CHAPTER 5

Preventive Conservation of Heritage Sites

In this chapter, study has been conducted on the various deteriorating agents affecting the Heritage Sites, their probable effects and natural methods to combat such harmful effects. The researcher stresses on preventive conservation of the sites through natural means which could prove effective in the future for protection of the entire site. The threats to the selected cultural and natural heritage sites have been discussed separately and the roles played, especially by different trees and shrubs surrounding a site have been dealt with collectively.

5.1. Deterioration Of The Heritage Sites

The growing expansion of urbanization and industrialization enhance deterioration of the Heritage sites. Lots of conservation efforts have been undertaken for protection of the sites. However, preventive pro-active measures if taken by natural means would not only act as long term protection of the sites but also be aesthetically appealing to the eyes of the visitors.

As already discussed in the Introductory Chapter of this thesis, the UNESCO Convention (1972)\(^1\) stresses the need for Protection of the World Cultural and Natural heritage sites for the following reasons -

1. Preserving the aesthetic and historical value of the sites.
2. Creating awareness to safeguard the sites.
3. Protection for lasting benefit of posterity.

According to Feilden, B.M. (1996:1)\(^2\), "We should target to save 90 percent of our heritage in the next decade". According to him, the following are the common causes of decay to our heritage:

1. **Climatic Causes**: Exceptional rainfall, frost, winds, snow, floods and radiation from sun, lightning and wild fire.
2. **Geological Causes**: Earthquake, Ground water changes, mining, etc.

3. **Biological Causes**: Algae, bacteria, lichens, moulds, fungi, insects, mice, rats, pigeons, etc. and also man.

4. **Economic Causes**: Lack of maintenance, development.

5. **Man made causes**: Neglect, pollution, vibration, fire and theft, vandalism, excessive tourism, road building, bad town planning.

Several agents may be working together and their individual effects may be therefore difficult to diagnose. Let us now analyze the causal agents affecting the sites individually.

### 5.1.1. Factors Causing Deterioration

Various factors are responsible for affecting the cultural as well as natural heritage sites. During her research study, the researcher has identified the combination of anthropogenic factors to be the main cause of deterioration in the studied areas.

The different factors affecting a site may be classified as follows:

I. **Natural Factors**

II. **Man-made / Anthropogenic Factors**

I. **Natural Factors for Deterioration**:

1. Due to earthquake, flood and landslides.

2. Damage due to micro organisms and growth of higher plants.

3. Damage due to excretory matter of bats and pigeons- they get dissolved and go inside stones.

II. **Man-Made / Anthropogenic Factors**:

Deterioration which are brought about as a result of increase in urbanization and developments leading to creation of various forms of Pollution like atmospheric pollution, noise pollution, soil pollution, water pollution, etc.
Further deterioration can be classified as:

I. **Physical deterioration**: Temperature, Relative Humidity, Wind, Light

II. **Chemical deterioration**: Atmospheric pollution liberating harmful gases that brings about atmospheric pollution, particulate matters, automobile and industrial fumes and secondary pollutants.

III. **Biological deterioration**: Include biological deteriogens like:
   a) Micro-organisms: Fungi/ algae/bryophytes/moss/ lichen
   b) Macro-organisms: Insects/ birds

IV. **Human Vandalism**: in form of graffiti, scribbling on surface of monuments, etc.

I. **Physical Deterioration**:

   The nature of physical deterioration is a slow but gradual process. The factors responsible for physical deterioration are different elements of climate such as light, heat or moisture. The visual signs of deterioration on the monument are Cracks and Stains. Severe storms, cyclones, thunderstorms may also bring about physical damage to the monument as well as the entire site.

II. **Chemical Deterioration**:

   The observations during repeated field works reveal that chemical deterioration is the most damaging and destructive for a cultural heritage site. Chemical deterioration is caused by both external and internal factors. The internal factors are caused due to intrinsic conditions existing within the element. These are visible only when the damage is made.

   External factors like climatic conditions, relative humidity, temperature, atmospheric pollutants accelerate the chemical deterioration. In her studies on cultural heritage sites, the researcher has identified atmospheric pollution as the major factor triggering chemical deterioration.
• **Atmospheric Pollution:**

The atmosphere is a dynamic system and pollutants may travel through it, disperse and react among themselves and other substances. Ultimately they may reach a sink, whether or not in their original form (Gupta, C.B. & Bhatnagar, I.K., 1994: 36). Air pollution may be defined as any atmospheric condition in which substances are present at concentrations high above their normal ambient levels to cause a measurable effect on the material or environment. A clear environment constitutes 0.78% Nitrogen (N\(_2\)), 0.03% Carbon-dioxide (CO\(_2\)) and 0.16 % Oxygen (O\(_2\)) by volume. Atmospheric pollutants are of two types:

1. Suspended particulate matters - include particulate matters and aerosol.
2. Gaseous pollutants.

1. **Suspended Particulate Matters:**

Suspended particulate matters are minute solid particles suspended in air. The main source of these particles is carbon, which originates from incomplete combustion of fuel, coal and diesel. These include:

- **Dust** - A major component of atmospheric pollution. It comprises fine dry particles or any finely powdered substance of earth or any other matter in the air. It also includes salts like Sodium chloride (NaCl), Magnesium chloride (MgCl\(_2\)). Dust brings about physical damage as well as accelerates chemical reactions.

- **Dirt** - A filthy substance and may induce growth of micro-organisms under favourable environment.

- **Soot** - A black flaky or powdery substance of carbon particles produced by imperfect combustion of coal, wood/ oil.

- **Smoke** - A mixture of various gases and suspended carbon particles produced from combustion of wood, peat, coal or other organic matters.

- **Fly ash** - Fine particles of ash, made of solid fuel, formed with waste gases during burning of fuel in the furnace.

Suspended particulate matters (SPM) stimulate the growth of micro-organisms that in turn may bring about biodeterioration in the long run. SPMs attract
moisture that in turn brings about chemical reactions. Acidic gaseous contents of the particulate matters Sulphur dioxide (SO$_2$), Nitrogen dioxide (NO$_2$), Carbon-dioxide (CO$_2$) are converted to Sulphuric acid (H$_2$SO$_4$), Nitric acid (HNO$_3$) respectively in presence of moisture and metallic ions like copper, iron that catalyze the chemical reactions. Moreover SPMs are hygroscopic, thereby absorbing moisture, stimulating biodeterioration.

2. Gaseous Pollutants:

Gupta & Bhatnagar (1994: 36) has classified gaseous pollutants under the following heads:

- **Sulphur containing compounds**
  - Hydrogen sulphide (H$_2$S), Sulphur dioxide (SO$_2$), Sulphur trioxide (SO$_3$), Sulphur Acids, Sulphur Salts.
  
  **Sources:**
  
  A) Petroleum refining and burning of fuel  
  B) Burning of fossil fuels- coke, coal and oil  
  C) Automobile fumes

- **Nitrogen containing compounds**
  - Nitrogen oxides and Ozone. Nitrogen dioxide dissolves in water to form Nitric acid which being an oxidizing agent, attacks calcareous marble.
  
  **Sources:**
  

- **Carbon containing compounds:**
  - This includes Carbon monoxide (CO) and Carbon dioxide (CO$_2$). Carbon dioxide is generally released from automobiles, coal and wood combustion. The percentage of CO$_2$ concentration is very high in urban areas as compared in rural areas. CO$_2$ is absorbed from the atmosphere and easily get dissolved forming Carbonic acid (HCO$_3$).
One of the most important sources of air pollution is vehicles. The pollution from automobiles may be highly significant particularly in congested and poorly ventilated roads. Congestion intensifies air pollution in form of Hydrocarbons (HC), oxides of Nitrogen (NO₂ and NO₃) and Carbon monoxide (CO), smoke and lead. On an average, automobiles contribute to more than 50% of the total pollutants emitted in the atmosphere.

The motor vehicles that normally ply on the roads of Kolkata are-

a) Buses  
b) Trucks  
c) Jeeps  
d) Cars  
e) Taxis  
f) Two wheelers  
g) Three wheelers

The total number of motor vehicles in Kolkata is steadily rising higher day by day. Now let us see the extent of atmospheric pollution brought about by these vehicles.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Idle</th>
<th>Cruising</th>
<th>Acceleration</th>
<th>Deceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spark Ignition Engine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>750</td>
<td>300</td>
<td>400</td>
<td>4000</td>
</tr>
<tr>
<td></td>
<td>(Less)</td>
<td>(Least)</td>
<td>(Less)</td>
<td>(Max.)</td>
</tr>
<tr>
<td>CO</td>
<td>52000</td>
<td>8000</td>
<td>42000</td>
<td>52000</td>
</tr>
<tr>
<td></td>
<td>(Max.)</td>
<td>(Least)</td>
<td>(Less)</td>
<td>(Less)</td>
</tr>
<tr>
<td>NO</td>
<td>30</td>
<td>1500</td>
<td>3000</td>
<td>12-30</td>
</tr>
<tr>
<td></td>
<td>(Less)</td>
<td>(Least)</td>
<td>(Max.)</td>
<td>(Max.)</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compression Ignition Engine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>250</td>
<td>65</td>
<td>115</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>(Max.)</td>
<td>(Least)</td>
<td>(Least)</td>
<td>(Max.)</td>
</tr>
<tr>
<td>NOx</td>
<td>60</td>
<td>260</td>
<td>850</td>
<td>10-50</td>
</tr>
<tr>
<td></td>
<td>(Less)</td>
<td>(Less)</td>
<td>(Less)</td>
<td>(Max.)</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Least</td>
<td>Least</td>
<td>Less</td>
<td>Max.</td>
</tr>
<tr>
<td>Smoke</td>
<td>Least</td>
<td>Least</td>
<td>Max.</td>
<td>Less</td>
</tr>
</tbody>
</table>

Table.5.1: Automobile emissions (µg/m³) at various operating conditions during driving of vehicles
Table 5.2: Pollutant Emissions from different kinds of automobiles- Gasoline and Diesel engines (in pounds/1000gal.fuel)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>2300</td>
<td>60</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>200</td>
<td>136</td>
</tr>
<tr>
<td>NOx</td>
<td>113</td>
<td>222</td>
</tr>
<tr>
<td>Particulates</td>
<td>12</td>
<td>110</td>
</tr>
<tr>
<td>Organic Acids</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>SOx</td>
<td>9</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 5.3: Composition of Diesel engine smoke (based on various reports)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>Less than 1000ppm</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>100-600 ppm</td>
</tr>
<tr>
<td>NOx</td>
<td>10-1000ppm</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>5-20 ppm</td>
</tr>
<tr>
<td>Particulates</td>
<td>50 mg/m³</td>
</tr>
</tbody>
</table>

Table 5.4: Composition of Gasoline engine exhausts (uncontrolled engines)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>3.5%</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>900ppm</td>
</tr>
<tr>
<td>NOx</td>
<td>1500 ppm</td>
</tr>
</tbody>
</table>

Carbon monoxide is the major pollutant from the exhaust gases which comprise about 50% of the total weight of the pollutant. Hydrocarbons contribute nearly 8% of the total pollutants in the exhaust, while the rest are oxides of nitrogen, particulates and other pollutants. Hydrocarbons and compounds of Carbon monoxide are the chemical products of combustion in the exhaust gases. Oxides of Nitrogen are generated mainly by chemical combination of Nitrogen gas and Oxygen at high combustion temperature. Particulates are produced because of improper combustion, and come out in the form of black smoke. Lead is the combustion product of inorganic additives. Considerable quantities of pollutants are also produced from the fuel tanks, carburetor and crankcase of the automobiles. The contribution of hydrocarbons from various parts of gasoline based motor vehicles is as follows:
1. Evaporation losses from tank and carburetor (20%)

2. Crank case blow-by (25%)

3. Exhaust (55%) (Fig.5.1)

➤ **Important Hydrocarbons present in the exhaust:**

Paraffins, Olefins (particularly low molecular weight mono and diolefins), Aromatics (benzene and toluene) and Acetylenes. Though a total of 80 compounds have been identified from the auto-exhaust, only Olefins and Polycyclics are of major concern.

➤ **Particulates from automobiles include:**

Salts of lead, alkaline earth compounds, iron oxides, soot, carbonaceous material and tars. This particulate material may vary in size from large flakes to submicron particles.

➤ **Benzo (a) pyrene** is usually present in high concentration in auto exhausts and is the product of high temperature combustion of carbonaceous matter.

❖ **Classification of Air Pollutants:**

- On basis of their Origin
- On basis of the State of Matter
- On basis of Chemical Composition

- On basis of origin -

1. **Primary Pollutants:** those emitted into the atmosphere as a result of some specific process and remain for a long time in the chemical form in which they are emitted. These include particulates, Sulphur dioxide (SO\(_2\)), Carbon monoxide (CO), hydrocarbons, Hydrogen sulphide (H\(_2\)S), Ammonia (NH\(_3\)).

2. **Secondary Pollutants:** Those formed in the atmosphere as a result of some reaction. This reaction may be photochemical or non-photochemical and may take place between two pollutants or between a
single pollutant and natural constituents of the atmosphere. Examples - Ozone, oxides of Nitrogen (NOx), Peroxy acetyl nitrate (PAN), photochemical smog and acid rain.

<table>
<thead>
<tr>
<th>Major classes</th>
<th>Sub-classes</th>
<th>Typical members of sub-classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Gases</td>
<td>Hydrocarbons</td>
<td>Hexane, benzene, ethylene, methane, butane</td>
</tr>
<tr>
<td></td>
<td>Aldehydes &amp; Ketones</td>
<td>Formaldehyde, acetone</td>
</tr>
<tr>
<td></td>
<td>Other organics</td>
<td>Chlorinated hydrocarbons, alcohols</td>
</tr>
<tr>
<td>Inorganic Gases</td>
<td>Oxides of nitrogen</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td></td>
<td>Oxides of sulphur</td>
<td>Sulphur dioxide, Sulphur trioxide</td>
</tr>
<tr>
<td></td>
<td>Oxides of carbon</td>
<td>Carbon monoxide, Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td>Other inorganics</td>
<td>Hydrogen sulphide, Hydrogen fluoride, Ammonia, Chlorine</td>
</tr>
<tr>
<td>Particulates</td>
<td>Solid particles</td>
<td>Dust, smoke, fume</td>
</tr>
<tr>
<td></td>
<td>Liquid particles</td>
<td>Mist, Spray</td>
</tr>
</tbody>
</table>

Table 5.5: Classification of Pollutants on basis of State of Matter

- **On basis of the State of Matter** –

  1. **Gaseous Pollutants** –

     Contaminants in the form of gases, behaving much as the air itself and may be organic and inorganic as stated above.

  2. **Particulate Pollutants** -

     These are finely divided solids or liquids. The larger particles tend to settle out quickly and are called dustfall particulates, more than 1 micron in size. Smaller particles remain suspended for a longer period and are called suspended particulate matter (SPM, particle size less than 1 micron). The smallest particles may behave almost as a gas and are readily transported by wind currents for longer distances without being deposited.

- **On basis of Chemical Composition:**

  1. **Organic pollutants** –

     Organic in nature and contain mainly carbon and hydrogen, but may also contain some other elements. Carbon monoxide and carbon dioxide are excluded from this category as these contain only carbon
and oxygen but no hydrogen. Eg: Hydrocarbons, Chlorinated hydrocarbons, Aldehydes, Alcohols.

2. Inorganic Pollutants –
Contaminants in the form of simple inorganics like CO, CO$_2$, NO$_2$, NO, SO$_2$, HF, H$_2$S, metals, etc. Most common pollutants of the atmosphere are of this category.

Types of Damages brought about by Air Pollutants:

1. **Abrasion**: Mechanical damage induced by abrasive activity of solid particles of various sizes.
2. **Deposition and Removal** of solid and liquid particles
3. **Direct chemical attack**: Air pollutants react irreversibly
4. **Indirect chemical attack**: Absorption of pollutants by certain materials causing degradation when pollutants undergo chemical changes. For example: Sulphuric acid from Sulphur dioxide reacts with Calcium carbonate of marble to form Calcium sulphate (Gypsum- CaSO$_4$.2H$_2$O).

III. Biodeterioration:
Deterioration brought about by means of Biodeteriogens like algae, fungi, lichens on the monuments is called biodeterioration.

The researcher has examined thoroughly and seen that four groups of macro-organisms such as algae, fungi, lichen, moss and liverworts as well as higher plants such as shrubs, herbs, grasses, bushes and trees like Peepal, Banyan, Neem are causative agents for biodeterioration. Pigeons, bats, Sparrows and Crows are among the harmful birds damaging historical monuments. (Bahadur, 1997: 175)

All the monuments are part of an ecosystem which comprises of the substrate (stone), in case of Cultural heritage sites, abiotic and biotic factors and as such, the growth of biological agencies is dependent upon several of these factors. The nature of the substrate and nature of the biodeteriogen itself are the two most important factors having a direct influence on biodeterioration of cultural
property. The nature of substrate is dependent upon the nature of constituent minerals of the stone. Stones may be polymineralic (sandstone, granite, basalt, etc.) or monomineralic (marble, limestone, etc.). Growth of biodeteriogens is also dependent upon the availability of the nutrients and light and climate (rainfall and temperature). In tropical climates, growth of biodeteriogens is much more as compared to colder climates (Jain, K.K. et al. 1993: 333).

