TAJ MAHAL: SAVING THE CORRODING BEAUTY

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ACKNOWLEDGEMENT

We'd like to thank Dr. Anupam Singhal for directing us to his informative articles and for prompting us to research a proposed explanation for the marble discoloration in the Taj Mahal. The talks and conversations got us to think in new ways and from different points of view, so we could write a full and fair review.

OBJECTIVE

Millions of tourists flock to India each year to see the Taj Mahal and its famous white marble domes. Over the past few decades, the marble on the outside of the Taj Mahal has changed color and needs to be cleaned carefully every few years to keep its original beauty.

The building's location and design make for a number of exposure scenarios that can be used to study how surface moisture makes it easier for pollutants to move from the ground to the air. up to the surface and into the air. At sunrise, the Taj is oriented so that the sun's rays will cast a shadow across the building's northern face. When the patterns of discoloration in the Taj's marble are looked at, they support the idea that the building is most exposed to air pollution in the morning, when dew is on the building and the air is moving enough to bring pollutants into contact with the building's surface.

People know that discoloration is caused by pollution in the air in the Agra area, but the exact sources of this pollution have not been found. In light of this, samples of ambient particulate matter (PM) were taken over the course of a year and found to contain relatively high concentrations of light-absorbing particles like black carbon (BC), light-absorbing organic carbon (brown carbon, BrC), and dust, all of which could potentially discolor the Taj Mahal's marble surfaces. Particles deposited on marble surrogate surfaces at the Taj Mahal have been analyzed. Based on the results, it looks like a lot of the outside surfaces are covered with both dust and carbonaceous particles.

Although industrial pollutants, vehicle exhaust, and biomass burning have all been blamed for the soiling, emissions from the burning of open municipal solid waste (MSW) may also have a significant impact. Biomass burning emissions, which would include MSW emissions, accounted for nearly 40% of organic matter (OM)—a component of PM—deposition to the surface of the Taj Mahal in a recent source apportionment study of fine particulate matter ($PM_{2.5}$); dung cake burning, used extensively in the region for cooking, was suggested as the culprit and is now banned within the city limits, but the burning of MSW, a ubiquitous practice in the area, may play a more important role.

Open municipal solid waste burning results in approximately 150 (130) mg m^{-2} yr^{-1} of PM2.5 being deposited to the surface of the Taj Mahal, while dung cake burning results in approximately 12 (3.2) mg m^{-2} yr^{-1}. Trash burning in lower socioeconomic class neighborhoods is the primary contributor to an estimated 713 (377-1050) premature deaths in Agra each year. The Taj Mahal, human health, and the built environment as a whole would all benefit from an efficient MSW management plan.

Ongoing investigations into these accounts have converged on the hypothesis that acid rain is the cause of an illness dubbed "Stone Cancer." Reports obtained from all across the world also documented such deterioration of stone structures, acid rain was revealed to be the root cause of this problem. Harmful gasses like NOx and SOx, together with chromium and other heavy metals, damage the atmosphere. In addition to industrial processes, automotive exhausts and even domestic processes can contribute to the accumulation of these pollutants in the atmosphere. These nitrogen and sulfur compounds emit acids when they combine with water. Hydrogen ions are found in greater concentrations in such precipitation, making it unusually acidic (pH is low). This is known as acid rain, and it is extremely hazardous to the health of vegetation, animals, and man-made structures alike.

As a result of our research, we have come up with a new way to figure out how these deposited particles affect the way visible light is reflected off of a surface and, in turn, how the human eye sees color. Carbonaceous particles (both BC and BrC from burning fossil fuels and biomass) and light-absorbing dust that have settled on the building may be what is making the outside of the Taj Mahal darker. In general, the results show that the deposition of light-absorbing particulate matter in areas with high aerosol loading is changing the look of both natural and man-made surfaces.

A contrasting image showcasing the different shades of Taj Mahal

LITERATURE REVIEW

Studies have shown that poor air quality is to blame for the soiling and discoloration, so steps have been taken to mitigate the effects of local air pollution near the Taj Mahal. These steps include limiting vehicle access to the complex, shutting down over 200 businesses in Agra, mandating that iron foundries install scrubbers and filters on their smokestacks, preventing the construction of new polluting businesses within a defined buffer zone around the mausoleum, and more. Biomass burning is responsible for roughly 40% of all organic matter (OM) deposition to the surface of the Taj Mahal, according to a recent source apportionment analysis of fine particulate matter (PM2.5, whose particles are less than 2.5 m in aerodynamic diameter).

The open combustion of municipal solid waste (MSW) and dung cake burning are two sources of biomass burning PM2.5 in Agra, both of which would be included in the assessment of deposited OM. As a result of the high concentrations of particulate matter (PM) in the air in Agra, visibility is reduced, further diminishing the Taj Mahal's aesthetic attractiveness.

The degradation of vision and the coloring of the Taj Mahal are likely the most apparent results of municipal solid waste (MSW) and dung cake burning in the vicinity; however, the health of the local population is also at risk. Among the 67 environmental factors linked to premature mortality, the Global Burden of Disease (GBD) ranks exposure to ambient PM pollution as the fifth leading cause of premature mortality in India, after high blood pressure, indoor air pollution (which is also affected by dung cake burning), smoking, and dietary risks. The greatest effect on mortality in India due to outdoor air pollution is due to energy use from homes and businesses, especially biomass burning for heating and cooking.

Agra's rapid population growth and inadequate municipal solid waste (MSW) management infrastructure have combined to produce inefficient waste management, leading to the accumulation of excessive amounts of trash on the city's streets. As a result of inefficient combustion and increased pollutant emissions, garbage is often burned in the open on roadsides and in residential and business locations in Agra and throughout India. According to the Central Pollution Control Board of India, municipal solid waste incineration accounts for between 5 and 11 percent of main PM emissions from urban sources. Chlorinated organics, dioxins, polyaromatic hydrocarbons (PAHs), various volatile organic compounds (VOCs), and heavy metals including lead, cadmium, and mercury can all be found in the combustion byproducts of plastics and other garbage, which are included in MSW emissions with biomass. The GBD strategy does not take into account the unique dangers posed by these harmful chemicals.

FIGURE 1. A clean surface and an area being prepared for cleaning on a marble Mosque dome at the Taj Mahal

In Indian cities, dung cake combustion as a cooking fuel has been extensively explored; 11% of rural Indian households rely on cow dung as their major cooking fuel. Burning of open MSW and dung cake appears to be more prevalent in locations with poorer inhabitants, hence worsening the exposures of more sensitive groups. Emissions of municipal solid waste and dung cake can also affect the radiative balance and result in regional and global change.

Contributions of MSW and dung cake burning to ambient OM and BC (pollutants known to discolor surfaces) concentrations in Agra, deposition to and soiling of the Taj Mahal, and health impacts are evaluated by quantifying location-specific MSW and dung cake burning emissions, performing air quality and deposition modeling, and conducting a health impact assessment. This data can be used to analyze the possible advantages of policy measures, such as improved MSW collection management techniques and the accompanying infrastructure in and around Agra.

Several variables combine to make the Taj Mahal an attractive and enlightening research topic. Particularly, its location causes regular dewfall, and the widespread use of high-sulfur coal in local lime kilns ensures high ambient concentrations of sulfur dioxide.
Moreover, discoloration of the Taj is noticeable in some areas, particularly those that are protected from falling rain.

