequences viz. increased transpiration rate leading to early and more severe water stress in spells of dry weather, and therefore, leading to a restriction of the growth, and easier access of toxic gaseous pollutants and fungal infections to mesophyll tissue where metabolic processes may be affected. There is a high potential in determining the magnitudes of stomatal responses under field conditions and the importance of vegetation in removing SO_2 from the atmosphere.

The studies on duckweed (*Lemna minor*) with 0.25 uL/Litre of ozone for 2 hrs in a Plexiglas chamber with controlled environmental conditions was carried out by Cracker [54], and observed a direct relationship between ozone and loss of chlorophyll in the leaves. The effects of ozone have also been demonstrated on protein content in tobacco mitochondria [167], on amino acid metabolism in beans [334], and on RNA content of cytoplasm and chloroplast ribosomes of bean leaves [44] and protein and RNA content of *Lemna minor* [55]. Ozone effects the RNA and the protein content by causing induction of the degradative enzyme systems viz. RNase and Protease, it also slows down the synthesis of RNA and Protein, thus reducing the growth and development.

The effects of SO_2 and NO_2 pollutants upon the ultrastructure of chloroplasts of *Vicia faba* was studied by [354]. Both the pollutants caused disturbance at the subcellular and metabolic levels by causing the swelling of the thylakoids within the chloroplasts.

Index of vegetation injury, after exposure of plants to air pollution, have been used as a method of indicating and evaluating the level of photochemical air pollution in a few widely scattered locations [56, 112, 117 & 221], and used tobacco (*Nicotiana tobacum*) (Bel W3) as an air pollution monitor for the demonstration of oxidant air pollution in Sudbury, Massachusetts [116 , 120 & 121] by growing seeds in carbon-filtered air for 8 weeks and then transplanted to the monitoring sites. It was observed that ozone, the primary oxidant air pollutant in the Northeast [122], formed by a photochemically induced reaction involving automobile exhaust [315] has a direct correlation with tobacco weather fleck injury [180].

The synergistic effects of SO_2 and NO_2 pollutants upon the enzyme activity in pea seedlings (*Pisum sativum*) was studied by Horseman and Wellburn [132], and found that RuDPc and Peroxidase levels ranged from ($P<0.01$) and ($P<0.0001$) at a concentration of 0-2 ppm (SO_2) and 0-0.1 ppm (NO_2) and peroxidase level was $P<0.001$ at a concentration within the ranges of 0-0.2 ppm of SO_2 and 0-1 ppm of NO_2. The increase in Glutamate-Oxaloacetate Transaminase (GOT) and Glutamate-Pyruvate-Transaminase (GPT) activity indicate a disturbance in amino-acid metabolism due to the pollutants.

The effects of SO_2 at concentration of 0.1, 0.15, and 0.25 ppm on (*Pisum sativum*) pea plant for the biochemical and physiological parameters through controlled chamber studies was studied by [144], and concluded that the effects of SO_2 can be detected at physiological and biochemical levels before the onset of macroscopic symptoms. It causes changes in photosynthetic CO_2 fixation, alterations in cell membranes, and malfunctions in enzymatic activity [142, 173, 214, 233, 234 & 372].

Earlier it was thought that exposures to SO_2 concentrations below 0.30 ppm were not detrimental to higher plants [11 & 325]. But, later on, however evidence was accumulated that concentration of SO_2 below 0.15 ppm, can be damaging to plants [10, 11, 25, 34 etc.]. The effect of extreme pollution sensitivity of grasses; viz. *Dactylis glomerata* L. Var., Aberystwyth S37 (Cockfoot); *Lolium multiforum* Lam. Var. Milamo (Italian ryegrass); *Phleum protense* L. Var. Eskimo (Timothy) and *Poa pratensis* L. Var.

Monopoly (Smooth-Stalked Meadowgrass), in a specially designed greenhouse was studied by Ashenden and Mansfield [11], and found that laboratory experiments (with one pollutant) can underestimate the amount of injury resulting in the field, where plants are exposed to several pollutants at the same time. When SO_2 and NO_2 are present in the atmosphere together, their short-term effects on plants have been shown to be atleast additive [40 & 330]. The results of the preliminary studies carried out by Ashenden and Mansfield [11] suggested that the combined effects of SO_2 and NO_2 could cause serious loss in the production of the plants growing in the polluted areas, and when SO_2 interacts with NO_2 there is an increase in the toxicity to the plants.

The synergistic effects of O_3 and SO_2 separately and in mixture on the chlorophyll and carotenoid pigments of *Oryza sativa* was studied by Agrawal et al. [4]. Earlier Menser and Heggestad [204] and Tingey et al. [330] found disruption in various metabolic processes and consequent effect on growth and development of plants. Both O_3 and SO_2 individually are known to reduce the chlorophyll content, an index of photosynthetic potential of the plants [3 & 4] and the carotenoid contents.

The effects of SO_2 on the enzyme activities viz. Ribulose Bisphosphate (RuBP) Carboxylase and Glycollate Oxidase, the important enzymes for photosynthesis, were studied in Jack Pine (*Pinus banksiana*), by Khan and Malhotra [154].

The variation in sensitivity of different species of peas cultivars to SO_2 fumigation was studied by Jager et al. [143], and found that variations in susceptibility correlates with the results of a screening of the plants. Plants with low buffering capacities for H^+ ions and lower superoxide dismutase activities are more sensitive or less tolerant species.

Some work have also been carried out on the Indian species, in order to study the impact of the air pollutants in different regions. Farooq et al. [73], have worked on Chilbil (*Holoptelea integrifolia*), and observed visible injuries and biochemical changes like increase in free sugars and decrease in starch and enhanced acid phosphatase in exposed plants. Effects of 0.5 ppm SO_2 on Jamun (*Syzygium cuminii* skeel.) and its amelioration by ascorbic acid was studied by Vijayan and Bedi [349]. The effect of automobile pollution on the morphology of *Pongamia pinnata* and *Albizzia lebbeck* was studied by Quadir and Iqbal [254]. Amelioration effects of ascorbic acid against the phytotoxicity of SO_2 was tested in Wheat plants by Sharma [299]. The functioning of the detoxificant enzymes like Catalase, Peroxidase, Superoxide Dismutase, in pumpkin grown in the polluted ambient air was studied by Ranieri et al. [260].

It has been suggested that superoxide dismutase in conjunction with peroxidase and catalase may function together as an enzymatic detoxification system [79] which would represent an essential defense against the potential toxicity of active forms of Oxygen. Superoxide Dismutase catalyses the reaction of the superoxide radicals (O_2^-) and hydrogen ions to yield H_2O_2 and O_2, while the peroxidase and catalyses are both involved in the elimination of hydrogen peroxide [210]. The peroxidases are considered to be the most sensitive indicator of the effects of pollutants on plants, even in the absence of visible injury [82]. The differential response of various cultivars or species of plants to air pollutants may depend on the dissimilar activity and/or polymorphism of these protective enzymes [132].

Growth and yield responses of spring wheat (*Triticum aestivum* L. cv. Turbo) to ozone and water stress was studied in Open Top Chamber by Fangmeier et al. [71] and found that ozone enhanced senescence and reduced growth and yield of the wheat plants. Gruters et al. [95], studied the stomatal responses of spring wheat (*T. aestivum* L. cv. Turbo) to ozone and different levels of water supply and found a well-defined boundary line for ozone dose, suggesting that increasing ozone dose causes stomatal closure. But at high ozone doses, co-acting senescence also seems to be responsible for the decrease in stomatal conductance. Experimental and numerical analysis of stomatal absorption of SO_2 and transpiration by pine needles was studied by Vesala et al. [348].

2.4.2 Field Studies

Problems related with atmospheric pollutants are not confined to areas where these compounds are emitted from point or area sources [340]. Effects have been observed far from the source as these pollutants can be transported over long distances [70].

Considerable attention has been paid to the significance of atmospheric pollutants and their reaction products during the last decade, particularly in relation to problems of acid rain and long range transport of air pollutants. Deleterious effects of pollutant deposition on man-made structures [35]; aquatic ecosystem [63 & 153] and forest ecosystem [198] were reported for North Eastern United States and other European Countries. However, considerable amount of work has been done on the phytotoxicity of air pollution in developing countries, and to some extent in India, by several researchers [64, 100, 101, 261 & 303] as well.

The limitation and shortcomings of experimental studies through fumigation or artificial systems have already been reported in the earlier section. Number of studies have been dedicated to the studies on response of plants to different pollutant in the real system through field studies. Though plant-environment interactions for the impacts have been well investigated [17, 51, 95 & 208], very little is known about the effects of various interacting stresses on the plants. In a field the stress effects on plants through a single experimental design can address a variety of practical questions.

Number of research work have been directed towards study of impact of different air pollutants on the different plant parameters viz. biochemical, physiological, phenological etc. Ricks and Williams [276], studied the effects of atmospheric pollution on deciduous woodland species, *Quercus petraea*, with respect to its stomatal diffusion resistance in leaves, and observed that there was a reduction in maximal diffusion resistance measured at night in the polluted site which resulted in enhancement of uptake of gases viz. SO_2 due to reduced stomatal diffusion resistance.

The effect of SO_2 pollution on cellular regulation in pea seedlings with respect to Glutamate Dehydrogenase (GDH) and Glutamic-Oxaloacetic-Transminase (GOT) was studied by Pauhlich [235], and found that GDH, a key enzyme in amino acid metabolism is activated in SO_2 polluted peas [23] whereas, GOT decreases by 25 percent in SO_2 treated peas.

The effect of particulate pollution on the photosynthetic pigments in leaves of *Q. petraea* was studied by Ricks and Williams [276], and found that chlorophyll 'a' is highly degraded as compared to chlorophyll 'b'. The relative carotenoid levels were reverse of that found in leaves undergoing normal senescence at the control site. The impact of acidic precipitation on terrestrial vegetation has been studied by Evans [69].

The effects of air pollution on leaf epidermis and the architecture of *Lycopersicon lycopersicum* (L Karst. Var. angurlata) was studied by Chaudhary et al. [46]. The effect of environmental pollution on leaf surface have been studied by a number of workers [5, 42, 60, 80, 86, 141, 219, 257, 295, 296, 297, 298, 369 & 370].

The effects of cement factory kiln exhaust on the nature of the stomata and the physiology of plants like *Azadirachta indica*, L., *Coccus nucifera* L., *Mangifera indica* L., *Prosopis cineraria* L., Druce and *Tamarindus indica* L. was studied by Swaminathan et al. [320], and observed that kiln exhaust cause retardation in the plant growth, necrosis, injuries on trunks, branches and leaves. Stomatal morphology, index, size, and number, and epidermal cells were not significantly affected by kiln exhaust, but the effects included plugging of stomatal aperture, closure of stomata, deformation of guard cells, and malformation of subsidiary cells. These effects in turn reduced the rate of photosynthesis, carbohydrate content and rate of respiration which led to retardation in growth of the plants.

Four different tree species viz. *Zizyphus mauritiana*, *Syzygium cuminii*, *Azadirachta indica*, and *Mangifera indica* were analysed by Rao and Dubey [262] for stomatal conductances, sulphate and protein contents, Superoxide Dismutase and Peroxidase activities for one year in an ambient environment with So_2 concentrations ranging from 90 to 10 μgm^{-3}. Low stomatal conductances, declined protein content and enhanced sulphate content, SOD, and POD activities were the general responses exhibited by these species. Results indicated that plants under SO_2 stress develop an ability to detoxify the phytotoxicity by undergoing certain biochemical changes. Plants which posses high initial POD activities coupled with greatly enhanced SOD activity (*Z. mauritiana*) or plants which can enhance both POD and SOD activities (*S. cuminii*) were more tolerant/least affected than that of *A. indica* and *M. indica*.

The effect of cement dust pollution on enzymatic activity (acid and alkali phosphatase) in trees like *Albizzia lebbeck*, *Bauhinia variegata*, *Ficus religiosa*, and *Pongamia pinnata* growing around Associated Cement Companies Ltd., Lakheri. was studied by Sharma and Sharma [300]. Observations suggest that the activities of these enzymes increase in response to cement dust pollution.

The stomatal clogging due to automobile, stone and cement particulate matter in the plants like *Polyalthia longifolia* Benth. *Guaicum officinale* L., *Eucalytus spp.*, *Ficus bengalensis* L., *Calotropis procera*, *Ingula grantioides*, *Prosopis glandulosa* and *Solanum surattense* was studied by Abdullah and Iqbal [1]. *P. longifolia* revealed highest percentage of clogged stomata (81.00%) at a highly polluted site by automobile dust (Gurumandir), whereas, leaves of *G. officinale* were less affected. Highest clogging of stomates (24.80%) in leaves of *I. grantioides* was found at National Cement Factory, whereas *P. glandulosa* showed the minimum.

The effects of air pollution on the guard cells of the injury resistant leaf of *Laurus nobilis* L. was studied by

Christodaulakis [47]. The guard cells did not show any signs of injury and it was also found that *L. nobilis* is a plant species with genetically based resistance against air-pollution-induced injuries.

The effects of industrial air pollution on growth parameters of Clover and Egyptian Mallow were examined at three locations in the industrial area of North of Cairo by Ali [6]. 60 percent reduction in chlorophyll and 50 percent reduction in plant growth and dry weights was correlated with the concentration of air pollutants. Egyptian Mallow plants accumulated lead and cadmium, which can pass into the human food chain, and hence, such plants can be used as biomonitors for industrial air pollution.

Effects of lime kilns' air pollution at Jhukehi region, M.P was studied on some plants viz. *Nerium odoratum*, *Cassia semea*, *Eucalyptus hybrid*, *Ailanthus excelsa* and *Dalbergia sissoo* by Gupta and Mishra [101] and on horticultural species viz. *Hibiscus rosachinensis*, *Nerium odoratum*, *N. oleander*, and *Rosa indica* by Gupta and Mishra [102]. Foliar injuries like chlorosis and necrosis and significant reduction in chlorophyll concentration of the leaves and reduction in rate of flowering were some of the prominent observations.

Air pollution affects the vegetation in a multiple ways and the effects being species-specific, region-specific, and pollution-specific, it becomes all the more difficult to quantifiy the impacts on plants due to the environmental alterations. Much of the research work on these aspects has been emphasized either on lower flora, agricultural crops, ornamental trees or tree seedlings in controlled or field conditions, paying very little attention to the forest trees, which contribute significantly in the resource managment and development of the system. It is, therefore, imperative to undertake extensive and interactive region-specific and species-specific studies in an integrated and pragmatic manner, to arrive at a better terrestrial ecosystem management plan of a region. In view of the significant differences observed in terms of structure and functioning of the sampled ecosystems, the need for such region-specific and issue-specific studies, as the present research work, is strongly felt.

2.5 AIMS & OBJECTIVES OF THE PRESENT STUDY

In short, the present study can be grouped under the following main objectives :

* Delineation of the study zones based on secondary data and initial survey
* Selection of study-grids on the basis of bio-environmental and pollutant-specific features
* Collection of baseline information on vegetation characteristics of the regions under study
* Study of spatial distribution of species through quantification of diversity indices

* Quantification of species-specific-sink-potential of the dominant species selected on the basis of diversity indices

* Application of process-based assimilative capacity model, in order to estimate region-specific-assimilative-capacity of the zones under study

* Delineation of Ecosystem-specific Environmental Management Plans

2.5.1 Data Needs

Information from various interacting subsystems have been analysed which include:

- Bio-environmental feature (Geography / meteorology / climate)

- Industrial Emissions/discharges/pollution loads

- Spatial/Temporal Structure of the Ecosystems under study

2.5.2 Work Plan

- Identification of representative species with respect to their importance within the ecosystem

- Study of the temporal and the spatial distribution patterns of these species

- Study of the structural components of the ecosystems through estimating abundance, frequency and density, and quantification through various diversity indices and appropriate modification of the other indices

- Study of their tolerance characteristics with respect to different environmental conditions, and development of assimilative capacity model

- Delineation of a suitable Environmental Management Plan (EMP) for the ecosystems under study, which include Doon Valley Region, National Capital Region and Jamshedpur Region.

CHAPTER III

VEGETATION CHARACTERISTICS OF THE SELECT ECOSYSTEMS

3.0 VEGETATION CHARACTERISTICS OF THE SELECT ECOSYSTEMS

3.1 INTRODUCTION

Study of biological environment is one of the important aspects in Environmental Impact Assessment in view of the need for conservation of environmental quality. Ecological systems consist of varieties of inter-relationships among abiotic and biotic components including dependence, competition and mutualism. Biotic component comprises both plant and animal communities which interact not only within and between themselves but also with the abiotic, physical and chemical components of the environment.

Generally, a (biological) community being dependent on the environmental conditions and resources of its location, may change if there are sufficient changes in the milieu. A number of variables like temperature, humidity, atmospheric conditions, soils, topography, etc., are responsible for maintaining the homeostasis (self regulating stability of a biological system) of the environment, and a change in any one of these variables may lead to stress on the ecosystem. Animal and plant communities in their natural habitat exist in a well organized manner. This natural setting may be disturbed by any external man-induced or nature-induced influences, and then it becomes practically impossible or takes a longer time to come to its original state. A change in the composition of biotic communities is reflected as a change in the distribution pattern, diversity, dominance of the natural species of flora and fauna existing in the ecosystem. These changes over a time span can be quantified and related to the existing environmental factors. The sensitivity of animal and plant species to the changes occurring in their existing ecosystem can, therefore, be used for Environmental Impact Assessment Studies.

Impact on forest ecosystem can be felt through multiple ways and mechanisms spread over different time scales. Effects may be direct or indirect. Vulnerability with respect to several biotic and abiotic stresses may appear as additive, antagonistic or synergistic consequences depending on the kind of pollutants, their concentrations and exposure characteristics.

Acute effects may result because of short term exposure to extremely high concentrations. On the other hand, long term exposure to lower concentrations results in chronic effects. Temperature, humidity, radiation and such other environmental parameters strongly influence plants response to a given pollutant dose. Moreover, plant response is a function of plant species, its growth stage and nutritional status.

The ecosystem behavioural modes of all the species are not the same. Different plants respond differently towards the changing influences of ecological factors e.g. precipitation, relative humidity, availability of light, temperature, topological and other biotic factors, and environmental alterations.

Effects on the ecosystems from air pollutant stress can be determined only after one knows the normal, constantly changing dynamics of the ecosystems, which are characterised by structure and the function. But details of these parameters are not well documented prior to the occurrence of the air pollution. Thus, the baseline data for making a post-pollutant evaluations are often lacking [339].

The analysis/assessment of the ecosystems can take on a number of forms, follow a number of paths, depending largely on the availability of the existing information about the ecosystem, ecosystem type, and the availability of an organised approach [292]. One approach follows a stepwise process of objective selection, and identification of data needs, followed by an iterative process that modifies objectives to meet the realistic data collection opportunities [289], and this is particularly important when the ultimate objective is ecosystem preservation and management.

Although, ecosystem analysis has advanced during the past decade as a result of improved understanding of how ecosystems are structured and how they function, the understanding of how ecosystem effects can be tested or predicted is limited, because of the fact that ecosystems respond to physical or chemical stress in a number of ways, and most of these responses are the result of changes in a large number of ecosystem components. Identifying and quantifying factors that define the conditions or state of an ecosystem in terms of health criteria can thus be valuable [292].

An ecosystem diagnosis/analysis begins with an initial characterisation of the ecosystem and identification of the factors, which may affect its state or condition. Generally, in the diagnostic/analytical approach, one should select suitable ecosystem traits, perform initial analysis, and compare these results with the data from a healthy ecosystem. The diagnostic information would then serve as a basis for selecting specific test systems for use in a detailed analysis in order to support an ecosystem-based assessment.

Five characteristics of ecosystem, critical for its maintenance, and which might get altered due to exposures to the pollutants, have been identified by Herricks and Schaeffer [125 & 126] and Schaeffer et al. [290] :

- Vegetation Studies

  (A) Plant Ecology

  (Species Composition, aboveground productivity, Stomatal Resistance)

  (B) Plant Chemistry (Major Cations, N, P, Zn)

  (C) Decomposition and Mineralisation of Vegetation

- Soil Chemistry (Bulk Density, Organic Matter, Total N, CEC, Cations, Extractable and Organic Phosphorous, Extractable NO_3/NH_3, Heavy Metals)

- Consumers (Soil, and Canopy Arthropods, Earthworms)

- Controlled Exposure Studies

- Toxicity (Soil and Plant surfaces)

Vegetation analysis is generally done taking into account the following:

- An understanding of the plant communities in the study area through diversity indices

- Spatial distributions of plants in the ecosystem, and

- Responses of plants communities to different environmental stresses

Ecological studies are carried out in two ways :

Autecology - It is concerned with the study of individuals or population of a particular species within its environmental complex

Synecology - It is the study of interactions of communities with their environment, it is also known as phyto-sociological studies.

3.2 OBJECTIVES AND METHODOLOGY

The objectives of the present study include :

* Delineation of study zones based on secondary data and initial (literature) survey

* Selection of study-grids on the basis of bio-environmental and pollutant-specific features

* Collection of base-line information on vegetation characteristics of the regions under study

* Study of spatial distribution of species through quantification of diversity indices

* Quantification of species-specific-sink-potential of the dominant species selected on the basis of diversity indices.

* Application of process-based assimilative capacity model, in order to estimate region-specific-assimilative-capacity of the zones under study

* Delineation of ecosystem-specific Environmental Management Plans

METHODOLOGY

Since plants occur in recognizable associations and interact with one another, special quantitative methods were used in assessing vegetation parameters. Besides considering the species composition, these methods provide information on the role and relative importance of individual plant species (such as dominance or rarity), relationships among plants, species distribution and spacing, number of individuals of each species, and structure of the plant community.

Collection of data for ecological characterisation of the terrestrial ecosystem warrants detailed survey of the study area. A preliminary or reconnaissance survey preceded intensive work in the study area. During the preliminary survey following attributes were observed :

* Distribution of different communities and other ecological groups

* Different climatic, edaphic and topographic data

* Biotic interferences

* Decision about the sampling techniques depending upon the vegetation stand

* Selection of critical areas (grid/zone) for more detailed structural and functional studies

The methodology applied to the different ecosystems under study was based on the type and accessibility of the forest regions, as also on the study region, so as to include maximum number of plant species. Studies on impact of air pollution on the vegetative features of biotic component is justified when one considers their crucial role as primary producers and cover almost 90 percent of the land. They also play a pivotal role in maintaining the microclimate of the region and in resource management.

The results obtained from these studies have been used for depicting the general characteristics in terms of species richness, and composition of forest in the study area. Selection of the sampling stations was done so as to cover and identify all important plant species occurring in different forest divisions and within the city for all the three regions under study.

The study area of Doon Valley Region comprises three forests divisions viz. Dehradun, Siwalik, and Mussoorie, and the City Region **(Figure 3.1)**. Sampling stations of Doon Valley region includes all the ranges falling in the different forests divisions and the city zones.

The study area of Jamshedpur region includes all the major industries of Tata Group. In order to cover the entire zone of the study area and to understand the impacts due to various environmental factors on the vegetation, the area was divided into three main grids with radii of 5,10, and 15 kms, considering TISCO as the centre **(Figure 3.2)**. Sampling has been done on randomly selected 30m x 30m quadrats [93 & 264] and different plant species at each quadrat were identified.

The National Capital Region comprises Union Territory viz. Delhi, and parts of Rajasthan, Haryana, and Uttar Pradesh. The sampling station mainly covers the Delhi City region, which is divided into three grids of radii of 5,10, 15 kms taking Tagore Garden as the centre of the study area **(Figure 3.3)**. The sampling points which were chosen for the vegetation survey were mainly the roadside avenues which were exposed to heavy vehicular pollution and parks and gardens, which were relatively pollution-free.

In order to characterise vegetation in the study area, the data has been collected and analysed for studying those properties of vegetation which give the species composition

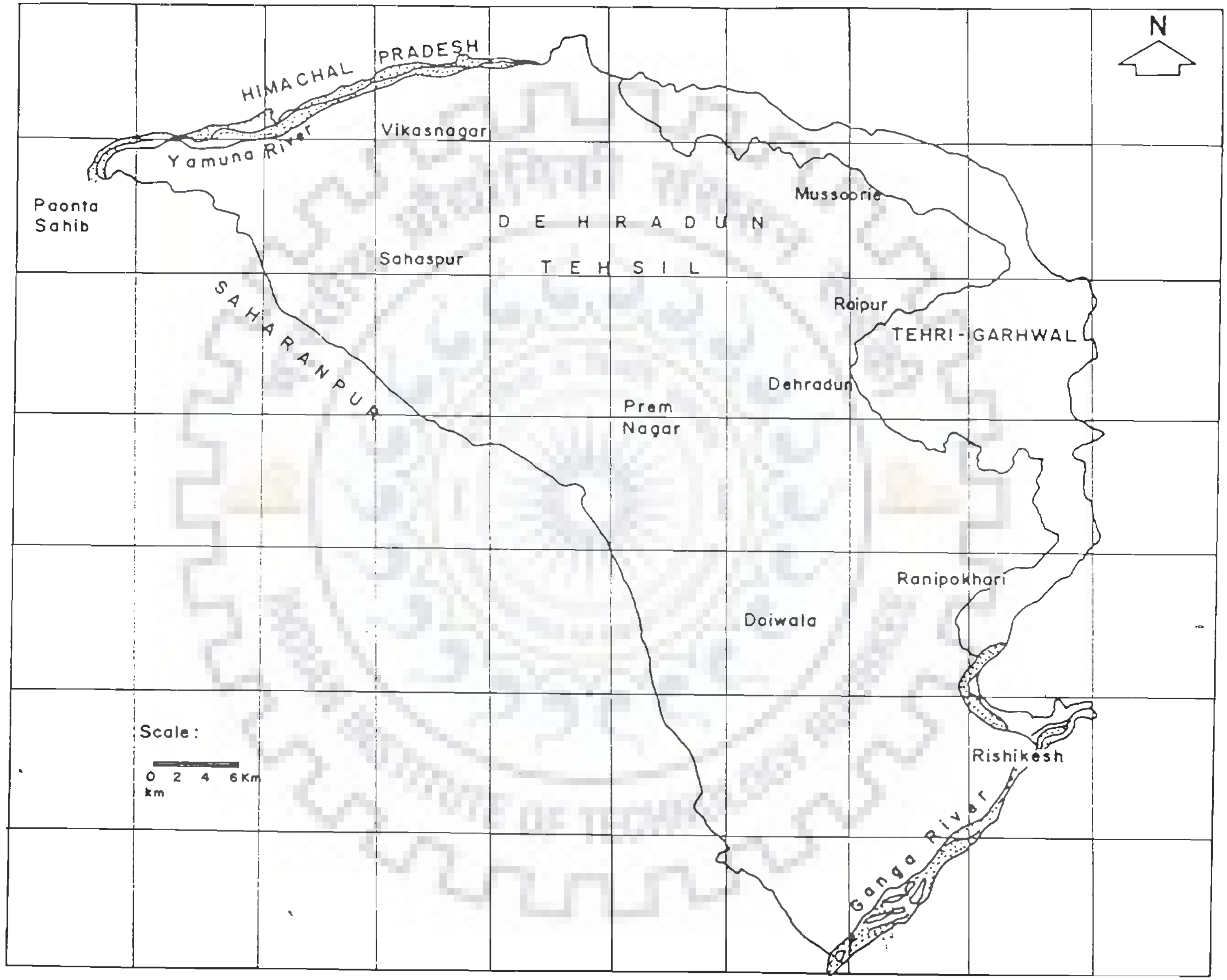


FIG. 3·1 : DOON VALLEY STUDY AREA MAP

FIG.3·2: FOREST STUDY AREA OF JAMSHEDPUR REGION

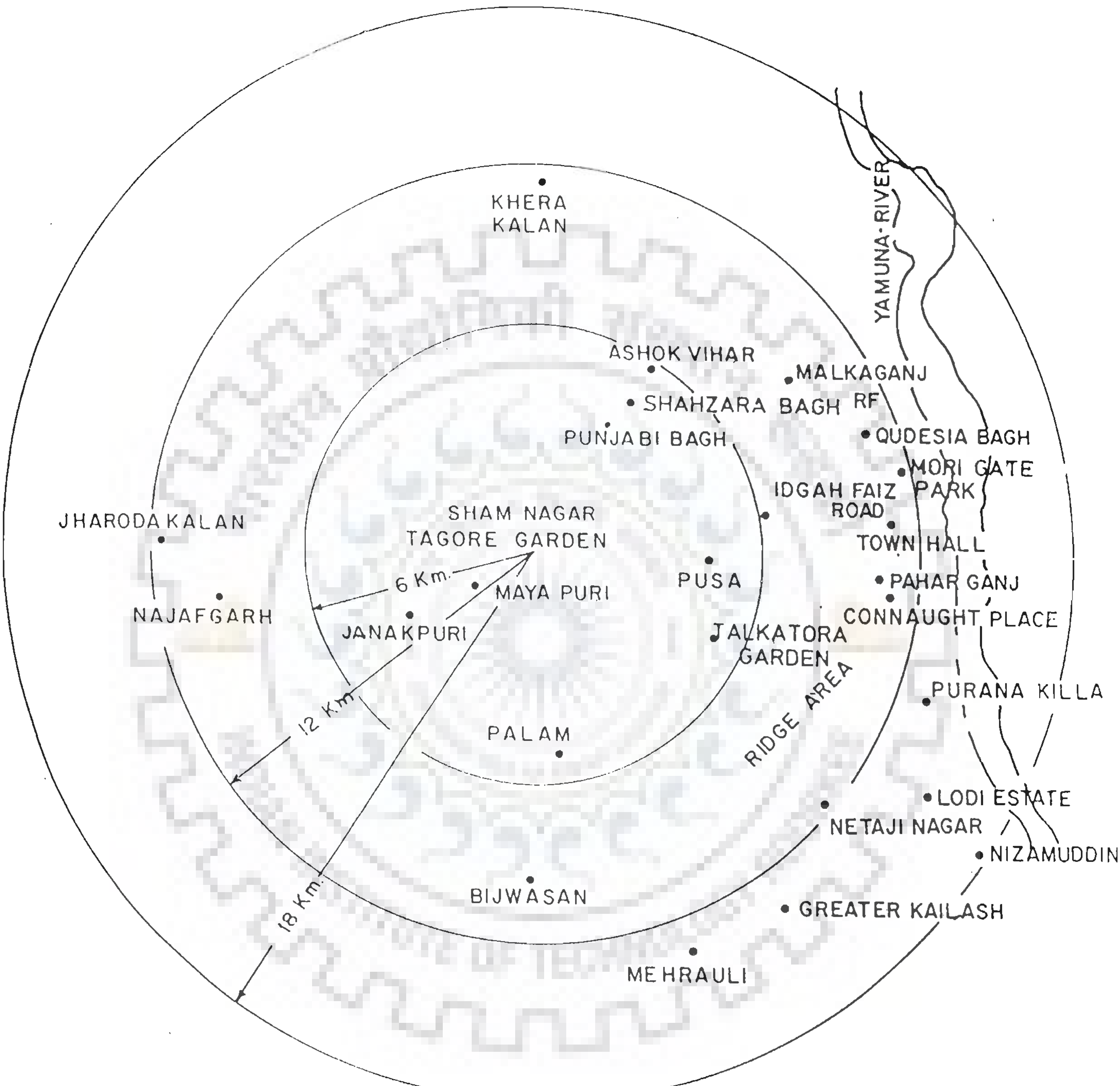


FIG. 3·3 : STUDY ZONES (DELHI CITY)

and its structural and functional attributes.

