The Effects of Air Pollution on Damages in Historical Buildings, the Case of Gaziantep, Turkey

Tulay Karadayi Yenice

***Abstract*— Conservation of historical buildings and monuments and handing them down to future generations is one of the main issues of architecture. Contrary to popular belief, preserving these constructions for centuries may be difficult under the changing conditions in the world, in spite of the opportunities of the improving technology. Air pollution is one of the greatest protection issues for these structures to be preserved against. The major causes of air pollution may include the use of fossil fuels in transportation and electricity generation, burning of the solid waste, industrial and local use of fuel, and industrial activities. The aim of this research is to determine the impact of air pollution on the deformations at the historical buildings in Gaziantep's historical city centre. The traditional monumental and civil architectural works made of stone materials constitute the basic material of the research. In the study, the effects of SOx and NOx, and particulate matters, the most important pollutants originating from the weather conditions and causing deformation at the stones, were evaluated and the harms were determined. As a result of this study, it is identified that the most important effect of air pollution on the stone material is the formation of crust. The crusting not only affects the structure of the stone but also it may cause exfoliation and stratification. Abrasion is another effect of air pollution on the stone. However, it has been seen that the importance of this effect is less than the other factors related to air pollution.**

***Index Terms*— Air pollution, cultural heritage, conservation, Gaziantep, restoration.**

I. INTRODUCTION

Air pollution can be defined as the amount that will harm the health of living things in a general expression atmosphere and the coexistence of one or more of the pollutants in time. The main sources of air pollution are the use of fossil fuels in the production of transportation and electricity, solid waste incineration, industrial and local fuel use and industrial activities. The most important effect of air pollution on stone material is crust formation. This crust affects the structure of the stone as well as exfoliation and separation into plates. Air pollution on the surface of the stone is cleaned together with the products and rain of the layer rising without scaling. Therefore, air pollution-related crust formation and spillage can often be observed in areas protected from rainwater. Another effect of air pollution on the stone is erosion. However, this effect has less precautionary effects than other factors related to air pollution [1].

It is known that the air pollution that occurs due to human activities in the atmosphere structure of the cities and the high level of SOx (sulfur oxide) and NOx (nitrogen oxides) contained in the atmosphere forms a crust on the surface by reaching to the surface of the rocks in a gaseous form with wind effect in the absence of rain or snow. In this process, the precipitation rate, porosity and humidity of the surface are important factors as well as the climatic characteristics such as precipitation time, wind speed, relative humidity, and brightness of sunlight [2].

The researches indicate that in the last twenty years the deterioration of historic buildings and monumental stones has accelerated to a great extent in a dirty urban atmosphere. The main atmospheric pollutant that affects building materials is primarily SO2, which is very reactive and corrosive. The main sources of sulfur gases are coal and crude oil [1]. The limestone, marble and travertine of various large-scale calcareous stones react more strongly with SO2. The main part of the change observed in the structure of the reaction occurring in the field is the reaction that the sulfur dioxide gas causes to form on the surface of the stone. The final product of chemical reactions; the calcium carbonate in the stone structure is the more soluble gypsum. The more soluble nature of the gypsum causes the structures to wear out more easily. Particularly, crust formation and breakup occur more rapidly in the rain water or the open areas of the buildings [1,3]. The degree of SO2 accumulation on the stone and other building materials, or the degree of absorption and degradation, depends on the natural structure of the pollution density, wind speed, surface moisture and building material. However, it is known that daytime sunshine and temperature increase strengthens this effect [4,5].

The purpose of this research is to determine the effect of air pollution in historic buildings in Gaziantep's historical city center. It is believed that the research will contribute to the work to be done on preserving historical buildings and transferring them to future generations.