Figure 1, which was previously exhibited, depicts localized staining of marble at the Taj Mahal, in an area where it appears that direct sunshine in the morning can evaporate dew from certain regions but not others. The view is gazing upwards, late in the afternoon, at the rain-protected underside of a niche in a north-facing wall. The right side of the niche receives the direct sunlight beam in the morning and so dries quickly after dew deposition at night; it is less discolored than the left side, which is obscured by the morning sun.

Vegetation is known to reduce pollution in an unexpected manner and can therefore be utilized in urban environments; social forestry is one method for combating pollution monsters. The government adopted this strategy, and soon a "Buffer Zone" was established around the Taj Mahal. This lush vegetation not only increased the attractiveness of the location, but also offered a viable solution for conserving the location and the marble marvel.

Our experiments on another part of the strategy revealed, to our surprise, that the trees that were supposed to defend the monument were in danger. The combination of a high SPM level and heavy metal pollution increased the infection potential of fungal pathogens. The buffer zone is predominantly populated by two species of trees, out of a number of other species. One was Mahogany and the other was Mimusops elangi, and their occurrence rate was approximately 50-55%.

METHODOLOGIES

Collecting and Analyzing Ambient Particles

Beginning on November 5, 2011, and ending in June of 2012, right before the start of the monsoon season, ambient aerosol samples were taken around the Taj Mahal to ascertain the impact that particulate matter (PM) had on the building. Every six days of the month, filters were collected to test for major anions, organic carbon, elemental carbon, and trace elements in PM2.5 (fine particulate matter with diameters less than 2.5 m) and total suspended particulate matter (TSP).

Upstream cyclone data was used to determine the PM2.5 threshold, whereas ambient air was measured directly by the TSP. Monthly composites were created by combining samples from each filter, and these were then extracted and evaluated by GCMS for source-specific trace organic chemicals. Chemical mass balance (CMB) modeling was employed to determine source contributions to particulate organic carbon based on quantities of trace organics.

Target Sampling and Analysis of Marble Deposits

Several precleaned marble deposition targets (with dimensions of 2X2X0.5 cm) were placed outside within about 300 m of the main dome of the Taj Mahal, in addition to ambient samples. Targets and air sampling equipment were placed in a less-visited area of the Taj Mahal that was only accessible to ASI employees. From April through June of 2012, precleaned marble cuboids were affixed to the Taj Mahal's superstructure with double-sided tape at various points. A few of the marble slabs were laid on their sides, while the others were set up vertically.

The marble samples were maintained in the freezer both before and after exposure to prevent the decomposition of the deposited particles.

Two parallel marble targets were subjected to scanning electron microscopy (LEO 1530, Carl Zeiss Microscopy) and energy dispersive X-ray spectroscopy (Oxford Instruments Xmax detector). To catch particles from 100 nm to 100 m in size, numerous images were taken at various magnifications. With the help of image processing in Matlab, we were able to extract information about particle sizes and shapes from SEM images. Around a thousand particles were analyzed using EDX on the identical marble targets. Chemical composition and particle concentration as a function of target area might be estimated using data from SEM/EDX studies of the marble target. Next, we'll explain how we used this data to calculate an approximation of the marble's surface color shift.

Relating Marble Surface Color to Deposition Particles

We devised a method that evaluates the impact of deposited particles on wavelength-dependent surface reflectance to predict the effect of particle deposition on the apparent colour change of the marble substrate. This technique expands upon earlier efforts to calculate the impact of particle deposition on plant leaves on the amount of light accessible for photosynthesis. To begin, we estimate the optical depth of the deposited particles as a function of wavelength (τ_λ) using SEM/EDX studies of the particles deposited to the marble targets.

$$\tau_\lambda = \frac{\pi}{4} \sum_{i=1}^{n} \mathrm{Ac}_i D_{\mathrm{p},i}^2 [Q_{\mathrm{s}\lambda} + Q_{\mathrm{a}\lambda}]_i \qquad \mathbf{1}$$

$Q_{s\lambda}$ and Q_{a_λ} are the wavelength-dependent Mie scattering and absorption efficiencies, respectively, determined based on particle size and composition, where Ac is the areal particle number concentration (number of particles deposited per area of the marble surface) for each size bin, i and D_p is the particle diameter for deposited particles.

Following the determination of the optical depth, the wavelength-dependent single scattering albedo, ω_λ (ratio of light scattering to extinction), is calculated as

$$\omega_\lambda = \frac{\sum_{i=1}^{n} \mathrm{Ac}_i D_{\mathrm{p},i}^2 Q_{\mathrm{s}\lambda,i}}{\sum_{i=1}^{n} \mathrm{Ac}_i D_{p,i}^2 [Q_{\mathrm{s}\lambda} + Q_{\mathrm{a}\lambda}]_i} \qquad \mathbf{2}$$

The single scattering albedo is a crucial element that governs the proportionate quantity of light absorption on the white marble's surface. The single scattering albedo for white, scattering-only particles is close to 1, and the surface reflectance of a white surface will not change.

The change in surface reflectance of the white marble surface is computed using SBDART, a radiative transfer model with input values including and estimated from **eqs. 1 and 2,** and the asymmetry parameter (relative amount of light scattering in the forward direction) as a function of wavelength using Mie theory.

To determine the perceived colour change of the white marble surface due to particle deposition and the corresponding change in spectral surface reflectance, we utilised the model described by D'Andrade and Romney to convert spectral reflectance to perceived colour according to the Munsell colour system. Value (lightness/darkness), hue (colour), and chroma (purity/saturation) are the three components that comprise the Munsell colour system. The model used to assess the perceived colour of the marble surface with deposited particles estimates the Munsell colour using the spectral reflectance from the radiative transfer model of the marble surface loaded with particles. The Munsell colour estimation also accounts for the human eye's reaction as a function of incident light wavelength.

The garbage and dung cake stockpiles can now be viewed

To measure the regional and temporal developments of open MSW burning, waste burn rate inventories were compiled in Agra using a recently established field transect method. Researchers walk the transect (route/line) and keep track of MSW burning episodes, estimated weight, and composition at a set distance from the transect line (usually the distance that can be seen). Next, we calculate the MSW burning occurrence density using the total number of incidents and the surveyed region.

This study used two different transect routes in Agra to assess the density, composition, and tonnage of rubbish burn over the course of three days for each route between May 30 and June 2, 2015. Based on census data from the tract level, these surveys evaluated MSW burning in 14 communities of varying socioeconomic status (SES). Since the very high levels of garbage burning found in neighbourhoods or near roads are not captured by satellite-driven studies at the global scale, the on-ground field technique is crucial to generating an enhanced PM emission inventory from MSW burning.

Using the SES-based trash burning rates, one may calculate the open waste burn rate, TWB_i (g-MSW day^{-1}), in a given electoral ward, i.

$$\begin{aligned} TWB_i \;=\;& WBR_{lowSES} * POP_{i,lowSES} \\ &+ WBR_{highSES} * (1 - POP_{i,lowSES}) \end{aligned} \quad (1)$$

in which $POP_{i,lowSES}$=illiterate population in the ward as recorded in the 2011 census and $WBR_{highSES}$=daily per capita trash burn rate of the high SES. In this research, literacy was used as the key indicator of social status, and 64 percent of the population of Agra was found to be literate. Electoral districts were used to compile waste burn inventories, with each district simulated using its own dedicated emission grid, and five more regions were also simulated.

