# INDUSTRIALISATION AND POLLUTION MONITORING BY USING GIS

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**ABSTRACT:** Kocaeli is a high dense industrialized city with more than 1020 industrial institutions in various sectors as Petroleum Refineries, automotive, chemistry, textile, machine, food, paper, wood, tanning, coal, etc.. Due to fast urbanization (traffic, population, building population etc.) and high dense industrialization the air pollution is inevitable in this city. GIS (Geographic Information Systems) Technologies has become an important tool for handling spatial data. In this study, it is aimed to determine the relationship between dispersion characteristics of air pollution with the density of industrial regions and topography by wind direction evaluation using GIS techniques and correlation analysis in Kocaeli case. The PM and $SO_2$ mean annual pollution parameters of 2015 were modelled in this study for the Kocaeli region. As a result of correlation analysis, it can be concluded that the mean annual PM distribution was strongly related with topography and mean annual $SO_2$ distribution was strongly related with density of industrial regions. Additionally, the wind direction may have an influence on reduction of correlation between pollution parameters and industrial region densities.

## 1. INTRODUCTION

Air pollution is defined as the amount and intensity of air impurities reaching above normal. It has become a global issue that causes death to humans, diseases, damage to animals, food crops, and natural or built environment. Air pollution can be evaluated in three different scales as: global, regional and local scale. Depletion of the ozone layer and the greenhouse effect is the events on a global scale. Acid rain is one of the specific effects of air pollution on a regional scale. Air pollution occurs in the residential and industrial areas are events on local scale (Müezzinoglu, 1987).

In parallel to the rapid increase in world population, increasing energy use, development of urbanization and the pollution out of the industry cause negative effects on human health and other living things. According to the latest urban air quality database of World Health Organization (WHO), more than 80% of people living in urban areas are exposed to air quality levels that exceed WHO limits and 98% of cities in low- and middle income countries do not meet WHO air quality guidelines (WHO, 2016). Depending on The World Air Quality Index project the Air Pollution in the World is published online and the Real-time Air Quality Index (AQI) is obtained freely from http://aqicn.org/city/ address.

There are mainly five important pollutants in terms of primary importance. These are Particulate Matter (PM), sulfur dioxide ($SO_2$), carbon monoxide (CO), carbon dioxide ($CO_2$), ozone ($O_3$), nitrogen oxides (NOx) and hydrocarbons (HC) that constitute almost 90% of all contaminants. Although air pollution caused by the entry of air impurities into the atmosphere meteorological factors such as, temperatures, pressure, precipitation, wind, humidity, solar radiation and the building density, population, location and topography has also influence to it.

Since 1980's the industrial sector in Turkey has developed with a remarkable rate. This can be attributed to three different factors, namely a shift from agriculture towards industry, the modernization of the existing industry, and the effect of international trade (KPMG, 2015). Depending on the data obtained from Turkey statistical Institue (TSI) the 91.8% of population living in the provinces and districts. Therefore, the pollution in the country caused mainly by warming, industry and vehicle. In order to establish air pollution policies in all provinces of Turkey and in order to bring better air quality conditions within the framework of these policies the Environment and Urban Ministry established National Air Quality Monitoring Network in the provinces. In 2005 (in 35 provinces) and in 2007 (in 46 provinces) air quality measurement stations were established by the Ministry. In addition to these stations the National Air Quality Monitoring Network were extended to 195 stations in total established by variety of institutions and organizations and by the established stations in 2014 and 2015 by the Ministry (HKİ, 2016). The data transmitted to the monitoring network are published simultaneously in www.havaizleme.gov.tr web address and can be downloaded freely. Air Quality Monitoring Stations measures hourly values of five primary pollutants and temperature, wind direction, wind speed, relative humidity and air pressure. Among the five primary pollutants the $PM_{10}$ and $SO_2$ values were measured more properly and permanently in Air Quality Monitoring Stations. İbret and Aydınözü, 2009 evaluate the topographic and climatic features to the air pollution in relation with the human and economic reasons in Kastamonu case.