In all about 25 forest stands were chosen from all the forests falling under the study area at Doon Valley and Jamshedpur Region. In each forest, the stands with the greatest number of species were selected, and in each stand, minimum of 25 plots were randomly selected so as to collect data on the basal area, density, dominance, and frequency, in order to determine the indices like Importance Value Index (IVI), Shannon Weiner Diversity Index (SWDI), Equitability Index (EI), Similarity Index (SI), Sink Potential Index (SPI), and Assimilative Capacity Index (ACI). Calculations were done on an IBM 386/Workstation HP-Apollo 9000/730, using computer codes in 'C' language.

Leaf samples of all dominant/representative species were collected in such a way as to allow spatial comparison of the Indices in ~~all~~ whole of the study region. The observations were mainly confined to the most important tree species in those zones. Leaves were washed and cleaned dry, and subsequently, sections were extracted for making slides for the microscopic observations [24 & 294] of the stomatal features viz. density, major and the minor axis, and the effective opening.

Estimation of Quantitative Structures of Plant Community

In a plant community, different species are represented by a few or a large number of individuals aggregating in different vegetational units. It is essential to know the quantitative structure of the community specially the numerical distribution and the space occupied by the individuals of different species, in order to assess the impacts of any environmental change of the given ecosystem. The vegetational units studied are detailed below:

Population Density

The density of a species gives an idea about the number of individuals present in an unit area. The density of a species refers to the adequacy of its different requirements and the availability of space. Density is determined by the following formula :

$$\text{Density (D)} = \frac{\text{No. of individuals of species in All the Sample Plots}}{\text{Total No. of Plots Sampled}}$$

For phytosociological studies it is generally expressed as -

$$\text{Relative Density (R.D)} = \frac{\text{No. of Individuals of a Species}}{\text{No. of Individuals of all the Species}} \times 100$$

Cover and Abundance

The area of the land or ground covered by the aerial/shoot system of the plant is referred to as 'cover'. In a multistoreyed community such a study is conducted for every stratum of vegetation separately as there is overlapping of plants. For mature trees, cover is generally studied as basal area which refers to the area of ground actually covered by the stem/trunk. The mean basal area of trees is calculated by the following formula :

$$\text{Basal area per tree (or mean basal area)} = \frac{\text{Total Basal Area}}{\text{Number of Trees}}$$

The basal area can be only a fraction of the total land area of the community but canopy of a tree species may cover (canopy cover) several times more than the land area. The basal coverage or the area covered by a species is used to express its dominance. Higher the coverage, greater is the dominance.

$$\text{Dominance} = \frac{\text{Total Basla Area of the Species}}{\text{Total No. of Plots Sampled}}$$

$$\text{Relative Dominance} = \frac{\text{Total Basal Area of the Species}}{\text{Total Basal Area of all the Species}} \times 100$$

Frequency

Individuals of a species are not evenly distributed within the community. While, individuals of some species are found to grow in clumps or in continuous mats, individuals of other species may grow widely distributed. The distribution pattern of the individuals of different species indicates their adaptability to the local environment and also their success in reproduction. Thus, the frequency of a species is expressed as the percentage occurrence of its individuals in a number of observations and is determined by following formula :

$$\text{Frequency} = \frac{\text{No. of Sample Plots in which the Species Occurs}}{\text{Total No. of Plots Sampled}}$$

$$\text{Relative Frequency} = \frac{\text{No. of Occurrence of Sps.}}{\text{No. of Occurrences of all Sps.}} \times 100$$

There are generally five frequency classes to express the distribution pattern of the vegetation in a given system:

Class	Frequency Range	Presence
1	1-20%	Rare (r)
2	21-40%	Seldom Present (s)
3	41-60%	Often Present (o)
4	61-80%	Mostly Present (m)
5	81-100%	Constantly Present (c)

Importance Value Index (IVI)

Importance Value Index is a reasonable measure which assesses the overall significance of a particular species in a forest stand as it takes into account density, dominance and frequency of the species in the vegetation. Stratified random plotless sampling method was adopted, which assumes that the individuals are randomly distributed. Information on girth perimeter, tree height, canopy cover of trees, were collected to compute different properties viz. Density, Dominance, Frequency, and IVI values of the species.

The density measurements reflect as to how many individuals were present, the dominance measurements denote which species is largest in terms of its presence, and the frequency measurements indicate how widely distributed a species is among sample plots. Hence, density measurements may over-emphasize the importance of a species that consists of many small individuals; dominance measurements may over-emphasize a species that consists of a few very large individuals and frequency measurements may over-emphasize the importance of distribution of individuals belonging to a particular species in the vegetation sampled, regardless of the size or number of those individuals. Therefore, importance value is an optimum measure for assessing the overall significance of a species since it takes into account several properties of the species in the system.

The overall value of the importance of a species with respect to its heterogeneous community can be obtained by adding the values of relative density (RD), relative dominance (RDM) and relative frequency (RF). The score out of total value of 300 is called Importance Value Index (IVI) of the species, and can be converted to 100 point scale by the following formula [93 & 164] :

$$\text{Importance Value Index} = \frac{\text{R. Density} + \text{R. Dominance} + \text{R. Frequency}}{3}$$

<u>Shannon Weiner Diversity Index (SWDI)</u>

The number of species and the individuals in each species comprise a measure of community richness called "species diversity". Species richness and species diversity are the best measures of community structure. They are sensitive to environmental stresses which affect the community. Diversity Index Value is derived by combining these parameters which help in the assessment of the community and in making a comparison between two different communities (Quinghong, 1995).

$$H = -\sum_{j=1}^{s} (n_i/n) \log_2 (n_i/n)$$

Where,

H = Species Diversity

n_i = No. of individuals of each species in sample

n = Total number of individuals of all species in the sample

Pielou Index or Equitability Index

Evenness Index, a popular index, given by Pielou, means the equal apportionment of individuals among the species. Three hypothetical communities containing 5 species and 100 individuals may have same diversity index but widely different evenness index depending on the apportionment of the 100 individuals among 5 species as given below:

SPECIES DIVERSITY FOR THREE HYPOTHETICAL COMMUNITIES

Commu-nities	Species n_1	n_2	n_3	n_4	n_5	Total No. of Indiv-iduals	Diversity Index	Shannon-Weiner Diversity Index	Evenness Index
A	20	20	20	20	20	100	0.5	2.32	3.30
B	50	35	7	5	3	100	0.5	1.67	2.39
C	96	1	1	1	1	100	0.5	0.32	0.46

Evenness is maximum when all species contain equal individuals as in case of community A in the above table while it is minimum when S-1 species contain only one individual each and rest all individuals belong to only one species as in the case of community C. A collection is said to have high diversity if it has many species and their abundances are fairly even. Conversely, diversity is low when the species are few and their abundances are uneven. Since diversity depends on two independent properties of a collection, ambiguity is inevitable; thus a collection with a few species and high evenness could have same diversity as another collection with many species and low evenness. Evenness/Equitability Index is given by the following formula :

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

Where,

E = Equitability Index (Range 0-1)

H = Observed Species Diversity

H_{max} = Maximum Species Diversity = $\log_2 S$

S = Number of Species in the community

Similarity Index

Similarity Index, also referred to as Coefficient of Similarity [93], is an ordination technique used to compare the similarity (or dissimilarity) between the two different forest ecosystems and is based on 0-1 scale where '1' indicates 100% similarity and '0' indicates 100%

dissimilarity and is given by the followiung formula:

$$S = \frac{2C}{A+B}$$

Where,

S = Similarity Index

A = No. of Species in forest A

B = No. of Species in forest B

C = No. of Species Common to both the forests

Sink Potential Index (SPI)

Possibility of using the cuticular features as indicators of environmental pollution has received little attention, even though foliar injuries have long been used as indicators of stress environment. While the damaging effect of air pollution on the foliar characteristics has been known for a long time, experimental influences on foliar epidermal features was quantified for the first time through a Stomatal Index known as Salisburys' Index, given by the formula:

$$\text{Stomatal Index } I_{(s)} = [S/(S+e)]*100$$

Where,

S = Stomatal Density

e = Epidermal Cells

While this index helps in observing the cuticular variations viz. size, shape, and frequency, it fails to give an account of pollution-related sink-potential of the vegetation system. As plant serve as a sink for the atmospheric pollution, the index evolved in the present study, and termed as Sink Potential Index, is an appropriate measure for quantifying the species-specific-sink-potential A higher value of SPI indicates higher sink-potential as it takes into consideration the differential count of the stomatal density of a reference species occurring in controlled as well as in the polluted zone, and is given by the following formula [229] :

$$SPI = [(n_2-n_1)/n_2]*S.D._{(N)}$$

Where,

n_2-n_1 = Difference in Stomatal Density for a reference species as found in controlled and the polluted zones

n_2 = Stomatal Density of the reference species in control environment

$S.D._{(N)}$ = Stomatal Density of the species under study

<u>Assimilative Capacity Index (ACI)</u>

Stomatal density has been observed to be different under different environmental conditions [294]. The differential changes in the stomatal densities of various dominant species collected from the various sampled zones, therefore, serve as an appropriate measure for quantifying region-specific assimilative capacity of these zones with respect to gaseous air pollutants. The dominant species of these regions, have been identified on the basis of importance value indices [93 & 264] estimated for various regions falling in the study area.

The model [228], which was developed for quantifying ecosystem-health (Schaeffer et al. 1988) exposure-risk (EHER) has been suitably modified for computing assimilative capacities of various forest zones. Differential changes in stomatal densities observed in dominant species (of various forest zones) have been included in the computer-code used for quantification purpose. Assimilative Capacity (AC) values for different study zones have been computed and compared for the identification of significant zones/hotspots, and subsequent delineation of appropriate management strategies.

The assimilative capacity model (ACM), combines functionalities which, among other things, are dependent on species-specific stomatal features, photosynthetically active radiation and sulphur dioxide concentrations. The differences in stomatal features observed along the pollution gradient have been suitably incorporated in the computer program. Dominant species for different zones have been selected on the basis of IVI values. Finally, the expression for Assimilative Capacity Model (ACM) which incorporates dependence on stomatal conductance and SO_2 concentration [103 & 228] assumes the following form :

$$ACM = [(a*b)*D*N/\{L(1.0+K/PAR)*(O_3)\}]*(IVI)$$

Where,

O_3 = Ozone concentration, predicted as a function of sulphur dioxide concentration

D = Diffusion Coefficient

N = Stomatal Density of the species under study (representing the ecosystem under study)

L = Effective Stomatal Opening

K = Curvature Constant for radiation dependency

PAR = Photosynthetically Active Radiation

IVI = Importance Value Index given by the equation (1)

The details of the different indices and the experimental followed used in the present study are presented in **Table 3.1 and Figure 3.4** respectively.

3.3 CASE STUDIES

3.3.1 Case Study I : Doon Valley Region

Doon Valley is a distinct and unique ecosystem in the foot hills of the Himalayas. The geological fragility and hydrological sensitivity of the Himalayan mountain system contribute to the ecological sensitivity of the Doon Valley ecosystem. The deterioration of this fragile ecosystem is aggravated by poverty-driven ecological degradation, in which resident population as well as migrants overexploit the forest, mineral and land resources to meet their short-

TABLE 3.1

INDICES USED IN THE PRESENT STUDY

Index	Formula	References
Importance Value Index	R.D.+R.Dom+R.F/3	Greig-Smith, 1983 Rau & Wooten, 1980 Risser & Rice, 1971
Shannon Weiner Diversity Index	$-\sum_{j=1}^{s} (n_i/N) \log (n_i/N)$	Quinghong, 1995 Odum, 1983 Risser & Rice, 1971
Equitability Index	H/H_{max}	Risser & Rice, 1971 Odum, 1983
Similarity Index	2C/A+B	Greig-Smith, 1983 Rau & Wooten, 1980 Pielou, 1975 Odum, 1983
Sink Potential Index	$[n_2-n_1/n_2]*[S.D.(N)]$	Pandey et al., 1993
Assimilative Capacity Index	$[a*b*D*N/\{L(1.0+K/PAR)*(O_3)\}]*(IVI)$	Pandey et al., 1995 (Communicated)

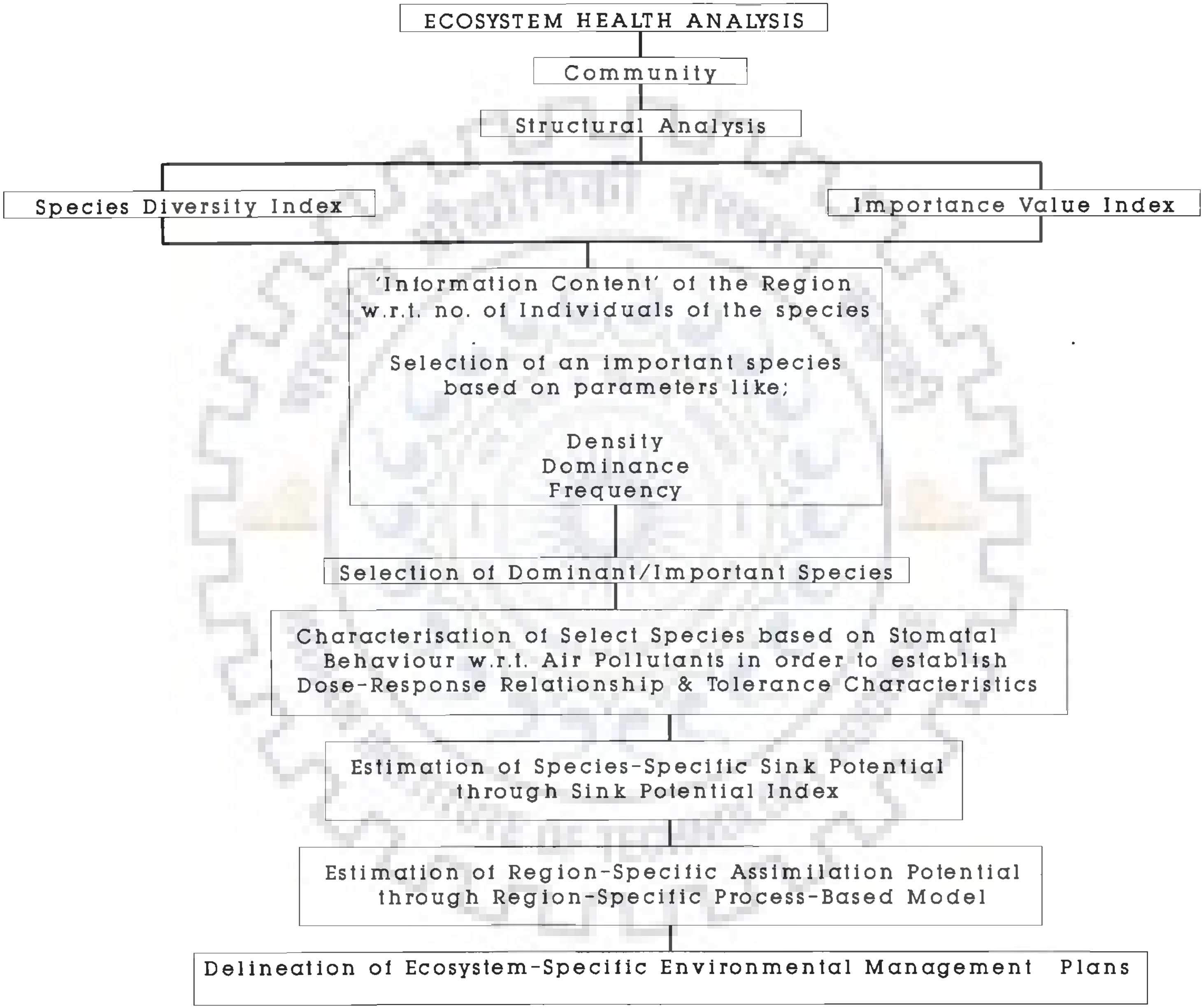

ECOSYSTEM HEALTH ANALYSIS
Community
Structural Analysis
Species Diversity Index
Importance Value Index
'Information Content' of the Region w.r.t. no. of Individuals of the species
Selection of an important species based on parameters like;
Density
Dominance
Frequency
Selection of Dominant/Important Species
Characterisation of Select Species based on Stomatal Behaviour w.r.t. Air Pollutants in order to establish Dose-Response Relationship & Tolerance Characteristics
Estimation of Species-Specific Sink Potential through Sink Potential Index
Estimation of Region-Specific Assimilation Potential through Region-Specific Process-Based Model
Delineation of Ecosystem-Specific Environmental Management Plans

Figure : 3.4

term needs at the cost of the long-term equilibrium between environmental and societal systems.

The boundaries of the valley are demarcated based on the watershed and mountain ridges. The valley is further subdivided into five geographical subregions, viz. Vikasnagar, Sahaspur, Raipur, Doiwala and Tehri-Garhwal.

Doon Valley **(Figure 3.1)** lies to the south of the main Himalayan boundary fault and is part of the sub-Himalayan belt. It is a longitudinal valley lying between longitudes of 77°35′ and 78°24′, and latitudes of 30°5′ and 30°35′, stretching in NW-SE direction. It is about 100 km in length and 25 km in breadth and approximately covers an area of 2250 sq.km. The elevation in the valley, varies between 300-1000 m and goes upto 2500 m at Mussoorie, Dhanaulti and Bhadraj. The maximum height of Siwalik range is 1400 m. Climate varies from sub-tropical to sub-temperate, the minimum temperature in winter frequently touching zero. The average rainfall of the region is 36.86 mm, relative humidity and optimum temperature being 76.08% and 19.97°C respectively. Well known towns of the Valley, where industrial activities are highly intense, are Dehradun, Hardwar, Rishikesh, Raiwala, Doiwala, Dakpathar and Sahaspur with Mussoorie and Dhanaulti being famous hill resorts.

Forests of the Valley are reported to have decreased by 25 percent over the last two decades [136] mainly due to limestone quarrying. Another important pressure on these forests comes from increasing population of the people and the livestock in the Valley, with subsequent increase in fuelwood demand, commercial logging, road construction and cultivation on steep slopes.

Forests of the Region

The Doon Valley has been known for its excellent Sal (*Shorea robusta*) forests. The forest cover on the north-eastern slopes of the Siwalik has 56% of its land covered with Sal forests of high density (i.e., average crown cover of over 60%). In contrast the valley proper has less than 50% of its area under forest, and only **one third** of the region is under dense Sal. The forest cover in the third region, i.e. the south-western slopes of the Himalayas, is in the most pronounced state of degradation. Though technically 60% of the land has forest cover, only about 10% has dense forests. There are virtually no Sal forests in this region and the dense cover consists of chir pine (*Pinus roxburghii*) and miscellaneous deciduous species. Almost 12% of the area is covered with scrub vegetation.

Accordingly, forest of the Doon Valley can be classified as:

Vegetation Type	Total Area in sq.km.	Percent
Sal (*Shorea robusta*)	655	63.90
Low-level miscellaneous	231	22.54
Chir-Pine	2	0.20
Unworkable Blanks	137	13.36
Total	1025	100.00

On the basis of formal forest classification, the valley proper and the north-eastern slopes of the Siwalik largely fall under "northern tropical moist deciduous" class of forests with Sal as its predominant species. Forests growing on the slopes of the outer Himalayan range, reaching upto the Mussoorie ridge, are generally sparse and of poor quality. They are classified as "Himalayan subtropical scrub" within "Himalayan sub-tropical pine" class of forests. The dominant species among whatever overwood is left are chir pine (*Pinus roxburghii*) and oak (*Quercus incana*), deodar (*Cedrus deodara*). Shrubs cover large tracts of degraded land.

The most dominant species amongst the shrubs are Dhaula (*Woodfordia latifolia*), and Siaru (*Debregeasia hypoleuca*). Kala Bansa (*Colebrookia oppositifolia*), and *Lantana camera* are major herb species found in the region.

The major forest types of the region according to Champion & Seth (1968) are :

- Moist Siwalik Sal Forest
- Moist Bhabhar Doon Sal Forest
- Dry Siwalik Sal Forest
- Khair-Sisoo Forest

Moist Siwalik Sal Forest is grouped under Tropical Moist Deciduous Forest. Sal (*Shorea robusta*) being the dominant species other major associates are *Anogeissus latifolia*, *Terminalia tomentosa*, *Dendrocalamus strictus*, *Colebrookia oppositifolia*.

Moist Bhabhar Doon Sal Forest is also grouped under Trpoical Moist Decisuous Forest. Sal (*Shorea robusta*) being the dominant species other major associates are *Lagerstroemia parviflora*, *Terminalia tomentosa*, *Mallotus philippinensis*, and *Ehretia laevis*.

Dry Siwalik Sal Forest is gropued under Tropical Dry Deciduous Forest. Sal (*Shorea robusta*) again being the major speices other major associates are *Anogeissus latifolia*, *Buchanania lanzan*, and *Woodfordia fruticosa*.

Khair-Sissoo Forest is also grouped under Tropical Dr Deciduous. The primary seral type of dry deciduous forests is Khair-Sissoo forest. A deciduous forest in which *Dalbergia sissoo* (Shishum) predominates. *Acacia catecheu* (Khair) is usually but not always present.

Dehradun Forest Division

It is situated between 20° 20′52" to 30°2′31" latitude and 78° 1′ 38" to 78° 19′22" longitude, in the Dehradun tehsil of Dehradun district.

Forest conservation in these areas started as early as in 1864. After the reorganisation of the Dehradun forest division in 1986, it now comprises five forest ranges viz; Lachiwala, Thano, Barkot, Jhajhra and Choharpur. The forests of the division are bounded in the north by Tehri Forest Division, in the South by Rajaji National Park, in the west by Siwalik Forest Division and in the east by river Ganga. Forests of the division are interspersed with numerous fields, farms, villages and townships. The main townships in the tract are Dehradun, Doiwala, Premnagar, Sahaspur, Vikasnagar, Bhaniawala and Rishikesh.

The major plant species found in this division are *Shorea robusta* (Sal) and *Mallotus philippinensis* (Rohini). Other associates are *Ougenia oogenensis* (Sandan), *Shyzium cuminii* (Jamun), *Dalbergia sissoo* (Shishum), *Acacia catecheu* (Khair), *Adina cordifolia* (Haldu), *Anogeissus latifolia* (Siris), *Emblica officinalis* (Aonla), *Lantana camera* (Ghaneri), *Clerodendron infortunatum* (Kadu), *Murraya koengii* (Gandhela), a few climbers and young seedlings of Sal and Rohini form the under growth of the forest of this division **(Annexure I)**.

Siwalik Forest Division

Siwalik division lies between 30° 15′ and 30° 25′ latitude and 77° 37′ and 78° 1′ longitude falling in the Dehradun Tehsil of Dehradun district. The division is bounded by the Asan river in the North, by Rajaji National Park in the East, and by Haryana State in the West. The major plant species found in this region are almost similar to those found in Dehradun Division **(Annexure I)**.

Mussoorie Forest Division

This division comprises five forest ranges, viz. Jaunpur which falls in Tehri district, Kempty and Raipur Ranges which fall in Dehradun and Tehri districts and Mussoorie and Langha Ranges which fall in Dehradun district.

Mussoorie Forest Division lies between 600 m. MSL and 3022 m. MSL. Nag Tibba is the highest peak in this division. At lower altitudes moist Siwalik Sal Forest are found and at higher altitudes, moist Deodar forests are dominant. At even higher altitudes, i.e. at Nag Tibba and just below that Fir, Spruce, high level Oak, Cherry, Ringal (thinner than Bamboo) are the dominant tree species. Shrubs like Aster, Cinnamon (Dalchini) are dominant at these altitudes **(Annexure I)**.

Hotspots

Forest ecosystem in the Doon Valley has been subjected to substantial and significant exploitation by various agencies for different purposes. Following statistics depicts the land distribution under various categories :

Doon forest cover	1,10,850 ha. (52.65%)
Sal forest cover	52% (East) and 75% (West)
Depleted forest area	5,275 ha. (4.76%)
Unproductive grassland cover	15% (East) and 8% (West)
Area under plantation cover	7% (East) and 3% (West)
Depleted forest area	5,275 ha. (4.76%)
Total geographical area of Doon Valley (1991 Census)	2,30,903 ha.

The most important factor affecting forests today, other than the issue of biomass collection by local inhabitants is migratory grazing. Doon forests have been traditional winter camping place for the Gujjar community - migratory graziers, who owing largely to the rapid growth of urban population in the valley have become more or less permanent settlers in the forests with their cattle.

