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Variations in air quality before, during and after COVID -19 and impacts of air pollutants on construction materials in Dhaka city

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In partial fulfillment of the requirement for the degree of

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Assistant Professor Dr. Amimul Ahsan and this work has not been submitted elsewhere for any purpose.

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ABSTRACT

We have done this study to determine the variations in air quality parameters before, during and after COVID -19 in Dhaka City. In recent years, Dhaka has been repeatedly reported as one of the most polluted cities in the world in terms of $PM_{2.5}$ concentration and Air Quality Index (AQI). We also assessed the impacts of air pollutants on construction materials in Dhaka City. The degradation of many building materials is affected by climatic conditions and air pollution. Chemical environmental loads degrade not only metal components, but also other building materials. One of the research focuses is the construction of corrosion maps for substances, which will not only aid in material protection but may also serve in risk prediction during design, analysis, and maintenance. The purpose of this paper is to provide an overview of the changes in the occurrence of different Air Quality Index classes in Dhaka City during the lockdown period, as well as a comparison of $PM_{2.5}$, NO_2, SO_2, and CO concentrations in Dhaka City air during the COVID-19-induced lockdown to the same period in previous years. This paper also includes attribution of missing data for AQI parameters from secondary data sources. Using a random forest algorithm to attribute missing data allows us to more efficiently analyze AQI data.

Climate change and pollution play a role in the decomposition of a variety of building materials. Chemical environmental stressors degrade not just metal components but also other construction materials.

CHAPTER ONE
INTRODUCTION

1.1 GENERAL

Air is a necessary and vital component of the environment for all living things, but its quality is susceptible to degradation, harming both human health and the ecosystem. Government agencies exert AQI to enlighten the public about how polluted and contaminated the air is and is expected to become in the future. As the Air Quality Index increases, so thus the risks to public health. Air quality indices vary by country and comply with different national air quality standards. In other words, the AQI is a scale that indicates how contaminated the air is, and the risks that come along with each ranking. The Air Quality Index is calculated using medically validated standards for permissible levels of major air pollutants.

Abrasion, deposition and accumulation, direct and indirect chemical attack, and corrosion are all process that air pollutants debilitate. In metropolitan places, air pollution is directly accountable for economic losses. Moisture, temperature, sunlight, air movement, and the position of the components all contribute to material deterioration in the atmosphere.

In the South Asian region, deteriorating and dropping of air quality constitute threat to sustainability and environmental health. Natural as well as manmade activities constitute a hazard to air quality. Natural occurrences like vegetation breakdown, volcanic activity, and forest fires regularly discharge particulates such as mineral dust, sea salts, and gases such as CO, SO_2, NH_3, and H_2S into the climate. Furthermore, fresh air is severely polluted and contaminated subsequently the multiplication of microscopic dangerous particles and gases released by numerous human activities, which have a far greater influence on the environment. Automobile exhaust, smoke, particle and heavy metal emissions from industries, radioactive chemicals, biomass combustion, and other forms of air pollution are all significant contributors to inadequate and poor air quality. The impact of air pollutants on human health is a complex issue that is one of the most researched in the field of air pollution (Shantanu Kumar Pani, April 2020). Chronic exposure to air pollution can result in a range of respiratory ailments, asthma, and, to a lesser extent, lung cancer and cardiovascular disease in humans (Dean E.Schraufnagel, September 2019). Air pollution can also cause oxidative stress, impairs the immune system, and reduces the host's ability and tolerance to viral infections (Babu et al., 2020). According to a study of the SARS pandemic in China, sick patients were more likely to die if their neighborhood had poor air quality (Yan Cui, November 2003) As a result, air pollution has a direct impact on human health. According to the global burden of illness report (2017), nearly one million people die each year in India due to air pollution. Furthermore, according to a recent UNICEF (United Nations International Children's Emergency Fund) study, children under the age of one who live in a polluted environment are more likely to have brain damage. After seeing a decline in the survival rates of patients brought to the city hospital in the 1980s, the administration in Dublin convinced the city to ban the most polluting types of coal (Grahame et al., 2014). As a result of the aforementioned considerations, it is plausible to conclude that combining air pollution and human health into a single policy would be advantageous.

The COVID-19 outbreak lockdown was initially deployed in China's Hubei region to contain the dangerous pandemic, and was quickly followed by many other countries around the world. In most countries, the initial phase of the lockdown severely restricted mobility, travel, and business and industrial operations other than essential services. The substantial reduction in air pollutants like NO_2, CO, Black Carbon (BC), particle matter (PM), and other pollutants recorded during the first phase of the shutdown in China and Europe is a noteworthy feature (Rui Bao, April 2020). It is worth noting that the lockdown has not only reduced the incidence of COVID-19, but it has also resulted in a significant reduction in environmental (air and water) pollution, which could become a benchmark for many cities experiencing severe pollution episodes in the absence of policies and regulatory interventions. The worldwide shutdown to prevent the spread of the COVID-19 pandemic has resulted in improved air quality. The total shutdown of outdoor activities in the initial phase resulted in significant reductions in particle and gaseous pollution concentrations. The air quality index (AQI) in South Asian megacities has dropped by up to 50% as a result of this. The most polluted cities in South Asia, such as Delhi (41%), Dhaka (16%), Kathmandu (32%), and Colombo (33%), as well as Islamabad and Kabul, saw considerable reductions. Gaseous pollutants including CO, NO_2, and SO_2 all showed significant reductions. The severe lockdown allowed the relevant authorities to review the large-scale transportation and industrial sectors in order to avoid unnecessary pollution emissions.

The impact of air pollution on materials is a significant issue, as it drastically reduces building service life. It is true that manufactured pollutants have a greater impact on building degradation than natural pollutants. Most notably, the impacts of SO_2 on soiling, deterioration, corrosion, and erosion are severe. Discoloration, material loss, structural failure, and soiling are all effects of air pollution on materials. Both discoloration and structural damage on buildings as a result of air pollution may be minor and costless. However, the expense of corrosion caused by acidic deposition is significant. Sulfur dioxide and nitrogen dioxide emissions, in particular, have a major impact. Calcium sulfate has had a strong effect and is likely to continue for a long time. Calcium sulfate is formed when calcium carbonate is dissolved with sulphuric acid. When calcium sulfate rains on stone, it cracks the building blocks' surface.

Dhaka has been named one of the most polluted cities in the world in terms of $PM_{2.5}$ concentration and Air Quality Index (AQI) in recent years (IQAir, 2018, 2019, 2020). This city is consistently ranked among the top five or ten cities with the worst air quality. The government of Bangladesh's Department of Environment (DoE) indicated that particulate matter in Dhaka City's air comes primarily from motor vehicles and brick kilns in and around the city (DoE, 2019). Begum et al. (2013) found that the brick kiln and vehicle emissions contributed roughly 22% and 36% of fine particulate matter in Dhaka's air, respectively. Furthermore, roadside dirt is one of the most significant sources of dust or coarse particulate matter, particularly during the dry season, which runs from November to February. Concurrent building of many megaprojects is also a major cause of air pollution in the city. (Md. Saiful Islam, 2021)

1.2 THE EFFECTS OF AIR POLLUTION ON MATERIALS

The effects of most materials are divided into four categories:

- Discoloration;
- Material loss;
- Structural failure;
- Soiling.

There are no value studies or material inventories available to estimate discoloration costs. However, these expenses are most likely insignificant. Structural failure caused by pollution appears improbable unless a building's design is fundamentally defective or upkeep is neglected. Attributing costs to air pollution is unreasonable in all cases, at least in the context of rich countries. Therefore, this study aims to examine the impact of acid deposition on corrosion. Furthermore, a simple approach was applied to measure building fouling caused by deposits. The impacts of these air pollutants should be considered in the context of significant natural weathering processes such as rain, bacteria, freeze-thaw cycles, and sea salt (in coastal regions). Even in the absence of air pollution, these natural elements would cause material deterioration. However, recorded degradation rates are 10 to 100 times lower than when air contaminants are present. (Watkiss, Paul, 2000).

Dry deposition of sulfur dioxide has the most corrosive effect of all air pollutants on a number of materials. Pollution deposition in the form of acidic rain has a corrosive effect on some materials, although it is usually weaker. The role of NO_2 in the atmosphere has not yet been determined. Although laboratory investigations have shown a significant synergistic effect with sulfur dioxide, this has not been confirmed in the field. (Watkiss, Paul, 2000)

1.3 PROBLEM STATEMENT

One of the research's key goals is to create corrosion maps of various materials, which will not help with material protection but may help with risk prediction during design, analysis, and maintenance. This paper examines changes in the occurrence of various Air Quality Index classes in Dhaka City during the shutdown as well as a comparison of $PM_{2.5}$, NO_2, SO_2, and CO concentrations in the air of Dhaka City during COVID-19-induced lockdown to the same period in the previous years. This report also includes attribution of missing AQI parameter values from secondary data sources. AQI data can be more effectively analyzed by using a random forest technique to attribute missing data.

Wet and dry depositions fall on the surfaces of structures and buildings. These depositions react with the components of the compounds that remain on the surface of structures that have already been built or on construction materials that have been exposed to the atmosphere during the construction of the structure. They react, causing rust and corrosion-like activity on building surfaces and unprotected construction elements.

1.4 PURPOSE AND THE OBJECTIVES OF THE STUDY

The specific objectives of this study are:

- To determine the variations in air quality parameters before, during and after COVID - 19 in Dhaka City.

- To assess the impacts of air pollutants on construction materials in Dhaka City.

CHAPTER TWO
LITERATURE REVIEW

2.1 GENERAL

The global COVID-19 epidemic caused Bangladesh's government to implement a lockdown from April to May 2020, restricting public mobility, shutting down industry, restricting motor vehicle traffic, and closing marketplaces, public places, and educational institutions. These sorts of stringent regulations helped to reduce urban air pollution.

The study of (Islam & Chowdhury, 2021) investigated this reduction of pollution an the air of Dhaka city and the reduction of air quality index(AQI). Time-series data of the concentration of $PM_{2.5}$, NO_2, SO_2 and CO have been collected from archive of the Air quality monitoring station of the US embassy in Dhaka and Sentinel-5P. The data was analyzed by descriptive statistics and appropriate formulas suggested by Environmental Protection Agency (EPA) were used to calculate AQI. The study found that the concentrations of the air pollutant parameters during April-May 2020 were reduced compared with the preceding years concentrations. The AQI also reduced during the lockdown period then same time of the previous year. But the magnitude of pollution reduction is lower in Dhaka then other cities and countries globally. The reasons for this can be because of the poor implementation of lockdown procedures and pre-existing pollution. This study can be used to help policymakers Figure out how to regulate pollution-sources and improve the air quality in Dhaka.

Similarly the studies of (Othman & Latif, 2021) observed the air pollution impacts from COVID-19 pandemic control strategies in Malaysia. A movement control order (MCO) was implemented in March18,2020. This pandemic control strategy restricted all outdoor activities and public movement. To investigate the impact of MCO, air pollutants like PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3 and CO in nine major cities in Malaysia were measured before and during the implementation of the MCO. The health risk assessments were determined using the United States Environmental Protection Agency (USEPA) health risk assessment method. Overall, the study showed that the air pollutants showed huge amounts of reduction in all of the affiliated cities. This study showed that the reduction of human activities significantly affects the air pollution and increases human health. The results of this study can be used to implement air pollution mitigation strategies and improve human health.

