REVIEW OF LITERATURE

3.1 Introduction

Air pollution has become one of the major problems in urban areas. Trees in city area are facing the adverse impacts of air pollution. The leaf is the most sensitive part exposed to air pollutants. Affected plants show some common effects such as decrease in chlorophyll content, inhabitation in photosynthesis and decreasing plant growth (Davision and Blakemore, 1976). Trees also show some other adverse impacts in the form of decreased stomatal density and stomatal index, decreased leaf length and width susceptibility to various diseases etc. To study the morphological and biochemical changes in plants the scientists have developed the Air Pollution Tolerance Index (APTI). Plant responses towards air pollution can be assessed by APTI. Air pollution tolerance varies from species to species in plants depending on their capacity to withstand the stress of pollutants. Sensitive tree species are suggested to be used as bio-indicators for the monitoring of air pollution in cities (Sing and Rao, 1983).

3.2 Air pollution and Trees

Air pollutants are known to produce serious hazards to animals and plants (Chauvan and Joshi, 2007). Tree canopies have a very large surface area and their leaves function as an efficient pollutant-trapping device. Trees are multifunctional they are useful to human society in various ways. Trees naturally clean the atmosphere by absorbing pollutant gases and some particulate matter through the leaves. It is observed that tree leaves in urban environment are strongly covered by dust particles suggesting that plant may contribute significantly to improve air quality (Smith and Staskawicz, 1977). Studies have shown that trees remove carbon monoxide from ambient air; they produce large quantities of oxygen which reacts with carbon monoxide to allow complete oxidation and resulting in the formation of much less hazardous carbon dioxide. Leaves reduce storm-water runoff and reduce or prevent the soil erosion.
In the recent studies air pollutants have found responsible for vegetation injury and crop yield losses, are causing increased concern (Joshi and Swami, 2007). Environmental stress, such as air pollution, is among the factors most limiting the plant productivity and survivorship (Woo et al., 2007). In urban environments, trees play an important role in improving air quality by taking up gases and particles. Plants provide an enormous leaf area for impingement, absorption and accumulation of air pollutants and reduce the pollutant level in the environment to a great extent with a varied extent for different species (Liu and Ding, 2008). The use of plants as monitors of air pollution has long been established as the plants are the initial acceptors of air pollution. They act as the atmospheric scavengers for many air borne particulates (Joshi and Swami, 2009).

The ozone concentrations are higher in suburban and rural areas as compared to the urban areas, whereas SO$_2$ and NO$_2$ concentrations are higher at urban sites (Tiwari et al., 2006). It has been also observed that plants particularly growing in the urban areas are affected greatly due to varieties of pollutants (Jahan and Iqbal, 1992). Air pollution can directly affect plants via leaves or indirectly via soil acidification when exposed to airborne pollutants. Vegetation is an effective indicator of the overall impact of air pollution. A large number of trees and shrubs have been identified and used as dust filters to check the rising urban dust pollution level (Rai et al., 2010). Pollutants can cause leaf injury, stomatal damage, premature senescence, decrease in photosynthetic activity, disturbed membrane permeability and stunted growth and reduced yield in sensitive plant species (Tiwari et al., 2006). A relationship between traffic density and photosynthetic activity, stomatal conductance, total chlorophyll content and leaf senescence has been reported by (Honour et al., 2009). Chlorophyll is found in the chloroplasts of green plants and is called a photoreceptor. Plant growth is dependent on chlorophyll content. Usually, the chlorophyll content exists in plant leaves. The response of plants in terms of photosynthesis depends mainly on chlorophyll content which has greater impact of incident solar radiation for the process of photosynthesis (Agrawal and Tiwari, 1997). Chlorophyll itself is actually not a single molecule but a family of related molecules, designated as chlorophyll ‘a’,
‘b’, ‘c’ and ‘d’. Chlorophyll ‘a’ is the molecule found in all plant cells and therefore its concentration is what is reported during the chlorophyll analysis (Joshi et al., 2009). Chlorophyll is an index of productivity of plant. Whereas certain pollutants increase the total chlorophyll content, others decrease it (Agbai and Esiefarienrhe, 2009).

The Ascorbic acid is generally known as vitamin ‘c’. Ascorbic acid also gets affected due to air pollution. It plays a significant role in light reaction of photosynthesis and under stress condition it can reduce water from water reaction II (Singh and Verma, 2007). Ascorbic acid is a natural antioxidant in plant. It had major importance in pollution tolerance (Joshi and Swami, 2007). Ascorbic acid plays active role in cell wall synthesis, defense and cell division. It plays an important role in carbon fixation with reducing power directly proportional to its concentration. The Ascorbic acid content is known to improve tolerance of the plants to air pollutants. Reductions in leaf area and leaf number may be observed due to decreased leaf production rate and enhanced senescence. The reduced leaf area results in reduced radiation absorption and subsequently in reduced photosynthetic rate (Tiwari et al., 2006). These results are in agreement with those of Dineva (2004), Tiwari et al., (2006) and Jahan and Iqbal (1992). Many changes in plant physiology and growth such as those caused by air pollution are biological compensatory responses to the environmental stress. The main stress compensatory strategy in plants is to minimize damage from stress (Woo et al., 2007).

