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Term Project Summary

Focusing on the Taj Mahal in Agra, India, I have talked about how the setting up of industries and increased transportation has lead to an increase in the amount of sulphur and nitrogen oxides in the atmosphere. The mixture of these gases with the moisture present in the atmosphere results in acidic precipitation. Acidic precipitation tends to have a chemical reaction with sculptures, buildings and monuments made of calcareous stone, causing corrosion and discoloration. It has also been seen to have harmful effects on the human respiratory system.

The Taj Mahal is a UNESCO world heritage site and is a symbol of India's rich heritage. Built in Agra by the Mughal emperor Shah Jahan in memory of his favorite wife, Mumtaz Mahal, the Taj Mahal is considered to be the greatest architectural achievement amongst the Indo-Islamic architecture. The mausoleum's famous white marble and relief work, as well as the intricate inlay work makes the structure unique and worthy of being called one of the seven wonders of the world.

In the article titled *Science Behind Acid Rain*, Prashant Mehta has defined acid rain as "...the term given to increased acidity of rain due to the dissolution of gases in rainwater..." It is formed through both natural and anthropogenic sources. Gaseous pollutants such as sulfur dioxide and nitrogen oxide evaporate into the atmosphere and oxidize in clouds to form their respective acids. These pollutants present in acidic precipitation not only cause damage to the environment but also cause problems in human respiratory systems. Acidic precipitation causes toxic metals to break loose from their natural chemical compounds but these chemical reactions vary depending on the amount of exposure, the reactivity of different materials and the amount of moisture present. Although all materials are affected by the deposition of acid, the degree of damage varies. The effects acidic precipitation has on various materials include – discoloration, material loss, structural failing or soiling.

Although buildings have always been subject to weathering, the effects of acid deposition on modern buildings is considerably less damaging than the effects on ancient monuments. Marble is considered a cultural symbol of tradition and refined taste, and was the go to medium for the Greeks and the Romans. This is why most heritage structures are built of marble and other calcareous stones, and are more vulnerable to degradation. The article, *Acid Rain and Other Airborne Pollutants*, mentions that this degradation of buildings and monuments due to acidic precipitation is a result of the industrial revolution, which lead to a high concentration of industrial discharge, salinity and humidity in the atmosphere. This in turn resulted in higher corrosion rates in certain areas.

The Taj Mahal is situated in an area surrounded by small lime kilns burning high-sulphur coal and experiences frequent heavy dewfall. As a result of industrial and population growth, illegal industrial constructions are springing up around the Taj. The pollutants released from these industries is causing serious damage to the famous white marble of the monument which is now appearing to be turning yellow. The article, *Marble Discoloration at the Taj Mahal* by

Hicks and Manju Kumari discusses how the marble discoloration patterns on the Taj Mahal reveal that the air pollutants cause the most damage to the surface of the Taj in the early morning, when the structure is wet because of dew. Surface moisture formed during the night will remain longest on stone surfaces that are not exposed to the early morning sun. This is because wet surfaces enhance the deposition of gaseous pollutants such as sulphur dioxide.

The scientific idea I incorporated into my project is that marble gets discolored and deteriorates when it comes in contact with acidic precipitation, and that the amount of discoloration depends on the amount of exposure and the amount of moisture present, as well as the reactivity of the material. This scientific idea has been incorporated into marble rings which have been exposed to certain acidic chemicals (sulfuric acid).

Each of these rings has a two inch, hexagonal shaped Italian Carrara White Marble with a brass base and ring shank. In history, the hexagon is an important and recurring shape. I chose to use the hexagonal shape because it is the shape I associate with islamic architecture. I also chose the shape because of its geometry and structural stability. Its regularity makes it possible to create a number of interesting shapes. The way I see it, the hexagonal shape helps incorporate the idea that the marble visually changes. Although the marble doesn't physically change its shape, it does change color. Furthermore, the shape is associated with chemistry. Because I am working with chemical reactions, I found that using this shape would be interesting. I chose to use brass because it echoes the yellowing of the marble which I am trying to portray.

The first ring is made of the original, unaffected marble. The second shows the effect on the marble after a short period of exposure, while a third shows the effect of an acid on the marble after a long period of exposure. These rings were then placed in a clear seven inch display case with labels in front of each ring stating the respective changes the rings have undergone when they came in contact with the acid. Behind the rings, stuck on the back walls of the display case are two diagrammatic sketches on paper done with black marker. The first diagram depicts the causes of acid precipitation, and its formation. It indicates that the sulphur and nitrogen gases from industries and cars is released into the atmosphere. It also indicates the direction of the wind which will eventually carry the gases towards the monument. The second diagram depicts the acidic precipitation on the Taj Mahal and the harmful effects it has. It indicates that the sulphur and nitrogen gases mix with the moisture in the atmosphere to form droplets of their respective acids. These acids are deposited on the monument in the form of acidic precipitation, which eventually results in deterioration and discoloration of the marble.