Air pollution and Climate parameters has high relevancy to the degradation of several types of building materials like construction metallic materials, concrete structures and plasters of buildings, bridges or art sculptures. Chemical environmental loads are causing the degradation of not only metal materials, but also other construction materials (concrete, glass, etc.) in Slovakia and across the world. Industrial activities can pollute the atmosphere and the hydrosphere. This causes increased corrosion aggressiveness of atmosphere. The works of (Ivaskova et al., 2015) observes the air pollution impacts on stone materials and carbon steel in Slovak Republic. In this research dose-response functions are used, which were developed based on long-term research (Ivaskova et al., 2015). Multi-annual climatic parameters and parameters of air pollution in Slovak Republic were used to generate the maps of annual average surface loss of stone materials and carbon steel.

The work of (Kucera et al., 2001) is a 8-year field exposure programmed involving 39 test sites in 12 European countries and the US and Canada shows the results of the international co-operative programmed on effects on materials including historic and cultural monuments (ICP Materials) within the United Nations Economic Commission for Europe (UN ECE). Dose-response functions (DRF) expressing the effect of dry and wet depositions as individual terms were obtained for wide range of materials including bronze, copper, weathering steel, zinc aluminum nickel, tin, stone materials, paint coatings and glass materials. The DRF's that were obtained includes parameters that are readily available on different geological scales.

The effect of corrosion on the national and global level is huge. The overall cost of corrosion of the worlds wise is over 3% of the entire worlds GDP. India alone loses over $45 billion ever year due to corrosion of infrastructure, industrial machinery and other historical heritage. The work of (Venkat Rao et al., 2016) focuses on how all forms of corrosions affect building materials and historical structures. The corrosion process is initiated in the form of chemical corrosion and electrochemical corrosion. The chemicals are categorized as direct oxidization corrosion by liquid metals, fused halides and non-aqueous solutions. Electrochemical corrosion is seen in the form of immersion corrosion, underground corrosion and atmospheric corrosion.

Rainwater harvesting systems were assessed to be potential in residential, industrial, educational and other institutions. The study of (Haque & Rinkey, 2019) was focused on the quality of the rainwear samples obtained from rooftop surface runoff of different locations of Dhaka City. The locations were based on residential, industrial, commercial zones of the area, motorized vehicle use, population, construction works etc. The main goal of this research was to compare the rainwater quality of different locations with the drinking water quality standards of Bangladesh and World Health Organization (WHO) to observe whether the water is qualified for potable use or if it needs further treatment. Physical tests like turbidity and chemical tests like pH, electric conductivity, total dissolved solids, nitrate, nitrite, sulfate, chloride and fluoride were tested from the samples. The results showed significant imbalance with the standards in terms of pH, nitrate and fluoride values. Other parameters were found within standards.

2.2 AIR QUALITY PARAMETERS

2.2.1 SULFUR DIOXIDE (SO_2)

SO_2 is a colorless gas with an unpleasant odor. It is made from the combustion of fossil fuels (coal and oil) and the smelting of sulfur-bearing mineral ores.

Eye discomfort is caused by SO_2. The respiratory system and lungs' functioning may also be compromised. (Li et al. 2015) Inflammation in the respiratory tract causes coughing, mucus output, asthma and chronic bronchitis to worsen, and renders patients more susceptible to respiratory infections (Padula et al. 2013). According to several studies, patients with asthma who are exposed to SO_2 for as little as 10 minutes suffer alterations in pulmonary function and respiratory symptoms (Gonzalez et al. 2013). On days with greater SO_2 levels, hospital admissions for heart illness and death rise. When SO_2 reacts with water, sulfuric acid is formed, which is the major component of acid rain, which contributes to deforestation. SO_2, one of the most common industrial pollutants, may have age-specific impacts on the development of Crohn's disease and ulcerative colitis, particularly in adults who work as drivers (Li et al. 2009). (Kaplan et al. 2010). Increasing SO_2 concentrations might potentially be a risk factor for maternal depression symptoms (Lin et al.2017) Increased levels of SO_2 and PM_{10} may lead to an increase in maternal mental stress (Lin et al.2017).

2.2.2 NITROGEN DIOXIDE (NO_2)

It is an discuss poison having a few connected exercises. anthropogenic outflows of NO_2 are through the combustion forms (warming, control era, and motors in vehicles and ships). Subsequently, the major source of NO_2 in surrounding discuss is street activity (Nishimura et. al. 2013). NO_x isn't so wellbeing perilous but it makes a difference within the generation of nitrate mist concentrates, which form a vital division of PM2.5 and, within the nearness of bright light, of ozone. At a short-term introduction of standard level (200 μg/m^3), it appears harmfulness which causes significant inflammation of the aviation routes.

2.2.3 OZONE (O_3)

Excess ozone in the air has a significant impact on human health. Respiratory disorders (acute and chronic), lung dysfunction, asthma, and preterm delivery are all explained by O_3 in combination with other indoor PM emissions (Zaidi et al., 2011; Yamamoto et al., 2014) The effects of ozone on heart development are unknown (Kannan et al. 2007). It is now one among the most dangerous air pollutants. According to several European studies, every 10 µg/m^3 increase in ozone exposure increases daily death by 0.3 percent and heart disease mortality by 0.4 percent (EEA, 2016) Another Hong Kong study found that O_3 exposure increased hospital admissions for asthma in children.

2.2.4 PARTICULATES MATTER ($PM_{2.5}$ and PM_{10})

Particulate matter Extraordinarily $PM_{2.5}$ isn't as it were a wellbeing unsafe toxin of Dhaka City or Bangladesh it may be a inconvenient toxin all over the world. Due to short-term PM introduction the rate of relative hazard increment for all-cause mortality has been evaluated to run from 0.4% to 1.5% per 20 $\mu g/m^3$ increment in coarser PM_{10} and from 0.6% to 1.2% per 10$\mu g/m^3$ increment in better $PM_{2.5}$ (Stieb et al. 2002), counting more than 60 million Medicare recipients from 2000 through 2012, watched that, for each increment of 10 $\mu g/m^3$ in $PM_{2.5}$, there was a related 7.3% increment in all-cause mortality. Long-term exposure to particulate matter also causes immune system deterioration in children, women, and the elderly, who are considered vulnerable groups (Gurley et al., 2012) due to the rising prevalence of cardiovascular, respiratory, and all-cause death (Jerrett et al. 2009; Levy et al.2005; Bell et al.2004). Furthermore, it is the greatest and most directly linked to cancer, cardiovascular, and respiratory disease-related mortality risks. This is currently one of the most serious global health threats, with illness burdens equivalent to those caused by tobacco use (WHO, 2014; WHO, 2015).

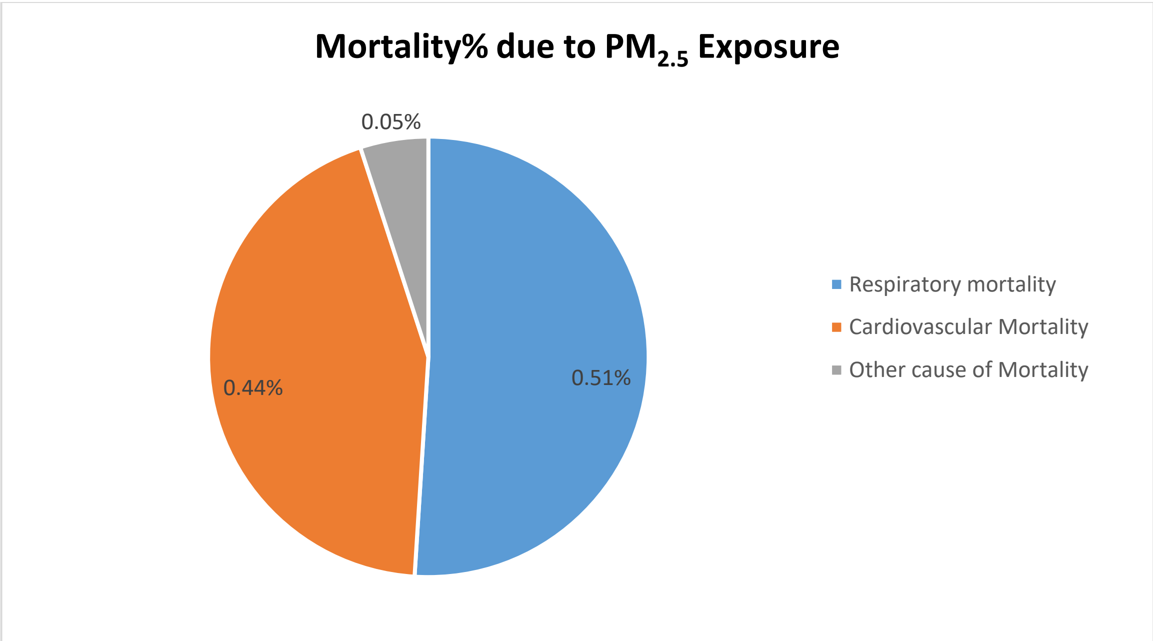

Figure 2.1: Mortality% due to PM2.5 Exposure

Figure 2.1 demonstrates a 0.38% increase in overall mortality, 0.51% increase in respiratory mortality, and 0.44% increase in cardiovascular mortality for every 10 $\mu g/m^3$ rise in $PM_{2.5}$. (WHO, 2012). In affluent nations, a large number of epidemiological and toxicological studies have linked higher particle concentrations (particularly $PM_{2.5}$) to an increased risk of early mortality. Various studies (e.g., USEPA 2007) suggest that $PM_{2.5}$ is the most harmful of the criterion air pollutants to human health. Air pollution (indoor and outdoor) has recently been identified as the world's greatest single environmental health concern, with an ever-increasing link to cardiovascular disease and cancer (WHO, 2014; Baklanov et al., 2016). PM_{10} has been linked to the rapid onset of maternal emotional stress. (Lin et al.2017).

2.3 EFFECTS OF AIR POLLUTANTS ON CONSTRUCTION MATERIALS

Building degradation has been observed since the beginning of the industrial revolution. Though there are numerous causes for degradation, air pollution is the most significant. Acid rain, which is caused by air pollution, may be the primary cause. Sulphur dioxide and nitrogen dioxides are the primary pollutants responsible for acid rain. These two gases are produced when fossil fuels like coal and oil are burned. The quantity of these emissions has increased as a result of growing industrialization. In industrialized countries such as the United Kingdom, the United States, Germany, France, and Japan, the amount of these emissions has skyrocketed. There is a scarcity of data on material damage caused by air pollution. However, data on the corrosive effects of acid precipitation on metals is available for a limited time.