Biodeterioration can be classified into two types:

1. Mechanical biodeterioration: In this type, the material is damaged mechanically by physical factors exerted by organisms.

2. Chemical biodeterioration: In this type, the material is damaged chemically by organisms. This type can be further divided into the following two types:
   
a) **Assimilatory deterioration**: In this process, the organism utilizes the material as a food source for their own metabolism.

   b) **Dissimilatory deterioration**: In this process, the material is damaged by excretory products liberated by organism.

- **Types of deterioration taking place as a result of bio-colonization** -

1. Biophysical deterioration: It has been studied that due to pressure exerted on surrounding surface during growth or movement of an organism or its parts (hyphae/ rhizhines/ extensive root systems). The substrate then becomes more susceptible to other deterioration factors, i.e. biochemical.

2. Biochemical deterioration: It is a fact that autotrophic organisms produce acids and heterotrophic organisms produce organic acids. These acids on reaction with the substrate may produce salts and chelates, which may cause stresses in pores, leading to crack formation (Jain, K.K. et al., 1993). Insoluble salts and chelates form crusts on the substrates.

3. Aesthetic Deterioration: Bio-colonization alters the appearance of the terracotta substrates due to chromatic alterations and formation of biological patinas. With passage of time, this aesthetic biodeterioration may lead to physiochemical damage.
The above mentioned factors of deterioration may either singly or in combination with each other be responsible for deterioration of the monument or the entire site. Keeping in mind the above mentioned factors, the researcher has conducted intensive survey of the areas of her research work and tried to analyze the factors for bringing about deterioration of the sites.

5.1.2. Deterioration Of Victoria Memorial Hall (VMH) Heritage Zone

It is a fact that Kolkata is one of the oldest, largest and most densely populated metropolitan cities of India (22°82′N and 88°20′E). The study site is Victoria Memorial Hall, Kolkata, India. This site is a busy zone with high traffic density (5,000–6,000 vehicles/hour, during peak hours). Constructions of buildings, bridges, roads as well as increase in transportation have resulted in discharge of gaseous and particulate contaminants into the atmosphere. The annual average concentration of Suspended Particulate Matter (SPM) and Respirable Particulate Matter (RSPM) at the study site exceeds the national standard limit as per West Bengal Pollution Control Board (WBPCB) Air-quality data⁹.

The environmental pollution and its impact on the Victoria Memorial Hall have been a cause of great concern. The deterioration of the Victoria Memorial Hall due to adverse environmental condition has been a well debated topic for a couple of decades. The Victoria Memorial Hall authority in 1990s undertook an in depth study through NEERI, a premier CSIR Institute based in Nagpur, with a view to assess the deterioration of the monument due to atmospheric pollution and to devise a monument protection plan. The West Bengal Pollution Control Board also conducted a study during December 2001 till January 2002 to assess the impact of vehicular pollution in and around the Victoria Memorial Hall and to suggest measures for reducing the pollution level with a view to protect the monument from effects of air pollution.

According to the findings of Air Pollution Control Board¹⁰:

a) The 24 hr mean value of Suspended Particulate matter (SPM) and Respirable Particulate Matter (RPM) was much above the National standard. When compared with the sensitive areas, this level was found even higher.
b) The 24-hrly mean value for Sulphur dioxide (SO$_2$) was found much below the National standard for residential and rural areas. The mean value of Nitrogen dioxide (NO$_2$) was found marginally lower than the National standard for residential and rural areas though some high Nitrogen dioxide (NO$_2$) values were also recorded.

c) Comparing the data obtained from this study with those recorded by NEERI during its study in 1991, it was found that values for SPM were marginally lower than that observed by NEERI.

d) Values for Sulphur dioxide (SO$_2$) were found decreased considerably during the last 10 years, but the values for Nitrogen dioxide (NO$_2$) were found to have increased considerably.

e) Air pollution level during night time was found higher compared with those during daytime.$^{11}$

- **Deterioration of Stone:**

  Geologically, stone can be classified as:

  1. Sedimentary
  2. Igneous
  3. Metamorphic- Fine, smooth, less porous: eg. Marble

  The physical parameters are related with state, nature, structure, texture, composition of rock and greatly affected by surrounding environmental conditions and with time bearing stress and strain.

  The deterioration of stone is termed as Weathering. This leads to mechanical destruction and chemical disintegration that are not stable in those conditions.

  The main composition of Victoria Memorial Hall is the metamorphic rock i.e. Marble.

- **Marble Deterioration:**

  As researched by Harinarayana (1971:90)$^{12}$, marble is mainly a carbonate of calcium and carbonic acid being a weak acid, carbonates is relatively less stable and so liable to be attacked by stronger acids and decomposed. Moreover, there is no formation of a complex compound as in other stones,
to confer stability against attack. Marble is easily susceptible as its beauty depends upon the polish and purity of its surface and yet this itself is most liable to damage. Its surface is easily spoilt by the action of the chemical agents of deterioration.

- **Nature of Marble:**
  Marble is recrystallized limestone, which is itself composed mainly of mineral calcite (CaCO₃). It gets heated more slowly and expands less with temperature.

- **Forms of deterioration:**
  Close observation of the monument and literature consultation have led to identification of the following forms of deterioration:
  1. Roughening of the surface accompanied by formation of opaque patches thus removing the polish of the marble surface and rendering it more porous and opaque in appearance.
  2. Staining: White marble is easily stained and the stain has got the tendency of becoming deep seated, getting into the interstices of the porous surface. Season after season of weathering leads to the formation of calcium sulphate layer. This creates a protective cover over it and the stains become impenetrable. Calcium sulphate is difficult to remove as it is insoluble in solvents. Strong acids cannot be used on marble due to its chemical susceptibility (Harinarayana, 1970:93).

- **Agents of Deterioration of Victoria Memorial Hall:**
  The location of Victoria Memorial Hall in a busy zone makes it prone to atmospheric pollution caused by huge number of vehicles.

  As already discussed in the previous chapter, the marble edifice is surrounded by a busy road network on all sides, i.e., Queen’s Way in the North, A.J.C. Bose Road in the South, Cathedral Road in the East and Hospital Road in the West.

  All the above mentioned roads are important junctures and as such bear heavy traffic loads throughout the day. Such an increase in load of vehicular
pollution inevitably affects the ambient air quality existing around the Monument.

Study revealed that the Pollutants released by innumerable vehicles around the monument may be grouped as:

a) Particulate matter
b) Unburnt Hydrogen
c) Carbon Monoxide
d) Nitrogen Oxide
e) Benzene
f) Polyaromatic hydrocarbons

Air Quality Assessment:

The Central Pollution Control Board (CPCB) has executed nationwide monitoring network under NAQMP (National Air Quality Monitoring Programme), consisting of 341 stations covering 126 cities/towns in 25 states and 4 Union territories. Sulphur dioxide, Oxides of Nitrogen (NO₂), Suspended Particulate matter (SPM) and Respirable Suspended Particulate Matter (RSPM / PM10), are regularly monitored at all locations in addition to the monitoring of meteorological parameters like wind speed and direction, relative humidity and temperature. The automatic Ambient Air Quality Monitoring Station at VMH compound is one of five such stations operating in West Bengal since 2003.

The air quality monitoring is undertaken continuously for 24 hours with a frequency of twice a week, to have about 104 observations in a year. The monitoring is being carried out by Central Pollution Control Board in association with State Pollution Control Board (SPCBs) and NEERI. Based on Air Quality Monitoring data, the trends in annual average concentration of the various pollutants can be deduced. (Parivesh, Highlights 2007, 2008:13).¹⁴

As per the Air Quality Monitoring Report prepared by the West Bengal Pollution Control Board, the parameters considered in Ambient Air Quality Monitoring include:
Sulphur dioxide (SO\textsubscript{2}), Carbon monoxide (CO), Respirable particulate matter (RPM), oxides of Nitrogen, total hydrocarbon, Methane (CH\textsubscript{4}), Non-Methane hydrocarbon (HCNM) & Ozone (O\textsubscript{3}).\textsuperscript{15}

The findings for a period of six years show that SPM and RPM are much above the National Standard and the value of Nitrogen dioxide has increased considerably.

The following table shows the impact of each of the pollutants on the monument surface:

**Table 5.6: Probable effects of the liberated pollutants on the Monument**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Pollutants</th>
<th>Effect on Structures and Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SO\textsubscript{2}, H\textsubscript{2}S, O\textsubscript{3}</td>
<td>Metallic corrosion, surface erosion of buildings, historical monuments, abrasion</td>
</tr>
<tr>
<td>2</td>
<td>Particulates</td>
<td>Stick to stone brick, forming film of tarry soot &amp; grit, which may be acidic</td>
</tr>
<tr>
<td>3</td>
<td>Acidic gases</td>
<td>Physiological degradation of stone, concrete, marble, limestone.</td>
</tr>
<tr>
<td>4</td>
<td>CO\textsubscript{2} &amp; Moisture</td>
<td>Formation of calcium bicarbonate. Washed away with rain leaving behind eroded building surface exposed to further reaction.</td>
</tr>
</tbody>
</table>

The deposition of pollutants on the heritage site leads to acceleration of decay of stone, especially limestone, marble and sandstone. Both wet and dry deposition of pollutants contributes to stone damage. In tourist destinations, the role of Sulphur dioxide (SO\textsubscript{2}), Nitrogen oxides (NO\textsubscript{x}) and Carbon dioxide (CO\textsubscript{2}) is considered fundamental in accelerating historical weathering.

- **Effect of Sulphur dioxide (SO\textsubscript{2})**:  
In case of Victoria Memorial Hall, it is revealed that transformation of Calcium carbonate to Calcium sulphate occurs due to deposition of Sulphur compounds. The process of sulphation occurs through the following two mechanisms and affects the structure of the heritage sites:
1. Dry deposition of Sulphur dioxide on the stone surface, leading to the fundamental process of sulphating in presence of moisture. This gives rise to the formation of Gypsum (CaSO$_4$. 2 H$_2$O). The oxides of Nitrogen (NOx) and Ozone play a major role in transformation of SO$_2$ into sulphate. The deposition of sulphate (associated with wet deposition of aerosols) directly attacks carbonate, leading to formation of Gypsum layer. The volume of Gypsum is 1.7 times higher than volume of CaCO$_3$, leading to breakage of stone building materials.

2. Dust fall or suspended particulate matter- dust laden winds tend to pit the surface of monuments due to the force with which they blow and can form nuclei for particles of acid bearing vapour (Sharma, R.K. & Gupta, H.O. 1993:12). The insoluble, soluble and volatile constituents need to be identified.

The extent of damage due to rain and wind are also examined when they carry grit, dust or organic matter. The sandstone and bricks underneath have been badly affected by saline action. The Sheorajpore and Mirzapore stone is stable than Chunar sandstone. Marble is affected in acidic atmosphere (Agarwal, P.K. 1991:49).

Due to Sulphur dioxide (SO$_2$) deposition, these materials (stones ad mortars) undergo two damage mechanisms - a) sulphation-primary degradation process leading to gypsum formation and b) interaction of gypsum with hydrated mortar compounds (Calcium aluminate or silicate) leading to formation of two secondary products- Ettringite and Thaumasite, which cause fractures and crack in the materials, with even more damaging consequences. (Report of committee 2005: 13, 14)

Pollutants affecting marble in VMH comes mainly from automobile exhausts, containing high amount of carbon and lead.

Sulphur dioxide is the most harmful gaseous pollutant that can corrode marble surfaces directly or indirectly resulting in conversion of Calcium carbonate to Calcium sulphate/ gypsum that is bound to affect life and lustre of marble. (Sharma, R.K. & Gupta, H.O, 1993:14)
• **Effect of Nitrogen Oxides (NO\textsubscript{x}):**

It may be stated here that Nitrogen oxides, especially nitrites react with water to form nitric acid, which is a contributor to acid precipitation. The acid in the presence of some minerals like Na, K and Ca together with sulphates, produces salts, that degrade stone.

Example: \textit{NaNO}_3 + KCl = KNO\textsubscript{3} + NaCl

Salt efflorescence can appear on strong materials. Presence of Nitrogen oxides (NO\textsubscript{x}) plays a major role in transformation of Sulphur dioxide (SO\textsubscript{2}) to sulphate.

• **Effect of Carbon-Dioxide (CO\textsubscript{2}):**

Carbon-dioxide is a product of hydrocarbon combustion, entering the atmosphere in large quantities.

Reaction of Carbon-dioxide with Marble:

\[
\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} = \text{Ca} (\text{HCO}_3)_2,
\]
dissolves stone materials, causing salt efflorescence.

\[
\text{CaCO}_3 + \text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2
\]
form bubbles on calcium carbonate surface.

• **Effect of Particulate Matter:**

On the basis of their morphology and elemental composition, atmospheric particles embedded within the damaged layers can be classified into three main categories- Carbonaceous, Aluminosilicate and Metallic. It is a known fact that carbonaceous particles are responsible for the black colours of the damaged layers causing aesthetic damage. Particulate matters of metallic origin play a typical role of catalyst for SO\textsubscript{2} oxidation.

The presence of white efflorescence on stone / building surface indicates chemical deterioration processes resulting from reaction of three components:

a) the materials themselves

b) water and polluting compounds present in the water

b) water and polluting compounds present in the atmosphere and

d) microorganisms.
Deterioration products resulting from reaction between these three components are: Water soluble salts - chlorides/ nitrites/ nitrates. Sometimes, Calcium carbonate insoluble in water can also be a deterioration product appearing in form of a surface incrustation.

- **Effect of Water & Soluble Salts on Stone Decay:**

  It is revealed that effects of water and soluble salts damage the sites substantially in the following ways:

  1. Etching, leaching or dissolution of one or more mineral constituents due to action of water or acidic solutions.

  2. Disruptive forces due to formation and growth of crystals at surface.

**Origin of Most Common Salts:**

1. **Sulphates:**
   
   **Hydrated Calcium sulphate (Gypsum)**

   a) sulphates are present in the surrounding land (through fertilizers) and can enter a wall by capillary action

   b) Some materials used in preparation of mortars and plasters can contain small quantities of sulphates as impurities. These can be dissolved in water present in masonry wall and brought to the surface as efflorescence.

   c) Microbiological.

   d) Atmospheric pollution, in the form of Sulphur dioxide.

   Gypsum formation had developed on the marble surface at a number of places, at the copper joints. Ugly green patches were also observed at a number of places on the monument

2. **Chlorides:**

   These salts include specially Sodium chloride and Calcium chloride, which are deposited on a wall. Chlorides can be the results of impurities in the materials (in sand) used to prepare mortars and plasters.
3. Nitrites & Nitrates:

Nitrites are not often found on walls because they rapidly oxidize into nitrates. The decomposition of nitrogenous organic material produces nitrites. It might be present where there is infiltration of sewage water or in the vicinity of old burial sites. Atmospheric pollution can also produce nitrates. The combustion of hydrocarbons in addition to creating Sulphur dioxide also produces various organic molecules and nitrogen oxides.

4. Carbonates:

Calcium carbonate is a normal constituent of both calcareous stones and of mortars.

Unlike other salts, Calcium carbonate is insoluble in water, but can be dissolved as bicarbonates when water contains high enough quantity of Carbon dioxide.

Cement contains several soluble alkaline salts besides sulphates, nitrites & nitrates which are added to give the final product. Thus if cement has been used in a building where there is some humidity in the walls, soluble salts present in the cement can migrate towards the original plaster and mortars causing destructive efflorescence or crystallization upon evaporation.

- **Effect of Water & Humidity**:

Excessive humidity can lead to the formation of -

1. Dissolution of airborne atmospheric pollutants in droplets.

2. Chemical reaction of stone constituents

3. Migration of soluble salts leading to crystallization or recrystallisation.

- **Efflorescence**:

When critical moisture content is reached, water retreats and if moisture contains dissolved salts, evaporation increases the salt concentration and crystallization starts at the stone surface, forming unsightly deposits. This is
called Efflorescence. In Limestone, incrustation becomes very hard due to formation of Calcium oxide (CaO).

- **Biological Factors:**

Deposition and colonization of stone surface by micro-organisms like bacteria, fungi and algae also bring about deterioration.

- **Deterioration to the Iron dowels:**

Iron dowels have been used in marble veneering. These dowels too show symptoms of decay. Due to moisture of atmosphere and leakage of water, iron gets oxidized. Oxidation causes volumetric increase in the dowels. Marble being brittle, is chipped off and may come out.

- **Visible Damages to Building: (Plate:52a-f, 53a-c)**

The researcher has recorded visible damage to the building which is probably the effect of a combination of the above mentioned factors:

1. Appearance of brownish-reddish spots at few places.
2. Green patches are noted at some places in the joints and iron statues.
3. Some carvings made up of buff colored Chunar sandstone have chipped off at some places.
4. Marble has turned pale yellowish at some places of building.
5. Blackish deposition predominant at some places.
6. Inner walls have developed few cracks. Growth of algae, moss at places where water accumulates.
7. Tiny saplings of Peepal, Banyan are found to be sprouting at many of the places, both on the building as well as the sculptures and statues in the compound.
8. Excreta stain on most of the marble statues in the compound.
• **Probable Causes of Deterioration**

1. Stains usually develop due to presence of mineral impurities due to iron in marble. Iron minerals by reaction with moisture and atmospheric oxygen, form iron salt that on getting oxidized forms a brown coloured stain of iron oxide on the surface.