In Turkey there is variety of studies related to pollution mapping. Hamzaoğlu et al., 2004 aimed to determine the causes and characteristics of deaths related to cancer in 2004 in Dilovası, Kocaeli by concerning industrial chemicals. Akyürek et al., 2013 created spatial distribution maps of 2013 summer values of $SO_2$ and PM for pollution in the province of Kocaeli. Menteşe and Tığıl, 2009 examined the relationship between particular matter and sulfur dioxide concentrations from parameters that cause air pollution and the city topography in Zonguldak city. Bozyazı ve İncecik, 2002 investigate the relationships between $SO_2$ concentrations with land uses and population using Geographical Information Systems.
In the literature Chattopadhyay et al., 2010 investigated the seasonal variation of ambient air quality status of Burdwan town in India and represented the spatial distribution of pollutants by digital elevation model (DEM). Weng and Yang 2006 obtained Ambient air quality measurements for sulfur dioxide, nitrogen oxide, carbon monoxide, total suspended particles, and dust level were for Guangzhou City in South China between 1981 and 2000 and investigates the relationship of local air pollution pattern with urban land use and with urban thermal landscape using a GIS approach. Tian et. al, 2016 characterize the sources of $PM_{10}$ and $PM_{2.5}$, in sampled data set in China during the period of 2006-2014.
In this study, it is aimed to determine the relationship between dispersion characteristics of air pollution with the density of industrial regions and topography by wind direction evaluation using GIS techniques and correlation analysis in Kocaeli case.

## 2. STUDY REGION

Kocaeli is one of the dense industrial provinces of Turkey through where D-100 and TEM highways pass through the city (Figure 1). It is the Turkey's second largest industrial center after Istanbul. Kocaeli was mainly a production, storage and transfer region for more than 1020 industrial institutions in various sectors as petroleum refineries, automotive, chemistry, textile, machine, food, paper, wood, tanning, coal, etc..
The city lies between the 29°22'-31°22' eastern longitude and 40°31'-42°42' northern latitude and it carries a geopolitical importance as it is located in junction point of roads connecting Asia and Europe. Kocaeli's climate, constitute a transition between the Mediterranean and Black Sea climate. The city center is hot in summers with low rainfall and mainly rainy and sometimes snowy and cold in winters. The highest temperature measured in the city center is 41, 6°C, the lowest temperature is -8.7°C, and the average annual temperature is 14.8 °C. The average annual precipitation in Kocaeli exceeds 835 mm. The mountains in the province of Kocaeli constitute 18.8% of the total area. The mountains are single hills in the north, and cordilleras in the southern part of the city. The altitude doesn't exceed 350 meters in the northern part. The whole city has an area of 3.505 km² and is divided into 12 urban sub-municipalities (Figure 1). Population of Kocaeli increased by 2.74% compared to the previous population census. The population reached 1.722.795 which has been the most populous province of the country after İstanbul. Due to fast urbanization (traffic, population, building population etc.) and high dense industrialization the air pollution is inevitable in this city.