Rajpur Industrial Zone (on way to Mussoorie) is one of the major industrial zones in and around Dehradun. M/s Pyrite Phosphate and Chemical Ltd., a Government of India Undertaking, is located at Maldeota, about 18 km. north-east of Dehradun. A number of limestone and brick kilns are concentrated in this zone.

Selakui Industrial Zone is located near Jhajhra forest range in Dehradun division, with major industrial units like R.S.P. Woollen Industries, Coffee Factory, Steel Factory, J.P. Spring Industry, and a few brick and limestone kilns.

Searsole Industrial Zone is situated at Kunwawala on way to Lachiwala Forest Range which falls under Dehradun division.

Mussoorie-Dehradun Region is well known for its mineral reserves, viz. limestone, marble, phosphorite, gypsum and dolomite, which are located in krol belt. High grade limestone/marble deposits occur in the south sloping hills facing the valley.

A 50 km. long mineral belt extends from Hathipaon in north-west to Ranipokhari in south-east. The most affected areas due to quarrying are Kiarkuli Bhatta and Hathipaon, where a massive afforestation programme has been undertaken by Eco-Task-Force, Dehradun.

3.3.2 Case Study II : Jamshedpur Region

The study area **(Figure 3.2)** is covered largely in Dhalbum and to some extent in Chaibassa Districts. The limits of the longitude of Dalbhum are 80^{o} 10′ to 86^{o} 54′ E and of the latitude 22^{o} 20′ to 20^{o} 50′ N. The climate of the region conforms to general tropical one. It is warm and humid, with three main seasons, with 106.6 mm of average rainfall per annum and 69.8% relative humidity, Maximum and Minimum temperatures reported in the region are 33.01 and 19.10^{o}C respectively.

The land spread of the region covers an area of 3171.53 sq.km where 987.86 sq km, comes under forests [31.1% of the total land area]. The forests occur on plains as well as on hills. 70 percent of forests are confined to hills at an altitude ranging from 91.44 m to 932.68 m above MSL. Dalma Pahar is the highest peak at 933 m above MSL.

The forests dealtwith are state-owned and are mainly classified under two categories namely 'Reserved' and 'Protected' forests. These forests in large compact blocks are confined to the north and south of the division with a hill range almost in the middle. The forests in the plain are scattered and form smaller blocks. 70% of the forests are mainly confined to hills situated in the northern and southern sides of the division. The forests have their altitude ranging from 91.44 m to 932.68 m above MSL of the 4 peaks with an altitude of over 600 m, Dalma Pahar (933 m) in Athkosi Taraf, falls in the study area.

The forests occurring in undulating and plain grounds are largely confined to Chakulia and Ghatsila ranges of the division. The steep slopes of the hills have got considerably eroded due to misuse of forest cover. Rocky ground is therefore invariably found near most of the hills.

The forests fall entirely in the catchment of the Subarnarekha river. The river originates from Nagri in Ranchi district and traverses the Dhalbum area, and joins with its main tributary Kharkai.

Dhalbhum is the eastern sub-division of Singhbhum zone, which is the richest mineral bearing district in Chhotanagpur division. Topography of the area included within Dhalbhum forest division is quite varied, constituting approximately 50% hilly and 50% plain areas. Soil is of generally sandy-loam and clayey-loam character. The depth of soil greatly varies. Nutrient status of soil is generally low and deficiency of Nitrogen (N) and Phosphorous (P) is pronounced.

All the rivers of the tract dry up in the summer. Subarnarekha river is dammed at several places and Kharkai in one place to hold water during the summer, which is used both for domestic and industrial purposes. Jamshedpur region is fed by Dimna reservoir, which impounds clean water as its entire catchment is well protected from all possible human interferences.

Sal (*Shorea robusta*), Padasi (*Cleistanthus collinus*) and Chironji (*Buchanania lanzan*) are the important tree species of the region.

VEGETATION

The forests of this region are of the following type :

Dry Peninsular Sal Forest

The main species are :

Shorea robusta, *Acacia catechu*, *Boswellia serrata*,, *Diospyros melanoxylon*, *Mangifera indica*, *Adina cordifolia*, *Buchanania lanzan*, *Madhuca indica*, *Pterocarpus marsupium*, *Terminalia tomentosa*.

The two associations are :

Shorea-Anogeissus-Woodfordia

Shorea-Gardenia-Eucalyptus

Northern Dry Mixed Deciduous Forest

The principal constituents of this forests are : *Shorea robusta*, *A. catechu*, *Adina cordifolia*, *Boswellia serrata*, *Madhuca indica*, *Bombax ceiba*, *Emblica officinalis*, *Garuga pinata*, *Kydia calyeina*, *Madhuca latifolia*, *Ficus spp.* *Holoptelea integrifolia*, *Lannea grandis* and *Terminalia spp.*

The two main associations are :

Cochlospermum-Euphorbia

Anogeissus-Mitragyna-Dendrocalamus-Daedelacanthus

Forest Zones

Dalma Forest

This comprises the core area of the forest, situated nearly 3328 mts, above the mean sea level. This zone showed the highest species diversity which changed at almost every 100 meters along the sanctuary road and also on both sides of it. Commonly found species on the tophills were Asan (*Terminalia tomentosa*), Makal (*Zizyphus oenoplia*) and Bel (*Aegle marmelos*) etc., whereas in the foothills the common species were Palas climber (*Butea monosperma*), Karam (*Adina cordifolia*), Doka (*Lannea grandis*), Kurchi (*Holarrhena antidysenterica*), and Padasi (*Cleistanthus collinus*). The forest being away from the sources of pollution, plants, in general, give a healthier look **(Annexure II)**.

Dimna Forest

This zone is close to the city. Being a tourist spot, it is subjected to continuous human interference. Plants in this zone were seen to be afflicted with various diseases, leaves showing various signs of injury. The commonly found species in this zone are Sal (*Shorea robusta*), Dhak (*Adina cordifolia*), (*Terminalia tomentosa*), and Kurchi (*Holarrhena antidysentrica*) **(Annxure II)**.

Nutandih Forest

In terms of distances from the city centre, this zone lies between Dalma Pahar and Dimna Forests. Numerous plant diseases were observed in this region, which can be attributed to the hydrocarbons emitted from the industry situated a few kilometers away from this forest zone [118]. The commonly occurring species of the zone were Mahua (*Madhuca indica*), Kurchi (*Holarrhena antidysentrica*), Chaile (*Moringa tinctoria*), Bija Sal (*Pterocarpus marsupium*), Asan (*Terminalia tomentosa*), Bhelwa (*Semicarpus anacardium*) **(Annexure II)**. Besides chlorosis and necrosis, several symptoms such as leaf curling, blisters, tip burns, black and red spots were observed on the leaves of the trees of this zone.

Hotspots

Bistupur

Bistupur is the main shopping area of the steel city. There is a continuous flow of traffic in this region, as a result of which, trees along the road side are exposed to the vehicular as also to the industrial emissions. The commonly occurring species in this zone are Datura (*Calotropis procera*), Neem (*Azadirachta indica*), Banyan (*Ficus bengalensis*) and Peepal (*Ficus religiosa*).

Mango

This zone comprises the northern boundary of Jamshedpur. It is bound on the southern side by the river Subernarekha and is a highly crowded locality, with a congested market area, and high vehicular traffic. Species commonly found in this zone were Mango (*Mangifera indica*), Neem (*Azadirachta indica*), Palas (*Butea monosperma*), banyan

(*Ficus bengalensis*), Kurchi (*Holarrhena antidysentrica*), Australian babul (*Acacia melanoxylon*), and *Cassia semia*.

Jugsalai Railway Station

It is located in the south-west region of Jamshedpur. and forms one of the most polluted zones, because of its exposure to both vehicular and industrial pollutants, which also includes pollutants due to railway engines. Trees commonly encountered in this zone were Maharukh (*Ailanthus excelsa*), and Neem (*Azadirachta indica*).

TELCO Industrial Area

A highly polluted zonedue to TELCO groupg of industries and is located in the south-east region of Jamshedpur. The commonly found species of this zone were Sal (*Shorea robusta*), Palas (*Butea monosperma*), Kurchi (*Holarrhena antidysenterica*), Banyan (*Ficus bengalensis*), Asan (*Terminalia tomentosa*) etc.

3.3.3 Case Study III : National Capital Region

The National Capital Region covers an area of 30, 242 sq km and lies between 27°18′ and 29°29′ north latitude and 76%09′ and 78%29′ east longitude. The physiography of the Region is characterised by the presence of the Ganga skirting it as its eastern boundary, the Yamuna traversing it north-south, forming the boundary between Uttar Pradesh and Haryana, and the sand dunes and barren low hills of the Aravalli chain and its outcrops in the west, flat topped prominent and precipitous hills of the Aravalli range enclosing fertile valleys and high table lands in the south-west, and the rolling plains dominated by rainfed torrents in the south. The rest of the Region is plain with a general slope of north-east to south and south-west.

The National Capital Region includes the Union Territory of Delhi and parts of the States of Haryana, Rajasthan and Uttar Pradesh. In Rajasthan sub-region forest cover is 4.3 percent with 'dry deciduous type' and Kikar and Dhak as the dominant trees. Uttar Pradesh sub-region has only 1 percent of the area under forests mainly due to extensive use of land for cultivation. It has dry deciduous forests. Dominant trees are Sal, Sishum and Teak. Haryana sub-region has least amount of forest cover, concentrated in Gurgaon district. Khair and Dhak form the important tree species in Aravalli Hills.

Delhi, the National Capital, has seen unprecedented growth, causing serious ecological degradation and lowering of living standards as also shortfalls in basic infrastructure.

The major vegetation found in Delhi **(Figure 3.3)** consists of road side plantation, parks and gardens. Major trees along roads and avenues are Neem (*Azadirachta indica*), Amaltas (*Cassia fistula*) Jamun (*Eugenia spp.*), Peepal (*Ficus religiosa*), Arjun (*Terminalia arjuna*), Sishum (*Dalbergia sissoo*), Devil's tree (*Alstonia scholaris*), Gulmohor (*Delonix regia*), Kijelia (*Kijelia pinnata*), Kabuli Kikar (*Prosopis juliflora*) and *Acacia spp.* **(Annxure III)**.

Forests

On account of population pressure and extensive cultivation, very little has been left of the natural vegetation. The study based on satellite imageries reveals that only 1.2% of the area of the Region is under forest cover. The forest cover is of 'tropical thorn type' ranging from open stunted forests to xerophytic bushes occurring both on plains and hills. The common tree types are Acacias, Khair, Dhak and Kikar.

In Rajasthan sub-region, the forest cover is about 4.3%, mostly accounted by hill forests of Alwar and Behror tehsils. The forests are mainly 'dry deciduous type' with dominant tree types being Kikar (*Prosopis juliflora*), and Dhak (*Adina cordifolia*). Other tehsils have only shrub vegetation. The hill forests of Alwar and Behror have been classified as reserved and protected forests. The forest cover on the hills could be described as dense or sparse. The dense forests are confined to narrow valleys in the hills where there is sufficient supply of water. The upper areas of the hills support only thorny shrub type forests (sparse) with occasional big trees. Sariska Wild Life Sanctuary covering an area of 492 sq km is located in the dense forest of Alwar tehsil.

In the Uttar Pradesh Sub-region forests account for only 1% of the area. This again is due to extensive use of land for cultivation. This area has dry deciduous forests. The dominant trees are Sal (*Shorea robusta*), Shishum

(*Dalbergia sissoo*), and Teak (*Tectona grandis*). In drier parts, the forests are of thorny type.

The Haryana Sub-region accounts for the least amount of forest cover. Most of this forest cover is concentrated in Gurgaon district. Khair (*acacia spp.*), and Dhak (*Adina cordifolia*) form the important tree species in the Aravalli hills. The other forest cover is mainly in the form of the orchards in the plains. Sultanpur Bird Sanctuary over an area of about 117 hectares is located near Gurgaon.

The existing forest area is under the jurisdiction of Forest Department of Delhi Administration and is divided into six blocks, namely, Mehrauli (South), Shahadara (East), Alipur (North), Nangloi (West), Najafgarh (West), and Saola Wildlife Sanctuary (South). In most of the blocks, panchayat lands are also designated forest areas. According to the Forest Department, the rapid decline in forest area can be attributed to encroachment and illegal felling.

Besides this, the only vegetation found in Delhi comprises the Road side plantations, parks and gardens. Due to efforts undertaken by New Delhi Municipal Corporation (NDMC), the Municipal Corporation of Delhi (MCD), the Central Public Works Department (PWD) and the Delhi Development Authority (DDA), Delhi today has 20 major district parks covering 4335 hectares, 53 city forests, over 500 local parks, 15 rock gardens, and 11 lakes. In congested old Delhi, the area around the medieval Idgah has been landscaped and there are parks behind the Red Fort and around the samadhis of national leaders.

The flora of Delhi comprises nearly 1000 species of flowering plants belonging to about 120 families. Sixty percent of the species are either indigenous or naturalized and the remaining ones have been introduced. More than 50% of the indigenous flora represents tropical species. Nearly 8% is from tropical Africa, 2% from temperate region and less than 40% from the New World. The multitude of plant species which are responsible for Delhi's green look is a combination of indigenous and exotic species.

Tree species commonly planted along major roads and avenues are Neem (*Azadirachta indica*), Amaltas (*Cassia fistula*), Jamun (*Eugenia jambolana*), Peepal (*Ficus religiosa*), Arjun (*Terminalia arjuna*), Shishum (*Dalbergia sissoo*),Devil's tree (*Alstonia scholaris*), Gulmohur (*Delonix regia*), Kijelia (*Kijelia pinnata*), Kabuli kikar (*Prosopis juliflora*) and *Acacia spp.* etc.

The major avenues of New Delhi such as Rajpath, Motilal Nehru Marg, Shanti Path are lined with old and mature jamun trees. Commercial areas have sturdy and hardy species such as Neem, Peepal and Jamun. Among the city's residential areas, the ones in South Delhi are amply dotted with trees and shrubs.

Hotspots

Southern Ridge Forest

Southern Ridge Forest is the only natural forest of

Delhi with 7,777 hectares area which is now facing threat mainly due to human encroachment and illegal felling. Between 1971 and 1983, Delhi lost 10 sq.km of forest area. In 1960-1961, Delhi had 14.15 sq.km under forests; this was reduced to 11.43 sq.km in 1970-1971 and again escalated to 14.34 sq.km (1983-84) and in 85-86 encompassed 15-61 sq.km. However, due to afforestation drives undertaken by concerned authorities, the forest area in Delhi UT has risen to 27 sq.km i.e. 1.8% of the total area of Delhi UT.

Industrial Areas

Thickly populated areas of the walled city, residential complexes of North and West Delhi are the most affected due to industrial units. Delhi records twelve times the national average for respiratory ailments mainly due to unchecked pollution or thick clouds of smoke that hang over the city. Places most affected due to industrial activity are Ghaziabad, Mohan Nagar, Sahibabad, NOIDA, Sikandarabad etc.

Old Delhi

Residential areas like Daryaganj, Paharganj, Sadar, Chandni Chowk etc. suffer from severe congestion. Factors mainly responsible for this are, lack of town planning, narrow lanes with no scope for Avenue plantation.

Major Traffic Intersections of Delhi

Various traffic intersections of Delhi are some of the major problem areas most affected because of the ever increasing threat due to vehicular pollution.

In the recent times, much attention is being paid in developing assessive and predictive models which are useful in impact assessment and abatement of air pollution.

Plants have long been studied as better monitors or indicators of environmental pollution than animals. Therefore, the most rational way of use of plants for environmental impact assessment is to employ those plants which in their presence or absence and in all features of their phenotype and physiology serve as index of their environmental status. They not only indicate the extent of damage, but also provide a clear insight into the composition of their surrounding environment. In fact, most pollutant resistant plants serve as both scavangers or indicators, thus in delineation of management strategies for different land-use, which include city regions - residential area, roads and national highways, as also the forest regions, knowledge of such plants in terms of their assimilative capacity for air pollutants is important. The analysis of the results obtained from the present study sites and the management plans for the same are presented in the next chapter.

CHAPTER IV
RESULTS & DISCUSSIONS

4.0 RESULTS AND DISCUSSIONS

4.1 ESTIMATION OF THE SPECIES DIVERSITY INDICES

The analyses of various indices viz. Shannon Weiner Diversity Index (SWDI), Equitability Index (EI), Species Richness Index (SRI), the Coefficient of Similarity/Similarity Index (SI), and Importance Value Index (IVI) for Doon Valley and Jamshedpur Regions are reported in **Tables 4.1 through 4.11**, The relative distribution of the species is depicted in **Figures 4.1 and 4.2**.

4.1.1 Doon Valley Region

Mussoorie Forest Division and Dehradun City are most diversified regions with a Shannon Weiner Diversity Index values of 1.21 and 1.20 and Equitability Index values of 0.84 and 0.85 respectively. Siwalik Forest Division has the least Equitability Index value of 0.50 **(Table 4.1)**.

Table 4.2 gives the Similarity Index Value of different forests stands at Doon Valley Region. The Coefficient of Similarity is highest (0.80) at Malhan-Timli, and Ramgad-Timli, followed by Asharodi-Jhajhra, Timli-Jhajhra, Malhan-Jhajhra, Ramgad-Jhajhra, Choharpur-Timli, Malhan-ramgad with a value of 0.67. Lachiwala-Choharpur, Lachiwala-Kempty, Circuit House-Kempty are the least similar forest with values of 0.12, 0.14, and 0.12 respectively. Sampling Stations 15 through 20 are the most dissimilar forests **(Table 4.2)**.

TABLE 4.1

DIVERSITY INDICES OF DIFFERENT FORESTS AT DOON VALLEY REGION

S. No.	Name of Forest Zones	Indices		
		Shannon Weiner	Equitability	Species Richness
Dehradun				
1.	Lachhiwala	1.26	0.61	1.85
2.	Thanno	0.97	0.47	2.02
3.	Barkot	0.43	0.24	1.18
4.	Jhajra	0.45	0.41	0.49
5.	Choharpur	0.75	0.54	0.73
Siwalik				
6.	Mohand	0.60	0.34	1.32
7.	Timli	0.32	0.46	0.24
8.	Malhan	0.70	0.63	0.48
9.	Asharodi	1.05	0.58	1.61
10.	Ramgad	0.92	0.84	0.67
City Vegetation				
11.	IIP, Guest House Mokhampur	0.97	1.40	0.33
12.	Santosh Nagar	0.60	0.43	0.90
13.	Arcadia Tea Garden	1.08	1.56	0.33
14.	Indira Colony	0.92	1.40	0.67
15.	Circuit House	1.49	0.68	2.67
Mussoorie				
16.	Mussorie	1.04	0.58	1.66
17.	Jaunpur	1.46	1.33	0.67
18.	Kempty	1.81	1.01	2.40
19.	Raipur	0.69	0.63	0.72
20.	Langha	1.05	0.56	1.67

Table 4.1(A)

DIVERSITY INDICES VALUES DIFFERENT ZONES AT DOON VALLEY REGION

Forest Division	Indices		
	Shannon Weiner	Equitability	Species Richness
Dehradun	0.21	0.50	2.87
Siwalik	0.72	0.60	2.43
Mussoorie	1.21	0.84	3.71
City Region	1.20	0.85	3.22

TABLE 4.2

SIMILARITY INDICES OF THE FORESTS AT DOON VALLEY REGION

S. No.	Sampling Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.	Lachiwala	1.00	0.37	0.42	0.54	0.33	0.57	0.40	0.14	0.36	0.36	0.00	0.18	0.33	0.00	0.12	0.00	0.00	0.14	0.18	0.29
2.	Thanno	0.37	1.00	0.28	0.36	0.17	0.28	0.20	0.00	0.18	0.18	0.00	0.18	0.33	0.00	0.00	0.00	0.00	0.00	0.18	0.14
3.	Barkot	0.42	0.28	1.00	0.22	0.40	0.33	0.50	0.00	0.44	0.44	0.00	0.22	0.20	0.00	0.00	0.00	0.00	0.00	0.22	0.17
4.	Jhajra	0.54	0.36	0.22	1.00	0.57	0.66	0.66	0.00	0.66	0.66	0.00	0.33	0.57	0.00	0.00	0.00	0.00	0.00	0.33	0.44
5.	Choharpur	0.33	0.17	0.40	0.57	1.00	0.40	0.66	0.00	0.57	0.57	0.00	0.57	0.25	0.00	0.00	0.00	0.00	0.00	0.29	0.40
6.	Asharodi	0.57	0.28	0.33	0.66	0.40	1.00	0.50	0.00	0.44	0.44	0.00	0.22	0.40	0.00	0.00	0.00	0.00	0.00	0.22	0.33
7.	Timli	0.40	0.20	0.50	0.66	0.66	0.50	1.00	0.00	0.80	0.80	0.00	0.40	0.33	0.00	0.00	0.00	0.00	0.00	0.40	0.50
8.	Mohand	0.14	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.	Malhan	0.36	0.18	0.44	0.66	0.57	0.44	0.80	0.00	1.00	0.66	0.00	0.33	0.28	0.00	0.00	0.00	0.00	0.00	0.33	0.44
10.	Ramgad	0.36	0.18	0.44	0.66	0.57	0.44	0.80	0.00	0.66	1.00	0.00	0.33	0.57	0.00	0.00	0.00	0.00	0.00	0.33	0.44
11.	IIP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.33	1.00	0.00	0.00	0.00	0.00	0.40	0.25
12.	Indira Colony	0.18	0.18	0.22	0.33	0.57	0.22	0.40	0.00	0.33	0.33	0.00	1.00	0.286	0.00	0.00	0.00	0.00	0.00	0.33	0.22
13.	Santosh Nagar	0.33	0.33	0.20	0.57	0.25	0.40	0.33	0.00	0.28	0.57	0.33	0.28	1.00	0.33	0.00	0.00	0.00	0.00	0.57	0.44
14.	Arcadia Tea Garden	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.33	1.00	0.00	0.00	0.00	0.00	0.40	0.25
15.	Circuit House	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.12	0.00	0.00
16.	Mussoorie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.44	0.14	0.00	0.00
17.	Jaunpur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	1.00	0.00	0.00	0.00
18.	Kempty	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.14	0.00	1.00	0.18	0.00
19.	Raipur	0.18	0.18	0.22	0.33	0.29	0.22	0.40	0.00	0.33	0.33	0.40	0.33	0.57	0.40	0.00	0.00	0.00	0.18	1.00	0.67
20.	Langha	0.29	0.14	0.17	0.44	0.40	0.33	0.50	0.00	0.44	0.44	0.25	0.22	0.44	0.25	0.00	0.00	0.00	0.00	0.67	1.00

TABLE 4.3

STRUCTRE OF FOREST RANGES OF DOON VALLEY REGION

S. No.	NAME OF SPECIES: COMMON NAME	NAME OF SPECIES: SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
Lachiwala Forest Range						
1.	Sal	*Shorea robusta*	40.91	80.69	34.62	52.10
2.	Rohini	*Mallotus philippinensis*	34.10	7.70	26.93	22.90
3.	Sandan	*Ougeinia dalbergioides*	11.40	3.50	19.23	11.36
4.	Dhavdi	*Lagerstroemia parviflora*	4.55	2.03	3.85	3.48
5.	Baheda	*Terminalia belerica*	2.26	3.74	3.85	3.28
6.	Jamun	*Eugenia spp.*	2.26	0.90	3.84	2.30
7.	Amaltas	*Cassia fistula*	2.26	0.72	3.84	2.29
8.	Chamror	*Ehretia laevis*	2.26	0.72	3.84	2.29
			100.00	100.00	100.00	100.00
Thanno Forest Range						
1.	Sal	*Shorea robusta*	71.90	78.87	47.06	65.94
2.	Bakhli	*Anogeissus latifolia*	6.25	1.89	11.76	6.63
3.	Haldu	*Adina cordifolia*	6.25	8.05	11.78	8.69
4.	Kharpat	*Garuga pinnata*	3.12	0.38	5.88	3.13
5.	Semla	*Bauhinia retusa*	3.12	1.13	5.88	3.38
6.	Jamun	*Eugenia spp.*	3.12	1.51	5.88	3.50
7.	Kanju	*Toddalia aculeata*	3.12	1.51	5.88	3.50
8.	Dhavdi	*Lagerstroemia parviflora*	3.12	6.66	5.88	5.23
			100.00	100.00	100.00	100.00
Barkot Forest Range						
1.	Sal	*Shorea robusta*	85.30	90.82	65.39	80.50

Contd...

TABLE 4.3 CONTD...

S. No.	COMMON NAME	SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
2.	Haldu	*Adina cordifolia*	4.41	3.55	11.54	6.50
3.	Bel	*Aegle marmelos*	5.88	1.63	11.54	6.35
4.	Peepal	*Ficus religiosa*	1.47	2.29	3.84	2.54
5.	Baheda	*Terminalia belerica*	1.47	1.48	3.84	2.26
6.	Rohini	*Mallotus philippinensis*	1.47	0.23	3.85	1.85
			100.00	100.00	100.00	100.0
Jhajhra Forest Range						
1.	Sal	*Shorea robusta*	76.67	97.01	58.33	77.34
2.	Rohini	*Mallotus philippinensis*	20.00	2.71	33.33	18.66
3.	Jamun	*Eugenia spp.*	3.33	0.28	8.34	4.00
			100.00	100.00	100.00	100.00
Choharpur Forest Range						
1.	Sal	*Shorea robusta*	86.67	98.72	71.43	85.61
2.	Rohini	*Mallotus philippinensis*	5.00	0.71	9.52	5.10
3.	Lantana	*Lantana camera*	5.00	0.37	9.52	4.96
4.	Karvanda	*Carissa karanda*	3.33	0.20	9.53	4.33
			100.00	100.00	100.00	100.00
Mohand Forest Range						
1.	Khair	*Acacia catechu*	79.55	92.00	61.11	77.6

Contd...

TABLE 4.3 CONTD...

S. No.	NAME OF SPECIES: COMMON NAME	NAME OF SPECIES: SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
2.	Ber	*Zizyphus jujuba*	9.09	3.30	16.65	9.6
3.	Phaldu	*Mitragyna parviflora*	4.55	2.00	5.56	4.2
4.	Bhander	*Zizyphus xylopyra*	2.27	1.90	5.56	2.9
5.	Amaltas	*Cassia fistula*	2.27	0.40	5.56	2.7
6.	Dhamun	*Grewia hainesiana*	2.27	0.40	5.56	2.7
			100.00	100.00	100.00	100.
Timli Forest Range						
1.	Sal	*Shorea robusta*	96.88	98.49	94.12	96.50
2.	Rohini	*Mallotus philippinensis*	3.12	1.51	5.88	3.50
			100.00	100.00	100.00	100.00
Malhan Forest Range						
1.	Sal	*Shorea robusta*	87.50	92.00	78.95	86.1
2.	Rohini	*Mallotus philippinensis*	6.25	0.39	15.79	7.4
3.	Jhingan	*Lannea coromandelica*	6.25	7.61	5.26	6.3
			100.00	100.00	100.00	100.0
Ramgad Forest Range						
1.	Sal	*Shorea robusta*	65.00	70.07	57.14	64.07
2.	Rohini	*Mallotus philippinensis*	25.00	1.73	28.57	18.44

Contd...

TABLE 4.3 CONTD...

S. No.	NAME OF SPECIES: COMMON NAME	NAME OF SPECIES: SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
3.	Sain	*Terminalia tomentosa*	10.00	28.20	14.29	17.49
			100.00	100.00	100.00	100.0
Asharodi Forest Range						
1.	Sal	*Shorea robusta*	45.00	95.34	30.77	57.0
2.	Kaladana		10.00	0.47	15.38	8.6
3.	Chamror	*Ehretia laevis*	20.00	1.55	23.08	14.8
4.	Jamun	*Eugenia spp.*	15.00	2.17	15.37	10.8
5.	Rohini	*Mallotus philippinensis*	5.00	0.16	7.70	4.2
6.	Timru	*Zanthoxylum alatum*	5.00	0.31	7.70	4.3
			100.00	100.00	100.00	100.0
Arcadia Tea Garden, Premnagar						
1.	Cha	*Camellia thea*	70.00	21.97	66.70	52.88
2.	Shishum	*Dalbergia sissoo*	30.00	78.03	33.30	47.12
			100.00	100.00	100.00	100.00
IIP Guest House, Mokhampur						
1.	Cha	*Camellia thea*	80.00	94.83	57.14	77.32
2.	Shishum	*Dalbergia sissoo*	20.00	5.17	42.86	22.68
			100.00	100.00	100.00	100.00

Contd...