2. Green patches are due to corrosion products on Copper clamps and dowels present between the marble pieces all over the structure. Corrosion leads to weakening of the dowels resulting in structural weakness.

3. Chipping of decorative carvings made from Chunar sandstone is due to salt formation and crystallization.

4. Blackish stain forms due to accumulation of carbonaceous matters like soot.

5. Main damaging factor is atmospheric pollution brought about by vehicles.

   ➤ **Steps of acidic pollution on Stone**:

   - Dry/ wet deposition of acid pollutants on stone surface.
   - Chemical reaction between acid deposition and chemical constitution of stone.
   - Combination of physical processes disrupting the surface.
   - Removal of decomposition products by wind or washed down by rain.

• **Visible Damages to the Garden surrounding Victoria Memorial Hall**

  (Plate 54A-D)

During her study, the researcher has identified and documented the following impacts of various factors upon the Garden:

1. During any event of natural calamities like storms, cyclones, a lot of trees within the garden get uprooted. The severe cyclone Aila, which hit India on May 25, 2009, caused massive loss of the trees as recorded by the researcher.
2. Most of the trees show signs of human vandalism in the form of graffiti, therefore creating a visual pollution.

3. The Notice Boards mentioning the rules/ regulations of the garden have fallen at a few places.

4. Soil in many places is strewn with plastics and polypacks.

5. Plastic bottles float in the waterbodies of Northern side.

6. In the South eastern part of the monument, the soil strewn with garbages and plastics, even below the notice board that warns the visitors not to carry any plastic bags. This causes soil pollution, and hence affects plant growth.

7. Inspite of the warnings on the notice boards that eating is not allowed, people do take food inside and throw the plates, plastic packets here and there.

The effects as discussed above may lead to long term deterioration to the vegetation that is bound to affect the Monument indirectly.

The visible damages on the Monuments reveal that Air pollution is a severe problem, both particulate and gaseous, seriously affecting the fabric of the Monument. Later in this Chapter we will see how the vegetation can form a shield against the harmful pollutants and therefore need protection. Loss of a single species of tree need to cared for at once.

5.1.3. Deterioration Of Bishnupur Group Of Temples

In the previous chapter, i.e. Chapter 4, a detailed discussion has been made regarding the architectural details, composition and surroundings of the Heritage temples of Bishnupur. In this part of Chapter 5, the researcher intends to highlight the different factors responsible for deterioration of the Terracotta temples as well as the surroundings.

As previously discussed, the temples are all Brick or Laterite built with decorated Terracotta tiles upon the brick. Firstly, the researcher will discuss the deteriorating factors affecting Terracotta.
Chapter 5

Deterioration of Terracotta: (Plate 55a-h)

So far as the climatic factors are concerned, West Bengal bears a tropical climate and the monuments are exposed to humidity. Brick work when prepared properly has durable properties inferior to those of stone. Its advantage is that since it is composed of small units, the flexibility gives it greater constructional possibility (Biswa, 2008)\textsuperscript{20}

The temples are built of burnt brick and clay as binding material. Terracotta refers to all kinds of fired clay, which when fired assumes a colour ranging from dull ochre to red. Its durability makes it suitable for use in sculpture decorations over monuments and architectural purposes. (Batra, 1996:158)\textsuperscript{21}

Threats to these terracotta monuments are:

A. Environmental pollution - Accumulation of dust and dirt from different sources on surface of Bishnupur temples.

B. Biological deterioration - Lower plants like Lichens and moss produce organic acids that damage the smooth surfaces of bricks, making them rough and brittle. Higher plants may bore into the brickwork, breaking them or making them unstable. Vegetation growth causes mechno-chemical action. The roots of vegetation go deep inside the walls. As a result cracks widen, dislodging the masonry. Due to biocolonisation, the following types of deterioration could take place in the near future:

a) Biophysical deterioration - Occur due to the pressure exerted on surrounding surface during growth or movement of an organism or its parts (hyphae/ rhizhines/extensive root systems). The substrate then becomes more susceptible to other deterioration factors, i.e. biochemical.

b) Biochemical deterioration - Results from assimilatory processes of the biological organisms. Autotrophic organisms produce acids and heterotrophic organisms produce organic acids. These acids on reaction with the substrate may produce salts and chelates, which may cause stress in pores, leading to crack formation (Jain, K.K., Mishra, A.K. and Singh, T., 1993: 333)\textsuperscript{22}. Insoluble salts and chelates form crusts on the substrates.
c) Aesthetic Deterioration - Bio-colonization alters the appearance of the terracotta substrates due to chromatic alterations and formation of biological patinas. With passage of time, this aesthetic biodeterioration may lead to physiochemical damage.

- Biodeteriogens - 

The probable biodeteriogens as generally observed in brick and terracotta temples of Bishnupur are as follows:

1. Cyanobacteria

These lower group of organisms also known as blue-green algae occur as solid black crusts on the walls of exposed roofs of the temples. The organisms in the crust liberate organic matter to the substratum which helps in the growth of other micro-organisms. The slimy surfaces of these bacteria facilitate the adherence of airborne particles of dust, pollen, oil and coal ash giving rise to hard crusts that are difficult to remove. (Kumar, R. et al. 1999: 14). They are principally green microalgae intermingled with lichen. Their presence may create a distinct microenvironment where respiration and photosynthesis occurs and may produce acids as by-products, which aids biochemical deterioration of the substrate. Repeated shrinkage and relaxation of the slimy sheath of cyanobacteria during their cycle of drying and moistening may lead to biophysical deterioration of the substrate. With excessive exposure to the hot sun, these organisms dry up turning black.

Most of the archaeologically important monuments look blackish-brown due to excessive growth of the Cyanobacteria as crusts /mats.

2. Fungi

Fungi are a group of heterotrophic organisms characterized by unicellular or multicellular filamentous hyphae. Since they cannot prepare their own food, they will colonise a substrate where organic food will be available. Waste products of algae, cyanobacteria, decaying leaves and bird droppings can provide such food sources. Fungi bring about biophysical deterioration by excessive penetration of its hyphae through cracks and crevices of the bricks. Biochemical decay may be produced through the liberation of organic acids.
which act as chelating agents (Kumar, R. et al. 1999:17)\textsuperscript{24}. Fungal presence is also evident by formation of coloured patches on the substrate.

\section*{3. Algae}

Extensive Algal growth on exteriors of monument is commonly seen in the tropics. Algae need dampness, warmth, light and inorganic nutrients for its growth. Loss of aesthetic value is perhaps the most obvious type of damage caused by algae. In well lit, dry environments, algae form thin, tough, green/gray/black patinas. In poorly lit and damp places, they are thick, gelatinous and of various colours. They cause staining, thus obscuring relevant details. Algae supports growth of more corrosive biodeteriogens like lichens, mosses, liverworts and higher plants (Kumar, R. et al. 1999:19)\textsuperscript{25} and aids in biochemical deterioration by production of organic acids. Some species of green algae may grow upon the brick floor making it very slippery (Mathur, 1980:26)\textsuperscript{26}.

\section*{4. Lichens}

Group of composite organisms formed by symbiotic association of chlorophyta or cyanobacteria and a fungus. The lichens as identified in the terracotta temples are of \textit{Crustose} type. They grow as crusts in strong attachment with the surface. They bring about biophysical deterioration from the penetration of the attachment devices of the thallus into cracks and pores of the bricks which may further widen by increase in mass of the thallus during growth. The porous nature of the bricks makes them susceptible to the physical penetration of the lichens. The organic acids produced by fungal component of the lichens may bring about biochemical deterioration. Bricks, mortar and plasters are vulnerable to lichen growth as they have greater capacity of retaining moisture (Awasthi, D. 1991:209)\textsuperscript{27}. Rough surfaces like that of bricks further favour their growth.

\section*{5. Mosses & Liverworts/ Bryophytes}

Sign of growth of mosses and liverworts are noted on the temples of Bishnupur.

Mosses and liverworts are bryophytes, a transitional group of the kingdom Plantae, forming a bridge between primitive plants without tissues or organs and evolved plants with differentiated tissues and organs. They are simple
photoautotrophic organisms containing pigments (chlorophyll and carotenoids) and possessing rudimentary root-like organs (rhizoids) but no vascular tissues. They frequently occur in association with algae only where excessive damp condition prevails and there occurs humus deposits, resulting from accumulation of dead algae. With death of mosses, indirect damage may be caused to the temple by supporting growth of more destructive higher plants. Since these grow in high humidity, these are found to occur at the base of porous monuments. They are capable of bringing about some degree of biochemical degradation.

6. Higher Plants

During her field work, the researcher has noticed the presence of higher plants near and on the temple sites. For higher plants, biophysical decay is mainly due to growth and radial thickening of the roots of plants inside the substrate, causing increased pressure in surrounding masonry. Woody species, due to the expansion of their root systems cause much damage as compared to herbaceous species. Biochemical deterioration results from the acidity of the root tips (Jain, Mishra, and Singh 1993:346). Presence of plants influences the microclimate by increase of relative humidity and water retention, favouring growth of other microorganisms. Their growth may occur due to dropping of seeds through bird’s excreta and scattering by rodents in the cracks and crevices. Roots go deep inside the walls and cracks and thus dislodge the masonry. Growth of peepal and banyan trees over the sikhara of the temple is quite prominent.

7. Animals (Bats, Birds)

The researcher observed during her field work that the birds commonly found to be roosting on the temples include sparrows, crows, pigeons, swallows, parrots. Bats are also known to hover around and within temples. These animals perhaps cause aesthetic deterioration of the temples by depositions of their excretory products. These excreta not only disfigure the temple surface, but provide food for growth of microorganisms (Bahadur, 1997:178). Phosphoric acid and Nitrates serve as favourable food for the fungi in humid conditions.
Thus the entire process of biocolonization on the temples of Bishnupur involves the interaction of micro-organisms, plants and animals, each of which are interlinked through their physiological functions. The development of any entity will inevitably accelerate the development of the other.

C. Salt action

Due to the action of salts, decorative terracotta tiles are often ladened with white salt accumulating due to reaction of Calcium oxide (CaO) from brick with moisture in the atmosphere to form Calcium hydroxide, which further reacts with atmospheric Carbon dioxide to form Calcium carbonate that is deposited as a solid white crust on and between the terracotta art-work. Salts of Sulphites and Nitrates may also be formed due to atmospheric reactions.

D. Dampness due to rise in water table

This occurs as a result of capillary action.

E. Human vandalism

The researcher has noticed varied forms of scribbling of names on the temple walls or fixing hanging offerings, both inside and outside and on the ceilings.

F. Leakages through peeling of plaster pose another problem towards safety of temple. Water during monsoon can enter through these weak areas making the parts heavy, leading to collapse of the regions, either partially or completely.

G. Carved wooden doors are susceptible to insect attack. (Joshi, J. 2008:59)30

Deterioration observed in the Bishnupur Group of Temples:

(Plates 56-61)
Rasa Mancha - Deterioration and Present Status:

The *Rasa Mancha* was founded by Archaeological Survey of India in a dilapidated state in the year 1920s. At that time, the deterioration was mainly physical and biological.

The damages recorded at that time were:

1. pillars had collapsed, cracked or bulged out
2. roof had fallen in at several places notably in northern and western galleries and in the ante-chamber and was leaking, specially at eastern gallery.
3. flaking of stucco.

These damages were repaired by Archaeological Survey of India (ASI), as evident from its Reports. *Syama Raya, Madana Mohana, Jor Bangla* were some of the other temples restored by ASI. However, further damages have been observed inspite of repairing. Though massive scale repairing has already been done, if these small damages are not taken care of, these can once again lead to severe damages in the near future.

During the repeated field study and examination of the temples by the researcher in different seasons and months of the year, the following signs of deterioration were noted:

a) Most of the temple surface show prominent *green to yellowish green patches* both on upper and lower surfaces of the wall, on the upper surfaces of the roof and basal plinth. In *Syama Raya and Madana Mohana*, the sloping roof of the temple is covered by green patch on all the four sides. During early June, the patches appear *black* and the same patches after monsoon appears *green* in colour.

This is probably due to the Colonisation by Cyanophyta / Blue-green algae. Rath (2012)\(^{31}\) has identified the presence of Cyanobacteria responsible for forming a solid blackish-brown crust and mat from *Syama Raya* temple. Rath has also shown that excessive growth of the cyanobacteria in subsequent years provide suitable habitats to support appearance of bryophytes and other higher plants which greatly damage these monuments.
b) *Greenish-white* circular patches are noted on the walls of the temples and sloping roofs. During summer, these appear as whitish patch but with onset of monsoon, they turn greenish-white. Similar coloured irregular patches are seen to colonise prominent terracotta panels at the basal region of the temples, in *Syama Raya*.

This is probably due to the Formation of Crustose Lichen on the temples.

c) Leafy plants at the cracks and crevices of terracotta panels in *Syama Raya*. This is probably due to development of Higher plants.

d) Chipping off terracotta at many places.

Decorative terracotta panels were fixed with lime-mortar on external surfaces. This lime mortar turns to powder with time, water gets access in between brick wall and terracotta panels and thus the decorative panels come out of their original position. Biocolonization may have led to formation of powder.

e) Salt accumulation on the surface of terracotta panels.

f) Formation of cracks at some terracotta panels. Biocolonization may be one of the factors.

g) Few parrots hover around the nooks and corners of *Syama Raya* Temple, even sighted upon the *sikhara*. The temples thus serve as roosting places of Parrots.

h) Excretory deposits on inner walls of both temples. One can infer that perhaps the temples are inhabited by bats.

Repeated field visits by the researcher in the tenure of research (2007-2012) showed the following signs of damage.

1. Physical: Flaking of plasters at different regions

2. Black staining on walls

3. Biological Colonization: Growth of moss at laterite plinth on eastern side. Plant growth on laterite plinth. Wasp nest is observed on the arches. Lichen growth is seen on the arches.

4. Human vandalism: Inscriptions of names on pillars in the Southern facing walls as well as inner walls.
Thus, it is seen that the terracotta and laterite-built temples in Bishnupur are prone to different types of threats. In all the cases, it has to be kept in kind that in no way should the salt incrustations affect or conceal the architectural beauty of the monuments. The studies reveal that the impact of pollution is not so prominent in case of Bishnupur. The deterioration is brought about mainly as a result of Biocolonization.

5.1.4. Threats & Deterioration of Sundarbans National Park - Natural Heritage Site (Plate: 62a-e)

The entire ecosystem of Sundarban Biosphere Reserve is getting deteriorated day by day. The actual problems/threats need to be identified before they can be solved. Some important site specific threats were observed by the researcher during her study period:

1. Natural Factors:

This includes natural catastrophies like Flood, Tsunami, Cyclones, Continuous rain, drought, Forest Fires, Earthquakes, etc. West Bengal being a tropical country its natural heritage gets affected by Flood, Tsunami, Cyclones and storms.

Seasonally, around 4-5 cyclonic thrusts, surges from the Bay and other natural calamities affect the mangrove ecosystem. During the tenure of the investigation by the researcher, Sundarbans was affected with Tsunami and Aila and has suffered great devastation.

2. Anthropogenic Factors:

This includes the damages due to human interference like deforestation, fishing, usage of boats, unmanaged tourism, etc.

Naskar, K.R. et. al. (1987)\textsuperscript{32} opined that several alarming situations have been identified in the Sundarbans mangals:

a) Large scale shrimp/ prawn seed collection cause tremendous detrimental effects on the aquatic environment of the estuaries of the Sundarbans (Naskar, K.R. et.al., 1999: 215)\textsuperscript{33}. Thousands of women and children collect wild tiger prawn seeds (Peneous monodon) for sale to shrimp
After catching hold of the seedlings, local people screen the estuarine water with nets of particular mesh size in search of target species, during which a large number of fin fish and shell fish juveniles are caught in the nets. These juveniles, being non-remunerative to the catchers, are just thrown away. According to the report of the Forest Department, several species of other fish juveniles are wasted, thus affecting the aquatic diversity.

b) Conversion of forest land into shrimp farm: During the researcher’s journey by launch, she had come across several areas revealing the destruction of vast stretches of mangrove forests.

c) Large-scale exploitation of the Mangroves for firewood to meet the local need of the urban people.

d) Conversion of mangrove forests and brackishwater fisheries for integrated fisheries/ shrimp farm development not only has adverse effect on the Sundarban, but also degrade and pollute the environment.

e) Construction of embankments: Generally, embankments in coastal areas act as a line of defense against wave action and coastal surges. However, due to such constructions, the drainage system is greatly hindered. In some areas, the freshwater discharge is totally cut off, making the adjacent regions hypersaline. Such a change in salinity may affect the floral and faunal community structure in that area.

f) Antifouling Paints and hydrocarbons: Fishing vessels, trawlers, boats and passenger vessels are the only means of transport across the waters. These need regular conditioning to prevent the accumulation of biofoulers, by application of antifouling paints, the ingredients of which are zinc, copper and lead. These may not only contaminate the ambient media but also lead to bioaccumulation in the existing flora and fauna of the system. Petroleum hydrocarbons of diesel fuel, originating in the harbours and ports pose negative stress on the planktonic community as the transparency of water is affected by presence of oil/ grease layer on water surface.

g) Loss of endangered species: Every month, one finds report of poaching and hunting of the following endangered animals like tiger, crocodile and
Chapter 5

deer is very much prevalent, resulting in the damage of the biodiversity pattern. A study in the existing literature reveals that the following animals are being hunted due to valuable products obtained from them.