Urban forest and trees in urban environment can improve air quality through filtering and uptake of gases and particles (Beckett et al., 2000; Freor-smith et al., 1997). Foliage from trees near air pollution source can even be coated with particulates (Ricks and Williams 1974, Lerman and Darley 1975) which may cause stomatal occlusion thus leading to reduced photosynthesis (Williams et al., 1971). Beside this a large number of trees and shrubs have been identified and used as dust filters to check the rising urban dust pollution level (Lorenzini et al., 2006). A large quantity of dust cover on vegetation has been observed by Yunus et al., (1985). The dust treated plant produce lesser number of fruits as compared to the untreated one. Unlike the inhabitation of shoot, length and area of leaflets and
intermodal elongation due to air pollution are reported by Indhirabai et al., (1989). As plants are very efficient in trapping atmospheric particles, leaves have been used as monitors of particulate pollution (Nriague, 1989, Freer-Smith et al., 1997). Deposition of dust depends on the physical characteristics of particles, such as, their size, shape and also the plant species (Harrison and Yin, 2000). Depending on the dust load, duration and tolerance of the plants, particulates may cause negative changes in the leaf surface ultra-structures, inhibit growth of the plants, reduce the area of leaves and hence, reduce the total biomass (Shukla et al., 1990). Hill and Thomas (1933) reported that SO$_2$ decreased the yield of alfalfa. Chamberlain (1934) observed that dirt, smoke and the gases of large city were fatal to conifers. Solberg and Adams (1956) reported that, fluoride and SO$_2$ destroyed the spongy mesophyll and the lower epidermis of plants. The automobile exhaust emitted by the moving vehicular exhaust on the road is the main source of various air pollutants. In many urban areas of the world, motor vehicle traffic is a major source of air pollution. Generally, the leaf has been regarded as a reference organ for describing the effects of gaseous air pollutants. It is the most sensitive organ to pollution; physiological activities of leaf like stomatal opening can be used as indicator. Foliage from trees near air pollution source can gets coated with particulates which cause stomatal occlusion, and leads to reduced photosynthesis. Trees improve air quality to a great extent (Freer-Smith et al., 1997). Removal of particulate by direct uptake by plant stomata mainly occurs with particulate sized less than 10 microns. Levels of SO$_2$ and NOx from atmosphere can be lowered by the trees. It is significant both to human health and the economy of our country.

Plants are an integral part of earth. Their growth gets affected by climatic conditions, nutrient supply and environmental parameters including pollution. These often try to adapt themselves to their surrounding environment by external as well as internal modifications (Moore, 1991). Plants to low light intensity and make use of available light energy. They invest their greater efforts towards the synthesis and maintenance of light harvesting machinery than full light exposed plants. The effect of light intensity on dry matter production and physiological yield characteristics in plants has been well established (Sing, 1988; Sing et al., 1988).
Their leaves with reduced dry matter accumulation have been reported in shade grown plants. Goodchild and his co-workers (1972) reported that, many rainforest species grown in shade have thick leaves with a high ratio of dry matter of leaf area and high chlorophyll content per unit of leaf area. Chlorophyll measurement is an important tool to evaluate the effects of air pollutants on plants as it plays an important role in photosynthetic metabolism. Dusted or crusted leaf surface is responsible for reduced photosynthesis and thereby cause reduction in chlorophyll content. Any reduction in chlorophyll corresponds directly to the reduced plant growth (Joshi and swami, 2009).

3.3 Trees and water pollution

Non-point sources water pollution mix rainwater and run off leads water quality impairment. These non-point sources include excess fertilizers, herbicides and insecticides from agricultural lands and residential areas oil, grease, and toxic chemicals from urban runoff, sediment from construction runoff and bacteria and nutrients from livestock, pet wastes and faulty septic systems. In fact, nutrient pollution primarily from fertilizers is the major problem faced in many areas and aquatic systems in India including estuaries and lakes. The dispersed nature of non-point sources makes them more difficult to control than point sources of pollution. Trees filter chemicals, sediment, and other pollutants from rainwater and runoff in different ways helping to ensure a cleaner water supply; especially from non-point sources (Coder and Kim, 1996) Trees remove pollutants from water in several ways by acting as sinks of pollutants. Many environmental pollutants are trapped in the forest. They are absorbed by the plants and used for growth or are transformed into non-harmful forms.

3.4 Trees and soil pollution

The organic carbon-rich forest floor helps to support a process called denitrification by which excess nitrogen is converted by soil bacteria into nitrogen gas which is released to the atmosphere. Some other harmful and toxic chemicals can also be broken down into less toxic forms by bacteria present in the soil. Most of the plants experience physiological changes before exhibiting the visible damage to
leaves (Liu and Ding, 2008). Plants that are constantly exposed to environmental pollutants absorb, accumulate and integrate these pollutants into their systems. Depending on their sensitivity level, plants show visible changes which would include alteration in the biochemical processes or accumulation of certain metabolites (Agbaire and Esiefarienrhe, 2009).

3.5 Trees and Environmental balance

Trees not only increases the beauty of the earth but provide many of the economic benefits too (Anderson et al., 1988; Morales et al., 1976). Trees have many more uses just than decoration (Sommer, 2003). In the past two- three decades, a number of studies have investigated the benefits of trees for humans and the stability of environment (Kaplan and Kaplan, 1989; Ulrich, 1993). According to McPherson and his co-workers (1999) trees moderate temperature variation, reduces wind speed, absorb and minimize noise, reduce surface water overflow, and air pollution, along with conversion and biofixation of solar energy. Various positive effects of trees on human beings, such as reducing stress and mental fatigue, lowering the level of violence and crime in the inner city and aiding in recovery from surgery are reported by many researchers (Kaplan and Kaplan, 1989; Kaplan, 1984; Kuo and Sullivan, 2001a). Trees are useful in enriching and beautification of the locality. They enrich the ecological importance of an area; add to the beautification of the city. For example, plants can soften building edges and provide a decorative background and screen areas for privacy (Booth, 1983; Cooper Marcus and Sarkissian, 1986). In urban areas, trees provide many economic benefits. They are associated with the increase of property values, which in turn can result in higher housing prices (Luttick, 2000; Martin et al., 1989). Trees contribute to better health and lower the amount of money spent on health care services directly and indirectly (Tyrvainen, 1997).

