EVALUATION OF AIR POLLUTION TOLERANCE INDEX AND ANTICIPATED PERFORMANCE INDEX OF TREES IN DTU CAMPUS

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CERTIFICATE

This is to certify that Ms. DEEPIKA (2K14/ENE/07), M. Tech. student in the Department of Environmental Engineering has submitted a dissertation on "Evaluation of Air Pollution Tolerance Index and Anticipated Performance Index of Trees in DTU Campus" in the partial fulfillment of the requirement for the award of degree of Masters of Technology in Environmental Engineering during the academic year 2015-16. It is remarked the work done by student was accomplished under my guidance and supervision.

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Declaration of Originality

I hereby declare that this project work and report is completely my own work and I am the sole author of this report. Any additional sources of information, quotations and techniques of work from other people are fully acknowledged and duly cited in accordance with the standard procedure of referencing. I undertake that this report is the true copy of my work as approved by my supervisor. This report has not been submitted for any other degree to any other University or Institution.

(Deepika)

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Abstract

In the present study, 23 tree and shrub species were collectively evaluated for air pollution tolerance index (APTI) and anticipated performance index (API) analysis which proves to be a practical approach for maintaining air quality and developing a sink for air pollution control. On the basis of APTI, tree species were classified as sensitive and tolerant with respect to air pollution. The results of the study show *M. indica*, *Eucalyptus* and *F.benghalensis* as best performers and more tolerant species with APTI values above 10.0 and API grade above 4, although lower relative water content (RWC). The species were observed to have high ascorbic acid content which helps in maintaining good chlorophyll levels. More than 75% of species had good RWC. On the other hand, *C. indica*, *Thevetia peruviana* and *B. variegata* were least scorers in analysis which can prove to be good for biomonitoring of air quality in the campus. It was observed that the trees with broad leaves and thick canopy had higher chlorophyll concentration compared to the trees with compound leaves and cone-type canopy. About 35% of the studied plants were classified as moderately tolerant to tolerant and rest as intermediately tolerant which may be a cause concern if the concentration of air pollutants rise. On an average the species studied are considered good for green belt development in and around the DTU campus area.

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List of Abbreviations and Symbols

DTU	Delhi Technological University
APTI	Air Pollution Tolerance Index
API	Anticipated Performance Index
AAC	Ascorbic Acid Content
TCh	Total Chlorophyll Content
CT	Total Chlorophyll Content
RWC	Relative Water Content
pH	Potential of Hydrogen
IPCC	Intergovernmental Panel on Climate Change
DSHB	Delhi Statistical Hand Book
WHO	World Health Organisation
USEPA	United States Environmental Protection Agency
CBD	Central Business District
UNDP	United Nations Development Program
EPHA	European Public Health Alliance
IEA	International Energy Agency
µ	Micron
S.No.	Serial Number
Et al	and others
SD	Standard Deviation
mg/g	milligram per gram
mg/l	milligram per litre
ppm	parts per million
ppb	parts per billion
mg/m^3	milligram per cubic metre

g	grams
nm	nanometre
kcal/kg	kilocalorie per kilogram
N	Normality
M	Molarity
D645	Optical density at 645 nanometers
D663	Optical density at 663 nanometers
FW	Fresh weight
DW	Dry Weight
TW	Turgid Weight
Chl *a*	Chlorophyll *a*
Chl *b*	Chlorophyll *b*
Pb	Lead
H_2SO_4	Sulphuric Acid
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CH_4	Methane
SO_2	Suphur Dioxde
H_2S	Hydrogen Sulphide
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter 2.5 micrometers or less in diameter
PM_{10}	Particulate Matter 10 micrometers or less in diameter
NO_x	Oxides of Nitrogen
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide

N_2O	Nitrous Oxide
N_2O_3	Dinitrogen Trioxide
N_2O_5	Dinitrogen Pentoxide
NO_3^-	Nitrate
HNO_3	Nitric Acid
NH_3	Ammonia
O_3	Ozone gas
PAN	Peroxyacetyl Nitrate
CFCs	Chlorofluorocarbons
SPM	Suspended Particulate Matter
VOCs	Volatile Organic Compounds
NMVOCs	Non-methane volatile organic compounds
HC	Hydrocarbons
TPY	Tons per Year
RDF	Refuse Derived Fuel
WTE	Waste to Energy
MSW	Municipal Solid Waste
SMW	Solid Waste Management
DPM	Diesel Particulate Matter

CHAPTER I

INTRODUCTION

Air is the dynamic system of continuously mixed wide range of solids, liquids and gases that surround the planet Earth. All living beings are dependent on air, particularly oxygen, for their survival on Earth. Even the organisms living in water or soil take it from the small concentrations of air dissolved in water. Air supports water cycle, helps in pollination of crops, maintains temperature on earth surface, bring monsoon, maintaining humidity balance, helps in aerodynamics, transportation by air, mixing of air pollutants, generation of energy from food by the means of plants etc. Clean and dry air comprises of 78.09% Nitrogen, 20.95% Oxygen, 0.93% Argon, 0.039% Carbon dioxide and small concentrations of other gases. It also contains a variable amount of water vapors, on an average 1% at sea level and 0.4% over the entire atmosphere. This composition of air is imbalanced and tempered with by various amounts of contaminants that continuously enter the atmosphere from natural and anthropogenic sources. To some extent these contaminants are endurable to life sustaining on Earth, this natural state of air in the outside environment that humans and animals breathe is known as the ambient air. When a gas or a liquid or a solid is dispersed through ordinary air in enough amounts to harm health of humans, animals, plants or disrupt any other aspect of environment is termed as air pollution.

Air pollution is an inevitable derivative of the growing development around the globe; the urbanization, industrialization and concrete forests not only deteriorate the air quality but also depreciate the chances of atmosphere of cleansing itself. Air pollution have long known to cause adverse effects on plants and now with multiplied boost of industrial processes and transportation, the harmful effects are tremendously high. But plants are also the solution to the deteriorating quality of air as trees can remove the gaseous air pollution either by uptake via leaf stomata or through the plant surface.

When gases diffuse inside the intercellular spaces of leaf, they are absorbed by water films to form acids and react with inner leaf surfaces. Also trees can remove air pollution by intercepting the airborne particles absorbed into the tree and retained on the plant surface, but apparently vegetation is a temporary site for retention of atmospheric particles as the intercepted particles are often washed off by rain, re-suspended into the atmosphere or dispersed through leaf fall. The primary factor that controls the absorption of gaseous particles by the leaves is the degree of opening of the stomata. With wide openings the absorption is maximum and lesser if the opening is smaller. This condition also controls the absorption of the Carbon dioxide gas to play its role in photosynthesis. High light intensity during morning hours, high relative humidity and adequate moisture supply and moderate temperature are contributing factors to the stomata opening. Due to the high levels of carbon dioxide and other gases heat is trapped in the atmosphere of earth, phenomenon known as the greenhouse effect. Therefore trees helps the carbon sequestration from the atmosphere during photosynthesis and return oxygen back to atmosphere, hence trees act as carbon sinks alleviating the greenhouse effect and also trees can reduce the greenhouse effect by shading the buildings and houses, the combination of CO_2 removal from the atmosphere, carbon storage in plants makes trees extremely efficient tools in combating the greenhouse effect. Planting trees is one of the utmost cost-effective ways to draw excess CO_2 from the atmosphere.

On the other hand, air pollution affects the plants through various means like acidification, reducing the amount of light reaching the leaf and clogging the stomata and hence reducing the carbon dioxide intake and interfere the photosynthesis. Thus air pollution is responsible for various physiological and biochemical changes brought up in trees and plants. Air pollutants affecting plants are sulphur dioxide, fluoride compounds, ozone, chlorine, hydrogen chloride, nitrogen oxides, ammonia, hydrogen sulphide, hydrogen cyanide, mercury, ethylene etc. Tissues that are severely injured by pollutants are often appears to have characteristic color like bleaching mostly associated with sulphur dioxide, ammonia leads to yellowing of leaf, browning with fluoride, silvering or bronzing is associated with Peroxyacetyl nitrate (PAN) injuries. Factors like sources of pollution in the vicinity such as transportation, industries, dumpsites, or climatic factors or sensitivity of the species itself, duration and amount of exposure to the plant, type and concentration of pollutant play important role in the extent of damage. Sulphur dioxide is one of the principal pollutants originating from industries. Sulphur dioxide and its by-product sulphuric acid that usually results in dry blotches that are white or tan and in case of chronic injuries can be brown, reddish brown or even black; also it causes interveinal chlorotic bleaching of leaves. Deposition of air pollutants from dumpsites on plant leaves can severely affect the morphological, physiological, and biochemical properties of plants. Studies have shown effects of such air pollutants on ascorbic acid content and chlorophyll content of plant leaves. Air pollution from dumpsites can either directly affect the plant by deposition on plant leaves or indirectly through soil acidification. Pollutants such CO, SO_2 and NO_2 from vehicular emissions not only have direct effects on plants but also contribute trendily as indirect means in the form of acid rain and PAN formation. Nitrogen dioxide and PAN often leads to suppressed growth and bleaching of lower leaf surface. As we have already discussed climatic factors such as duration and intensity of light, temperature, humidity are imperative, but sensitivity plays role of domineer here, as response of plants to pollutants can vary not only between genuses but between varieties within a given species too. Some plants that show sensitivity to one pollutant can be resistant to other and one plant may not show similar susceptibility to same weather conditions as other, such variations is just a function of genetic variability.

The physiological and biochemical changes that occurs in plants due to their exposure to air pollution can be determined by evaluating various factors. These factors can be the visible changes or chemical changes. But it is reported in studies that before exhibiting visible changes over the leaves, most plants experience physiological changes when exposed to air pollution. These physiological changes are studied to determine if a particular plant species is sensitive or resistant to that particular environment and conditions. This is done by focusing on four major parameters viz. pH of leaf extract, relative water content (RWC), total chlorophyll (TCH), and ascorbic acid content (AAC). These four parameters are used to finally calculate the Air Pollution Tolerance Index (APTI) for plant species. Henceforth, APTI values can be used to categorically select species that are more tolerant to air pollution and stressed conditions. Studies can be performed in various permutations and combinations such as comparative studies for different areas, APTI studies are firmly area specific, then there can be studies for seasonal variations to determine which plant species perform better in which season. Based on various biological and socioeconomic aspects, APTI values can be further used to calculate the Anticipated Performance Index (API). API uses combination of various parameters and gives relative performance of individual plant species in different environmental conditions; and API gives more reliable outcomes than a single parameter analysis. API is the index based on various factors influencing the performance of a certain species of plant; it is calculated by evaluating various socioeconomic, biochemical, and biological characteristics of the plant such as APTI, plant habits, canopy structure and economic value. Then API score is given to each species according to a grading system that is used to categorize the plants into good to poor performers. Hence API and APTI is an efficient approach in assessing tolerance of trees and plant to air pollution which can be applied to development of green belt in an area and for other avenue purposes for roadside, industrial, commercial, residential areas. Efficient use of plants for green belt not only provides aesthetic value and improves air quality but also helps in defining the air quality by the changes brought in plants due to the air. The changes in chemical composition and effectiveness of the pollutant tests by which the effectiveness of certain substances are determined through responses of living things. Those responses, therefore, allow assertions regarding effects, while chemical and physical analyses provide a basis for determining the risk to which living things are exposed. Plants exhibit differential sensitivity to gaseous pollutants, and this differential behavior can be employed to develop appropriate environmental indicators.

Acknowledging the above facts and information, the contemporary study was carried out with following objectives:

1. To determine the Air Pollution Tolerance Index of the tree species of university campus of Delhi Technological University.
2. To determine the Anticipated Performance Index of the tree species considered in the study.
3. To classify trees as per their sensitivity towards air pollution.
4. To suggest trees for green belt development on basis of their performance index for air quality amelioration.

CHAPTER II

REVIEW OF LITERATURE

Air pollution is one of the most severe problems arising in today's time. Air Pollution is not a "single" problem, but an assemblage of threats to living beings and environment. It works in form of a wide range of pollutants acting in a variety of combination with the natural and anthropogenic sources to effect the environment. The air we breathe is an essential ingredient for our wellbeing and a healthy life but unfortunately polluted air is common throughout the world especially in developed countries from 1960s (EPHA, 2009; Kan, 2009). Rapid growth in urban population, growing industrialization, and escalating demands for energy and motor vehicles are some of the reasons for worsening the air pollution levels as stated by Mishra *et al.*, (2003). It further adds other factors, such as poor environmental regulation, less efficient technology of production, congested roads, and age and poor maintenance of vehicles, that adds to the problem. As reviewed by Arsalan (2011) air pollution is cause of ill health and death by natural and man-made sources, major man-made sources of ambient air pollution include tobacco smoke, combustion of solid fuels for cooking, heating, home cleaning agents, insecticides industries, automobiles, power generation, poor environmental regulation, less efficient technology of production, congested roads, and age and poor maintenance of vehicles. The natural sources include incinerators and waste disposals, dust storms in desert areas, forest and agricultural fires (EPHA, 2009). Air pollution kills more than 2.7 million people annually, with more than 90 percent of these deaths in developing countries and two-thirds of them in Asia (UNDP, 1998). It also suggests that once the almost entire air pollution concentrated to industrial countries is now growing rapidly in the developing ones and that rapid industrialization in many countries has immensely increased the pollution levels. Also the mounting demand for motorized vehicle ownership is increasing the emissions all over globe as vehicle exhaust is one of the major pollution sources.