1. The Bengal Tiger (*Panthera tigris tigris* L.): for skin, teeth, nails

2. Estuarine Crocodile (*Crocodylus porosus* Schneider)

3. Olive Ridley turtle (*Lepidochelys olivacea* Eschscholtz)

4. Spotted deer (*Axis axis* Erxleben)

5. Hose-shoe crabs (*Carcinoscorpius rotundicauda* Latreille and *Tachypleus gigas* Muller), the Living fossils existing in Sundarbans, are often killed to obtain the amoebocytes, which form important sources of bioactive substances- TAL and CAL. With reference to this, it is noteworthy that the researcher during her course of her survey had seen two mating horse-shoe crabs at Jambu Island.

h) Fishing: During the field survey, the researcher had come across lots of fishermen on the tidal waters. Excessive fishing due to earning of livelihood poses a threat and disturbs the biodiversity diversity. The probable effects are as follows:

- Overfishing and excessive fishing can reduce the spawning biomass of a fishery below desired levels such as maximum sustainable or economic yields.

- A change can occur in species composition with progressive reduction of large, long-lived, and high value predator species and the increase in small, short-lived, and lower value pelagic and demersal prey species, a process described as ‘fishing down the food chain’.

- Non-selective fishing gear that is not modified to exclude or otherwise deter the entanglement of fish and turtles as a result, may lead to entanglement of juvenile fish, benthic animals, marine mammals, marine birds, vulnerable or endangered species, etc., that are often discarded and eventually die. While bycatch and discard problems are usually measured in the potential loss of human food, the increased risk of depletion for particularly vulnerable or endangered species (e.g. small cetaceans, turtles) can be significant.\(^{34}\)
i) High population growth: The ever increasing population growth in rural and
backward Sundarbans leads to rapid degradation and heavy pressure on
the mangroves and mangrove ecosystems.

j) Pollution: Pollutants, sewage discharge from urban areas, industries,
tanneries, paper mills, semi-intensive shrimp/ fish farms, washing of
pesticides from agricultural fields, and also oil spills from country boats,
motor launches, and steamers pollute the mangals every day.
Development of harbours, construction activities, open tourism may also
have detrimental effects on the mangrove ecosystem.

k) Unscientific Mode of Afforestation: Although several hectares of river flats,
river slopes and degraded mangrove forest zones have been developed
with artificial mangrove plantations especially with the quick growing
species, losses still result as these plantations were not done scientifically.

l) Tourism: Tourism is fatal to the natural heritage site, unless governed by
proper set of rules and regulations, i.e. the practice of Ecotourism. This
point will be dealt in details in the following Chapter, i.e. Chapter 6.

So, we see how each of the heritage sites, under study is getting affected by
different types of factors that pose a future threat for their existence. Larger
number of Organizations, Institutions, Projects, NGOs have started functioning
with the objective of identifying the cause of such problems and to overcome
them. But prior to different conservation measures, if we try to deduce any
preventive measure that will minimize the intensity of the threats that will
perhaps be much more effective.

The main focus of this research, is to intensively study the natural means of
Preservation of a site, be it Cultural or Natural. The researcher has tried to
deduce the effect of the surrounding Vegetation (in case of Cultural Heritage
Site) and the biodiversity itself (in case of a Natural Heritage Site) upon
Preventive conservation of the site. This approach has been discussed in the
following paragraphs.
5.2. Conservation Protocol: Preventive Conservation - Meaning & Significance

Preventive conservation is based on the concept that deterioration and damage to any site or monument can be substantially reduced by controlling some of the major causes of deterioration. These measures are indirect and do not interfere with the materials and structures of the items. In this thesis, the researcher has suggested “Environmental monitoring” as an important mode of preventive conservation especially for outdoor conservation like that of any monument or a site as a whole.

5.2.1. Effectiveness of surrounding Biodiversity in Preventive Conservation of a Heritage Site

- Biodiversity of the Surrounding:

Preservation of the monument is directly and indirectly influenced and regulated by its surrounding biodiversity pattern. Intensive study by the researcher showed that biological regulation of the microclimate will modify the overall macroclimate of the zone.

- Green belts: Role in Control of Atmospheric Pollution

The concept of green belt has been taken into consideration especially for the protection of cultural and natural heritage site.

The green areas or parks not only determine the structure and provide aesthetic value, but also important in controlling atmospheric pollution. The plants absorb gaseous pollutants like oxides of Sulphur and Nitrogen besides many others, directly from the air. Trees provide roughness to the surface, which promote turbulence in air. The increased turbulence prevents accumulation of pollutants in atmosphere by allowing greater dispersal and dilution. Green areas also stimulate the sedimentation of aerosols and dust present in air.

Green areas reduce the noise from industries as they interrupt with sound and shock waves. Plants are also useful in providing oxygen and water vapours to the atmosphere.
Microclimate is greatly influenced by presence of green areas. These are normally cooler than surrounding areas. If green belts are arranged radially in an urban area, it will promote the flow of cooler fresh air from surrounding along green belts, with the rise of urban air due to the heat island effect. This will result in presence of fresh, cleaner and cooler air in green areas. Green areas are thus different from other areas with respect to temperature, moisture and wind. Effect of green areas increases with increase in width and variability in its components, i.e. a green area containing a variety of plants in different layers (trees of various heights and shrubs), clumps of trees, open spaces and small water pond will be more effective in controlling the environment.

Das et al. (1986)\textsuperscript{35} have carried out dust collection efficiencies of various trees. They found that evergreen trees with simple leaves having rough and hairy surface, are relatively better dust collectors as compared to deciduous trees. \textit{Ficus} sp., \textit{Mangifera} sp., \textit{Tectona} sp. and \textit{Polyalthia} sp. have been reported to be efficient dust collectors. Many authors have reported \textit{Solanum melongena} and \textit{Cyamopsis tetragonoloba} to be efficient removers of Sulphur dioxide.

Trivedy remarks that Hydrogen fluoride (HF), Sulphur dioxide (SO\textsubscript{2}), Nitrogen dioxide (NO\textsubscript{2}), Ozone (O\textsubscript{3}) and Chlorine (Cl\textsubscript{2}) can be effectively absorbed by vegetation. PAN is absorbed to a lesser extent whereas Carbon monoxide (CO) is not effectively absorbed.

Establishment of green belt helps in attenuation of air and noise pollution. Green covers ensure soil protection and are known as shelter belts in abating soil erosion. Green enhances aesthetic value of the area and can take up waste water for its growth, thus solving problem of water pollution to some extent.

Considering the view-points of different authors, the researcher comes to the conclusion that for a Greenbelt plantation:

1. Tall trees with height more than 10 m should be planted around the source.
2. Planting of trees should be in appropriate encircling rows, each row alternating the previous one to prevent further fanning and horizontal pollution dispersal.

3. Since tree trunks are normally devoid of foliage, it would be appropriate to have small shrubs in front and in between the tree species.

- **Role of Trees: (as environmental purifiers)**

  The airborne dust particulates get deposited on the canopies by three means- Sedimentation, Impaction and Precipitation.

  The CPCB Guideline for Green Belt development (1999-2000)\textsuperscript{36} too listed the following mechanisms for deposition of airborne dust particulates on the canopies pollutants:

  1. Sedimentation by gravity action- mainly on upper surface of plant
  2. Impact under influence of eddy current
  3. Deposition under precipitation

  Literature survey reveals that various environmentalists have been working on the study of the role and significance of leaves of trees and shrubs in minimizing the extent of atmospheric pollution. Their findings could be taken into account specially to protect the cultural and natural heritage sites as a model project.

  1. Trees act as sink and living filters, minimizing air pollution by absorption, adsorption, detoxification, accumulation or metabolization without serious foliar damage or decline in growth. (Shannigrahi, A.S. et.al. 2003)\textsuperscript{37}.
  2. Vegetation naturally cleanses the atmosphere by absorbing gases and some particulate matter through leaves. Plants have a very large surface area and their leaves function as an efficient pollutant-trapping device.
  3. Trees improve air quality by providing oxygen.
  4. Plantation of evergreen, colourful flowering plant species beautify the surroundings and abate pollution impact.
  5. Morphological features of leaves:
a) Smaller leaves are efficient particle collectors, which are deposited at leaf tip and margins. The effectiveness in retaining atmospheric particles depends on shape, size, wetness, surface texture, solubility and insolubility. Tree leaves act as efficient filters of airborne particles because of their large size and high surface to volume ratio of foliage.

b) Often plants have materials on exterior that react with or fix and destroy pollutant.

c) Shape of canopy: Plant canopies are capable of providing a naturally absorbing surface with a favourable surface area/volume ratio and a long life span. Each plant has two sides with respect to the way the dust is carried by wind and captured by plant canopies i.e. (Fig.5.2)

- Front/ Luff side, whereby the air current diverts or redirected before entering the plant
- Lee Side or the back side, where the wind current falls after passing through the canopy.

d) Leaf surface characters such as roughness, length, frequency of trichomes and frequency of stomata play a significant role in capturing re-suspended dust. Dust interception capacity of plants also depends upon their shape and size, phyllotaxy and leaf characteristics such as hairs, cuticle, height and canopy of trees.

6. Trees reduce mean and average speed of wind, thereby augmenting particle deposition. (Pokhriyal, T.C.et.al.,1986)\textsuperscript{38}

7. Cut down noise level by absorbing high decibel noise (Pokhriyal, T.C. et.al., 1986:578)\textsuperscript{39}

8. Moist or wet plant surfaces enhances the pollutant removal rate by up to 10% and, under such conditions, stems, branches, twigs and leaves are engaged in the absorption process and thereby stimulate sedimentation of aerosols and dust present in the air. (Shannigrahi et. al. 2004:126)\textsuperscript{40}

9. Light also has a pronounced effect on the foliar removal of pollutants by stimulating physiological activities and stomatal opening.

10. Leaves are efficient collectors of heavy metals like lead and mercury from air.
The airborne dust particulates get deposited on the canopies by three means—
Sedimentation, Impaction and Precipitation.

Thus, selection of appropriate plants having suitable morphological features is
an important aspect of air pollution abatement strategy.

- **Experimental Findings regarding plant tolerance to Pollution:**

  **Air Pollution -Tolerance Index -**

  Air pollutants in urban and industrial areas may be adsorbed, absorbed,
accumulated or integrated into the plant body. If toxic, it may injure them to
some degree. The level of injury will be high in sensitive species and low in
tolerant ones. Sensitive species are useful as early warning indicators or bio-
indicators of pollution, and the tolerant ones help in reducing the overall
pollution load, leaving the air relatively free of pollutants.

  Plants differ considerably with reference to their responses towards
pollutants, some being highly sensitive and others hardy and tolerant. On the
basis of the Air Pollution Tolerance Index (APTI) and some relevant biological
and socio economic characters, the anticipated performance index (API),
from best to not recommended, of various plant species was determined for
Green Belt (GB) development.

  Air Pollution Tolerance Index (APTI) is an empirical value for tolerance level
of plants to air pollution. It can be determined by calculation of the Air
Pollution Tolerance Index (APTI) which can be found out using the formula:

  \[ \text{APTI} = A \cdot (T + P) + R \]

  A-Ascorbic acid

  T-Total chlorophyll

  P-Leaf extracts PH

  R-Relative Water Content of the leaf

  According to the study by Shannigrahi, A.S. et.al. (2004:132), high values of
APTI were recorded in *Mangifera indica*, *Moringa pterydosperma*, *Cassia
renigera* and *Ailanthus excelsa*. 
It has been studied that plants such as: Neem \((Azadirachta indica)\), Peepal \((Ficus religiosa)\), Banyan \((Ficus benghalensis)\), Almond \((Terminalia catapa)\) have the potential to serve as excellent quantitative and qualitative indices of pollution level.

**Characteristic Features of Plants For Absorption of Gaseous Pollutants and Suspended Particulate Matters (SPM):**

According to the *Guidelines for Developing Greenbelts* by Central Pollution Control Board (2000: 39)\(^{42}\), the following features facilitate the absorption of gaseous pollutants and SPMs respectively by plants -

**For Absorption of Gases:**

1. Plants should be tolerant to pollutants at concentrations that are not too high to be instantaneously lethal.
2. Plants should be Evergreen.
3. Plants should bear freely exposed foliage through
   - adequate height of crown
   - openness of foliage in canopy
   - big leaves with large broad laminar surfaces.
   - large number of stomatal apertures
   - stomata well exposed

**For Removal of Suspended Particulate Matter (SPM):**

1. Canopy should be spreading
2. Plant height- Tall shrubs help in trapping particles from 50-100 µm and tall trees of about 10-15 m height help in trapping particles less than 50 µm.
3. Leaves should be supported on firm petioles.
4. Abundance of surfaces on bark and foliage through:
   a) Roughness of bark
   b) Epidermal outgrowths on petioles
   c) Abundance of Axillary hairs
   d) Hairs/ scales on laminar surfaces
e) Stomata protected (by wax, arches, rings, hairs, etc.)

After consultation with several literatures, it has been observed that Dust deposition on tree leaf depends upon:

1. Leaf size
2. Leaf margin
3. Nature of leaf surface
4. Curvature of lamina
5. Epidermal and cuticular features
6. Phyllotaxy and orientation of leaves.

Evergreen trees with simple leaves, rough and pilose surface are better dust collectors than deciduous trees with compound leaves having glabrous surface. Curvature of lamina on adaxial surface help in retaining dust from being drifted away (Sharma, R.K. et.al., 1994: 6). According to the study conducted by Sharma, R.K. et.al. in 1994, the degree of dust deposition and pH decrease with height but the presence of percent soluble dust and volatile combustible matter increase with height. Therefore they inferred that lighter particles are rich in volatile dust, carbon particles, water soluble salts and acid droplets can get deposited easily at height whereas heavy particles (dust) settling due to gravitational forces deposit at lower heights.

Since automobiles generate both gaseous pollutants as well as particulate matters, choice of plants should be such that are capable of absorbing both types of pollutants.

✧ **Role of Surrounding Water Bodies in Absorption of Pollutants:**

Presence of water-bodies (ponds, Lakes, reservoirs, etc.) in the vicinity of a cultural heritage site or in the area adjoining the site proves to be of immense help in preventive conservation of the site.

**Carbon dioxide (CO₂)** is about 1.53 times as heavy as air. In the lower layers of the atmosphere, concentration of carbon dioxide is more in comparison to upper layers of the atmosphere. It is fairly soluble in water, i.e. one volume of
water dissolves one volume of the gas at ordinary temperature. So, the water bodies help in monitoring the environment by dissolving the carbon dioxide, a threat to marble monuments. (Prasad, L.K., 1980: 6)

**Carbon monoxide (CO)** is almost as heavy as air and slightly soluble in water. So, the carbon monoxide also gets dissolved to some extent.

**Hydrogen sulphide (H$_2$S)** is slightly heavier than air (density 1.1906 with respect to air) and fairly soluble in water (at 15°C, one volume of water dissolves 3 volumes of Hydrogen sulphide. So, water bodies also help in dissolution of Hydrogen sulphide from the polluted atmosphere.

**Sulphur dioxide (SO$_2$)** is about 2.26 times heavier than air and is highly soluble in water. One volume of water dissolves 80 volumes of the gas forming Sulphurous acid (H$_2$SO$_3$).

With the presence of water body, the polluting agents existing in the ambient environment can be minimized to an extent.

❖ **Role of Grasses on Ground surface of Monuments:**

Cultivation of tropical grasses of **C$_4$** (CAM Plants) types in the field around monuments would help to purify the surrounding environment by decreasing the concentrations of both Carbon dioxide and Carbon monoxide and thereby protects marble, stones, human beings, animals and so on. **C$_4$** plants bind more carbon dioxide per unit time and have low Carbon dioxide compensation point (Prasad, L.K, 1980: 21). Cultivation of grasses around the monument adds to the beauty and makes monuments look more attractive.

About 7600 species of plants use **C$_4$** carbon fixation, which represents about 3% of all terrestrial species of plants. All these 7600 species are angiosperms. **C$_4$** carbon fixation is less common in dicots than in monocots, with only 4.5% of dicots using the **C$_4$** pathway, compared to 40% of monocots. Despite this, only three families of monocots utilise **C$_4$** carbon fixation compared to 15 dicot families. Of the monocot clades containing **C$_4$** plants, the grass (Poaceae) species use the **C$_4$** photosynthetic pathway most. Forty-six percent of grasses are **C$_4$** and together account for 61% of **C$_4$** species. Of the dicot clades containing **C$_4$** species, the order Caryophyllales contains the most species. Of the families in the Caryophyllales, the Chenopodiaceae use **C$_4$** carbon fixation.
the most, with 550 out of 1400 species using it. About 250 of the 1000 species of the related Amaranthaceae also use C\textsubscript{4}.

Members of the sedge family Cyperaceae, Asteraceae, and some members of Euphorbiaceae also use C\textsubscript{4}.

Hence, grass plants have the capability to minimize the impacts of Carbon dioxide (CO\textsubscript{2}) and Carbon-monoxide (CO) on monuments.