Cow dung cake usage as a cooking fuel was evaluated using census data.
The percentage of homes utilizing various cooking fuels was reported by the census at the ward/precinct level. The number of houses using cow dung as a fuel for cooking in each ward/precinct was multiplied by the yearly per-household consumption to get the annual burning inventory, which was then converted to the daily average emission rate. Additionally, the effects of firewood and crop residue on air quality were modeled using the same approach.

Inventory of municipal solid waste and dung cake burns for use in AERMOD dispersion modelling

Open MSW and dung cake burn rates were incorporated into AERMOD, a Gaussian plume dispersion model, in order to spatially characterize the yearly mean ambient PM2.5 concentrations from MSW and dung cake burning. AERMOD is a recommended regulatory air pollution dispersion model, but it does not account for atmospheric chemical processes or secondary pollution production, so it has limits. The results provided here are source-specific consequences from emissions within the study domain; background transport is not taken into account. AERMET, a meteorological input to AERMOD, utilized integrated hourly surface data from the National Climatic Data Center (NCDC) at the Agra Station of the National Oceanic and Atmospheric Administration (NOAA) and upper air data from the US National Weather Service

(NWS) at the Delhi Station. The Global 30 Arc-Second Elevation (GTOPO30) Digital Elevation Models were utilised in AERMAP, a terrain processing input to AERMOD.

Using published emission factors, we calculated the OM and BC source emission rates for both MSW and dung cake burning. In this work, PM2.5 component-specific emission parameters for MSW burning are based on measurements of waste burning in peri-urban settlements near Mexico City at different combustion phases. OC(CO_2) and black carbon (BC) emission factors were 5.3 (±4.9) and 0.65 (±0.27) g kg^{-1} respectively. In recent studies of garbage burning in Nepal, several samples were enriched for specific compositions of plastic and foil; these emission factors are within the stated range of 0.04-9.97 g BC kg^{-1} burned, but are less than the reported range of 8.4-73.9 g OC kg^{-1} burned. As a result of differences in MSW composition and combustion stage, estimates of MSW emissions are often subject to large margins of error. Households all throughout the Indo-Gangetic Plain had their emissions from dung cake burning measured. The emission parameters for OC were multiplied by a factor of OM/OC of 2.1 to take into account the presence of components other than carbon in organic compounds.

Dry deposition and contamination of the Taj Mahal

Pollutant deposition on the Taj Mahal's surface contributes to its browning, hence the impacts of wet and dry deposition from municipal solid waste and dung cake emissions were assessed. Using predicted concentrations, measured size distributions, and size-dependent deposition velocities, dry deposition rates were estimated. The deposition velocity is a parameter that combines the aerodynamic transport across the atmospheric surface layer, the transport across the quasi-laminar sublayer, and the uptake at the surface. The average particle size of carbonaceous PM species at the surface of the Taj Mahal was determined using scanning electron microscopy (SEM) (LEO 1530, Carl Zeiss Microscopy) and energy dispersive x-ray spectroscopy (Oxford Instruments Xmax detectors). The average particle size was less than 1 micron.

The PM2.5 component specific mass fluxes (g m^{-2} s^{-1}) of OM and BC to the surface of the Taj Mahal due to dry deposition were determined to be as follows:

$$F_i(t) = -V_{D,i}(d_{p,\mathrm{ave}})^*[C_i(t)],$$

where V_D is the velocity of size-specific surface deposition (m s^{-1}) and $d_{p,ave}$ is the mean particle diameter. The pollutant concentration utilised here, $[C_i(t)]$, is the yearly average ambient pollutant concentration from open garbage and dung cake burning at the Taj Mahal, as measured by AERMOD. In this research, wet deposition was included to account for precipitation; nevertheless, wet deposition loadings were minor compared to dry deposition loadings.

From the modelled number of particles deposited per area of the surface and the total surface area of the aerosol deposited per area of the surface, we were able to calculate the percentage of the Taj Mahal's surface that is covered by pollutant deposition from MSW and dung cake burning emissions. N, the number of particles per square metre, was calculated using the following sources and pollutants:

$$N_i = \frac{\sigma_i}{\rho_i d_{p,\text{ave}}{}^3/6},$$

where σ_i (mg m^{-2} yr^{-1}) is the source-specific pollutant loading, ρ_i is the pollutant (OM or BC) density, and $d_{p,ave}$ is the measured mean particle size (1 m) at the monitoring site.
Wi, the fractional coverage of PM2.5 emissions in a year due to MSW and dung cake burning, was then calculated using the average particle surface area as follows:

$$\Omega_i = \frac{6\sigma_i}{\rho_i d_{p,\text{ave}}}.$$

The origin of the infectious agent

Mahogany and Mimusops elangi trees were planted in the buffer zone around the Taj Mahal, and the infected leaves of both species' leaves were gathered from those trees.

The growth media

Each and every growth medium came from Merck Specialties Pvt. Ltd., which was the vendor (Mumbai, India). The potato dextrose agar medium was used for the cultivation of all of the cultures (PDA). In order to determine the degree of germination inhibition caused by the fungal spore, the widely used fungicide blitox was tested. In order to provide an acidic environment around the leaves, nitric acid was utilized. Absolute ethanol was obtained from Changshu Chemical for this particular application (Yangyuan, China).

Microscopy

All of the leaf slices and spores were observed with the use of a compound light microscope, and a cotton blue stain made of lactophenol was utilized.

Determination of the SPM count and pH of the leaves gathered from the Taj Mahal

The leaves were washed in sterile, distilled water before the SPM count was calculated. Following the washing of the leaves, this water was put through a pH meter, and the pH level of the water was calculated. All of these measurements—dissolved oxygen concentration, conductivity, and number of SPMs—were taken with the same instrument.

Tables and figures:

Table1: showing the following parameters determined for the leaves collected from Taj Mahal

Name	Electrical conductivity (μs)	SPM (in mg)	pH
Mahogany	4.302	67.3	5.568
Mimusops elangi	35.80	120.6	5.965


(a)

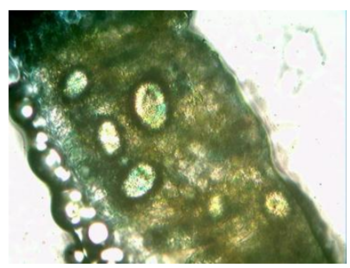
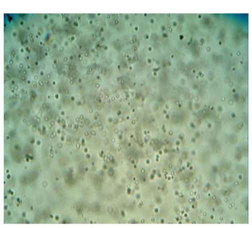

(b)

Fig1.(a) and (b) shows growth of fungal pathogen inside the cells of the leaf


(a)

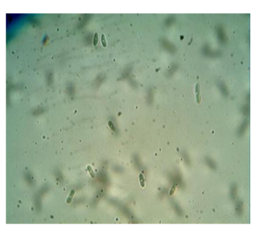

(b)

Fig 2: (a) shows *Cladosporium* sp. And (b) shows *Mycospharella* sp.

