

Impact of acid precipitation on historical monuments and statues

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Abstract

A host of deleterious factors can impact the aging and integrity of historical monuments and statues. These may include natural causes such as water, wind, and temperature variation as well as the even more detrimental human causes of industrial pollution, urban warming, and fossil fuel emissions from vehicles all of which contribute to the development of acid precipitation. In addition, where the use of fossil fuels is wide-spread the occurrence of acid precipitation tends to be more prevalent and as a result serious damage can occur to the natural environment. Acid precipitation causes irreparable damage to vegetation, wildlife, and fish populations in lakes, streams, and rivers. Also, damage caused by acid precipitation can be quite recognizable on historical monuments and statues constructed from carbonate-based stone. The stone derived from carbonate sources such as limestone, dolomite, and marble have been widely used for thousands of years in the construction of monuments and statues. Carbonate-based stone was often chosen because of its abundance, suitability for shaping, and robust quality. Many historic works of art which not only characterize a period of art but also create powerful images of the artist and artwork have survived for thousands of years. The emergence of acid precipitation though has caused irreparable damage and destruction to many of these irreplaceable works of art, monuments, and statues. In this study, the research focuses on better understanding of acid precipitation and its impact on items of cultural heritage such as historical monuments and statues. Sample cases were chosen to emphasize and evaluate deleterious impact which may have occurred to these items of cultural heritage. According to research evaluation results from this study the researcher has provided recommendations for resolving the impacts of acid precipitation on these historical monuments and statues.

Keywords: fossil fuels, acid precipitation, historical artefacts, marble statues.

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1. Introduction

Numerous historical monuments and sculptures which have existed for thousands of years continue to face significant damage. Over the past hundred years the damage to these monuments and sculptures has accelerated. Except for the physical and chemical destruction which occurs due to the natural weathering process the main source for the accelerated damage to these structures has been pollutants and gases produced from human-based activities. Environmental destruction as well as damage to cultural assets is a result of excessive and inappropriate use of fossil fuels due to unchecked urbanization and industrialization. As a result, acid rain has become a hot button issue over the past decades and throughout the world a variety of legislation has been passed to combat its deleterious effects on the environment. Efforts to protect and repair if necessary the negative effects which have occurred to historical monuments and sculptures from human-made pollutants continue to be of importance.

2. What is acid rain?

Except those occurring through natural causes, the primary sources for the production of SO_2 (sulphur dioxide) and NO_x (nitrogen oxide) are emissions from power plants, factories, and combustion engines. When in contact with water molecules (H_2O) these compounds become sulphuric acid (H_2SO_4) and nitric acid (HNO_3). Acid precipitation or acid rain occurs when sulphuric acid and nitric acid fall to earth within precipitation such as fog, rain, and/or snow. As with acid precipitation, another factor that causes great harm in nature and to cultural artefacts is dry accumulation (Hultberg & Skeffington, 1998). The process of dry accumulation takes place when a variety of particles and gases are carried with the wind and deposited in the environment and on cultural artefacts as stronger and more harmful acid particles. These accumulated particles demonstrate a much stronger caustic effect when they react with rain. The term of acid rain was first used in 1852 by Robert Angus Smith to describe a degree of increased acidity found in the precipitation of an important industrial city of the time, Manchester, United Kingdom (Cowling, 1982). Even though Smith discovered a relationship between acid rain and air pollution resulting from an increased use of fossil fuel and the process of industrialization the phenomena of acid rain was not taken seriously until the 1960s. Acid rain garnered increased attention following the discovery of mass fish deaths in rivers and lakes as well as the emergence of major damages to vegetation in industrial zones resulting from the degree of increasing acidity. Following this catastrophic destruction the culprit of acid precipitation began to be recognized as not only a significant problem but a global problem.

Acid rain is caused by pollutants from industrial sources and is damaging not only for the natural environment such as soil, streams water sources, and vegetation and but also for various cultural assets such as historic buildings and statues. The pH value of precipitation is normally 5.6. With acid rain these values further decrease and depending on the rate of decrease the amplified effect of acid is revealed. Precipitation is generally defined as acid rain if the pH value falls below 4.4. The higher degree of acidity means the potential for a higher level of environmental damage. When a body of water such as a lake is damaged by acid rain and the pH level reaches 4.2 then there is the potential for the death of fish to take place. The harmful impact of acid rain on the environment can cause major havoc on an ecosystem as well as negatively affect various cultural structures, historic buildings and statues which in many cases causing damages which cannot be reversed. Normally, precipitation has a slight acid content which occurs because of natural carbon dioxide (CO_2) in the air. Carbonic acid ($\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$) is formed as a result of the reaction of carbon dioxide with water. While normal precipitation has limited negative effects on objects the effect of acid precipitation can cause dramatic deleterious effects.

In the past century, depending on the levels of industrial development, air pollution has increased. Nowadays, this increase not only impacts environmental and human health but also the stones such as marble used for constructing historical monuments. The significance of the damage these pollutants can cause is dramatic. Under current conditions, the damage and deterioration of architectural monuments and statues which occurred over 1000 years under normal circumstances can now come about in the span of only 15 to 20 years. Since ancient times, stone types of carbonate

origin (i.e., marble, limestone, travertine and dolomite) have been the most widely used in the construction of ancient and historical architecture and sculpture.