TABLE 4.3 CONTD...

S. No.	COMMON NAME	SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
Santosh Nagar						
1.	Sal	*Shorea robusta*	67.86	61.79	54.54	61.4
2.	Jamun	*Eugenia spp.*	7.14	35.45	18.18	20.2
3.	Shishum	*Dalbergia sissoo*	21.43	2.21	18.18	13.9
4.	Sain	*Terminalia tomentosa*	3.57	0.55	9.10	4.4
			100.00	100.00	100.00	100.0
Indira Colony						
1.	Sal	*Shorea robusta*	70.00	99.64	45.50	71.70
2.	Kadu	*Clerodendron infortunatum*	20.00	0.35	36.36	18.91
3.	Lantana	*Lantana camera*	10.00	0.01	18.14	9.39
			100.00	100.00	100.00	99.91
Circuit House						
1.	Buddhas' Coconut	*Sterculia alata*	31.25	72.56	20.00	41.40
2.	Khajur	*Phoenix spp.*	12.50	0.91	10.00	7.80
3.	Silver Oak	*Grevillia robusta*	6.25	1.37	10.00	5.90
4.	Kapur	*Cinnamomum camphora*	6.25	3.96	10.00	6.80
5.	M. Champa	*Michelia champaka*	12.50	6.55	10.00	9.70
6.	Bamboo	*Dendrocalamus strictus*	12.50	2.13	10.00	7.70
7.	Mango	*Mangifera indica*	6.24	6.70	10.00	7.70
8.	Sandan	*Oogenia dalbergioides*	6.24	3.23	10.00	6.50

Contd...

TABLE 4.3 CONTD...

S. No.	NAME OF SPECIES: COMMON NAME	NAME OF SPECIES: SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
9.	Chalta		6.27	2.59	10.00	6.50
			100.00	100.00	100.00	100.00
Mussoorie Forest Range						
1.	Banj	*Quercus incana*	40.00	36.36	36.00	37.57
2.	Pankhar	*Esculus indica*	10.00	8.39	18.00	12.19
3.	Deodar	*Cedrus deodara*	35.00	46.62	18.00	33.29
4.	Walnut	*Juglans regia*	5.00	0.46	10.00	4.85
5.	Chir	*Pinus roxhburgii*	5.00	5.12	9.00	6.40
6.	Palm	*Phoenix spp.*	5.00	3.05	9.00	5.70
			100.00	100.00	100.00	100.00
Raipur Forest Range						
1.	Sal	*Shorea robusta*	75.00	94.06	57.15	75.40
2.	Shishum	*Dalbergia sissoo*	18.80	4.10	28.57	17.15
3.	Toona	*Cedrella toona*	6.20	1.84	14.28	7.45
			100.00	100.00	100.00	100.00
Langha Forest Range						
1.	Sal	*Shorea robusta*	75.00	69.85	50.00	64.93
2.	Shishum	*Dalbergia sissoo*	4.99	6.80	10.00	7.31
3.	Toona	*Cedrella toona*	4.99	10.20	10.00	8.40
4.	Teak	*Tectona grandis*	4.99	4.50	10.00	6.50

Contd...

TABLE 4.3 CONTD...

S. No.	COMMON NAME	SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
5.	Rohini	*Mallotus philippinensis*	4.99	1.65	10.00	5.54
6.	Sain	*Terminalia tomentosa*	5.04	7.00	10.00	7.32
			100.00	100.00	100.00	100.00

Kempty Forest Range

S. No.	COMMON NAME	SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
1.	Toona	*Cedrella toona*	37.50	28.08	16.66	27.41
2.	Sandan	*Ooogenia dalbergioides*	12.50	2.30	16.66	10.48
3.	Cyprus	*Cupressess spp.*	12.49	26.65	16.66	18.60
4.	Acrot		12.49	2.29	16.66	10.48
5.	Bhimal	*Grewia oppositifolia*	12.49	38.39	16.66	22.53
6.	Walnut	*Juglans regia*	12.53	2.29	16.70	10.50
			100.00	100.00	100.00	100.00

Jaunpur Forest Range

S. No.	COMMON NAME	SCIENTIFIC NAME	RELATIVE DENSITY	RELATIVE DOMINANCE	RELATIVE FREQUENCY	IMPORTANC VALUE IND
1.	Banj	*Quercus incana*	30.00	13.13	36.34	26.49
2.	Chir	*Pinus roxburghii*	30.00	16.27	27.30	24.51
3.	Deodar	*Cedrella deodara*	40.00	70.60	36.36	49.00
			100.00	100.00	100.00	100.00

TABLE 4.4

STRUCTURE OF DEHRADUN FOREST DIVISION

S.No.	Name of the Species: Common	Name of the Species: Scientific	Relative Density	Relative Dominance	Relative Frequency	IVI Value
1.	Sal	*Shorea robusta*	74.61	89.55	55.73	73.30
2.	Sandan	*Ougenia dalbergioides*	1.88	0.74	4.42	2.35
3.	Rohini	*Mallotus philippinensis*	11.73	1.49	15.04	9.42
4.	Amaltas	*Cassia fistula*	0.37	0.00	0.88	0.42
5.	Chamror	*Ehretia laevis*	0.37	0.00	0.88	0.42
6.	Baheda	*Terminalia belerica*	0.75	0.74	1.76	1.10
7.	Dhavdi	*Lagerstroemia parviflora*	1.13	1.49	1.76	1.46
8.	Bakhli	*Anogeissus latifolia*	0.75	0.74	1.76	1.09
9.	Haldu	*Adina cordifolia*	1.88	2.98	4.42	3.10
10.	Kharpat	*Garuga pinnata*	0.39	0.00	0.88	0.42
11.	Semla	*Bauhinia retusa*	0.39	0.00	0.88	0.42
12.	Jamun	*Eugenia jambolana*	1.51	0.74	3.53	1.93
13.	Kanju	*Toddalia aculeata*	0.40	0.00	0.90	0.42
14.	Peepal	*Ficus religiosa*	0.40	0.74	0.90	0.70
15.	Karvanda	*Carissa karanda*	0.80	0.00	1.78	0.84
16.	Ghaneri	*Lantana camera*	1.13	0.00	1.78	0.95
17.	Bel	*Aegle marmelos*	1.51	0.79	2.70	1.66
			100.00	100.00	100.00	100.00

TABLE 4.5

STRUCTURE OF SIWALIK FOREST DIVISION

S.No.	Name of the Species: Common	Name of the Species: Scientific	Relative Density	Relative Dominance	Relative Frequency	IVI Value
1.	Sal	*Shorea robusta*	66.04	73.33	50.00	63.12
2.	Rohini	*Mallotus philipinensis*	6.70	0.83	10.00	5.20
3.	Khair	*Acacia catechu*	17.00	17.50	14.20	16.03
4.	Ber	*Zizyphus jujuba*	1.89	0.83	4.00	2.20
5.	Amaltas	*Cassia fistula*	0.50	0.00	1.56	0.60
6.	Phaldu	*Mitragyna parviflora*	0.50	0.00	1.56	0.60
7.	Bhander	*Zizyphus xylopyra*	0.50	0.00	1.56	0.65
8.	Dhamun	*Grewia hainesiana*	0.50	0.00	1.56	0.80
9.	Jhingan	*Lannea coromandelica*	1.90	2.51	1.56	2.00
10.	Chamror	*Ehretia leavis*	1.90	0.00	5.00	2.00
11.	Timru	*Zanthoxylum alatum*	0.57	0.00	2.00	0.80
12.	Sain	*Terminalia tomentosa*	1.00	5.00	2.00	3.00
13.	Jamun	*Eugenia jambolana*	1.00	0.00	5.00	3.00
			100.00	100.00	100.00	100.00

TABLE 4.6

STRUCTURE OF MUSSOORIE FOREST DIVISION

S.No.	Name of the Species: Common	Name of the Species: Scientific	Relative Density	Relative Dominance	Relative Frequency	IVI Value
1.	Banj	*Quercus incana*	16.67	0.00	17.78	11.48
2.	Pankhar	*Esculus indica*	2.38	3.44	4.44	3.42
3.	Walnut	*Juglans regia*	2.38	0.00	4.44	2.47
4.	Chir	*Pinus roxburghii*	8.33	6.89	8.89	8.03
5.	Palm	*Pheonix spp.*	1.19	0.00	2.22	1.13
6.	Deodar	*Cedrus deodara*	17.86	41.37	13.33	24.19
7.	Toona	*Cedrella toona*	5.95	3.44	6.66	5.39
8.	Sandan	*Oogenia dalbergoides*	1.19	0.00	2.22	1.13
9.	Cyprus	*Cupressess spp.*	1.19	3.44	2.22	2.28
10.	Acrot	-	1.19	0.00	2.22	1.13
11.	Sal	*Shorea robusta*	32.14	31.03	20.00	27.72
12.	Shishum	*Dalbergia sissoo*	4.76	3.48	6.66	4.95
13.	Teak	*Tectona grandis*	1.19	0.00	2.23	1.13
14.	Rohini	*Mallotus philipinensis*	1.19	0.00	2.23	1.13
15.	Sain	*Terminalia tomentosa*	1.19	3.47	2.23	2.22
16.	Bhimal	*Grewia regia*	1.20	3.44	2.23	2.20
			100.00	100.00	100.00	100.00

TABLE 4.7

STRUCTURE OF CITY VEGETATION

S.No.	Name of the Species: Common	Name of the Species: Scientific	Relative Density	Relative Dominance	Relative Frequency	IVI Value
1.	Cha	*Camellia thea*	29.53	59.16	19.56	36.10
2.	Shishum	*Dalbergia sissoo*	15.33	16.25	15.21	16.00
3.	Jamun	*Eugenia jambolana*	1.90	0.42	4.34	2.22
4.	Sain	*Terminalia tomentosa*	0.95	0.00	2.17	1.10
5.	Sal	*Shorea robusta*	31.43	16.66	23.91	21.00
6.	Kadu	*Clerodendron infortunatum*	3.81	0.00	8.69	4.50
7.	Ghaneri	*Lantana camera*	1.90	0.00	4.34	2.10
8.	B. coconut	*Sterculia alata*	4.75	5.84	4.34	6.00
9.	Silver Oak	*Grevillia robusta*	0.95	0.00	2.18	1.08
10.	Khajur	*Pheonix spp.*	1.90	0.00	2.18	1.40
11.	Kapoor	*Cinnamomum camphora*	0.95	0.42	2.18	1.20
12.	Chalta	*Alstonia scholaris*	0.95	0.00	2.18	1.08
13.	M.Champa	*Michelia champaka*	1.90	0.42	2.18	1.60
14.	Mango	*Mangifera indica*	0.95	0.42	2.18	1.20
15.	Bamboo	*Dendrocalamus strictus*	1.90	0.00	2.18	1.42
16.	Sandan	*Ougenia dalbergioides*	0.90	0.41	2.18	2.00
			100.00	100.00	100.00	100.00

TABLE 4.8

DIVERSITY FEATURES AT JAMSHEDPUR REGION

S. No.	Forests	Indices		
		Shannon Weiner	Equitability	Species Richness
1.	Dimna Forest (Near Reservoir)	0.41	0.41	0.40
2.	Dimna Forest-2	2.63	0.94	2.41
3.	Nutandih P.F.	2.22	0.64	2.80
4.	Nutandih P.F. (Near Chandil Dam)	2.83	0.79	2.98
5.	Dalma Pahar P.F. (Foot Hills)	3.11	0.87	2.98

TABLE 4.9

SIMILARITY INDICES OF THE FORESTS AT JAMSHEDPUR REGION

Forests	Dimna-1	Dimna-2	Nutandih-1	Nutandih-2	Dalma Pahar (Foot Hills
Dimna-1	1.00	0.20	0.31	0.29	0.14
Dimna-2	0.20	1.00	0.33	0.21	0.11
Nutandih-1	0.31	0.33	1.00	0.52	0.26
Nutandih-2	0.29	0.21	0.52	1.00	0.17
Dalma Pahar	0.14	0.11	0.26	0.17	1.00

TABLE 4.10

STRUCTURE OF DIFFERENT FOREST ZONES AT JAMSHEDPUR REGION

Common Name	Scientific Name	Relative Density	Relative Dominance	Relative Frequency	Sum	Importance Value Index
Dimna - 1						
Sal	*Shorea robusta*	91.67	97.93	75.00	264.59	88.20
Tendu	*Diospyros melanoxylon*	8.33	2.07	25.00	35.41	11.80
		100.00	100.00	100.00	300.00	100.00
Dimna - 2						
Kachnar	*Bauhinia retusa*	25.00	98.66	33.33	156.99	52.33
Palash	*Butea monosperma*	8.33	0.15	11.11	19.59	6.53
Asan	*Terminalia tomentosa*	8.33	0.26	11.11	19.71	6.57
Neem	*Azadirachta indica*	16.67	0.29	11.11	28.07	9.36
Peepal	*Ficus religiosa*	8.33	0.19	11.11	19.63	6.54
Sal	*Shorea robusta*	25.00	0.39	11.11	36.50	12.17
Siris	*Albizzia lebbeck*	8.33	0.07	11.11	19.51	6.50
		100.00	100.00	100.00	300.00	100.00
Nutandih - 1						
Asan	*Terminalia tomentosa*	15.26	15.26	13.33	43.85	14.62
Bhelwa	*Semicarpus anacardium*	0.49	0.49	3.33	4.32	1.44
Chironji	*Buchanania lanzan*	2.62	2.62	3.33	8.57	2.86
Dhaura	*Anogeissus latifolia*	7.57	7.57	3.33	18.48	6.16
Galgal	*Cochlospermum gossypium*	35.23	35.23	3.33	73.79	24.60
Hartaki	-	2.98	2.98	3.33	9.30	3.10
Karka	-	0.29	0.29	3.33	3.92	1.31
Mahua	*Madhuca latifolia*	15.09	15.09	30.00	60.19	20.06

CONTD....

TABLE 4.10 CONTD...

Common Name	Scientific Name	Relative Density	Relative Dominance	Relative Frequency	Sum	Importance Value Index
Sal	*Shorea robusta*	1.82	1.82	30.00	33.64	11.21
Siris	*Albizzia lebbeck*	1.78	1.78	3.33	6.90	2.30
Tendu	*Diospyros melanoxylon*	16.85	16.85	3.33	37.04	12.35
		100.00	100.00	100.00	300.00	100.00

Nutandih - 2

Common Name	Scientific Name	Relative Density	Relative Dominance	Relative Frequency	Sum	Importance Value Index
Aasan	*Terminalia tomentosa*	0.15	0.15	3.33	3.64	1.21
Chirongi	*Buchanania lanzan*	38.49	38.49	6.67	83.65	27.88
Dau	*Artocarpus lakoocha*	1.76	1.76	6.67	10.18	3.39
Dhak	*Butea monosperma*	9.11	9.11	16.67	34.88	11.63
Dhaora	*Anogeissus latifolia*	0.32	0.32	6.67	7.30	2.43
Jamun	*Eugenia jambolina*	21.04	21.04	6.67	48.75	16.25
Kurchi	*Holarrhena antidysentrica*	0.56	0.56	3.33	4.45	1.48
Mahua	*Madhuca latifolia*	1.37	1.37	6.67	9.40	3.13
Ratangarur	*Etaedendron glaucum*	0.30	0.30	3.33	3.94	1.31
Sal	*Shorea robusta*	26.07	26.07	26.67	78.82	26.27
Sidha	-	0.68	0.68	10.00	11.36	3.79
Tendu	*Diospyros melanoxylon*	0.15	0.15	3.33	3.64	1.21
		100.00	100.00	100.00	300.00	100.00

Dalma Pahar Patamda

Common Name	Scientific Name	Relative Density	Relative Dominance	Relative Frequency	Sum	Importance Value Index
Amattas	*Cassia fistula*	1.36	1.36	2.94	5.65	1.88
Bamboo	*Dendrocalamus strictus*	0.66	0.66	2.94	4.27	1.42
Bhaura	-	0.00	0.00	2.94	2.94	0.98
Dhaura	*Anogeissus latifolia*	23.09	23.09	14.71	60.88	20.29
Doka	*Lanner spp.*	0.09	0.09	14.71	14.88	4.96

CONTD...

TABLE 4.10 CONTD...

Common Name	Scientific Name	Relative Density	Relative Domina-nce	Relative Freque-ncy	Sum	Importance Value Index
Harmo Doka	*Lanner grandis*	0.01	0.01	2.94	2.96	0.99
Kachnar	*Bauhinia variegata*	5.42	5.42	2.94	13.79	4.60
Karam	*Adina cardifolia*	4.86	4.86	17.65	27.37	9.12
Karami	-	0.00	0.00	8.82	8.83	2.94
Padasi	*Cleistanthus collinus*	34.32	34.32	17.65	86.29	28.76
Siris (white)	*Albizzia procera*	24.77	24.77	8.82	58.36	19.45
Tendu	*Diospyros melanoxylon*	5.42	5.42	2.94	13.79	4.60
		100.00	100.00	100.00	300.00	100.00

TABLE 4.11

STRUCTURE OF JAMSHEDPUR FOREST REGION

Common Name	Scientific Name	Relative Density	Relative Dominance	Relative Frequency	Importance Value Index
Sal	*Shorea robusta*	36.14	31.55	35.69	34.46
Tendu	*Diospyros melanoxylon*	7.68	6.12	8.65	7.49
Kachnar	*Bauhinia retusa*	15.26	12.54	18.13	28.46
Palash	*Butea monosperma*	8.33	0.15	11.11	6.53
Asan	*Terminalia tomentosa*	7.91	5.22	9.25	7.46
Neem	*Azadirachta indica*	16.67	0.29	11.11	9.36
Peepal	*Ficus religiosa*	8.33	0.19	11.11	6.54
Siris	*Albizzia lebbeck*	11.62	8.87	7.75	9.41
Bhelwa	*Semicarpus anacardium*	0.49	0.49	3.33	1.44
Chironji	*Buchanania lanzan*	20.55	20.55	5.00	14.66
Dhaura	*Anogeissus latifolia*	10.32	10.32	28.23	9.62
Galgal	*Cochlospermum gossypium*	35.23	35.23	3.33	24.60
Mahua	*Madhuca latifolia*	8.23	8.23	18.33	11.59
Dhaora	*Anogeissus latifolia*	10.32	10.32	5.00	4.29
Jamun	*Eugenia jambolina*	21.04	21.04	6.67	16.25
Kurchi	*Holarrhena antidysentrica*	0.56	0.56	3.33	1.48
Amaltas	*Cassia fistula*	1.36	1.36	2.94	1.88
Bamboo	*Dendrocalamus*	0.66	0.66	2.94	1.42
Karam	*Adina cordifolia*	4.86	4.86	17.65	9.12
Padasi	*Cleistanthus*	34.32	34.32	17.65	28.76

The Importance Value Index Values for different forest ranges at Doon Valley Region **(Table 4.3)** depicts that Sal (*Shorea robusta*) is the most important species at almost all the sampling stations except at Mohand Forest Range, IIP Guest House, Arcadia Tea Garden, Circuit House, Mussoorie, Kempty, and Jaunpur. Khair (*Acacia catecheu*) and Sissoo (*Dalbergia sissoo*) are the most important species at Mohand Forest, Buddha's coconut (*Sterculia alata*) being at Circuit House, Banj (*Quercus incana*) at Mussoorie, Toona (*Cedrella toona*) at Kempty, Deodar (*Cedrus deodara*) at Jaunpur, and Cha (*Camellia thea*) is the most important species at IIP Guest House, Mokhampur, and at Arcadia tea Garden, Premnagar.

The geographical, physical features and the altitudinal variations have resulted in the formation of two distinct floristic zones in the hill region. In the Siwaliks, the main forest type is the dry deciduous forest. Sal is the dominant species, and it can be broadly classified into Doon Valley Sal and Siwalik Sal. But, with the Champion and Seth's Classification, there are three sub-types viz. Moist Siwalik Sal Forest, Moist Bhabhar Doon Sal Forest and Dry Siwalik Sal Forest. The Forests at Doon Valley Region mainly fall under Moist Siwalik Sal Forest type, Moist Bhabhar Doon Sal Forest type, and Khair-Sissoo Forest Type.

Sal (*Shorea robusta*), is the most important species in all the three forest divisions viz. Dehradun (73.30), Siwalik (63.12), Mussoorie (27.72), whereas Cha (*Camellia thea*) is the most important species in the city region

Fig. 4·1 : Relative Distribution of Major Tree Species at Doon Valley Region

FORESTS	DENSITY OF TREE / 100 m²	Shorea robusta	Terminalia tomentosa	Anogeissus latifolia	Diospyros melanoxylon	Cleistanthus collinus	Butea monosperma	Buchanania lanzan	Adina cardifolia	Albizzia sp.	Others
DIMNA - I	1.10	••••••••••		•	•						
DIMNA - 2	0.29	•••	•				•			•	•••••
NUTANDIH - I	18.41	•	••	•	••			•		•	•••••
NUTANDIH - 2	3.83	••	•	•	•		•	••••			
DALMA PAHAR	3.73			•••	•	••••			•	•••	•

LEGEND

(empty)	ABSENT
•	0 UP TO 10%
••	10 TO 20%
•••	20 TO 30%

FIG. 4·2 : RELATIVE DISTRIBUTION OF MAJOR TREES IN STUDY AREA
(JAMSHEDPUR REGION))

(36.10) **(Table 4.4. through 4.7 and Graphs 4.1 through 4.4).**

4.1.2 Jamshedpur Region

Dalma Forest region shows the highest diversity with SWDI value of 3.11 and EI of 0.87, while the lowest diversity being at Dimna forest (0.41) with an equal EI value **(Table 4.8).**

Table 4.9 gives the details of similarity index observed between two different forest stands. Nutandih 1 and Nutandih 2 are most similar forests with a high value of 0.52, and on the other hand the most dissimilar forests are Dimna 2 and Dalma Pahar with a value of 0.11 followed by Dimna 1 and Dalma Pahar with a value of 0.14. The dissimilarity in these forests can be attributed to the different physical features and altitudinal variations. Relative distribution of major trees observed in study area is depicted in **Figure. 4.2**

Table 4.10 gives the values of the importance value index of Dimna 1 forest, where it has been observed that (Sal) *Shorea robusta* is the most dominant (97.93) and most frequent plant (75.00) with an IVI value of 88.20. Most important plants at Dimna 2 forest are *Bauhinia retusa* and *Shorea robusta* with an IVI value of 52.33 and 12.17 respectively. *Bauhinia retusa* is the most dominant (98.66) plant in the forest.

The most important plants at Nutandih 1 is *Cochlospermum gossypium* and *Madhuca latifolia* with IVI values of 24.60 and 20.06, respectively. Whereas, at Nutandih-2 the important plants are *Buchanania lanzan*, *Shorea robusta* and *Eugenia jambolana* with IVI and dominance values of 27.88, 26.27, 16.25 and 38.49, 26.07 & 21.04 respectively.

In Dalma Pahar, Patamda Forest, *Cleistanthus collinus* is the most dominant and important species dominance and IVI values of 34.32 and 28.76 respectively; followed by *Anogeissus latifolia* and *Albizzia procera* with dominance and IVI values of 23.09, 24.77 and 20.29, 19.45 respectively. The least important plant is Bhaura with a value of 0.98. The most important species at Jamshedpur region are Sal (*Shorea robusta*) (34.46), Padasi (*Cleistanthus collinus*) (28.70), Kachnar (*Bauhinia retusa*) (28.46), Galgal (*Cochlospermum gossypium*) (24.60) **(Table 4.11 and Graph 4.5)**.

4.1.3 NCR - Delhi Region

Since Delhi City has mainly artificial vegetation the sampling technique adopted here varies from that of Doon Valley and Jamshedpur Regions. The sampling points which were chosen for vegetation survey are mainly roadside avenues which were exposed to heavy vehicular pollution, and parks and gardens which were relatively pollution-free. **Table 4.12** gives the details of the dominant species found in the Delhi Region, which were enlisted through extensive field survey and by laying quadrats of 25x50 meters. in the selected sampling stations within the city region.

TABLE 4.12

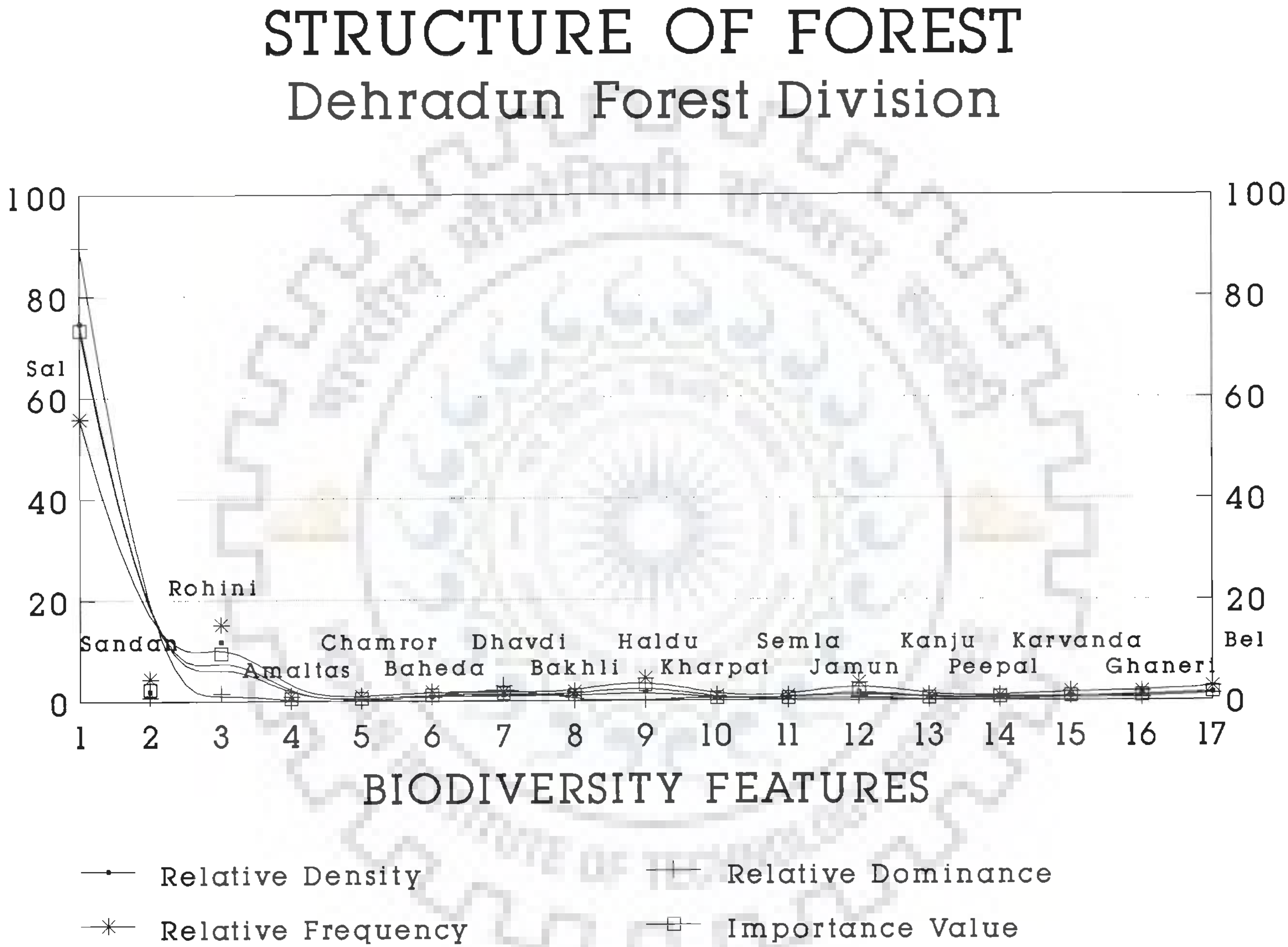
DOMINANT SPECIES IN VARIOUS SAMPLING SITES IN DELHI

S. No.	Name of the sampling site	Name of the dominant species: Common Name	Botanical Name
1.	Malka Ganj, Sabji mandi	Australian babul	*Acacia melanoxylon*
		Cassia	*Cassia saemia*
		Papri	*Pongamia pinnata*
		Kabuli kikar	*Prosopis juliflora*
2.	Idgah Faiz Road	Peepal	*Ficus religiosa*
		Papri	*Pongamia pinnata*
		Safeda	*Eucalyptus* spp.
		Kijelia	*Kijelia pinnata*
3.	Mori Gate Park	Peepal	*Ficus religiosa*
		Jamun	*Eugenia jambolana*
		Palm	*Roystonea* spp.
		Ashok	*Polyalthia longifolia*
4.	Qudesia Bagh	Ashok	*Polyalthia longifolia*
		Jarul	*Lagerstroemia* spp.
		Bougainvillea	*Bougainvillea* spp.
5.	Humayun's Tomb	Neem	*Azadirachta indica*
		Pitrunia	*Pitrunjia roxburghii*
		Shisham	*Dalbergia sissoo*
6.	Purana Qila	Kikar	*Prosopis* spp.
		Bamboo	*Bambusa* spp.
		Bottle brush	*Callistemon lanceolatus*

Contd...