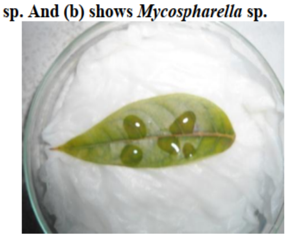


Fig 3: low infection in absence of SPM and acid vapors

Fig 7: Absence of germination in presence of fungicide Blitox

RESULTS AND IMPACT ANALYSIS

Ambient particulate concentrations

For both TSP and $PM_{2.5}$ during the sample period, Figure 2a displays the average mass concentrations of particulate organic carbon mass (OM), ions, dust, and elemental carbon (EC). TSP and PM2.5 have respective mean daily concentrations (and standard deviations) of 135 (55) and 60 (39)μgm^{-3}. The results show that the area has poor air quality since they are much higher than the yearly World Health Organization (WHO) PM recommendations for PM_{10} and $PM_{2.5}$ of 20 μgm^{-3} and 10 μgm^{-3}, respectively. The percentage of particles larger than 2.5 μm is around 60%, and it is mostly caused by coarse mode dust, which goes from making up 15% of the mass of $PM_{2.5}$ to 30% of the total suspended particle mass. In addition to dust, elemental carbon (EC), which makes up 2% of the TSP mass, and OM, which makes up 39% of the TSP mass, are other PM components that absorb light in the visible spectrum and may, thus, affect the color of the outer white marble surfaces.

According to estimates of the sources of OM in the mass fraction of $PM_{2.5}$ illustrated in Figure 2b, biomass burning, a well-known source of BrC, is responsible for almost half of the OM, with considerable contributions from vehicle emissions.

It should be noted that biomass burning OM can result from a range of processes, including the burning of trash and other waste that is common in the area, wood and dung combustion, crop residue burning, and the combustion of crop residue. Since elemental and organic carbon, as well as dust, are common light-absorbing aerosols in Agra, it is possible that PM deposition to the white marble surfaces is what is causing the famous Taj Mahal dome and other exterior Taj Mahal buildings to discolor.

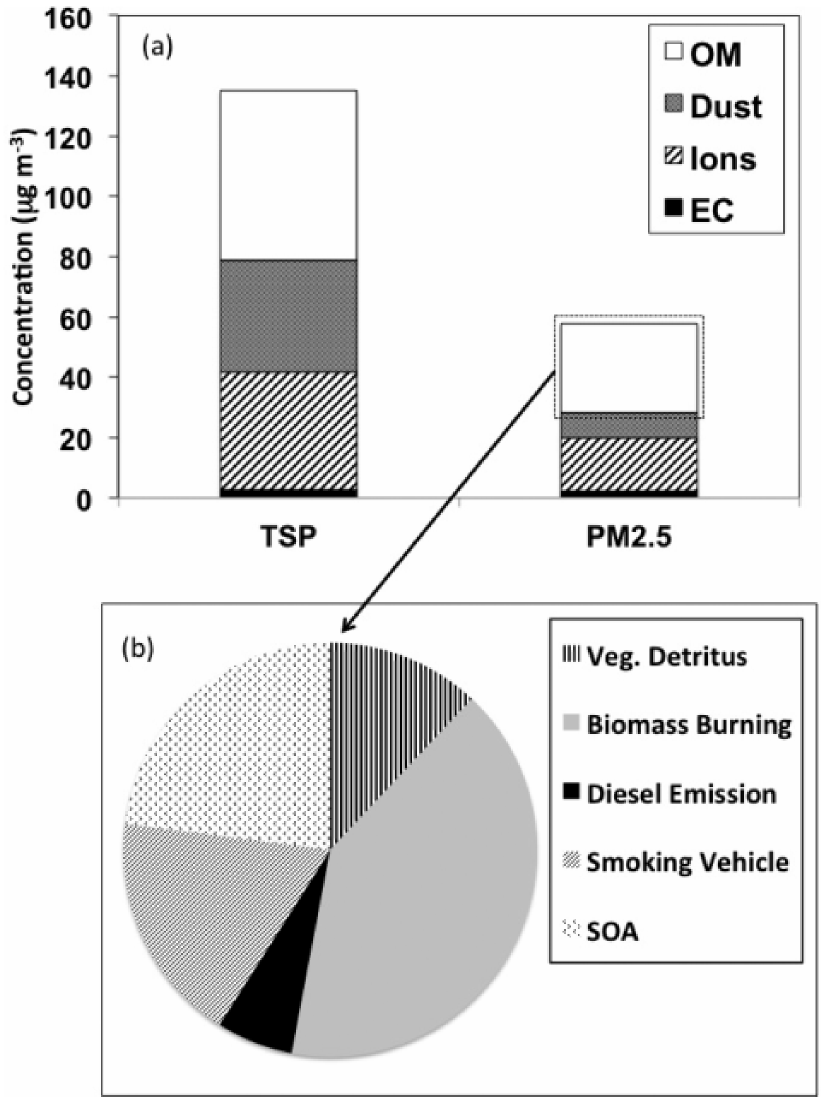


Figure 2. General chemical composition of (a) total suspended particulate matter (TSP) and fine particulate matter ($PM_{2.5}$), and (b) source apportionment of $PM_{2.5}$ organic mass (OM) based on filter sampling at the Taj Mahal.

Size and Composition of Particles Deposited to Marble Targets -

Figure 3a displays a scanning electron microscope (SEM) image of a marble deposition target that was horizontally positioned at the Taj Mahal and exposed for approximately two months in the 2012 pre-monsoon season. The distribution of particles as a function of particle size deposited to the marble target (Figure 3b) shows peaks in particle size at approximately 12 µm and another mode at 4–5 µm. Surface area concentration (surface area of particles per unit marble surface area per micron) is a measure of the density of particles on surfaces. About 30% of the surface is thought to be coated by particles.