II. MATERIAL AND METHOD

Gaziantep is Turkey's sixth and Southeastern Anatolia is the largest city. The city, which has a population of about 2 million, has rich historical and cultural texture as well as industrial character. Gaziantep is one of the oldest settlements in Anatolia and is located at the intersection of Mesopotamia and the Mediterranean Region (Figure 1). The city has hosted many important civilizations in history such as the Ottomans, Seljuks, Byzantines, and Rome and maintained its importance in every period of history. Gaziantep has been added to the list in the gastronomy category of UNESCO's Creative Cities Network in 2015.

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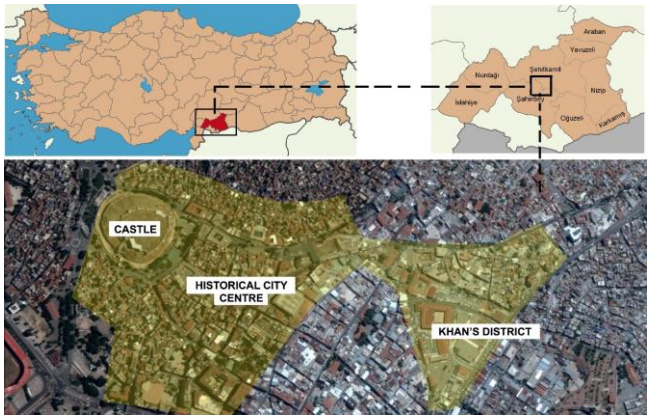

Figure 1. Gaziantep Historical City Centre and Khan's District

Besides all these, it can be said that the air quality of the city of Gaziantep is very dirty. This pollution is mainly based on three factors: fuels used in heating, industrial production and emissions from traffic. Nearly all of the current air pollution in the city is due to warming. The use of poor quality coals for heating in residential areas is the most important reason for air pollution. Particularly in the winter months, atmospheric pollutant gases and particulate matter are spreading considerably. Gaziantep has been identified as the fifth dirtiest city in Europe according to the World Health Organization's 2017 report.

The subject of this research is the traditional monumental and civil architectural examples made of stone materials located in the historical city of Gaziantep. In this context, traditional buildings affected by air pollution in the historical city center of Gaziantep are examined. In the study, a method was observed which came from two stages. In the first stage, various types of deterioration examples were found on the ceiling due to air pollution. These deteriorations are often seen as breaks, darkening, crusting. The second stage is to examine the factors that cause deterioration on the samples taken. In this frame, the solutions causing the deterioration are estimated by making solutions with various solutions.

III. RESULT AND DISCUSSION

The basic construction material of the traditional buildings located in the historical city center of Gaziantep is basalt and limestone, which are limestone based stones. Researchers, such as Harter [6] and Lipfert [7] do not put attention to the effects of air pollution especially on silica-based stones, however they draw attention to the dangerous effects of air pollution on travertine and limestone, which are limestone-based and extensively used in Gaziantep region. It can be observed that the deterioration of these stones due to air pollution is caused by the dissolution of CaCO3 in their bodies. In particular, the effects of gaseous pollutants such as SO2 and the effect of acid rain on the stone structure cause dissolution and break-offs in the stone. In various scientific studies, it has been seen that natural stones are separated by a size of up to 4 mm. pieces can break off from the body of natural stones due to air pollution [8]. One of the most important pollutants caused by weather conditions affecting the decay of stones in historical buildings in Gaziantep is SO2. It can be said that the level SO2 is very high in Gaziantep (Table 1).

Table 1: Annual and winter season average sulfur dioxide values in Gaziantep (µg/m³)

Annual average sulfur dioxide values (µg/m³)							
2004	2005	2006	2007	2008	2009	2010	2011
51	48	41	25	25	16	19	17
Winter seasons average sulfur dioxide values (µg/m³)							
2004	2005	2006	2007	2008	2009	2010	2011
58	86	68	46	47	23	32	30

*Data compiled from TURKSTAT Air Quality Statistics [12].

When the annual average SO2 distribution of the last eight years is examined, it is seen that the average of the six years is above the threshold level set by the World Health Organization (Table 2). It can be said this value reached a high level for all years when examined during the winter season (Chart 1 and Chart 2).