Table 4.12 (Contd...)

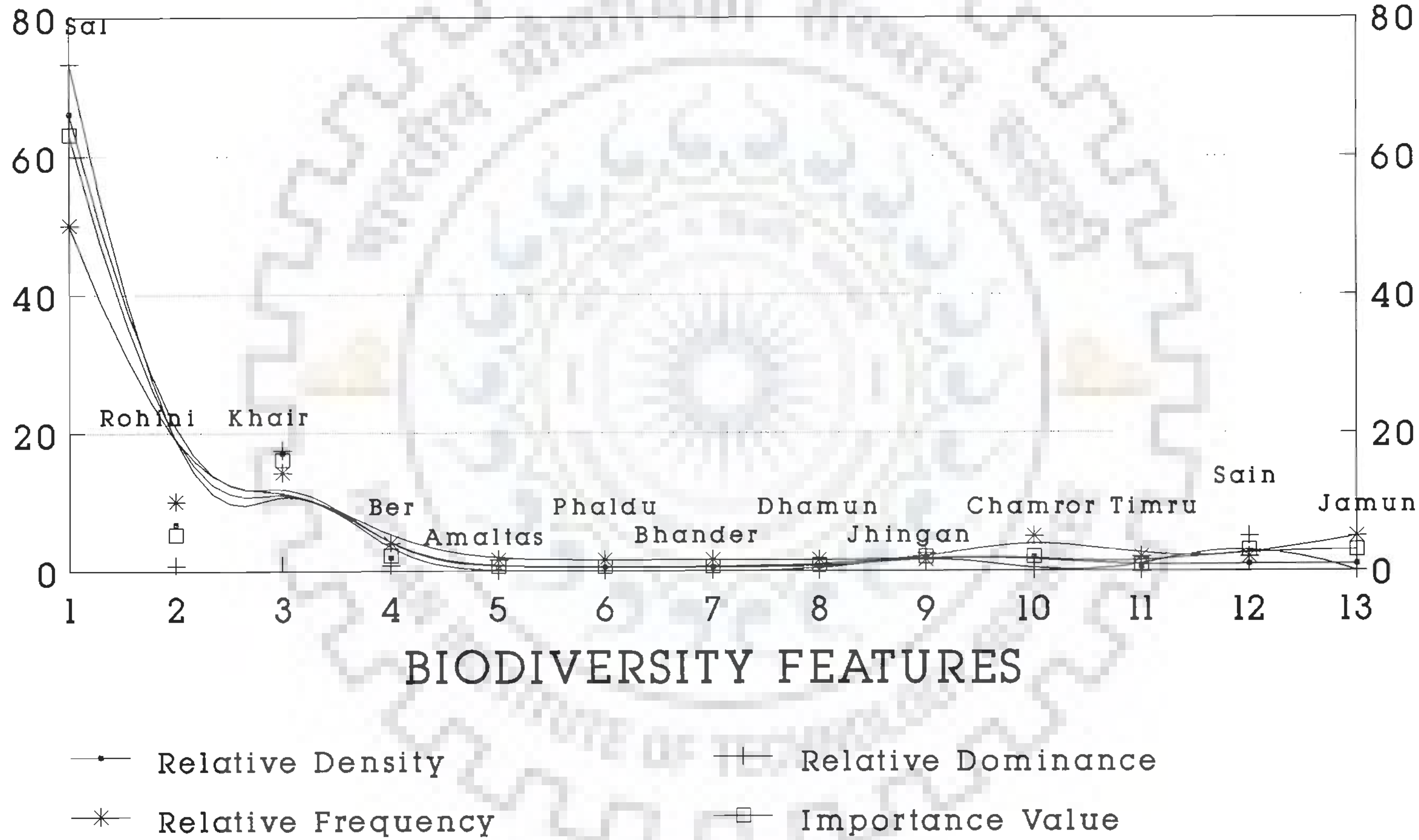
S. No.	Name of the sampling site	Name of the dominant species: Common Name	Botanical Name
7.	Connaught Place	Peepal Kikar Jamun Kaner	*Ficus religiosa* *Prosopis* spp. *Eugenia jambolana* *Nerium* spp.
8.	Punjabi Bagh	Amaltas Safeda Papri Neem	*Cassia fistula* *Eucalyptus* spp. *Pongamia pinnata* *Azadirachta indica*
9.	Greater Kailash	Safeda Kikar Peepal	*Eucalyptus* spp. *Prosopis* *Ficus religiosa*
10.	K.S.Krishnan Marg, Pusa	Safeda Acacia	*Eucalyptus* spp. *Acacia* spp.
11.	S.Ridge, Rajendra Nagar Pusa Hill	Kikar Papri Ashok	*Prosopis* *Pongamia pinnata* *Polyalthia longifolia*
12.	Talkatora Garden	Siris Kabuli kikar Acacia	*Albizzia procera* *Prosopis juliflora* *Acacia* spp.
13.	Lodi Garden	Kikar Acacia Bamboo	*Prosopis* *Acacia* spp. *Bambusa* spp.
14.	Palam Airport	Acacia Kikar Mango	*Acacia* spp. *Prosopis* *Mangifera indica*


STRUCTURE OF FOREST
Dehradun Forest Division
100
80
60
40
20
0
Sal
Sandan
Rohini
Amaltas
Chamror
Baheda
Dhavdi
Bakhli
Haldu
Kharpat
Semla
Jamun
Kanju
Peepal
Karvanda
Ghaneri
Bel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
BIODIVERSITY FEATURES
Relative Density
Relative Dominance
Relative Frequency
Importance Value

Graph : 4.1

STRUCTURE OF FOREST

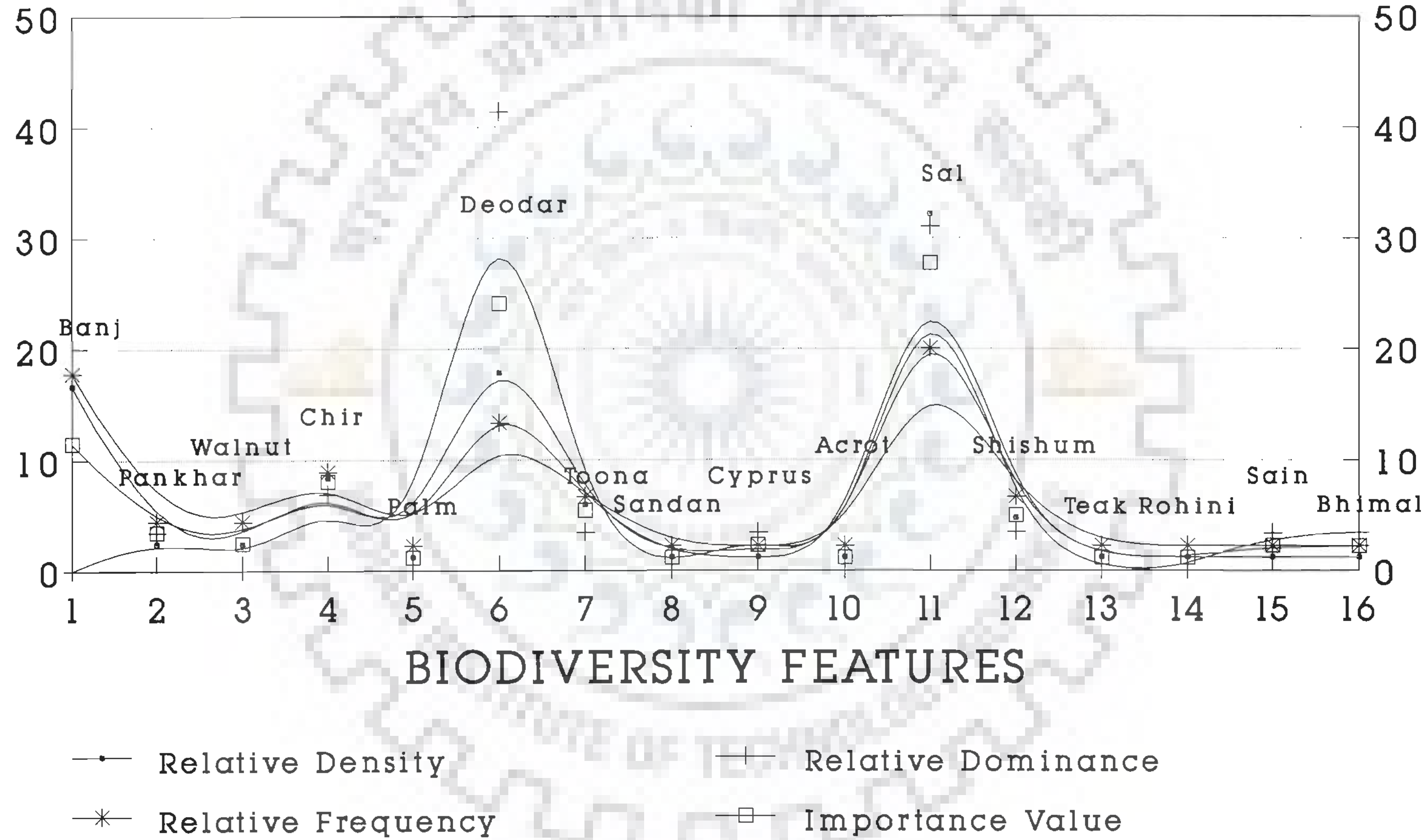
Siwalik Forest Division



Graph : 4.2

STRUCTURE OF FOREST

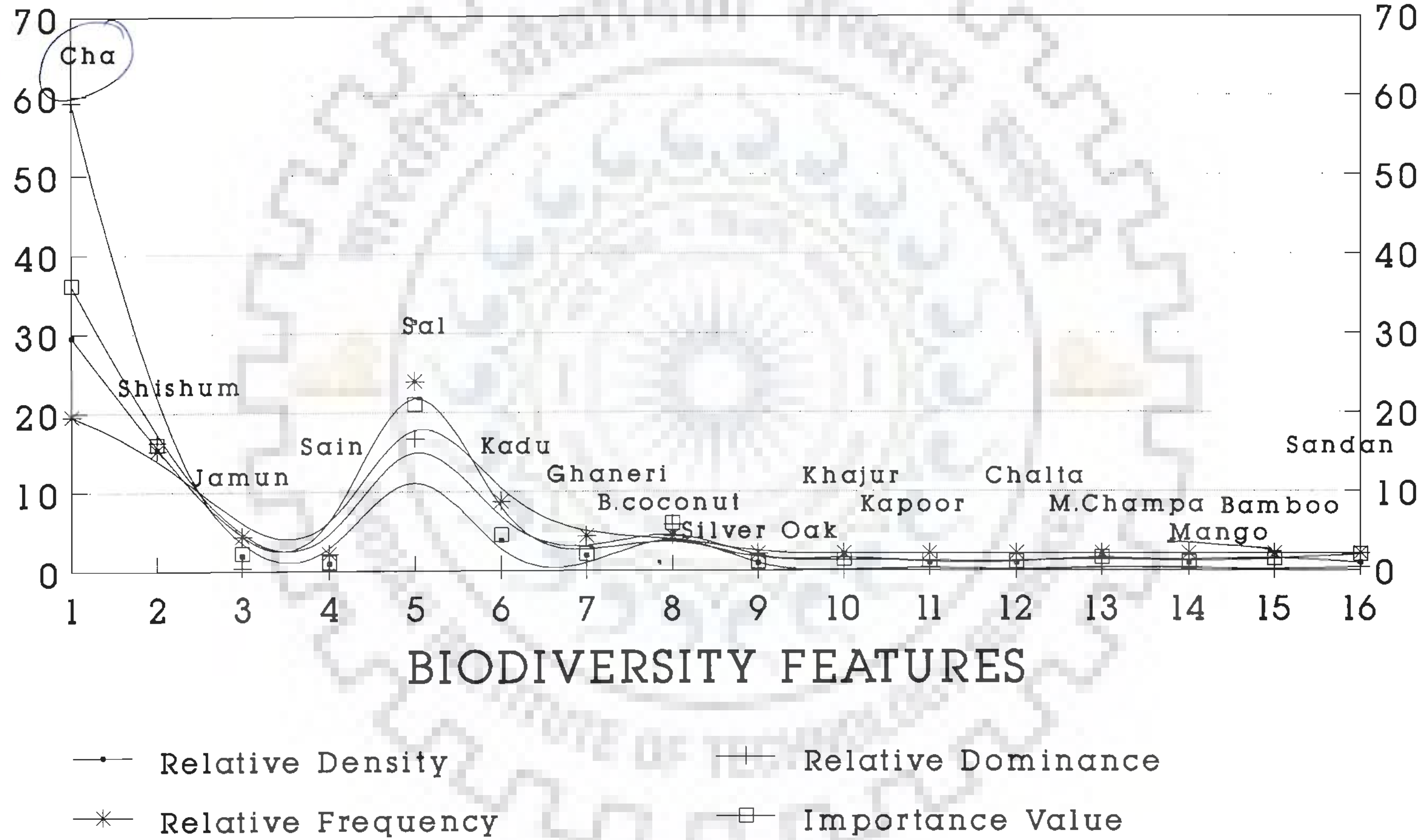
Mussoorie Forest Division



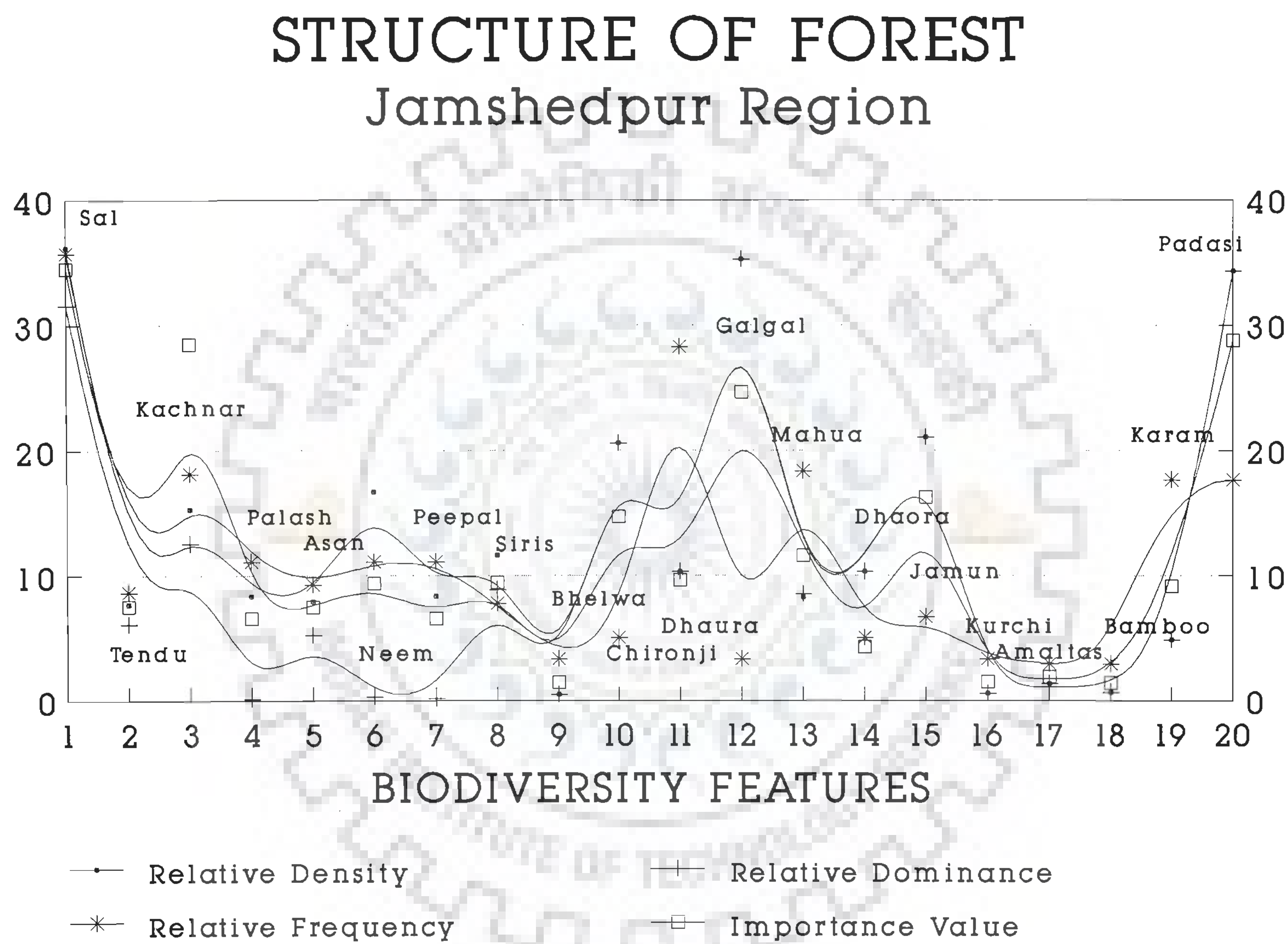
Graph : 4.3

STRUCTURE OF CITY VEGETATION

Doon Valley Region



Graph : 4.4


STRUCTURE OF FOREST
Jamshedpur Region
Sal
Padasi
Galgal
Kachnar
Mahua
Karam
Palash
Peepal
Asan
Siris
Dhaora
Jamun
Bhelwa
Dhaura
Kurchi
Bamboo
Tendu
Neem
Chironji
Amaltas
BIODIVERSITY FEATURES
Relative Density
Relative Dominance
Relative Frequency
Importance Value

Graph : 4.5

4.2 ESTIMATION OF SINK POTENTIAL INDEX

Plant leaves have evolved to function as efficient gas exchange systems, having large surface area bearing stomatal pores and with an internal structure which allows rapid diffusion of water and soluble gases. The diffusion of a gas and its assimilation by vegetation is strongly dependent on the frequency and size of stomata [133, 183 & 348]. Sink Potential Index [229] for dominant species representing all the three regions are reported in (**Table 4.13**).

4.2.1 Doon Valley Region

Sterculia alata (Buddha's Coconut) has the highest Sink Potential Index value of 151.00 mm^{-2} at Circuit House, City Region, followed by *Shorea robusta* (Sal) at Siwalik, Dehradun, Mussoorie Forest Divisions, and the City region with SPI values of 136.00, 124.50, 118.50 and 118.50 mm^{-2}, respectively.

4.2.2 Jamshedpur Region

Banyan (*Ficus bengalensis*) at Bistupur and Jugsalai Railway station, showed the SPI values of 145.85 and 139.70 mm^{-2}, respectively. Sal (*Shorea robusta*) at Dimna Forest showed SPI values of 144.50 mm^{-2}. Kurchi (*Holarrhena antidysentrica*) at TELCO Industrial Area, and Mango had SPI values of 139.50 and 98.38 mm^{-2}, respectively. Padasi (*Cleistanthus collinus*) at Dalma Forest showed the least SPI i.e. 64.50 mm^{-2}, followed by Chironji's (*Buchanania lanzan*) at Nutandih Forest (93.50 mm^{-2}).

SINK POTENTIAL INDEX FOR DOMINANT SPECIES (Pg 116 - 4.2)

TABLE 4.13

SINK POTENTIAL INDEX VALUES FOR DIFFERENT ZONES

Sampling Zone	Common Name	Scientific Name	Sink Potential Index (mm^{-2})
Doon Valley Region			
Dehradun Forest Division	Sal	*Shorea robusta*	124.50
Siwalik Forest Division	Sal	*Shorea robusta*	136.00
Dehradun City	Sal	*Shorea robusta*	118.50
Arcadia Tea Garden Premnagar	Cha	*Camellia thea*	72.00
Circuit House	Buddha's Coconut	*Sterculia alata*	151.00
Mussoorie Forest Division	Sal	*Shorea robusta*	118.50
Jamshedpur Region			
1. Dalma Forest	Padasi	*Cleistanthus collinus*	64.50
2. Nutandih Forest	Chironji	*Buchanania lanzan*	98.50
3. Dimna Forest	Sal	*Shorea robusta*	144.50
4. TELCO I. Area	Kurchi	*Holarrhena antidysenterica*	139.50
5. Bistupur	Banyan	*Ficus bengalensis*	145.85
6. Jugsalai Rly. Stn.	Banyan	*Ficus bengalensis*	139.70
7. Mango	Kurchi	*H. antidysenterica*	98.38
8. Kalimandir	Kurchi	*H. antidysenterica*	89.25
National Capital Region - Delhi			
1. Malka Ganj (old)	Australian Babul	*Acacia melanoxylon*	128.50
2. Humayun's Tomb, Nizamuddin	Neem	*Azadirachta indica*	169.50
3. Connaught Place	Jamun	*Eugenia jambolana*	173.50

CONTD...

TABLE 4.13 CONTD...

Sampling Zone		Common Name	Scientific Name	Sink Potential Index (mm^{-2})
4.	Punjabi Bagh	Amaltas	*Cassia fistula*	95.00
5.	Greater Kailash	Peepal	*Ficus religiosa*	41.00
6.	Lodi Garden	Bamboo	*Dendrocalamus strictus*	99.00
7.	Qudesia Bagh	Ashok	*Polyalthia longifolia*	87.50
8.	Mori Gate Park	Peepal	*Ficus religiosa*	41.00
9.	Idgah Faiz Road	Peepal	*Ficus religiosa*	46.55
10.	South Ridge	Kabuli Kikar	*Prosopis juliflora*	33.55
11.	Purana Killa	Bamboo	*Dendrocalamus strictus*	93.10
12.	Dr. Krishnan Marg	Neem	*Azadirachta indica*	162.05
13.	Talkatora Garden	Siris	*Albizzia procera*	139.70
14.	Shahzada Bagh	Peepal	*Ficus religiosa*	72.65
15.	Paharganj	Peepal	*Ficus religiosa*	74.50
16.	Netaji Nagar	Peepal	*Ficus religiosa*	175.10
17.	Town Hall	Peepal	*Ficus religiosa*	74.50
18.	Janpath	Peepal	*Ficus religiosa*	63.35
19.	Najafgarh Industrial Area	Peepal	*Ficus religiosa*	80.10
20.	Mayaprui Industrial Area	Peepal	*Fisuc religiosa*	65.70
21.	Mayapuri	Neem	*Azadirachta indica*	156.50
22.	Ashok Vihar	Peepal	*Ficus religiosa*	87.55
23.	Shakoor Basti	Peepal	*Ficus religiosa*	44.70
24.	Janakpuri	Peepal	*Ficus religiosa*	169.50
25.	Connaught Place (Palika Bazar)	Peepal	*Ficus religiosa*	54.00

4.2.3 NCR - Delhi Region

Peepal (*Ficus religiosa*) at Netaji Nagar has the highest value of SPI (175.10 mm^{-2}) and 169.50 mm^{-2} at Janakpuri. Jamun (*Eugenia jambolana*) at Connaught Place showed 173.50 mm^{-2}, whereas Neem (*Azadirachta indica*) at Humayum's Tomb, Dr. Krishnan Marg, and at Mayapuri showed SPI values of 169.50, 162.05 and 156.50 mm^{-2}, respectively. The minimum SPI value (33.55 mm^{-2}) was found in Kabuli Kikar (*Prosopis juliflora*) at South Ridge, followed by Peepal (*Ficus religiosa*) at Greater Kailash and Mori Gate Park (41.00 mm^{-2}), Shakoor Basti (44.70 mm^{-2}), Idgah Faiz Road (46.55 mm^{-2}), and Palika Bazar (54.00 mm^{-2}).

It was mainly because of these variations that species-specific investigations for dominant species were undertaken for quantifying SPI as a function of species-specific stomatal density.

4.3 ESTIMATION OF ASSIMILATIVE CAPACITY OF THE ECOSYSTEMS

Assimilative Capacity (AC) values for all the three regions as also the input values are presented in **Tables 4.14** and 4.15 and **Figures** 4.3 through 4.6.

4.3.1 Doon Valley Region

It is observed that the Mussoorie Forest Division has the least assimilative capacity (2.02 $m^4\mu g^{-1}s^{-1}$), followed by City Region (2.11 $m^4\mu g^{-1}s^{-1}$), highest being at Siwalik Forest (7.15 $m^4\mu g^{-1}s^{-1}$). Least Assimilative Capacity at Mussoorie is indicative of its exposure to more pollutants

TABLE 4.14

S. No.	Forest Zones	Dominant Species: Common	Dominant Species: Scientific	Stomatal Features: b (µm)	a (µm)	L (µm)	N (mm^{-2})	RIVI	SO_2 (μgm^{-3})
DOON VALLEY REGION									
1.	Dehradun Division	Sal	*Shorea robusta*	11.73	20.56	11.22	334.90	1.00	40.00
2.	Siwalik Division	Sal	*Shorea robusta*	11.59	19.96	10.68	377.20	0.86	28.00
3.	Mussooire Division	Sal	*Shorea robusta*	14.11	23.18	16.80	445.00	0.38	48.00 ?
4.	City Region	Cha	*Camellia thea*	17.34	33.94	20.83	195.00	0.50	38.00
DELHI REGION : NCR									
1.	Humayums Tomb	Jamun	*Eugenia spp.*	19.15	30.24	16.46	465.00	-	9.20
2.	Maharani Bagh	Neem	*Azadirachta indica*	19.82	30.24	12.69	455.00	-	23.40
3.	Najafgarh I.A.	Peepal	*Ficus religiosa*	18.48	29.57	21.84	215.00	-	37.20
4.	Netaji Nagar	Banyan	*Ficus bengalensis*	19.82	25.54	15.79	470.00	-	36.50
5.	Ashok Vihar	Neem	*Azadirachta indica*	16.80	25.87	12.76	465.00	-	16.30
6.	Janakpuri	Jamun	*Eugenia spp.*	15.79	26.21	16.13	455.00	-	17.20
7.	Town Hall	Peepal	*Ficus religiosa*	19.15	26.21	19.82	200.00	-	90.30
8.	Shakoor Basti	Peepal	*Ficus religiosa*	16.13	31.58	25.54	120.00	-	13.20
9.	Punjabi Bagh	Amaltas	*Cassia spp.*	11.76	22.51	15.79	450.00	-	16.00
10.	Shahzada Bagh	Peepal	*Ficus religiosa*	13.78	22.51	16.80	195.00	-	17.70
JAMSHEDPUR REGION									
1.	Dimna (Sonari)	Sal	*Shorea robusta*	11.75	17.46	9.07	390.00	1.00	35.00
2.	Nutandih (Deoghar)	Chironji	*Buchanania lanzan*	8.70	12.44	6.50	265.00	0.32	7.00
3.	Dalmapahar (Asaboni)	Padasi	*Cleistanthus collinus*	18.48	26.88	15.79	175.00	0.33	9.00

CONTD...