2.1. Classification of Air Pollutants

Air pollutants can be broadly classified in two major categories based on their origin as Primary and Secondary Pollutants (Daly, 2007)

Primary Pollutants: These are the pollutants that are emitted directly from the identifiable source. Some of the major primary pollutants that are known to cause harmful effects in high concentrations are:

- Carbon compounds such as CO_2, CO, CH_4
- Sulphur compounds such as SO_2, H_2S
- Oxides of Nitrogen such as NO, N_2O, NH_3
- Halogen compounds such as Fluorides, Chlorides, Bromides
- Particulate Matter in form of solids or liquids, finer particles of size less than 100 µ or coarser particles of size greater than 100 µ
- Organic compounds
- Radioactive compounds

Secondary Pollutants: These are the pollutants which are not emitted directly from identifiable source but are produced from interaction among two or more primary pollutants in the atmosphere. Some major secondary pollutants known to cause harm in high enough concentrations are:

- Ground level Ozone formed from photochemical reactions of nitrogen oxides and VOCs
- NO_2 and HNO_3 formed by NO
- Formation of acid mists i.e. Sulphuric acid and Nitric acid droplets
- Sulphate and nitrate aerosols
- Organic aerosols from VOCs
- Formaldehyde

- PAN
- Photochemical smog

According to chemical composition, air pollutants can be categorized as organic and inorganic pollutants. Organic pollutants are primarily consists of carbon and hydrogen; in addition, oxygen, nitrogen, sulfur and phosphorus may also be present for example hydrocarbons, organic sulfur compounds, aldehydes, ketones, carboxylic acids. Inorganic Pollutants are purely inorganic in nature for example carbon dioxide, carbon monoxide, oxides of sulfur, oxides of nitrogen, ozone. Based on source type, air pollutants can be classified as mobile sources and stationary sources type. Mobile Sources are the pollutants which have a definite route; they can be line sources and area sources. Stationary Sources are those which have a fixed location, these can be point sources and area sources. Air pollutants can be divided into two types based on their state in which they exist in atmosphere (Kampa *et al.,* 2008). Particulate Pollutants are pollutants constituting of the solids like dust, smoke and fly ash and liquids like mist, spray and fog dispersed in the atmosphere. Gaseous Pollutants are the organic and inorganic gases present in air as pollutants. For example methane, aldehydes, carbon dioxide, sulphur dioxide, nitrogen dioxide, ammonia.

2.2. Sources of Air Pollution

Air pollution is an evident fact and is not a single parameter entity but an assembly of factors active in combinations bringing out the changes all over the world. There are various sources categorized on different basis to make their identification and detection much lesser complicated. The sources that contribute to air pollution can be broadly classified as natural and anthropogenic (man-made) sources (USEPA, 2011). There are numerous natural and anthropogenic sources of air pollution that contributes to the present day outdoor air quality (Kampa, 2008).

2.2.1. Natural Sources of Air Pollution are those that originate from source of nature which are often much greater than their man-made counterparts. These include volcanic eruptions, forest fires, and sand storms, decomposition of organic matter, pollen grains and natural fog (Gupta *et al.*, 2009). Suspended soil dust and road dust are found abundant in the atmosphere in India, plants being the acceptors of air pollutants acts as scavengers to the later and during prevailing dry weather conditions, deposition of particles through dust fall is the major pathway of removal of pollutants(Sahu & Sahu, 2015; Gupta *et al.*, 2015). Dust from natural sources like soil suspension is another major concern regarding air pollution especially in developing countries like India. Airborne particulate matter represents a complex mixture of organic and inorganic substances varying in size and is capable of entering an organism or plant in many ways (Agarwal *et al.*, 1999). Many plant species are very sensitive to such air pollutants and most obvious damage that occurs targets the leaf of the plant as stated by Ulrich (1984). Leaves provide surface area for absorption, adsorption and impingement of air pollutants and dust particles and dust particles accumulating on leaf surface affects the availability of light for photosynthesis and blocks the stomatal pores used for its metabolism (Eller *et al.*, 1977; Escobedo *et al.*, 2008). Deposition of atmospheric dust with very high or low pH may perhaps have negative impact on plant growth and photosynthesis but despite the huge dust fall deposition on foliar surface, some plant species survives due to production of biochemical like ascorbic acid, proline and polyphenols which are considered as expression of resistance against abiotic stresses in plants (Eller *et al.*, 1977; Gupta *et al.,* 2009; Kumar *et al.,* 2014). Although the natural sources of air pollution contributing to environmental degradation is much higher but the major concern that rises today is the upsurge in air pollution due to anthropogenic sources, as chances of humans to control the natural sources are less likely and the fact that man-made sources of air pollution have much more severity in terms of damages that are produced; anthropogenic activities when interact with natural sources modify their chemical properties and proves to be more harmful (Kulshrestha *et al.*, 2015; Kumar *et al.*, 2014).

2.2.2. Anthropogenic Sources of Air Pollution are those that are introduced into the atmosphere by human activities. The present composition of air is suspected to undergo major changes under the influence of evolution of man-kind, both in terms of population growth as well as in industrial, agricultural and household development in simple word civilization (Rai *et al.*, 2013). The energy consumption and technical evolution is one of the major reasons of the man-made pollution, causing modification of the air quality much high above the permissible limits, postulated liberally in legislature, adapted and modified according to the level of knowledge, permanently. These anthropogenic sources are exhausting varied specific species to the atmosphere and stressing over the limit the natural likelihood of the ecosystem to adapt or to cover these caused concentration growth. One should know that all these man-made sources from industries, agriculture, transportation, household sources are contributing to the air quality level in addition to the natural sources of pollution that exists since the Earth was created and are in direct dependence to it.

Human made sources of emissions are very diverse and our environment is entangled with the anthropogenic activities. Civilization in itself is the main reason for rising levels of air pollution and its development in terms of industrialization, urbanization, transportation, advanced agricultural practices, technical development have played its key role in doing its part with impunity. The major anthropogenic sources of air pollution are:

- Industrialization; industrial processes, power plants, and industrial waste
- Transportation; vehicular emission and vehicle production
- Burning of fossil fuels including domestic burning of biomass
- Agricultural activities
- Waste Management
- Construction activities
- Mining

- Metallurgical processes
- Deforestation
- Nuclear testing
- Power generation
- Incineration

Transportation

The major cause of air pollution is fuel combustion through any of these sources. Transport is the primary source of air pollution in India's major cities (Shrivastava *et al.,* 2013). In India, a total of 3000 tons of pollutants blanched out every day from transport sector itself, out of which the contribution of Delhi city is about 66%. According to 2010 data, there has been an enormous increase in the number of vehicles in last two decades. There has been a spike of 185% in the number of vehicles as compared to 1994 in Delhi itself and beside the local sources; Delhi also gets air pollution through long-range transport and nearby states agriculture burning and brick kilns emissions from Haryana, Punjab and Uttar Pradesh (DSHB Handbook, 2009-11; Singh *et al.,* 2014). Both gaseous as well as particulate pollutants like CO_2, CO, NO_x, SO_2, PM, HC are emitted as vehicular emissions.

Industrialization

Industries and their advancement is important for the development of human race, take us one step forward with every new invention and technology but their adverse effects on environment do more harm than good. Uncontrolled use of fossil fuel in industries leads to increase in concentration of gaseous pollutants like SO_2, NO_x, SPM, CO, HC and particulate matter is also of great concern in relative to their adverse impact on human health and vegetation (Rai *et al.,* 2013). Small quantities of water vapor, lead, mercury, cadmium, aldehydes are also emitted. In India, problem of air pollution has anticipated severe proportions in most major metropolitan cities where transportation sector contributes around 72% and almost 20% contribution is from industrial emission (Garg *et al.*, 2001); but in last two decades greater impacts have been experienced in rural and more remote areas too due to the changing pattern of air pollution emissions. Chemical and metallurgical industries emit large quantities of SO_2 during roasting and treatment of non-ferrous sulphide materials; iron and steel industries include dust, fumes, HCs, tars, H_2S, CO, CO_2 and SO_2; petroleum refineries generate mercaptans, catalyst dust, metallic vapors and water vapors along with other gaseous pollutants; food and agriculture sector produces dusts from grinding, milling and handling operations. Air pollutants from industries may be absorbed and accumulated or integrated into plant body and their toxicity can injure them to a great degree. Level of injury to plant depends on their tolerance to the pollutants and their capability in reducing the overall pollution load (Rao *et al.*, 1983).

Municipal Solid Waste and Biomass Burning

Municipal solid waste dumping and incineration along with domestic biomass burning is another burning issue contributing its harm to the environment and being a major source of air pollution. Indecorous practices of waste dumping; burning of waste and biomass especially in rural areas of India makes an unnecessary front to add up to the emissions. The relative contribution of open and domestic biomass burning emissions to the global annual emission for CO is 25 %, NO_x is 18 % and for non-methane volatile organic compounds (NMVOC) and CH_4 is 6 % (IPCC, 2001). According to Sustainable solid waste management in India report by Annepu (2012); open burning of solid wastes and landfill fires emit nearly 22,000 tons per year of pollutants into the air in the city of Mumbai alone. As present status in India, 6.7 million TPY of recyclable material which could have been used as secondary raw materials in manufacturing industries, due to the absence of source separation; 9.6 million tons of compost which could have been used as a fertilizer supplement, due to the absence of source separation and enough composting facilities; and 58 million barrels of oil energy equivalent in residues of composting operations that could have been used to generate electricity and displace fossil fuels in RDF co-combustion plants or WTE power plants; due to the absence of WTE facilities, and proper policies and pollution control regulations for co-combustion of MSW in solid fuel industries. MSW generation is increasing at an annual rate of 8-10% with over 150 million tons of waste being produced every year worldwide (Annepu, 2012). Number of gaseous pollutants like CO, SO_2, CFCs, NO_x and VOCs are reported to emit from MSW dumpsites (Daly, 2007). Pollutants from combustion of MSW at dumpsites have major effects on fruiting, periodicity, phenology, flower development, leaf, senescence, leaf surface wax characteristics, biomass production, seed germination, seedling growth, physiological and biochemical characteristics and plant growth (Iqbal *et al.,* 2015). MSW dumped in landfills generates greenhouse gases like methane that has 21 times more global warming potential than carbon dioxide; Improper SWM contributes to 6% of India's methane emissions and is the third largest emitter of methane in India. This is much higher than the global average of 3% methane emissions from solid waste; it currently produces 16 million tons of CO_2 equivalents per year and this number is expected to rise to 20 million tons of CO_2 equivalents by 2020 (IEA report, 2009).

Construction Activities and other Miscellaneous Sources

Industries and transport sector especially in urban areas of India are major source of deterioration of air quality by adding toxic gases and other substances to the atmosphere. As well; there are other miscellaneous but equally important factors like construction activities, improper waste management, growing the concrete forest etc. Goodall (1995) refers even tourism as the potential to damage the human and animal health, plants and trees including rainforests as well as the wider environment as reviewed in Tropical Rainforest Animal-Report (2008). Speaking of construction activities Delhi being capital city is center to all sorts of socioeconomic, cultural and political activities of the country as have been witnessed by all throughout the Commonwealth Games of 2010, which became a reason of not only increasing a lot on transportation front but city went through a lot of major constructions to make the event a success (Bansal *et al.,* 2016). The same study states that construction activities contributing to air pollution include land clearing, operation of diesel engines, demolition, burning and toxic materials and also earthwork excavation, refilling, handling and transportation of construction materials like sand and aggregate; construction of earthen ramps produce large volumes of dust, if it is not done properly, which can carry for large distances for over a long period of time. Construction dust is mostly classified as PM_{10}, particulate matter less than 10 microns in diameter, invisible to the naked eye. Another main source of PM_{10} on construction sites comes from diesel engine exhausts of vehicles and heavy equipment known as diesel particulate matter (DPM) and consists of sulphate and silicates, which is supposed to readily combine with other toxins in the atmosphere, increasing the health risks of particle inhalation. Diesel is also responsible for emissions like carbon monoxide, hydrocarbons, nitrogen oxides and carbon dioxide. Noxious vapors from oils, glues, thinners, paints, treated woods, plastics, cleaners and other hazardous chemicals that are widely used on construction sites, also contribute to air pollution. Also due to sheer volume, cement concrete is another major contributor to embodied energy in most structures and hence contributes most to carbon emission in the initial stages of constructional activities.

2.3. Major Air Pollutants and their Effects on Plants

It has been known for at least for 250 years that air pollution can have damaging effects on plants and vegetation (Edward *et al.,* 2004). Injury caused by air pollution is often evident on plants before it can affect humans or other animals.

In general, the visible injury to plants is of three types:

- collapse of leaf tissue with the development of necrotic patterns,
- yellowing or other color changes, and
- alterations in growth or premature loss of foliage.

Along with injury from air pollution, plants also seem to have similar kind of symptoms caused by fungi, bacteria, viruses, nematodes, insects, nutritional deficiencies and toxicities, and the adverse effects of temperature, wind, and water. There are six most common air pollutants known as "criteria pollutants" viz. ground-level ozone, particle pollution ($PM_{2.5}$ and PM_{10}), lead, nitrogen dioxide (NO_2), carbon monoxide (CO), and sulfur dioxide (SO_2), as recognized by USEPA, which are supposed to cause the thoroughgoing damage to environment; these along with a few other pollutants will be discussed in this section which seemingly cause damage to plants and vegetation.

Sulphur Compounds

The criteria pollutant SO_2 and H_2S gas are major concern of sulphur compounds in their contribution to damage to plants and trees. Sulphur dioxide is a stable nonflammable non-explosive, colorless gas that can be detected by taste at concentration as low as 1000mg/m^3 or by smell at concentration above 10,000mg/m^3 which is produced by the combustion of sulphur bearing fossil fuels for thermal power generation, heating, cooking, and transportation, petroleum refining and ore smelting are additional sources (Stern, 2013). The influence of SO_2 is the most concerned of direct phytotoxic impact on plants (Warminski *et al.,* 2005; Bytnerowicz *et al.,* 2007). Similar to other gases, SO_2 belongs to the group of abiotic stress factors that cause decline in biomass growth (Noe *et al.,* 2011).

Acute exposure to high levels of the gas kills leaf tissue, a condition called leaf necrosis; at a concentration of about 85 mg/m^3 (0.03 ppm) of SO_2 chronic plant injury and excessive leaf drop can occur (Linzon *et al.,* 2012). At concentration of about 145 to715 mg/m^3 (0.05 to 0.25ppm), SO_2 can react with either ozone or NO_2 in short-term exposures to produce moderate to severe injury to sensitive plants. Chronic exposure of plants to SO_2 causes chlorosis (Stern, 2013).

Figure 1. Chlorosis, yellowing on exposure to SO_2 (Source: Skelly, 2003).

Plants injury surges with increasing relative humidity; plants incur most injury from SO_2 when their stomata are open. The degree of injury increases with the increase in concentration of SO_2 and the length of exposure. SO_2 exposure causes yellowing of leaves; condition known as chlorosis; as shown in Figure 1. and leaves lose their photosynthetic pigment (Skelly, 2003). Plants are at most risk to sulfur dioxide during periods of bright sun, high relative humidity, and adequate plant moisture during the late spring and early summer (Edward *et al.,* 2004). The exposure of broad-leaved plants to SO_2 and its by-product sulfuric acid typically results in dry spots that are generally white, tan, or straw-colored and marginal or interveinal (Figure 2a). On some species, chronic injury causes brown to reddish brown or black blotches (Figure 2b). The upper and lower leaf surfaces are both affected; the leaf veins normally remain green and chlorosis is yellowing of leaf and a gradual bleaching of the surrounding tissue. Growth suppression, reduction in yield, and heavy defoliation may also occur. Middle-aged leaves and young plants are most susceptible to sulphur dioxide. Sulphur dioxide injury can be severe 30 miles or more from its source. Injury, however, is usually greatest in the vicinity of the source (less than 1 to 5 miles away).