I chose to focus on an architectural monument because jewelry has always had strong connections with architecture and draws a lot of its inspiration from architecture. With the help of these pieces, I wish to spread awareness about the harmful effects of acidic precipitation and pollution in general to those who are capable of bringing about change. Jewelry like fashion has always had an impact on people and therefore it would be a good way to communicate the problem. Jewelry pieces such as the ones created for this project can be sold at artisan festivals like those held at the Chhatrapati Shivaji Maharaj Vastu Sangrahalaya in Mumbai, India. These artisan festivals attract people who are invested in maintaining India's culture. These include environmental activists who can be considered to be the target audience of this project. In the past environmental activists in India have been able to make changes in a number of areas such as protecting the mangroves along the coast. I reckon that if they are made aware of the problem, they are more likely to make a conscious effort to get the government to reduce the amount of

sulfur and nitrogen gases being released into the atmosphere from transport vehicles and industrials power plants. This in turn will reduce the likelihood of acidic precipitation.

## Annotated Bibliography

I have decided to connect my term project to the chapter from week 9 on Pollution: Nutrients and Toxins. The key question I will be relating my research to is "What risks does pollution pose to human health".

Human activities have added to the substances that circulate naturally among ecosystems. Focusing on the Taj Mahal in Agra, India, I will discuss how the setting up of industries and increased transportation has lead to an increase in the amount of Sulphur and Nitrogen Oxides in the atmosphere. These gases mix with the moisture present in the atmosphere, producing acid precipitation (acid rain). Acidic precipitation tends to have a chemical reaction with buildings and monuments made of limestone, sandstone and marble, causing corrosion and discoloration. It also has adverse effects on the human respiratory system.

1. Centre, UNESCO World Heritage. "Taj Mahal." UNESCO World Heritage Centre, whc.unesco.org/en/list/252.

The Taj Mahal is a symbol of India's rich history and is a UNESCO world heritage site. It is a mausoleum made of white marble built in Agra by the Mughal emperor Shah Jahan in memory of his favorite wife, Mumtaz Mahal. It is considered to be the greatest architectural achievement amongst the Indo-Islamic architecture. It is perfectly symmetrical with emphasis of bilateral symmetry along the central axis. The relief work in marble as well as the intricate inlay work gives it its unique feature. The exquisite octagonal marble lattice screen also shows superb workmanship.

 Cowling, Ellis B. "Acid Rain and Other Airborne Pollutants: Their Human Causes and Consequences." Population and Development Review, vol. 16, 1990, pp. 205–220. JSTOR, www.jstor.org/stable/2808071.

Abstract:

Almost all human activities which occur on a large scale tend to influence the chemistry of the atmosphere, adding to it more substances than those that circulate naturally. The main sources of pollution are volatile waste products from the combustion of fossil fuels in power plants, transportation vehicles, and water heating installations. This article classifies sulfur dioxide and nitrogen oxides as primary air pollutants while it classifies acid deposition as an important secondary pollutant.

Airborne chemicals are carried by wind and are deposited on vegetation, water surfaces, soil, as well as buildings and monuments. There has been concern about the possible effects of airborne chemicals on historical and cultural monuments all around the world such as the Parthenon in Greece, the Taj Mahal in India, and the Statue of Liberty in New York. Acid deposition and atmospheric haze is also considered to have detrimental effects on society. Prior to the industrial era, the concentration of chemicals present in the atmosphere was relatively low. But now, aquatic and terrestrial ecosystems are exposed to a greater amount of acidic and toxic substances, as well as climate and growth altering chemicals than they were exposed to during the pre-industrial period.

3. Hicks, B B, and Manju Kumari. Marble Discoloration at the Taj Mahal: A Proposed Explanation. 28 Jan. 2011, openarchive.icomos.org/id/eprint/717.

## Abstract:

The Taj Mahal is situated in an area surrounded by small lime kilns burning high-sulphur coal and experiences frequent heavy dewfall. This article studies the role of surface wetness as a promoter of the exchange of pollutants from the air to the surface of the monument. The marble discoloration patterns on the Taj Mahal reveal that the air pollutants cause the most damage to the surface of the Taj in the early morning, when the structure is wet because of dew. Surface moisture formed during the night will remain longest on stone surfaces that are not exposed to the early morning sun. This is because wet surfaces enhance the deposition of gaseous pollutants such as sulphur dioxide.

4. Ghosh, S, and M P Singh. "A Scavenging Model Analysis around a Large Coal-Fired Power Plant in New Delhi with a Particular Reference to the Scavenging Action of the Monsoonal Rains." Philosophical Transactions of the Royal Society B: Biological Sciences, The Royal Society, 2 May 2002, doi.org/10.1016/0270-0255(87)90616-6. (Academic journal found at the Pratt Library.) Abstract:

There have been reports in the recent past about the problem of sulfur dioxide pollution over India. The rise in the acidity of precipitation is a result of fumes from vehicles and combustion of products in factories and thermal power plants. Although there is excessive amounts of pollution in the atmosphere, the high dust rate neutralises the acids that are present. Experimental analyses have been undertaken in certain metropolitan cities to address the problem of sulfur dioxide pollution. Rainwater analyses show that low pH of precipitation occurs downwind of major industries and power plants. It is observed that maximum pollution is brought into the city from power plants during the month of October, and the acid deposition is greatest during the month of August. This is because during the monsoon months, the wind is South Easterly and a lot of sulfur dioxide is scavenged by the rainwater.