2.3.1 EFFECTS AIR POLLUTANTS ON ZINC

We present the results of a laboratory investigation into the role of, and in the subparts per million range on the atmospheric corrosion of zinc. Each sample was individually exposed to synthetic atmospheres with pollutant concentrations, relative humidity, and flow conditions carefully controlled. Furthermore, we investigated the pollutants' interactions with zinc using time resolved trace gas analysis and accelerate zinc corrosion in humid air containing. While catalyzing the oxidation of on zinc, it oxidizes loosely bound four-valent sulfur on the zinc surface to sulfate. The increased formation of sulfate and hydrogen ions on the surface causes solid corrosion products to dissolve and metal dissolution to accelerate. The acceleration of zinc oxidation and deposition is becoming increasingly important. (Johansson, 1993)

2.3.2 EFFECTS OF AIR POLLUTANTS ON COPPER

Within a few days or weeks, outdoor corrosion of copper produces a passivating corrosion layer, which progresses from reddish brown to dark brown or black due to copper oxidation and the formation of cupric and cuprous oxides, the latter being thermodynamically more stable27 and also commonly observed, as well as cuprous hydroxides. This layer is generally thought to be dense, providing good protection against further corrosion. A greenish-blue texture with a layered structure forms during the subsequent corrosion stages, which can last up to 20 years depending on the environmental conditions. It is primarily made up of the basic copper sulphate brochantite (Cu SO_4(OH)). However, antlerite (Cu_3S $_4(OH)_4$) and Posnjakite ($Cu_4(SO_4)(OH)_6 \cdot H_2O$) as well as Copper. (S.Oesch, September 1997)
When exposed to air, copper oxidizes as a result of a reaction with oxygen and liquid water or moisture in the air. Oxidation is responsible for the characteristic red outer layer (rust) that forms when iron corrodes.

2.3.3 EFFECTS OF AIR POLLUTANTS ON ALUMINIUM

Aluminum's corrosion resistance against atmospheric degradation is primarily due to a thin, compact, low electron-conducting corrosion layer that forms quickly and is reformed in the event of destruction. Aluminum hydroxides and oxides, as well as their hydrated compounds, make up the corrosion layer that forms in the presence of water. Because this protection layer is unstable at pH 4 and pH > 9, it can be locally destroyed by pollutant accumulations in the atmosphere. In the presence of chlorides, pitting was observed, whereas in the presence of Sulphur dioxide and particles, a uniform but locally enhanced corrosion attack was observed.

Pitting occurs in the presence of chlorides due to the formation of Aluminum chlorides. They are less stable than aluminum hydroxides or oxides and thus react more, liberating chloride and allowing the corrosion process to continue. Sulphate, on the other hand, is captured and inactivated in stable amorphous Aluminum sulphates. Aluminum hydroxides and oxides can be converted to aluminum sulphates due to their lower stability." Pitting was also observed in solutions at higher sulphate levels. Furthermore, samples exposed to airborne particles contain nitrates, ammonium, and metal ions, as well as trace amounts of carbonates. However, no aluminum nitrates or carbonates were found in field exposures, and no naturally formed minerals are known. This is due to the nitrates and carbonates' high-water solubility.

2.3.4 EFFECTS OF AIR POLLUTANTS ON LIMESTONE

The most contentious issue is the crust weathering of limestone caused by the transformation of calcium carbonate into calcium sulfate as a result of the impact of air pollutant concentrations in the atmosphere and anthropogenic sulfur deposition. Although SO2 concentrations have decreased in recent decades, degradation associated with weathering crusts continues to be observed. Acid rain affects stone material and corrodes rock-forming minerals as a result of rain water contamination with sulfur, nitrogen oxides, and carbon oxides. Pollution has evolved into a complex multi pollutant situation, with increased particulate matter, which increases the acidic impact of dust deposition.

CHAPTER THREE
METHODOLOGY

3.1 GENERAL

Dhaka has been named one of the most polluted cities in the world in terms of PM2.5 concentration and Air Quality Index (AQI) in recent years (IQAir, 2018, 2019, 2020, 2021). This city is consistently ranked among the top five or 10 cities with the worst air quality. The government of Bangladesh's Department of Environment (DoE) indicated that particulate matter in Dhaka City's air comes primarily from motor vehicles and brick kilns in and around the city (DOE, 2019). Begum et al. (2013) found that the brick kiln and vehicle emissions contributed roughly 22% and 36% of fine particulate matter in Dhaka's air, respectively. Furthermore, roadside dirt is one of the most significant sources of dust or coarse particulate matter, particularly during the dry season, which runs from November to February. Furthermore, other megaprojects are under construction at the same time.

However, the worldwide COVID-19 epidemic, which began in China in December 2019, has prompted people to restrict their movements and shut down companies all around the world. To combat the virus, Bangladesh's government issued a public vacation, essentially a lockdown, in the last week of March 2020. Motor vehicle travel was suddenly prohibited, with the exception of emergency transport such as medication and food. The brick kilns, as well as other enterprises in and around Dhaka, remained shuttered. In these circumstances, there was a worldwide reduction in pollution, particularly in metropolitan areas. According to one estimate, the pandemic reduced public movement by 90%, resulting in a nearly 30% drop in pollution in illness epicenters such as Wuhan, Italy, Spain, and the United States (Muhammad et al., 2020). Similar air pollution reduction findings have been reported in the capital city of a nearby nation, namely Delhi (e.g., Mahato et al., 2020; Sharma et al., 2020). Furthermore, Nakada and Urban (2020) discovered that during a partial lockdown for the COVID-19 pandemic in So Paulo, Brazil, NO, NO_2, and CO concentrations were dramatically lowered.

3.2 STUDY AREA AND DATA COLLECTION

Table 3.1: List of data sources used in this study

Data	**Period**	**Time Resolution**	**Spatial resolution**	**Source**
PM2.5	2016-2021	Hour	Station	US Embassies and Consulates | AirNow.gov
NO_2, SO_2, CO, O_3	2016-2021	Day	Station	Department of Environment (DoE)
Precipitation, temperature, relative humidity, and wind speed	2016-2021	Day	Station	World Weather Online Team

This study is based on secondary time series data of PM2.5 concentrations from 2016 to 2021, as well as NO_2, SO_2, CO concentrations and AQI values from 2016 to 2021. The PM2.5 time series data were acquired from the archive of a real-time air quality monitoring system administered by the United States Environmental Protection Agency (US EPA), which is located at the US Consulate in Dhaka. The Air Quality Monitoring Station is erected on a rooftop in a city. NO_2, CO, SO_2, and O_3 were measured at the Department of Environment's stations CAMS-1, CAMS-2, and CAMS-3 (DoE).

The Air Quality Monitoring Station is located on a city rooftop. The monitoring station's surroundings include built-up areas with adequate road connectivity and regular traffic activity, including residential and commercial land use. Although the study's goal years are 2021, 2020, and 2019, data from the prior three years have also been collected to show the shift in pollution levels. PM2.5 concentrations are recorded hourly. In addition to the raw pollutant concentration on an hourly basis, the US EPA compiles Now Cast data based on the weighted average of the most recent 12-h data to compute AQI. In this study, the Now Cast PM2.5 concentration was used to determine AQI values rather than the hourly raw concentration. The daily and yearly averages, on the other hand, were computed from hourly raw data. Furthermore, time-series data of NO2, SO2, and CO concentrations during April–May in 2019, 2020, and 2021 were analyzed using remote techniques from the Sentinel-5P satellite.

Table 3.2: Classes of AQI values and their health implications

AQI level	Numeric value	Meaning
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable; however, for some contaminants, there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101-150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151-200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
Very Unhealthy	201-300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301-500	Health alert: everyone may experience more serious health effects

US EPA (2018)

Before analyzing the hourly concentration of PM2.5, certain quality control checks were carried out. The producers have previously identified several missing and erroneous values in the data series. That is, the PM2.5 time series data were subjected to a quality check before being made accessible for general use. During the current analysis, the missing data were interpolated using the linear interpolation approach, and the erroneous values were omitted.

3.3 DATA ANALYSIS

3.3.1 AIR QUALITY INDEX (AQI)

Various government agencies calculate the Air Quality Index to report how polluted the present air is or will be. The AQI was derived using the following formula (Eq) using the NowCast concentration of PM2.5 (from 2016 to 2018) and the concentration of other pollutants, e.g., PM2.5, NO_2, SO_2, CO (from 2019 to 2021). (US EPA, 2018). This formula yields a value between 0 and 500.

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}. \tag{3.1}$$

Here,

I_P = the index for pollutant p.

C_P = the truncated concentration of pollutant p.

BP_{Hi} = the concentration breakpoint that is greater than or equal to C_P.

BP_{Lo} = the concentration breakpoint that is less than or equal to C_P.

I_{Hi} = the AQI value corresponding to $BP_{Hi.}$

I_{Lo} = the AQI value corresponding to BP_{Lo}

How can I compute the AQI using the table, equation, and my concentration data?

Assume you have an ozone value of 0.08853333 throughout an eight-hour period. To begin, reduce the value to 0.088. Then look at the 8-hour ozone chart to see what values are above and below the value (0.071-0.085). The 0.088 number in this example lies between the index values of 101 and 150. You now have all of the numbers you'll need to solve the problem.

$$\frac{(150 - 101)}{(0.085 - 0.071)} * (0.088\text{-}0.071) + 101 = 160.5$$

So, an 8-hour value of 0.08853333 corresponds to an index value of 160.5.

3.3.2 NITROGEN DIOXIDE, SULFUR DIOXIDE, CARBON MONOXIDE, OZONE MEASUREMENT

Satellite equipment may detect air pollutants including NO_2, ozone, sulfur dioxide (SO_2) and carbon monoxide (CO). These tools compute backscattered solar energy throughout a wide spectral range, from ultraviolet (UV) to infrared wavelengths. To convert observed radiation to pollutant concentrations, such as a tropospheric column density of NO_2, advanced retrieval methods are used. On July 15, 2004, the National Aeronautics and Space Administration (NASA) launched the Aura satellite, which is equipped with an ozone monitoring instrument (OMI) to monitor changes in air quality in numerous places around the world. It is being utilized in this study to track variations in NO_2 emissions over Bangladesh prior to and during the COVID-19 outbreak.

3.3.3 DATA LOCKDOWN PERIOD

To identify the lockdown time for the Dhaka city of interest, sources such as media, official government websites (Department of Environment, DoE), and research papers were consulted. It should be emphasized that the time is measured from the commencement of the lockdown or severe social distance policy until the date the lockdown began to lighten, as reopening is a complicated process that may encompass numerous phases. To compare AQI data during the lockdown period to historical data, the same period of data for 2016, 2017, 2018, and 2019 were used. The average AQI of each pollutant was compared to the previous year (2019) and to the 3-year average of the same time to compute the decrease or growth of each pollutant.

3.3.4 ATTRIBUTE MISSING DATA USING RANDOM FOREST ALGORITHM

It was assumed that X = (X_1, X_2, ..., X_p) is a n x p-dimensional data matrix. For missing observations, it was recommended to use the random forest approach. The random forest technique has a built-in process for dealing with missing values by weighing the frequency of variables with the vicinity of a random forest after training an initially imputed mean data set. This method necessitates the inclusion of a comprehensive and meaningful response variable for forest training. Instead, estimation was done for the values of all missing values directly using a random forest trained on the observed data set, where X is the whole data matrix. X_s contains all missing values at entries $i_{mis}^{(s)} \subseteq \{1, \ldots, n\}$. The data set can be separated into four parts:

1. $y_{obs}^{(s)}$: the observed values of X_s.
2. $y_{mis}^{(s)}$: the missing values of X_s.
3. $x_{obs}^{(s)}$: the observations, $i_{obs}^{(s)} = \{1, \ldots, n\} \setminus i_{mis}^{(s)}$, that belong in the other variables X_s
4. $x_{mis}^{(s)}$: the observations, $i_{mis}^{(s)}$, that belong in the other variables X_s

It should be noted that $x_{obs}^{(s)}$ and $x_{mis}^{(s)}$ are not completely observed, as the index $i_{obs}^{(s)}$ corresponds to the observed values of the variable X_s.