(a) **(b)**

Figure 2. Marginal and interveinal necrosis (a) and dark, reddish pigmentation (b) on leaves exposed to SO_2. Source: Skelly (2003)

Ground Level Ozone

Ozone belongs to secondary air pollutants. It is formed as a result of photochemical reactions involving precursor substances such as nitric oxides and VOCs under favorable atmospheric conditions as high temperature and insolation (Baciak *et al.*, 2015). The majority of European countries as well as the United States considerably limited the emissions of ozone precursors, but it does not completely eliminate potential dangers of ozone; high industrialization of India and China contributes to constant supply of precursors that can travel long distances across the borders and cause ozone formation in different places of the globe as well as harm forest ecosystems (Cape, 2008). Ozone is phytotoxic in exposures of even few hours at about 0.2 ppm (Edward *et al.*, 2004). It causes a variety of symptoms on broad-leaved plants like tissue collapse, interveinal necrosis, and markings on the upper surface of leaves known as stipple that is pigmented yellow, light tan, red brown, dark brown, red, black, or purple, flecking is silver or bleached straw white, mottling, chlorosis or bronzing, and bleaching (Figures 3a and 3b). Ozone stunts plant growth and depresses flowering and bud formation. It also causes marginal rolling and scorching of leave. Leaves frequently show a yellow to brown mottling and tip burn, or a yellow to brown or orange-red flecking and banding of the needles (Figure 3c). Ozone usually attacks nearly mature leaves first, succeeding to younger and older leaves. Young plants are generally the most sensitive to ozone; mature plants, relatively resistant.

(a) **(b)**

(c)

Figure 3. Bronzing of lower surface of potato leaf (a), bleaching of upper surface of watermelon leaves (b) and tip burn on eastern white pine (c) exposed to ozone. Source: Skelly (2003)

At the physiological level, trees damaged by ozone had a decline in chlorophyll content as well as more rapid ageing of leaves and needles. Other physiological effects include increased respiration rate, lower photosynthesis rate, disruptions of carbon assimilation and transportation of water and nutrients between roots and branches, which cause overall decline of tree biomass growth (Tjoelker *et al.*, 1995; Karnosky *et al.*, 2007; Augustaitis & Bytnerowicz 2008). Trees growing in the areas with high ozone pollution showed lower increment of tree trunk compared to trees growing in less polluted places (Weinstein *et al.*, 2005). Morphological changes are revealed through appearing chlorotic stains on the surface of leaves and needles, which quickly change into necrosis. With time, such stains cover the whole area of the leaf, which indicates its complete dying (Ashmore, 2004; Hayes *et al.*, 2007). Phytotoxicity of ozone is significantly affected by meteorological conditions including high air humidity, strong sunlight and soil moisture. During the day and whilst having optimal soil moisture content, stomata apertures are open, which results in increased gas intake, also including ozone, into leaves (Ashmore, 2004). Besides that, ozone hinders closing functions of stomatal pores, which in turn results in over intensive losses of water during transpiration. Various studies allowed concluding that increased watering intensified ozone infiltration process through stomatal apertures, which induced visual damage in plants.

Nitrogen Compounds

Nitrogen oxides include Nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), di-nitrogen trioxides (N_2O_3), and nitrogen pentoxide (N_2O_5). The two oxides of nitrogen encountered in atmosphere are NO, and NO_2. Nitrogen oxides are emitted by natural and anthropogenic sources such as lightening, volcanic eruption, and bacterial action in soil and anthropogenic sources such as combustion of fuels in internal combustion engine, thermal power plant, industrial and heating facilities, and incinerators. The chemistry of nitrogen oxides and other reactive inorganic nitrogen species is very important in the atmosphere in areas such as formation of photochemical smog, production of acid rain, and depletion of stratospheric ozone (Stern, 2013). Toxicity of nitric oxides is most likely related to inefficiency of nitrate (NO_3^-) reductive pathway. Disruption of cell metabolism occurs as an effect of lower pH of cytoplasm and disruptions in ion transportation. Nitric acid III (nitrous acid) and nitric acid V, which are formed from absorbed nitric oxide as the result of chemical and biochemical reactions (Hu & Sun 2010), can damage biological membranes and chloroplasts as well as cause chlorophyll degradation. Indirect influence of nitric oxides includes soil and water acidification by the compounds which as a result of plant nutrient uptake infiltrate plant interior causing various types of damage. Favorable sunlight conditions cause wider opening of leaf stomata, which increases intensity of nitric oxides penetration into leaf interior. This process intensifies in the conditions of high humidity (Bobbink & Lamers, 2004). Photosynthesis is much less sensitive to the presence of nitrogen oxides than other pollutants; inhibition has only been detected at 500-700 ppb nitrogen dioxide in short-term fumigations (< 8 h) and 250 ppb over 20 hour period. Nitric oxide was found to be four times as inhibitory as nitrogen dioxide at 1000 ppb in a 4 d fumigation of a range of greenhouse plants (Saxe, 1986). Plants growth may be inhibited by continuous exposure to 0.5 ppm of NO_2. Levels of NO_2 in excess of 2.5 ppm for periods of 4 hours or more produce necrosis (Hill & Bennett, 1970; Capron & Mansfield, 1976). Higher concentration of NO_x affects the leaves of the plants, retard the photosynthetic activity and cause chlorosis. Another major compound of nitrogen is ammonia, not being criteria pollutant, but ammonia is a gas of intermediate toxicity. Mostly its toxicity is traced to ammonia derived from organic sources such as urine, chicken manure, cottonseed meal and animal manure but another source of ammonia reaching plants is fumigation of plants.

Particulate Matter

Particulate matter consists of fine solids and liquid droplets, other than pure water, that are dispersed in air. PM originates from natural sources including wind-blown solid dust, volcanic ash, forest fires sea salt, and pollens. Anthropogenic sources includes thermal power plants, industries, commercial and residential facilities, and motor vehicles using fossil fuels. Nearly all PM emitted by motor vehicles consists of fine particles and a large fraction of these particles has an aerodynamic diameter less than 1 mm. $PM_{2.5}$ can also formed in the atmosphere as aerosols from chemical reactions that involve such gases as SO_2, NO_2 and VOC. $PM_{2.5}$ can also form as a result solidification of volatile metal salts as crystals following cooling of hot exhaust gases from vehicle in ambient air (Winchester, 1989). A number of recent studies observed that in urban atmospheres the concentrations of PM_{10} and $PM_{2.5}$ airborne aerosols show a great deal of agreement with traffic-related pollutants and other combustion processes (Prajapati & Tripathi, 2007). As indicated by Gupta *et al.* (2015), biochemical changes in *Terminalia arjuna* plant was found to have negative correlation with chlorophyll *a*, chlorophyll *b* and total chlorophyll in polluted site when compared to controlled site with less particulate matter exposure of plant. Depositions of atmospheric particle onto vegetation surface have three major routes:

- wet deposition,
- dry deposition, and
- occult deposition.

These are obscured from measurements that determine wet and dry deposition, by fog, cloud-water, and mist interception (Cape, 1993). Dust on the leaves of crops, trees and shrubs inhibit photosynthesis and plant growth. In addition PM can scatter sunlight and cause reduction in solar radiation, thereby affecting crop productivity. Dusts with pH values of ≥ 9, may cause direct injury to leaf tissues on which they are deposited or indirectly through alteration of soil pH (Hope *et al.*, 1991; Vardak *et al.*, 1995) and dusts that carry toxic soluble salts will also have adverse effects on plants (Prajapati & Tripathi, 2008). Dust deposited on leaf surface alters its optical properties, particularly the surface reflectance in the visible and short wave infrared radiation range and the amount of light available for photosynthesis (Eller 1977; Hope *et al.*, 1991; Keller & Lamprecht, 1995). Dust accumulating on leaf surfaces may interfere with gas diffusion between the leaf and air. In dusty environments species having stomata in grooves, covering of wax on stomata might be affected less than species in which the stomata are located at the outer surface of the leaf. Broad leaf plants provides more surface to such accumulation.

Carbon Compounds

Carbon monoxide and carbon dioxide are photo production from plants (Steven *et al.*, 1985; Matthew *et al.*, 1995), but their excess due to their increasing concentration in environment via. anthropogenic sources have brought adverse effects on plants. The carbon monoxide concentration in the troposphere has important effects on atmospheric composition; of primary interest are the controlling effects of CO on hydroxyl radical concentration (Matthew *et al.*, 1995). Also CO is important in the regulation of tropospheric ozone. Increased CO levels may reduce hydroxyl radical concentrations (Pitts & Pitts, 1986; Cicerone, 1988; Khalil & Rasmussen, 1988), thereby limiting the removal of atmospheric pollutants such as hydrocarbons and halogenated hydrocarbon. Many metabolic and growth processes are affected by CO_2 concentrations including photosynthesis and stomatal conductance. Carlson, (1983) found that the level of inhibitory activity detected upon fumigation with up to 1.1 ppm SO_2 at ambient carbon dioxide concentrations (300 ppm) was reduced when carbon dioxide concentrations were elevated to 450, 600 and at 1200 ppm.) Study found inhibition of photosynthesis in *Medicago sativa* fumigated with SO_2 at high concentrations of CO_2 and similarly found that the depression of photosynthesis progressed more slowly when it did occur (Hou *et al.*, 1977).

Lead

Motor vehicles fueled with leaded gasoline are the main source of Pb in ambient air. Tetraethyl lead is added to increase the fuel's octane number, which improves the antiknock characteristics of the fuel in spark ignition engines. About 70 to 75% of this lead to transformed into inorganic lead into vehicle's engines upon combustion and emitted to the atmosphere through the exhaust pipe along with 1% of the organic lead that passes through the engine unchanged (Stern, 2013). Organic lead emission usually occurs as vapor, while inorganic lead is emitted as PM, often less than 1 mm in size. Inorganic lead leads in ambient air also originate from emissions from coal combustion and various lead based industries such as lead smelters and lead battery plants. Plants that are growing near highways are regularly exposed to fumes and smoke discharged from automobiles. There is little absorption of lead through root system of plants. It gains entry through stomata and is absorbed by the tissues with in. Leafy vegetables, therefore, are likely to possess a higher lead concentration as compared to others. Lead is accumulated in plants and passed on to higher trophic level.

Halogens

Apart from fluorides halogens are relatively unimportant air pollutants which might cause injury to vegetation but chlorine is two to three times more toxic even than sulphur dioxide, however, hydrogen chloride is less toxic than sulphur dioxide. Injury caused by chlorine is marginal and interveinal. On broad-leaved plants, necrotic, bleached, or tan to brown areas tend to be near the leaf margins, tips, and between the principal veins. Injured grass blades develop progressive streaking toward the main vein in the region between the tip and the point where the grass blade bends. The streaking usually occurs alongside the veins. Middle-aged leaves or older ones are often more susceptible than the young ones. Bleaching and tissue collapse can occur (Edward, 2004). Hydrogen chloride causes a chlorotic margin on the leaf which may become necrotic. At high concentration, above 10 ppm for a few hours of exposure may produce lesions.

Figure 4. Tip necrosis on needles of eastern white pine exposed to fluorides

Hydrogen fluoride behaves somewhat similar to sulphur dioxide. The typical injury by gaseous or particulate fluorides is either a yellowish mottle to a wavy, reddish brown or tan scorching at the margin and tips of broad-leaved plants or a tip burn of grasses and conifers (Figures 4). A narrow, chlorotic to dark brown band often occurs between living and dead tissue.

Peroxyacetyl Nitrate

The most plant-toxic oxidant, next to ozone, is PAN. PAN causes a collapse of tissue on the lower leaf surface of numerous plants. The typical leaf marking is a glazing, bronzing, or silvering that commonly develops in bands or blotches. On some plants, such as petunia, Pinto bean, tomato, and tobacco, the collapse may be through the entire thickness of the leaf blade. In grasses, the collapsed tissue has a bleached appearance, with tan to yellow, transverse bands. Conifer needles turn yellow. Early maturity or senescence, chlorosis, moderate to severe stunting, and premature leaf drop may also occur. PAN is most toxic to small plants and young leaves (Temple, 1982).

Ethylene

Ethylene is another pollutant resulting from fumigation of plants. Damage caused by ethylene (H_2C-CH_2) is often associated with PAN and ozone in urban areas. Ethylene modifies the activities of plant hormones and growth regulators, which affect developing tissues and normal organ development, without causing leaf-tissue collapse and necrosis. Injury to broad-leaved plants occurs as a downward curling of the leaves and shoots (epinasty), followed by a stunting of growth. Ethylene is one of the many products of auto, truck, and bus exhaust. Ethylene also results from the incomplete combustion of coal, gas, and oil for heating and is a by-product of polyethylene manufacture (Edward, 2004).

Volatile Organic Compounds

The major anthropogenic sources of airborne VOCs are industrial processes, oil refining and distribution, and transport exhaust emissions and incomplete combustion fuel. Many experimental studies have investigated effects of VOCs on plants; mostly involves short-term exposure to very large concentrations are found relative to ambient air but the lack of long-term measurements, along with the available evidence that effects are not linearly related to dose measured as the product of exposure concentration and time of exposure, means that the possibility of adverse effects of VOCs on vegetation cannot be ignored, particularly in urban and industrial areas (Cape, 2002). The major effect on plants of the VOCs is recognized in their contribution to the formation of photochemical ozone, photochemical production of phytotoxic concentrations of ozone requires the presence of volatile organic compounds (VOCs), nitrogen oxides and sunlight (Moller, 1998).

