Urban Trees in Bangalore City:
Literature Review and Pilot Study on the Role of Trees in Mitigating Air Pollution and the Heat Island Effect
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Quantification of the Benefits of Trees in Urban Bangalore

Urban forests are a vital component of the urban ecosystems and are gaining importance as the quality of this ecosystem is deteriorating. The main problem with urban greening today, is that very little information is available to planners and legislators regarding the costs and benefits of urban trees. This factors has led to a marked decrease in urban forests of cities like Bangalore, which has been greened only fairly recently (in the last 50-60 years). Numerous research projects have been conducted on the ecological, social, and economic value of trees, but very few Indian studies have been carried out on the subject. The pollutant removal, oxygen producing and heat mitigating qualities of trees were known many decades ago,[1-9] however, quantification of these abilities has only begun recently and India-specific information is largely unavailable. This study was carried out using previous international studies as a model. It was found that removal of Sulphur Dioxide (SO_2) and Nitrogen Oxides (NOx) is measurable, but may not be statistically accurate due to changes in wind direction. Removal of particulate matter was found to be significant, and effected by mechanisms including direct stomotal uptake and dry deposition on leaves and tree surfaces.

Studies suggest that a forest cleans the air of micro-particles of all sizes twenty fold better than barren land. Leaves with complex shapes and large circumference collect particles most efficiently, indicating that conifers may be more effective particle traps than deciduous species. Trees mainly absorb gases through their stomata, gases then diffuse into intercellular spaces and are absorbed by water films or react with inner-leaf surfaces to form new compounds or get broken down.[10] Although some smaller particles are absorbed by leaves, most particulate matter is deposited on leaf surfaces and consequentially, tree surfaces are mainly temporary retainers of particulate matter.[11]

Economic and Health Implications

Forests and trees filter rainwater and runoff (chemicals, sediment, and other pollutants) in many ways helping to ensure a cleaner water supply, especially from non-point sources.[12] Non-point sources are a leading cause of water quality impairment. Examples of 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 number one problem facing many areas 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 remove pollutants from water in several ways. They can serve as filters, sinks or transformers of pollutants. Pollutants are trapped in the forest and are then used by the plants as food for growth or are transformed by the forest into non-harmful forms. The organic carbon-rich forest floor helps to support a process called "de-nitrification," by which excess nitrogen is converted by bacteria into nitrogen gas which is simply released to the atmosphere. Studies have shown that nitrogen in runoff and shallow groundwater can be reduced as much as 80% by this process. Some other harmful chemicals (such as pesticides and chemicals in parking lot and highway runoff) can also be broken down into less toxic forms by bacteria in the soil around trees. Although studies have shown that trees remove very little, if any, carbon monoxide (CO) from ambient air, they produce large quantities of oxygen which reacts with CO to allow complete oxidation and formation of the much less hazardous carbon dioxide (CO_2)

Leaves and tree surfaces reduce storm-water runoff by significant amounts, one study estimated that for every 5% increase in tree cover, run-off from storms can be reduced by 2%.[13] This represents huge potential savings in storm-water drainage.

The Center for Disease Control and Prevention (CDC) states that excessive heat claims more lives in the United States each year than hurricanes, lightning, tornadoes, floods, and earthquakes combined. Between 1979-1998, the CDC estimates that 7,421 deaths resulted from exposure to excessive heat in the U.S.[14] Trees reduce temperatures and mitigate the impacts of "urban heat islands"; average daytime summer air temperatures in a newly constructed and unshaded community can be some 3 to 5 degrees Fahrenheit higher than in an adjacent area with older, established trees.[15] The same insulating effect, but in reverse, can be felt in winter. This study also estimates that air conditioning to cool cities from this (heat island) effect accounts for 5 to 10% of urban peak electric demand. These temperature effects are also linked to how forests retain moisture and block wind. By keeping the air trapped in forests, temperature variations are less dramatic.

Sound Buffers

Noise pollution is so prevalent in our lives that it is often not recognized to be as harmful as it is. Excessive levels of noise can cause high blood pressure, stress, and hearing damage. Trees can reduce noise pollution. Many high-speed highways abroad (especially in urban areas) are now literally walled in. Sound barriers, various concrete or wooden walls, help separate residential areas from a deafening highway drone. Unfortunately, the trees often removed to construct these sound barriers were themselves good natural sound buffers. Trees can reduce noise levels by 7dB per 100 ft of forests, and in case of solid walls of trees, this value increases to a reduction of 15dB.[16]