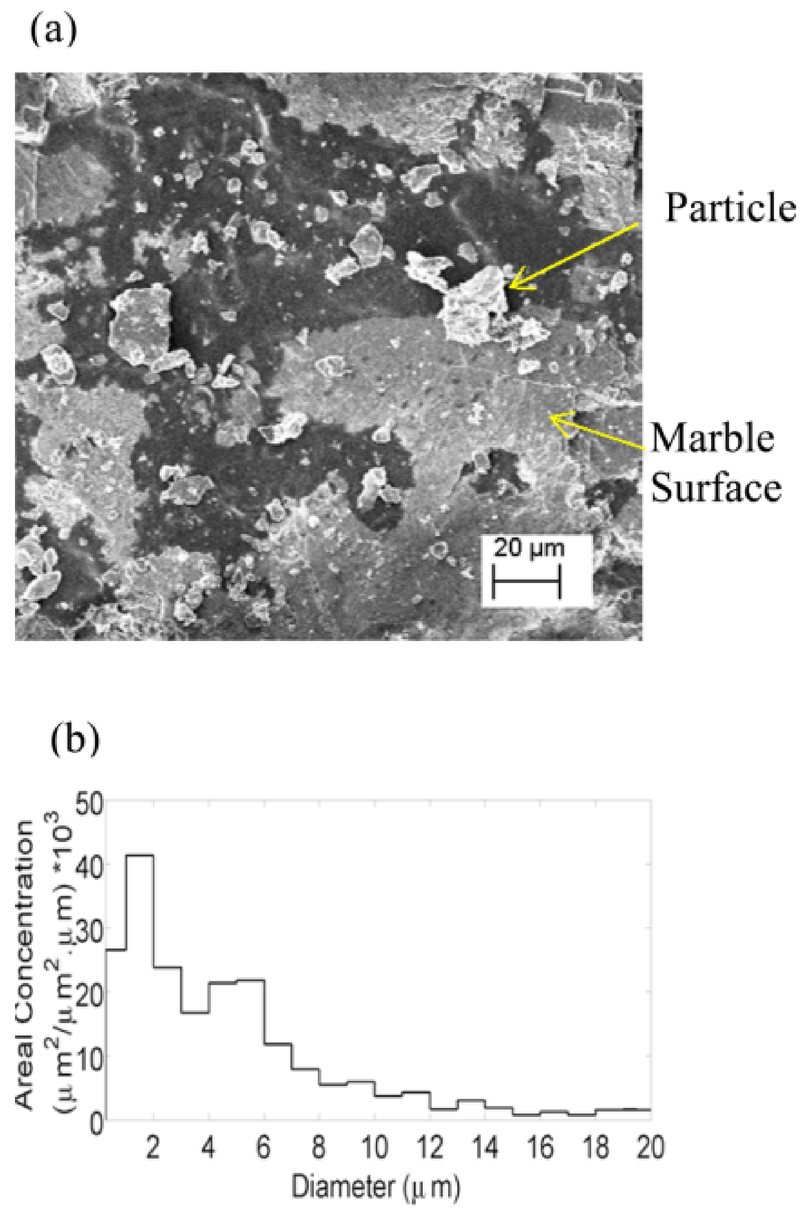


Figure 3. (a) SEM image of marble target from Taj Mahal indicating deposited particles and (b) surface area concentration of deposited particles on the marble target as a function of particle diameter.

A significant portion of the particle surface area concentration is caused by the deposition of coarse particles, as evidenced by the fact that roughly 70% of the deposited particle surface area is for particles with diameters greater than 2 µm. The relative high concentration of dust particles found in Agra and the fact that the dry deposition velocity of coarse (5 µm) particles is nearly 100 times larger than that of accumulation mode (1.0 μm) aerosol particles are both contributing factors to the dominance of coarse particles.

Given the comparatively low precipitation in Agra throughout the autumn through spring, when particle loadings are high and the summer monsoon rainfall is not there, it is likely that dry deposition is the predominant mode of particle transport to the Taj surface. It is also crucial to keep in mind that once deposited, water insoluble particles (including dust, BC, and a small amount of OM) are probably difficult to remove from the Taj Mahal surface by precipitation wash-off. This is based on parallel observations of the accumulation of water-insoluble particles on leaf surfaces made in China's Yangtze delta, a region with significant PM loadings.

The EDX tests show that more than 70% of the particles are largely of crustal origin, with crustal components predominating in the spectrum. The majority of the crustal particles belonged to the coarse size fraction, with diameters greater than ~2 to 3 μm. Significant levels of carbon were also present in particles with diameters less than 2 μm, which make up about 30% of the deposited particle surface area and are most likely from the OM sources shown in Figure 2b's CMB data. SI section S2 provides more thorough information on the EDX analyses, including sample particle EDX analysis spectra.

Deposited Particles and Perceived Color -

To estimate τ^{λ}, we assume that particles with diameters smaller than 3 μm are predominantly made of light-absorbing organic carbon (BrC) with wavelength-dependent refractive indices as reported by Liu et al. This assumption is based on the fact that ambient filters indicated that roughly half of the $PM_{2.5}$ was carbonaceous, as well as the fact that we did not observe the presence of major ion-related elements (i.e., S) deposed to the marble targets, but did observe a predominance of carbon particles in the less than 3 μm particle size range. In addition, we assume that 10% of the particles smaller than 3 μm are black carbon (BC) particles with a refractive index comparable to that of soot. We probably overestimate the effect of BrC and BC absorbing light because we think that all particles smaller than 3 m are made of carbon and not of elements or ions.

The contributions of dust, BrC, and BC to aerosol optical depth at 400 nm are estimated to be 0.222, 0.144, and 0.016, respectively, demonstrating the significance of light extinction by all three components. The single scattering albedo at 400 and 700 nm is estimated to be 0.64 and

0.95, respectively, demonstrating that near-ultraviolet wavelengths absorb more light than the longer 700 nm wavelength.

Figure 4a depicts the surface reflectance of a pure marble surface in addition to the estimated surface reflectance for multiple situations, including the influence of each light-absorbing particle component independently (BC, BrC, and dust), and the case when all components are combined. As seen in the graph, BC absorbs uniformly across all wavelengths, whereas brown carbon exhibits preferential absorption near 400 nm for shorter wavelengths. Because hematite absorbs light at shorter wavelengths, dust greatly reduces the surface's ability to reflect light at all wavelengths, but especially at shorter wavelengths. Dust, BrC, and BC, when combined, are anticipated to significantly affect the surface reflectance with increased absorption (i.e., lower surface reflectance values) at shorter wavelengths.

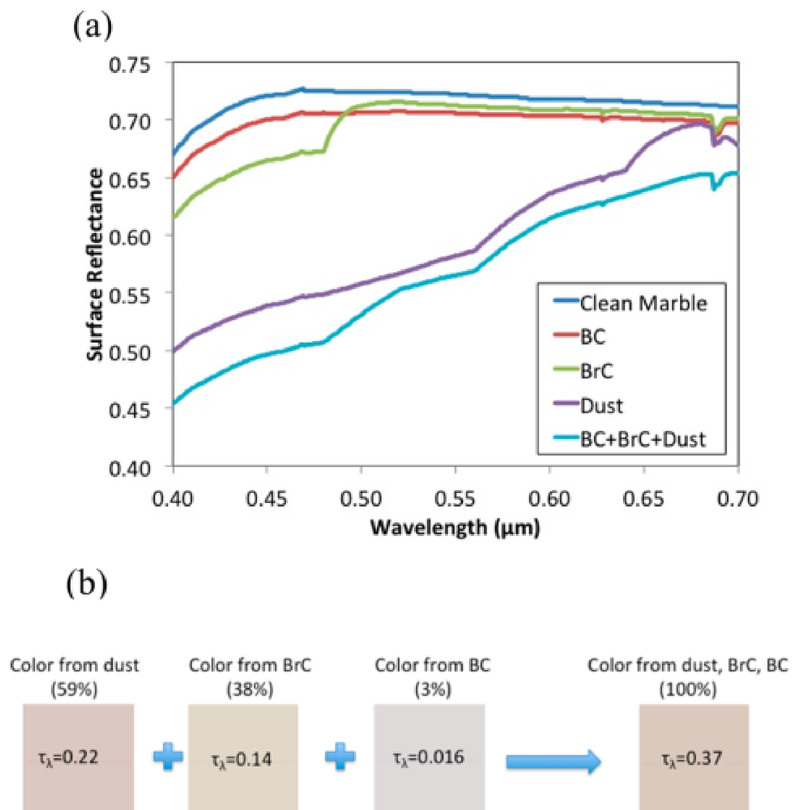


Figure 4. (a) Estimated marble target surface reflectance for a clean surface and surface area coverage of particles based on Figure 3 for black carbon (BC), brown carbon (BrC), dust and all particles (BC +BrC+dust) (b) Change in color of white marble surface for dust, BrC, BC separately and combined. Values in parentheses represent fraction of total surface area concentration contributed by each component with AOD values estimated by eq 1 at 400 nm.

Figure 4b depicts the estimated change in color of the white surface due to the deposition of light-absorbing particles, as observed in Figure 3b, over the two-month exposure time of the targets. The results suggest that each component individually contributes to the discoloration of the Taj Mahal's white marble surfaces. Due to the proportional change in surface reflectance at each wavelength, the color change for BC alone (which we think makes up 3% of the total particle surface area) is a grayish color. BrC (~30% of the total particle surface area) and dust have an effect on color, with UV absorption resulting in yellowish-brown colors. When mixed, the observed surface color moves toward darker yellow-brown tones. It should be noted that our sample targets were mounted for a relatively short period of time (~2 months) compared to the typical time between cleanings of the outer Taj Mahal surfaces (several years), so it is reasonable to expect that the perceived color of the marble target would be less intense than that of the white surfaces of the Taj Mahal.