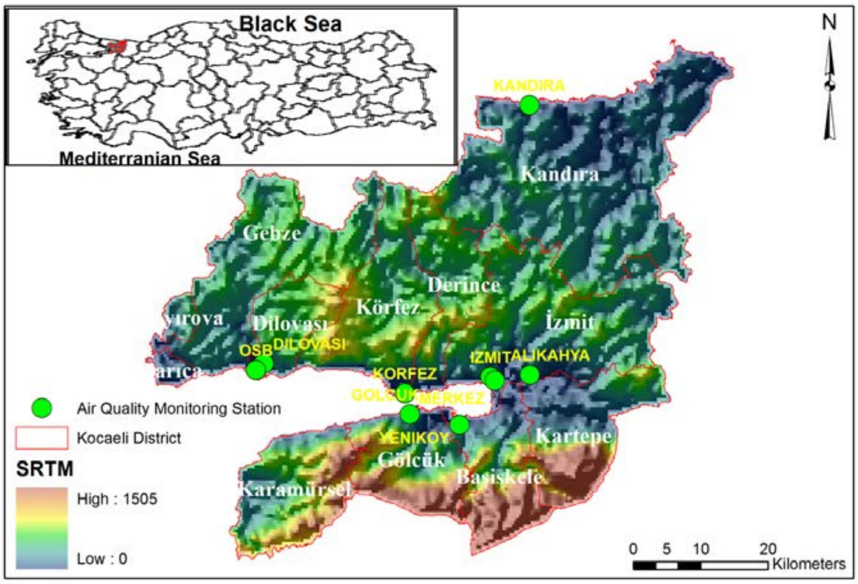


**Figure 1.** Kocaeli with 12 urban sub-municipalities and pollution stations with green dots overlaid onto SRTM data

There are 9 National Air Quality Monitoring stations in total where 3 (Kocaeli-OSB-Dilovası) of them are under the control of the Environment and Urbanism Ministry and 6 (İzmit-Körfez-Alikahya-Gölcük-Yeniköy-Kandıra) of them are under the control of Marmara Clean Air Center Directorate. These stations do constant measurements since 1987 and provide data freely from the web environment.

## 3. METHOD AND ANALYSIS

In this study the dispersion characteristics of air pollution is identified by mapping the spatial distribution of pollutants. Among the five primary pollutants provided from the Air Quality Monitoring Stations the 2015 values of $PM_{10}$ and $SO_2$ provide more proper and constant measurements. Therefore, the mean annual values of these parameters were obtained and used for the analysis. The monthly mean values of PM and $SO_2$ was presented in Figure 2.

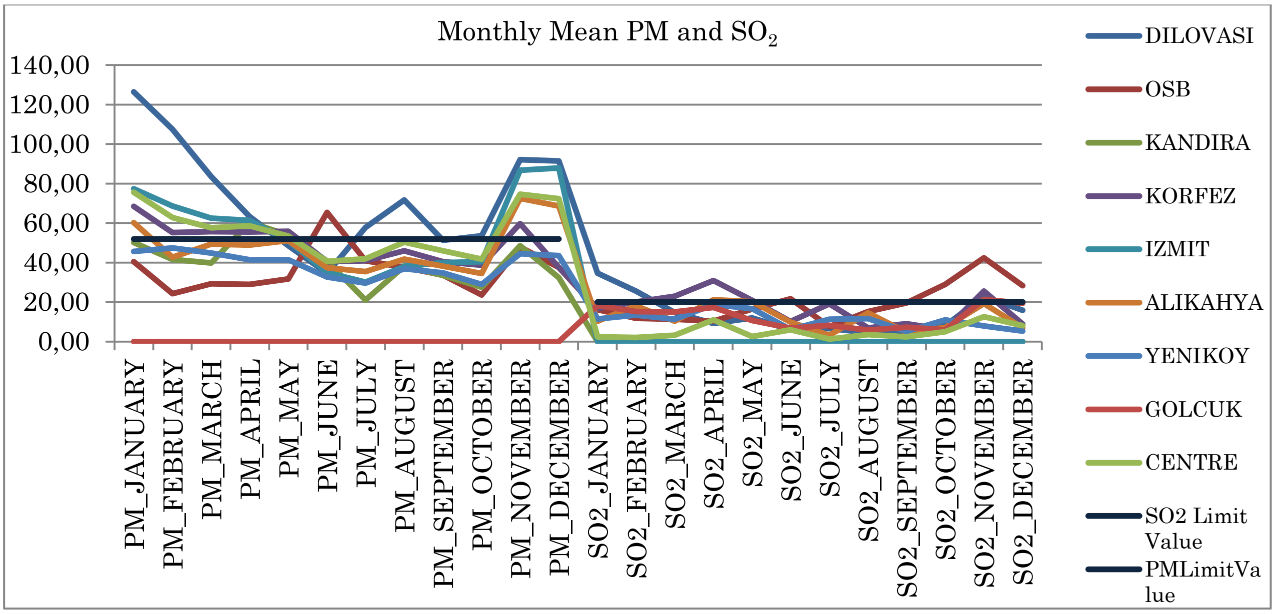


Figure 2. Monthly mean values of PM and $SO_2$

Sulphur dioxide ($SO_2$), is one of the most well-known primary air pollutants and non-flammable colorless gas among the gaseous pollutants. Retention time in the atmosphere is up to 40 days. It often occurs by the combustion of fossil fuels. Sulfur dioxide is usually high in value in the regional center of the city where the use of coal is widespread for domestic heating purposes and around the environment of industrial areas.