3.6 Air pollution in cities

Over the years there has been a tremendous increase in human population, road transportation, vehicular traffic and industries which has led to increased concentration of gaseous and particulate air pollutants in cities. Pollutants which
are present in atmosphere and directly pollute the air are called primary pollutants while those are formed in the air when primary pollutants react or interact are known as secondary pollutants (Anonymous, 2008). Air is polluting due the introduction of chemicals, particulate matter, or biological materials in to the atmosphere and cause harm or discomfort to humans or other organism, or damage the environment. Air pollutants damage leaves, impair plant growth and limit primary productivity according to the sensitivity of plants to pollutants (Ulrich, 1984). Damages caused by air pollutant to plants include chlorosis, necrosis and epinasty (Katiyar and Dubey, 2000). In response to these adverse effects various biochemical changes also occur such as decreased chlorophyll content and increased ascorbic content (Mandal and Mukherji, 2000). Air pollutants can directly affect plants. Joshi and Chauvan (2008) reported that primary air pollutants such as suspended particulate matter (SPM), SO$_2$, and NO$_2$ emitted from automobiles have adversely affected and reduced the plants Chlorophyll, Carotenoid, pH, relative water content and air pollution tolerance index.

Urban air pollution is a serious problem in both developing and developed countries (Li, 2003). The increasing industries and automobile vehicles are continuously adding toxic gases and other substances to the environment (Jahan and Iqbal, 1992). Significant effect of automobile exhaust on the phenology, periodicity and productivity of tree species was also reported by Bhatti and Iqbal (1988). India and other developing countries have experienced a progressive degradation in the air quality due to industrialization, urbanization, lack of awareness, number of motor vehicles, and use of fuels with poor environmental performance, badly maintained poor roads and inactive environmental regulation (Joshi and Chauhan, 2008). Our economy is growing fast but the adverse impacts are also being seen on our environmental conditions. A study comparing the rates of economic growth and the rate of growth of vehicular and Industrial pollution shows that during 1975-1995 Indian economy grew up by 2.5 times but at the same time industrial pollution load increased by 7.5 times (Kumar et al., 1999). In many of the Indian cities like Aurangabad, Pune, Nagpur, Mumbai, Delhi, Chennai and Kolkata Industrial development is rapid but at the same time environmental
pollution is also increasing manifold. According to the World Bank report the Indians spend Rs. 4550 crores every year on treatment of diseases caused by ambient air pollution.

### 3.7 Trees to reduce noise and temperature

Trees solve the problem of noise pollution (Aylor, 1972). Noise pollution is a serious health problem which leads to adverse impact on health and working efficiency of peoples living in city areas. Excessive levels of noise can cause high blood pressure, stress, and hearing damage. Trees can reduce noise pollution. Trees absorb sound waves and can reduce noise levels up to 7dB per 100 ft of forests or wooden walls. This noise reduction value may increase up to the 15dB (Coder and Kim, 1996). Many organic compounds stick to the cuticle that covers plant leaves and needles. Micro-organisms dominate the surface of plants; these organisms adsorb volatile organic compounds and provide additional surface area for pollution collection. Power plants burn more fossil fuels; they increase pollution levels in our atmosphere. Compared to rural areas, cities experience higher rates of heat-related illness and even death, access to air conditioning, pre existing health conditions, incidences of the other factors contributing to heat-related illness and death in urban areas.

### 3.8 MoEF Recommendations on trees

The ministry of environment and forest (MoEF) through its R and D support activities reached to the conclusion that also has found some of the trees can help to reduce the city air pollution. Age-old favorite trees like Neem and Mango are the trees which have a high air pollution tolerance index (APTI) and can receive absorb and contain dust or smog, absorb gaseous air pollutants and improve the ambient air quality. According to the study of conservator of forest when these trees are planted in a larger number in cities they absorb different types of pollution, neem is the good for absorbing noise pollution while bamboo and peepal are good for absorbing dust and other emissions. The ministry has also recommended that these trees should be planted especially around industrial areas. This will create a barrier which will absorb pollutants and save the adjoining
residential areas from harmful effects. The ministry has divided the list of trees into four parts viz. part-I). Trees like Mango that has a dense tree canopy and can screen all type of pollutants. Part-II) it includes the trees that may be raised to absorb pollutants and improve the air’s ambient quality. The next list III) includes species that absorb leftover pollutants which include tree species like Neem and Ashoka while the fourth part of the list includes trees that have low APTI but are the indicators of air pollution level; it includes the trees like silver oak and jamun.

Plants which can be used to restore the natural environment and landscape, garbage dumps are babool, subabool, arjuna, gulmohar and eucalyptus, while the trees which can check the noise pollution are ashoka, banyan, peepal and jungle jalebi. Lastly plants suitable for areas where gaseous pollutants are dominant are mauha, hibiscus and tamarind (Ind. Exp. Newspaper, 1999).

3.9 Trees and Human beings

Trees play an important role in human life Dwyer (1985). The environmental condition ties to human emotion, behavior, and health. It shows that there are problematic environmental stressors which affect a person’s psychology, physiology, and behavior. These environmental stressors are mainly categorized into density and crowding, temperature, noise, and air pollution. It is observed that when people are exposed to these environmental stressors, their behavior changes. These changes include stimulation, stress, mental fatigue, organ damage, increased heart rate, aggression, and violence. The space, crowding, and territoriality shape a person’s emotion and behavior. People generally have their own territoriality, but it is difficult to understand the territorial boundaries in public spaces. The delimitation of spaces in the environment is associated with environmental psychological disorders such as crime, delinquency, and fear. It has also been reviewed that some places have more opportunities for disorder, due to their location and types of land use.