In fact, the marble target surface appeared lighter in hue than the color estimates in Figure 4b, despite being qualitatively identical. There are numerous uncertainties involved in predicting perceived color, such as the loading, particle size, and optical characteristics. Analyses (included in SI section S3) indicate that the results are fairly sensitive to both particle loading and particle size. Assuming a 50% uncertainty for aerosol loading, for instance, has a moderate effect on the perceived color and does not alter the conclusion that dust and carbonaceous particles contribute to the observed color change of the Taj Mahal.
Overall, the results indicate that light-absorbing particles play a significant role in the discoloration of the Taj Mahal's surface, and that dust, as well as BC and BrC primarily derived from biomass combustion, trash/refuse burning, and mobile sources, all contribute significantly to the discoloration.

In places of high aerosol loading, the deposition of light-absorbing particulate matter on both natural and man-made surfaces results in a significant discoloration, according to this study. Through the changing of surface albedo and consequently perceived color, the deterioration affects not only cultural relics, but also the aesthetics of the surroundings. The measurement/modeling approach developed in this paper permits the estimation of surface color changes based on the relative amounts of light-absorbing particles deposited on surfaces, and can be used to develop future control strategies to prevent the discoloration of the environment by particle deposition, which will also improve air quality.

Open MSW and dung cake burning emissions to modeled concentrations throughout Agra and model evaluation -
Using the field transect method devised by Nagpure et al., the total average trash burn rate in Agra was calculated to be 130 g MSW per capita per day, with greater per capita burn rates seen in low socioeconomic status (SES) areas. In the city, burn rates were higher in the morning than in the evening, while the difference was smaller in rural areas (areas outside the city).

If Agra's per capita average garbage burn rate is extended to the total population of India, the annual national burn rate would be 68,000 Gg yr^{-1}, which is consistent with the model results of 35,000–75,000 Gg yr^{-1} for India by Wiedinmyer et al. The total cow dung cake burning emissions by ward in Agra were computed from household fuel consumption data and ranged from 0 to 9100 kg day^{-1} ward-1 within the study domain, whereas open waste burning emissions ranged from 490 to 25000 kg day^{-1} $ward^{-1}$. According to a survey on sustainable solid waste management in India, the average daily trash creation rate in Agra is 580 g $capita^{-1}$. Using this MSW generation rate, the average MSW combustion rate in Agra is 23%, which is greater than the 5%–10% estimates from earlier studies of trash combustion in Indian cities.

Using emission parameters from the literature and actual burn rates, the annual cumulative emissions in Agra from open waste and dung burning were estimated to be 2500 (2200) kg yr^{-1} for the OM and BC components of $PM_{2.5}$, respectively. The Taj Mahal had concentrations of 4.1 (3.8) and 0.24 (0.10) μg m3 for OM and BC from MSW burning and 0.32 (9.1×10^{-2}) and 0.019 (9.7×10^{-4}) μg m3 for OM and BC from dung cake burning, according to AERMOD simulations (figure 1 and SI figure 5). Due to changes in the types of waste and the stage at which they are burned, uncertainty was only looked at for the emission variables, which are where most of the uncertainty lies. The calculation doesn't take into account how these sources' gaseous emissions also cause PM2.5 to be made.

Using measurements from a recent $PM_{2.5}$ source apportionment research at the Taj Mahal, it was shown that biomass burning emissions contribute 12 μg m3 to OM (which can come from a range of combustion activities, including wood, crop, dung, and MSW burning) at the Taj Mahal. MSW is the largest contribution of the modeled biomass burning sources.
Maximum combined yearly average impacts on $PM_{2.5}$ in Agra were 33 (30) μg m3 from burning municipal solid waste and 3.3 (0.90) μg m3 from burning dung cake.

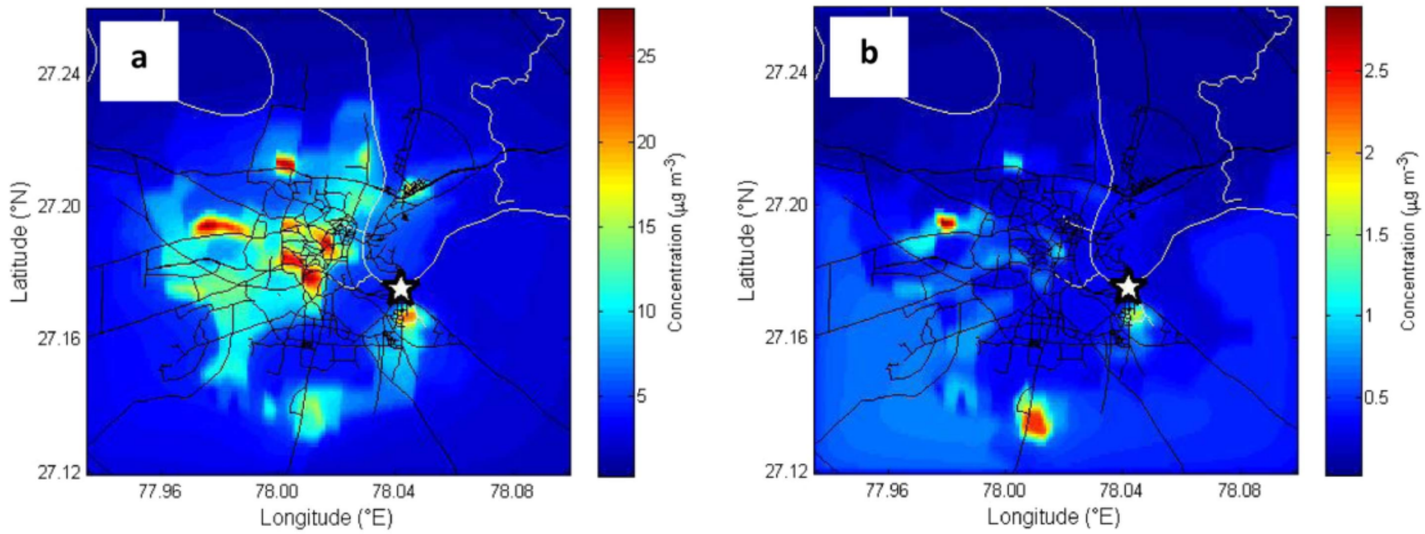


Figure 1. Annual average fine particulate matter ($PM_{2.5}$) concentrations in Agra from: (a), open MSW burning (b), dung cake burning. Modeled [$PM_{2.5}$] at the Taj Mahal (depicted by the white star) was 4.3 ($\pm$3.9) $\mu g\ m^{-3}$ from MSW emissions and 0.34 ($\pm 9.1 \times 10^{-2}$) $\mu g\ m^{-3}$ from dung cake burning emissions. These concentration profiles generated in AERMOD showed higher pollution from both forms of biomass burning concentrated in areas of lower socioeconomic status. Organic matter (OM) and black carbon (BC), the $PM_{2.5}$ components modeled, concentration profiles show the same spatial variation, but OM concentrations contribute more than BC to ambient $PM_{2.5}$ (SI figure 5).