2.4. Related Studies on APTI

Any change in the atmosphere is reflected on the plant health thus it becomes essential to observe and analyze the changes in plants that indicate air pollution (Krishnaveni *et al.*, 2013). When plants are exposed to pollutants in the atmosphere, they are the initial acceptors; especially leaves continuously exchange gases and pollutant present is reflected on health of plants as the act as scavengers to air pollution. Thus plants can be effectively used as bi indicators of air quality as well as beautification agents. Sensitivity of plants to air pollution is variable as pollutants entering into leaves accumulate causes chemical transformation resulting into severe injuries whereas some shows minimal effects; species which are more sensitive acts as biological indicators and species which are more tolerant to air pollution can be used in reducing the air pollution as they can act as pollution sink and improving the air quality by providing an enormous leaf area for impingement, absorption, adsorption, accumulation and integration of air pollutants level in the environment with varying extents (Varshney *et al.*, 1985; Rao *et al.*, 2006; Das *et al.*, 2010). Plants proves to be important for determining as well as maintaining ecological balance by active participation in cycling of gases and nutrients; also trees contribute to improve local air quality by refining microclimate and can also help in lowering local temperature by evapotranspiration (Jim *et al.,* 2008; Agbaire, 2009). Vegetation intercepts radiation and produce shade that also contribute to reduce urban heat release. The decrease and fragmentation of large vegetated areas such as parks not only reduce these benefits but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and urbanized areas (advection), which is known as the 'park cooling effect'(Enete *et al.,* 2013). Street plants and shrubs are highly effective at ameliorating urban warmth at the micro-scale, referring to ground to building height. Tree shading reduces the amount of heat stored within urban surfaces while ornamental shrubs reduce urban heat Island by cooling the air layer above them using water from transpiration. Study of single parameter may not provide sufficient indication for the various changes in the plants due to air pollution as the use of different parameters has given conflicting results for the same species (Han *et al.,* 1995), therefore to investigate the response of plants to pollution at physiological and biochemical levels air pollution tolerance index is used to determine the tolerance levels of plant species (Singh & Verma 2007; Lui & Ding, 2008). APTI is species dependent plants attribute which expresses the inherent ability of plants to encounter stress arising from pollution; it provides a reliable method for selection of large number of plants with respect to their sensitivity and susceptibility to air pollutants. To screen plants for their sensitivity/tolerance level to air pollutants, large number of plants parameter has been used including leaf or stomatal conductance, ascorbic acid, relative water content, membrane permeability, peroxidase activity, chlorophyll content and leaf extract pH (Choudhary & Rao, 1977; Keller & Schwager, 1977; Sivakumaran & Hall, 1978; Farooq & Beg, 1980; Winner, 1981; Eckert & Houston, 1982; William & Christopher, 1986; Singh *et al.,* 1991; Tripathi *et al.,* 1991; Namita *et al.,* 2009).A total of four factors viz. leaf extract pH, relative water content, total chlorophyll content, and ascorbic acid content are used to calculate APTI (Singh & Rao, 1983). Several studies have shown the impacts of air pollution on plant biochemical parameters, such as the ascorbic acid content (Hoque *et al.,* 2007), chlorophyll content (Flowers *et al.,* 2007), leaf extract pH (Klumpp *et al.,* 2000) and relative water content (Rao, 1977).

Biochemical Parameter pH

Leaf extract pH is simply the pH of the extract of leaves. It signifies the tolerance capacity of the leaf species. Studies have shown that plants with lower pH are more susceptible to air pollution that is they are found to be sensitive while those around pH 7 are tolerant species (Singh and Verma, 2007). Also photosynthetic efficiency strongly depends on pH; photosynthesis is reduced in plants when the leaf pH was low (Liu and Ding, 2008). pH is a biochemical parameter that acts as an indicator for sensitivity to air pollution (Scholz & Rick, 1997; Joshi & Bora, 2011). It has been reported that in the presence of an acidic pollutant which may be due to the presence of SO_2 and NO_X in the ambient air, the leaf pH is lowered and the decline is greater in sensitive than that in tolerant plants (Singh & Verma, 2007; Rai & Panda, 2013). A pH on higher side improves tolerance against air pollution (Agarwal, 1986; Shannigrahi *et al.,* 2004). A study by Patel *et al.,* (2012); observed that plants with low pH were more susceptible while plants with pH around 7 were more tolerant in modifying the toxicity of SO_2 from automobile exhaust in Surat city, India. The photosynthetic efficiency is strongly dependent on leaf pH (Yan & Hui, 2008) and photosynthesis is reduced in plants with low pH (Turk & Wirth, 1975). pH value does not exhibit any significant correlation with air humidity and temperature as observed in seasonal variation study done by Das & Prasad (2010); but pH is affected by pollution in atmosphere. The pH of all plant species in study by Nayak *et al.,* (2015) were observed to be decreasing in the city area where air pollution levels were higher as compared to Agricultural University area as control site. Similar results have been found when experiments have been taken to industrial areas (Begum & Harikrishna, (2010); Thambavani & Prathipa (2012); Rai *et al.,* (2013); Dhankar *et al.,* (2015). Similar results for vehicular exhausts from roadside plants can be seen in various studies like Jyothi & Jaya (2010); Patel *et al.*, (2012); Tsega & Prasad (2013); Jain & Kutty (2014) and many others.

Relative Water Content

Relative water content is the amount of water that a plant holds when it is incapable of taking in more water; this is state of full saturation. It is indicative of the capacity of cell membrane to maintain its permeability under polluted conditions. A plant does not need to be in this state in order to survive but knowing the percentage of water that a plant is capable of holding is the way to determine if a plant is stressed. The higher the water content within a plant body it will help to maintain its physiological balance under stress condition such as exposure to air pollution when the transpiration rates are usually high, higher RWC favors drought resistance in plants. If the leaf transpiration rate reduces due to the air pollution, plant cannot sustain well due to losing its locomotive that pulls water up from roots to supply for photosynthesis. RWC is a direct measure of deficit in leaves and indicates the capacity if the cell membrane to maintain its permeability under polluted conditions (Subramani & Devaanandan, 2015). High relative water content in plant helps in maintaining its physiological balance under stressed conditions hence species are more tolerant to air pollution (Gonalez *et al.*, 2001; Jaya & Jyothi, 2010; Enete *et al.*, 2013) and it also serves as an indicator of drought resistance in plants (Seyyednjad *et al.*, 2011). Higher RWC also help maintain chlorophyll concentration even under chemical stress. Reduction in RWC is due to impact of pollution on transpiration rate in leaves; if leaf transpiration rate is reduced due to air pollution then plants lose their ability to pull water and minerals from roots for biosynthesis (Masuch *et al.*, 1988; Swami *et al.*, 2004; Liu & Ding, 2008; Mohammed *et al.*, 2011). Low level of pollution and high water content is suggested by Shyam *et al.*, (2006). Leaf water status is intimately related to several leaf physiological variables such as leaf turgor, growth, stomatal conductance, transpiration, photosynthesis and respiration (Kramer & Boyer, 1995).

Chlorophyll Content

Chlorophyll content of leaves provides valued information about physiological status of plants. Depletion in chlorophyll content directly causes decrease in productivity of plant and also affects growth of plant. Plants that uphold their chlorophyll even in polluted environment are considered as tolerant species. Chlorophyll content of plants signifies its photosynthetic activity as well as growth and development of biomass (Kartiyar & Dubey, 2001). Study by Kutty *et al.*, (2014) have suggested low chlorophyll content in winter season might be due to higher pollution level, temperature stress, low sunlight intensity and short photo period; also it was observed that the trees with thick and broad canopy, broad leaves, with moderate height had higher chlorophyll concentration compared to the trees with pinnately compound leaves or slender cone type canopy. Photosynthetic pigment is a light dependent attribute and its degradation has been widely used as an indicator of stress (Ninave *et al.*, 2001). Chlorophyll also depends on difference of species, age of the leaf, height of the tree, type of canopy, size and shape of leaf, and phyllotaxy. Chlorophyll content also varies with sensitivity of the plant or shrub species; higher the sensitivity of plants, lower is the chlorophyll content (Beg *et al.*, 1990; Jyothi & Jaya, 2010). In analysis of APTI for seasonal variation by Das & Prasad (2010) it was observed that all plant species exhibit high TCh content during rainy season and further analysis also showed that chlorophyll content is positively related to leaf relative water content and negatively related to extract pH. Different pollutants play a significant role in inhibition of photosynthetic activity that may results in depletion of chlorophyll and carotenoid content of the leaves of various plants (Chauhan *et al.*, 2008). Rao & Leblanc (1966) have also reported reduction in chlorophyll content brought by acidic pollutants like SO_2 which causes phaeophytin formation by acidification of chlorophyll. Some other studies too have linked synthesis or degradation of chlorophyll with the tolerance capacity of plants to SO_2 (Spedding & Thomas, 1973;

Bell & Mudd, 1976). Thus plants having high chlorophyll content under field conditions are more tolerant to air pollutants.

Ascorbic Acid Content

Ascorbic acid content is the amount of ascorbic acid that is present in the leaf of a plant. Ascorbic acid is a strong reducing agent, higher its amount in plant shows the tolerance capacity of plant for air pollution. It plays vital role in photosynthetic carbon fixation and in light reaction of photosynthesis activates defense mechanism and replace water from light reaction under stressed conditions. Ascorbic acid is a strong antioxidant found in the growing parts of plant, influences their resistance towards adverse environmental conditions like air pollution (Keller & Schwager, 1977; Pathak *et al.*, 2011). It plays important role in cell wall synthesis, defense and cell division, photosynthetic carbon fixation with reducing power directly proportional to its concentration in plant (Raza and Murthy 1988; Conklin, 2001; Agbaire, 2009). Study by Jyothi & Jaya (2010) showed elevation in the concentration of ascorbic acid with respect to the control site in all the plant species selected. Chaudhary & Rao (1977) and Varshney (1984) are of the similar opinion that higher ascorbic acid content of the plant is a sign of its tolerance against SO_2 pollution. Lower ascorbic acid contents in the leaves of other plant species studied supports the sensitive nature of these plants towards pollutants particularly automobile exhausts. Tripathi & Gautam (2007) also reported increase in the concentration of ascorbic acid in the leaves of *Mangifera indica*, near roadsides due to enhanced pollution loads of automobiles. Ascorbic acid being a strong reducing agent protects chloroplasts against sulphur dioxide induced hydrogen peroxide, oxygen and OH accumulation and this protects the enzymes of the carbon dioxide fixation cycle and chlorophyll from inactivation (Chaudhary & Rao, 1977, Singh *et al.*, 1991). Thus, tree species maintaining higher ascorbic acid level under polluted condition are considered to be tolerant to air pollutants. Furthermore, the reducing activity of ascorbic acid pH controlled, being more at higher pH levels because high pH may increase the efficiency of conversion of hexose sugar to ascorbic acid and is related to the tolerance to pollution thus higher levels of leaf extract pH means more tolerance to air pollution (Singh & Verma, 2007; Liu & Ding, 2008). In study by Das & Prasad (2010) ascorbic acid content in most of the plant species were maximum in winter season followed by rainy and summer season except in *Acacia mangium*, *Thevetia nerifolia* and *Tabernaemontana coronaria*.

APTI and API

Air Pollution Tolerance Index is a guiding tool to determine the sensitivity of plant species when they are exposed to polluted air. It can be used as a monitoring tool as well as an assessment tool for measuring air quality. It can be used by landscapers to identify the most tolerant species and applied in development of green belt around polluted sites like industries or nearby roadsides or commonly for aesthetic purpose. On the basis of air pollution tolerance and some other relevant phyto-socioeconomic characters API of plant species can be calculated and trees can be categorized on the basis of their performance in that environment as very good, good, moderate, poor and very poor sensitive categories. Species belonging to first four categories may be recommended for plantation. Gradation of plant species were based on seven categories of characters based on their biological, biochemical and economic characteristics like air pollution tolerance index, plant habitat, structure, canopy cover, plant type, lamina structure and economic value for planting in contaminated areas. The usefulness of evaluating APTI for the determination of tolerance as well as sensitiveness of plant species provides valuable information for landscapers and greenbelt designers to select the sensitive as well as tolerant varieties of plant species (Jyothi & Jaya, 2010). In the study by Seyyednjad *et al.,* (2011) of APTI of four plant species around petrochemical station in south west of Iran, samples were taken from the tree species in two places, polluted area and unpolluted area. Plants were randomly selected from the immediate vicinity of the station. Three replicates of fully matured leaves were used and immediately taken to the laboratory in the ice for analysis. APTI was measured using the four parameters: relative leaf water content (RWC), total chlorophyll content (T), leaf extract pH, and ascorbic acid (AA) content. The result showed order of tolerance in polluted area as *E. camaldulensis* (8/5) > *A. lebbeck* (8/1) > *C. salignus* (7/9) > *P. juliflora* (5/8) and in unpolluted area as *E. camaldulensis* (8/4) > *A. lebbeck* (6/7) > *C. salignus* (6/2) > *P. juliflora* (6/6). The results show that in cases that APTI increase from control site to polluted site improves the species tolerance to pollution stress. In another study by Enete & Ogbonna in (2012), five species of ornamental shrubs that were growing along central business district (CBD) of Enugu Urban City of Nigeria were selected and evaluated for its APTI. Result indicates that ornamental shrubs had varied degree of tolerance index to air pollution. The APTI ranged from 10.60 to 14.32 with *Ixora Red* having the highest APTI value and *Yellow Bush* with lowest APTI value. The data suggested that ornamental shrubs growing in polluted environment often respond and show significant changes in their morphology, physiology and biochemistry. In this study, the orders of tolerance of ornamental shrubs are in this order: *Ixora Red, Yellow Ficus, Masquerade Pine*, *Tuja Pine*, and *Yellow bush*. The implication is that *Ixora Red* should be preferred where pollution appears high because of its ability to tolerate more pollutants. Ornamental shrubs like *Yellow Bush* showed are used as indicators of poor air quality. A periodic evaluation of APTI of selected tree species such as *Polyanthia longifolia, Alstonia scholaris, R. Br., Mangifera indica, L*., and shrubs *Clerodendron infortunatum, L., Eupatorium odoratum, L.,* and *Hyptis suaveolens, (L.) Poit.*, growing adjacent to the National Highway – 47 passing through Thiruvananthapuram District which lies on the south-west coast of India, was carried out with a view to find out the air pollution tolerance as well as sensitivity of the plant species during different seasons (Jyothi & Jaya, 2010). Among the trees in the roadside areas studied, *Polyalthia longifolia,* expressed highest APTI values and proved to be a tolerant variety and the others as sensitive species to air pollutants. In the case of shrubs, *Clerodendron infortunatum, L.*, exhibited highest APTI values (7.34) and found to be more tolerant compared to the other two shrub species studied. In 2003, APTI and API study by Shannigrahi, APTI of 30 species was evaluated and further categorized according to their performance index for the green belt development in and around an industrial/urban area; it suggests *Magnifera indica* was the most tolerant plant to grow in industrial areas and can be expected to perform well. It has a dense plant canopy of evergreen like foliage, which may afford protection from pollution stress. The economic and aesthetic value of this tree is well known and it may be recommended for extensive planting as a first curtain. *Ficus benghalensis*, *Ficus infectoria* and *Mimusops elengi* were judged to be excellent performers, while *Artocarpus integrifolius*, *Dalbergia sissoo*, *Eugenia jambolan* and *Saraca indica* qualified for the very good performer category. Besides these 10 good performing species, 12 were found to be unsuitable as a pollution sink because of their lower anticipated performance but have been planted in industrial areas for their aesthetic value and other economic uses. The latter species are attractive plants that certainly enhance the aesthetic value of the industrial/urban areas. Thus shows that an evaluation of anticipated plant performance might be very useful in the selection of appropriate species. From the view point of air pollution mitigation the plants judged best find their use in GB plantation. The effectiveness of the GB depends on the selection of the right type of plant species particular tolerant of pollutants to that area (Rao, 1985; Ahhmed *et al.*, 1991; Bhattacharya *et al.*, 1994;; Millard, 2000). Mondal *et al.*, (2011) suggests *Ficus benghalensis, Magnifera indica, Swietenia mahoganii* and *Saraca indica* as excellent species for green belt in urban areas whereas *P. guajava*, *Ficus religiosa* and *Polyanthia longifolia* as good; *Dalbergia sissoo* and *A. scholaris* as moderately good and *Ficus hispida* as very poor. The grading pattern of 29 plant species evaluated by Pandey *et al.*, (2015), and plant species which fit into the grading pattern with respect to their anticipated performance index (API) were recommended for the development of urban forest in Varanasi city. *F. benghalensis L.*