3.10 Social benefits of trees

Trees have various environmental and social benefits in urban settings (Grey and Deneke, 1978; Miller, 1988; Robinette, 1972). These benefits include
providing an beautiful nature, shading, screening, clean air, erosion prevention, wind velocity reduction, and a balanced microclimate (Booth, 1983; Tyrvainen, 1997). According to Ulrich (1979) study, patients who have view of a natural setting have a faster recovery from surgery than patients who have a view of an urban setting. Peterson (1976) reports that generally people look for neighborhoods that are well-vegetated, have trees, small parks, and walking paths. People who live in such areas have higher satisfaction and social interactions in their community (Kweon et al., 1998). There are studies regarding the effects of plants on indoor air quality on people’s work performance health and mood. One way to change an office space is to arrange foliage plants (Shibata and Suzuki, 2002). People bring plants to work with the hopes that they reduce their stress and mental fatigue (Kondo and Toriyama, 1989). There are similar research outcomes suggesting that looking at plants in work environments bring out creative tasks (Stone and Irvine, 1994). People feel more pleasant and lively when plants are there in their environment Tennessen and Cimprich (1995) stated that students who see more plants from their dormitory windows had better performance on their attention and in their studies.

People are always being affected by the environment whether they are aware of it or not. The environment is not merely visual and objective, but also everything that humans confront in their settings. The relationship between people and their environment is complex and difficult to understand. Human emotion is a key aspect in understanding this relationship, because emotions are linked to places. When people stay in a certain place, the atmosphere’s affective quality impresses them. The affective quality of places gives relief and promotes positive emotional changes such as reduction in feelings of stress, depression, peace, or delight. Trees are useful to us in various ways. The functions of trees include purifying air, keeping moisture in soil and modifying air temperature. There are numerous positive effects of tree on human physiology. In city environment, trees help reduce metal fatigue and the level of violence, trees have numerous benefits for human society, such as purifying air (Tyvainen, 1997; Schroeder, 1989), modifying air temperature (Booth, 1983), and offering an aesthetic experience
(Booth, 1983). Trees in urban areas create psychological effects in human beings. Kweon et al., (1998) pointed that spending time in green outdoor spaces is related to making stronger social interaction among residents. Recovery from mental fatigue is possible due to the vegetation (Kaplan, 1984; Kaplan and Kaplan, 1989; Kuo and Sullivan, 2001a). Trees in urban environments have positive psychological effects on urban resident’s behavior and mental conditions.

3.11 Function of leaf stomata

Morphological characters of plants are very important in determining plant resistance to air pollution. Characteristics, such as shrunken stomata, thick cuticle, small and dense cells are in favor of reducing pollutant entry into leaves and cells (Pal et al., 2002). Pollutants also cause erosion of epicuticular wax, which protects the entry of pollutants through leaf cuticle by serving as a barrier. Therefore, the structural resistance of epicuticular wax to the erosion effect of air pollutants would be an important factor in providing overall resistance of plants to air pollution (Dixit, 1988; Huttunen, 1994; Bacic, 1999).

3.12 Dust pollution and trees

Seinfeld and Pandis (1998) reported that the deposition of dust dependence on the physical characteristics of the particles such as size, shape and also the morphological characters of leaf surface. Further, these dust particles are reported to affect stomatal movement, leaf temperature (Borka, 1984), photosynthesis, transpiration, penetration of toxins and the removal of cuticular wax (Eveling, 1986). The organic hydrocarbons adsorbed onto the particulates containing reactive substances on the plant leaf surfaces may accelerate the degradation of epicuticular wax (Bermadinger et al., 1988; Finlayson-Pitts and Finlayson, 1989). The leaves may act as persistent absorbers in the polluted environment and they act as pollution receptors and therefore reduce the dust concentration of the air.

The dust filtering ability of the plant species is directly correlated with foliar surface characteristics. As reported by Musselman (1988), in stressed conditions, damage to the plant tissue first appears in epidermal cells, which can collapse,
reduce in size and further increase in their numbers in the absence of any obvious damage to the cuticle.

The sticky particulate matter emitted from the automobile exhausts is the major constituent of particulate pollution, which is deposited on the leaf surface of common roadside plants. The movement of stomata in response the air pollution is extremely complex. The purpose behind many of the changes in stomatal aperture which occur on a daily basis is the balancing of two opposing priorities, the need for CO$_2$ for photosynthesis and the prevention of excessive water loss by transpiration. Stomata close as the CO$_2$ concentration increases but not by the constant amount. The reactivity of stomata to CO$_2$ is regulated by two hormones, ascorbic acid and indol-3-yl acetic acid (Snaith and Mansfield, 1982) and appears to vary according to the water status of the plant (Raschke, 1975). Guard cells are able to sense the CO$_2$ concentration in the substomatal cavity, not in the air external of leaf (Heath, 1948) Opening and closing of stomata are achieved by changes in the relationship between guard cells and neighbors.

Air pollutants are absorbed by leaves with large stomata and high stomatal conductance than by the leaves with small stomata and low stomatal conductance. The stomata and epidermal cells of the two leaf surfaces seem to correspond to pollution differentially at different stages of plant development. Negative effects of air pollutants on stomatal densities and openings have been found, reduction in stomata is also found in response to elevated CO$_2$ concentration frequently in tree leaves present in city centers. The reduction in stomatal densities and their pore size may be important for controlling absorption of pollutants. Guard cells appear more shrunken on the polluted leaves and lower epidermis collapse (Verma et al., 2006). Polluted environmental conditions create an adverse effect on the growth of plant. It causes the reduction in biomass and the rate of photosynthesis. Leaves from relatively less polluted environment are longer in length as compared to the leaves from polluted environment. The plant parts are smaller in polluted areas or yield is reduced where plants are exposed to constant air pollution level by traffic. It suggests that air pollution adversely affects or inhibits reproduction of plant. Stomatal frequencies are always higher on the lower surface of the leaves. Stomatal
frequency of the entire selected tree species studied was higher in unpolluted areas while it was low in polluted areas (Sonwane and Chavan, 2011b).