5.3.1. Preventive Conservation Approach in Victoria Memorial Hall

As already discussed, the main deteriorating factor affecting Victoria Memorial Hall, Kolkata is atmospheric pollution. Air pollution control is more complex than most other environmental challenges. Once released into the air, pollutants are widely dispersed. No physical or chemical method is known to ameliorate aerial pollutants.

A biological method involving Preventive Conservation is through an intensive study of the natural properties of the surrounding vegetation to minimize the pollution effect. To check the spread of air pollutants emitted from an industrial complex, many scientists recommend growing green vegetation in and around the industrial/urban area.

Earlier, attention was given to the gaseous pollutants, but with the developments in monitoring systems and characterization tools and techniques, it has been realized that particulate matters are the real hazardous materials.

So, the researcher has studied the usefulness of vegetation cover around Victoria Memorial Hall with respect to combating atmospheric pollution. With this known fact, an intensive survey has been conducted in the premises of the Victoria Memorial Hall to prepare an inventory of the existing trees and shrubs and study how efficiently they help in removal of the dust and other particulates.

In the present work, the researcher attempts to validate the use of leaves of the trees and shrubs of the Garden surrounding the Monument as absorbers of vehicular pollutants. The present study also aims to study how the morphological features help the canopies to adsorb dusts and other pollutants and thus analyze distribution of trace elements in dust over the leaves.
In essence the overall objective of the present study is to establish the dual nature of plant canopies as an intervener of air pollution.

Higher Plants: Potent Tool for abatement of Atmospheric Pollution

Extensive and intensive study revealed that there are large varieties of species existing within the Victoria Memorial Hall garden, of which the following species are known to be efficient collectors of atmospheric pollutants:

1. *Albizia lebbek* (L.) Willd.
3. *Alstonia scholaris* (L.) R. Br.
4. *Antherochalas cadamba* (Roxb.) Miq.
5. *Mangifera indica* L.
6. *Mimusops elengi* L.
9. *Ficus bengalensis* L.
10. *Terminalia arjuna* (Roxb.) Wright & Arn.

The researcher tried to delve deep into the extent of deposition of particulate matter on the leaves of the above mentioned trees with her experiments.

Plant canopies act as absorbers of air-borne dust particles. Characterization of the dusts present over the leaf surfaces indicate the nature of contaminant present in the surrounding area and possible sources as well. Dust particulates get adsorbed on both the surfaces of leaves, however more dust particulates get deposited on the upper surface. These dusts contain many inorganic elements.

Some dominant trees existing in the Garden within the Victoria Memorial Hall Complex have been selected for study. The study zone includes the entire Garden surrounding the Victoria Memorial Hall in all the four directions, North, South, East and West.
Chapter 5

The trees under my investigation are listed below:

Table 5.7: Zonation of Leaf sample Collection from Garden of Victoria Memorial Hall

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Area of collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Delonix regia</em> (Boj., ex Hook.) Raf.</td>
<td>Krishnachura</td>
<td>North</td>
</tr>
<tr>
<td>2</td>
<td><em>Bougainvillea spectabilis</em> Willd.</td>
<td>Bougainvilia</td>
<td>North</td>
</tr>
<tr>
<td>3</td>
<td><em>Azadirachta indica</em> A.Juss.</td>
<td>Neem</td>
<td>North</td>
</tr>
<tr>
<td>4</td>
<td><em>Aegle marmelos</em> (L.) Correa</td>
<td>Bael</td>
<td>North</td>
</tr>
<tr>
<td>5</td>
<td><em>Alstonia scholaris</em> (Linn.) R. Br.</td>
<td>Chhatim</td>
<td>North</td>
</tr>
<tr>
<td>6</td>
<td><em>Lagerstroemia indica</em> (L.) Pers.</td>
<td>Jarul</td>
<td>North</td>
</tr>
<tr>
<td>7</td>
<td><em>Terminalia arjuna</em> (Roxb.) Wight &amp; Am.</td>
<td>Arjun</td>
<td>South</td>
</tr>
<tr>
<td>8</td>
<td><em>Polyalthia longifolia</em> (Sonn.) Th.</td>
<td>Debdaru</td>
<td>South</td>
</tr>
<tr>
<td>9</td>
<td><em>Dalbergia sissoo</em> Roxb.</td>
<td>Sishoo</td>
<td>South</td>
</tr>
<tr>
<td>10</td>
<td><em>Mimusops elengi</em> L.</td>
<td>Bakul</td>
<td>South</td>
</tr>
<tr>
<td>11</td>
<td><em>Mangifera indica</em> L.</td>
<td>Mango</td>
<td>South</td>
</tr>
<tr>
<td>12</td>
<td><em>Terminalia catappa</em> L.</td>
<td>Kathbadam</td>
<td>East</td>
</tr>
<tr>
<td>13</td>
<td><em>Ficus bengalensis</em> L.</td>
<td>Banyan</td>
<td>East</td>
</tr>
<tr>
<td>14</td>
<td><em>Bauhinia acuminata</em> L.</td>
<td>Swet Kanchan</td>
<td>East</td>
</tr>
<tr>
<td>15</td>
<td><em>Cassia fistula</em> L.</td>
<td>Bandarlathi</td>
<td>West</td>
</tr>
<tr>
<td>16</td>
<td><em>Ficus religiosa</em> L.</td>
<td>Peepal</td>
<td>West</td>
</tr>
<tr>
<td>17</td>
<td><em>Albizzia lebbeck</em> (L.)Benth.</td>
<td>Siris</td>
<td>North</td>
</tr>
<tr>
<td>18</td>
<td><em>Putranjiva roxburghii</em> Wall.</td>
<td>Putranjiv</td>
<td>North</td>
</tr>
<tr>
<td>19</td>
<td><em>Tectona grandis</em> L.</td>
<td>Teak</td>
<td>North</td>
</tr>
<tr>
<td>20</td>
<td><em>Anthocephalus chinensis</em> (Lamk.) A. Rich ex. Walp</td>
<td>Cadam</td>
<td>North</td>
</tr>
<tr>
<td>21</td>
<td><em>Saraca asoca</em> (Roxb.) Wilde</td>
<td>Ashok</td>
<td>East</td>
</tr>
<tr>
<td>22</td>
<td><em>Cassia siamea</em> Lamk.</td>
<td>Cassod Tree</td>
<td>South West</td>
</tr>
</tbody>
</table>

Besides the above mentioned Trees, Lichen specimens have been collected from the Bottle palm- *Hyophorbe lagenicaulis* (L.H. Bailey) H.E. Moore.

For each of the samples mentioned above, the following methodologies have been followed:

- **Methodology:**

  1. Equally matured leaves from each of the above mentioned trees were collected at different heights, i.e. 5ft, 10 ft and 15 ft from the ground. Sampling was done during September–October 2013.
2. The outline of each leaf/leaflet was traced on a Millimeter Graph paper for calculating the leaf area. The total area of the leaf is expressed in form of cm$^2$.

3. The leaves were placed inside air tight Zipper bags and taken to the Laboratory for dust and particulate analysis.

- **SEM Analysis**

The leaves were air dried and were carried out to the laboratory in polythene pouches to prevent further contamination and subjected to Scanning Electron Microscope (SEM). The objective of inspection was to find out the heights at which there will be a maximum accumulation of dust particulates and the part of leaf bearing maximum pollutants.

Discs of 1 cm$^2$ area were cut from unwashed leaves with a sharp device, wearing polyethylene gloves and were air-dried in a clean and closed chamber. Small strips were trimmed from areas between the margin and midrib of leaves. Each leaf strip was mounted on an aluminum stub, over double-sided stick tape and subjected to Scanning Electron Microscope.

For each and every leaf sample small or big, at different heights, SEM micro images were taken for the following three zones in two different magnifications- 100X and 500X.

- Leaf tip
- Middle of leaf across midrib
- Lower portion of leaf

Table 5.8: Area of Individual Leaf/Leaflet Samples (Calculated Graphically) (Fig.5.3)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Scientific Name</th>
<th>Family</th>
<th>Common Name</th>
<th>Leaf/Leaflet Area (in cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Mangifera indica</em> L.</td>
<td>Anacardiaceae</td>
<td>Mango</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td><em>Delonix regia</em> (Boj. ex Hook.) Raf.</td>
<td>Caesalpiniaeae</td>
<td>Gulmohar</td>
<td>0.91 (single leaflet)</td>
</tr>
<tr>
<td>3</td>
<td><em>Ficus benghalensis</em> L.</td>
<td>Moraceae</td>
<td>Banyan</td>
<td>157.6</td>
</tr>
<tr>
<td>4</td>
<td><em>Cassia fistula</em> L.</td>
<td>Caesalpiniaeae</td>
<td>Bandarlathi</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td><em>Ficus religiosa</em> L.</td>
<td>Moraceae</td>
<td>Peepal</td>
<td>78.2</td>
</tr>
<tr>
<td>6</td>
<td><em>Azadirachta indica</em> A.Juss.</td>
<td>Meliaceae</td>
<td>Neem</td>
<td>7.82</td>
</tr>
<tr>
<td>7</td>
<td><em>Terminalia arjuna</em> (Roxb.) Wight &amp; Arn.</td>
<td>Combretaceae</td>
<td>Arjun</td>
<td>40.6</td>
</tr>
<tr>
<td>8</td>
<td><em>Alstonia scholaris</em> (Linn.) R. Br.</td>
<td>Rubiaceae</td>
<td>Chhatim</td>
<td>36.3</td>
</tr>
</tbody>
</table>
### Analysis using Scanning Electron Microscopy (SEM):

From the result of study it can be stated that each of the leaves on subjecting to SEM, revealed the presence and accumulation of dust particulates on their surface. The observations of individual micro-images obtained after SEM are enlisted below. Prior to the observations, let us state the full forms of the various abbreviations used in the descriptions:

**Abbreviations and Order of Presentation -**

No. Serial no.
Fam: Family
L.N: Latin name (with author citation)
C.N.: Common name
S/T: Sensitive/ Tolerant (to air pollution)
HA: Habit
HT: Height
E/D: Evergreen / Deciduous
CS: Crown shape
MF: Morphological features of the leaf
MPCH: Maximum particulate concentration at which Height (5ft/10ft/15ft)
MPCS: Maximum particulates on which surface (Dorsal- D / Ventral- V)
MPCZ: Maximum particulate concentration at which Zone (lower/middle/tip)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Scientific Name</th>
<th>Family</th>
<th>Common Name</th>
<th>Leaf/Leaflet Area (in cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Lagerstroemia indica (L.) Pers.</td>
<td>Combretaceae</td>
<td>Jarul</td>
<td>97.72</td>
</tr>
<tr>
<td>10</td>
<td>Polyalthia longifolia Sonn.</td>
<td>Anonaceae</td>
<td>Debdaru</td>
<td>69.4</td>
</tr>
<tr>
<td>11</td>
<td>Dalbergia sissoo Roxb.</td>
<td>Fabaceae</td>
<td>Sissoo</td>
<td>27.68</td>
</tr>
<tr>
<td>12</td>
<td>Mimusops elengii L.</td>
<td>Sapotaceae</td>
<td>Bakul</td>
<td>40.31</td>
</tr>
<tr>
<td>13</td>
<td>Albizia lebbeck (L.) Benth.</td>
<td>Mimosae</td>
<td>Siris</td>
<td>8.16</td>
</tr>
<tr>
<td>14</td>
<td>Tectona grandis L.</td>
<td>Verbenaceae</td>
<td>Teak</td>
<td>319.6</td>
</tr>
<tr>
<td>15</td>
<td>Anthocephalus cadamba (Lamk.) A. Rich ex. Walp</td>
<td>Rubiaceae</td>
<td>Cadam</td>
<td>126.3</td>
</tr>
<tr>
<td>16</td>
<td>Aegle marmelos (L.) Correa</td>
<td>Rutaceae</td>
<td>Bael</td>
<td>45.17</td>
</tr>
<tr>
<td>17</td>
<td>Bauhinia variegata L.</td>
<td>Nyctaginaceae</td>
<td>Swet Kanchan</td>
<td>211.8</td>
</tr>
</tbody>
</table>
LPS (in µm): Size of largest particle in visible area
SPS (in µm): Size of smallest particle in visible area

1. *Terminalia arjuna* (Roxb.) Wight & Arn. (Plate: 63A)
   Fam: Combretaceae
   C.N: Arjun
   S/T: T
   HA: Tree
   HT: 15 m
   E/D: D
   CS: Oblong/ Round
   MF: Oblong, surface- hairy
   MPCH: 15 ft followed by 5 ft
   MPCS: D
   MPCZ: Leaf tip
   LPS: 36.9 µm
   SPS: 5.6 µm

2. *Dalbergia sissoo* Roxb. (Plate: 63B)
   Fam: Fabaceae
   C.N: Sissoo (Beng.); Shisham (Hindi)
   S/T: T
   HA: Tree
   HT: 10 m
   E/D: Evergreen
   CS: Round
   MF: Round with mucronate apex, surface: smooth
   MPCH: 5 ft followed by 15 ft.
   MPCS: D
   MPCZ: Leaf Tip, adjacent to petiole
   LPS: 31.3 µm
   SPS: 2.8 µm

3. *Polyalthia longifolia* (Sonn.) Th. (Plate: 63C)
   Fam: Anonaceae
   C.N: Devdaru (Beng. & Hindi)
   S/T: S
HA: Tree
HT: 15 m / 5 m
E/D: E
CS: Conical / Rounded
MF: Leaves- linear, surface: hairy
MPCH: 15 ft, then followed by 5 ft
MPCS: D
MPCZ: At leaf tip and in the middle portion, particulate is concentrated towards midrib
LPS: 65.9 µm
SPS: 2.2 µm

4. *Mangifera indica* L. (Plate: 63D)
   Fam: Anacardiaceae
   C.N: Mango, Aam (Beng & Hind)
   S/T: S
   HA: Tree
   HT: 15 m
   E/D: E
   CS: Round/ Oblong
   MF: Oblong, presence of trichomes in large concentration
   MPCH: 5 ft, 10 ft towards lower side and 15 ft.
   MPCS: D
   MPCZ: Heavy accumulation at the leaf tip. Large to medium sized particulates entangled within trichomes.
   LPS: 79.5 µm
   SPS: 4.1 µm

5. *Mimusops elengi* L. (Plate: 63E)
   Fam: Sapotaceae
   C.N: Bakul (Beng. & Hindi)
   S/T: T
   HA: Tree
   HT: 10 m
   E/D: E
   CS: Oblong / Round
   MF: Presence of trichomes
   MPCH: 10 ft followed by 5 ft.
   MPCS: D
Chapter 5

MPCZ: At leaf tip and at lower part of leaf, concentrated on both sides of midrib.
LPS: 31.9 µm
SPS: 2.5 µm


Fam: Moraceae
C.N: Banyan; Bat (Beng.), Bargad (Hindi)
S/T: T
HA: Tree
HT: 20 m
E/D: E
CS: Spreading
MF: Oblong, leaf surface wooly on dorsal side, smooth margin
MPCH: 15 ft
MPCS: D
MPCZ: At leaf tip and lower surface of leaf. Some particulates are entangled within the hairs.
LPS: 46.9 µm
SPS: 3.4 µm


Fam: Meliaceae
C.N: Neem tree, Nim (Beng. & Hind.)
S/T: T
HA: Tree
HT: 20 m
E/D: E
CS: Spreading
MF: Opposite, pinnately compound, linear, margin- serrated, petiole- short
MPCH: 15 ft
MPCS: D
MPCZ: Maximum concentration at leaf tip, moderate at lower part and few in middle.
LPS: 27.4 µm
SPS: 2.8 µm


Fam: Nyctaginaceae
C.N: Bougainvillea

Fam: Combretaceae
C.N: Indian Almond Tree, Kath Badam (Beng.), Deshi Badam (Hind.)

S/T: T
HA: Tree
HT: 35 m
E/D: D
CS: Spreading and conical
MF: Large, ovoid, broad, simple, leathery, glossy dark green, presence of minute hairs towards tip

MPCH: 10 ft
MPCS: D
MPCZ: Concentration at the leaf tip.
LPS: 54.2 µm
SPS: 1.7 µm


Fam: Caesalpiniaceae
C.N: Golden shower, Bandarlathi (Beng. & Hindi)

S/T: T
HA: Tree
HT: 12 m
E/D: D
CS: Round
MF: Long, pinnately compound, presence of hairs

MPCH: 15 ft
MPCS: D
MPCZ: Large concentration at leaf tip, middle as well as lower side.
LPS: 62.1 µm
SPS: 2.2 µm


Fam: Caesalpiniaceae  
C.N: Swet Kanchan  
S/T: T  
HA: Shrub  
HT: 3 m  
E/D: D  
CS: Oblong/ round  
MF: Bilobed, 6 cm long, 15 cm broad with apical cleft upto 5 cm, petiole 1.5 cm long, smooth  
MPCH: 10 ft  
MPCS: D  
MPCZ: Large concentration of particulates at leaf tip and middle portion.  
LPS: 49.2 µm  
SPS: 2.8 µm


Fam: Caesalpiniaceae  
C.N: Gulmohar, Krishnachura (Beng.)  
S/T: S  
HA: Tree  
HT: 15 m  
E/D: D  
CS: Spreading / Flat topped  
MF: Full of hairs including leaf petiole  
MPCH: 15 ft  
MPCS: D  
MPCZ: At lower part of leaf including the petiole and leaf tip. Very less deposition in middle.  
LPS: 34.1 µm  
SPS: 2.2 µm
Fam: Moraceae
C.N: Peepal tree, Ashthwa (Beng.) Pipal (Hindi)
S/T: Tree
HA: Tree
HT: 20 m
E/D: E
CS: Round / Oblong
MF: Cordate with extended tip, 10-17 cm long, 8-12 cm broad with a long petiole.
MPCH:15 ft
MPCS: D
MPCZ: Maximum at leaf tip.
LPS: 48.7 µm
SPS: 2.8 µm

Fam: Lythraceae
C.N: Crape myrtle
S/T: Tree
HA: Tree
HT: 30 m
E/D: E
CS: Spreading
MF: Opposite, Simple, Entire
MPCH:15 ft
MPCS: D
MPCZ: Maximum concentration at leaf tip, lowest at the lower part.
LPS: 82.9 µm
SPS: 2.2 µm

15. *Alstonia scholaris* (Linn.) R. Br.  (Plate: 63O)
Fam: Apocynaceae
C.N: Devil's Tree, Chhatim (Beng.), Chattiyan (Eng.)
S/T: Tree
HA: Tree
HT: 15 m
E/D: E
CS: Round
MF: Upper side glossy, underside greyish, in whorls of 3-10, leathery leaves- narrowly obovate, base- cuneate, apex- rounded

MF: Trifoliate, tiny hairs present, alternate, aromatic, ovate-lanceolate, crenate, pellucid-punctate, lateral sub-sessile, terminal long-petioled.