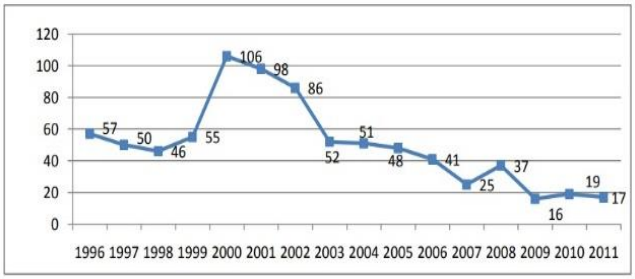

Chart 1. Annual average SO2 change (1996-2011)

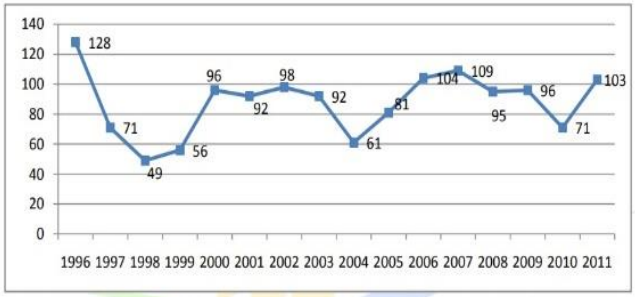

Chart 2. Annual average PM_{10} change (1996-2011)

Table 2: Accepted SO_2 upper values for air quality in the world and in Turkey

	EU Countries	WHO	USA (EPA)	Turkey
24 hours	125	125	365	400
Winter season	20	-	-	250
Annual	-	50	80	150

* Data compiled from Anonymous (2006), Anonymous (2011) [9,10]

In measurements made on 29.11.2011, it is seen that the sulfur dioxide value of Gaziantep is 122 µg / m³. These findings indicate that the value of SO2 increases especially in the winter months. The deterioration effects on the Gaziantep Historic Buildings due to air pollution can be seen in the form of color change, salt accumulation, crust formation and separation on the facades of the structures (Figure 2).

Figure 2. Examples of darkening - color change on the surface of a building

Liquid or solid materials in the atmosphere are particulate matters in air pollution [1]. It is known that particulate matter (PM10) acts as a catalyst in the oxidation of SO2 on the surface of a stone and plays an active role in the formation of gypsum minerals, as well as causing the building surface to darken. When air the measurement values of the city of Gaziantep is analyzed according to the PM10 value, it can be said that it is quite high (Table 3). As a matter of fact, it is seen that the PM10 value of Gaziantep is 143 µg / m³ in the measurements made on 29.11.2011.

Table 3: Gaziantep annual and winter season average for Particulate matter PM_{10} values

Annual average PM_{10} values (µg/m³)							
2003	2004	2005	2006	2007	2008	2009	2010
50	57	46	59	79	60	67	83
Winter season average PM_{10} values (µg/m³)							
2002 2003	2003 2004	2004 2005	2005 2006	2006 2007	2007 2008	2008 2009	2009 2010
69	73	74	77	71	87	49	82

* Data compiled from TURKSTAT Air Quality Statistics [12]

These findings indicate that there is a high level of PM10 in the air structure of the city. When the average annual PM10 values of the city of Gaziantep are examined; according to the EU, World Health Organization and EPA norms (Table 4), this difference increases even more in winter. Deteriorations due to particulate matter in the buildings of the historical region of Gaziantep are seen as darkening on building facades (Figure 3).

Figure 3. Examples of darkening due to air pollution in building stones

Another pollutant that causes deterioration due to air pollution in historical buildings is nitrogen oxides (NOx). Nitrogen oxides are soil and water based arising from traffic, agricultural activities and exhaust gases [1]. Compared to sulphur dioxide, the rapid cleaning of NOx from the surface of the stone due to the high solubility of calcium nitrate and other reaction products makes it difficult to detect their effects [2]. However, some research suggests that due to the increase of NOx sources, they may play a more important role in stone detoriation in the future [11].