Depending on the data, the procedure begins with an initial approximation for the missing values in X using a mean imputation technique or any other imputation method. Then, the predictors were sorted X_s, s = 1,…, p, ascending or descending, X_s, s = 1,…, p, according to the number of missing values. Then, for each variable X_s, the missing values are imputed by random forest (i.e., the first fitting) with response $y_{obs}^{(s)}$ and predictors $x_{obs}^{(s)}$. Next, the missing values $y_{mis}^{(s)}$ are estimated by applying the trained random forest to $x_{mis}^{(s)}$. The imputation procedure should be performed until a condition is met.

Here, the difference for the set of continuous variables N is defined as:

$$\Delta N = \frac{\sum j \varepsilon N (X_{new}^{imp} - X_{old}^{imp})^2}{(X_{new}^{imp})^2}, \tag{3.2}$$

and that for the set of categorical variables F as:

$$\Delta F = \frac{\sum_{i=1}^{n} I X_{new}^{imp} \neq X_{old}^{imp}}{\#NA} \quad (3.3)$$

Set the stopping criterion (ɤ) and the starting guess for missing values for X, which is a n x p matrix. k ← vector of sorted indices of columns in X w.e.t. increasing number of missing values. X_{old}^{imp} ← stores the previously imputed matrix. Fit a random forest $y_{obs}^{(s)} \sim x_{obs}^{(s)}$. Predict $y_{mis}^{(s)}$ using $x_{mis}^{(s)}$, X_{new}^{imp} ← update the imputed matrix using the predicted $y_{mis}^{(s)}$. Update ɤ and the imputed matrix X^{imp}. Where #NA is the number of missing values in the categorical variables F.

After imputing the missing values, the performance is assessed using the normalized root mean squared error for the continuous variables, defined by:

$$\text{NRMSE} = \sqrt{\frac{mean\,((X^{true} - X^{imp})^2)}{var(X^{true})}} \quad (3.4)$$

where X^{true} and X^{imp} are the complete data matrix and the imputed data matrix, respectively. In this study, all predictors are classified as continuous observations. The mean and variance are used as a short notation for empirical mean and variance computed over the missing values only.

It was employed the out-of-bag (OOB) estimate of an error for the variable when fitting an RF to the portion that is seen on it. Average was done the halting criterion (ɤ) over the variable set of that type to approximate the actual imputation mistakes. The accuracy of this estimate is determined by comparing the absolute difference between the OOB imputation error estimate and the genuine imputation error over all simulation runs.

3.4 EFFECTS OF AIR POLLUTANTS ON CONSTRUCTION MATERIALS

3.4.1 GENERAL

The effect of air pollutants and mostly visible on the building and structures that have been existing for quite some period. The effects of air pollutants take significant amount of time to become visible. But throughout study the existence of air pollutants has been proved (Tidblad). The effects do prevail on the whole structure but on certain materials that has been used for construction and that has been exposed to open air or air containing the pollutants like (SO_2, O_3, NO_2).

Due to COVID-19 Pandemic the Bangladesh Government issues several Lock Downs Shut Downs or Restriction of different manner and period. All these restrictions and lockdowns has significantly caused variation in the air pollutant quantity in the air as was founded from the comprehensive study.

Now it was ought to observe the effect of air pollutants found in the air of Dhaka city on the construction materials that has been used to construct several infrastructures and buildings. For the observation of the harmful effects of air pollutants in the construction materials like Zinc (Zn), Aluminum (Al), Copper (Cu), Sandstone & Limestone, Dose-Response Function [Tidblad] was used. The Dose- Response function that was used is applicable for data sets over 8-year period. It was predicted that the future conditions of construction materials (Cu) by using multiple linear regression. By using multiple linear regression modelling an equation was founded that pictures a future scenario of the effects of air pollutants on the particular construction material (Cu).

3.4.2 DATA COLLECTION

The data that were required for the study are:

- [SO_2], [O_3] Concentration
- [Cl^-] Concentration
- Acidity precipitation [H^+]
- Rain water Precipitation
- Relative Humidity
- Temperature
- Time

The data regarding [SO_2] & [O_3] Concentration was collected from The Department of Environment (DoE) [DoE] & US Embassy Air quality observation Wing [USEPA]. The data was collected in the range of the years 2013 – 2021. But there were several data missing and for which the results were affected and couldn't be presented with proper accuracy Random Forest Modelling was used to recover the missing data and put into computation.

Later for data related to Amount of Precipitation, Temperature, Relative Humidity were collected from a website called "World Weather Online."(World weather online, 2018)

The data of [Cl^-] Concentration & Acidity Precipitation [H^+] was taken from a research paper studying the physical parameters of rainwater. They collected samples from the top of the buildings in various regions of Dhaka. (Haque & Rinkey, 2019)

3.4.3 ANALYZING EFFECT OF DRY & WET DEPOSITION BY DOSE RESPONSE FUNCTION

Study was conducted for the effect of two types of depositions, they are: Dry & Wet. These depositions are sourced from the atmosphere and they affect the materials that are directly exposed to them.

Dry Deposited Compounds: SO_2, O_3 (Pollutants affecting the most)

Wet Deposited Compounds: Rainwater (P^H, [Cl^-], H^+)

This deposition will fall/stay on the unsheltered construction materials & will react with them allowing a corrosion/corrosion like action which will allow the materials to degrade. The corrosion/decay that occurs are two types.

Corrosion/Decay

- Surface Recession (µm) → (In case of Stone type materials, example: Sandstone, Limestone)
- Mass Loss (gm^{-2}) → (In Case of Metallic materials, Example: Cu, Zn, Al)

The Dose-Response Function is a way to measure the effect of wet and dry deposition on the exposed construction materials. By this mean the cost analysis and expenditure can be benefitted and an idea of durability of the elements can be predicted.(Tidblad)

3.4.4 SELECTION OF ENVIRONMENTAL PARAMETERS

Table 3.3: Environmental Parameters that is considered in the Dose-Response Functions

Symbols	*Description*	*Unit*
t	Time	Years
T	Temperature	^oC
Rh	Relative Humidity	%
$[SO_2]$	SO_2 concentration	$\mu g/m^{-3}$
$[O_3]$	O_3 Concentration	$\mu g/m^{-3}$
$[H^+]$	H^+ concentration	mg/l
$[Cl^-]$	Cl^- Concentration	mg/l
Rain	Amount if Rainfall	mm

(Kucera et al., 2001)

3.4.5 LIST OF DOSE-RESPONSE FUNCTIONS

Table 3.4: Dose-Response Functions based on 8-Year Results

1. $ML_{zinc} = 1.4[SO_2]^{0.22}e^{0.018Rh}e^{f(T)}t^{0.85} + 0.029Rain[H^+]t$
   where $f(T) = 0.062(T - 10)$, when $T < 10°C$; otherwise, $f(T) = - 0.021(T - 10)$

2. $ML_{copper} = 0.0027[SO_2]^{0.32}[O_3]^{0.79}Rhe^{f(T)}t^{0.78} + 0.050Rain[H^+]t^{0.89}$
   where $f(T) = 0.083(T - 10)$, when $T < 10°C$; otherwise, $f(T) = - 0.032(T - 10)$

3. $ML_{Aluminum} = 0.0021[SO_2]^{0.23}Rhe^{f(T)}t^{1.2} + 0.000023Rain[Cl^-]t$
   where $f(T) = 0.031(T - 10)$, when $T \leq 10°C$; otherwise, $f(T) = - 0.061(T - 10)$

4. $R_{Limestone} = 2.7[SO_2]^{0.48}e^{-0.018T}t^{0.96} + 0.019Rain[H^+]t0.96$

5. $R_{Sandstone} = 2.0[SO_2]_{0.52}e^{f(T)}t^{0.91} + 0.028Rain[H^+]t^{0.91}$
   where $f(T) = 0$, when $T \leq 10°C$; otherwise, $f(T) = - 0.013(T - 10)$

(Kucera et al., 2001)

3.4.6 MATHEMATICAL COMPUTATION

Table 3.5: Average of Humidity, Temperature & Amount of Rainfall Data for the Year 2017 for Dhaka City

	2017		
	Humidity (%)	Temperature (c)	Rainfall (mm)
January	46	24	0
February	44	27	14.8
March	57	28	84
April	68	31	241.9
May	66	33	174.2
June	78	31	435.9
July	78	31	374.9
August	74	32	331
September	73	32	316.2
October	72	30	249.3
November	58	29	14.5
December	59	26	56.4
Average=	64.42	29.5	191.09

Table 3.6: Average of SO2 & O3 Data For the year 2017 for Dhaka City

	SO_2 Data	**O_3 Data**
	20.4	13.8
January	7.28	16.3
March	6.4	6.19
April	11.5	5.355
May	5.8	16.5
June	7.4	12.2
July	2.9	2.955
August	4.62	2.57
September	1.2	3.5
October	3.7	4.825
November	47	4.75
December	49	1.52
Average	13.93 ppb	7.54 ppb
	35.95 $\mu g/m^{-3}$	19.45 $\mu g/m^{-3}$

Using Formula 2 from Table 3.4

f(T) = − 0.032(T − 10);

Putting the value from *Table-3.6*, f(T)= -0.624

Now,

$ML_{copper} = 0.0027[SO_2]^{0.32}[O_3]^{0.79}Rh e^{f(T)} t^{0.78} + 0.050Rain[H^+]t^{0.89}$

Putting the Values from Table-4 & f(T)=-0.624; thus $ML_{copper} = 0.0066\ gm^{-2}$

3.5 MULTIPLE LINEAR REGRESSION

Multiple linear regression model was used to predict the condition and the course of effect of air pollutants on the construction materials. For this modelling the data of Copper (Cu) was used.

Table 3.7: Correlation Factor

	Y	**X_1**	**X_2**
Y	1.00	0.131	0.91
X_1	0.131	1.00	-0.24
X_2	0.91	-0.24	1.00

Table 3.8: Analysis of Variable Table

Source	**DE**	**Sum of Square**	**Mean Square**	**F Statistic**	**P-Value**
Regression (Between $\hat{y}_i$; and y_i)	2	0.0000181672	0.00000908362	94.830432	0.0000288365
Residual (Between y_i & $\hat{y}_i$)	6	5.74728e-7	9.57880e-8		
Total (Between y_i; and y_i)	8	0 0000187420	0.00000234275		

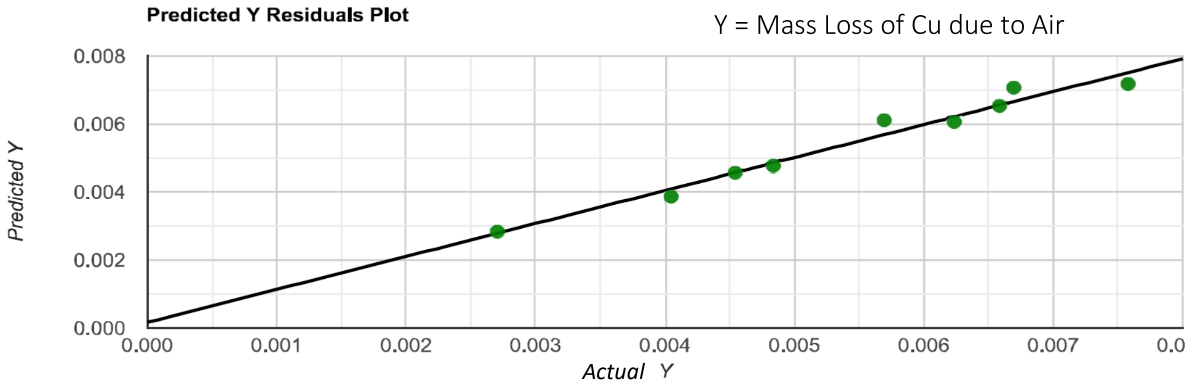

Figure 3.1: Comparison of Actual & Predicted graph of MLCu

As it can be seen from the graph that the predicted curve is well matched with the actual curve of the ML_{Cu}.