The impact of air pollution on plants often varies reflect with differences in functioning of stomata, stomatal size, the extent of stomatal openings and stomatal index. Stomatal behavior determines the extent of absorption of pollutants by plants while the pollutants in turn influence stomatal behavior. The rate of absorption of air pollutant by the plants depends on pollutant concentration gradient from exterior to interior of leaf and on the stomatal conductance which play an important role in determining the impact of air pollution on plants. Stomatal behavior determines the extent of absorption of air pollutants by plants while the air pollutants in turn influence stomatal behavior.

3.13 Effect of air pollution on leaf characteristics

Leaf is the most sensitive part of trees to the environmental pollutants. It shows various adverse effects upon the exposure to air pollutants. To study the effect of air pollution on leaf characteristics initially Sharma et al., (1980) studied four populations of Kudzu in rural, unpolluted and industrial area of north-west Tennessee. They found adverse impacts such as reduced leaf length, leaf width and petiole length of plants grown in polluted areas as compared to control areas. The impact of air pollution on plant in the form of morphological and anatomical studies of leaves of roadside trees such as Ficus bengalensis L., Guaiacum officinale L. and Eucalyptus sp. In polluted and unpolluted areas was evaluated by Jahan et al., (1992). All the plants showed no visible morphological and anatomical changes. However, some reductions in these characters were observed in leaves which were collected from the city center. Significant reduction in length and area of leaflets and length of petiole of G. officinale of polluted plants was recorded. Similarly the reduction in the anatomical characteristics of polluted leaves of the above mentioned species was also observed. Significant reduction was particularly recorded in spongy parenchyma and lower epidermis in F. bengalensis and Eucalyptus sp., respectively. Similarly, reduction in anatomical characters of polluted leaves was observed. In case of Ficus bengalensis leaf length was 13.3 cm
at unpolluted while at polluted it was 12.3 cm. In case of *Guaiacum officinale* leaf length at control and polluted site was 1.2 cm. The breadth was 1.6 cm at control and 1.0 cm at polluted site. In case of *Eucalyptus* species the leaf length at control site was 18.3 cm. and 17.2 cm. at polluted site while the breadth of leaves at control site was 1.4 cm. at control and polluted sites.

Nighet et al., (2000) studied the effect of air pollution caused by thermal power plant on *Ruellia tuberosa*. It indicated the reduction in width of stomata, length of stomatal pore, stomatal density, photosynthetic rate, stomatal conductance and chlorophyll content of all selected tree species. Length of stomata on adaxial epidermis at polluted site was 35.00 um, at unpolluted site it was 37.20 um while on abaxial epidermis it was 30.02 um at polluted site and at unpolluted site it was 30.10um. Width of stomata on adaxial epidermis at polluted site was 22.95 um, at unpolluted site it was 25.20 um while on abaxial epidermis it was 23.22 um at polluted site and at unpolluted site it was 23.85 um. Stomatal density mm² on adaxial epidermis at polluted site was 6.77 mm², at unpolluted site it was 8.91 mm² while on abaxial epidermis it was 9.62 mm² at polluted site and at unpolluted site it was 11.05 mm². Stomatal index on adaxial epidermis at polluted site was 75.16, at unpolluted site it was 72.44 while on abaxial epidermis it was 57.12 at polluted site and at unpolluted site it was 65.28. All these results were carried at the pre flowering stage of the plant.

Apart from pollution and other aspects shade is one of the major aspects which can create changes in plant. Sudha et al., (2006) studied the growth of *French bean* under tree canopy and in open light to study the impact of shade and observed that chlorophyll content was higher (1.103) under tree canopy while in open light it was lower (0.753) due to the increase in number and size of chloroplast and better grana development in the plant leaves. In the pollution studies conducted by Gostin et al., (2007) the variation in mesophyll thickness, the distribution and frequency of stomata in both upper and lower epidermis of leaf was observed. An apparent disturbance in the ornamentation of cuticle was observed in the leaves collected from polluted sites. The pollution affects the
tolerance power of plants and weakens the plants to fight against pollution or diseases.

Plants can be used to intercept dust particles which are of potential health hazards to human beings. Dust is another factor affecting the plant health. Prajapati et al., (2008) assessed the dust interception efficiency of some selected tree species and evaluated impact of dust deposition on chlorophyll and ascorbic acid content of leaves. *Ficus religiosa, Ficus benghalensis, Mangifera indica, Dalbergia sissoo, Psidium guajava,* and *Dendrocalamus strictus* were the plant species selected for study. It was found that all species had maximum dust deposition in the winter season followed by summer and rainy seasons. Chlorophyll content decreased and ascorbic acid content was increased with the increase in dust deposition. There was significant negative correlation between chlorophyll and ascorbic acid content. Maximum dust interception was recorded by *Dalbergia sissoo* and least by *Dendrocalamus strictus*.

The leaf morphological characters were studied by Gostin (2009) in the plants growing in the industrial areas and near the major roads. Plants absorb the pollutants at their foliar surface. Histological changes were induced by air pollutants in *lotus corniculatus L., Trifolium montanum L., T. pretense L.* and *T. repens*. The tolerance degree of plants was indirectly correlated with intensity of injuries which occur on plant structure. Leaf thickness, height and length of epidermal cells, stomatal cells, stomata length and stomatal index were shown differences in polluted and unpolluted environment. The stomata decreased in size and increased in density in all species from polluted sites. Pollution adversely affects chlorophyll content of the plant (Chauvan, 2010b). There was maximum (43.36%) reduction in chlorophyll ‘a’ content in the leaves of *Ficus religiosa* and minimum (26.57%) reduction in *Mangifera indica.* (Chauvan, 2010) found significant changes in all biochemical parameters like chlorophyll, ascorbic acid content, relative water content and Air Pollution Tolerance Index were recorded from the samples collected from polluted sites exposed to automobile exhaust in comparison to control site. There was maximum (38.13%) reduction in chlorophyll ‘a’ in the leaves of *Ficus religiosa* and minimum (20.13%) in *Mangifera indica.*
The maximum (38.87%) reduction in ascorbic acid was observed in the leaves of *Dolonix regia* and minimum (21.38%) reduction in the leaves of *Polyalthia Longifolia*.