Table 4. Accepted PM_{10} upper values for air quality in the world and in Turkey (µg/m³)

	EU Countries	WHO	USA (EPA)	Turkey
24 hours	50	50	150	100
Annual	20	20	50	60

* Data compiled from Anonymous (2006), Anonymous (2011) [9, 10]

Another pollutant that causes deterioration due to air pollution in historical buildings is nitrogen oxides (NOx). Nitrogen oxides are soil and water based arising from traffic, agricultural activities and exhaust gases [1]. Compared to sulphur dioxide, the rapid cleaning of NOx from the surface of the stone due to the high solubility of calcium nitrate and other reaction products makes it difficult to detect their effects [2]. However, some research suggests that due to the increase of NOx sources, they may play a more important role in stone detoriation in the future [11].

It can be said that acid rain is another factor that brings deterioration due to air pollution on the historical Gaziantep constructions. A high level of sulphur and particulate matter causes deterioration. These pollutants, which can be suspended for 2-7 days in the air, bring acid when they react with water and this water comes down to the earth as acid rain. Water drops with a low level of pH value cause erosion on the exterior facades of buildings.

As a result, the surfaces where the rainwater is infiltrated and wetted the roofs, the wet areas formed by the water rising from the walls in regions where collecting the water around the building is insufficient, and the reaction and damage of the particulate matter and gases causing air pollution on the surface of the buildings can be seen in the historical buildings in Gaziantep. It is seen that dry surfaces are cleaner and healthier (Figure 4).

Figure 4. Wet areas on stone surfaces: color change, crusting, salt accumulation

IV. CONCLUSION

As a result of the research, it has been observed that various distortions occurred in the traditional buildings in Gaziantep city historical urban fabric depending on the air pollution. Especially in the winter months, the deterioration effects on the Gaziantep Historic Buildings can be seen in the form of color change, salt accumulation, crust formation and separation in the fronts of the buildings. Another type of degradation is the formation of gypsum minerals by acting as a catalyst in the oxidation of SO2 on the surface of the

particulate (PM10) matter. These minerals lead to the blackening of the building surface.

It is known that the main cause of air pollution in Gaziantep is caused by poor quality fuel used for heating especially in winter season. It should not be forgotten that the prevention of air pollution will be ensured by local governments with policies that are determined for the whole city in a short and long term. These policies can be based on large and small scale solutions, ranging from urban green space regulations and air circulation corridors to the development of the public transport system to reduce the use of individual vehicles, to the type of fuel used in buildings. The main target is to minimize the sources and elements that cause air pollution and to remove pollution from the urban atmosphere.

The widespread use of natural gas in the historic city center of Gaziantep will reduce the use of poor quality coal used for domestic heating. Therefore, it is thought that it will have a decreasing effect of air pollution caused by the use of fossil fuel for heating purposes. It is also important to reduce the traffic intensity around historic structures as air pollution, such as nitrogen and oxide, caused by intense pollution, accelerates the chemical reactions that sulfur dioxide gas and particles form on the surface of the stone. In this framework, the completion of the pedestrianization projects in the old city center will contribute to the preservation of historical buildings.

There are not enough researches and findings on the effect on the long-term structure of the surface-protective chemical substances, while reducing the deterioration effects of the short-term. For this reason, it is considered that the use of surface preservative chemical substances in reducing the deterioration due to air pollution in the Gaziantep buildings is not an appropriate approach in today's conditions. If air pollution is reduced, deterioration caused by air pollution will not progress. However, a separate investigation should be carried out to determine the protection methods applied to the degraded stones. It may be necessary to remove the salts that have affected the degradation of the stones. How to do such a study or how to clean the contaminated areas without damaging the stone should be determined by working with a material protection laboratory that conducts research on these matters.

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