3.5.1 PREDICTED EQUATION FOR ML_{CU}

$$\mathbf{Y} = -0.000817868 + 0.0000662266\, \mathbf{X_1} + 0.000255026\, \mathbf{X_2} \qquad (3.5)$$

Here,

X_1 = Concentration of SO_2(µg /m^3)

X_2 = Concentration of O_3 (µg /m^3)

Y = Mass Loss of Cu due to air pollutants

Y and X relationship

R square (R^2) equals 0.969335. It means that the predictors (X_i) explain 96.9% of the variance of Y.

Adjusted R square (R^2) equals 0.959113.

The coefficient of multiple correlation (R) equals 0.984548. It means that there is a very strong direct relationship between the predicted data (ŷ) and the observed data (y).

Goodness of Fit

Overall regression: p-value = 0.0000288365. Since p-value < α (0.05)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 AIR QUALITY PARAMETRS

4.1.1 OZONE (O_3)

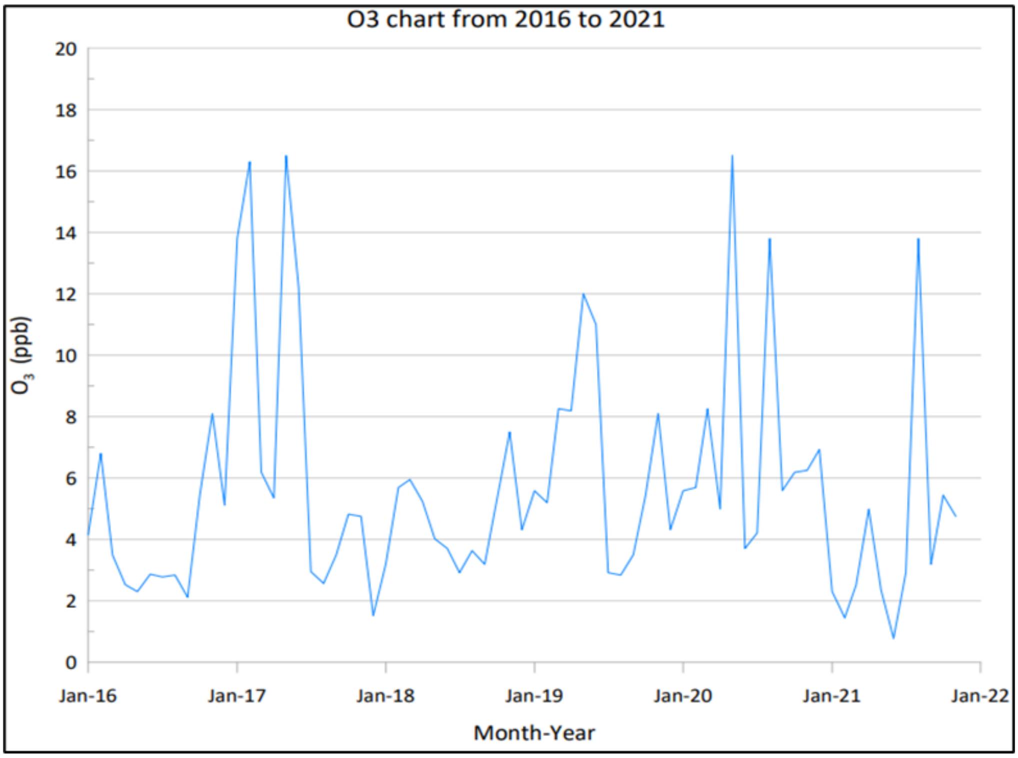

Figure 4.1: O_3 From 2016- 2021

From Figure 4.1, during the beginning of 2018, the amount of O_3 ranged from 16 (ppb) to 16.5 (ppb). Between the middle of 2020 and 2021, the amount of O_3 in the atmosphere decreased dramatically, ranging from 1 (ppb) to 1.5 (ppb). According to the statistics, the rate of increase in O_3 concentrations is significant, ranging from. The lowest measured quantity of O_3 during the lockdown was roughly 1 (ppb).

4.1.2 SULFER DI-OXIDE (SO_2)

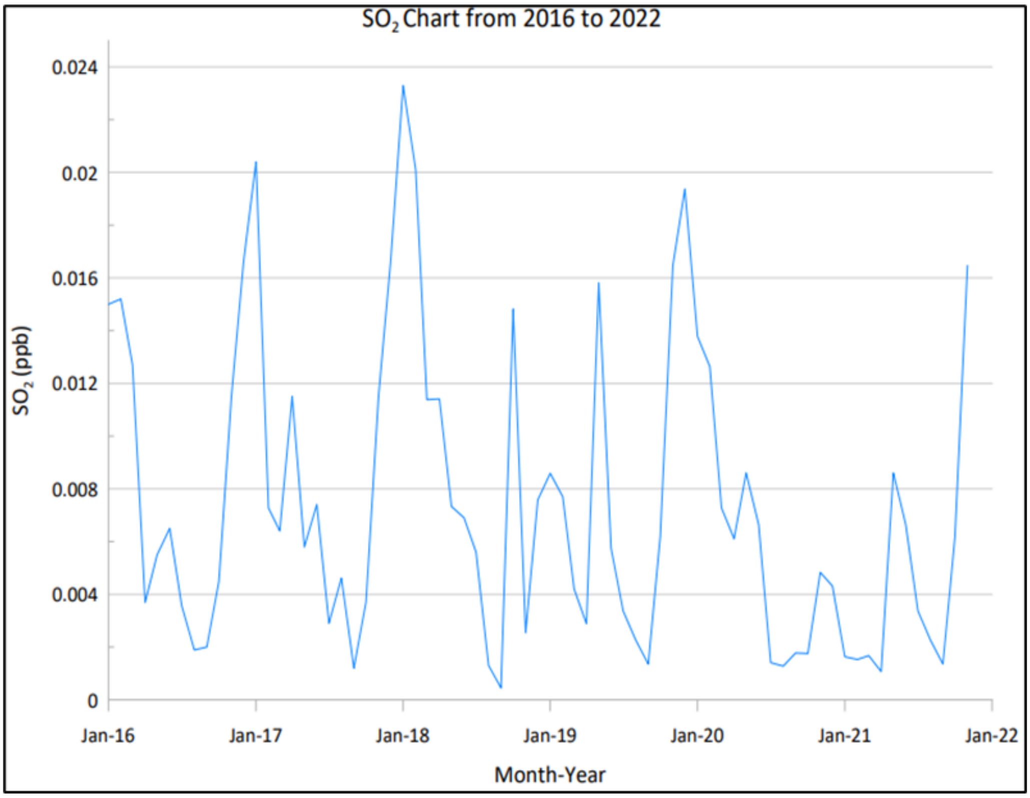

Figure 4.2: SO_2 From 2016- 2021

From Figure 4.2, during the time frame of 2016- 2018, the amount of SO_2 ranged from .015 (ppb), 0.02 (ppb) and 0.023 (ppb). Between the middle of 2020 and 2021, the amount of SO_2 in the atmosphere decreased dramatically, ranging from 0.0019 (ppb) to 0.0020 (ppb). According to the statistics, the rate of increase in SO_2 concentrations is significant, ranging from the lowest measured quantity of SO_2 during the lockdown was roughly 0.00195 (ppb).

4.1.3 NITROGEN DI-OXIDE (NO_2)

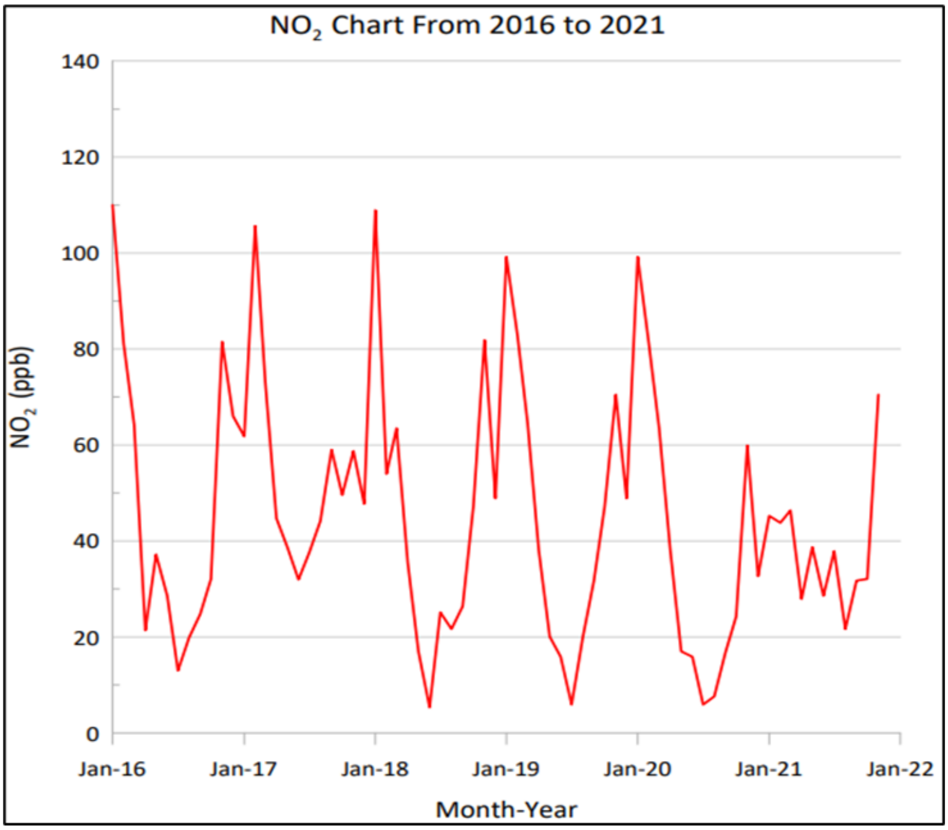

Figure 4.3: NO_2 From 2016- 2021

Form Figure 4.3, During the year of 2016, 2017, 2018 in the month of January 105 (ppb) to 110(ppb). Meanwhile in 2019 and 2020 the amount was 98(ppb) to 100 (ppb). The amount of NO_2 change significantly in the period of 2021, range of 30 (ppb) to 50 (ppb).