The remarkable differences in the growth parameters and micro morphological features can be seen in dust treated plants when compared to control. The reduction in growth parameters, the size of epidermal cells, reduced stomata and cuticle damage are the effects of environmental pollution on plant leaf characteristics. The dust treated plants of *Abelmoschus esculentus*, *Phaseolus vulgaris* produced lesser number of fruits as compared to untreated one (Rai et al., 2010). Significant reduction in epidermal cell size and stomata were also found. About 75% of the stomata were found clogged because of dust deposition in *A. esculentus*, *C. blume*, *S. melongena* and *Z. elegans*. To evaluate pollution mitigating ability of plants Kulshreshta et al., (2009) studied roadside plant species for their leaf morphological characters. The tree species were *Bougainvillea* ‘mahara’, *Terminalia arjuna*, *Cassia fistula* and *Polyalthia longifolia* from sites with heavy particulate pollutants atmosphere compared to control atmosphere and found variable results with respect to different species and site. Particles deposited on leaf surface were 2.5 to 10.00 μm in size and the dust load was reduced in the trend of *T. arjuna* (2.31 mg/cm²), *C. fistula* (1.47 mg/cm²), *B. mahara* (1.33 mg/cm²) and *P. longifolia* (0.97 mg/cm²). The increase in size of epidermal cells and stomata were observed, while cuticle rupture was observed in *T. arjuna*, *C. fistula* and *P. longifolia* due to heavy dust load.

### 3.14 Effect of Pollution on Air Pollution Tolerance Index (APTI) of tree species.

The responses of plants to air pollution provide a simple and low cost monitoring and control method for gaseous pollutants. Trees have their own tolerance abilities against the air pollution. When the pollution load increases, their tolerance capacity reduces. Different plant response indicator parameters like visible foliar injury, membrane permeability, ascorbic acid content, relative water content, chlorophyll content and leaf extract pH reflect the tolerance values of such
four parameters we put in the standard formula for calculating the APTI, Air pollution tolerance index of tree species can be determined by substituting the values of ascorbic acid content, relative water content, chlorophyll content and leaf extract pH in the formula prepared by Singh and Rao (1983).

Singh et al., (1991) evaluated the susceptibility level of plants to air pollutants by introducing the new concept of impact of air pollution on plants in the form of studies on ‘Air Pollution Tolerance Indices (APTI)’ in their study they evaluated values of 69 plant species, including herbs, shrubs and trees, growing in the urban-industrial Lahartara region of Varanasi. Plants with a high index value were more tolerant to air pollutants and vice-versa. On the basis of their indices, different plant groups were categorized into sensitive, intermediate, moderately tolerant plant groups were categorized into sensitive, intermediate, moderately gigantea, C. roseus, etc. were tolerant and D. sissoo, L. chinensis, C. carandus, C. rottleri, etc. were found sensitive to air pollution. The susceptibility level of plants to air pollution indicated through their index values was compared well with the responses of plants observed. It is clear from the pollution studies that air pollution tolerance index can be used as good indicator of impact of pollution on plants. Singh (1993) studied the impact of pollution on plants at four sites. The air pollution tolerance index of these plants showed a marked gradation as the pollutant load decreased from polluted to control zone.

Air pollution tolerance varies from species to species, depending on the capacity of plants to withstand the effect of pollutants without showing any external damage. (Shanigrahi et al., 2004) The Mangifera indica, Moringa pterygosperma, Cassia renigera and Ailanthus excels in control areas had more APTI than polluted areas. The same work of APTI was again carried by Karthikeyini et al., (2005) and studied 27 plant species to determine their APTI values. It was found that Azadirachta indica is most tolerant tree species while in shrubs Ricinus communis. Amaranthus viridis in herbs and in climbers Cucurbita pepo are most tolerant species.
The work of APTI was again followed by Joshi et al., (2007). They studied the physiological response of few economically important tree species viz., Mango (*Mangifera indica*), Eucalyptus citriodora, Sagon (*Tectona grandis*) and Sal (*Shorea robusta*) exposed to roadside automobile pollution by determining some physiological parameters. Impact of automobile exhaust on these species was assessed. All these parameters were studied in the leaf samples collected from roadside trees and trees exposed to automobile exhausts in comparison to control. Higher value of air pollution tolerance index (APTI) was recorded for *S. robusta* (9.02) while the minimum value of APTI was recorded for *M. indica* (6.76).

Higher concentration of SO$_2$ and particulate matters in surrounding areas of coal-fired industries influences the distribution pattern of plants. Sensitive plant species are abolished from such areas, however, only pollution tolerant species survive under such stress conditions. The plants sensitive or resistant air pollution their air pollution tolerance index (APTI) value was calculated by Dwivedi and his co-workers (2007). *Ricinus communis* with APTI 81.10 was found to be the most resistant wild plant showing uniform distribution at all the polluted sites. On the other hand, *Lepidium sativum* with APTI 5.27 was recorded as the most sensitive plant and found to be present only at the clean or less polluted sites.

