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Correlation between Air Quality Index and Traffic Volume

Omar Alruwaili*, Ivica Kostanic**
**Department of Computer Engineering and Sciences, Florida Institute of Technology, Melbourne, USA*
*** Department of Computer Engineering and Sciences, Florida Institute of Technology, Melbourne, USA*

ABSTRACT
Measurements of the Air Quality using a set of inexpensive electrochemical sensors is considered. The sensors measure all pollutants prescribed by US Environmental Protection Agency for calculation of the Air Quality Index (AQI). The sensors are placed at the street level and connected to a central server through the Internet of Things. Alongside pollution measurements, traffic density measurements next to the sensor location are performed as well. A mathematical model that relates traffic density and AQI is developed. The model shows that some gaseous pollutants have a very strong correlation with the traffic density. Overall, AQI and traffic density show significant correlation.
Keywords-Internet of Things (IoT), Air Quality Index (AQI), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3), Particulate Matter (PM) and Sulphur Dioxide (SO2).

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I. INTRODUCTION

Pollution is defined as the introduction of pollutants into the natural environment. Pollutants are often chemical contaminants, but they may also be more broadly defined to include other contaminants, such as light or noise. Pollutant gases emitted through car exhaust consist of chemicals such as carbon monoxide (CO), nitrogen dioxide (NO2), ozone (O3), sulphur dioxide (SO2) and particulate matter (PM) and [1], as shown in Fig.1. Based on its origin, pollution may be classified as either "point source" pollution or "nonpoint source" pollution. Point source pollution comes from a single identifiable place, while nonpoint source pollution comes from many diffuse sources. Pollution coming from the car exhaust is regarded as a "nonpoint source" pollution.

The problem of air pollution is well known and of great concern in municipalities throughout the world. One of the most significant sources of this pollution is vehicular emissions. This pollution harms not only humans but also animals and vegetation [2][3].

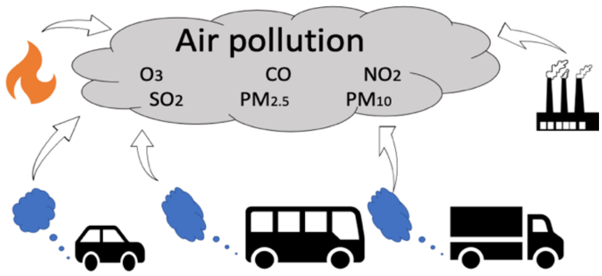

Fig. 1. Air Pollution

The air pollution becomes smog, which hangs over cities and poses a major threat to health and climate. The gases in smog are combined with dust and are emitted by cars and factories. One of the most prevalent gases that effect air pollution in cities is ozone. According to the World Health Organization (WHO), air pollution accounts for about 4 million deaths per year contributing to strokes, heart disease, congestion, chest pain, lung cancer and chronic respiratory diseases. Approximately 91 percent of the world's population lives in areas where poor air quality exceeds WHO limits. The WHO and individual countries are working together to monitor air pollution and improve air quality [4].

To control pollution, one needs to be able to measure concentrations of various pollutants. Current methods used for these measurements are very expensive, and therefore they cannot be done on a massive scale. This paper considers a possibility of using inexpensive sensors coupled with the Internet of Things (IoT) for close to real time measurements of pollution. Moreover, the methodology is illustrated through the evaluation of street level air pollution and its relationship to the number of vehicles.

A. Internet of Things

The Internet of Things (IoT) is a system of physical objects such as sensors and connectivity that enables transfer, collection and exchange of data. Nowadays, the IoT is regarded as one of the most significant technologies being developed. This is in part due to its capabilities for improving human health and assisting with societal issues. The advent of the IoT in many fields has begun to make an impact on the global economy as well. There have been much research in this field leading to new services including opportunities to connect physical devices and between virtual worlds and devices located in houses, cars, streets, and other public environments. The IoT involves applications such as smart cities, smart homes, smart health care, smart transportation and smart traffic management [5]. The IoT is important in the development of inexpensive air pollution sensing devices as well. Such devices may be placed around a city to measure humidity, temperature, and concentration of ozone, carbon monoxide, nitrogen dioxide, noise, and particles [6]. The devices may be configured to send alarms if any of the concentration for any of the pollutants goes above a set threshold. This type of architecture addresses the main problem of air pollution monitoring - expensive and cumbersome measurement systems. With the IoT, one may possibly deploy hundreds of sensors for near real-time monitoring of air quality over larger geographical areas.