16. *Aegle marmelos* (Linn.) Correa  *(Plate: 63P)*

Fam: Rutaceae
C.N: Bael tree, Bael (Beng. & Hind.)
S/T: T
HA: Tree
HT: 12 m
E/D: E
CS: Oblong
MF: Trifoliate, tiny hairs present, alternate, aromatic, ovate-lanceolate, crenate, pellucid-punctate, lateral sub-sessile, terminal long-petioled.

17. *Albizzia lebbeck* Benth.  *(Plate: 63Q)*

Fam: Mimoseae
C.N: Siris tree (Beng. & Hind.)
S/T: T
HA: Tree
HT: 20 m
E/D: D
CS: Round/ spreading
MF: Bipinnate, with 1-4 pairs of pinnae, hairy on outer margins, lower surface very much hairy

MF: Bipinnate, with 1-4 pairs of pinnae, hairy on outer margins, lower surface very much hairy

MPCZ: Maximum concentration at lower side of leaf, many entangled within hairs.

SPS: 2.2 µm
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LPS: 33
SPS: 3.3 µm

18. *Putranjiva roxburgii* Wall. (Plate: 63R)

Fam: Putranjivaceae
C.N: Putranjiva
S/T: T
HA: Tree
HT: 12 m
E/D: E
CS: Round/ spreading
MF: Simple, alternate, dark green, shiny, elliptic-oblong, distantly serrated
MPCH: 15 ft
MPCS: D
MPCZ: Maximum concentration at lower side of leaf, many entangled within hairs. Small concentrations present at tip.
LPS: 67 µm
SPS: 3.2 µm

19. *Tectona grandis* L. (Plate: 63S)

Fam: Verbenaceae
C.N: Teak, Segun (Beng.) Sagwan (Hind.)
S/T: T
HA: Tree
HT: 20 m
E/D: D
CS: Oblong/ Round
MF: Ovate-elliptic, 15- 45 cm long, 8-23 cm wide, held on petioles 2-4 cm long, margin- entire, very rough, stiff hairs present.
MPCH: 5 ft
MPCS: D
MPCZ: Maximum concentration at lower side of leaf and tip of leaf. Small concentrations present at tip.
LPS: 47.5 µm
SPS: 2.8 µm

20. *Anthocephalus chinensis* (Lamk.) (Plate: 63T)

Fam: Rubiaceae
C.N: Kadamba, Kadam (Beng.(), Mar (Hind.)
S/T: T
HA: Tree
HT: 40 m
E/D: D
CS: Spreading
MF: Simple, long
MPCH: 5ft
MPCS: D
MPCZ: Maximum concentration at lower end of leaf. Towards the leaf tip, much concentration of particulates is seen along the midrib.
LPS: 97.8 µm
SPS: 1.7 µm

21. Saraca asoca Roxb. De Wilde (Plate: 63U)
Fam: Fabaceae
C.N: Ashok (Beng. & Hind.)
S/T: T
HA: Tree
HT: 5 m
E/D: E
CS: Spreading
MF: Compound, deep green, smooth
MPCH: 10ft
MPCS: D
MPCZ: Maximum concentration at leaf tip, distribution at middle of leaf and lower surface is more or less the same.
LPS: 23.4 µm
SPS: 3.3 µm

Fam: Caesalpinaceae
C.N: Cassod tree, Minjri (Beng.)
S/T: T
HA: Tree
HT: 10-12 m
E/D: E
CS: Oblong
MF: Alternate, pinnately compound, with slender axis and 6-12 pairs of leaflets on short stalks, rounded at both ends, small trichomes present

MPCH: 15ft
MPCS: D
MPCZ: Maximum concentration leaf tip. Few particulates scattered at middle of leaf and at lower end.

LPS: 54.2 µm
SPS: 1.1 µm

23. *Pongamia pinnata / Milletia pinnata* (L.) Panigrahi (Plate: 63W)

Fam: Fabaceae
C.N: India Beech, Karanj (Hind.)
S/T: T
HA: Tree
HT: 15-25 m
E/D: D
CS: Spreading
MF: Alternate, imparipinnate, short stalked, rounded/ cuneate at base, ovate-oblong at length, obtuse-acuminate at apex, glossy, deep green

MPCH: 10 ft
MPCS: D
MPCZ: Maximum concentration at leaf tip followed by many at lower end. Very few particulates are observed on lower side of the leaf.

LPS: 40.8 µm
SPS: 2.2 µm

**Results of Analysis and Discussion:**

Thorough analysis of the SEM images of the above mentioned leaves led to the following deductions:

1. Leaves are capable of capturing dust particulates in the range of 1.1 micron (µm) to around 92.4 micron (µm) on either of its surfaces, i.e. both dorsal and ventral surface. However, the dorsal leaf surface in all the plants studied has adsorbed more dust in comparison to that of the ventral surface.

2. Variation in dust capturing capacity depends on:
   a) characteristic variations in the leaf surface such as roughness, length, frequency of trichomes.
b) studies have shown that in plants with thick, spreading canopies, the incoming air current can easily enter and settle the impurities inside the plant. In plants with thin conical canopies, dust concentration will fall rapidly before entering the plant, leaving maximum amount of dust in front side and carrying the rest to the leeward side.

c) It has been observed that surface roughness, large contact area, foliar structures like trichomes and stomata on leaves facilitate capturing of air-borne dust. In some of the plants, dust particulates are found to be inside the stomata (Plates, 64, 65) and in some plants, dust particulates are found to be entrapped within the trichomes.

d) In the visible area under SEM, larger dust particulates have been found to be trapped in the leaves of the plants as listed below in Table 5.9.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Scientific Name</th>
<th>Particulate Size (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aegle marmelos (Linn.) Correa</td>
<td>92.4</td>
</tr>
<tr>
<td>2</td>
<td>Lagerstroemia indica L.</td>
<td>82.9</td>
</tr>
<tr>
<td>3</td>
<td>Mangifera indica L.</td>
<td>79.5</td>
</tr>
<tr>
<td>4</td>
<td>Polyalthia longifolia (Sonn.) Th.</td>
<td>65.9</td>
</tr>
<tr>
<td>5</td>
<td>Cassia fistula L.</td>
<td>62.1</td>
</tr>
</tbody>
</table>

In the rest of the leaves under study, the average large particulate size has been seen to be varying between 29 µm to 55 µm.

The study shows that plants are capable of adsorbing re-suspended dust particulates. Thus one can conclude that trees improve urban air quality by capturing airborne dust particulates. The observation that more amount of dust particulates get deposited on the dorsal surface of the leaves can be attributed to the fact that dust get settled on the upper surface by sedimentation and on the ventral surface by impaction due to wind current. The researcher therefore connects her views with different authors that the continuous process of dust deposition will definitely reduce the concentration of particulate matters in the ambient air. The origin of the dust particulates can be attributed largely to wind borne ground dust and particulates arising out of vehicular exhaust.
The observations show that vegetation cover acts as a persistent adsorber of the airborne dust particulates. Dust depositions on leaf surface are found to be contaminated with trace elements. Thus, the plants can be used as Passive air pollution monitoring. Canopy shapes as well as leaf morphology of plants are to be considered when making future plantations. The smallest particulate size varies from 1.1 µm (in Bael) and 1.7 µm (in Kathbadam) to around 2.8 µm in the others.

**Discussion:**

1. The study shows that vegetation cover aids natural cleansing of the atmosphere by absorbing gases and some particulate matter through leaves. The leaves function as efficient pollutant-trapping device.
2. Some plants are highly sensitive to air pollutants and serve as bio-indicators, whereas others are hardy and tolerant, helping in reduction of the overall pollution load, thus leaving the air relatively pollution-free. According to Shannigrahi, A.S. et.al., (2004:131)\textsuperscript{79}, the level of tolerance is species-specific depending upon their individual capacity to withstand pollutant effect without any visible external damage.
3. The effectiveness of vegetation in intercepting and retaining atmospheric pollutants depends on following factors:
   - Shape, Size, Moisture Level, Surface texture and nature/solubility of both particulate matter and gas and intercepting plant parts.

   • **SEM-EDX:** *(Appendix 4)*
   
   After subjecting the leaves for SEM, EDX was performed for each of the leaves for detection of the elements. A scanning electron microscope with energy-dispersive analysis (SEM-EDX) was chosen for this study as this can perform the functions of imaging and elemental analysis.

   After obtaining the micro-images using SEM, the samples were subjected to Energy Dispersive X-Ray Analysis (EDAX) to obtain the composition and percentage distribution of the deposited particulates under SEM. During the experiment some points (dust particles) were selected on the leaf surface over which the point analyses were done.
Observation
The SEMEDS spectrum of the dusts on the leaf surface has revealed the chemical signature of Mg, Al, Si, Cl, K, Ca, Ti, Cr, Mn, and Fe. More dust particulates are found on the upper surface of leaves in comparison to that of lower surface. Hence, as the amount of dusts deposited varies, the abundance of trace elements on both the surfaces, will also vary. Si, Al, Ca, Fe and Mg were found to be most abundant elements on the leaf surfaces, which indicates the presence of cement dust particles over the leaves. When the air containing cement grain passed through the plant canopies, the grains get adsorbed on the leaf surfaces. The morphological features that help in adsorption of dusts are the trichomes (hairy growth) on the leaf surfaces and as well as the surface roughness.

In the present investigation, results have shown the chemical signature of various elements from which the chemical composition as well as possible sources of dust particle present in the atmosphere can be assessed.

*Lichens: indicator of atmospheric pollution: (Plate: 66a-d)*
While monitoring higher plants, a notable group that is often observed is the Lichen, which is an association between algae and fungi. They generally occur as green patches on barks of various trees at the onset of monsoon. The representative lichen species in Victoria Memorial Hall is *Dirinaria applanata* (Fee) D. D. Awasthi. It was collected from bark of the Bottle Palm [*Roystonea regia* (Kunth) O.F.Cook] from Northern Side, air dried and subjected to Scanning Electron Microscopy. Particulate deposition on the thallus of the lichen was evident.

Scanning electron microscopy with energy-dispersive X-ray analysis (SEM-EDX) of particulate matter on lichen *Dirinaria applanata* (Fee) D. D. Awasthi was assessed. Analyses of the lichen thallus surface (away from surface particulates) revealed high levels of heavy metals.

Lichens are widely used in biomonitoring studies as they can provide cost effective tools for mapping spatial and temporal patterns of atmospheric contamination. Lichens accumulate metals either through the interception of soluble chemical species in wet deposition or contained as particles in dry
deposition. The presence of metal-rich particles on the thallus surface and in thallus interiors has been directly demonstrated by SEM and electron microprobe investigations.

- **Materials, Method and method development:**

**Field Sampling:**
Epiphytic Lichens of the same species, i.e. *Dirinaria applanata* (Fee) D. D. Awasthi, are found on the trunks of Bottle Palm (*Roystonea regia* (Kunth) O.F.Cook) existing within Garden of Victoria Memorial Hall Garden. Few lichen thalli (of approximately 3-4 cm diameter) were collected with underlying bark from trunks of bottle- palm from northern side of Victoria Memorial Hall Garden at a height of 10 ft from ground level. Great care was taken to minimize damage and contamination during collection.

**Sample preparation:**
The tips of upward-directed lobes of 2–3 mm length were taken (one lobe from each thallus). Samples were mounted on their lower surfaces onto aluminium 12.5-mm diameter SEM stubs (Agar, UK), using a thin layer of Araldite, and then each stub was carbon coated.

**SEM-EDX:**
The stubs were loaded into a JEOL 5900LVSEM with an Oxford Instruments INCA analysis system. Images were obtained for three randomly chosen areas on thalli. The images were saved in .tif format (640=480 pixels). Many of the particles, approximately 20–30%, consist of aggregates of materials of different composition.

**Findings:**
Dust particles of various sizes have been located and photographs have been taken. The micro images reveal the presence of particulates on leaf surfaces as well as the tip of thallus of the lichen sample.

EDAX reveals the presence of higher amount of heavy metals, silicon, sulphur, lead and tin from both the leaf samples as well as the lichen sample.
• Major conclusions from the present study are as follows:
  o Dust particles are deposited on both abaxial and adaxial surfaces of leaves. This observation further supports the fact that vegetation cover acts as persistent adsorber of airborne dust particulates. Hence, plant canopies can be used for air pollution mitigation by creating green belts around the city under pollution threat.
  o Dust deposited over the lichen surface/thalli are contaminated with trace elements, which are of different origin and can deteriorate human health. Thus roadside plants can be used for passive air pollution monitoring.
  o Moreover, policy makers around the globe, before selecting the plants for pollution abatement or for urban & peri-urban greening in the form green belts must consider morphology of leaves and canopy shapes.

❖ Importance of the Study:

The presence of pollutants on a small part of leaf surface reveals how the entire leaf as well as the entire tree can play a positive role in reducing detrimental effects of the pollutants on the monument. Similarly, the role of Lichens in trapping of air pollutants is indeed evident. The experiments show how the leaves of various trees can function as effective reducers of air pollution. Scanning Electron Microscopy proves to be one of the efficient methods of detecting the accumulated particulate matter on leaf surfaces as well as on lichens. Further analyses with the samples may be done for qualitative study.

The findings show that the greenery around the complex surrounding any monument does play a positive role in minimizing the deleterious effects of air pollution. So, instead of reducing the green cover, more and more of such effective species may be planted in a scientific manner followed by regular biomonitoring of the responses of the species towards air pollution. Such a step can perhaps lessen the particulate matters originating from air pollution from affecting the marble monument located in a pollution infested zone.

Moreover, it is seen how green plants are capable of absorption of particulate matters. The calculated area shows the area of a single leaf in a tree or shrub. So, the entire tree consists of leaves and leaflets. So, if a single leaf can hold so
much of particulate matters, we can imagine how the entire tree will be beneficial in trapping down the particulate matters.

In a similar way, the trees located in and around Bishnupur temples help in trapping the particles present in the air, thus protecting the terracotta monuments from being subjected to deterioration.

In case of Cultural Heritage Site, the surrounding vegetation does help in preventing deterioration from air pollution.

In case of natural heritage sites, we will see how each of the biotic entities themselves help in protecting themselves from the various threats and help in maintaining the ecological balance.

5.3.3. Preventive Conservation approach for Natural Heritage Sites - Sundarbans National Park

❖ **Role of Individual Mangroves of Sundarbans:**
As already discussed in the early part of this chapter, a mangrove ecosystem is susceptible to varying factors of deterioration. Mangroves possess various characteristic features that enable them to counteract the threats and maintain the ecological balance of the environment. Mangroves themselves act as a protective shield against various deteriorating factors. Since mangroves form the main component of the Ecosystem of Sundarbans, the researcher has dealt with the biological features of only the true mangroves. The researcher has also conducted some experiments with a few representative species of Sundarban to find out the degree and extent of deposition of particulate matters on their leaves.

A) **Mangrove Adaptations:**

Mangrove taxa, apart from their morphological characters, have some unique leaf anatomical features which are very much related to their adaptation as the plants grow in unstable, variable and saline environments with regular tidal influence.
- **Presence of glandular hairs:** Salt-secreting glandular hairs are present on both the abaxial and adaxial surfaces in *Aegialitis rotundifolia*, *Aegiceras comicum* and *Avicennia spp*. The non-glandular hairs develop only on the abaxial surface in *Avicennia spp.*, *A. ilicifolius* and *Heritiera sp.*

- **Succulent leaves:** Succulent leaves are a common feature of most mangroves. The highest leaf thicknesses occur in *Kandelia candel* (1.6 mm), followed by *Xylocarpus mekongensis* (0.94 mm) and *Sonneratia apetala* (0.9 mm) and lowest in *Nypa fruticans* (0.28 mm), *Aegialitis rotundifolia* (0.3 mm) and *Heritiera fomes* (0.37 mm).