and *F. religiosa* are expected to be excel-lent performers. Comparable results were reported by previous workers also (Prajapati & Tripathi, 2008; Pathak *et al.*, 2011; Rai & Panda, 2014). On the other hand, *P. longifolia, Ficus glomerata (Roxb.), Anthocephalus indicus* and *Mangifera indica* are predicted to be very good performers. In the same manner *C. fistula L., D. roxburghii, Terminalia arjuna, Psidium guajava L., Millingtonia hortensis* and *Dalbergia sissoo* are likely to be good performers. Six plant species were recognized as moderate performers while seven plant species as poor performers. The remaining two plant species either were very poor performers or not recommended for plantation. Many other researchers estimated the APTI and API of various plant species for green belt development and found similar results (Shannigrahi *et al.*, 2003; Govindaraju *et al.*, 2012; Thambavani & Maheswari, 2012). An ideal plant for use in a GB should have the following characters as given by Shannigrahi *et al.*, 2003:

- fast growth rate for quick development of a canopy;
- strong branches for a durable canopy to withstand storms;
- large leaf size for enhanced retention of pollutants;
- dense foliage for better trapping of pollutants;
- relatively good tolerance to insects and diseases;
- tolerance to soil compaction and nutrient stress; and
- long life span for, an extended longevity of the GB itself.

From various APTI studies, tree species *M. indica, F. benghalensis, F. religiosa, T. arjuna, P. guajava, D. sissoo* have come out as most efficient in their contribution to air quality amelioration in tropical regions. APTI and API thus proves to be an effective approach in not only defining susceptibility of trees to air pollution; it also helps in developing a scheme for improvement of air quality.

CHAPTER III

MATERIALS AND METHODS

3.1. Overview of the Study

The study aims to determine APTI of the major tree species found in the university campus of Delhi Technology University situated in Shahbad Daulatpur area of Delhi. The 23 tree species used in the experimental study were selected on the basis of previous works on APTI like Pandey *et al.*, (2015); Tiwari & Tiwari (2006); Chodhury & Banerjee (2009); Shannigrahi *et al.*, (2003) etc. Specific objective is to determine and calculate the four biochemical factors RWC, TCh, AAC and pH of extract of the 23 species. Further using these four factors to calculate APTI for species and categorizing viz. tolerant, moderately tolerant, intermediate and sensitive species. Furthermore, APTI values are used along with other biological and socioeconomic factors to determine the API of specified tree species and categorizing these species as excellent, very good, good, moderate, poor, very poor and not recommended performers in the study area. The results obtained can be put to good use of recommending trees for green belt development in and around the campus.

Characteristics of Plant Species used in the Study

Trees like *M. indica, P. guajava, S. cumini,* are not only fruitful but are very economic and serve for various other purposes such as their wood is extensively used for low cost furniture, floor, ceiling boards, match splints etc. Fruits are eaten as canned, preserved, as jam, butter marmalade etc. Dried flower of these trees is of medicinal value and used for dysentery and wasp sting. A tree like *F. virens, F. benghalensis,* and *F. religiosa* bark is used for making ropes and their wood is used for well-curbs, cheap furniture and fuse box fittings etc. *F. virens* has become popular as an avenue tree in and around New Delhi and Noida.

Table 1. Characteristics of plant species used in the present study

S.No.	Scientific Name	Common Name	Family	Habitat*	Type**
1.	*Magnifera indica*	Mango	Anacardiaceae	T	E
2.	*Syzygium cumini*	Jamun	Myrtaceae	T	E
3.	*Saraca asoca*	Asoka	Caesalpinioideae	T	E
4.	*Ailanthus altissima*	Tree of Heaven	Simaroubaceae	T	D
5.	*Bombax ceiba*	Cotton Tree	Bombacaceae	T	D
6.	*Ficus religiosa*	Peepal	Moraceae	T	E
7.	*Dalbergia sissoo*	Sissoo	Fabaceae	T	E
8.	*Azadirachta indica*	Neem	Meliaceae	T	E
9.	*Ficus virens*	Pilkhan	Moraceae	T	D
10.	*Ficus benghalensis*	Banyan	Moraceae	T	E
11.	*Neolamarckia cadamba*	Kadamba	Rubiaceae	T	E
12.	*Thevetia peruviana*	Korubi	Apocynaceae	S	E
13.	*Alstonia scholaris*	Chattiyan	Apocynaceae	T	E
14.	*Bauhinia variegata*	Kachnar	Caesalpiniaceae	T	D
15.	*Eucalyptus globulus*	Eucalyptus	Myrtaceae	T	E
16.	*Bougainvillea glabra*	Booganbel	Nyctaginaceae	S	D
17.	*Canna indica*	Canna	Zingiberaceae	H	E
18.	*Psidium guajava*	Guava	Mytraceae	T	E
19.	*Butea monosperma*	Palash	Fabaceae	T	D
20.	*Terminalia arjuna*	Arjun	Combretaceae	T	D
21.	*Melia azedarach*	Bakain	Meliaceae	T	D
22.	*Lagerstroemia indica*	Crape Myrtle	Lythracea	T	D
23.	*Delonix regia*	Gulmohar	Fabaceae	T	D

**Habitat – Tree (T), Shrub (S), Herb (H); **Type – Deciduous (D), Evergreen (E)*

Figure 5. Plants used in the study

The wood of *A. scholaris* is used for manufacturing packaging cases of tea, writing boards, lamina boards. Neem i.e. *A. indica* has proved to be a very economical and useful plant with its medicinal purpose and easily grown low maintenance required. The tree is grown for fuel wood purpose in India, seeds yield oil having strong healing proficiencies for bleeding gum and pyrrohoea. Neem seed cake after oil extraction is valued as fertilizer. It is also regarded as good fodder tree for goats and some cattles. *Bombax ceiba* wood is dark brown strong, hard and easy to polish and work, though its wood is not durable like timber, so mostly used as packing cases, posts, scantling rafters etc. *D. sissoo* is the second most important cultivated timber tree in India after teak, planted on roadsides, and as a shade tree for tea plantations. *Sissoo* makes first class cabinetry and furniture. It is used for plywood, agricultural, and musical instruments, skis, carvings, boats, floorings, etc. The leaves are used for fodder. *Canna indica* was used as an experimental specie as it has not been used in such studies but it is used for phytoremediation of industrial and wastewater, so for their usage around industries and polluted areas how much it could stand the polluted air around it. *L. indica* is good as charcoal and fuel wood, bark and leaves contain tannin which is used for making skins. *S. asoca* is considered as best female tonic, fruits chewed as substitute for areoa nuts, seeds are strengthening and the ash of plant is good for external application in rheum arthritis. *T. arjuna* timber is used for carts, agricultural purposes, boat building, mine props etc. Its wood has high calorific value makes good for firewood. Gulmohar i.e. *D. regia* wood principle use is as firewood for its high calorific value being 4600kcal/kg. Species such as *D. regia, Thevetia peruviana, Bougainvillea, Bauhunia variegata* are economical as well as have aesthetic value to beautify the surroundings with their beautiful flowers. These are mainly valued for their seeds, leaves and ornamental values. All the trees in the experimental study are known to have economic and avenue standards in Delhi-NCR region.

Study Area

The study area was Delhi Technological University of Delhi, India. It is located at 22.7501º N, 77.1177º E in north-west region of Delhi. The total area of the campus is 663684 sq. meters. There is a decent enough total of 4816 trees and shrubs over the area which makes about 48 percent green area out of the total area of the campus. There are 297 trees alone around the pond of DTU campus. The campus is considered as less polluted area with small influence of vehicular and construction activities. There are few small scale factories around east side of the campus and a busy two way road at front gate. The samples for the study were taken from the campus area of Delhi Technological University during the month of April 2016. Laboratory works were conducted at Environmental Microbiology Laboratory of Department of Environmental Engineering, DTU.

Figure 6. Delhi Technological University Campus

3.2. Methodology

3.2.1. Sample Collection

All the tree species and few shrubs as for their aesthetic values were considered for the study and sample leaves were taken for analysis. The leaves samples were collected from the study location and stored in the polythene bags in order to retain their moisture level, keep away the dryness; and polythene were immediately named as per the sample. The fresh leaf weight was taken immediately upon getting to laboratory. Then leaf samples were preserved in refrigerator at 4º C for biochemical analysis. Due precautions were taken during collecting samples and their storage, such as leaves were plugged out along with their twigs and not alone the leaf so as to easily identify for impending reference.

3.2.2. Chemicals and Materials Used

- Visible Spectrophotometer from Labtronics Model LT-290
- Centrifuge from Eltek model multispin 650-D
- Mortar and Pestle
- pH meter
- Orbital Shaker
- Laboratory glassware
- Chemicals used: Acetone, Sulphuric acid, Oxalic acid, Iodine solution, Starch indicator, Distilled water.

3.3. Evaluation of APTI and API

To determine APTI values of species, the four biochemical parameters pH of leaf extract, relative water content, total chlorophyll content and ascorbic acid content is measured and to evaluate API, APTI valued obtained are used and also some other biological and socioeconomic characteristics of plants observed are noted.

3.3.1. Determination of pH of Leaf Extract

pH of leaf extract is determined by the method reported by Agbaire and Esiefarienrhe, (2009). Fresh mature leaves were plucked. 0.5 grams weighed leaves were grounded and crushed and homogenized in 10 ml of deionized water. Thus obtained mixture is centrifuged at 5000 rpm for 10 minutes. The supernatant obtained was used to measure the pH of leaf extract after calibrating pH meter with buffer solution of pH 4 and 7.

3.3.2. Determination of RWC

Relative water content is determined by using the method described by Singh (1997). Fresh weight is recorded by weighing the fresh leaves. For obtaining the turgid weight, the leaves are immersed in water overnight, blotted dry and then weighed. To get the dry weight, the leaves are dried in an oven at 70º C for overnight and then taken the dry weight.

The Relative Leaf Water Content in % was calculated using the formula:

$$RWC = \frac{(FW - DW)}{(TW - DW)} x100\%$$

Where:

FW = Fresh Weight (mg)

DW = Dry Weight (mg)

TW = Turgid Weight (mg)

3.3.3. Determination of TCh

Total chlorophyll was carried out according to the method described by Babu *et al.*, (2013). TCh analysis was obtained as follows 0.5 g fresh leaves grounded and diluted to 20 ml of 80 % acetone.

Figure 7. Weighing of sample (a); Grounding of leaves (b); Measurement of total chlorophyll content using spectrophotometer (c).

The mixture obtained was centrifuged at 5000 rpm for 10 minutes and supernatant was obtained. Optical density was read at 645 nm (O.D645) and 663 nm (O.D663) of the leaf extract using Visible Spectrophotometer. Chlorophyll '*a*' and chlorophyll '*b*' are calculated using the absorbance obtained at these two specific wavelengths. Total chlorophyll is then calculated by values obtained. Optical density of TCh is the sum of chlorophyll '*a*' (O.D645) density and chlorophyll '*b*' (O.D663) density as follows:

$$TCh = 20.2(O.D645) + \ 8.02(O.D663)$$

Chlorophyll *a* and *b* are given by the following formulas; also total chlorophyll is sum of chlorophyll '*a*' and chlorophyll '*b*':

$$Chlorophyll\ 'a'\ (mg/L) = 12.70\ x\ O.D663 - 02.69\ xO.D645$$

$$Chlorophyll\ 'b'\ (mg/L) = 22.90\ x\ O.D645 - 04.68\ x\ O.D663$$

All the above calculations give results in mg/L. These can be converted to chlorophyll content in mg/g dry weight as follows:

$$Chlorophyll\ a\ (\frac{mg}{g}) = \frac{12.3\ x\ O.D663 - 0.86\ x\ O.D645}{1000\ x\ W} xV$$

$$Chlorophyll\ b\ (\frac{mg}{g}) = \frac{19.3\ x\ O.D645 - 3.6\ x\ O.D663}{1000\ x\ W} xV$$

Total Chlorophyll = $a + b$

O.D645 = Optical density at 645 nm

O.D663 = Optical density at 663 nm

V = Final volume of leaf extract

W = Dry weight of leaf

3.3.4. Determination of AAC

Ascorbic acid content (expressed in mg/g) was measured using method reported by Ballentine (1941). For iodimetry 5% starch mucilage indicator and 0.01 N of sodium thiosulphate pentahydrate solution was prepared and later was standardized using 50 ml of 0.01 M potassium iodate containing 2g of solid potassium iodide. 0.05 M iodine solution was in turn standardized with 0.07 M standard sodium thiosulphate solution 0.05 M H_2SO_4. For extraction of ascorbic acid and analysis, 2.5 g each of fresh leaves were weighed and grounded in a mortar with pestle. 30 ml of 0.03 M H_2SO_4, 20 ml distilled water and 0.5 g oxalic acid were added. The mixture was stirred for about 20 minutes in shaker and immediately centrifuged at 5000 rpm for 10 minutes to obtain leaf extract. The supernatant was quickly titrated to end point with 0.001 N Iodine solutions using 5% starch as indicator.