TABLE 4.14 CONTD...

S. No.	Forest Zones	Dominant Species		Stomatal Features				RIVI	SO_2 (μgm^{-3})
		Common	Scientific	b	a	L	N		
				(μm)			(mm^{-2})		
CITY ZONES									
1.	TELCO I. Area	Kurchi	*H.antidysnetrica*	14.11	29.90	19.82	375.00	-	29.00
2.	Bistupur	Banyan	*Ficus bengalensis*	18.48	30.58	15.46	390.00	-	73.00
3.	Jugsalai Rly.	Banyan	*Ficus bengalensis*	18.14	26.21	12.77	375.00	-	88.00
4.	Mango	Kurchi	*Holarrhena antidysentrica*	18.82	23.52	7.39	265.00	-	31.00
5.	Kalimandir	Kurchi	*H.antidysentrica*	10.08	19.15	11.09	239.50	-	9.00

TABLE 4.15

Values of Assimilative Capacity (AC), Ecosystem-Health Exposure-Risk (EHER), Stomatal Resistance (Rsm) and O_3 for Doon Valley Region

Zone/Region	Species	O_3^* ($\mu g m^{-3}$)	R_{sm} ($s cm^{-1}$)	ACM ($m^4 \mu g^{-1} s^{-1}$)	EHER ($\mu g m^{-2} s^{-1}$)
<u>DOON VALLEY REGION</u>					
Dehradun	Sal	182.44	6.95	5.25	17.50
Siwalik	Sal	130.71	6.11	7.15	14.20
Mussoorie	Sal	216.93	5.77	2.02	25.00
City Region	Cha	173.82	9.08	2.11	12.74
<u>NCR REGION</u>					
Humayums Tomb	Jamun	49.68	3.05	43.80	10.81
Maharani Bagh	Neem	110.89	2.32	25.80	31.70
Najafgarh Area	Peepal	170.37	9.29	4.20	12.20
Netaji Nagar	Banyan	167.36	3.31	12.00	33.59
Ashok Vihar	Neem	80.28	3.15	26.23	16.91
Janakpuri	Jamun	84.17	4.28	18.45	13.07
Town Hall	Peepal	399.30	9.87	1.69	26.90
Shakoor Basti	Peepal	66.92	20.89	4.76	2.13
Punjabi Bagh	Amaltas	78.99	6.63	12.70	7.93
Shahzada Bagh	Peepal	86.32	13.88	5.55	4.13
<u>JAMSHEDPUR REGION</u>					
Forest Zones					
Dimna	Sal	160.89	5.66	7.29	18.90
Nutandih	Chironji	40.20	11.33	4.68	2.36
Dalma Pahar	Padasi	48.81	9.08	4.95	3.57
City Zones					
TELCO I. Area	Kurchi	135.02	6.26	7.86	14.33

CONTD....

TABLE 4.15 CONTD....

Zone/Region	Species	O_3^* (μgm^{-3})	R_{sm} (scm^{-1})	ACM ($m^4\mu g^{-1}s^{-1}$)	EHER ($\mu gm^{-2}s^{-1}$)
Bistupur	Banyan	324.68	3.51	5.84	61.60
Jugsalai Rly. Stn.	Banyan	389.35	3.58	4.77	72.30
Mango	Kurchi	143.65	3.15	14.70	30.33
Kalimandir	Kurchi	48.82	11.99	11.36	2.71

* Predicted Values

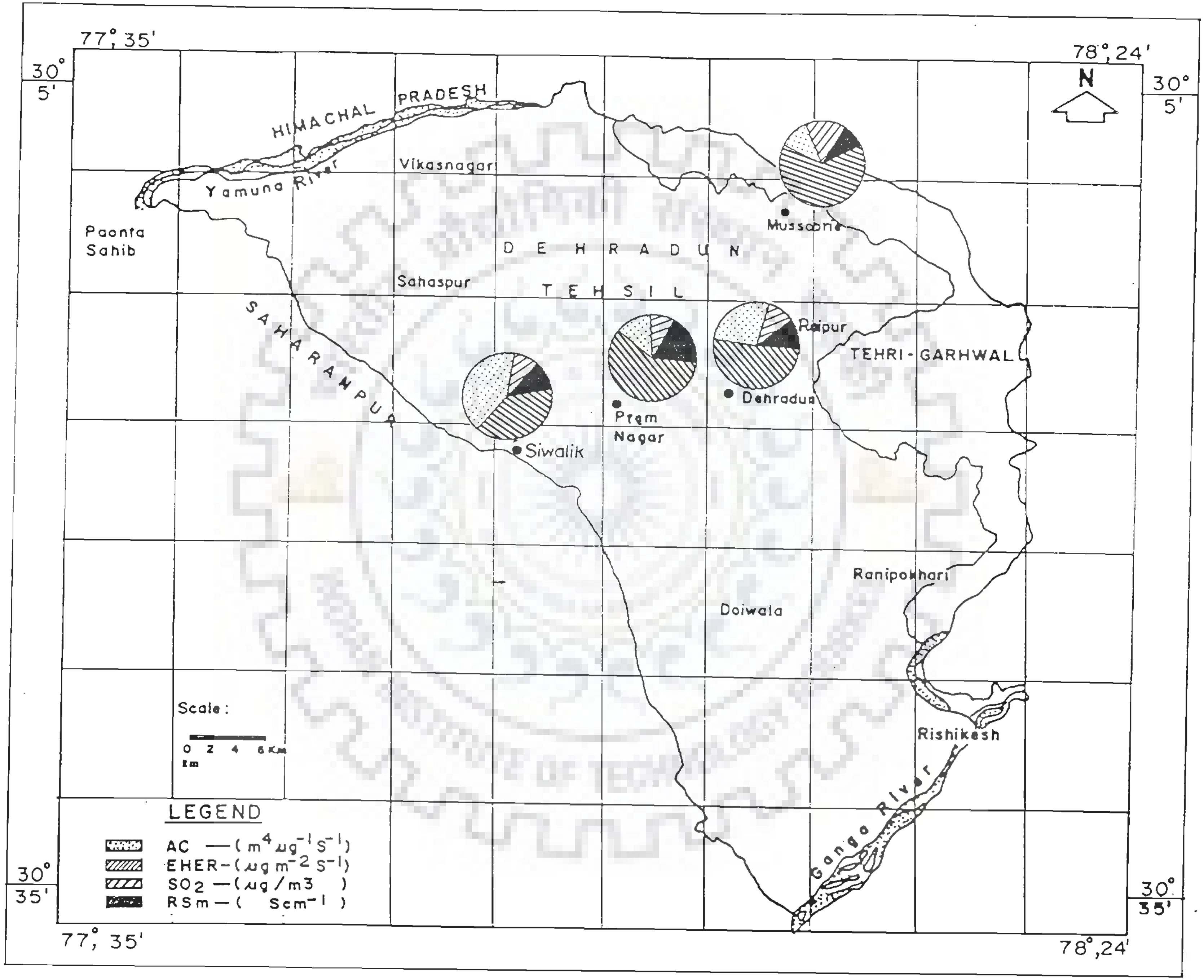


FIG. 4·3 : DOON VALLEY REGION

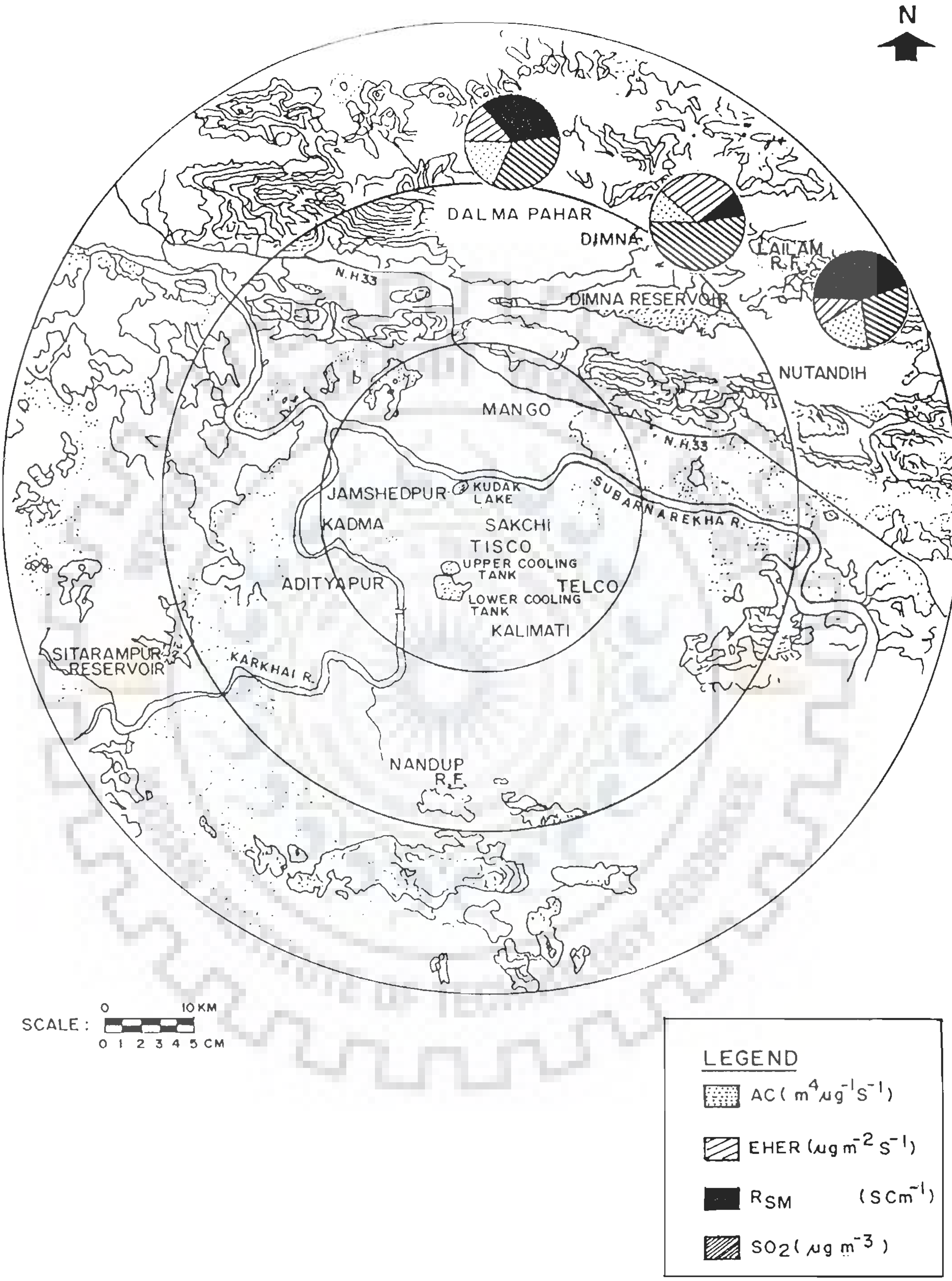


FIG. 4·4 JAMSHEDPUR - FOREST REGION

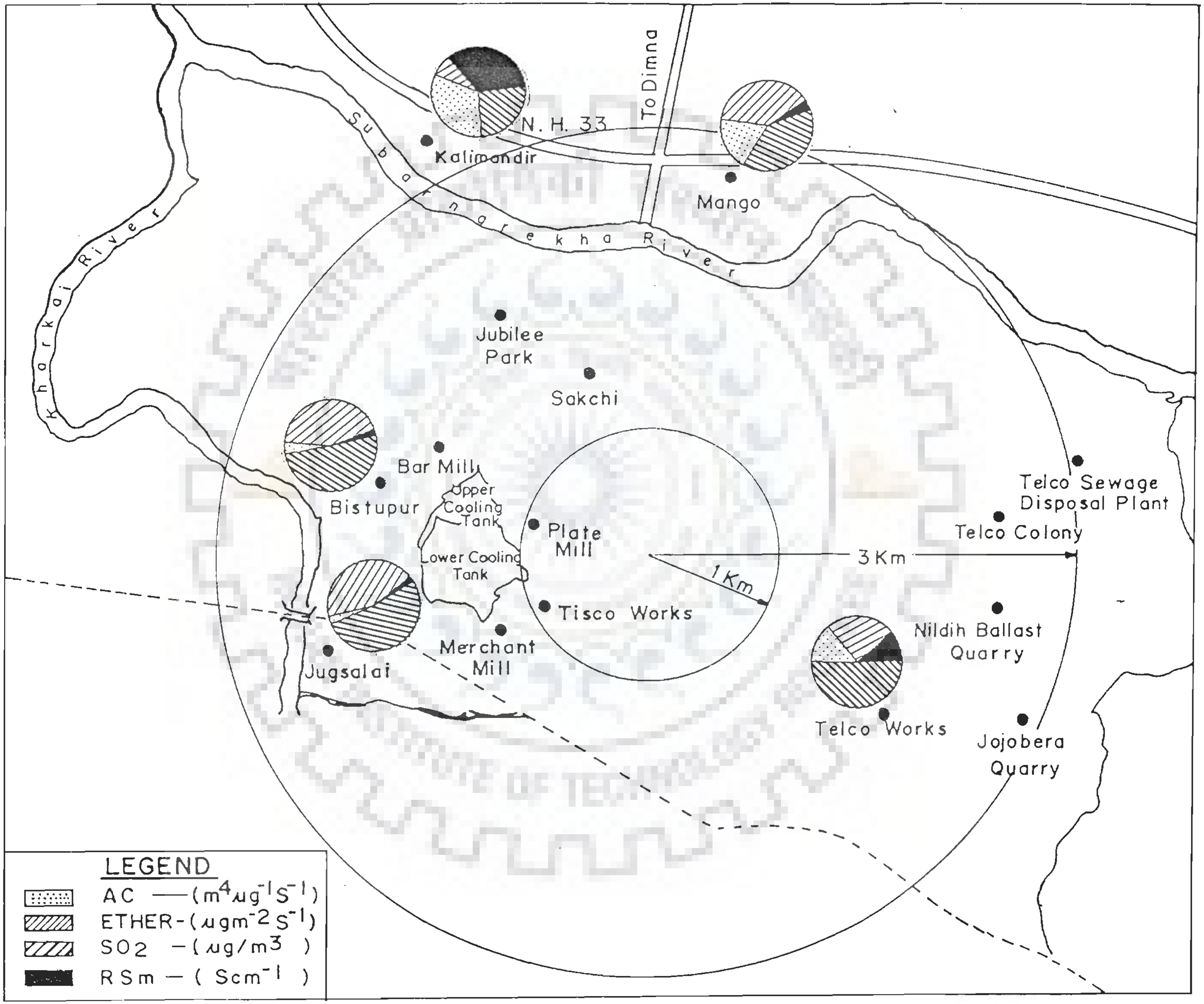


FIG. 4·5 : JAMSHEDPUR - CITY REGION

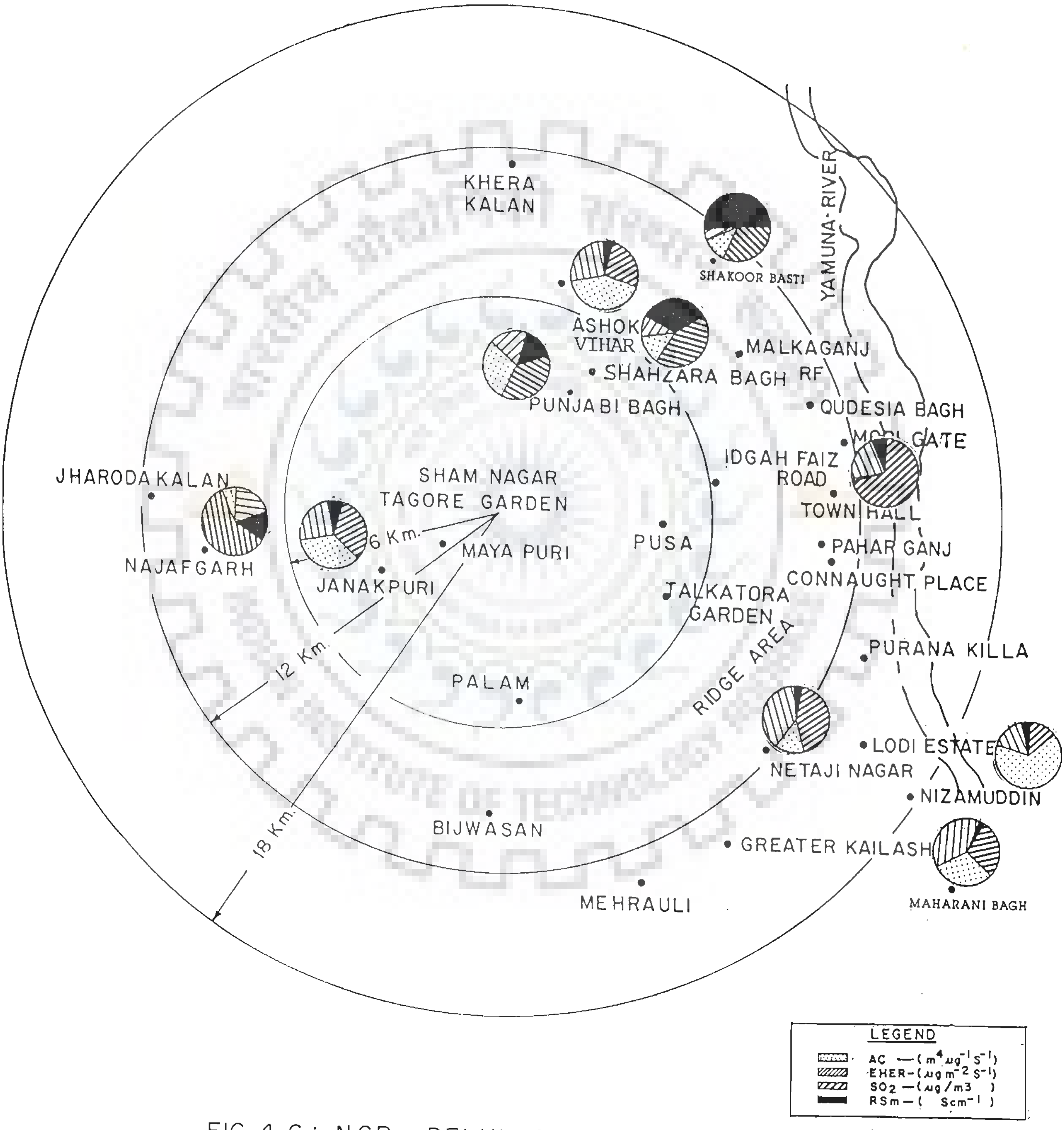


FIG. 4·6 : NCR - DELHI REGION

as is evident through EHER values (25.00 $\mu gm^{-2}s^{-1}$) also. Highest value of Assimilative Capacity at Siwalik Region (7.15 $\mu gm^{-2}s^{-1}$) indicates more healthy status of the region with a lower EHER value of 14.20 $\mu gm^{-2}s^{-1}$. The least value of EHER (12.74 $\mu gm^{-2}s^{-1}$) as observed in the city region can be attributed to highest stomatal resistance (R_{sm}) value (9.08 s cm^{-1}).

4.3.2 Jamshedpur Region

Dimna has the highest AC and EHER values of 7.29 $m^4\mu g^{-1}s^{-1}$ and 18.90 $\mu gm^{-2}s^{-1}$ respectively with least R_{sm} values (5.66 scm^{-1}). Least AC and EHER being at Nutandih 4.68 $m^4\mu g^{-1}s^{-1}$ and 2.36 $\mu gm^{-2}s^{-1}$ with highest R_{sm} of 11.33 scm^{-1} followed by 9.08 s cm^{-1} at Dalma Pahar.

In the city zone, Jugsalai Railway Station has the highest EHER of 72.30 $m^4\mu g^{-1}s^{-1}$ with least AC of 4.77 $m^4\mu g^{-1}s^{-1}$, followed by Bistupur with EHER and AC values of 61.60 $\mu gm^{-2}s^{-1}$ and 5.84 $m^4\mu g^{-1}s^{-1}$ respectively. The least EHER at Kalimandir (2.71 $\mu gm^{-2}s^{-1}$) again is correlated with highest R_{sm} of 11.99 s cm^{-1}.

4.3.3 NCR - Delhi Region

The Humayuns' Tomb area of Delhi region, has the highest AC values of 43.80 $m^4\mu g^{-1}s^{-1}$, whereas Shakoor Basti has the least EHER value of 2.13 $\mu gm^{-2}s^{-1}$ with highest R_{sm} of 20.89 s cm^{-1}. Netaji Nagar has the highest risk (33.59 $m^4\mu g^{-1}s^{-1}$) which can be attributed to high automobile pollution and the plant species (Banyan) with a least R_{sm}

value of 3.31 s cm^{-1}, whereas Town Hall has the least AC value of 1.69 $m^4 \mu g^{-1} s^{-1}$.

Of all the fundamental ecological variables, diversity is the one that best characterizes the biotic component of ecosystem and the community of organisms [135, 255, 258 & 352]. The concept of diversity is related to the richness of a population. The natural alterations in existing environmental conditions due to any developmental activity and consequent temporal site variability in a forest is one of the potent causes of variable forest composition (41, 306, 307 & 308]. Variability results simply from the constant flux of microsites in which different species can get established and grow. There exists a complex relationship between species diversity of an ecosystem and ecological processes such as productivity, water cycle, soil generation, etc. The outcome depends on the type of species and ecosystem involved. For example, the loss of a species from a particular region may have little or no effect on net primary productivity, even if its competitors take its place/niche in the community (redundant species) whereas in some cases, loss of certain species from an ecosystem could substantially decrease the productivity of the ecosystem (keystone species).

Any plant in a natural community is usually the descendent of a long line of individuals [41]. Natural selection winnows out the individuals (and genotypes) which cannot survive under the prevailing conditions. The plants which survive are, therefore, those, that are adapted to the environment in which they find themselves and thus, are the better representative of their ecosystem communities. However, they maintain a genetic pool which permit variations in each new generation to adjust to the shifts in environmental conditions. Each plant is also phenotypically plastic (stretchable) to some degree, and can also adjust to the variable conditions which prevail as it grows. By acclimation it can also adjust to some degree of environmental variation throughout the year.

The plant community has its own characteristic structural composition of life forms e.g. trees, shrubs, herbs, annuals, epiphytes etc., which is largely defined by the set of the climatic conditions with a selected set of plant species. In other words, the life-forms of the vegetation are the indicators of the regional climatic conditions.

Changes in the character of a biotic community can have major societal implications and a change in the community type is likely to have biological significance because large numbers of species and large areas are potentially involved. The most commonly used community characteristics in environmental monitoring are the species number, species evenness, and the species diversity, and can serve as one of the important potential assessment "endpoints" in ecosystem-risk/health assessment studies [319]. Because, they conveniently summarize the data generated by biotic survey, and are easily measurable for macroorganisms and can temporally integrate acute and chronic exposures.

Since last several years, one of the principle objective of the ecological studies was to characterise the composition and the structure of the community [7] with special reference to the environmental factors, viz. temperature, rainfall, humidity, trans-evaporation, light, and wind [131], and thus, relate the species composition with the environmental variations, because pollution does exert an influence on the structure and the physiology of the ecosystem [84, 198 & 366]

In order to study the spatial pattern of species distribution, in a forest ecosystem, it is necessary to opt for a technique which is more convenient for the field work and gives more information of the system within less time period and through inexpensive means. Indices studies have many advantages over mere description of the ecosystem community, notably in their simplification of a complex mass of data and in their communication which is vital for the ecosystem management. Morevoer, an index selects a component or set of components from the data mass, such that any change in the selected components(s) mirrors the change in the system as a whole. In the present study, field data, viz. distance between the two nearest trees in the quadrat, diameter at the breast height (DBH), height, canopy cover have been collected in order to estimate the density, dominance, and the frequency of the species to arrive at the importance value of the species. During the past several years, a number of investigators [39, 48, 53, 76, 241, 242 & 243] have made use of measurements of distances between plants, rather than counts in sample areas, to study their density and pattern of distribution, because where a species is randomly distributed, density is directly related to the distance [87].

The distance between the two plants in a plot under study have also been used in phytosociological studies, in order to study the spatial relationships in different populations [48, 53, 241 & 327]. In the quarter method, for e.g. distances are measured from each sample point to the nearest tree in each of the four quadrants centering on that point, and the mean distance is derived from these values [9 & 53]. This point-to-nearest species data is used to obtain an estimate of the density, which is characteristically unbiased if the population is random [20] as in the case of Doon Valley and Jamshedpur Region, and biased if the population is uniformly or continuously distributed as in the Delhi City Region.

Species composition and richness tend to change and also result in simplification [310] with the change in environmental factors, which also include air pollutants, and may also be replaced with the healthy/tolerant species as evidenced by Anderson [7], while analysing the Limestone Grassland in Monks' Dale, Derbyshire, the vegetation, characterized initially by 'Calcicolous' species was gradually replaced by 'Calcifuge' type of vegetation. Thus, the characterisation of the structure of any vegetation, warrants, detailed data on the bio-environmental features of the region, enabling establishment of the relationships between the plants and their abiotic factors. This is also important in order to demarcate the impacts on the species composition which may be nature-induced or pollution-induced. Moreover, studies at the foliar-air interface of the plants should focus upon the properties and the characteristics of the vegetation [133]. The vegetation should be carefully described and characterised with respect to plant structure, stage of development, key physiological and metabolic activities, plant sink potential, and ability to tolerate the exposures.

The concept of biodiversity can be applied to a variety of ecological features, even though most of the research has focussed on the species diversity [305]. The measurement of diversity is well developed with a number of available methods which are appropriate and different for different studies. According to Smith [312], nowhere in the biological literature has a fundamental definition of diversity been given. Nevertheless, a generally accepted *de facto* definition has emerged which states that the diversity of a community is the number of its species (i.e. the community's species richness) and their relative abundance, variously called as evenness, equitability, or the dominance. The indices used in the present study viz. Shannon-Weiner Diversity, Species Richness, Equitability, Similarity, are the most commonly used indices in the ecological studies. Both Hill [128] and Patil and Taillie [231] showed that these and other such indices are related and can be specified by a single equation, and thus different indices can be obtained by just varying one parameter in the equation. The number of species found in an assemblage varies with the sample size, whether the sample is a collection of individuals or is a geographic area [252 & 301]. If one has to make a valid comparison between the diversity of differnet assemblages of species, the bias due to these two factors must be eliminated. Several techniques have been developed to correct for the number of individuals in the sample, with the rarefaction method being widely used [301]. But the use of this or the other complex techniques is not practical for ecological evaluation because the necessary data on abundance is often lacking. The effect of area can be factored out using the regression techniques [52].

However, the use of these techniques depend on the objectives of the research, in the application of the diversity concept, which can be different for different workers. The rationale for using the concept of the diversity is generally not explicitly mentioned in the literature [305], even though several rationales do exist. The most common one being the bio-information of the region, in order to delineate conservation strategies for the region under study. It is therefore, important to have maximum information content on the ecosystems, communities, and the species of the region under study [175]. The concept of diversity is also linked with that of stability. Some workers [191] believed that stable ecosystems may in fact be less resilient and thus more at risk. Even more fundamentally many ecologists contend that the long-held notion that more the species diversity more the functional complexity, thus more biomass and productivity and ultimately more is the stability, is no longer tenable [50, 89, 194, 247 & 357]. Smith and Therberge [306] have also proved that more diverse plant communities do not always have the highest production, although it is generally assumed that communities demonstrating high diversity are most efficient in capturing energy and converting it into biomass [225]. Conversely some studies [8] affirm the conjection given by MacArthur [176] that complexity may be positively related to some aspects of community stability. The concept of diversity is also often linked to the genetic variability [197], because of the fact that large number of species in general possess a greater amount of genetic variation, as compared to a small number of species. Area of high vegetation diversity in general provide the interspersion of habitats necessary for more life cycle components of more species than area of more uniform vegetation [305].