- **Thickness of Cuticle:** The cuticle is considerably thick in *Bruguiera gymnorrhiza* (0.01 4 mm), *Avicennia officinales* (0.009 mm), *Ceriops decandra* (0.009 mm), *K. candel* (0.009 mm) and *S. apetala* (0.009 mm) and thin in *A. corniculatum* (0.001 mm), *N. fruticans* (0.003 mm) and *P. paludosa* (0.003 mm).

The cuticular surface is usually smooth except in *A. rotundifolia* and *S. apetala*, where it is uneven. The cuticle layer is interrupted due to the presence of stellate hairs in *Heritiera sp.* and uniseriate capitate hairs on the abaxial epidermis of *Avicennia spp.* The epidermis is always cutinized, either wholly in *A. corniculatum*, *Ceriops sp.* and *Rhizophora sp.* or only the outer tangential walls in *Avicennia sp.*, *Bruguiera sp.* and *S. apetala*.

Special stomatal structures with extended cuticles render the transpiration rate in many taxa. The presence of glandular and non-glandular hairs on the abaxial and/or adaxial leaf surfaces in some taxa are related to salt secretion of these plants. It is noted that *Heritiera sp.* is unsuitable to the highly saline habitat of the Sundarbans forest region because of some anatomical peculiarities.

Considerably thick cuticles are present on the epidermal layer of mangrove taxa, which also restricts non-stomatal water loss. Due to the presence of colorless water storage tissue at different levels of mesophyll and hypodermal layers, mangrove leaves become thick and succulent, which can be correlated with the extra water storage capacity. Comparatively succulent leaves occur in those plants which usually grow in the slope region, where the tidal influence of sea water is maximal (twice a day), such as in *B. gymnorrhiza*, *C. decandra,*
Kandelia sp. and Sonneratia sp. The leaf succulence of mangroves increases with the increase of substrate salinity.

- **Presence of Aerial roots: (Plate: 67a-g)**
  Presence of aerial roots is an important adaptive feature, whereby the plant is able to respire even in times of high tides. As mangroves grow in anaerobic soil, these aerial/breathing roots help them in their survival. The different types of rooting patterns as observed in mangroves are:

  - **PNEUMATOPHORES**: being negatively geotropic, they perform the physiological function, like atmospheric respiration.
  
  - **STILT ROOTS**: these are the above ground roots, but positively geotropic in nature, performing both physiological function and mechanical support.
  
  - **KNEE ROOTS**: these grow above the ground, arising from widely spreading cable roots and generally provide mechanical support to the plants in these loosely concentrated soil strata.
  
  - **BUTTRESS ROOT**: these are positively geotropic and facilitate both aeration and mechanical support.
  
  - **PNEUMATOTHODS**: these are negatively geotropic erect roots from the fibrous horizontally spreading roots of Phoenix paludosa. They resemble pointed pencil, with a height of about 20 cm, without any appendages.
  
  - **FLANGES**: Stilt roots from plant base are fused, forming several ribbed conical trunk bases, as in Ceriops spp.
  
  - **Surface Cable Roots / Plank Roots**: In some species like Heritiera sp., Xylocarpus spp., the horizontal spreading roots often look wavy or straight plank like, which may be formed due to cambial activities and functioning of upper surface of horizontal roots.
Spreading snake like Roots: In some mangroves, there is absence of aerial roots. The underground spreading horizontal roots passes through the shallow depth of substratum and on tidal flow and soil erosion, these get exposed to the air. These surface roots not only help in respiration, but holds the soil firmly in frequent tidal inundated deltaic lands thereby preventing soil erosion. Eg., as in *Excoecaria agallocha*.

Examples of Mangrove species exhibiting such root architectures are:

1. *Rhizophora* spp:
   Occur frequently in intertidal river slopes. Bear profuse arching Stilt Roots from trunk bases and horizontal branches and hanging aerial roots.
   
   The dense roots of *Rhizophora* provide nursery for fish and crabs and they get entrapped during low tide. The roots of mangroves form habitat for different varieties of algal species which in turn provide an important source of food for the fish and crabs.

2. *Bruguiera* spp:
   Occur frequently in inundated river banks and ridge forests. Trunk base fused with stilt roots. Buttress root present.

3. *Ceriops* spp:
   Occur in ridge forests and river slopes. Knee roots, stilt roots are fused and buttress roots are present.

4. *Kandelia candel*:
   Occur in ridge forests. Variable aerial roots like buttress root, fused stilt roots.

5. *Avicennia* spp:
   Pioneer species of river flats. The base of the plant bears unbranched slender pencil like pneumatophores. Hanging aerial roots from trunk bases may be present on stress conditions.
6. *Sonneratia* spp:  
Pioneer species of river flats. Bear unbranched or branched, slender, upto 2 m tall pneumatophores.

7. *Lumnitzera* sp.  
Occur in sandy river flats and ridge forests. Looped pneumatophores arise from horizontal roots.

8. *Nypa fruticans*:  
Occur frequently in tidal river flats. No specialized aerial roots.

9. *Heritiera fomes*:  
Occur in ridge forests and river banks. Buttresses occur at base of trunk bases.

10. *Xylocarpus* spp.  
Occur in mature soils. Pneumatophores are unbranched, buttresses present.

11. *Excoecaria agallocha*:  
Occur in all zones. Well developed snake-like roots to prevent soil erosion.

12. *Phoenix paludosa*:  
Occur on mature soil and ridge forests. The presence of unbranched pencil-like pneumatotethodes is its unique feature.

- **Salinity Tolerance and Salt Regulation:**  
Mangrove species are capable of surviving in the frequently tidal inundated saline environment through three types of osmoregulatory mechanisms:

  a) **Salt Exclusion:** an effective selection mechanism that may be performed due to the presence of ultrafiltration mechanism in their roots.  
  By this ultrafiltration mechanism, when water is absorbed, the salt ion is

b) **Salt Extrusion**: this mechanism is controlled by the salt gland, present in the leaves. Eg: *Avicennia marina*, *Aegiceras* sp., *Aegialitis* sp., *Acanthus* sp.

c) **Salt Accumulation**: many mangrove species deposit the sodium and chloride ions in their stem barks and pneumatophores or knee roots as well as older leaves. These mangroves mostly bear succulent leaves. By this mechanism, excess salts are removed from metabolic tissues. Eg. *Excoecaria agallocha*, *Lumnitzera* sp, *Sonneratia* spp, *Xylocarpus* spp. *Lumnitzera racemosa* and *Sonneratia* spp. accumulate excess salt in its salt glands, present on both sides of the leaves, and as such the leaves are succulent and fleshy.

d) *Avicennia* spp, *Aegiceras* sp., *Acanthus* sp. and *Aegialitis* spp. have salt glands that actively secrete salt from the leaves.

e) *Rhizophora* spp. Excludes excess salt at root level by ultra-filtration process.

f) Deciduous species like *Xylocarpus* spp. and *Excoecaria* sp. exclude salt during removal of leaves and excess salt prior to the onset of new growing and flowering or fruiting season.

g) In *Excoecaria agallocha*, the gall-like tumorous outgrowth on trunk bases aids in the removal of excess salt through lateral perforation.

- **Viviparous Germination**: During her field work, the researcher had come across the unique feature of mangroves, i.e. viviparous germination. This is a special type of germination found in mangrove plants. In viviparous germination, the seeds germinate while still attached to the mother plant. The embryo grows out of the seed and then comes out of the fruit and projects from it in the form of a green seedling. One can see the root and the hypocotyl. Due to the increase in weight the seedling separates from the parent tree and falls into the water and develops lateral roots. This adaptation prevents the fruit from being carried away by high tide at early stages of development and is known as viviparous germination. Vivipary is seen in *Rhizophora* spp., *Cercops* spp., *Kandelia candel*. (Fig. 5.4)
Role Of Mangroves In Maintaining The Biodiversity Of The Ecosystem:
A major role played by Mangroves is the import of nutrients from the land to the mangrove environment and export of organic matter from mangrove to the sea. Several fauna and mangrove dwellers thereby depend on the primary producers in the mangrove environment. Examples are cited below:

1. *Crassostrea cuculata*, very common in the mangrove environment are found attached to lower trunk of mangroves.
2. The mudskipper- *Periophthalmus* sp. and *Boleophthalmus* spp. are mangrove dwelling air breathing fishes depending on mangrove habitat and algae growing on mangrove tree trunks.
3. The Molluscan species - *Telescopium telescopium* and *Cerithidea singulata* depend on the mangrove habitat algal species.
4. Hermit crabs often occupy the shells of *Telescopium* and *Cerithidea* and thus collect algal food from mangrove environment.
5. Mac Nae (1968)\(^{46}\) pointed out that -
   “Certain Penaeid prawns are dependent on Mangrove Forest for shelter during their juvenile stages.”
   These include *Peneaus indicus*, *P.merguienis*, *P.monodon* and species of *Metapeneous*. The lower group of animals as mentioned above form the “consumer” levels for higher fauna groups, completing the food web of mangrove ecosystem.

Moreover, other fauna like terrestrial tree dwellers including insects, birds, Mangrove soil dwellers like Crabs, Amphibia, Reptilia, Arthropoda, Annelida, both fin fish and shell fish depend upon the mangrove ecosystem for food and shelter. Mangroves thereby serve as feeding and breeding zones of lower groups of animals.

Dust Collecting Efficiency of Mangrove Leaves:
To find out the efficiency of Mangrove leaves in trapping dust particulates, the researcher had collected some leaf samples of some representative species of Sundarban- *Gneoa*, *Sundari*, *Golpata* and *Kankra*, and subjected them to Scanning Electron Microscopy in a way similar to that as mentioned in the earlier part of this chapter.
Observation:

a) *Excoecaria agallocha* L. (Plate: 68A)

Fam: Euphorbiaceae  
L.N: *Gneoa*  
S/T: Shrub  
HA: Medium sized shrub  
E/D: Evergreen  
CS: Spreading  
MPCS: Ventral  
MPCZ: Tip  
LPS: 2.2 micrometre  
SPS: 28.5 micrometre

b) *Nypa fruticans* Wurmb. (Plate: 68B)

Fam: Arecaceae  
L.N: *Golpata*  
S/T: Shrub  
HA: Small shrub  
E/D: Evergreen  
CS: Spreading  
MPCS: Ventral  
MPCZ: Equal distribution in lower, middle and upper zones  
LPS: 54.8 micrometre  
SPS: 2.2 micrometre

c) *Bruguiera gymnorrhiza* (L.) Lamk. (Plate: 68C)

Fam: Rhizophoraceae  
L.N: *Kankra*  
S/T: Shrub  
HA: Small shrub  
E/D: Evergreen  
CS: Round  
MPCS: Ventral  
MPCZ: Maximum at Tip
LPS:  61.1 micrometre  
SPS:  2.8 micrometre  

d) *Heritiera fomes* Buch. Ham. (Plate:68D)  
Fam: Sterculiaceae  
L.N:  *Sundari*  
S/T: Tree  
HA: Tree  
E/D: Evergreen  
CS: Round  
MPCS: Ventral  
MPCZ: Tip, all very scattered  
LPS: 39.7 micrometre  
SPS: 1.7 micrometre  

The observations and records show that of the four species, *Bruguiera* sp. has the capability of adsorption of maximum particulates and *Heritiera fomes* the least. So the leaves of mangroves are also efficient adsorbers of dust particulates. The stems also form lichen habitat. So, the entities themselves help in maintaining the ecological balance. Hence the preventive conservation measure in case of a natural heritage site is proper scientific conservation of the mangroves.  

Thus it is seen how the Biodiversity, either surrounding a Cultural Heritage Site, or forming an important component (in case of Natural heritage site) can itself help in preventive conservation of a monument or an entire ecosystem. So, protection and conservation of these natural entities are of prime concern. Since anthropogenic factors are significant at either a cultural or natural heritage site, the following chapter deals with how the humans can be made aware about the various damages.
REFERENCES:
4. Ibid
8. Ibid
10. Ibid.
11. Ibid
13. Ibid, p.93
15. op.cit. Report of the Committee on Improvement of the Environment of Victoria Memorial Hall.


24. Ibid. p.17

25. Ibid. p.19


29. op.cit. Bahadur, A.K. p. 178


39. Ibid, p.578
41. Ibid, p.132
42. op.cit. CPCB Guideline for Greenbelt development 1999-2000, p.39
Fig. 5.1: Origin of Pollutants from different parts of an automobile

Fig. 5.2: Different Types of Crown Shapes of Trees
Fig. 5.3: Graphical Representation of Areas of Leaf Samples collected for Analysis
Plate 52: Visible Deterioration at Victoria Memorial Hall, Kolkata

52a

52b

52c

52d

52e
52a: Damage on bronze plaque
52b: Stains on Marble
52c: Seepage of water leading to long term deterioration
52d: Black stain on Marble surface
52e: Scratches on surface of bronze figure
52f: Growth of higher plants on marble surface
Plate 53: Vehicles around the Memorial Complex: A Potent Factor Causing Atmospheric Pollution

53a-b: Vehicle load on the Northern side
53c: Vehicle load on Eastern side
Plate 54:A. Impact of *Aila* on plantations of Victoria Memorial Hall, Kolkata
54a: *Mimosops elengi* uprooted on South-Western side
54b: Bottle palm uprooted over the path on the Northern side
54c-f: Trees uprooted on Western side
54g-h: Trees uprooted on South-Eastern side
54i-j: Bottle palm- after being struck by heavy thunderstorm
Plate 54B: Factors leading to Deterioration of Victoria Memorial Hall Complex, Kolkata

a: Notice stating Rules and regulations of the Garden
b: Notice banning use of Plastics
c: Lady carrying a plastic bottle and plastic
d: Non-biodegradable objects floating on the Western side of the building
e: Garbage accumulation at Southern side of the Memorial
Plate 54C: Deterioration of Garden of Victoria Memorial Hall

a-d: Plastic bottle thrown here and there inspite of the Notice banning use of Plastics
Plate 54D: Human Vandalism within the Victoria Memorial Garden

a. Graffiti on the pedestal bearing statue of George Frederick Samuel Robinson at Eastern side of Victoria Memorial Hall Complex
b. Magnified view of the damage
c. Graffiti on base of trunk of a tree
d. Graffiti on a Fruit
Plate 55: Deterioration of Brick/Terracotta

55a

55b

55c

55d

55e
Chapter 5

Plate 56: Signs of deterioration on studied Temples of Bishnupur

55a-b: Biodeterioration: Formation of Moss on terracotta motifs
55c-d: Biodeterioration: Formation of Lichen on terracotta panels
55e: Biocolonization: Growth of higher plants at base of temple
55f-g: Salt incrustation on terracotta motif and brick
55h: Human vandalism: Graffiti on brick surface
Plate 56: Signs of deterioration on studied Temples of Bishnupur

56a: Black Patches on roof of Syama Raya

56b: Black Patches on curved roof of Madana Mohana

56c: Black Patches on sloping roof of Jor Bangla

56d: Syama Raya- Higher plant at cracks and crevices of terracotta panels

56e: Radha Vinoda: Growth of plant at base of terracotta panels
Plate 57: Chipping off Terracotta at the Studied Temples of Bishnupur

57a: Outer wall of Syama Raya

57b: Base of temple of Syama Raya

57c: Rasa Mancha

57d: Base of Radha Vinoda

57e: Madana Mohana

57f: Jor Bangla
57g: Jor Bangla

57h: Jor Bangla
Plate 58: Growth of Moss on some studied Temples of Bishnupur

58a: Rasa Mancha

58b: Syama Raya

58c: Radha Syama

58d: Base of Lalji

58e: Jor Bangla
Plate 59: Black Staining on Bricks/ Terracotta of the studied Temples at Bishnupur

59a: Syama Raya

59b: Radha Syama

59c: Radha Govinda

59d: Mallesvara

59e: Madana Mohana

59f: Lalji

59g: Jor Bangla
Plate 60: Peeling of Plaster of some of the studied Temples at Bishnupur

60a: Rasa Mancha

60b: Rasa Mancha

60c: Mallesvara

60d: Madan Gopala

60e: Madana Mohana
Plate 61: Human Vandalism (Graffiti) at some studied Temples of Bishnupur

61a: Inner wall of *Rasa Mancha*

61b: *Inner walls of one of the Jor Mandir Group of Temples*

61c: *Inner walls of Kalachand*

61d: *Rasa Mancha*

61e: Inner wall of *Nandalala*
Plate 62: Threats to the Ecosystem of Sundarbans

62a: Fishing

62b: Separation of fish fingerlings from the catch

62c: Clearing of Mangroves for construction

62d: Catching of tiger prawns and crabs from tidal waters

62e: Mangrove patch converted to brick kilns
Plate 63: Scanning Electron Micrographs of Selected Leaf Samples showing their Ability to Trap Suspended Particulates

63A: Leaf surface of *Terminalia arjuna* (Roxb.) Wight & Arn.