4.1.4 CARBON MONO-OXIDE (CO-8HR)

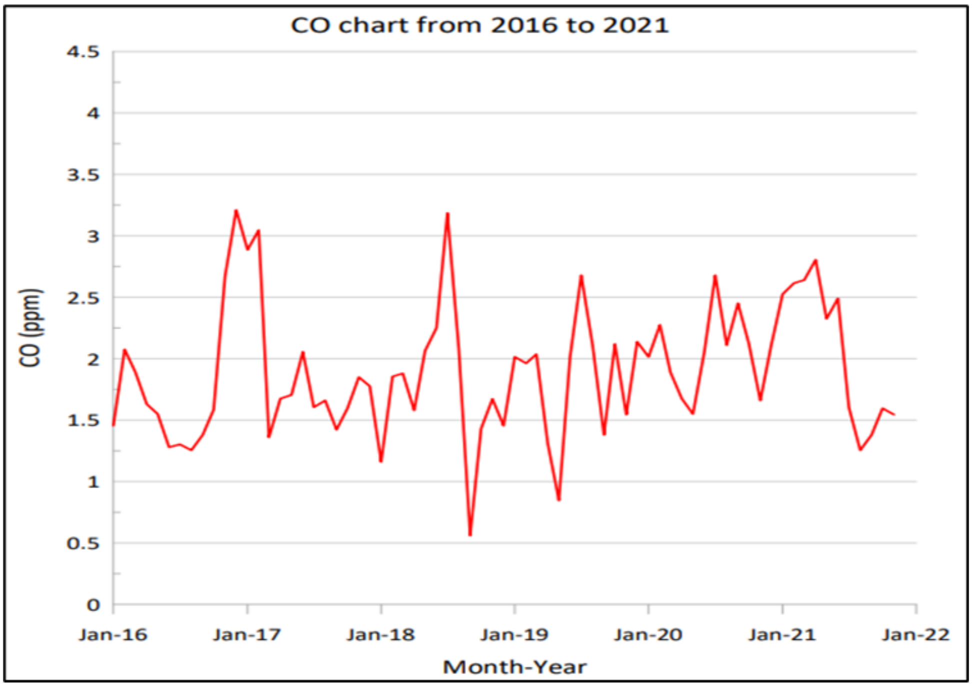

Figure 4.4: CO From 2016- 2021

From Figure 4.4 we can see that during the year of 2016 to 2021 the amount of CO ranges around from 0.68 (ppm) to 3.47 (ppm). During 2017 to 2018 the highest Co recorded in.

4.2 AIR QUALITY INDEX (AQI)

On average, the Air Quality Index has dropped by 35%. During the lockdown period in 2020, the AQI varied from 81 to 205, with an average of 127.78, whereas in 2018 and 2019, it ranged from 91 to 214 and 86 to 255, with mean values of 140.80 and 153.48, respectively. According to the data, air quality in 2019 was worse than it was in 2018. The air quality improved during the lockdown period in 2020, compared to the same period in 2018 and 2019. The AQI increased by 9.00% in 2019 compared to 2018, but decreased by 9.57% in 2020. When comparing the years 2019 and 2020, it was discovered that the AQI in 2020 was 16.74% lower than in 2019.

4.3 OBSERVATION OF AIR POLLUTANT EFFECTS ON CONSTRUCTION MATERIALS

After through study and observation from our collected data by the help of Dose response function we have achieved the following results.

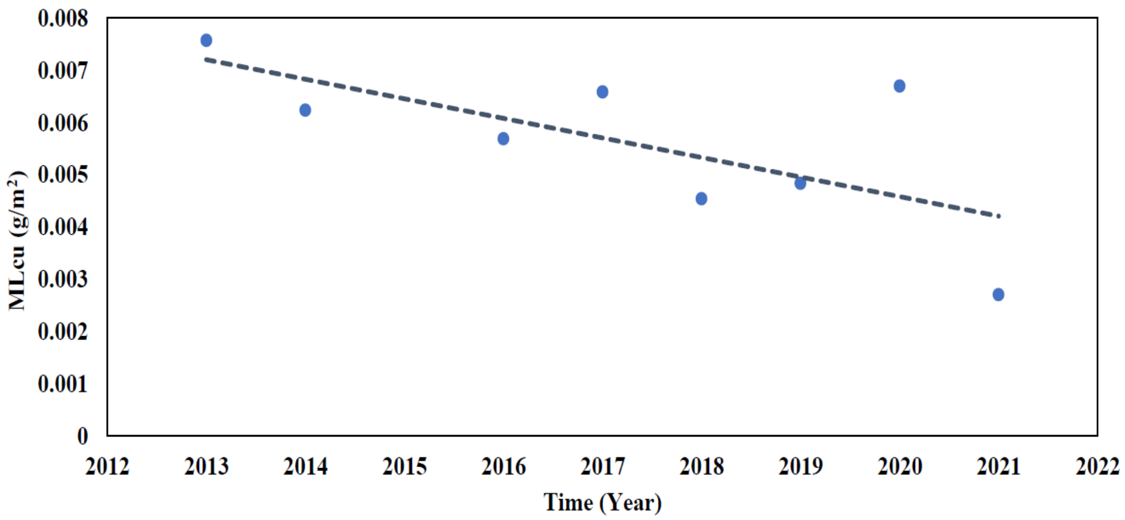

Figure 4.5: Mass Loss of Cu due to air pollutants 2013-2021

In this Figure 4.5 we have calculated the mass loss of Cu due to air pollutant from the year 2013 to 2021 by the help of Dose response function. Here we can see the trend line is downwards and results in the year 2020 and 2021 are significantly lower than the previous years. This is because of the decrease in emission of air pollutants from industries, factories and other sources. The movement restriction from 2020 to 2021 caused the significant drop in the effects of air pollutants on Cu.

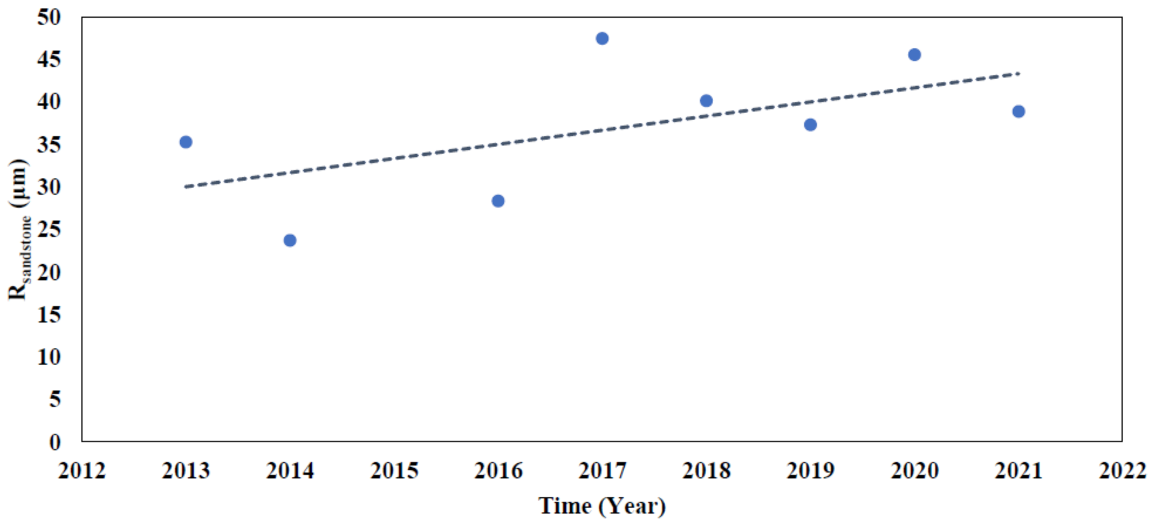

Figure 4.6: Surface Recession of Sandstone

In this Figure 4.6 we have calculated the Surface Recession of Sandstone due to air pollutant from the year 2013 to 2021 by the help of Dose response function. Here we can see the trend line is upwards but results in the year 2020 and 2021 are lower than the previous years. The trend line is upward because the effects of air pollutants take significant amount of time to prevent if we continue to control the emission rate of air pollutants the effects will minimize overtime. This is because of the decrease in emission of air pollutants from industries, factories and other sources. The movement restriction from 2020 to 2021 caused the significant drop in the effects of air pollutants on Sandstone.

It was discovered that during the COVID-19 epidemic, corrosion of other construction materials was lower than the previous year too. Pollutants in the air have decreased as a result of lower emissions from companies and cars. It was observed that the effects of air pollution on construction materials will never be zero using Multiple Linear Regression modeling. Although the effect will be minimal, the declining action will continue.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. The concentration of fine particulate matter (PM2.5) has decreased by 26% during the lockdown period.
2. The concentrations of NO_2, SO_2, CO and O_3 have decreased by 30, 07, 11% and 07%, respectively.
3. The Air Quality Index has decreased by about 35% on average.
4. Our predictors (X_i) explain 96.9% of the variance of Y
5. The p-value is $0.0000288365 < 0.05$, so the result is significant.
6. The deterioration of construction materials sandstone, Zinc, Limestone and Aluminum have decreased by 14.68%, 5%, 13.94%, 15% respectively

5.2 RECOMMENDATIONS

1) Further increasing the data set.
2) Assuring the accuracy of the acquired data.
3) Collecting data from numerous areas.
4) To improve accuracy, variables cam be increased.
5) Further extensive study on other construction materials

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APPENDIX A

Table A.1: Sensitivity of materials to air pollution

Material	Sensitivity to air pollution
Brick	Very low
Mortar	Moderate to high
Concrete	Low
Natural stone (sandstone, limestone, marble)	High (Severely affected by SO_2)
Unalloyed steel	High (severely affected by SO_2)
Stainless steel	Very low
Copper	Low
Aluminum	Very low
Lead	Very low
Zinc and galvanized steel	High (Especially in SO_2-polluted environment)

APPENDIX B

Table B.1: Rainfall and Air Pollutant Data (2016, 2017)