A Sink for Odorous and Other Forms of Pollution

Volatile Organic Compounds (odour producing compounds) have been shown to stick to the cuticle that covers plant leaves and needles; research on this is currently underway. Micro-organisms dominate the surface of plants; these organisms adsorb volatile organic compounds and provide additional surface area for pollution collection. These organisms also have the ability to metabolize and breakdown these compounds. In addition to this, the following characteristics are attributed to trees in urban forests:

- 1 acre of new forest will sequester about 2.5 tons of carbon annually. Trees can absorb CO_2 at the rate of 6 kg/tree/year. Trees reach their most productive stage of carbon storage at about 10 years
- Planting 100 million trees could reduce the amount of carbon by an estimated 18 million tons per year and at the same time, save consumers $4 billion each year on utility bills in America alone
- For **every ton of new wood** that grows, about 1.5 tons of CO2 are removed from the air and **1.07 tons of life-giving oxygen is produced**. During a 50-year life span, one tree will generate Rs. 14 lakhs in oxygen, recycle Rs. 16 lakh worth of water, and clean up Rs. 28 lakh worth of air pollution or Rs. 58 lakh total per tree without including any other values

- Depending on location, species, size, and condition, shade from trees can reduce utility bills for air conditioning in residential and commercial buildings by 15-50 percent. Trees, through their shade and transpiration, provide natural "low-tech" cooling that means less need to build additional dams, power plants, and nuclear generators
- Research indicates that trees help reduce stress in the workplace and speed up recovery of hospital patients.[17]
- One sugar maple (12" DBH) along a roadway removes in one growing season 60mg cadmium, 140 mg chromium, 820 mg nickel, and 5200 mg lead from the environment
- Trees reduce topsoil erosion, prevent harmful land pollutants contained in the soil from getting into our waterways, slow down water run-off, and ensure that our groundwater supplies are continually being replenished. For every 5% of tree cover added to a community, stormwater runoff is reduced by approximately 2%.
- Research by the USFS shows that in a 1 inch rainstorm over 12 hours, the interception of rain by the canopy of the urban forest in Salt Lake City reduces surface runoff by about 11.3 million gallons, or 17%. These values would increase as canopy increases

The US Department of Agriculture's Forestry Service has carried out studies related to all the above data, and results are published on their website at http://www.fs.fed.us/psw/programs/cufr/, it is an excellent source of information for the role of trees in mitigating pollution and the heat island effect

Temperature Reduction

Smog is created by photochemical reactions of pollutants in the air. These reactions are more likely to occur and intensify at higher temperatures. In Los Angeles, for example, for every degree Fahrenheit the temperature rises above 70°F, the incidence of smog increases by 3%. [18]

Higher ambient temperatures in heat islands also increase air conditioning energy use. As power plants burn more fossil fuels, they increase both pollution levels and energy costs. Compared to rural areas, cities experience higher rates of heat-related illness and death. The heat island effect is one factor among several that can raise summertime temperatures to levels that pose a threat to public health.

Other factors that contribute to heat-related illness and death in urban areas are pre-existing health conditions, access to air conditioning, population age, and within-season temperature variation.

Under certain conditions, "excessive heat" also can increase the rate of ground-level ozone formation, or smog, presenting an additional threat to health and ecosystems within and downwind of cities.

While researchers are still studying the extent to which heat islands affect temperature-related mortality in a city, implementing heat island reduction strategies like installing cool roofs, using cool paving, and planting shade trees and vegetation, can minimize vulnerability among sensitive populations

SECON's Study

Taking information and methods collected from studies into consideration, this study has attempted to quantify the removal of particulate matter by trees at 4 locations in Bangalore City. Trees, shrubs and green cover in general, are hereafter referred to collectively, as 'trees'. Locations are chosen on a comparative basis, with values taken from two sites (as a set) chosen based on the following:

- Both sites to be compared had similar traffic volumes
- The sites had similar morphological/geological characteristics
- Satellite images were studied to ensure that sites did not possess other features which may affect ambient temperatures and particulate levels

Adopting the criteria above would help ensure that a comparison done between ambient air temperatures and pollutant concentrations could be correlated to the presence of tree cover.