In the present study species diversity has been used in order to enlist the most dominant species representing the ecosystem communities under study, estimation of sink potential and application of the Assimilation Capacity Model, to arrive at the assimilative capacity of the region, thus enabling delineation of better biodiversity conservation and management strategies. Species diversity for biological conservation can be most conveniently assessed by measuring species richness, specially with the vegetation component as it requires least field work, and other forms of diversity could be correlated [128, 231 & 305]. When sufficient data for all the species are not available, certain well documented groups of species can also be selected as "indicators" for the assessment of the biotic diversity [248].

Since long, in the literature, diversity has been equated to the Shannon-Weiner function [193, 211, 226, 255 & 359], numbers of species, their abundances and the distribution of biomass or biochemical compounds [225 & 357].

The Shannon-Weiner Diversity, was correlated [278] with the density and the dominance, and was assumed that more the abundant a particular species is, more important it is. However, especially in communities which include large ranges in sizes of individuals, the importance of fewer but larger individuals may be under estimated [62 & 359], hence it is imperative to take into consideration the sum of all the three parameters viz. density, dominance, and the frequency to arrive at the importance value of the species [93, 226, 264 & 278].

The tree-species diversity in 61 Oklahoma upland forest stands was studied by Risser and Rice [278]. Most stands were dominated by *Quercus stellata* and *Quercus marilandica*, but the stands with the greatest diversity were those dominated by other species. They observed a decrease in the species diversity and an increase in the concentration of the dominance along the precipitation gradient from the east to west. In the present study also, it has been observed that at Doon Valley Region, where most of the stands at Dehradun and Siwalik Forest Division **(Tables 4.4 and 4.5 & Plate 1)** were mostly dominated by Sal (*Shorea robusta*) showed a very low speices diversity and a high concentration of the dominant species viz. Sal (*Shorea robusta*), but the stands with the greatest diversity (Mussoorie Forest Division) were equally dominated by other species viz. Deodar (*Cedrus deodara*), Banj (*Quercus incana*), and Chir (*Pinus roxhburghii*). Risser and Rice [278] concluded that an East-West environmental gradient exists in the state, which is apparently determined by the moisture. Such a spatial variations have also been observed at Doon Valley and Jamshedpur regions, where the vegetation pattern gradually change from Sal-Rohini (Dehradun Forest Divisions) to Deodar-Banj-Chir (Mussoorie Forest Division), **(Plate 2)** similarly at Jamshedpur from Sal-Tendu-Kachnar (Dimna) to Dhaura-Padasi-Siris (Dalma pahar), with the change in the environmental conditions and altitudinal variations. The concept of diversity was related to the geograhic scale and spatial context by Wilhm and Dorris [358], by introducing the idea of alpha, beta, and gamma diversity, which have gained wide usage in the ecological studies.

Path Analysis [124] was used by Westman [355] to determine the most likely route of causation of the decline in the forest cover in the California Coastal Sage Scrub

A view of Undisturbed Sal (<u>Shorea robusta</u>) Forest Stand at Timli Forest Range, Siwalik Forest Division, Indicating Least Disturbance in the Region

A view of Sal (<u>Shorea robusta</u>) Forest Stand at Jhajhra Forest Range, Dehradun Forest Division. A Low Species Diversity can be Attributed to the Anthropogenic Activities in the Near Vicinity

PLATE : 1

A View of Oak (<u>Quercus incana</u>) Forest Stand at Mussoorie Forest Range, Mussoorie Forest Division. A Change in the Vegetation Type from Sal to Oak can be Observed

The Chir (<u>Pinus roxburghii</u>) Forest Stand on way to Dehradun-Mussoorie. The Change in the Vegetation Pattern is Depicted

PLATE : 2

Community in certain California sites and concluded that these studies offer useful examples of the kinds of synecological methods and provide indications towards the need for more detailed analysis of the pollutant effects [209].

The calculated values of Shannon-Weiner diversity Index [245]; Evenness [361]; and Co-efficient of Community [245] was employed by McClenahen [196] to describe overstorey, subcanopy, shrub, and the herb layer composition in seven deciduous forest stands along a 50 km portion of the upper Ohio River Valley. These stands were subject to chloride, sulphur dioxide, and fluoride along a dose gradient. Species richness, evenness, and the Shannon-Weiner Diversity Index were depressed within the overstorey, sub-canopy, and the herb layers. Similarity in species composition, as indicated by coefficient of community, decreased with the increasing chronic pollutant exposure. McClenahen [196], concluded that these are adequate qualitative estimation of the environmental effects of the industrial development on the vegetation. The beta and the gamma diversity were used by Rudis and Ek [284] in their mathematical model for selecting natural areas for their conservation.

One of the largest studies attempted on the terrestrial ecosystem impacts by air pollutants relates to the San Bernardino Mountain study [209], where the researchers have evaluated, by and large, the regional and the point source emissions on agricultural and forest ecosystems. Existing approaches and models on ecosystems analysis and derived predictions of impacts on ecosystems are highly complex [209]. Because, it is not so much the atmospheric concentration of a pollutant that should be of concern but the actual concentration of the pollutant that gets into the plants, hence, pollutant uptake by the plants is more critical [339]. The conductance of the stomata, regulating the passage of air pollutants into the cells, is especially critical, which depends not only on the concentration gradient between the ambient air but also on the sorptive sites within the leaf [98]. Since these conditions, as also other environmental factors viz. wind velocity, temperature, humidity, light, changes during the exposures, the ambient dose to which the plant is exposed, therefore, does not necessarily reflect the actual cellular exposure. Therefore, it becomes imperative to undertake region-specific and species-specific investigations in order to assess the impacts due to any environmental alterations. The important morphological components which influence uptake of the pollutants are the pubescence viz. the trichomes, the cuticles and the cuticular wax. Stomatal resistance, on the other hand, is critical, which is determined by the stomatal number, the size, anatomical characterstics such as the degree to which they may be sunken in the leaf, and the size of the stomatal aperture [339].

Assimilative Capacity Model applied in the present study is dependent on the stomatal characteristics, which include parameters responsible for stomatal resistance. Hosker and Lindberg [133] have also stated that stomatal resistance or the stomatal control of the diffusion of the pollutants into the leaf is a major factor influencing the exchange of gaseous pollutants within the internal tissues [77, 81 & 322]. Numerous studies have concluded that stomatal resistence is the principle/sole factor controlling the uptake of air pollutants and the foliar injury [98]. It has also been observed that stomata of coniferous forest are also the major sinks of SO_2 [348], thus, the differential count of stomata for different species can serve as species-specific sink potentials of air pollution. Vesala et al. [348], have also studied the SO_2 uptake by the Pines (*Pinus sylvestris*) with the objective of analysing crucial factors viz. radii of the stomata, number of stomata per unit area and stomatal geometry, with respect to SO_2 and water vapour exchange. The increase in the stomatal resistance is followed by the closure of the stoma and the decrease in the pollutant uptake. Conversely, when stomatal resistances decreases the pores open [16], as is also evident from the present studies, where it has been observed that the species with high stomatal resistance viz. Cha (9.08 scm^{-1}) at city zone in Dehradun City Zone, Doon Valley, Peepal (20.89 scm^{-1}) at Shakoor Basti in New Delhi, and Chironji (11.33 scm^{-1}) at Nutandih Forest in Jamshedpur Region have least Assimilative Capacity values of 2.11, 1.69, and 4.68 $m^4 \mu g^{-1} s^{-1}$, respectively. However, changes or the fluctuation in the normal readings as found in the case of Sal (*Shorea ronbusta*) at Mussoorie Forest Division, Doon Valley Region, and Banyan (*Ficus bengalensis*) at Jugsalai Railway Station in Jamshedpur Region, with low stomatal resistance and

Assimilative Capacity values of 5.77 s cm^{-1} and 2.02 $m^4\mu g^{-1}s^{-1}$ and 3.58 s cm^{-1} and 4.77 $m^4\mu g^{-1}s^{-1}$, respectively. On the other hand, Kurchi (*Holarrhena antidysentrica*) at Kalimandir, Jamshedpur Region showed a high stomatal resistance as well as high AC values viz. 11.99 s cm^{-1} and 11.36 $m^4\mu g^{-1}s^{-1}$ respectively, which might be because of the fact that stomatal function is mainly controlled by the plant's physiological processes [202], as well as by the bio-environmental factors [95 & 133]. Thus, both environmental and the physiological factors cause large fluctuations in the stomatal aperture, and in some cases the internal factors can override the stomatal resistance in influencing the gas exchange [19], which might be because of the impairment of the guard cells resulting in the reduction of stomatal resistance leading to stomatal opening [95].

As a primary pathway for the exchange of gases between internal leaf surfaces and the atmosphere, stomates play an important regulatory role in the leaf physiological processes. It has always been assumed that adsorption into the leaves through the outer layer and the stomata of the leaves play the sole role in the elimination of the pollutants by the plants [220]. The environmental alterations due to the population explosion since the past century have imposed physiological stresses, which make stomatal action a potentially important mechanism for protection against damage due to the pollutants [133], and thus an important criteria to be incorporated in studies related to ecosystem health assessment.

The role of stomatal action in plant response to air has been examined in several studies during the last three decades [65, 133, 204, 342], which reveal that stomata respond differently to the air pollutants, specially to SO_2 in the atmosphere, and the same plant may respond differently under different environmental conditions, as also observed in the present study with Sal at Doon Valley, and Peepal at Delhi Region with different stomatal resistance and AC values at different regions. This fact is also supported by the studies carried out by Majernik and Mansfield [184] on the broad beans. The effects of 0.15 ppm SO_2 and/or 0.15 ppm O_3, on the stomatal resistance of three plant species viz. Soyabean, Radish, and Cucumber was studied by Beckerson and Hofstra [22]. Soyabean which exhibited antagonistic effects, whereas radish and the cucumber exhibited synergistic response. A mixture of SO_2 and O_3 caused an increase in the resistance much greater than O_3 alone. Thus, the response of the stomata to the pollutant itself may well be a major determining factor of plants' resistance to the environmental pollutants. Despite the apparent significance of the stomatal resistance, or conversely the stomatal conductance, results of the studies attempting to correlate it with injury have been inconsistent [98]. The genetic sensitivity of the individual species and the cultivars remains the overriding determinant of the injury.

Movement of a pollutant in the liquid phase from the substomatal regions to the cellular sites of the perturbation must also be considered to be the part of the uptake. A pollutant encounters many obstacles along this intercellular pathway. Scavenger reactions, such as with the ascorbate, may absorb or neutralize a pollutant, or as with O_3, it may react to form other toxic substances like, aldehydes, ketones, or H_2O_2 [260 & 332] and free radicals [260].

Exposure to oxidative stresses such as those caused by O_3 and SO_2 pollution may result in the formation of various highly reactive compounds in plant tissue viz. peroxyl and superoxide radicals, hydrogen peroxide, etc. [288]. As a result many functions in the plants are altered [304 & 365]. The ability of the plants to grow under these adverse conditions depends on the prevention of the free radical production and the increase of free radical scavenging, and thus on their tolerance capacity. Both these abilities are related to plant productivity [140]. Different plant species and different varieties within the same species may differ widely in their tolerance to oxidative stresses [259], but the basis for these differences is still in question [260].

The influence of air pollutants in the plant photosynthetic processes has historically been of great interest to plant researchers interested in understanding the pollutant impacts on the plant growth and yield. Air pollutants are generally considered to affect the photosynthesis primarily as a result of changes in the stomatal aperture or the reversible inhibition of the enzymes systems [198, 213 & 373]. Understanding the mechanisms of the response and the recovery of the photosynthetic system following exposure to gaseous pollutants is important in that it may both identify protective strategies by which plants respond to the stress and provide a mechanisms for evaluating its physiological severity.

The fate of the pollutants absorbed by the leaf tissues is important both to the exchange process and to the pollutants effects on the plants. Pollutants may have multiple fates in the plants, making the simple description of the tissue pathways and the sink location difficult or tenuous [29]. Estimates of the reference concentrations or mean absorbed dosages within the leaves, however, can be valuable in assessing the potential for a given pollutant exposure to induce injury and reduce sink capacities of the foliar receptors [133].

The capacity and the effectiveness of the cell as a persistent sink for air pollutants depend upon the effects of the toxicants on the cell structure and the function. Available information on the physiology and the metabolism of the cells and the tissues has not been correlated with the cell's capacity to act as a sustained sink for pollutants [133]. Injury resulting in the cellular death destroys the continued effectiveness of the biological sinks, but milder disturbances may just depress this capacity by reducing the enzymatic activity, or by causing less drastic structural alterations. Injury may reduce the sink capacities directly or affect pollutant uptake indirectly by interfering with the plant physiology functions such as the water and nutrient balance, or the stomatal function. It is, therefore, important to evaluate the physiological status of the test plants, and the experimental conditions which assure normal plant development and realistic pollutant exposures during experimentation.

Research on pollutant effects on the forests represents a paradoxical challenge in the sense that methodologies best suited to understanding the initial reactions on one hand and ultimate effects on community productivity and stability on the other are very different. Focusing on either end of the spectrum exclusively ensures that a true understanding of either the causes or the consequences of pollution effects are ultimately lacking. An appropriate balance between scales of resolutions in studies of air pollutant impacts on forests have only rarely been achieved in the past [198]. Proper and scientifically sound experimental design and data acquisition are preludes to all subsequent analysis and application of such data. Therefore appropriate data acquisition is essential for ecosystem health analysis [168 & 291]. But collection of data necessary to address the issue of air pollutant-vegetation interactions adequately is not a straight forward task [171]. Because pollutants may influence forest growth and development through multiple pathways and mechanisms, and over widely varying time scales. Air pollutants have been reported [274] to result in net photosynthetic reduction through suppression of stomatal uptake. Consequently, alterations in growth responses are not ruled out. The responses of individual tree may range from reduced productivity with shifts in species composition to simplification with altered function and stability, which would render it more vulnerable to damage and other stresses [308].

The environmental performance indicator which is synonymous with the "Valued Ecosystem Components" concept of Beansland and Duinker [21], is required by the EIA analysts to prepare forecasts in terms of measurable characteristics of the components. If the ecological impacts are to be detected and understood, monitoring needs to be accompanied by the insightful process-based modeling, because, the strongest evidence of the impact during and after an intervention in the environment comes from the combination of the results based on the field-monitoring coupled with the process-based modeling, as the one used in the present study.

4.4 ENVIRONMENTAL MANAGEMENT PLAN

During the past 300 years the global human population has grown elevenfold, from an estimated 500 million to more than 5.5 billion. This event and its ramification dominate how and for what purposes earths' ecosystems will be managed [287]. Every living being needs space and resource to survive. The more of any particular species there is, the more space and resources must be devoted its existence. Thus, growth in the human population means that there is now only one-ninth the space available per person as there was at the dawn of the industrial revolution. It also means that less space and resources are available for all other living things on the earth except those that benefit from human-modified habitats; hence the so-called biodiversity crisis [362]. The central premise is that with the continuing exponential growth and the globalisation of the economy, the nature of man-environment relationships has changed dramatically and irreversibly in the past few decades [271]. The symptoms of cumulative global change viz. ozone depletion, atmospheric and incipient climatic change, deforestation and soil degradation, and the loss of the biodiversity proves the fact that "the world has reached the limits" [88]. Such an argument is also supported by the studies on human carrying capacity which show that the "ecological footprint" of the global economy already exceeds the land area of the planets [268, 269, 270 & 350].

Moreover, the forests need to be managed and protected because of the fact that forests and their products play a vital role in the economic development of the country and also in the preservation of the environment and the ecosystem which influences the climatic pattern for better. Their presence is also essential as a safeguard against flood and erosion. They also provide us with various resources essential for our survival.

The present pattern of excessive and uncontrolled pressure on the forest resources results in reduction of forest cover, loss of soils and their nutrients, decrease in the regeneration capacity. Therefore, a suitable land-use planning demands conservation inputs and a concomitant ecological development of the buffer forests for people's long-term use and for the population surviving in and around the forests. The support of all sectors of Central and State Government aided by interested conservationists, voluntary organisations, NGOs and individuals is imperative in ensuring successful implementation.

Sustained forest productivity may be envisaged in two senses:

a) as a continuity of forest growth, and

b) as a continuity in harvest yield.

It is, therefore, important to develop such analytical tools to aid comprehensive planning and management of the environmentally significant areas, through proper assessment and identification of the sensitive regions. The strategy should be such that it identifies regions with ecological significance, and the regions which serve the human society through the functioning of the natural environment. This is important because of the identifiable or potentially identifiable benefits to be derived through conservation on one hand, and because of the fact that those organisms/species "have the right to exist" for the recognizable benefits to be derived from their mere existence [191].

The role of the area, its size, shape and the possible subdivision in the conservation of species is an important aspect. Studies on the conservation of the ecosystems show that larger areas hold more species, and the relationship between these two variables is such that a 100 percent increase in the area produces roughly a 25 percent increase in the species. Thus, two small habitat islands which have more than 25 percent difference in their species composition, hold more species than a single habitat island of the same total area, which is probably due to microhabitat differences. Yet even against a constant ecological background, stochastic fluctuation (turnover) of the species due to random colonization and extension will cause inter-island variation in the species composition. In theory, large nature reserves or parks reduce the risk of extinctions because they contain sizeable populations of the endangered species of the plants and the animals. According to the conservation biology theory, large protected areas minimize the risk of extinction arising from the genetic isolation because they contain sizable population, corridors between the parks further reducing the isolation as in the case of the Doon Valley Region [78 & 313]. With less land available per person, and the ever increasing environmental pollution, leading to destruction of the ecosystems, demands significant improvements in the agricultural and the forest productivity through integrated and research-oriented management strategies. Ecosystem management certainly poses a new paradigm for managing the forests [137], and the conservation strategies differ variably for different regions with different objectives.

In general, plans for biodiversity conservation tend to emphasize *in situ* preservation of naturally occurring communities. While vital, such efforts alone cannot preserve all species or communities, given such threats as increasing development pressure, pollution, climatic change, and growing human populations. One such strategy which has been generally overlooked, but holds great promise is *restoration* [146]. In restoration, the goal is to return the degraded biological communities to their original state with human help, which is possible with the peoples' participation [18]. Though such efforts have generally played a minor role in conservation efforts aimed at conserving diversity, it seems likely that this role will increase as pristine habitat becomes scarcer and as the opportunities to recycle ecosystems disturbed by the human activities have become more common a phenomena.

While restoration refers to the recreation of the entire communities of the organisms, closely modeled on those occurring naturally, *reclamation* refers to the deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition which involves *revegetation* of a mined or the abandoned area with exotic vegetation. The distinction between restoration and the reclamation is not a sharp one, however. In fact, restoration is a broadly used term by many workers [146] to refer to many kinds of environmental management, which also include reclamation, and revegetation.

The new National Forest Policy of 1988 clearly states that management of forest resources in India should include people's participation [18 & 195]. The involvement of the local people should be legalized through institutional arangements. The recent decision of Government of India to create a decentralized administration through creation of eco-development centres, village panchayats, ban panchayats (forest councils) in the villages as developed at Harda Forest Division, Hoshangabad, Madhya Pradesh [18], would give impetus to these grass root level organisations. Such viable community-based institutions should be established with full legal, administrative and technical support. These institutions should be empowered to plan the use of common lands, to decide on the plant species to be planted, promoted, protected and to work out the modalities of sharing the forest products in a sustainable manner. Forest management has been guided by the Forest Policy, which has undergone numerous revisions since 1988 [195]. The main objectives are :

- maintenance of environmental stability through preservation and restoration of ecological balance
- conservation of biodiversity and genetic resources
- control of soil erosion, denudation, and desertification
- substantial increase in the forest cover through afforestation and social forestry

- meeting of fuelwood, fodder, minor forest produce and small timber requirements of rural and tribal populations

- efficient utilisation of forest produce and maximum substitution of wood; and

- people's participation and active involvement of women for achieving the above objectives to minimise pressure on the forests.

Forest management policy is determined keeping in view the purpose/requirements of the owner/consumer in relation to the resources availability. It involves understanding of the following factors :

* Physical resources
* Human resources
* Demand potential of the forest produce

All these factors are subject to change and the priorities differ for different regions. Political, economic and social factors play an important role in deciding the area and kind of forest that a region should have. Hence, forest planning begins with the recognition and expectations of a region from its forests.

A careful planning of the technical issues like choice of species to be raised, the type of land to be brought under forests, are the essential ingredients of a better management. While deciding the above factors, other factors like the edaphic, climatic conditions of the region, intensity of competition from other land-uses and forestry benefits through other means including imports of forest products should also be taken into account.

4.4.1 Doon Valley Region

The study area as earlier mentioned comprise three forest divisions viz. Dehradun, Siwalik, and Mussoorie, and the City region. On the basis of the importance value index, the important species of the region are Sal (*Shorea robusta*), Rohini (*Mallotus philippinensis*), Cha (*Camellia thea*), Sandan (*Oogenia dalbergioides*), Shishum (*Dalbergia sissoo*).

Some of the factors affecting the sustainability of the Valley are:

* The Gujjars (nomadic tribes) living in the forests of the Rajaji National Park
* The fragmentation of the habitat of the elephant population and
* The limestone quarrying operations.

The Gujjars

Rajaji National Park, with an area of 831 sq. km, forms a part of the study area spreading across Saharanpur, Dehradun and Pauri-Garhwal districts. About 55 percent of the total area of the park forms the forest land. Fourteen percent of land is grass or herb land including the Gujjar's habitation clearings. The major threat to the forest in the park, is the growing tendency amongst the Gujjars to stop migrating to the hills in the summer, resulting into deforestation due to heavy demand for fuelwood and overgrazing by their cattle.

The increasing pressure on forest lands from discontinuation of seasonal migrations and increase in the traditional family of 500 with 5,000 buffalo population has serious implications on the sustainability of the region.

Recommended Measures

It is essential that State Government take an immediate action to rehabilitate the Gujjars at Pathri as decided earlier [324].

The Elephant Population

Other major issue affecting the sustainability of the park is the elephant population which needs a forest area to support their population depending upon the biomass production of the region. The availability of forage and water for the elephant varies from place to place which results in the migration of the population in tune with the seasonal cycles, which is conducive to the natural, sustainable regeneration of the forage land. With the formation of the dammed lake at Corbett, the elephant population which earlier belonged to one single population from Corbett to Rajaji Park has now been artificially divided into two unequal populations. This bifurcation of the habitat due to the loss of the corridors between the parks is another major problem faced by the Rajaji National Park.

Recommended Measures

State Government should take action to re-develop the corridor as proposed earlier by Thadani [324], one each on the North and South of Raiwala of 1 km wide and 3-4 kms long for the sustainability of the region [78 & 313].

The Limestone Quarrying Operations

Mussoorie-Dehradun region is well known for its mineral reserves. The mining lease areas for different mines vary from 1 to 97 hectares. The most affected areas due to quarrying are Kiarkuli Bhatta and Hathipaon. Since mining operations are carried along the hill slopes they lead to a number of environmental problems viz. deforestation, decline in the soil fertility, soil erosion and landslides, siltation of water bodies, air pollution due to dust and finally affecting the socio-economic status of the local people.

Recommended Measures

Eco-restoration [146] of the abandoned mine areas can be achieved through afforestation and by constructing check dams to prevent soil erosion. Massive afforestation programme has already been undertaken by Eco-Task-Force, Dehradun, and Forest Research Institute at Kiarkuli region by planting major tree saplings like Shishum (*Dalbergia sissoo*), Khair (*Acacia catecheu*), Chir (*Pinus spp.*), Bukain

(*Melia azederach*), Semla (*Bauhinia retusa*), Deodar (*Quercus incana*) and other species. The afforestation programme should further be intensified at these and other such regions with the help of the Forest Departments, Voluntary Organisations, Institutions, and by involving the local community [18].

Raipur Industrial zone, which is concentrated by a number of limestone kilns for processing the raw materials brought from the quarrying sites at Mussoorie **(Plate 3)**, should be taken up for plantation by the social forestry authorities, by making a proper choice of the species viz. Sal (*Shorea robusta*), Silver Oak (*Grewellia robusta*), Bukain (*Melia azedarach*), Amaltas (*Cassia fistula*) Bottle Brush (*Callistemom viminalis*) etc. depending upon the site-specificity and their sink potentials.

Dehradun City, the largest urban centre of Doon Valley is ecologically the most critical sub-region due to its special location and morphological aspects, with high natural resources viz. Forests, Basmati Rice, Litchi, and Limestone. Due to the rapid industrialisation and human population explosion, there is a serious impact on land and other natural resources. In order to guide and control the future development of the region, the town area as well as the area around it is designated as "Regulated Area" according to the Master Plan [61] for Dehradun City prepared by Government of Uttar Pradesh through its Town and Country Planning Department.

In the existing landuse, the area under forest (open and close) is 78,184 ha., out of total geographical area of 2,08,025 hectares. The area under parks and open spaces in the developed areas is reduced from existing 6.5 percent to 3 percent .

The proposed land-use planning should therefore, take into consideration the following :

* None of the existing forests should be converted for other uses viz. Industrial zone, urban area, and agricultural zone

* Steps should be taken especially by forestry sector to bring the natural slopes under 60 percent of forest cover as per the National Forest Policy

* Existing orchard area south and south-west of Indian Military Academy (from Prem Nagar to Harbanswala) should be retained and developed as greenbelt consisting of orchards and forests

* Immediate steps should be taken for reducing the number of limestone kilns concentrated at three industrial pockets viz. on Raipur road, north of Adhoiwala, and between Sahastradhara and Rispana Rao. A greenbelt development programme at these zones should be immediately taken up by the forest authorities.

4.4.2 Jamshedpur Region

The study area covers the entire Jamshedpur region

A View of Brick Kiln on Way to Jhajhra Forest Range, Dehradun Forest Division. Large No.of Brick Kilns are Situated in and around the Study Area.

A View of Limestone Processing Unit at Raipur Industrial Zone, used for Processing the Raw Material brought from Mussoorie Region

PLATE : 3

which includes all the major industries of Tata Group and is covered largely in Dalbhum and to some extent in Chaibassa Districts. The climate conforms to general tropical climate and the major species found in this region are Sal (*Shorea robusta*), Asan (*Terminalia tomentosa*), Kurchi (*Holarrhena antidysentrica*), Mahua (*Madhuca indica*), Dhak (*Butea monosperma*), Jamun (*Eugenia jambolana*), Karam (*Adina cordifolia*).

Management Scenario

The Forests :

The major impact on the forest which are existing in Dalma Pahar, Nutandih and near Dimna reservoir is the illegal felling and encroachment by the local inhabitants to meet their fuelwood, fodder, housing, medicinal and other economic demands **(Plate 4)**.

On the basis of Importance Value Index studies, Sal (*Shorea robusta*), Tendu (*Diospyros melanoxylon*), Kachnar (*Bauhinia retusa*); Asan (*Terminalia tomentosa*), Galgal (*Cochlospermum gossypium*), Mahua (*Madhuca latifolia*), Chironji (*Buchanania lanzan*), Dhak (*Butea monosperma*), Jamun (*Eugenia jambolana*), Dhaura (*Anogeissus latifolia*), Padasi (*Cleistanthus collinus*), Siris (*Albizzia procera*) are the important representative species of the region, and can be termed as "Keystone species" as they play a vital role in the ecological processes within the forest ecosystem **(Plate 5)**.