Year/ Month	Month	Avg Temp C	Rainfall (mm)	Humidity	Pressure- (MB)	PM2.5 (µg/m3)	NO2 (ppb)	SO2- (ppm)	CO-8hr (ppm)	O3-8hr (ppb)
2016	Jan	24	0.71	51	1014.7	179	110	0.015	1.455	4.15
2016	Feb	28	14.6	46	1013.2	140.5	81.1	0.0152	2.075	6.8
2016	Mar	32	74.9	47	1010.1	105.2	64.2	0.0127	1.89	34.9
2016	Apr	33	138.3	63	1005.1	44.97	21.4	0.0037	1.63	2.53
2016	May	33	240.99	67	1003.9	52.76	37.2	0.0055	1.55	23
2016	Jun	32	151.77	74	1002.2	29.95	28.6	0.0065	1.28	2.87
2016	Jul	31	153.88	78	999.7	18.75	13	0.0036	1.30333	2.78
2016	Aug	31	134.02	75	1000.7	31.6	19.9	0.0019	1.255	2.84
2016	Sep	31	206.3	77	1004	32.7	24.8	0.002	1.38	2.12
2016	Oct	30	110.4	74	1006.6	44.1	32.1	0.0045	1.585	5.44
2016	Nov	28	46.24	69	1011.3	105	81.5	0.0115	2.67	8.1
2016	Dec	26	0	59	1013.2	169	66	0.0166	3.21	5.12
2017	Jan	24	0	46	1014.3	190.7	61.8	0.0204	2.88667	13.8
2017	Feb	27	14.8	44	1013.2	161.7	105.7	0.0073	3.04667	16.3
2017	Mar	28	84	57	1009.5	92.6	73.2	0.0064	1.36	6.19
2017	Apr	31	241.9	68	1006.5	61.9	44.75	0.0115	1.675	5.355
2017	May	33	174.2	66	1004.3	50.3	38.7	0.0058	1.705	16.5
2017	Jun	31	435.9	78	1000.6	32.5	32	0.0074	2.055	12.2
2017	Jul	31	374.9	78	1000.7	29.9	37.6	0.0029	1.605	2.955
2017	Aug	32	331	74	1002	33.2	44.18	0.0046	1.66	2.57
2017	Sep	32	316.2	73	1004.7	37.2	59	0.0012	1.42333	3.5
2017	Oct	30	249.3	72	1007.4	50.2	49.6	0.0037	1.59667	4.825
2017	Nov	29	14.5	58	1011.2	95	58.73	0.047	1.85	4.75
2017	Dec	26	56.4	59	1013.8	144.1	47.79	0.049	1.77667	1.52

Table B.2: Rainfall and Air Pollutant Data (2018, 2019)

Year/ Month	Month	Avg Temp C	Rainfall (mm)	Humidity	Pressure- (MB)	PM2.5 (µg/m3)	NO2 (ppb)	SO2- (ppm)	CO-8hr (ppm)	O3-8hr (ppb)
2018	Jan	24	0	47	1012.7	202.2	108.9	0.0233	1.16	3.215
2018	Feb	27	2.8	43	1012.6	160.7	54	0.031	1.855	5.69
2018	Mar	32	22.49	45	1008.9	110	63.5	0.0114	1.88	5.955
2018	Apr	32	209.09	56	1007.2	70.2	35.58	0.0114	1.58	5.24
2018	May	32	452.7	69	1004.9	43.4	17	0.0073	2.065	4.025
2018	Jun	32	322.6	73	999.4	29.5	5.34	0.0069	2.25	3.71
2018	Jul	31	257.6	76	998.7	23.3	25.13	0.0056	3.185	2.92
2018	Aug	31	286.3	75	999.5	27.3	21.69	0.0013	2.08333	3.6367
2018	Sep	32	202	70	1005.2	51.1	26.4	0.0005	0.26	3.19
2018	Oct	29	36.7	64	1010.5	79.82	47.16	0.0148	1.43	5.295
2018	Nov	29	15.8	56	1012.9	131	81.85	0.0025	1.6735	7.5
2018	Dec	24	37.4	54	1014.4	156.1	48.89	0.0076	1.455	4.3167
2019	Jan	25	0.2	46	1015.6	181.8	99.17	0.0086	2.015	5.585
2019	Feb	26	37.3	48	1013.8	145.7	82.7	0.0077	1.96333	5.195
2019	Mar	30	56.2	48	1010.4	107.4	64.55	0.0042	2.03667	8.26
2019	Apr	33	222.5	57	1007.1	70.2	38.05	0.0029	1.31	8.19
2019	May	34	303	65	1003.8	52.2	20.1	0.0158	0.84667	12
2019	Jun	33	208.1	70	1000.6	35.8	15.9	0.0058	2.015	11.005
2019	Jul	31	315.4	78	1000	36.2	5.93	0.0034	2.679	2.92
2019	Aug	31	239.9	78	1000.4	31.3	19.9	0.0023	2.11	2.84
2019	Sep	30	239.3	78	1005.7	37.7	31.75	0.0014	1.38	3.5
2019	Oct	29	164.6	74	1009.5	64.6	47.16	0.0062	2.12	5.44
2019	Nov	29	42.8	65	1011.2	94.2	70.49	0.0165	1.545	8.1
2019	Dec	24	1.4	53	1014.7	146.3	48.89	0.0194	2.1379	4.3167

Table B.3: Rainfall and Air Pollutant Data (2020, 2021)

Year/ Month	Month	Avg Temp C	Rainfall (mm)	Humidity	Pressure- (MB)	PM2.5 (µg/m3)	NO2 (ppb)	SO2- (ppm)	CO-8hr (ppm)	O3-8hr (ppb)
2020	Jan	23	3.9	50	1013.8	184.4	99.17	0.0138	2.015	5.585
2020	Feb	26	3.1	38	1013.3	147.1	81.1	0.0126	2.275	5.69
2020	Mar	31	19.6	38	1009.2	94.3	63.5	0.0073	1.89	8.26
2020	Apr	33	292.4	54	1007.3	54	38.05	0.0061	1.675	4.99
2020	May	33	152.5	59	1003.9	38.6	17	0.0086	1.55	16.5
2020	Jun	32	395.3	71	1001.2	28.5	15.9	0.0066	2.055	3.71
2020	Jul	31	471.2	76	1001.5	24.2	5.93	0.0014	2.679	42.164
2020	Aug	31	259.4	75	999.8	24.5	7.65	0.0013	2.11	13.795
2020	Sep	31	461.4	75	1003.5	30.3	16.78	0.0018	2.45	5.59
2020	Oct	31	340.3	71	1005.2	51.7	24.27	0.0018	2.12	6.1866
2020	Nov	28	0.6	54	1012.1	82.6	59.89	0.0048	1.66	6.255
2020	Dec	26	0	46	1013	165.7	32.68	0.0043	2.11	6.93
2021	Jan	26	2	40	1012	188.3	45.23	0.0016	2.525	2.305
2021	Feb	28	0.6	34	1011.3	157.9	43.79	0.0015	2.615	1.45
2021	Mar	33	6.3	41	1007.4	118	46.37	0.0017	2.64	2.51
2021	Apr	35	65.8	47	1006.4	70.6	27.94	0.0011	2.805	4.99
2021	May	33	289.3	63	1004.3	62.07	38.7	0.0086	2.325	2.36
2021	Jun	30	327.4	77	1001.4	52.56	28.6	0.0066	2.49	0.78
2021	Jul	30	228.4	77	1001.5	76.13	37.9	0.0034	1.605	2.92
2021	Aug	30	419.7	79	1003.6	97.5	21.69	0.0023	1.255	13.795
2021	Sep	30	271	76	1005.5	95.83	31.75	0.0014	1.38	3.19
2021	Oct	30	258.1	69	1007.6	152.38	32.1	0.0062	1.59667	5.44
2021	Nov	27	0.1	53	1011.4	194.83	70.49	0.0165	1.545	4.75
2020	Jan	23	3.9	50	1013.8	184.4	99.17	0.0138	2.015	5.585