Suvarna Lakshmi and her co-workers (2008) studied 24 samples of different tree species from industrial area of Vishakhapatnam to determine air pollution tolerance index. APTI values of less than 16 were reported in 20 tree species and suggested to use as indicator of air pollution. Tree species like *Ficus religiosa* (25.77), *Ziziphus Jijuba* (22.32), *Phyllanthus emblica* (18.88) and *Cassia Fistula* (18.69) showed moderate responses by changing their biochemical contents and identified as moderately tolerant to air pollution. Yan-Ju Liu and his co-workers (2008) suggested that a variety of physiological parameters to give a more reliable results. Some species exhibit air pollution tolerance index variation related to changes in air temperature and water status of plants. The results highlighted the
need of measurement of air pollution tolerance index throughout the season, when evaluating pollution tolerance of individual species.

Agbaire and his co-workers (2009) examined by air pollution tolerance indices (APTI) of ten plant species around the Erhoike-Kokori oil exploration station of Delta state. The result showed that combining variety of these parameters gave a more reliable result than those of individual parameter. The order of tolerance was as follows *Psidium guajava* < *Elaesis guineensis* < *Musa paradisiacal* < *Bambosa bambosa* < *Anacadium occidentale* < *Terminalia catappa* < *Manihot esculenta* < *Impereta cylindrical* < *Chromolaena odorata* < *Manifera indica*. Agbare (2009) examined the air pollution tolerance indices (APTI) of six plant species around Otorogun gas plant in Ughelli-south local government area of Delta state. The result showed order of tolerance in decreasing order such as *Emilia Samtifolia* (1.49%) *Manihot esculenta* (2.19%) *Elaesis guineensis* (2.41%) *Impereta cylindrical* (25.56%) *Eupatorium Odoratum* (35.17%) *Psidium guayava* (45.11%).

The susceptibility level of plants to air pollutants can be indicated through their index values, compared well with the responses of plants. Tripathi and his co-workers (2009) studied the relative tolerance of the plant species, ten different plant species i.e. *Ficus rumphii, Pongamia pinnata, Alstonia scholaris, Holoptelea integrifolia, Saraca indica, Pithecolobium dulcis, Cassia simea, Bauhinia variegata, Azadirachta indica* and *Grewelia robusta* was taken from residential, industrial and commercial area of the city as this flora is very much common to the Brass city and is planted on the roadside. The quality of air with respect to SPM, SO₂ and NO₂ was assessed on respective sites to see its effect on biochemical parameters to evaluate the air pollution tolerance index of various plants. *Lstonia scholaris* 21.5, *Cassia Simea* 6.09 and *Bauhinia variegata* 18.22 have less APTI value than control their findings show that Brass and allied industries are the prominent sources responsible for the elevated level of air pollutants at the industrial site. Later Choudhary and Banerjee (2009) studied thirty plant species The APTI sore of <10 is considered sensitive. Value within 10-16 is considered as
intermediate and >17 is considered as tolerant. The pH value ranged between 5.53 (Psidium guajava) and 7.60 (Osmium Sanctium). Total chlorophyll varied between 7.4 and 14.3 mg/g. Ascorbic acid content ranged between 2.89 to 9.1mg/g, where as relative water content varied between, 35% to 91.5%. Based on APTI score, which ranged between 4.50 and 18.5 it was observed that 55% of the species were sensitive to pollution. Among them Thevetia peruviana and Rosa cinensis showed lowest APTI. Species like Mangifera indica, Ficus , Psidum, Eucalytus were intermediate to tolerant zone of the index.

To identify the APTI of 20 common plant species, Sasmita and her co-workers (2010) studied different biochemical parameters and found that plant species like Acaia mangium and Swietenia mahagoni are tolerant while Anthocephalus indicus, Caesalpinea pulcherima were moderately tolerant and Albizia lebbeck and Alstonia scholaris were sensitive to pollution. In the latest study of APTI recently Jyothi and her co-workers (2010) developed the usefulness of plants as bioindicators and presented a periodic evaluation of air pollution tolerance index (APTI) of selected tree species such as Polyalthia longifolia, (Sonner) Thw., Alstoniascholaris, R. Br., Mangifera indica, L., and shrubs Clerodendron in fortunatum, L., Eupatorium odoratum, L., and Hyptissuaveolens, (L.) growing adjacent to the National Highway passing through Thiruvananthapuram district. Among the trees in the roadside areas studied, Polyalthia longifolia, (Sonner) expressed highest APTI value (13.61) and proved to be a tolerant variety and the others as sensitive species to air pollutants. In the case of shrubs, Clerodendron in fortunatum, L.,exhibited highest APTI values (7.34) and found to be more tolerant compared to the other two shrub species studied. Chauhan and his co-workers (2010) also studied the plant species like Ficus religiosa, Mangifera indica, Polyalthia longifolia, Delonix regia. Reduction in chlorophyll ‘a’, chlorophyll ‘b’, total chlorophyll content, ascorbic acid, carotenoid, pH, relative water content and APTI was recorded in the leaf samples of all selected trees collected from polluted site when compared with samples from
control area. There was maximum (43.36%) reduction of chlorophyll content in the leaves of *Ficus religiosa* and minimum (26.57%) reduction was in the *Mangifera indica*, while maximum (30.99%) carotenoid was depleted in *Polyalthia longifolia* and minimum (18.42%) depleted in *Mangifera indica* at polluted site as compared to control site. The maximum (44.67%) reduction of ascorbic acid was observed in the leaves of *Delonix regia* and minimum (22.93%) reduction was observed in the leaves of *Polyalthia longifolia*

The values of biochemical constituents of control plants were higher than polluted sites Sharma et al., (2010). The observed APTI value of mango was (17.02), neem (15.81) and sheesham (25.87). Abida and his co-workers (2010) showed highest APTI value, 35.6 and 32 respectively with heavy metal concentration. The seasonal variation in APTI was also evaluated by Das and others (2010) in the plant species to compare the tolerance level of each plant according to the variation in seasons. Highest value of APTI found in *Azadirachta indica* was (16. 57) in rainy season, followed by winter (16.54) and summer (11.93). In case of *Mangifera indica* highest APTI value was recorded in rainy season (15.42) followed by winter (14.41) and summer (13.64).