Particulate matter (PM) is very small grained solid or liquid particles, emitted in the atmosphere. In terms of mass and composition; they are divided into two groups such as: the coarse particles where aerodynamic diameter is larger than 2.5 mm and the fine particles where aerodynamic diameter is smaller than 2.5 mm. PM may occur due to sources such as fuel, diesel engines, construction, industrial activities, and dust.

The air quality limit values of Turkey and EU for 2016 are provided in Table 1 (http://www.havaizleme.gov.tr/hava.html). The limit values are quite higher than the EU for PM and equal for $SO_2$. These limit values and national legislation are used to regulate air quality index for measurements of each pollutants.

**Tablo 1.** Air Quality Limit Values (http://www.havaizleme.gov.tr/hava.html)

| **Pollutant Parameters** | **Measurement Period** | **Limit Value** | |
|---|---|---|---|
| | | **Implemented Turkey (2016)** | **Implemented in EU** |
| Sulphur dioxide **$SO_2$ (μg/m$^3$)** | Hourly | 440 | 350 |

| | | | |
|---|---|---|---|
| | Daily | 200 | 125 |
| | Warning Threshold (3 consecutive hours) | 500 | 500 |
| | Annual (ecosystem) | 20 | 20 |
| Particulate matter **PM10 (μg/m$^3$)** | Daily | 80 | 50 |
| | Annual | 52 | 40 |

Inverse Distance Weighting (IDW) was used in order to interpolate the pollution measurements to the region. Annual mean values of $SO_2$ and PM are used to obtain distribution map of the region in GIS (Figure 3). Some stations in the study region such as: Gölcük station for PM values and Kandıra and İzmit stations for $SO_2$ values were not included in to the interpolation analysis in order to reduce the error term. The $SO_2$ almost reached the limit level (annual limit 20) in the western part of the region by 19.22 values (Figure 3). Nonetheless, the PM exceeded the limit values (annual limit 52) in the western part of the region by 85.38 values (Figure 3). Monthly mean values of $SO_2$ and PM values exceed the yearly limit values usually in, autumn and winter which might be due to the fossil fuel consumption for warming (Table 1).