APPENDIX C

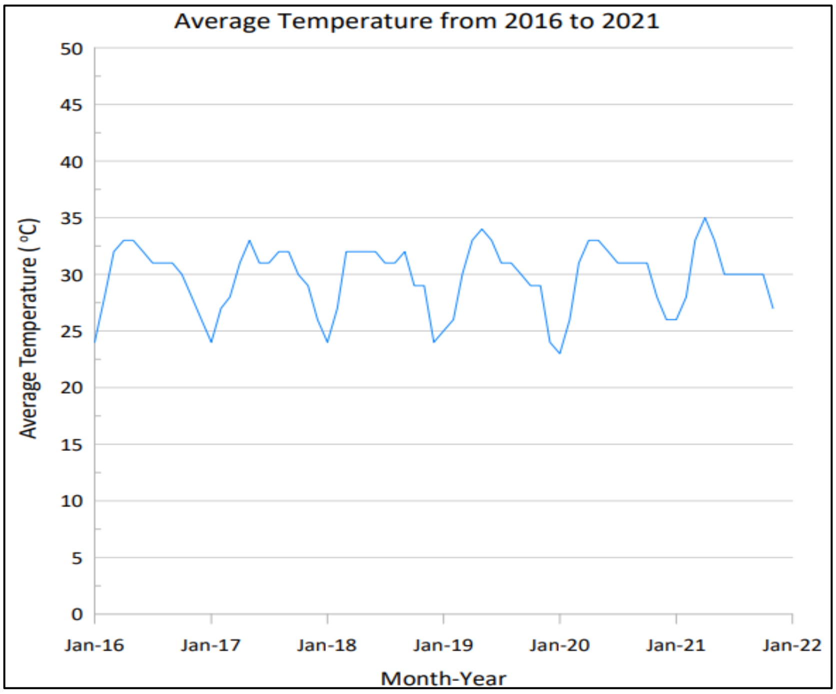

Figure C.1: Average Temperature 2016 to 2021

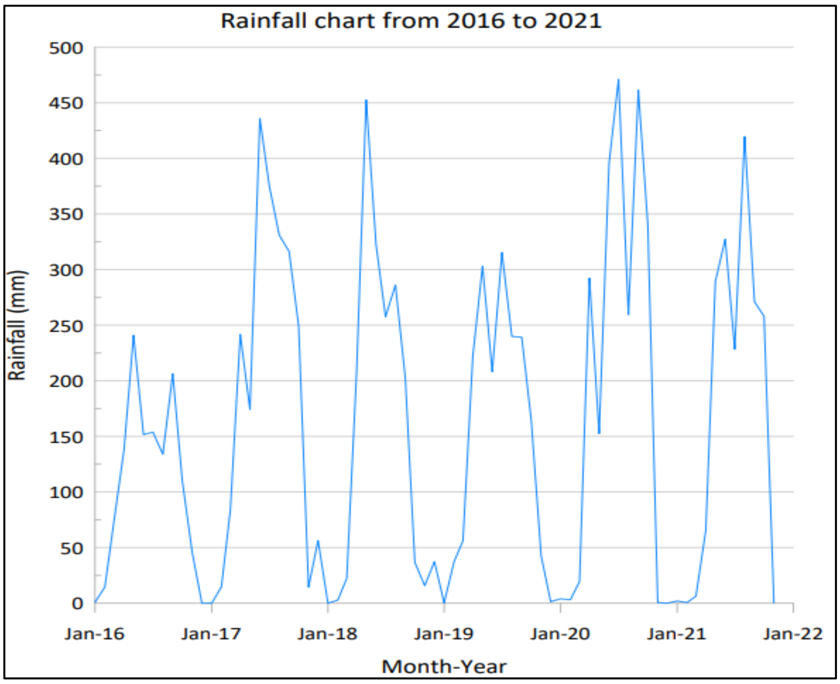

Figure C.2: Rainfall from 2016 to 2021

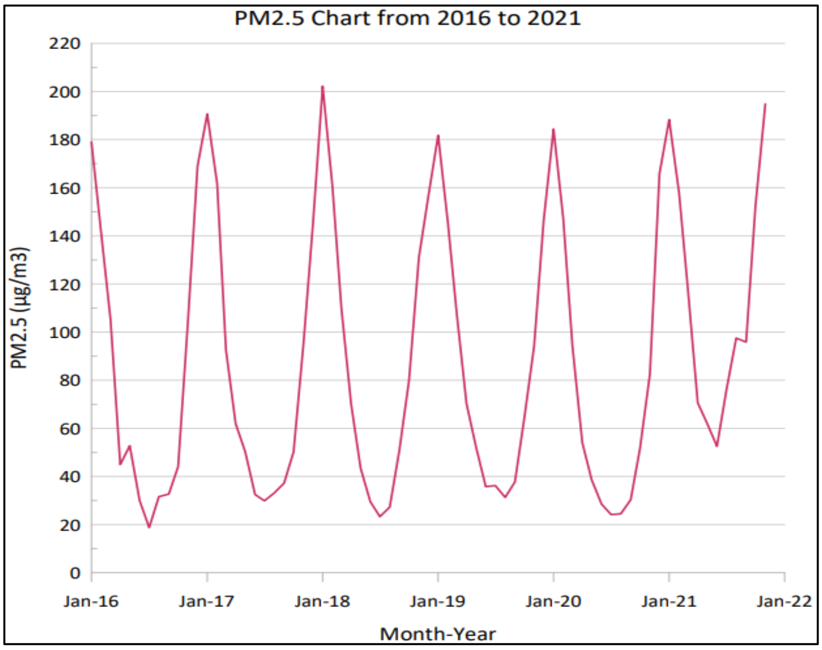

Figure C.3: $PM_{2.5}$ from 2016 to 2021

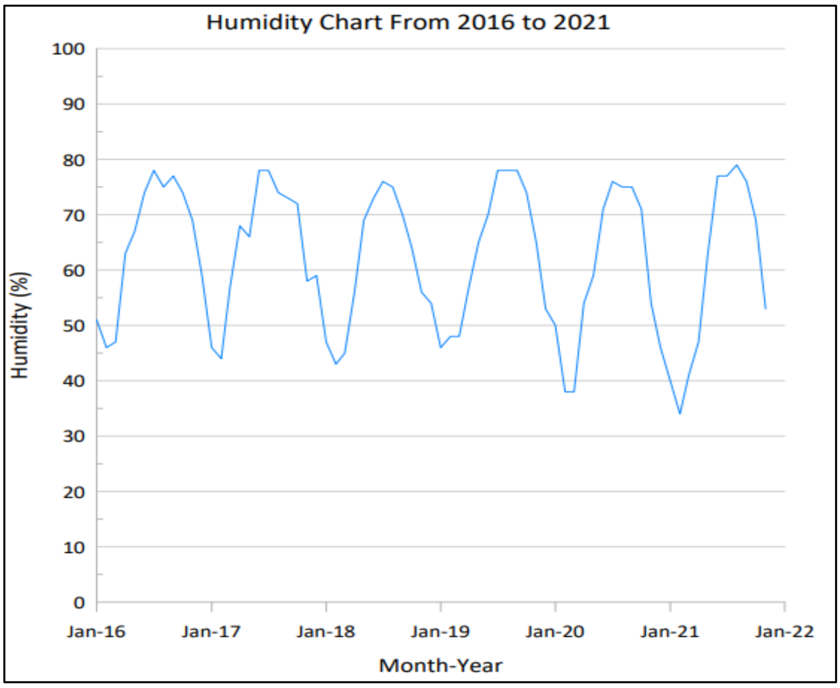

Figure C.4: Humidity from 2016 to 2021

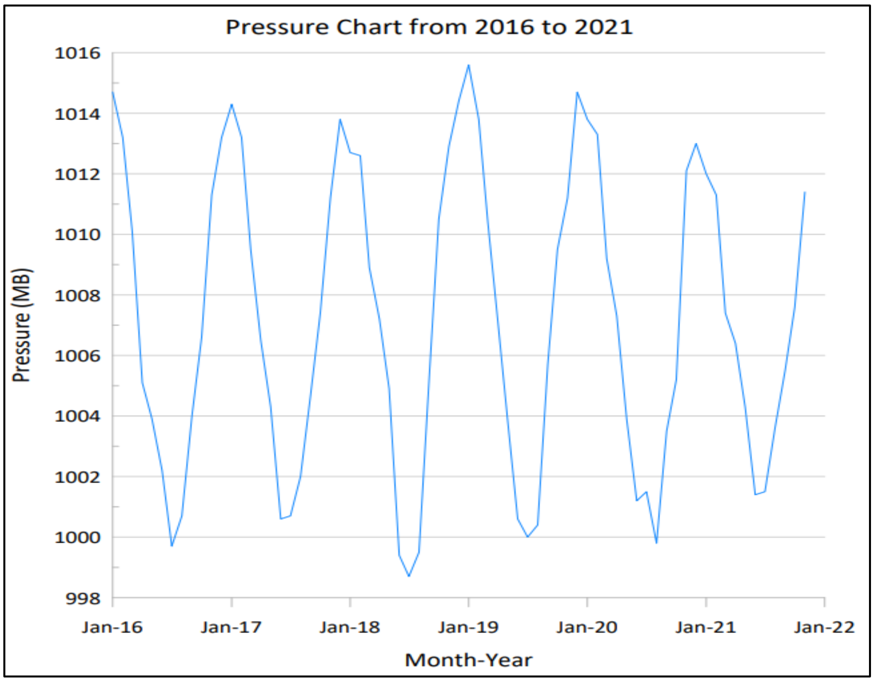

Figure C.5: Pressure from 2016 to 2021

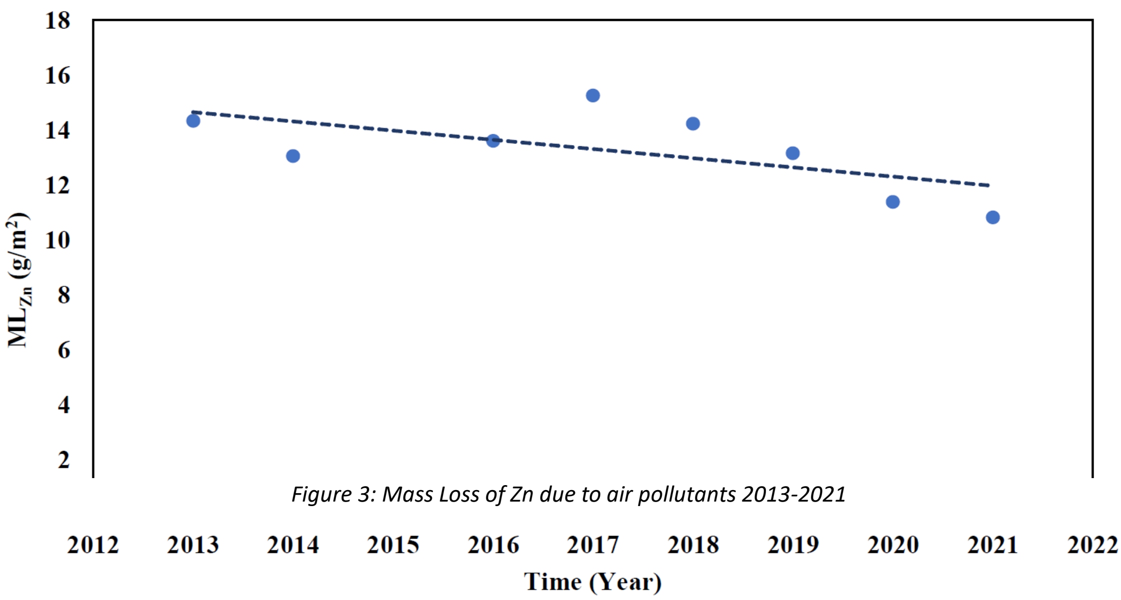

Figure C.6: Mass Loss of Zn due to air pollutants 2013-2021

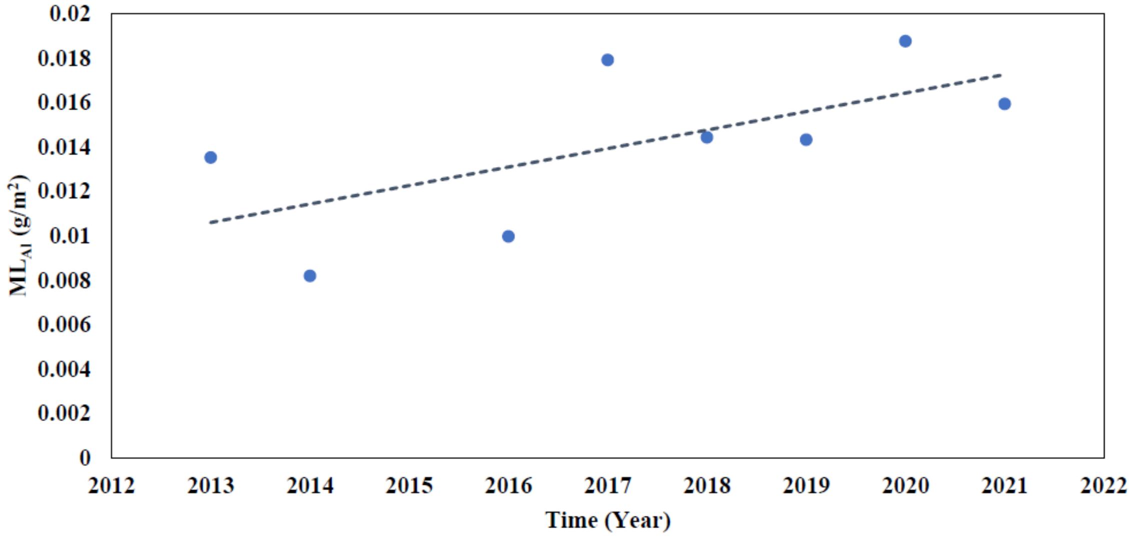

Figure C.7: Mass Loss of Al due to air pollutants 2013-2021

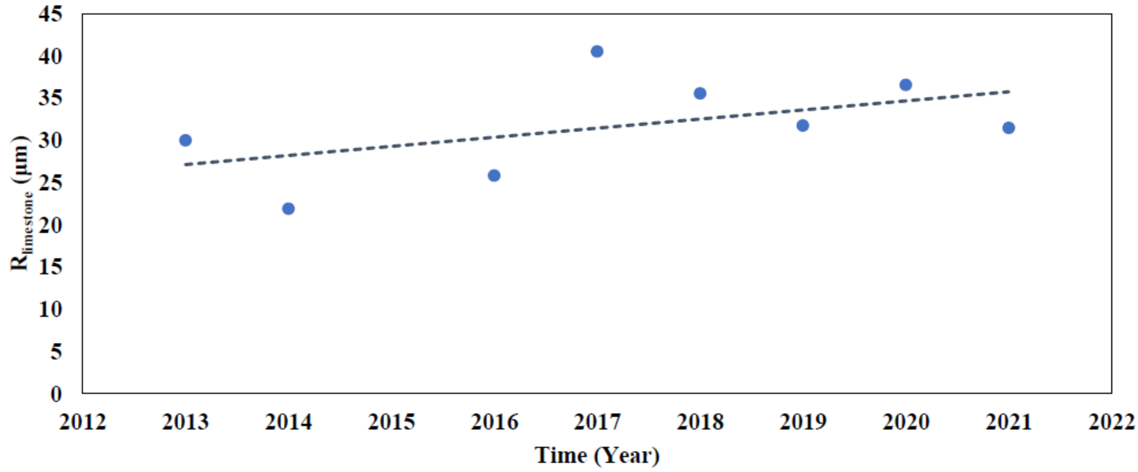

Figure C.8: Surface Recession of Limestone