More recently Adamsab and his co-workers (2011) found APTI of different tree species. *Azadirachta indica* (37.74), *Mangifera indica* (28.90), *Eucalyptus mysoresins* (27.93), *Carica papaya* (24.62), *Ricinus communis* (22.46) and *Polyalthia longifolia* (20.76) showed descending order of APTI while according to the study done by Seyyednjad and others (2011) *E. camaldulensis, A. lebbeck, C. salignus P.* and *Juliflora* the APTI value recorded were 8, 8, 7 and 5 respectively in unpolluted area which were slightly higher than APTI values of polluted area.
Table 3.1: Studies on effect of air pollution on leaf characteristics of tree species.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Tree species</th>
<th>Parameters studied</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kudzu</td>
<td>Leaf length and width</td>
<td>Sharma et. al., (1980)</td>
</tr>
<tr>
<td>4</td>
<td>French bean</td>
<td>Chlorophyll and chloroplast</td>
<td>Sudha et. al., (2006)</td>
</tr>
<tr>
<td>5</td>
<td><em>Ficus religiosa, Ficus benghalensis, Mangifera indica, Dalbergia sissoo, Psidium guajava, and Dendrocalamus strictus</em></td>
<td>Dust deposition, Chlorophyll and Ascorbic acid</td>
<td>Prajapati et. al., (2008)</td>
</tr>
<tr>
<td>8</td>
<td><em>Bougainvillea, Terminalia arjuna, Cassia fistula and Polyalthia longifolia</em></td>
<td>Dust deposition</td>
<td>Kulshreshta et al., (2009)</td>
</tr>
</tbody>
</table>
Table-3.2: Studies on APTI of tree species in India and other countries.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Selected tree species</th>
<th>Country</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69 plant species including <em>Gigantea</em>, <em>C. roseus</em>, <em>D. Sisoo</em>, <em>L. Chinesis</em>, <em>C. Carandus</em>, <em>C. rottleri</em></td>
<td>India</td>
<td>Singh et al., (2004)</td>
</tr>
<tr>
<td>4</td>
<td><em>Mangifera indica</em>, <em>Eucalyptus citriodora</em>, <em>Tectona graudis</em>, <em>Shorea robusta</em></td>
<td>India</td>
<td>Joshi et. al., (2007)</td>
</tr>
<tr>
<td>5</td>
<td><em>Ricinus Communis</em>, <em>Lepidum Sativum</em></td>
<td>India</td>
<td>Dwivedi et al., (2007)</td>
</tr>
<tr>
<td>6</td>
<td>24 tree species including <em>Ficus religiosa</em>, <em>zizipus jujube</em>, <em>Phyllanthus emblica</em>, <em>Cassia fistula.</em></td>
<td>India</td>
<td>Suvarna lakshmi et al., (2008)</td>
</tr>
<tr>
<td>7</td>
<td>10 plant species including <em>Ficus rumphii</em>, <em>Pongamia pinnata</em>, <em>Saraca indica</em> and <em>Azadirachta indica</em></td>
<td>India</td>
<td>Tripathi et al., (2008)</td>
</tr>
<tr>
<td>8</td>
<td><em>Psidium guajava</em>, <em>Elaeis guineensis</em>, <em>Bambosa indica</em> etc.</td>
<td>Delta state</td>
<td>Agbaire et al., (2009)</td>
</tr>
<tr>
<td>9</td>
<td><em>Imperata cylindrical</em>, <em>Manihot esculenta</em>, <em>Emilia Samtfolia</em> etc.</td>
<td>Delta state</td>
<td>Agbaire et al., (2009)</td>
</tr>
<tr>
<td>10</td>
<td>30 plant species including <em>Thevetia peruviana</em>, <em>Rosa cinensis</em>, <em>Mangifera indica</em>, <em>Ficus</em>, <em>Psidum</em>, <em>Eucalyptus</em></td>
<td>India</td>
<td>Chaudhary et al., (2009)</td>
</tr>
<tr>
<td>No.</td>
<td>Plant Species</td>
<td>Location</td>
<td>Authors</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>11</td>
<td>20 common plant species including Acacia mangium, Swietnia mahagoni, Anthocephalus indicus, Caesalpina pulcherima, Albizia lebeck and Aonia scholaris</td>
<td>India</td>
<td>Sasmitha et al., (2010)</td>
</tr>
<tr>
<td>12</td>
<td>Polyalthia longifolia, Mangifera indica, Alstiniasholaris, Clerodendronin fortunatum, Hypstissuaveolens.</td>
<td>India</td>
<td>Jyothi et al., (2010)</td>
</tr>
<tr>
<td>13</td>
<td>Ficus religiosa, Mangifera indica, Polyalthia longifolia, Delonix regia.</td>
<td>India</td>
<td>Cahuvan et al., (2010)</td>
</tr>
<tr>
<td>14</td>
<td>Mangifera indica, Azadirachta indica, Dalbergia sissoo.</td>
<td>India</td>
<td>Sharma et al., (2010)</td>
</tr>
<tr>
<td>15</td>
<td>Azadirachta indica and Mangifera indica</td>
<td>India</td>
<td>Das et al., (2010)</td>
</tr>
<tr>
<td>16</td>
<td>Azadirachta indica, Mangifera indica, Eucalyptus mysoresins, Carica papaya, Ricinus communis, Polyalthia longifolia</td>
<td>Shivamogga City, South Asia</td>
<td>Adamsab et. al., (2011)</td>
</tr>
<tr>
<td>17</td>
<td>E. camaldulensis, A. lebeck, C. salignus,</td>
<td>Industrial zone, South Iran</td>
<td>Seyyednjad et al., (2011)</td>
</tr>
</tbody>
</table>