High levels were discovered in low-income areas where MSW and dung cakes are commonly burned. In the city of Agra as a whole, burning trash in the open is more of a problem than burning dung cakes, except in rural areas where dung cakes are the main cooking fuel. In Agra, the combined annual average $PM_{2.5}$ concentration from open trash and dung cake burning was 4.3 (3.8) μg m3 for OM and 0.25 (0.10) μg m3 for BC. Recent ambient OC and elemental carbon concentration measurements throughout Agra ranged from 10.2 (7.2) to 30 (13) μg m3 and 1.3 (0.8) to 4.0 (1.5) μg m3, respectively, indicating that the source effect modeling results averaged across the study domain are consistent with ambient data.

Adverse health and premature mortality assessments -

According to estimates of premature mortality linked to $PM_{2.5}$ (BC OM +) emissions from burning MSW and dung cake, there are 713 (377-1050) cases of premature mortality from outdoor exposure each year in Agra, with 380 (247-540) cases attributed to IHD, 231 (98-362) cases attributed to stroke, 94 (31-170) cases attributed to COPD, and 7 (1-12) cases attributed to LC for adults (age 25). An extra 0–2 cases (age 5 years) of premature mortality from ALRI from MSW and cow dung cake burning occur each year in Agra. The total human YLL is estimated at 10087 years (5480-14 520) from one year of exposure for all-cause mortality (i.e., ALRI, COPD, IHD, stroke, and LC) attributable to $PM_{2.5}$ emissions from MSW and cow dung cake burning, where IHD (56%) is the highest contributor followed by stroke (32%), COPD (11%), and LC(1%).

Deposition and soiling of the Taj Mahal -

Using the simulated concentrations, observed size distributions, and rainfall data, the deposition of MSW and dung cake burning emissions to the Taj Mahal via dry and wet deposition was quantified. The Taj Mahal's average surface area median diameter of the carbonaceous particles that were deposited to outdoor surfaces was determined to be ~1 μm by detailed size distributions measured on-site, which was used in conjunction with deposition velocity relationships to derive a deposition velocity of 0.11 cm s^{-1}. In earlier studies in metropolitan areas, similar deposition velocities for particles of similar size and content were measured. The Taj Mahal receives an estimated total yearly combined $PM_{2.5}$ dry deposition of 150 (130) mg m^{-2} from open waste burning and 12 (3.2) mg m^{-2} from burning dung cake (table 2).

Wet deposition loadings were lower than dry deposition. Although brown carbon (BrC), which absorbs light, makes up approximately eight times as much of an organism's mass as black carbon (BC), which is a powerful light absorber. Since both sources also produce gaseous emissions, this approach is probably underestimating the overall OM deposition from the two sources because emission factor measurements do not take secondary production into account. In order to more accurately assess discoloration, the Taj Mahal's surface pollution was assessed. If the Taj Mahal's perceived colour is affected by pollution, the fractional surface area coverage will likely surpass.

Dung cake burning emissions generated an additional 5.7×10^{-2} (1.6×10^{-2}) annually, while MSW burning emissions exhibited a fractional cover of 0.73 (0.67). Since 1994, there have been four treatment cleanings. Given the intervals between cleanings, the influence of burning emissions from MSW and dung cake is expected to be more than a fractional coverage of 1, indicating that the combined deposition of both substances will result in surface discoloration.

Possible pollution threat to the Green Buffer Zone around the Taj Mahal -

After a 14-day incubation period, the isolated leaf patches gave birth to cottony fungal pathogendevelopment. Similar leaf spot disease was produced in fresh leaves by spore suspension made from the spores mentioned above that were seen. The pathogen was isolated as a result of this supporting Koch's Postulates. According to investigations done under a microscope, the fungal growth on the underlying mesophyll cells and the infection thread that runs along the leaf lamina. The two different leaves were determined to be infected by two distinct species. While a pathogen that produced long, rod-shaped spores was found to be infecting mahogany leaves, a pathogen that also produced small, circular spores was found to be infecting Mimusops elangi.

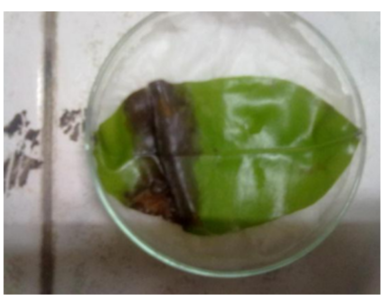
On the agar slant, it was also noticed that the spores appeared crimson. According to studies, mahogany leaves have a similar spot disease that was caused by organisms that looked like Mycospharella. The other organism resembled Cladosporium in appearance quite a bit.


(a)

(b)

Fig 4: comparison showing greater infection(b) in presence of SPM & acid vapors

Fig 5: Absence in infection in absence of SPM and acid vapors


(a)

(b)

Fig 6:comparison showing greater infection (b) in presence of SPM & acid vapors

The average length and width of the elongated spores were measured to be 1.5 µm and 0.25 µm, respectively. Interesting findings came from the three-setup. While the one with SPM content displayed roughly 45% infection, the one without SPM and acid vapours only produced 15% infection. Further observation revealed that practically the entire leaf of the plant producing both SPM and acid vapours was infected. In one investigation, Blitox was found to entirely prevent spore germination in the slide bio-assay, which was found to completely inhibit the percentage of infection.

Studies done on different plants have shown that SO_4 can cause foliar harm that progresses into necrotic lesions and can impede a plant's net assimilation.
Studies done in the United States on perennial weeds that were fumigated showed that the plants were hurt in ways like browning of the leaves, cell death, and necrosis.
Mimusops elangi was exposed to various levels of NO_2 in one experiment, and the effects included a reduction in shoot length, fresh and dry weights, and ascorbic acid levels, which led to a greater vulnerability to fungus infections.

The phyto-toxicity of SO_2 in Cicer arietinum led to a variety of morphological, physiological, and biochemical reactions, including a decrease in metabolic rate and cellular functioning.
When comparing the results from the aforementioned study to those from other studies, it can be concluded that a high SPM count combined with atmospheric NOX and SOX levels causes the observed leaf damage. The infection process in these leaves may have been started by this injury.

In an experiment using field applications of seedling plants, it was discovered that blitox (copper oxychloride) inhibits the growth of Cladosporium oxysporum. In Queensland, Australia, Mycospharella musicola-caused banana leaf spot disease was effectively controlled with a mixture of white oil emulsion, malachite green, and copper oxychloride (BLITOX).
In laboratory trials, Copper oxychloride was found to have a considerable impact on reducing the germination of both pathogens. Roadside plants may therefore promote urban forestry if protected with antifungal dusting, if this result is compared to the previously reported research. Also, it could be said that trees that produce less wood but could be treated with antifungal spray could be used to restore the social forest belt around the Taj Mahal and protect the monument in the future.

However, today's antagonists are black and organic carbon particles generated by cars and other polluting devices.

CONCLUSION

Recent research shows that pollution is still hurting the Taj Mahal's white marble, which is a safe conclusion to draw. In the 1980s, people thought that sulfur dioxide was the only thing that made the sparkling facade turn yellow.

In 1996, the Supreme Court noted that "a yellow hue permeates the entire monument." According to the petitioner, the Taj's yellow hue is being accentuated by unsightly brown and black blotches, and the monument is on the road to deterioration owing to atmospheric pollution. Despite investigations attributing the deterioration to different causes, such as microscopic algae, the buildup of dirt, and the application of a resin designed to maintain the monument, nothing but pollution was found.