 "Changing Trends in Sulfur Emissions in Asia: Implications for Acid Deposition, Air Pollution, and Climate." ACS Publications, 20 Sept. 2002, pubs.acs.org/action/showCitFormats?doi=10.1021%2Fes011509c. Abstract:

In the early 1990s, it was estimated that the emissions of sulfur dioxide in Asia might grow by 2020. In China, the use of high sulfur coal was restricted, which resulted in a reduction in sulphur dioxide emissions, as well as reduction in acid deposition. It also helped improve visibility and reduced health problems. After China, other countries began to appreciate the dangers of uncontrolled sulfur emissions and introduced measures to limit the sulfur content of petroleum products. The largest increase in the level of sulfur dioxide occured in India. Although the sulfur emissions were originally relatively low, industrial growth lead to increased reliance on fossil fuels and thus an increase in sulfur emissions and deposition. Even though steps are being taken to reduce the sulfur content of petroleum products, the demand for electricity in India has lead to the construction of several hundred new power stations which will invariably result in an increase of sulfur emissions. 6. Mehta, Prashant. Science behind Acid Rain: Analysis of Its Impacts and Advantages on Life and Heritage Structures.

www.researchgate.net/profile/Prashant\_Mehta6/publication/265824342\_Science\_behind\_ Acid\_Rain\_Analysis\_of\_Its\_Impacts\_and\_Advantages\_on\_Life\_and\_Heritage\_Structure s/links/55dd390e08aeb41644aedcda/Science-behind-Acid-Rain-Analysis-of-Its-Impactsand-Advantages-on-Life-and-Heritage-Structures.pdf. Abstract:

Acid rain is the term given to increased acidity of rain due to the effects of gases which dissolve in rainwater to form various acids. It is formed through both natural and anthropogenic sources. Two primary sources of acid rain is sulfur dioxide and nitrogen oxide. These gases evaporate into the atmosphere and oxidize in clouds to form their respective acids. The pollutants in acid rain not only cause damage to the environment but also cause problems in human respiratory systems. Acid rain causes toxic metals to break loose from their natural chemical compounds but these chemical reactions vary depending on the amount of exposure, the reactivity of different materials and the amount of moisture present. Although buildings have always been subject to weathering, the effects of acid deposition on modern buildings is considerably less damaging than the effects on ancient monuments. This is because acid deposition especially affects materials such as limestone, sandstone and marble.

7. Bashkin, Vladimir N, and Miroslav Radojevic. "Acid Rain And Its Mitigation In Asia." Taylor and Francis Online, 17 Sept. 2010, www.tandfonline.com/doi/abs/10.1080/00207230290015711. Abstract:

Recent industrial developments in Asia have raised concerns about actual and potential acidification in the region. Over the last ten years, the presence of acid rain has been identified at numerous sites in Asia. The mitigation strategy being very comprehensive in Japan, Singapore, and Hong Kong, seems insufficient in other countries which are the major polluters in the Asian domain, like China, India and Thailand. It is difficult to make reliable predictions about the future incidence of acid rain in East and Southeast Asia due to the unpredictable economic situation.

 Laver, Marilyn E., and Ian N. M. Wainwright. "An Investigation of the Dissolution of a Marble Petroglyph Site by Acidic Precipitation." Studies in Conservation, vol. 40, no. 4, 1995, pp. 265–273. JSTOR, www.jstor.org/stable/1506501. Abstract:

This article talks about the effects of acid precipitation on a complex of pecked or carved marble at Petroglyphs Provincial Park in Canada. This site is unlike many others which consisted of red ochre rock paintings on granite. The site was not acutely affected by local urban or industrial pollution but was affected by long range transport of air pollutants. Although its primary mode of deterioration can be considered to be dry decomposition, acidic precipitation might have been a significant factor in the dissolution of the rock. This is because the source of water affecting the site is in the form of atmospheric precipitation and the deterioration was caused due to frost weathering and algae.

 Rao, N Venkat, et al. "Detrimental Effect of Air Pollution, Corrosion on Building Materials and Historical Structures." American Journal of Engineering Research (AJER), 2014, www.ajer.org/papers/v3(3)/ZT33359364.pdf. Abstract:

The degradation of buildings is a result of the industrial revolution. The industrial revolution lead to a high concentration of industrial discharge, salinity and humidity in the atmosphere. This in turn resulted in higher corrosion rates in certain areas. Like the Taj Mahal which is one of the seven wonders of the world, most heritage structures are built of limestone and calcareous stones which are most vulnerable to corrosion. Although all materials are affected by the deposition of acid, the degree of damage varies. The effect of air pollution on materials could be discoloration or material loss or structural failing or even soiling. As a result of industrial and population growth, as well as traffic fumes, illegal constructions are springing up around the Taj and heavily polluting the water of the Yamuna River. This is causing serious damage to the famous white marble of the monument which is now seen to be turning yellow. A series of banning measures have been undertaken by the government, including avoiding running of vehicles 500 meters away from the monument.