Figure 8. Titration for AAC determination

Ascorbic acid content is determined by using the following formula:

$$AAC\ \left(\frac{mg}{l}\right) = \frac{N\ x\ V\ x\ E\ W}{Volume\ of\ extract}$$

$$AAC\ \left(\frac{mg}{g}\right) = \frac{AAC\ \left(\frac{mg}{l}\right)\ x\ 1000}{Weight\ of\ leaf}$$

Where,

N is Normality of titrant

V is volume of sample (ml)

Volume of extract in ml

E W is equivalent weight of Ascorbic Acid

3.3.5. Determination of APTI

APTI is evaluated as suggested by Singh & Rao (1983) to assess the tolerance of plants against pollution. The formula of APTI is given by:

$$APTI = \frac{[A(T + P) + R]}{10}$$

Where:

A= Ascorbic Acid Content (mg/g on DW basis)

T= Total Chlorophyll Content (mg/g on DW basis)

P= pH of leaf extract

R= Relative Water Content (%)

APTI is further used to categorize the plant species into tolerant, moderately tolerant, intolerant and sensitive species by using the criteria as given in Table 2.

Table 2. Selection criteria for sensitivity assessment

S.No.	Category	Criterion for Assessment
1.	Tolerant	APTI > Mean APTI + SD
2.	Moderately tolerant	Mean APTI < APTI < Mean APTI + SD
3.	Intermediate	Mean APTI – SD < APTI < Mean APTI
4.	Sensitive	APTI < Mean APTI – SD

Source: Liu & Ding (2008)

3.3.6. Evaluation of API

API is evaluated based on method given by Prajapati & Tripathi (2008). The APTI values were combined with related biological and socioeconomic characteristics such as plant habit, canopy structure, type of plant and economic values; depending upon the grading given as described in the Table 3. and then plants are given scoring as per the criteria described in Table 4. Based on grading system, a plant species can secure 16 as maximum number of positive points which equals to hundred percent; the scoring for API is scaled to percent to categorize plants for their performance assessment. Most suitable species of trees for development of green belt and air quality enhancement can be determined for any area with the help of performance index. Using the API values plants are given evaluations for their performance under ambient conditions and suggested for the green belt area development in and around study area. API evaluation along with APTI is more reliable approach for assessment of plants than evaluation of single parameter. The scoring from the Table 4. based on the grades helps to categorize the plant species to be assessed as per their performance and persistence predispositions in their existing environment. Thus obtained assessment and category to which the plants belong is used for recommending species for green belt development in and around the campus.

Table 3. Gradation of plant species based on air pollution tolerance index (APTI) as well as biological parameters and socioeconomic importance

Grading Character	Pattern of Assessment	Grade Allotted
a) Tolerance		
APTI	5.0 – 9.0	+
	9.0 – 13.0	++
	13.0 – 17.0	+++
	17.0 – 21.0	++++
	21.0 – 25.0	+++++
b) Biological and Socioeconomic		
Plant Habit	Small	-
	Medium	+
	Large	++
Canopy Structure	Sparse/irregular/globular	-
	Spreading crown/open/semi-dense	+
	Spreading dense	++
Type of Plant	Deciduous	-
	Evergreen	+
c) Laminar Structure		
Size (S)	Small	-
	Medium	+
	Large	++
Texture (T)	Smooth	-
	Coriaceous	+
Hardiness (H)	Delineate	-
	Hardy	+
d) Economic Value	Less than three uses	-
	Three or four uses	+
	Five or more uses	++

Maximum grades that can be scored by a plant = 16 Source: Prajapati & Tripathi (2008)

Table 4. Anticipated performance index (API) scoring and assessment

Grade	Scores (%)	Assessment category
0	Up to 30	Not recommended
1	31 – 40	Very poor
2	41 – 50	Poor
3	51 – 60	Moderate
4	61 – 70	Good
5	71 – 80	Very Good
6	81 – 90	Excellent
7	91 – 100	Best

Source: Prajapati & Tripathi (2008)

CHAPTER IV

RESULTS AND DISCUSSION

This study aimed to determine to determine the APTI and API of major tree species found in university campus of DTU, Delhi. This was done by determining biochemical, physiological and socioeconomic characteristics of species. Plant species with APTI values greater than 15.0 were considered tolerant that act as air pollution scavengers, those between 15.0 to 10.0 were considered moderately tolerant, between 10.0 to 5.0 as intermediate and those below 5.0 were considered as sensitive species as given criteria by Liu & Ding (2008).

4.1. Evaluation of Major Parameters

The four contributing parameters to APTI were first analyzed individually to procced to the required results. These are pH of leaf extract, relative water content, total chlorophyll and ascorbic acid content.

4.1.1. pH of Leaf Extract

Table 5. pH of plant species in the present study

S.No.	Name of Plant	pH	S.No.	Name of Plant	pH
1.	*Magnifera indica*	7.17	13.	*Alstonia scholaris*	5.42
2.	*Syzygium cumini*	6.18	14.	*Bauhinia variegata*	6.11
3.	*Saraca asoca*	6.29	15.	*Eucalyptus globulus*	5.28
4.	*Ailanthus altissima*	5.91	16.	*Bougainvillea glabra*	6.01
5.	*Bombax ceiba*	6.41	17.	*Canna indica*	6.33
6.	*Ficus religiosa*	6.38	18.	*Psidium guajava*	6.98
7.	*Dalbergia sissoo*	6.62	19.	*Butea monosperma*	6.10
8.	*Azadirachta indica*	6.16	20.	*Terminalia arjuna*	6.07
9.	*Ficus virens*	5.18	21.	*Melia azedarach*	6.33
10.	*Ficus benghalensis*	6.11	22.	*Lagerstroemia indica*	5.06
11.	*Neolamarckia cadamba*	4.67	23.	*Delonix regia*	5.44
12.	*Thevetia peruviana*	6.04			

The maximum pH was 7.17 found in *M. indica* and minimum in *N. cadamba* as 4.67. Leaf extract pH plays important role in regulating SO_2 sensitivity of plants (Zhang *et al.,* 2013). Rao, (1977), suggested that in presence of acidic pollutants the leaf pH is lowered and the decline is greater in sensitive species. Most species have pH around 6, *S. cumini* 6.18, *S. asoca* 6.29, *F. religiosa* 6.38, *Dalbergia sissoo* 6.62, *P. guajava* 6.98, *Bombax ceiba* 6.41, *A. indica* 6.16, *F. benghalensis* 6.11, *Thevetia peruviana* 6.04, *Bauhinia variegata* 6.11, *Bougainvillea* 6.01, *T. arjuna* 6.07, *M. azedarach* 6.33. Similar results can be seen in studies carried out by Tiwari & Tiwari (2006), Pandey *et al.,* (2015), Tripathi & Prajapati (2008) and many others for same species. Species with pH inclining towards alkaline are more tolerant to pollution than those favoring to acidic side as by Patel *et al.,* (2012). The low value of pH in species like *N. cadamba* 4.67, *Eucalyptus* 5.28, *L. indica* 5.06 suggests they are more susceptible to pollution and serve as indicator species of air quality. *Delonix regia* 5.44, *Ailanthus altissima* 5.91, *F. virens* 5.18, *A. scholaris* 5.42 also shows pH slightly moving from alkaline to acidic side may be suggested as samples for these species were taken from the outer circle ring of the campus area where most of the vehicular exhaust pollution is supposedly concentrated. The observations of alkaline pH around 6 in above mentioned species may be due to the fact they were plucked from departmental parks and around the pond side area and areas not reachable to vehicles.

4.1.2. Relative Water Content (RWC)

Relative water content in plants is associated with protoplasmic permeability in cells which causes loss of water and dissolved nutrients resulting in early senescence of leaves (Masuch *et al.,* 1988). More water content in leaves helps plant to maintain its physiological balance under stressed conditions. High relative water content value helps to maintain chlorophyll concentration even under stress conditions. High water content values were obtained for species in present study as shown in Table 6.

Table 6. Relative water content of plant species (%)

S.No.	Name of Plant	FW (mg)	TW (mg)	DW (mg)	RWC (%)
1.	*Magnifera indica*	1687.9	1886.4	926.0	79.33
2.	*Syzygium cumini*	977.2	1291.7	320.7	67.61
3.	*Saraca asoca*	860.3	1026.0	346.3	75.62
4.	*Ailanthus altissima*	239.4	323.0	81.5	65.38
5.	*Bombax ceiba*	669.9	877.2	186.3	70.00
6.	*Ficus religiosa*	2365.0	3100.4	720.1	69.10
7.	*Dalbergia sissoo*	330.3	450.3	98.4	65.90
8.	*Azadirachta indica*	160.2	195.2	37.4	77.82
9.	*Ficus virens*	791.5	1276.5	285.4	51.06
10.	*Ficus benghalensis*	1647.5	2105.3	621.3	69.15
11.	*Neolamarckia cadamba*	1892.3	2156.7	547.2	83.57
12.	*Thevetia peruviana*	675.9	1269.4	190.1	45.01
13.	*Alstonia scholaris*	931.9	1498.4	294.3	52.95
14.	*Bauhinia variegata*	520.2	748.1	265.2	52.81
15.	*Eucalyptus globulus*	850.9	1095.6	432.6	63.09
16.	*Bougainvillea glabra*	355.0	458.2	101.4	71.08
17.	*Canna indica*	2084.4	2209.1	387.3	93.16
18.	*Psidium guajava*	394.7	506.9	161.9	67.48
19.	*Butea monosperma*	1615.0	1705.8	507.0	92.43
20.	*Terminalia arjuna*	2090.0	2860.4	560.1	66.51
21.	*Melia azedarach*	308.7	363.6	88.7	80.03
22.	*Lagerstroemia indica*	1723.0	2701.2	485.3	55.86
23.	*Delonix regia*	401.4	566.1	138.1	61.52

FW- Fresh Weight, TW- Turgid Weight, DW- Dry Weight, RWC- Relative Water Content in %

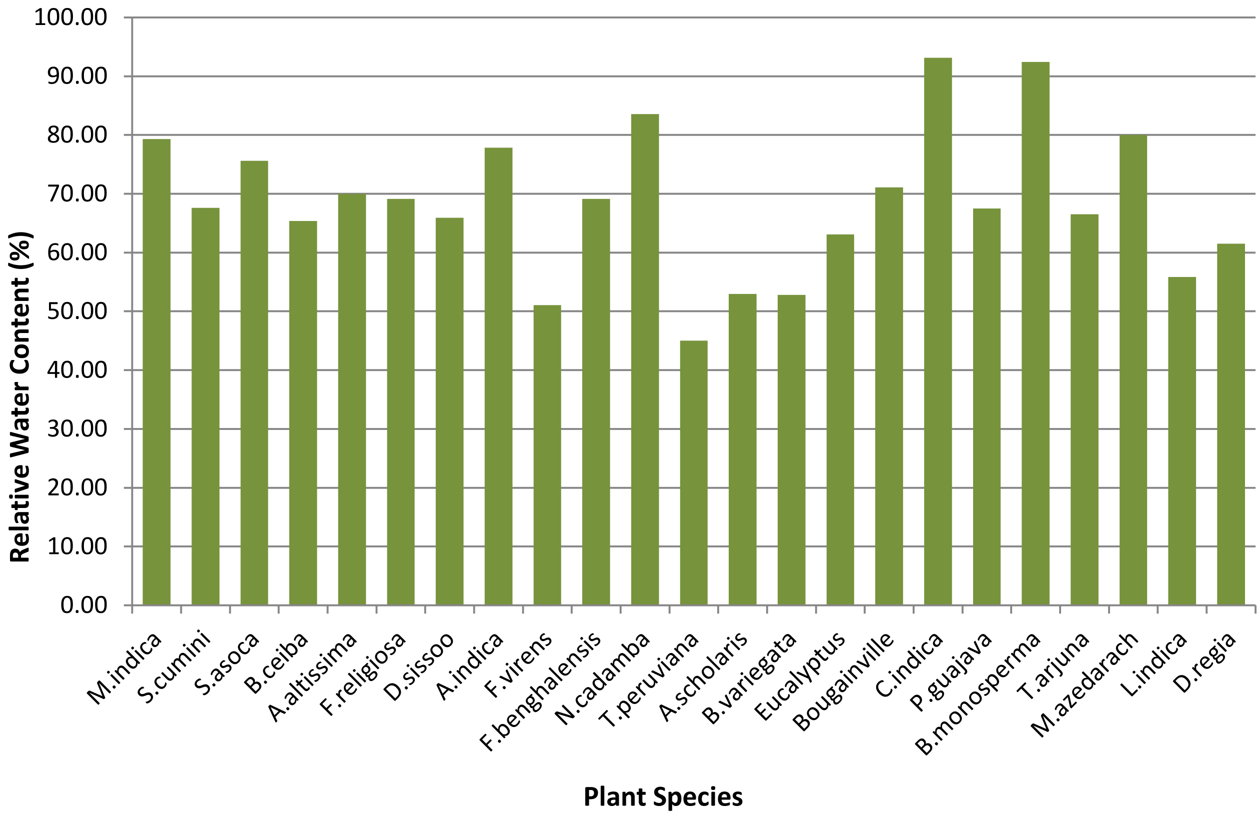

Figure 9. Relative Water Content (%) of plant species in the present study

As evident in the graphical representation of observed RWC in the sample species, water content in the trees is not extremely varying except for few species like *F. virens* with 51.06 %, *N. cadamba* with lowest RWC value 45.01 %, *A. scholaris* and *Bauhinia variegata* 52 and *L.indica* 55.86 % indicates somewhat stressed conditions for the plants. Low RWC of leaf means lower rate of availability of water in soil along with high rate of transpiration (Kramer & Boyer, 1995). Hence, in the present study plants with high RWC may be tolerant to air pollution. High relative water content favors drought resistance in plants. Plants with higher values of RWC are B. monosperma 92.43 %, N. cadamba 83.57 % and M. azedarach 80.03 %. *Canna indica* show the highest RWC 93.16 % may be due to its vicinity to the microbiology laboratory and fact that its watered more frequently manually than other trees of the campus as many times waste water from laboratory use which is not otherwise harmful is gushed in that area. Most of the RWC remains in the range of 60 % to 80 % for the major trees growing in the DTU campus, like *M. indica, S. cumini, S. asoca, Ailanthus, F. religiosa, D. sissoo, A. indica, F. benghalensis, Eucalyptus, Bougainvillea, P. guajava, T. arjuna* and *D. regia*. This indicates a moderate environment for the species to grow inside the campus.