The 1996 court order prompted a variety of anti-pollution initiatives. The ongoing discoloration, on the other hand, shows that the Court's orders haven't been followed or that "something new and different" needs to be done.

Here are some of the main reasons why the Taj Mahal is in the shape it is in now:

- **Natural Causes**:
  Minerals that aren't pure enough and are in the marble oxidize and leave brown stains. Rain and snow can also cause chips and cracks in marble, in addition to wearing it down. The iron dowels used to secure the marble slabs to the building corrode, and the rust is deposited on the marble by the rain.

- **Tourists:**
  The number of tourists, which can reach more than 50,000 on some days, is the biggest threat to the Taj Mahal. Constant foot traffic degrades the marble floors. The building gets more humid when people come in, and the grease on their hands causes dirt to build up on the walls. The red sandstone used in the Mehman on either side of the Taj faces the greatest threat. In contrast to marble, red sandstone is porous.

- **Air Pollution:**
  A recent Indo-American study found that air pollution is making dust and carbon-containing particles fall on the Taj Mahal and change its color. Before, the "yellowing" of the monument was blamed on the Mathura refinery and small factories. This led the Supreme Court to order that these units use cleaner fuels.

- **Receding, polluted Yamuna:**
  According to news reports from 2011, the Yamuna is shrinking, which is making the sal wood in the Taj's foundations weaker. The wood needs constant moisture to keep from cracking, which is why the Yamuna is shrinking. The round wells that were cut into the project, consisting of food plazas and shopping malls planned between the Agra Fort and the Taj, were shelved on the Supreme Court's orders because it posed a threat to the monument. The ASI says that sandstorms can damage the marble surface when sand builds up in the reclaimed riverbed. The plot has not yet been converted into a green belt as the court ordered.

RECOMMENDATIONS

To preserve its unique appearance, the Taj Mahal is a global icon that requires immediate attention. In light of their grave worries, the Archaeological Survey of India (ASI) has taken a variety of measures to make the Taj Mahal more functional. The American Society of Internal Medicine (ASI) approves using mud packs as a therapy method. All the surfaces that weren't marble were polished until they shone like new. Dirt, grease, and even insect and bird droppings can be removed from marble by spreading a thick paste of clay (preferably Multani Mitti) and letting it sit for a time, then washing it with purified water. Even though this method has been tried and tested, it is hard to use and takes a lot of time. Therefore, this occurs every few years on average (1924, 2001, 2008, 2014).

ASI also gave the government a "Site Management Plan" that explains most of the steps they plan to take. This includes maintaining regular landscape upkeep, using shoe covers for guests, Taj and having roads automatically washed with water within a 5 km radius of the area.

It is the factory exhaust that poses the most threat. So, if we make it illegal for these factories to run, we might be able to cut down on or get rid of both waste in waterways and air pollution. There may also be a change in how cars are mostly used in urban areas. Gasoline-powered and electric automobiles are also viable options. Because the area has naturally low pollution, NBC should keep a close eye on it. There is a lot of smog and dust because of the crematory that is conveniently located nearby. As a result, we need to switch to electric crematoriums and shut down the factories in historic districts.

As shown by the numbers, the companies and plants along the Yamuna have wasted a total of 2,000 metric tons of water. Cleaning up the area within a 500-meter radius of the TTZ will keep it looking as good as new from any angle. In and around Agra, there is room to decrease plastic use.

Today, India is a model nation, drawing visitors from all around the world who help boost the economy. The current administration makes every effort to protect this Mughal masterpiece. However, we urbanites have a duty to treat this landmark with the awe and reverence it deserves. It's possible that the original skin on the outside of the building has been fixed up and changed many times. Its worth transcends the centuries and remains constant.

- Cleaner fuels should be utilised such as compressed natural gas (CNG) and liquid petroleum gas (LPG).
- Changing to unleaded gas in cars.
- Relocating polluting factories and businesses to less populated areas.
- Vehicles and nearby factories contribute to Agra's air pollution by creating harmful substances including sulphur dioxide (SO2), nitrogen dioxide (NO2), smoke, dust, soot, etc. Unleaded gasoline, which has no lead and does not emit toxic compounds, is one example of a cleaner fuel that reduces pollution. This is why the Indian Supreme Court has proposed these measures to preserve the Taj Mahal.
- Agrichemical runoff and pesticide use are major causes of environmental degradation.

After the Uttar Pradesh government gave a rough plan for protecting the Taj Mahal, the Indian Supreme Court told them to do better. When the state's lawyer tried to pretend that he was surprised that the state government hadn't consulted the Archeological Survey of India (ASI) before writing the report, the Supreme Court blasted him. People all around the country are anxious about the Taj Mahal's alleged yellowing due to pollution.

The judges even asked Attorney General KK Venugopal what would happen if UNESCO took the Taj Mahal off the list of World Heritage sites. In addition, the Supreme Court urged Venugopal to clarify who exactly is in charge of the upkeep of the 10,400-square-kilometer Taj Trapezium Zone (TTZ). While the next hearing in the case has been scheduled for August 28, we must have answers as to how we can help protect India's most treasured monument from environmental degradation immediately.

- Keep India's crown jewel in pristine condition from the time it was erected in 1653 by Mughal emperor Shah Jahan by keeping the area around the TTZ litter-free.
- Reducing the usage of single-use plastics in and around Agra is another crucial step we can take to safeguard the 17th-century tomb. While a statewide ban on plastics has been enacted by the government of Uttar Pradesh, enforcement of the prohibition remains spotty at best.

- Another step we're doing to protect what has been called "the jewel of Muslim art in India and one of the globally adored marvels of the world's heritage" is prohibiting the use of gasoline and diesel vehicles within a 500-meter radius of the mediaeval dome.
- The Supreme Court heard testimony from an environmental attorney who said that insects from the River Yamuna creep into the Taj Mahal and leave their faeces on the marble floors of the massive, 42-acre structure. We need to know that the New7Wonders of the World (2000-2007) project winner is being negatively impacted by the sewage that the city of Agra is dumping into the river.
- The world's most lavish symbol of love, the Taj Mahal, has been severely damaged by acid rain created by smoke from industrial chimneys. While much of such efforts consist of just adhering to rules which are already in place, the Supreme Court's comment of what we would do if UNESCO decided to revoke the world heritage classification from a site that gets approximately 8 million tourists annually prompts some serious thought.
- Building a new dam to assist restore the flow of water to the Yamuna river, turning off some of the 52 discharge pipes spilling waste into the water, and strengthening local sewage treatment plants are all current initiatives to save the Taj.
- For many years, the ASI has relied on mud packs as one of its primary tools for cleaning the yellow stains that have developed on the Taj Mahal's white marble exterior. The technique is commonly used to clean marble and it is believed that it would help bring back the monument's original luster and hue.
- The Indian government has established the Taj Trapezium Zone (TTZ), a 10,400-square-kilometer (4,000 sq mi) area around the monument where stringent emissions limits are in place, to assist reduce air pollution.

Here are things one can do to help preserve the Taj Mahal's splendor for future generations: For starters, the government should impose a limit on the number of tourists who can enter the country in a given time period. The Archaeological Survey of India has fixed up the Mehtab Bagh, which is right behind the Taj Mahal. Along the other bank of the river, the state government has planted a thick green barrier. The authorities are using a mud therapy treatment to keep the monument at its best. The damage that insects cause to the monument is also being mitigated.

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