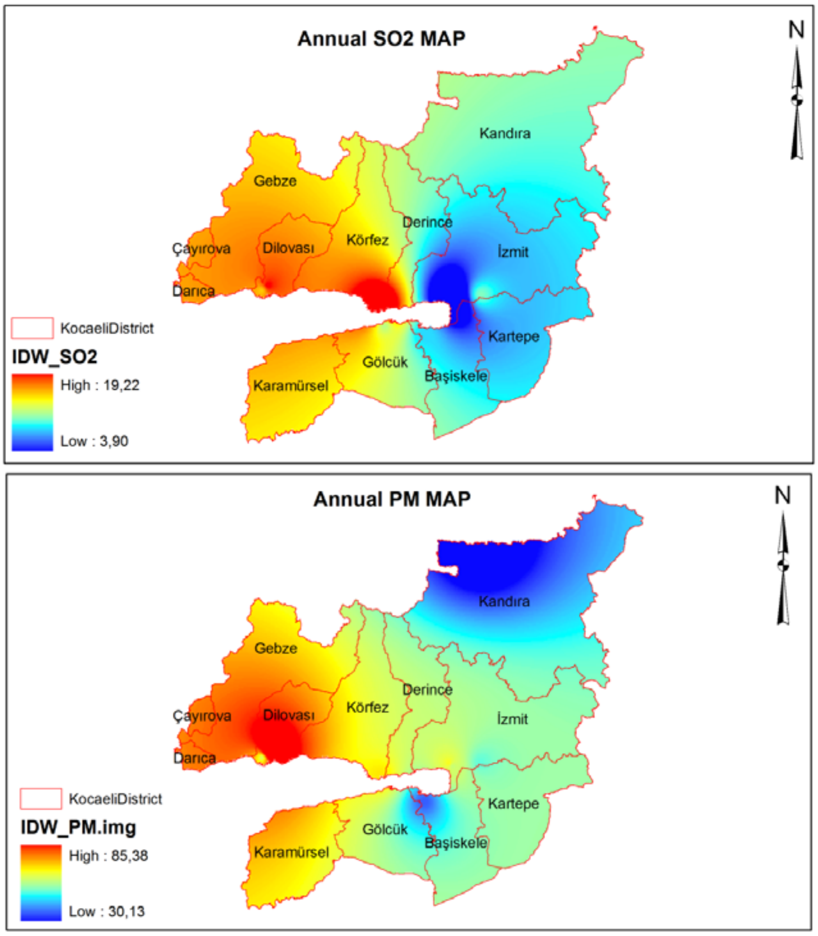


Figure 3. $SO_2$ and PM distribution map of the region

The industrial regions were obtained from the 1/25000 scale land use map by SQL analysis. The density of these industrial regions was obtained using a moving kernel over the region (Figure 4). The optimum moving kernel radius was selected as 5000 for the study.

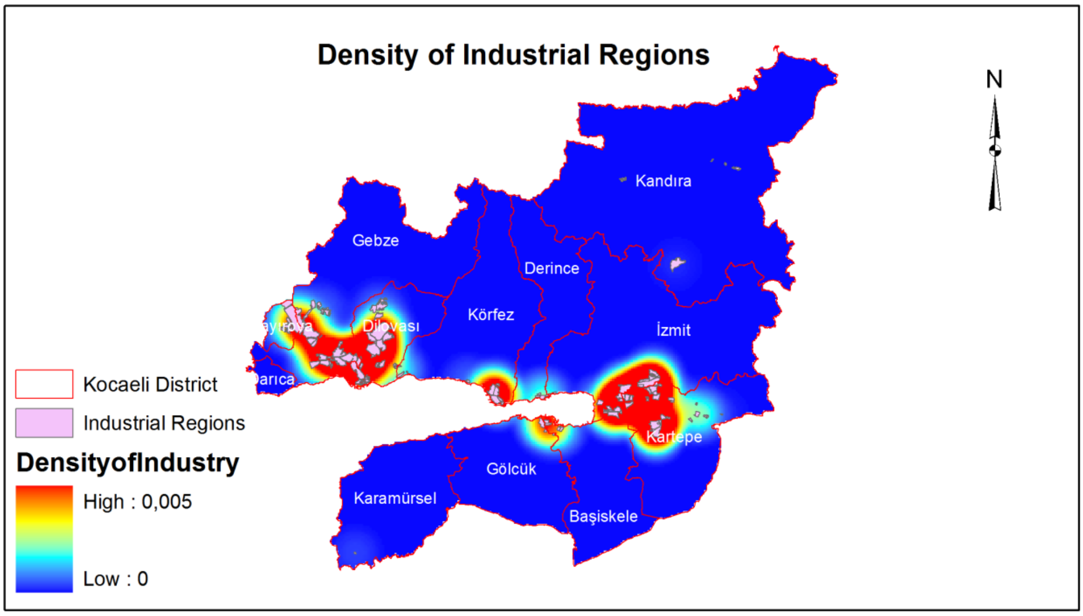


Figure 4. The distribution map of industrial regions

Winds may have a direct impact on air pollution as they remove the polluted air from the environment or they move the polluted air to a clean environment. Depending on the data recorded at the Kocaeli Meteorology Station in years between 1970-2010 annual wind diagrams was prepared by Kocaeli Report, 2015 using wind blowing values (Figure 5).

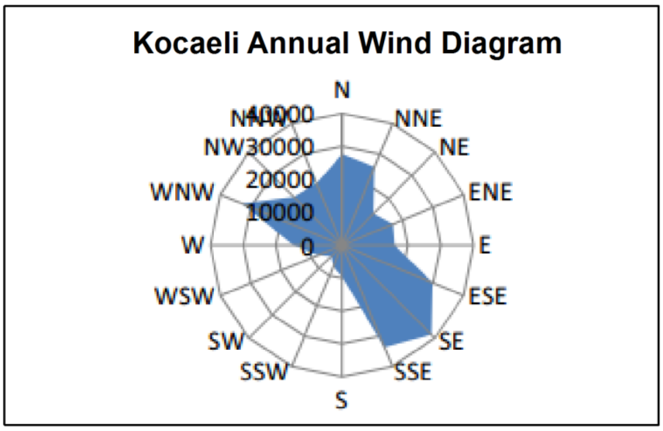


Figure 5. Kocaeli Annual wind diagram (Kocaeli Report, 2015)

According to the Kocaeli Meteorology station observation records in Figure 5, the prevailing wind direction was south east (SE) direction in the city of Kocaeli and the west northwest (WNW) direction follows it. The annual mean wind speed was 1.6 m/s. The maximum wind speed and wind direction was 33.6 m/s and west northwest (WNW) direction, respectively.