4.1.3. Total Chlorophyll Content (TCh)

Chlorophyll *'a'* and *'b'* were calculated for all the species and final evaluation of total chlorophyll was done. All the plant species exhibited TCh in the range of 0.11 to 5.0. The comparison of chlorophyll content in different species can be easily represented in graphical manner. Chlorophyll content is functions of the pigments which are involved in the process of photosynthesis are called photosynthetic pigment. Chlorophyll is the index of productivity in plants that decreases under the stresses of pollution (Spedding & Thomas, 1973). Thus plants having high chlorophyll content under field conditions are considered as tolerant species to air pollution. In the present study the chlorophyll content of trees like *A. indica* with highest TCh 5.16, *M. azedarach* 4.0, *Bougainvillea* 3.38, *D. sissoo* with Tch 3.02 are the ones with high values comes out to be more tolerant of species whereas most other species lies in the range below 2.0 in their chlorophyll content. Thus averagely, all the species studied can be considered intermediately tolerant. Similar kind of results have been obtained in various studies for similar species for moderately and slightly polluted areas for instance Shannigrahi *et al.,* (2003); Krishnaveni *et al.,* (2013) for species at Perumalmalai hills in Salem region Tamil Nadu in India. Comparable results have been observed by Das & Prasad (2010) in the same season in which this study have been conducted for similar sort of species growing commonly in India. Other comparable studies are Dhankar *et al.,* (2015) for species in university campus of Rohtak, Haryana; Mondal *et al.,* (2011); Marimuthu *et al.,* (2014), Rai *et al.,* (2014); Karda *et al.,* (2015) etc. The present study reveals that total chlorophyll content of species is slightly low may be due to increasing vehicular exhaust in and around the campus. Following were the findings:

Table 7. Chlorophyll content of plant species (mg/g) in the present study

S.No.	Name of Plant	Chlorophyll *a*	Chlorophyll *b*	TCh
1.	*Magnifera indica*	0.26	0.23	0.48
2.	*Syzygium cumini*	1.24	0.47	1.70
3.	*Saraca asoca*	0.18	0.10	0.28
4.	*Ailanthus altissima*	1.53	0.00	1.53
5.	*Bombax ceiba*	2.49	0.00	2.49
6.	*Ficus religiosa*	1.19	0.15	1.34
7.	*Dalbergia sissoo*	1.97	1.04	3.02
8.	*Azadirachta indica*	2.78	2.38	5.16
9.	*Ficus virens*	0.41	0.12	0.54
10.	*Ficus benghalensis*	0.57	0.13	0.70
11.	*Neolamarckia cadamba*	0.87	0.33	1.20
12.	*Thevetia peruviana*	0.26	0.16	0.42
13.	*Alstonia scholaris*	0.23	0.09	0.32
14.	*Bauhinia variegata*	0.39	0.17	0.56
15.	*Eucalyptus globulus*	0.33	0.14	0.47
16.	*Bougainvillea glabra*	2.28	1.10	3.38
17.	*Canna indica*	1.57	0.94	2.51
18.	*Psidium guajava*	0.49	0.27	0.75
19.	*Butea monosperma*	0.58	0.20	0.78
20.	*Terminalia arjuna*	0.06	0.05	0.11
21.	*Melia azedarach*	2.23	1.77	4.00
22.	*Lagerstroemia indica*	1.34	1.09	2.42
23.	*Delonix regia*	0.21	0.13	0.34

TCh- Total Chlorophyll Content

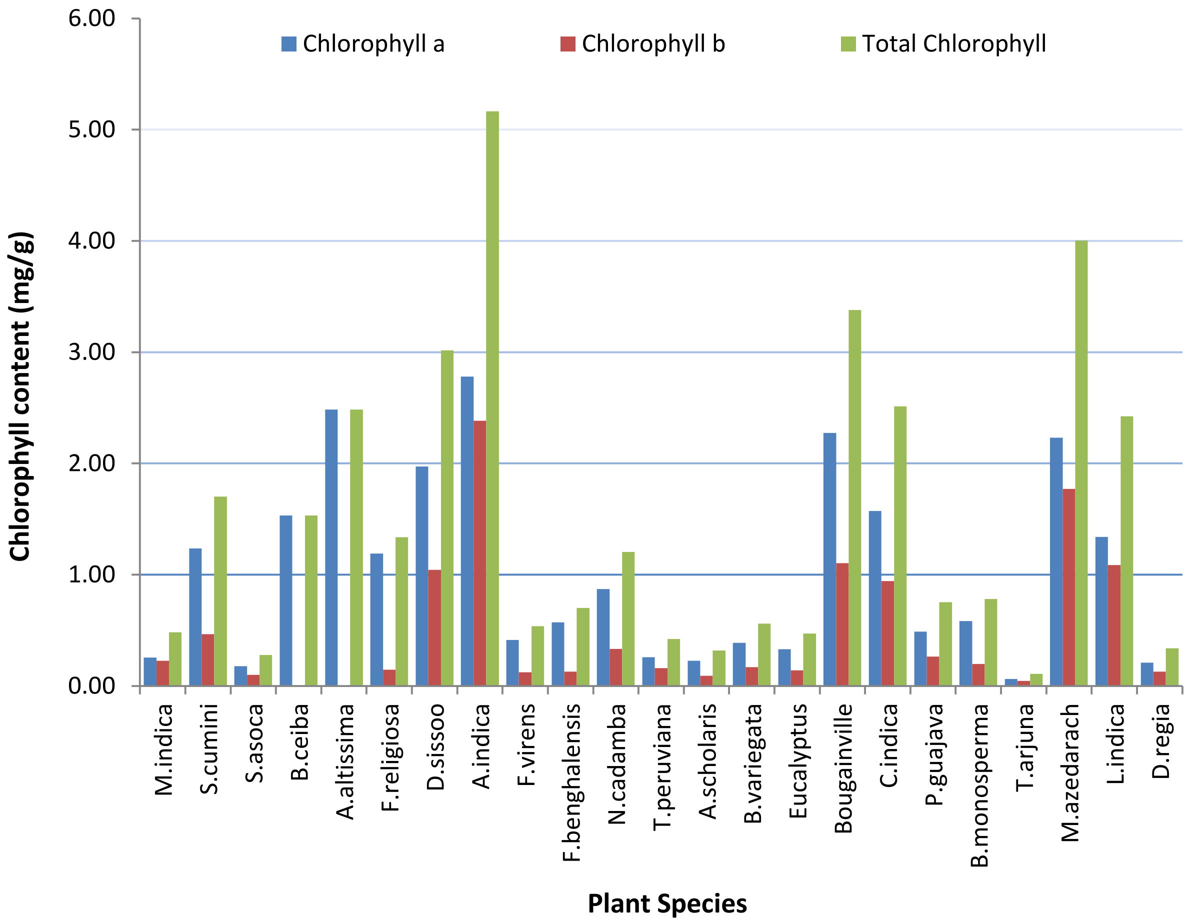

Figure 10. Chlorophyll Content of tree species in the present study

Decrease in chlorophyll content of leaves may be due to the alkaline condition created by dissolution of chemical present in dust particles i.e. metals and polycyclic hydrocarbons in cell sap which block the stomatal spores for diffusion of air and thus put stress on plant metabolism resulting in chlorophyll degradation (Rai *et al.*, 2014). Mandal (2000) depicted that the reduction in the concentration of chlorophyll might have also been caused due to the increased in chlorophyllase enzyme activities which in turn affects the chlorophyll concentration in plants. The chlorophyll content might not be significantly low but it does serve as an indicator to take precautionary actions in advance to deal with the inevitable increasing pollution. Chl *a* and Chl *b* both capture light energy and transfer it to reaction center of plant, they differ in structure only at third carbon position. Significantly Chl *a* is most commonly used photosynthetic pigment and absorbs blue, red and violet wavelengths and Chl *b* primarily absorb blue light and used to complement the absorption by Chl *a*. Chlorophyll *a* values are observed higher for all species than Chl *b*. Chl *a* and *b* adds up to give total chlorophyll TCh. Evaluation of TCh have been validated by using both formulas as given for finding total chlorophyll content of plants and adding up the two types.

4.1.4. Ascorbic Acid Content (AAC)

The ascorbic acid content evaluated on dry weight basis in mg/g. Results are as follows:

Table 8. Ascorbic acid content of plant species (mg/g)

S.No.	Name of Plant	AAC	S.No.	Name of Plant	AAC
1.	*Magnifera indica*	19.3	13.	*Alstonia scholaris*	0.1
2.	*Syzygium cumini*	0.5	14.	*Bauhinia variegata*	2.6
3.	*Saraca asoca*	0.2	15.	*Eucalyptus globulus*	32.5
4.	*Ailanthus altissima*	1.6	16.	*Bougainvillea glabra*	1.8
5.	*Bombax ceiba*	0.8	17.	*Canna indica*	0.1
6.	*Ficus religiosa*	0.6	18.	*Psidium guajava*	11.7
7.	*Dalbergia sissoo*	0.6	19.	*Butea monosperma*	13.0
8.	*Azadirachta indica*	3.0	20.	*Terminalia arjuna*	5.0
9.	*Ficus virens*	3.0	21.	*Melia azedarach*	1.3
10.	*Ficus benghalensis*	8.1	22.	*Lagerstroemia indica*	0.4
11.	*Neolamarckia cadamba*	4.9	23.	*Delonix regia*	6.8
12.	*Thevetia peruviana*	1.5			

Ascorbic acid being a strong reductant which is found in large amounts in growing plants, it protects chloroplasts of leaves against SO_2 induced accumulation on leaves and protects enzymes of CO_2 fixation cycle and chlorophyll for inactivation together with leaf pH (Chaudhary & Rao, 1977); thus it influences resistance of plants to adverse environmental conditions including air pollution (Keller & Schwager, 1977). High ascorbic acid content is a direct stress indicator as has been found for present study in *M. indica, F. benghalensis, N. cadamba, Eucalyptus, P. guajava* and *B. monosperma* with AAC exceeding 10.0. Almost all other species have shown AAC in the range of 0.1 to 5.0 which may indicate that they are less exposed to air pollution. Plants with high values of AAC and still in upright condition shows they are more tolerant species to air pollution as was observed for *F. benghalensis, Eucalyptus, B. monosperma,* and *D. regia* whereas *M. indica and P. guajava* were still in growing stage and were planted near the outer circle of campus where there is more exposure to vehicular pollution might be a reason for their high AA content. Below is shown a graphical representation of AAC of all species which easily distinguishes the species with high AAC to those with lower values. Studies like Dhankhar *et al.*, (2015); Marimuthu *et al.*, (2014) have comparable results for species like *A. scholaris, B. variegata, S. asoca, F. virens, S. cumini, A. indica, F. religiosa, F. benghalensis* etc.

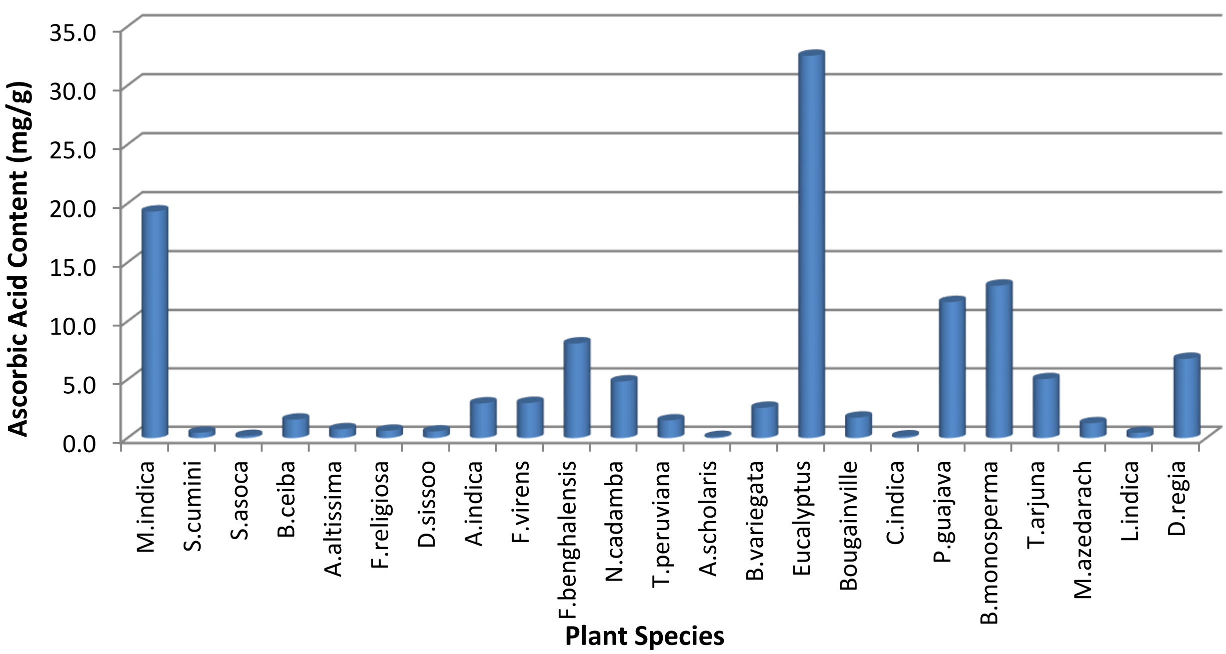

Figure 11. Ascorbic Acid Content of the tree species used in the study

4.2. Air Pollution Tolerance Index

APTI determination provides a reliable, easy and economical method for screening large number of plants in regard to their susceptibility to air pollution. The tolerant species proves to be good for recommendation of plantation as they act as sink to air pollution and ameliorate the air quality; and sensitive species can be used as bio indicators for air pollutants. The highest APTI was found for *M. indica* 22.28 and *Eucalyptus* 24.25; and minimum for *A. scholaris* 5.35. Most number of species had APTI values in the range of 5.0 to 10.0. The sensitivity of the species to air pollution was graded, based on APTI spectrum, into four categories: tolerant (T), moderately tolerant (M), intermediate (I) and sensitive (S) as per criteria given by Liu & Ding (2008) described in Table 1. The most tolerant species according to the study were *M. indica, P. guajava* and *Butea monosperma* whereas *F. benghalensis and N. cadamba* are moderately tolerant. Most of all other species, almost 70% of the species were classified as intermediate category and none were found to be in the sensitive category; all these plants indicate of increasing air pollution exposure, that it might raise an issue if the pollution levels in area further upsurge. In the study, relatively good levels of ascorbic acid may be the reason for higher APTI values and tolerant behavior of most of the species. However the least APTI was found in *A. scholaris* 5.35, *T. peruviana* 5.43 and *L. indica* 5.82. These shows characteristics of sensitiveness towards air pollution with APTI values falling too low and act as bio indicators to air pollution. It is suggested that tolerant to moderately tolerant species may be preferred for green belt development in the campus. The following table shows the result of APTI found in various species used for the present study. Graphically, the APTI of different plants are shown in Figure 12. indicating their sensitivity.