Among the most important reasons for choosing carbonate stone types are:

- Their abundance in nature.
- Their durability.
- Their architectural strength.
- They are easy to work with.
- High resistance to weathering.
- They offer a variety of colours and textures.

Due to these properties, natural stones have been extensively used in many parts of the world since ancient times to the present day. Ancient civilizations that widely used natural stones in the construction of their architecture and sculpture were Mesopotamia, Egypt, Persia, Greece and Rome (Yuceil, 2015). Marble works used in various structures and monuments have come to represent a symbol of prosperity among cultures throughout history.

3. The use of marble

The use of marble was widespread in ancient Egyptian temples, the Greek Acropolis, the amphitheatres of the Roman period, medieval castles, Gothic cathedrals, works of the Renaissance, as well as, the palaces, mosques, public baths and fountains of the Seljuk and Ottoman period. Furthermore, structures such as railway stations, airports, administrative buildings, shopping centres and homes of modern ages (Yuceil, 2015). The Temple of Artemis, a memorial temple built in the 4th century B.C. for Caria at Halicarnassus in the Greco-Persian style, was not only one of the Seven Wonders of the World it was also the first monument on earth created utilizing marble. Other wonderful examples of marble being used in the construction of ancient architecture and sculpture are the altars of Zeus and Athena in Pergamon (2nd century B.C.), the Apollo temple in Didim, and giant marble Claros statues (Yuceil, 2015). Unfortunately, the world's important cultural assets, especially those near large cities and industrial zones, are extremely threatened due to air pollution.

4. How are these works getting destroyed?

Sulphur dioxide (SO₂), which is considered as one of the most critical components causing air pollution, reacts with calcite crystals (CaCO₃) making up the structure of marble and the resulting reaction creates gypsum (CaSO₄ 2H₂O). Compared to calcite crystals the gypsum crystals are easily dissolved in water, and as a result, acid rain can significantly damage and destroy marble surfaces (Bernal, 2003; Dubey, 2013). In some cases the damage to historical structures and statues constructed from marble thousands of years ago can be destroyed completely from these pollutants. Natural weathering also causes some deleterious effects to historical monuments and sculptures located outdoors; however, the rapid attrition and damage caused from acid precipitation on historical works reveals the immediacy of this situation and the necessity for taking urgent action.

5. What can be done?

Except natural factors such as volcanic activity, swamp gas and lightning strikes, the most important cause of acid precipitation is the use of fossil fuels. Using clean and renewable energy sources in industry, transportation and heating instead of fossil fuels can greatly minimize the problem of acid precipitation. Unfortunately, even though the solution of the problem is very simple its implementation can be very difficult. Even when international treaties and protocols in this regard are rigorously implemented, the main target is not to eliminate this problem but instead to not to increase it. Under current conditions, completely eliminating acid precipitation is impossible but in the case of repairing and further protecting historical buildings and statues located outdoors from acid rain is of the utmost importance. The first step in the preservation of the works located in

affected areas where acid precipitation is present is taking physical precautions to preventing the contact of acid precipitation with these structures and statues.

Particularly with sculptures, the following precautions can be taken:

- Enclose them using materials such as glass, acrylic, PVC.
- Temporarily protect them with plastic covers where air pollution is seasonal.
- Protect the surface using various chemical substances (acrylic-silicone, etc.).
- In cases where other options are not applicable, especially if they are extremely valuable artefacts, they must be relocated indoors.

Also necessary is to repair and restore works which are already damaged. Appropriately performed repair and renovation work can prevent further destruction to the artefacts so that future generations can experience and enjoy them fully.

For this purpose, some of the procedures can be performed are listed below:

- Consolidation.
- Plastic repair.
- Cosmetic repair.
- Laser repair.

5.1. Consolidation

If valuable works and artefacts have been compromised through weakening because of breaking, cracking, dispersion, and flaking, the process of consolidation can be utilized to improve their durability, rigidity, and overall strength. Materials such as stabilizer are use to fill in gaps in the stone. The consolidation process combines the weaker compromised surface layers to the more solid and strong inner layers.

5.2. Plastic repair

Plastic repair is another repair process utilizing filler material to repair damaged stone. Plastic filling is prepared according to the characteristics of the stone's colour, texture, and structure.

5.3. Cosmetic repair

In artefact repair and restoration, cosmetic repair is a frequently and successfully used methodology. In cosmetic repair, minor damage and holes are filled with aggregate and mortar according to the suitable colour and texture.

5.4. Application of the laser beam

Another useful method is the use of lasers to clean away darkening and superficial deterioration on works surfaces. Although it is a successful method for superficial cleaning, it is also considered a controversial method because of the exposure of works to heat and light of the effect. With the laser technique it is critical to take every precaution because if the application is done incorrectly this process of conservation and restoration can adversely affect the homogeneity of the stone and possible degrade the works more rapidly.

We are the stewards of these ancient and historical cultural artefacts for future generations and for this reason, marble monuments and statues, especially those located in the outdoors should be protected to avoid further exposure to acid precipitation both before-and-after the restoration process.

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