The topographic map of the region is obtained from SRTM data and the altitude of Kocaeli range between 0 to 1505 m. as presented in Figure 1. The topographic characteristics of the location of the city directly affect the air pollution. Therefore, the effect of topography was also analyzed by using the correlation analysis. In order to provide the correlation analysis initially a database was created. The database was created by obtaining 1392 sample points over the entire region where more cover the industrial regions. Then, the values of PM, $SO_2$, topography and density values of industrial regions were extracted to these sample points. Lastly, the database was exported to SPSS environment for correlation analysis. The results of the analysis were presented in Table 2.

Table2. The correlation table of desity of Industrial regions with PM and $SO_2$

| Variable | Test | Mean Annual $PM_{10}$ | Mean Annual $SO_2$ |
|---|---|---|---|
| Topography | Spearsmans rho | 0.53** | -0.007 |
| | Sig.(2-tailed) | 0.000 | 0.787 |
| Density of Industrial Regions | Spearsmans rho | 0.22** | 0.46** |
| | | 0.000 | 0.000 |

**Correlation is significant at 0.001 level

As the Spearman's rho measures the rank-order association between two variables, it work regardless of the distributions of the variables additionally, the outliers have less of an effect on the parameter. Therefore, the relation between $PM_{10}$ and $SO_2$ values with topography and density of industrial regions was tested with Spearman's rho parameter.

## 4. RESULTS AND DISCUSSION

The country's development in industrial production resulted in higher levels of pollution and greater risks to the country's environment. Unplanned urbanization and used fuel has great influence to air pollution.

The average distribution of $SO_2$ and $PM_{10}$ (mg/µ3) in Figure 3 seems to show a similar pattern in 2015. $SO_2$ and PM values were intense in the western part of the city neighborhood that were Dilovası, Gebze, Körfez, Çayırova, Darıca, Karamürsel and western part of Gölcük. $SO_2$ distribution was lowest in the western part of Izmit and northern part of Başiskele and PM distribution was lowest in the northern part of Kandıra and southwest part of Başiskele.

The distribution map of industrial regions in Figure 4 indicates that the industrial regions were more intense in central parts of Dilovası and southern parts of Gebze and also in the southern parts of İzmit, northeast part of Başiskele and southwest part of Kartepe. By visual analysis the distribution map of industrial regions overlaps on Dilovası regions with $SO_2$ and PM distribution maps with high values. However, the distribution of industrial regions doesn't overlay with $SO_2$ and PM distribution on İzmit, Kartepe and Başiskele regions. $SO_2$ and PM distribution was lowest in the eastern part of the region which might be due to the prevailing wind direction which was south east (SE) and west northwest (WNW) direction. Although there was an intense industrial region on the in the southern parts of İzmit, northeast part of Başiskele and southwest part of Kartepe, the wind may evacuate the polluted air on these parts. This may also the reason to reduce the correlation of pollution with the industrial regions.

Topographic condition, one of the physical environmental factors, may reduce or influence the impact of air pollution damage to people and other living things. Therefore, the topography was also analyzed with the industrial density in the correlation analysis.

The correlation reported in Table 2 was negative (-0.007) for topography and $SO_2$ distribution, although not significantly different from 0 because the p-value of 0.787 is greater than 0.10. Hence the topography doesn't have an appreciable effect on $SO_2$. On the other hand, there is a significant and fairly strong positive correlation between PM10 distribution and topography with 0.53 correlation value. The correlation between density of industrial regions and mean annual $PM_{10}$ distribution is positive however the density of industrial regions has a higher positive correlation with $SO_2$ by 0.46 correlation value. As a result it can be concluded that the mean annual PM distribution was strongly related with topography and mean annual $SO_2$ distribution was strongly related with density of industrial regions.

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