Table 9. APTI and Sensitivity of Plant Species in the present study

S.No.	Name of Plant	APTI	Sensitivity
1.	*Magnifera indica*	22.28	Tolerant
2.	*Syzygium cumini*	7.10	Intermediate
3.	*Saraca asoca*	7.69	Intermediate
4.	*Ailanthus altissima*	7.56	Intermediate
5.	*Bombax ceiba*	7.57	Intermediate
6.	*Ficus religiosa*	7.32	Intermediate
7.	*Dalbergia sissoo*	7.04	Intermediate
8.	*Azadirachta indica*	9.99	Intermediate
9.	*Ficus virens*	6.72	Intermediate
10.	*Ficus benghalensis*	12.08	Moderate
11.	*Neolamarckia cadamba*	10.82	Moderate
12.	*Thevetia peruviana*	5.42	Intermediate
13.	*Alstonia scholaris*	5.35	Intermediate
14.	*Bauhinia variegata*	6.94	Intermediate
15.	*Eucalyptus globulus*	24.25	Tolerant
16.	*Bougainvillea glabra*	8.36	Intermediate
17.	*Canna indica*	9.38	Intermediate
18.	*Psidium guajava*	15.28	Tolerant
19.	*Butea monosperma*	17.49	Tolerant
20.	*Terminalia arjuna*	9.70	Intermediate
21.	*Melia azedarach*	8.98	Intermediate
22.	*Lagerstroemia indica*	5.82	Intermediate
23.	*Delonix regia*	9.93	Intermediate
Mean APTI		10.13	
Standard Deviation (SD)		4.97	
Mean APTI + SD		15.10	
Mean APTI – SD		5.16	

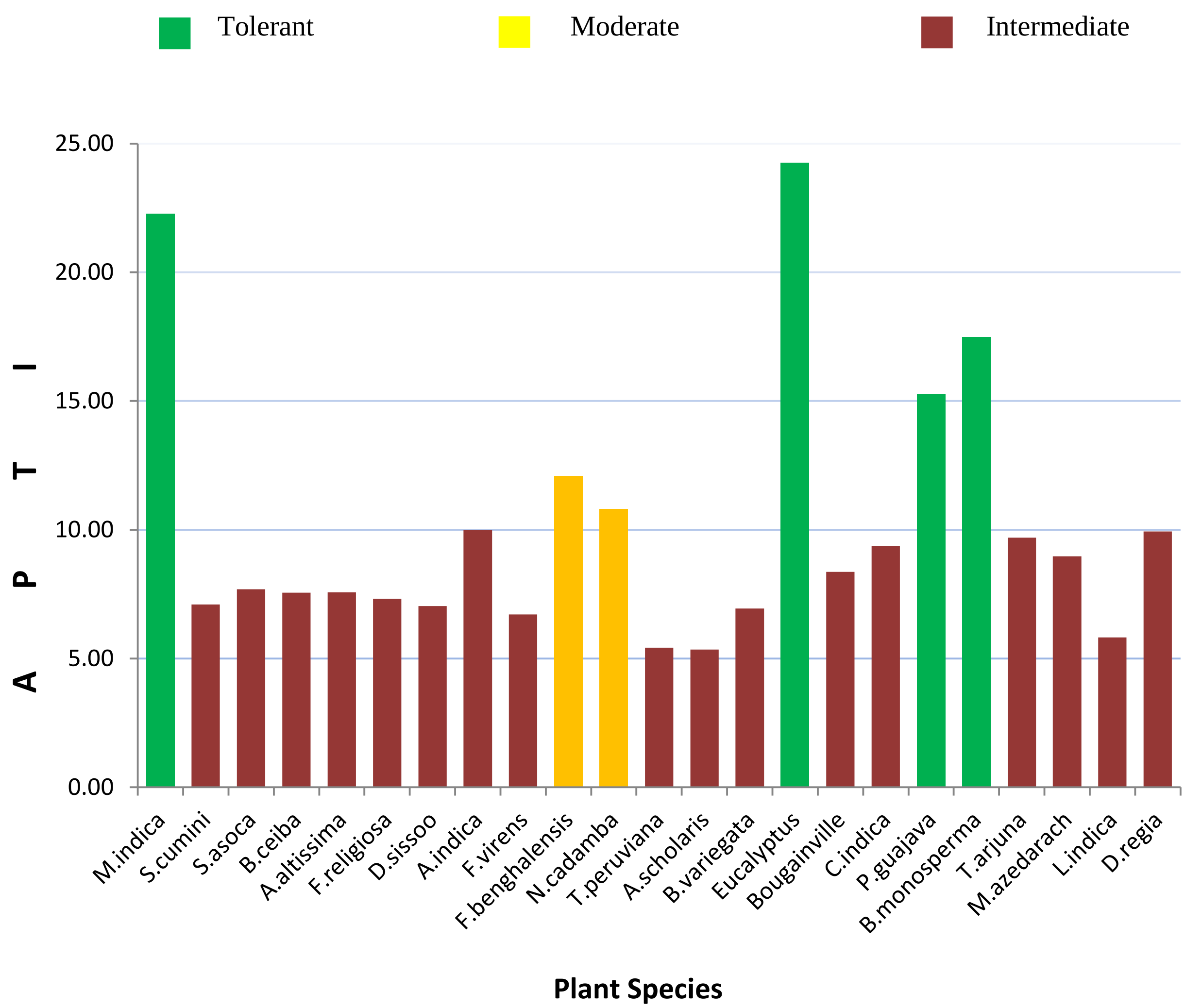

Figure 12. APTI of the tree species in the present study

The trees with high APTI values were found in upright condition shows they are more tolerant to air pollution and helps in ameliorating the air quality of the campus. Though APTI can be used to categorize the plants into sensitive and tolerant species but APTI alone may not be sufficient enough to provide knowledge required for more critical analysis of tree species hence other biological parameters are analyzed to find API. API is more reliable parameter that add more value to the selection criteria of the plant species and thus mostly both are used together to analyze the performance and sensitivity of plants towards air pollution. The API of all the species is evaluated in the next section based on the results obtained for APTI.

4.3. Anticipated Performance Index (API)

API is estimated by analyzing various biological and socioeconomic as well as biochemical characteristics namely APTI, plant habit, canopy structure, type of plant, laminar structure economic value. The parameters are subjected to a grading scale as advocated in Table 3. which apt into the grading pattern with respect to their API; as per these grading scores are given to each specie as recommended in Table 4. The Table 10. show the API grading and percentage scoring of the species which is further used for assessing the performance of plants in Table 11. Plant for GB development can be recommended on the basis of their API grade and assessment category. Green belt plantation around a polluted area may not be claimed for elimination of air pollutants at the region, but effectively planted trees in the green belt may potentially eliminate toxic gases and particulates in considerable amount as stated by Leena *et al.*, (2003). It is evident from many studies; comparison of APTI in residential, commercial and industrial areas that tree plantation or green belts are one of the proficient strategies for air quality amelioration (Bhattacharya, 1994; Thambavani & Maheswari, 2012; Karda *et al.,* 2015). The performances of species in present study are given in Table 10. The above table evidently indicates the species which are good and bad performers in the environment of present study area. *M. indica, S. cumini, F. benghalensis, Eucalyptus, A. indica, B. monosperma* and *M. azedarach* are proving to be surviving well in the conditions and are best recommended for the green belt development of area as they will act as air pollution scavengers and help in the air quality improvement of campus area. Species which are assessed as moderate performers like *S. asoca, B. ceiba, F. religiosa, N. cadamba, A. scholaris, B. glabra, P. guajava* can also be suggested as air pollution sink and good for green belt; in fact species like *B. glabra* are even recommended for their aesthetic value. The poor performers like *A. altissima, D. sissoo, T. arjuna, L. indica, D. regia, T. peruviana* and *F. virens* may be suggested as bio indicators of air pollution.

Table 10. Anticipated Performance Index Grading of tree species used in study. (Prajapati & Tripathi, 2008).

S.No.	Plant Name	APTI	Tree Habit	Canopy Structure	Type of	Laminar		Economic Value	Hardiness	Grade Allotted		API Grade
						Size	Texture			Total +	% Scoring	
1.	*M. indica*	+++++	++	–	+	+	+	++	+	13	81.25	6
2.	*S. cumini*	+	++	++	+	++	+	+	+	11	68.75	4
3.	*S. asoca*	+	++	+	+	++	–	+	+	9	56.25	3
4.	*B. ceiba*	+	+	+	+	+	+	+	+	8	50	2
5.	*A. altissima*	+	++	+	–	++	+	+	+	9	56.25	3
6.	*F. religiosa*	+	++	+	+	+	+	+	+	9	56.25	3
7.	*D. sissoo*	+	+	+	+	+	+	+	+	8	50	2
8.	*A. indica*	++	++	++	+	++	–	++	–	11	68.75	4
9.	*F. virens*	+	+	+	+	+	–	–	–	5	31.25	1
10.	*F.benghalensis*	++	++	++	+	++	+	+	+	12	75	5
11.	*N. cadamba*	++	++	+	+	+	–	+	+	9	56.25	3

12.	*T. peruviana*	+	+	+	+	+	+	_	+	7	43.75	2
13.	*A. scholaris*	+	++	+	+	++	_	+	+	9	56.25	3
14.	*B. variegata*	+	+	_	_	_	+	_	_	3	18.75	0
15.	*E. globulus*	+++++	++	+	+	+	_	+	+	12	75	5
16.	*B. glabra*	+	+	++	+	++	+	+	_	9	56.25	3
17.	*C. indica*	++	+	_	_	_	+	_	_	4	25	0
18.	*P. guajava*	+++	++	_	_	+	+	++	_	9	56.25	3
19.	*B.monosperma*	++++	+	+	_	+	+	+	+	10	62.5	4
20.	*T. arjuna*	++	++	+	_	+	+	+	_	8	50	2
21.	*M. azedarach*	++	++	++	_	++	+	+	_	10	62.5	4
22.	*L. indica*	+	+	+	+	+	_	+	+	7	43.75	2
23.	*D. regia*	++	+	_	_	++	+	+	_	7	43.75	2

Table 11. API Scoring and Assessment of tree species used in study

Plant Species	Grade		API Value	Assessment Category
	Total +	% Scoring		
M. indica	13	81.25	6	Excellent
F. benghalensis	12	75.00	5	Very Good
E. globulus	12	75.00	5	Very Good
S. cumini	11	68.75	4	Good
A. indica	11	68.75	4	Good
B. monosperma	10	62.5	4	Good
M. azedarach	10	62.5	4	Good
S. asoca	9	56.25	3	Moderate
B. ceiba	9	56.25	3	Moderate
F. religiosa	9	56.25	3	Moderate
N. cadamba	9	56.25	3	Moderate
A. scholaris	9	56.25	3	Moderate
B. glabra	9	56.25	3	Moderate
P. guajava	9	56.25	3	Moderate
A. altissima	8	50.00	2	Poor
D. sissoo	8	50.00	2	Poor
T. arjuna	8	50.00	2	Poor
T. peruviana	7	43.75	2	Poor
L. indica	7	43.75	2	Poor
D. regia	7	43.75	2	Poor
F. virens	5	31.25	1	Very Poor
C. indica	4	25.00	0	X* (Suitable for horticulture)
B. variegata	3	18.75	0	X*(Suitable for horticulture)

X*- Not recommended (Prajapati & Tripathi, 2008)

Performance of all these species can also prove to be useful in development of green belt just outside the campus area which is indeed exposed to more pollution due to busy traffic roads and some small scale industries but an idea can be taken from the present study to envisage the performance of these species in the region. The species with high API value can certainly be taken as good performers in improving the air quality of the area if proper plantation is done by the roadside just outside the campus as done in the campus. A large number of green employments inside the campus give the area more aesthetic and livable value even with the highly increasing pollution. *Canna indica* and *Bauhinia variegata* are found to be the only species which proves not much good in serving the air quality improvement obligation of plants in the study area but their liability makes them better stress indicators in the situation. It is manifested from the results obtained that APTI and API values proves to be of great assistance in not only representing the assessment of air quality but provides a solution also to decipher the issue.

CHAPTER V

CONCLUSION

The present study shows that with the increasing air pollution, APTI and API evaluation proves to be of great importance in landscaping, assessment of air quality and effects of the air quality on the plant species. Together APTI and API analyses forms an efficient selection criterion to designate the different plant species for their performance in a particular area and also the approach benefits in landscaping as it is imperative to have knowledge of tolerance or sensitivity and performance of plants for planning of green belt development. From the fallouts of the study *M. indica* with second highest APTI 22.28 and highest API value 6 has been found as most tolerant specie to air pollution around the DTU campus and recommended as best for plantation. Average pH was 6.01, which is on higher side. Other good performers which are also moderately tolerant and can act as air pollution sink based on all the biochemical parameters and their final APTI and API values are *F. benghalensis* with APTI 12.08 and API 5 and also it has AAC of 8.1 mg/g which indicates stressed conditions; *E. globulus* with APTI and API 24.25 and 5 respectively having highest AAC 32.5 was still found in upright condition and significantly good concentration of total chlorophyll confirmed that plants are tolerant to stress. *B. monosperma* and *N. cadamba* with APTI as 17.48, 10.82 and API 4, 3 respectively and also two highest values of RWC 92.43% and 83.57% as high RWC values help maintain chlorophyll concentration even under chemical stress, even though *N. cadamba* was found to have pH nearly acidic i.e. 4.67. Apart from that, ascorbic acid safeguards chlorophyll during low RWC and chemical stress. In present study, relatively good levels of ascorbic acid may be the reason for higher APTI values and tolerant behavior of most of the species. The species with low scores and poor performance indicating stress in the air around were *T. peruviana* with APTI 5.43, *L. indica* having APTI 5.82, *C.*

indica APTI 9.38, *B. variegata* APTI 6.94, *F. virens* with APTI 6.72 and *A. scholaris* with APTI 5.35; all these species scored less than 3 in API. Hence these low scorers have potential to function as indicators of air pollution. It is recommended that moderately tolerant to tolerant species may be preferred for green belt development. Thus the study concludes the tree species are anticipated to perform well for the green belt in and around the DTU campus area and is obligated to improve the air quality around.

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