(i) At a height of 5ft: Dorsal, Basal Part

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

5ft Dorsal, Middle Part

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

5ft Tip

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
63A. (ii) 10ft Dorsal, Basal Part

View of dust particulate accumulation under 100x magnification showing presence of Trichomes on leaf surface

Largest and Smallest Particulate under Magnified Zone
Chapter 5

10 ft Middle

View of particulate accumulation under 100x magnification

Largest and Smallest particulates under Magnified Zone
10 ft Tip

View of particulate accumulation under 100x magnification

Largest and smallest particulates under Magnified Zone
Chapter 5

63A. (iii) 15ft dorsal, basal part

Particulate distribution as seen under 100x magnification

Largest and Smallest particulates under visible area of 500X magnification
Distribution of Dust particulates on leaf surface as viewed under 100X magnification

Largest and Smallest particulates under Magnified Zone
Particulate deposition across the midrib of the leaf

Particulate deposition across stomata of the leaf
Chapter 5

Stomata blocked by dust particulates

Leaf Tip

High concentration of particulates at leaf tip as seen under 56X magnification
High concentration of particulates at Leaf tip as seen under 500X magnification

High concentration of particulates at Leaf tip around Trichomes as seen under 500X magnification
Different types of particulate distribution on the leaf surface

Largest and Smallest particulates at Leaf tip around Trichomes
Trichomes at ventral surface of leaves

Deposition of dust particulates around stomata
63 B. Leaf surface of *Dalbergia sissoo* Roxb.

(i) At a height of 5 ft – Leaf Base

Concentration of particulates at leaf base as seen under 100X magnification

Largest particulates under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

5ft Middle

Distribution of particulates along the leaf surface under 100X magnification
Largest particulates under Magnified Zone

Smallest particulate under Magnified Zone
5ft tip

Distribution of particulates along the leaf surface under 100X magnification

Largest Particulates under Magnified Zone
Smallest Particulates under Magnified Zone

63B (ii) 10ft low

Scanty distribution of particulates under 109X magnification
Chapter 5

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
10 ft middle part of Leaf

Distribution of particulates as seen under 100 X magnification

Largest Particulates under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

10 ft Tip of Leaf

Scanty distribution of particulates as seen under 100 X magnification
Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
63B (iii) 15ft Leaf Base

Distribution of particulates on leaf surface under 100X magnification

Largest particulate under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

15ft Middle portion of Leaf

Distribution of Particulates along the leaf surface
Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
Chapter 5

15 ft Tip of Leaf

Distribution of Particulates along the leaf surface

Largest particulate under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

63C: Leaf surface of *Polyalthia longifloia* (Sonn.) Th

63C. (i) 5ft Low

Distribution of particulates on leaf surface
Chapter 5

Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
5ft Middle portion of Leaf

Distribution of particulates on leaf surface

Largest particulate under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

5ft Tip of Leaf

Distribution of particulates on leaf surface
Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
Chapter 5

63 C. (ii) 10 ft Lower part of Leaf

Distribution of particulates on leaf surface

Largest particulate under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

10ft Middle of Leaf

Distribution of particulates on leaf surface
Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
Chapter 5

10ft Tip of Leaf

Distribution of particulates on leaf surface

Largest Particulate under Magnified Zone
Smallest particulate under Magnified Zone

63C (iii) 15ft lower part of Leaf

Distribution of particulates on leaf surface
15ft Middle part of Leaf

Large particulates under Magnified Zone

Small particulates under Magnified Zone
Chapter 5

Middle part of Leaf

Distribution of particulates on leaf surface

Largest Particulate under Magnified Zone
Chapter 5

Smallest particulate under Magnified Zone

15ft Tip of Leaf

Particulate distribution along the tip of leaf
Chapter 5

Large Particulates under Magnified Zone

Small Particulates under Magnified Zone
63D. Leaf surface of *Mangifera indica* L.

(i) 5ft Lower part of leaf

![Distribution of particulates on leaf surface](image1)

![Large Particulates under Magnified Zone](image2)
Small Particulates under Magnified Zone

ii) 5ft Middle part of leaf

Distribution of particulates on leaf surface
Chapter 5

Large Particulates under Magnified Zone

Small Particulates under Magnified Zone
5ft Tip of Leaf

Distribution of Particulates on leaf surface

Largest Particulate under Magnified Zone
Chapter 5

63D. (ii) 10ft Lower part of Leaf

Particulate distribution on the leaf surface
Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

10ft Middle Part of Leaf

Particulate distribution on the leaf surface

Largest Particulate under Magnified Zone
Chapter 5

Smallest Particulate under Magnified Zone

10ft Tip of Leaf

Particulate distribution on the leaf surface
Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
63D. (iii) 15ft Lower part of Leaf

Scanty particulates on the lower side of the leaf

Largest Particulate under Magnified Zone
Smallest Particulate under Magnified Zone

15ft Middle of Leaf

Particulate Distribution along the middle of leaf
Chapter 5

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

15ft Tip of Leaf

Particulate Distribution at tip of the Leaf

Largest Particulate under Magnified Zone
Smallest Particulate under Magnified Zone

63E. Leaf surface of *Mimusops elengi* L.

(i) 5ft Lower part of Leaf

Particulate Distribution at base of the Leaf
Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

5ft Middle of Leaf

Particulate Distribution at Middle of the Leaf

Largest Particulate under Magnified Zone
Chapter 5

Smallest Particulate under Magnified Zone

5ft tip of Leaf

Particulate Distribution at Tip of the Leaf
Particulate Distribution at Tip of the leaf under 500X magnification

63D. (ii) 10ft Lower part of Leaf

Particulate Distribution at lower part of the Leaf
Chapter 5

Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Chapter 5

Particulate Distribution at Middle part of the Leaf

Smallest Particulates under Magnified Zone
Chapter 5

Largest Particulates under Magnified Zone

10ft Tip of Leaf

Particulates distributed throughout leaf tip
Chapter 5

Smallest Particulate under Magnified Zone

Large Particulates under Magnified Zone
63E (iii) 15ft Lower part of Leaf

Particulate distribution throughout lower surface of leaf

Large Particulates under Magnified Zone
Smallest Particulate under Magnified Zone

15ft Middle of Leaf

Particulate distribution throughout lower surface of leaf
Chapter 5

Large Particulates under Magnified Zone

Smallest Particulate under Magnified Zone
15ft Tip of Leaf

Particulate distribution throughout tip of leaf

Large Particulates under Magnified Zone
Smallest Particulate under Magnified Zone

63F. Leaf surface of *Ficus benghalensis* L.

Lower part of Leaf

Particulate distribution throughout tip of leaf
Largest Particulate under Magnified Zone

Smallest Particulate under Magnified Zone
Measurement of particulates on Trichome of the leaf

Middle of Leaf

Particulate distribution in the middle of the leaf
Large and small particulates on Trichome and Leaf surface

Tip of Leaf

Particulate distribution in the Middle of the leaf
Particulates on Trichomes of the leaf

Smallest Particulate under Magnified Zone
63G. *Azadirachta indica* A.Juss.

(i) Lower part of Leaf

Particulate distribution in the Middle of the leaf

Large and small Particulates on Trichome and Leaf surface
(ii) Middle of Leaf

Particulate distribution in the Middle of the leaf

Largest and Smallest Particulates on Leaf surface under Magnified Zone
(iii) Tip of Leaf

Particulate distribution in the Tip of the leaf

Largest and Smallest Particulates on Leaf surface under Magnified Zone
63H. *Bougainvillea spectabilis* Wiild.

(i) Lower part of Leaf

Particulate distribution at leaf surface

Largest and Smallest Particulates on Leaf surface under Magnified Zone
(ii) Middle portion of Leaf

Particulate distribution on leaf surface

Largest and Smallest Particulates on Leaf surface under Magnified Zone
(iii) Tip of Leaf

Distribution of particulates at Leaf Tip

Largest and Smallest Particulate on Leaf surface under Magnified Zone
63l. *Terminalia catappa* L.

i) Lower Part of Leaf

Scanty particulates on lower part of leaf

Smallest particulate on leaf surface
Largest Particulate on Leaf surface under Magnified Zone

(ii) Middle

Scanty particulates on middle part of leaf
Largest and Smallest Particulates on Leaf surface under Magnified Zone

(iii) Tip of Leaf

Scanty particulates on Tip of leaf
Largest and Smallest Particulates on Leaf surface under Magnified Zone

63J. *Cassia fistula* L.

(i) Lower Part of Leaflet

Scanty particulates on Lower part of leaflet
Large and small particulates entrapped within trichomes

(ii) Middle part of Leaflet

Particulate distribution on Lower part of Leaflet
Largest and Smallest Particulates on Leaflet surface under Magnified Zone

(iii) Tip of Leaflet

Particulate distribution on Tip of leaflet
Largest and Smallest Particulates on Leaflet surface under Magnified Zone

63K  *Bauhinia acuminata* L.

(i) Lower Part of Leaf

Particulate distribution on Tip of leaf
Chapter 5

Largest and Smallest Particulates on Leaf surface under Magnified Zone

(ii) Middle of Leaf

Particulate distribution on Middle of Leaflet
Largest and Smallest Particulates on Leaflet surface under Magnified Zone

(iii) Tip of Leaf

Particulate distribution on Tip of leaflet
Chapter 5

Largest and Smallest Particulates on Leaflet surface under Magnified Zone

63L. Delonix regia (Bojer) Rafin.

(i) Lower Part of Leaflet

Scanty distribution of Particulates on Leaflet
Chapter 5

Large and Small Particulates on the Leaflet

(ii) Middle Part of Leaflet

Scanty distribution of particulates on middle part of leaf
(iii) Tip of Leaflet

Scanty distribution of particulates on middle part of leaf
Chapter 5

Large and Small Particulates on the Leaflet

63M. *Ficus religiosa* L.

(i) Lower part of Leaf

Scanty distribution of particulates on leaf surface
Chapter 5

Large and Small Particulates on the Leaf

(ii) Middle of Leaf

Distribution of particulates on middle part of Leaf
Large and Small Particulates on the Leaf

(iii) Leaf Tip

Particulate Distribution on the Leaf tip
Large and Small particulates on surface of leaf

63N. *Lagerstroemia indica* L.

(i) Lower part of Leaf

Scanty distribution of Particulates on leaf surface
Large and Small particulates on surface of Leaf

(ii) Middle of Leaf

Distribution of Particulates on middle part of Leaf
Large particulates on surface of Leaf

Small particulates on surface of Leaf
(iii) Tip of Leaf

Distribution of Particulates on Tip of Leaf

Large and small particulates under Magnified Zone
63 O. Alstonia scholaris (Linn.) R. Br.

(i) Lower Part of Leaf

Distribution of Particulates on leaf surface

Large and small particulates under Magnified Zone
(ii) Middle of Leaf

Distribution of Particulates on Middle of Leaf

Large and small particulates under Magnified Zone
(iii) Leaf Tip

Distribution of Particulates on Leaf surface

Large and small particulates under Magnified Zone
63P. *Aegle marmelos* (Linn.) Correa

(i) Lower Part of Leaf

Distribution of Particulates on Lower part of Leaf

Large and small particulates under Magnified Zone
(ii) Middle of Leaf

Distribution of Particulates on Middle part of Leaf

Large and small particulates under Magnified Zone
Particulate trapped on Trichome of the Leaf

(iii) Tip of Leaf

Distribution of Particulates on Tip of Leaf
Large and small particulates on Tip of Leaf

63 Q. *Albizia lebbeck* Benth.

(i) Lower part of Leaflet

Particulates distributed throughout the leaflet
Chapter 5

(i) Middle of Leaflet

(ii) Middle of Leaflet

Particulates distributed throughout the leaflet
Chapter 5

Largest particulate under Magnified Zone

Smallest particulate under Magnified Zone
(iii) Tip of Leaflet

Particulates distributed on the leaflet surface

Large particulates under Magnified Zone
Small particulates under Magnified Zone

63R. *Putranjiva roxburgii* Wall.

(i) Lower Part of leaf

Particulates distributed on the leaflet surface
(ii) Middle of Leaf

Particulates distributed on leaf surface
Largest and Smallest particulates under Magnified Zone

(iii) Tip of Leaf

Particulates distributed on leaf tip
Largest particulate under Magnified Zone

Small particulate under Magnified Zone
63S. *Tectona grandis* L.

(i) Lower part of Leaf

Particulates deposited along midrib of the leaf

Largest and Smallest particulates under magnified zone
(ii) Middle of Leaf

Particulate deposition on leaf surface

Largest Particulate on leaf surface
Smallest Particulate on leaf surface

(iii) Tip of leaf

Particulate deposition on leaf surface
Large and Small Particulates on leaf surface

63T. *Anthocephalus chinensis* (Lamk.)

(i) Lower Part of Leaf

Particulate deposition on leaf surface
Chapter 5

Largest Particulate on leaf surface

Smallest particulate on Leaf surface
(ii) Middle Part of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on leaf surface
(iii) Tip of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on leaf surface
63U. *Saraca asoca* Roxb. De Wilde

(i) Lower Part of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on Leaf surface
(ii) Middle part of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on Leaf surface
(iii) Tip of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on Leaf surface
63V. *Cassia siamea* Lamk.

(i) Lower Part of Leaflet

Particulate deposition on leaf surface

Largest and smallest particulates on leaf surface
(ii) Middle Part of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on leaf surface
(iii) Tip of Leaflet

 Few Particulates on Leaf Surface

 Largest and smallest particulates on leaf surface
Particulates within Trichome of the leaf

63W. Pongamia pinnata (L.) Panigrahi

(i) Leaf Base

Particulate Distribution on Leaf Surface
Chapter 5

Large Particulates in the magnified zone of the leaf

Smallest Particulate in the magnified zone of the leaf
(ii) Middle Portion of Leaf

Particulate deposition on leaf surface

Largest and smallest particulates on leaf surface
(iii) Tip of Leaf

Particulate deposition on leaf surface

Large and small particulates on leaf surface
Plate 64: Scanning Electron Microimages of Leaves showing Trichomes as facilitator for trapping of suspended particulates

a. Particulate accumulation, within trichomes on leaf of *Terminalia arjuna*

b. Particulate accumulation, within trichomes on leaf of *Terminalia arjuna*

c. Particulate accumulation, within trichomes on leaf of *Polyalthia sp.*
d. Particulate accumulation, within trichomes on leaf of *Ficus benghalensis*

e. Particulate accumulation, within trichomes on leaf of *Cassia fistula*

f. Particulate accumulation, within trichomes on leaf of *Putranjiva sp.*
g. Particulate accumulation, within trichomes on leaf of Cassia fistula
Plate 65: Scanning Electron Microimages of Leaves showing Stomata as facilitator of trapping of suspended particulates

a-b: Leaf of *Terminalia arjuna*: Particulate accumulation inside stomata
c. Particulate trapped within leaf stomata - *Ficus religiosa*

d. Particulate trapped within leaf stomata - *Aegle marmelos*
Plate 66: Scanning Electron Micrographs of Lichen showing its ability to trap Particulates

10ft from base of trunk

66a. Dust particulates over the thallus lobe of the Lichen under 100X magnification

66b. Magnified Image of the Dust particulates on the thallus lobes under 500X magnification
66c. Largest Particulate on the magnified zone of the Lichen thallus

66d. Smallest Particulate on the magnified zone of the Lichen thallus
Plate 67: Aerial Roots–Diagnostic Feature defining Mangroves

67a: *Rhizophora* sp.: Stilt roots

67b: *Ceriops* sp.: Knee like roots
67c: *Avicennia sp.:*
Pencil-like slender pneumatophores

67d: *Bruguiera sp.:* Knee-like roots

67e: Roots of *Sonneratia sp.*
67f: *Excoecaria agallocha*: Snake-like spreading roots

67g: Gall-like tumerous outgrowth on trunk bases of *Excoecaria* sp:
Aids excess salt removal

Fig. 5.4. Viviparous Germination in Mangroves
Plate 68: Scanning Electron Microimages of some selected Mangroves showing their ability to trap Particulates

68A. *Excoecaria agallocha*  
(i) Basal Part of Leaf

Particulate distribution on the leaf base

Largest particulates on the leaf in the magnified region

Smallest particulates on the leaf in the magnified region
(ii) Middle Portion of Leaf

Particulate distribution on the leaf surface

Largest particulate on the leaf in the magnified region
Smallest particulates on the leaf in the magnified region

(iii) Leaf Tip

Particulate distribution on the leaf surface
Chapter 5

Largest particulate on the leaf in the magnified region

Smallest particulate on the leaf in the magnified region
68B. *Nypa fruticans*

(i) Lower Part of Leaf

Particulate distribution on the leaf base

Largest and smallest particulate on the leaf in the magnified region
(ii) Middle part of Leaf

Particulate distribution on the leaf base

Largest particulate on the leaf in the magnified region
Particulates trapped within stomata of *Nypa fruticans* 

(iii) Leaf Tip 

Particulate distribution on the leaf surface
Largest particulate on the leaf in the magnified region

Smallest particulate on the leaf in the magnified region
68C. *Bruguiera gymnorrhiza*

(i) Base of Leaf

Particulate distribution on the leaf base

Largest and smallest particulates on Leaf surface
(ii) Middle Part of Leaf

Particulate distribution on the leaf surface

Largest and smallest particulates on Leaf surface
(iii) Leaf Tip

Particulate distribution on the leaf surface

Largest particulate on the leaf in the magnified region
Smallest particulate on the leaf in the magnified region

68D. *Heritiera fomes*

(i) Leaf Base

Particulate distribution on the leaf surface
Largest and smallest particulates in the magnified region

(ii) Middle part of Leaf

Particulate distribution on the leaf surface
Largest and smallest particulates in the magnified region

(iii) Leaf Tip

Particulate distribution on the leaf surface
Largest and Smallest Particulates on the leaf in the magnified region