Air quality data was collected simultaneously at both sites using an Envirotech model APM 460BL Respirable Dust Sampler with the APM411TE Thermoelectrically cooled gaseous sampling unit and Envirotech HVS with APM 411 attachment. Particles were collected in two size ranges, one at 10µm and the other at 100µm, the 10µm size class is known as respirable particulate matter (RPM) as it has the ability to penetrate more deeply into the human respiratory system. Sampling was carried out as per CPCB recommendations for a period of 8 hours, gaseous samples were then maintained at 4ºC to avoid loss of sample. Samples were tested as per standards; IS-5182 Part II for SO2, IS-5182 Part VI for NOx, and IS-5182 Part IV for SPM Temperature data was collected using a digital thermometer and noise levels were recorded using a digital noise level meter. Noise levels were taken behind a buffer of roadside trees, at a minimum distance of 10m from the road, as recommended by USFDA road noise assessment protocol. Noise levels measured were A-weighted levels in dB, percentile method was used and levels are reported as per L_{50}, or the level of noise (in dB) that is exceeded 50% of the time. This is standard US protocol for road noise assessments. Ambient air temperature, noise level and humidity data was collected at intervals of 10 minutes, road temperature at intervals of 20 minutes, and wind speed (IMD data) at intervals of 1 hr.

<u>The first set of sites compared was as follows:</u>

- Nrupatunga rd (opposite RBI), at 12°58' 21.74"N and 77º35'11.91"E
- Circle at termination of Nrupatunga rd at 12°58'03.89"N and 77º35'14.93"E

Levels of all primary pollutants were found to vary at these two locations as follows:

	Nrupatunga Rd.	**Circle**	**Limits**
NOx	34 µg/m^3	35 µg/m^3	80 µg/m^3
SO_2	29 µg/m^3	31 µg/m^3	80 µg/m^3
SPM (total)	156 µg/m^3	282 µg/m^3	200 µg/m^3
Percentile Noise Level (L_{50})	76.5 dB	78.6 dB	65 dB

Table 1: Comparison of gaseous pollutants and noise levels for Site 1&2

While relatively small changes occurred in concentrations of NOx and SO_2 at these sites, there was a marked decline in the concentration of SPM, from 282μg/m^3 in the tree-less area, to 156μg/m^3 in the treed areas. The positive impact of particle uptake by, and deposition onto, trees in this area have brought SPM concentration to within the limits set by the CPCB. Noise levels over a period of 8hrs were shown to be 2.1 dB lower when it was measured behind a buffer of roadside trees.

Ambient air temperatures and road temperatures, collected at intervals of 10 minutes and 20 minutes respectively, are as follows:

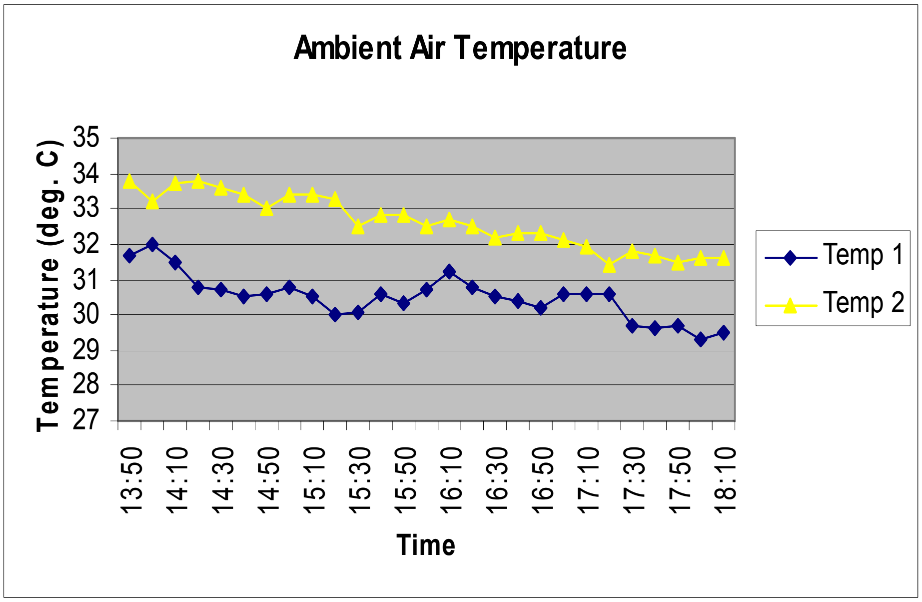

Figure 1: Ambient air temperatures at Nrupatunga Rd and Circle sites

Mean temperature over the study period at the Nrupatunga rd site was 30.5ºC, while at the Circle site, the mean temperature was found to be 32.6ºC. This difference of 2.1ºC (4ºF), after studying the area, is hypothesized to be mostly a factor of tree cover and shade thereby provided. Figure 2 below shows a comparison of road temperatures at the same two sites:

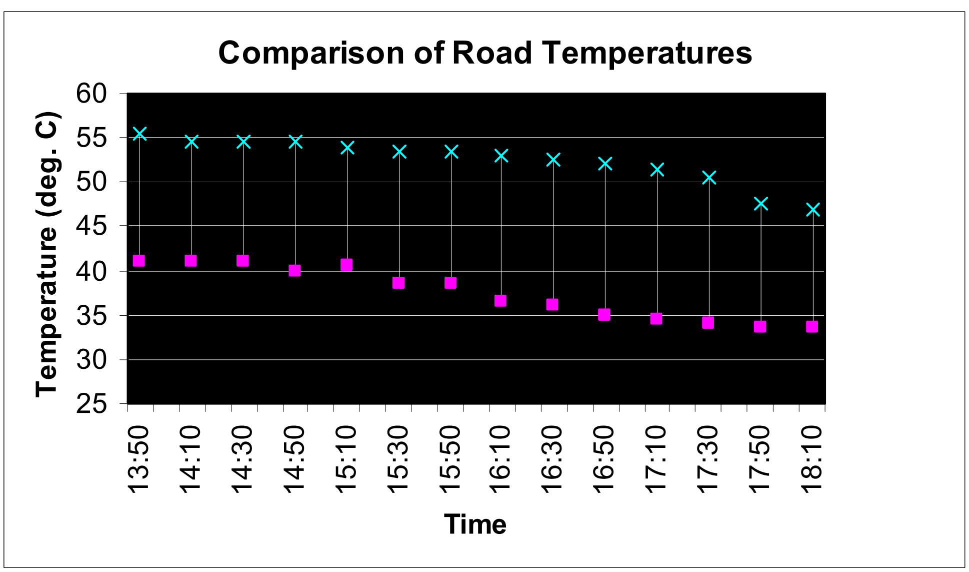

Figure 2: Road temperatures at Nrupatunga rd and Circle sites

Mean road temperature at the Circle site, was found to be 52.4ºC while at the Nrupatunga rd. site, it was found to be 37.4ºC over the same period. After studying recent maps of the area and its geological characteristics, this difference of 15ºC is hypothesized to be a factor of the difference in tree cover; more specifically, of the shading of the road provided by trees at the Nrupatunga rd. site.

The second set of sites compared in this study is as follows:

- Sarjapur rd after Aghara, at 12º55'20.02"N and 77º39'31.74E
- Bellandhur gate (bakery), at 12º55'37.73"N and 77º40'44.93E

Levels of all primary pollutants were found to vary at these two locations as follows:

	Sarjapur rd	**Bellandhur gate**	**Limits**
NOx	27 µg/m^3	29 µg/m^3	80 µg/m^3
SO_2	24 µg/m^3	25 µg/m^3	80 µg/m^3
SPM (total)	169 µg/m^3	214 µg/m^3	200 µg/m^3
Percentile Noise Level (L_{50})	71.3 dB	74.6 dB	65 dB

Table 2: Comparison of gaseous pollutants and noise levels for Site 3&4

While relatively small changes occurred in concentrations of NOx and SO_2 at these sites, there was a marked decline in the concentration of SPM, from 214 µg/m^3 in the tree-less area to 169µg/m^3 in the treed area. Noise levels over a period of 8hrs were shown to be 3.3 dB lower when measured behind a buffer of roadside trees. The positive impact of particle uptake by, and deposition onto, trees in this area have brought SPM concentrations within the limits set by the CPCB at these two sites as well. This is important with regard to the numerous health effects that particulate pollution in known to cause, especially in sensitive individuals. Ambient air temperatures were also taken for the same two sites simultaneously, and the results are as follows:

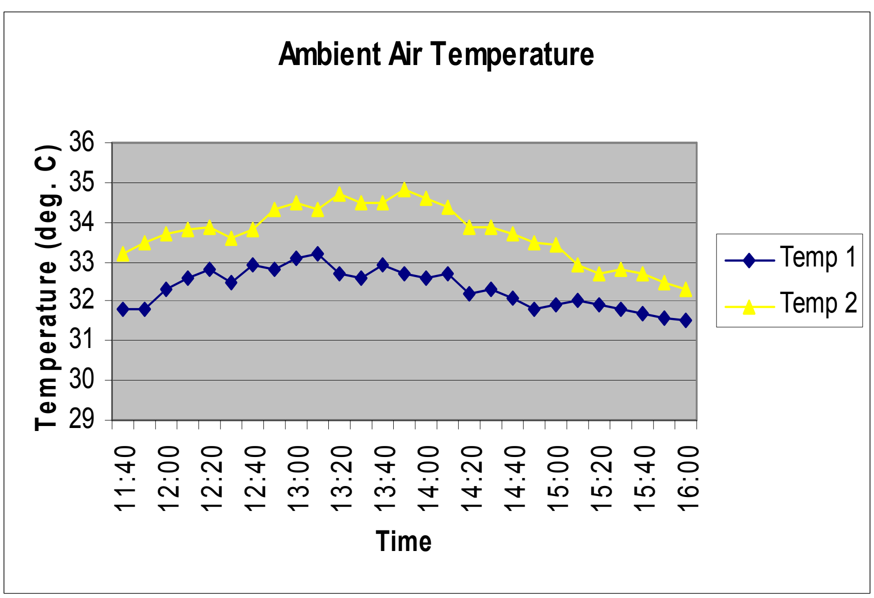

Figure 3: Ambient air temperatures at Sarjapur rd and Bellandhur gate sites

Mean ambient air temperatures over the study period at the Sarjapur rd site was 32.3ºC, while at the Bellandhur gate site, the mean temperature was found to 33.7ºC. Maps of the area were studied to identify other factors contributing to temperature differences and following this, the difference of 1.4 ºC (3ºF) in ambient air temperatures is hypothesized to be largely a factor of tree cover and the shade it provides to the area. Similar observations were made when road temperatures from the same area were compared and graphed, as seen below:

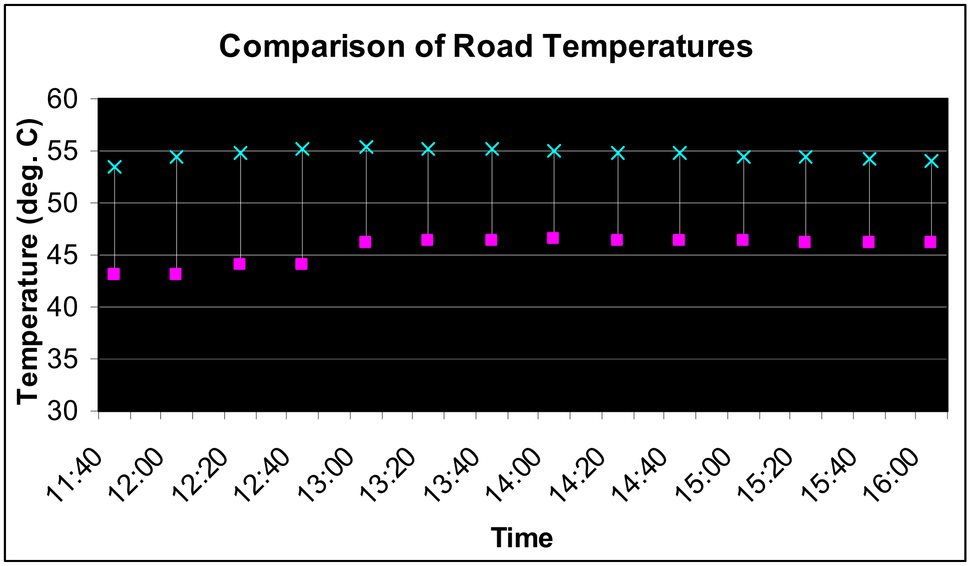

Figure 4: Road temperatures at Sarjapur and Bellandhur gate sites

Mean road temperature over the study period at the Bellandhur gate site was observed to be 54.7°C. At the Sarjapur Road site, the mean temperature was observed to be 45.5°C over the same period using the same measurement techniques. This difference in road temperatures (of 9.2°C), is hypothesized to be entirely a factor of the additional tree cover present at the Sarjapur road site, and the complete lack of trees, hence tree shade, at the Bellandhur gate site.

It is seen from the data presented, that removal of several types of air pollutants by trees seems to be significant, especially removal of particulate matter in the range of 10-100µm. Literature shows that removal of particulate by direct uptake by plant stomata mainly occurs with particulate sized less than 10 microns in size and hence this could not be measured in the present study. Levels of SO_2 and NOx appear to be lowered by the presence of trees, however, more in-depth studies are required in Bangalore City to provide statistically significant data on this phenomenon. Such studies in other parts of the world, (notably the USA) have already proven this relationship (see references). Significant decreases in ambient air and road temperatures were seen in the areas with tree cover over areas lacking tree cover. This reduction is significant both to human health and the economy in terms of reducing the severely damaging effects of the urban heat island effect. Taking the results of this study into consideration, it seems clear that additional studies on the role of pollution mitigation by trees are required to be carried out. Data from existing studies will suffice for the purpose of formulating guidelines and policy on tree planting for pollution remediation and alleviating dangerous temperature rises linked to urban heat islands. However, India-specific studies are required to quantify the potential benefits of urban trees, and to present cost-benefit analysis figures. These figures can be the basis of tree planting and preservation laws completely immune change and dilution, and impossible to bypass.

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