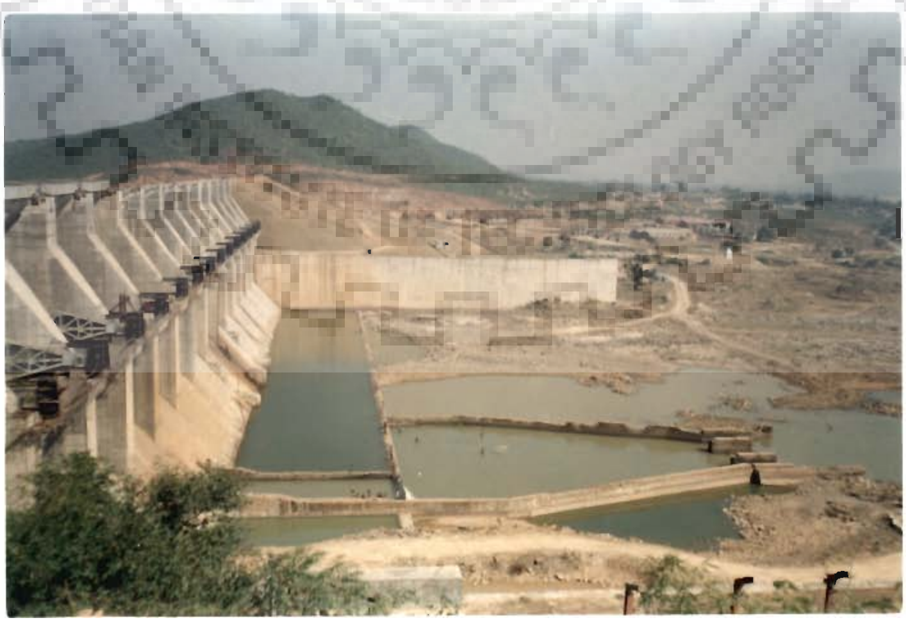
It is therefore essential to adopt measures to work on these species in terms of their regeneration capacity, massive plantation and protection against the illegal approaches. This is possible through active involvement of local people in participatory manner by formation of Village Forest Protection Committees (VFPCs), Ban Panchayats in collaboration with voluntary organisation, Forest Departments.

Some forest species with high timber yield viz. Bija Sal (*Pterocarpus marsupium*), Teak (*Tectona grandis*), Asan (*Terminalia tomentosa*), Galgal (*Cochlospermum gossypium*), which are dominant in Nutandih Forest, undergo intensive felling because of their economic importance. Consequently, special attention should be given for conservation of these species by preserving the zones in which they are dominant as "Protected Forest", so as to achieve higher biomass and productivity.

The City Vegetation

The city of Jamshedpur is one of the most important industrial cities of the country, with Tata Group of Companies viz. Tata Oils, Tata Pigments, TELCO, TISCO Mines. Hence, the threat to the flora of the region from air pollution needs to be considered in the formulation of forest management strategies as they are expected to alter the forest productivity and species composition by bringing about significant changes in the spatial and temporal distribution of key climatic parameters.

A view of Illegal Felling and Cutting of Trees with high Timber Yield, at Nutandih Forest Zone, Jamshedpur



An overview of the Chandil Dam, being Constructed near to Nutandih Forest Zone. A Direct Impact on the Forest Resources - DEFORESTATION

PLATE : 4

A view of Undisturbed, Diversified Forest Stand at Dalma Forest Zone, Jamshedpur

A view of Wild Life Sanctuary at Dalma Forest Zone, Jamshedpur

PLATE : 5

It has been found that Neem (*Azadirachta indica*), Jamun (*Eugenia jambolana*), Mango (*Mangifera indica*), Peepal (*Ficus religiosa*), Kurchi (*Holarrhena antidysentrica*) with high stomatal density can be selected for intensifying the afforestation in and around the industrial region. The details of the management plan is tabulated in **Table 5.1**.

4.4.3 NCR - Delhi

Against the National Forest Policy stipulation of an average of 33% (20% in plains and 60% in hills), NCR has a meagre 2.18% of its land under forest cover (as per land records) and 1.2% as per satellite imageries. Thus, the entire region has become environmentally sensitive and, the ecosystem is already disturbed. In Delhi Union Territory, owing to low rainfall and gravelly substratum, the upper strata of the soil does not support any dense perennial vegetation. The 7,777 hectare Delhi ridge, Delhi's only natural forest, is fast fading due to encroachments which are clear violations of Forest Conservation Act and Environmental Protection Act.

Viewing the situation region, the vegetation cover should be increased in any form such as protected, reserved, community and social forestry in all those areas which are not fit (mainly) for agricultural use.

Afforestation Programme

* To afforest and vegetate barren lands, rocky areas, culturable waste land, peripheral agricultural areas,

road side avenues etc., so that the forest or vegetative cover is raised atleast to 10% of the land area.

It can be done by adopting the following methods :

a) Green belt/Green wedge development

The peripheral agricultural zones in the immediate vicinity of the urbanisable area is very vulnerable to encroachment by development. To arrest undesirable growth in this zone and, to ensure orderly and compact urban development, a control belt is proposed all around the expected developable area. The development should be restricted or strictly controlled in this green belt zone. The activities compatible with open character of land should only be permitted. The major landuses which could be permitted in these zones are as under:

a) Agriculture, particularly high value cash crops
b) Gardening
c) Dairying
d) Social forestry/plantation
e) Cemeteries
f) Social institutions such as school, hospital
g) Recreation

In the cases of settlements particularly those which are in close vicinity to each other either along the roads or interior, the intervening space between the settlements should be kept green which can be designated as green wedge.

b) Green buffer along major transport corridors

Undesirable industrial development beyond the urbanisable area limits of the towns along the Highways could become a serious problem in the near future. To prevent this, a green buffer should be designed :

a) A green buffer, a width of 100 metres on either sides along the National Highways and proposed Express ways should be developed by selecting the species with high sink potential and site-suitability

b) A width of 60 metres on either sides along the State Highways

Only activities permitted in the green belt as indicated earlier should be allowed in the green buffer. The species with high sink potentials viz. Neem (*Azadirachta indica*), Jamun (*Eugenia jambolana*), Acacia (*Acacia* spp.) and ornamentals like Gulmohur (*Delonix regia*), Ashoka (*Polyalthia longifolia*) etc., should be planted in the city zones (residential, roads and highways, industries etc.) **(Plates 6 through 9)**.

Conservation Programme

Conservation Area

Special attention should be given to check the damage to natural environment by man's interference for development purposes. The major natural features which should be conserved with utmost care and afforested with suitable species are :

- Ridge, which is an extended part of the Aravalli Range
- Sariska Wild Life Sanctuary in Rajasthan Sub-region
- Sultanpur Bird Sanctuary in Haryana Sub-region
- Forest Areas

Conservation programme should also include identification of alternate sources of energy for fuel and also find methods of increasing the efficiency in the use of the forest fuel especially from the social community forests. These should be taken up in a phased and planned manner so that afforestation and vegetation sustain and stabilise over time.

Plants are considered as important sinks for the air pollutants and also serve as important buffers for dust pollution. The management plan for city should therefore be delineated by making a proper choice of the species viz. fast growing, tolerant/robust species for afforestation of the region, specially for places like National Highways, Residential and Industrial Complexes, Roadside Avenues. Stomata play a central role in regulating photosynthetic and water loss, and serve as a port for exchange of gases during photosynthesis and respiration. Hence, the choice of the species, on the basis of the stomatal characteristics viz. stomatal density, having high sink potentials would serve as one of the important parameters in the implementation of management plan.

A view of Silver Oak (Grewia robusta), Peepal (Ficus, religiosa), Neem (Azadirachta indica) at Purana Killa, an Example of Maintained/Artificial Vegetation

A view of Acassia Spp. at Nehru Park, near Connaught Place, New Delhi

PLATE : 6

A view of Jamun (Eugenia jambolana) at Connaught Place, one of the busiest Traffic Zone at New Delhi

A view of Ficus spp. at Netaji Nagar - A Residential Zone, with High Exposure to Automobile Pollution

PLATE : 7

A Smoky view due to Rubber Factory at Shahzada Bagh, New Delhi

A view of Mayapuri Industrial Zone, New Delhi

PLATE : 8

A view of Shazada Bagh, New Delhi, Needs a Better Environment to Live in !

A view of Shakoor Basti, New Delhi

PLATE : 9

The introduction of the sustained yield management principle into practical forestry is essential in order to ensure that the needs for timber yield and environmental protection are met simultaneously and steadily. Under the conditions of intensive, multi-objective forest use, the following approaches and means to solve the problems are recommended :

* Adoption of an optimal forest thinning system in the different forest zones with conditional high density, to meet the timber and fuel-wood demand

* Site-specific management of reserve forests of high density to form stands of maximum productivity

* Establishment of local standards for stands of maximum productivity in different regions. This will help forest management at regional and local levels

* The forestry sector should be integrated and developed based on the regional economic priorities

Biotic community plays a vital role in in maintaining the ecosystem health by assimilating various pollutants through tissue uptake, accumulation, metabolism and physiological biodegradation. Green plants not only serve as sinks/air purifiers/assimilators of the air pollutants, but are also the primary producers, because of their photosynthetic capacity, and form the first baseline organisms for the attack, deposition and assimilation of the pollution. Though plant-environment interactions have been explored, and the mechanisms responsible for the impacts have been well investigated/documented [17, 51, 95 & 208 etc.) very little is known about the effects of various interacting stresses due to pollutant impacts, and the management strategies in combination.

Thus, the study of the present kind help in quantifying species-specific sink potentials and region-specific assimilative capacity, on the basis of such ecosystem-specific planning models, aimed at protection of the environmental quality and human health.

CHAPTER V
CONCLUSIONS

5.0 CONCLUSIONS

Stomata play an important regulatory role in the leaf physiological processes. Moreover, stomata also take part in elimination of pollutants by the plants. In the present study, the differences in the rate of assimilation of pollutants by the dominant/representative species is modelled and quantified on the basis of stomatal density and opening under various environmental conditions.

The assimilative capacity model (used in the present study), which combines the functionalities based on species-specific stomatal features, is a modified version of the earlier developed Ecosystem-Health-Exposure-Risk (EHER) Model. It is a process-based ecosystem-model used for quantifying the assimilative capacity of the regions based on the species specific sink potentials. This model has distinct advantages over most of the existing models which are mainly statistical in nature and overlook certain essential processes interlinking atmosphere and vegetation. The judicious application of the model will be of immense help while designing green belts around industries depending upon the type and concentration of the pollutants and the type of trees required to assimilate and absorb them to the required extent thereby affording the protection of ecosystem and human health. Thus, assimilative capacity values for different zones, viz. Doon Valley, NCR - Delhi, and Jamshedpur Regions have been computed and compared for the identification of significant zones/hot spots, and subsequent delineation of appropriate management strategies.

Mussoorie Forest Division in Doon Valley region has very low assimilative capacity (2.02 $m^4\mu g^{-1}s^{-1}$) followed by the city zone (2.11 $m^4\mu g^{-1}s^{-1}$). This can be attributed to the fact that Mussoorie region represents a highly stressed environment due to deforestation, soil erosion, tourism and quarrying operations. Low assimilative capacity value for Dehradun City (2.11 $m^4\mu g^{-1}s^{-1}$), on the other hand, can be attributed to industrial/vehicular pollution, and improper city development. Siwalik Forest Division has comparatively high assimilative capacity value (7.15 $m^4\mu g^{-1}s^{-1}$) which is indicative of healthy status of the region with high sink potential (136.00 mm^{-2}).

The high assimilative capacity value (49.68 $m^4\mu g^{-1}s^{-1}$) at Humayun's Tomb in the National Capital Region study is indicative of least impacts in the zone, whereas low assimilative capacity values (1.69 $m^4\mu g^{-1}s^{-1}$) at Town Hall and Najafgarh Industrial Area (4.20 $m^4\mu g^{-1}s^{-1}$) are indicative of their high exposure to pollutants. This is also evident from the analysis of EHER values of 26.90 and 12.20 $\mu gm^{-2}s^{-1}$, respectively. The residential zones, viz. Maharani Bagh and Netaji Nagar are exposed to high pollutant risk due to vehicular traffic as evident from their EHER values (31.70 and 33.59 $\mu gm^{-2}s^{-1}$, respectively). All these zones require intensive plantation of suitable and appropriate species specially along the transport corridors.

In Jamshedpur region, a high assimilative capacity value (7.29 $m^4\mu g^{-1}s^{-1}$) at Dimna forest zone can be attributed to the high sink potential (144.50 mm^{-2}). Low assimilative capacity (4.78 $m^4 \mu g^{-1} s^{-1}$) as well as low stomatal resistance values (3.58 s cm^{-1}) at Jugsalai Railway Station and Bistupur area (5.84 $m^4 \mu g^{-1} s^{-1}$ and 3.51 s cm^{-1}, respectively) are due to high exposure to pollutants emitted by heavy vehicular traffic as evident from high EHER values (72.30 and 61.60 $\mu g m^{-2} s^{-1}$, respectively). While assimilative capacity values at both Mango (14.73 $m^4 \mu g^{-1} s^{-1}$) and Kalimandir (11.39 $m^4 \mu g^{-1} s^{-1}$) are observed to be high, Kalimandir has very low EHER values (2.71 $\mu g m^{-2} s^{-1}$) as compared to Mango which has significantly very high EHER value (30.33 $\mu g m^{-2} s^{-1}$) due to its exposure to higher levels of pollution.

On the basis of the findings of this study, need for eco-restoration of the abandoned mined areas at Doon Valley region and regeneration of the forest zones at all the regions have been recommended. Eco-restoration should be based on site-suitability, and species-specificity and their sink potentials. The species with high density and dominance should be used for regeneration at the impacted forest zones, thus enhancing the productivity, and ultimately the forest health. Rehabilitation of the Gujjars and the elephant population is also recommended in order to minimize the impact on the forest resources.

Green-belts for the city regions in all the three study areas, viz. Dehradun (Doon Valley); Delhi (NCR); Jamshedpur city (Jamshedpur) have been suggested depending upon species-specific sink potentials and site-suitability. The plants with high sink potentials and site-suitability, as also the agencies which should be involved in this task of afforestation and green-belt development have been presented in **Table 5.1**. Development of green buffers along major transport corridors, specially in Delhi region, as also conservation of the Wild Life at Dalma Pahar in Jamshedpur region, and Sariska Wild Life Sanctuary in NCR region which deserve attention from environmental management point of view.

5.1 FUTURE RESEARCH NEEDS

Well known damage symptoms and available empirical data on the physiological responses of plants to pollutants (including green house gases) have established the importance and need for incorporating additional factors, viz. climatic (temperature & humidity); edaphic (soil pH, soil moisture); and biogeochemical (nutrient and water availability) in future studies. Key indicator processes, viz. stomatal behavior, transpiration, and photosynthesis should be monitored and studied on a regular basis and used for characterising the sink potentials of the species under study. The model can also be modified through the incorporation of additional processes and parameters so as to quantify ecosystem-specific assimilative capacity with added precision.

Table 5.1

Zone/Region	Major Source of Pollutants/ Impacts	Plants Recommended for Afforestation	Source/ Institutions to be involved
DOON VALLEY REGION			
Dehradun Forest Division	Industrial/ Anthropogenic/ Natural	Sal, Rohini, Khair, Toona, Semal, Dhak, Sain, Teak	FD/NGO/SFD VO/VPFC/BP
Siwalik Forest Division	Anthropogenic/ Natural	---------Do-----------	-------DO-----
Mussoorie Forest Division	Anthropogenic/ Natural/Tourism/ Industrial/Mining	Chir, Thuja, Banj, Palm, Toona, Cupress, Deodar, Semal, Silver Oak	TD/SFD/VO/NGO/ VFPC/BP/ETF
City Region	Anthropogenic/ Urban/Industrial	Sal, Bottle Brush, Kadu, Silver Oak, Rohini	FD/VO/NGO/JMC/ SFD
JAMSHEDPUR REGION			
Forest			
Dimna	Anthropogenic	Sal, Asan, Karam, Kurchi	VPFC BP/FD
Nutandih	Industrial/ Anthropogenic	Mahua, Kurchi, Asan, Dhak, Chironji, Bija Sal, Teak, Jamun, Arjun, Sida, Doka	------Do------
Dalma	Anthropogenic	Kachnar, Karam, Kurchi, Palash, Padasi, Siris, Doka, Bamboo, Semal, Peepal, Bargad, Dhaura	-------Do-----
City Zones			
Jubilee Park	Vehicular/ Anthropogenic	Acacia, Cassia, Gulmohor Maharukh, Bargad, Nerium, Bamboo	SFD/NGO/VO/ TISCO Authorities
Jugsalai	Industrial/ Vehicular	Jamun, Neem, Mango, Bargad, Kurchi	------Do------
Bistupur	Industrial/ Vehicular	Jamun, Neem, Mango, Bargad, Kurchi	------Do------

CONTD.....

TABLE 5.1 CONTD....

Zone/Region	Major Source of Pollutants/ Impacts	Plants Recommended for Afforestation	Source/ Institutions to be involved
Mango	Vehicular	Jamun, Neem, Mango, Bargad, Kurchi	------Do------
TELCO	Industrial	Jamun, Neem, Mango, Bargad, Kurchi	------Do------
NCR - DELHI REGION			
Residential Zones			
Shahadra	Anthropogenic/ Industrial	Jamun, Peepal, Badgad Mahua	DMC/DDA/ASI/ MCD/HD/FD/SFD
Nizamuddin	Anthropogenic/ Vehicular	------------DO--------	-------DO-----
Ashok Vihar	----DO---	------------DO--------	-------DO-----
Netaji Nagar	----DO---	Jamun, Peepal, Badgad, Mahua, Ashoka, Bougainvillea	-------DO-----
Greater Kailash	----DO---	------------DO--------	-------DO-----
Punjabi Bagh	----DO---	------------DO--------	-------DO-----
Quedesia Bagh	----DO---	------------DO--------	-------DO-----
Malkaganj	----DO---	------------DO--------	-------DO-----
Janakpuri	----DO---	------------DO--------	-------DO-----
Maharani Bagh	----DO---	------------DO--------	-------DO-----
Traffic Zones			
Connaught Place	Vehicular	Jamun, Neem, Peepal, Acacia	--------DO----
Paharganj	----DO---	------------DO----------	-------DO-----
Idgah Faiz Rd.	----DO---	------------DO----------	-------DO-----

CONTD.....

TABLE 5.1 CONTD....

Zone/Region	Major Source of Pollutants/ Impacts	Plants Recommended for Afforestation	Source/ Institutions to be involved
Town Hall	----DO---	------------DO----------	-------DO-----
ITO Intersection	----DO---	------------DO----------	-------DO-----
Industrial Zones			
Najafgarh	Industrial/ Vehicular	Neem, Peepal, Jamun, Kikar Shishum	-------DO-----
Mayapuri	----DO-----	------------DO------------	-------DO-----

VFPC - Village Forest Protection Committee
BP - Ban Panchayat
VO - Voluntary Organisation
NGO - Non-Governmental Organisation
SFD - Social Forestry Division
FD - Forest Department
HD - Horticulture Department
JMC - Jamshedpur Municipal Corporation
DMC - Delhi Municipal Corporation
MCD - Municipal Corporation of New Delhi
DDA - Delhi Development Autjority
ASI - Archeological Survey of India
TD - Tourism Department
ETF - Eco-Task-Force

CHAPTER VI
REFERENCES

6.0 REFERENCES

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ANNEXURES

ANNEXURE I

LIST OF FLORA OBSERVED IN DOON VALLEY REGION

COMMON NAME	SCIENTIFIC NAME
TREES	
Akash Neem	*Mallingtonia hortensis*
Am	*Mangifera indica*
Amaltas	*Cassia fistula*
Anjiri	*Ficus palmata*
Aonla	*Emblica officinalis*
Arru	*Ailanthus excelsa*
Asna (Sain)	*Terminalia alata*
Babul	*Acacia nilotica*
Bahera	*Terminalia bellerica*
Bakain	*Melia azedarach*
Bakli	*Anogeissus latifolia*
Bargad	*Ficus bengalensis*
Barhal	*Artocarpus lakoocha*
Bel	*Aegle marmelos*
Ber	*Zizyphus mauritiana*
Bhainsh	*Salix tetrasperma*
Bhilawa	*Semicarpus anacardium*
Burans	*Rhododendron arboreum*
Chamror	*Ehretia laevis*
Chatuin	*Alstonia sholaris*
chir	*Pinus roxburghii*
Chironji	*Buchanania lanzan*
Dalchini	*Cinnamum tamala*
Dhak	*Butea monosperma*
Dhaman	*Grewia elastica*
Dhauri	*Lagerstroemia parviflora*
Dhudi	*Holarrhena antidysentrica*
Ekdania	*Bridelia retusa*
Gular	*Ficus glomerata*
Gamhar	*Gmelina arborea*
Gauj	*Derris scandens*
Haldu	*Haldina cordifolia*
Harra	*Terminalia chebula*
Harshingar	*Nyctanthes arbortristis*
Imli	*Tamrindus indica*
Jamun	*Syzygium cumini*
Jangli Neembu	*Citrus medica*
Jhingan	*Lannea coromandelica*
Kachnar	*Bauhinia variegata*
Tumri	*Phoebe lanceolata*
Kala Siris	*Albizzia lebbeck*
Kala Tendu	*Diospyros malabarica*
Kusum	*Schleichera oleosa*

CONTD...

ANNEXURE I (CONTD...)

COMMON NAME	SCIENTIFIC NAME
Kanju	*Holoptelea integrifolia*
Kathber	*Zizyphus glaberrima*
Kandhara	*Xylosma longifolium*
Kapoor	*Cinnamom camphora*
Kumbhi	*Careya arborea*
Khajur	*Phoenix sylvestris*
Khair	*Acacia catechu*
Kharpat	*Garuga pinnata*
Khatua Khatti	*Bauhinia malabarica*
Mahuwa	*Madhuca indica*
Mainphal	*Xeromphis spinosa*
Moru	*Quercus himalayana*
Neem	*Azadirachta indica*
Pachnala	*Flacourtia indica*
Phaldu	*Mitragyna parviflora*
Phalsa	*Grewia sapida*
Pipal	*Ficus religiosa*
Putranjiva	*Putranjiva roxburghii*
Rohini	*Mallotus philippinensis*
Safed Siris	*Albizzia procera*
Sagaun	*Tectona grandis*
Sainjna	*Moringa oleifera*
Sal	*Shorea robusta*
Sandan	*Ougeinia oojeinensis*
Semal	*Bombax ceiba*
Semla	*Bauhinia retusa*
Shahtut	*Morus alba*
Shishum	*Dalbergia sissoo*
Tendu	*Diospyros tomentosa*
Timru	*Zanthoxylum armatum*
<u>SHRUBS AND HERBS</u>	
Ak	*Calotropis procera*
Banbijora	*Citrus medica*
Bansa	*Adhatoda vasica*
Chakunda	*Cassia tora*
Chameli	*Jasminum arborescens*
Dhaula	*Woodfordia fruticosa*
Gandhela	*Murrya koenigii*
Gauj	*Millettia auriculata*
Karunda	*Carissa opaca*
Karani	*Caesalpinia bonduc*
Karu	*Clerodendron viscosum*
Phalsa	*Grewia sapida*
Unknown	*Lantana camera*

CONTD...

ANNEXURE I (CONTD...)

COMMON NAME	SCIENTIFIC NAME
CLIMBERS	
Agla	*Acacia pinnata*
Amarbel	*Cayratia trifolia*
Akashbel	*Cuscuta reflexa*
Kanj	*Toddalia asiatica*
Malha Bel	*Butea parviflora*
Maljhan	*Bauhinia vahlii*
Maruabel	*Marsdenia roylei*
Medha singhi	*Cryptolepis buchanani*
Panibel	*Ampelocissus latifolia*
Roel	*Combretum roxburghii*
BAMBOOS	
Bans	*Dendrocalamus strictus*
GRASSES	
Bhabhar	*Eulaliopsis binata*
Dhaula	*Chrysopogon fulvus*
Kans	*Saccharum spontaneum*
Sirhi	*Imperata cylindrica*

ANNEXURE II

LIST OF FLORA OBSERVED IN JAMSHEDPUR REGION

Local Name	Hindi Name	Botanical Name
Ashing or Gonyour	Dhanman	*Grewia tiliaefolia*
Ambe of Ambau	Amara	*Spondias mangifera*
Asanda	Kumbhi	*Careya arborea*
Bai	Barh	*Ficus bengalensis*
Bandu	Maula	*Butea parviflora*
Baru	Kusum	*Schleichera trijuga*
Burja	Kachnar	*Bauhinia variegata*
Burui	Dekamali	*Gardenia guniffera*
Burumat	Bans	*Dendrocalamus strictus*
Dau	Barhar	*Artocarpus lakoocha*
Edel	Semal	*Salmalia malabarica*
Gara hesel	Phansi	*Anogeissus sp.*
Gara tiril	Makar kendu	*Diospyros embroyopteri*
Hatna	Asan	*Terminalia tomentosa*
Hari	Analtas	*Cassia fistula*
Hesel	Dhauraor Dhautha	*Anogeissus latifolia*
Hid	Bija or Piasal	*Pterocarpus marsupium*
Hupu	Galgal	*Cochlospermum gossypium*
Huhir	Sinwar or Sinduar	*Vitex negundo*
Jojo (Tetul)	Imli	*Tamarindus indica*
Jomalar	Mahular (ehope)	*Bauhinia vahlli*
Koka	Kajhi	*Brindelia retusa*
Kanthar or Kanthan	Kathal	*Artocarpus heterophyllus*
Ka-man	Karaunda	*Carissa spinarum*
Karkatta	Katber or Kokar	*Zizyphus xylopyra*
Kiri	Sissoo	*Dalbergia latifolia*
Kita Khajur	Khajur	*Phoenix acaunis*
Koroj or Kornjo	Karanj	*Pongamia glabra*
Kuda	Jamun	*Eugenia jambolana*
Kumba or Kurumba	Karam	*Adina cardifolia*
Kundrujaman	Arar	*Acacia pinnata*
Kuar or Towa	Koraiya or Kurchi	*Holarrhena antidysenterica*
Lowa, Dumar	Gular	*Ficus glomerata*
Bel, Lobagasi	Bel	*Aele marmeles*
Lupung	Bahera	*Terminalia belerica*
Madukan	Mahua	*Madhuca latifolia* *Bassia latifolia*
Mur or Murud	Palas	*Butea monosperma*
Neem	Neem	*Azadirachta indica*
Anam, Doka	Genjan	*Lanner grandis* Syn. Odina wodier)
Pandrai	Siris (Safed)	*Albizzia procera*

Contd...

ANNEXURE II (CONTD....)

Local Name	Hindi Name	Botanical Name
Pasu or Parasu	Karla or Kargeli	*Cleistanthus collinus*
Rola	Harre	*Terminalia chebula*
Saratiril	-	*Diospyrous montana*
Sarjom	Sakhua, Sal	*Shorea robusta*
Sekri	sidha	*Lagerstroemia parviflora*
Sengel Sali	Bherul	*Chlorxylon swietenia*
Sim-Janga	Charaiguri	*Vitex peluncularis*
Singa or Singara	Koenari	*Bauhinia purpurea*
Sos-o	Bhelwa	*Semicarpus anacardium*
Tiril	Tend or Kend	*Diospyros melanoxylon*
Tarob Piar	Piar	*Buchanania latifolia*
Uli	Aam	*Mangifera indica*
Kandmer	Kekar	*Garuga pinnata*
Armu, Kandior, Karonda	-	*Barcera serrata*
Rohini	Rohan	*Soyamida febrifuga*
Jam Jamun	Ber	*Zizyphus jujuba*

ANNEXURE III

LIST OF FLORA OBSERVED IN NCR - DELHI REGION

Scientific Name	Common Name
Trees	
Acacia arabica	Kikar
Acacia leucophloea	Ronj
Acacia senegal	Khor
Acacia catechu	Khair
Butea monosperma	Dhak/Palas
Anogeissus pendula	Dhau
Balanites roxburghii	Hingan
Prosopis spicigera	Kherji
Zizyphus jujuba	Ber
Ehretia laevis	Tambolia
Tecomella undulata	Rori
Common Shrubs and Herbs	
Salvadora persica	Pilu
S. oteoides	Jhar
Capparis sepiaria	Kataran
Carissa spinarum	Karwand
Adhatoda vasica	Vasuka
Barleria spp.	
Indigofera tinctoria	
Tephrosia purpurea	
Corchorus aestuans	
Tribulus terristris	
Cleome viscosa	
Pupalia lapacea	
Justica simplex	
Common Weeds	
Xanthium strumarium	
Solanum surattense	
Digeria alternitolia	
Fumaria indica	Gajri
Lathyrus sativus	Kesari
Anagallis arveusis	Krishan Neel
Euphorbia prostrata	Chirya Bajra
Stellaria media	