B. Health Effects

Gas emissions from cars are the most important contributors to air pollution. These emissions cause many adverse effects to the health of humans. The most sensitive groups are children and older adults, especially the people that are active outdoors. The most significant health effects are respiratory problems such as coughing, congestion, chest pain, and throat irritation. The pollution also worsens respiratory diseases such as asthma, bronchitis, and emphysema. Some gases like SO2 react with other parts of the atmosphere and create particles that penetrate deeply into sensitive parts of lungs. Particulate matter is linked to numerous problems such as premature death with people with lung diseases, nonfatal heart attacks, irregular heartbeat, aggravated asthma, and a decrease in lung function [7].

C. Air Quality Index

To help manage different types of pollution, government agencies regularly monitor air quality. Unfortunately, the methodology for monitoring is not standardized. Within the United States, the Environmental Protection Agency (EPA) categorizes air quality into six ranges. Each range has different levels of potential health concerns. The Air Quality Index (AQI) is calculated by measuring the levels of five main pollutants: ground level (or tropospheric) ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The AQI ranges from 0 to 500. When the AQI is in the range 0-50, the air quality is considered "Good" and the pollution poses little to no health risk. For AIQ values 51-100, the air quality is "Moderate" and acceptable for most people, but a potential health concern for a very small number of people particularly sensitive to air pollution. When the AQI is in the range 101-150 the air quality is "Unhealthy for Sensitive Groups". Although the general population is not likely to suffer consequences for being exposed to air in this range, people with lung disease, older adults, children, and asthmatics are at risk. Between 151-200, the air quality is "Unhealthy". Everyone might experience some adverse health effects, and members of sensitive groups may suffer serious, or even life-threatening effects. Between 201-300, the air quality is "Very Unhealthy". This usually triggers a health alert warning for people to avoid unfiltered outside air as much as possible because everyone is at risk for more serious health effects. Between 300-500, the air quality is "Hazardous". This calls for an emergency health warning, with the entire population likely to be affected. Keeping informed about the AQI value is an important way to stay healthy; the Table in Fig. 2 summarizes the AQI ranges. Each range is associated with a specific color (green to black). Colors are used in a consistent manner to improve clarity of messages that are communicated to the general public [7].

0 - 50	Good
51 - 100	Moderate
10 1- 150	Unhealthy for Sensitive Groups
151 - 200	Unhealthy
201 - 300	Very Unhealthy
301 - 500	Hazardous

Fig. 2. AQI Scale

Air quality is closely related to both the climate of the earth and to the global ecosystems. The carbon dioxide emissions of the world continue to rise, driven by the same sources as air pollution in general. Other pollutants, including both ozone and particulate carbon, have a strong effect on agricultural production as well as on the continuing warming of the planet. As a result, some international and national bodies have begun to implement policies aimed primarily at reducing the health effects and climate effects of air pollution. Among them, the World Health Organization has been in the forefront of those efforts. This organization works with health professionals throughout the world to address their much-needed participation in reducing this health hazard. The WHO is responsible for establishing a Global Platform on Air Pollution and Health. Working jointly with governmental and academic experts, they make certain that monitoring of exposure and improved surveillance methods are implemented on not only a national but also on a global scale. The WHO also has led an effort to establish the BreatheLife campaign, in collaboration with the UN Environment and the Climate and Clean Air Coalition. The goal of this collaboration is to increase the awareness of the connections between air pollution and climate change and health among not only health care professionals but also among municipal governments, national governments, and the public [8].

II. LITERATURE REVIEW

There is much research about the Air Quality Index, some of which is presented in this section. According to [2], emissions due to automobile exhausts represent 60 percent of air pollution in India. In addition, many organic chemical compounds, either in gaseous form or in particulate form or in the combined forms, are contained in these emissions. A two-month study was done in three locations in the city of Bhopal, India (Govind Pura, T. T. Nagar, and Hamidia Road). The study was designed to monitor air quality pollutants such as PM10, PM2.5, SO2 and NOx. The experiment utilized HVS (APM 460) to get air sampling. All the pollutants were analyzed per Central Pollution Control Board (CPCB) guidelines. Moreover, they used AQI to measure the ratio of the pollutants concentrated in different places. The study found PM10 and PM2.5 to be more than the permissible limit but NOx and SO2 less than the acceptable limit. The excesses of PM10 and PM2.5 cause significant environmental risks that threaten those with heart disease and respiratory symptoms in the population.

The IoT can help provide air quality measurement in real time. In [9] by using IoT the authors propose development of smart Low-Power Wide-Area network (LPWAN) sensors that enable long-range monitoring of air pollution in real-time. There are five types of smart sensor for air pollution. These sensors can monitor carbon monoxide (CO), ozone (O3), noise level (dB), carbon dioxide (CO2), and particulate matter (PM10). The sensors then calculate the AQI and transmit data using LTE technology, NB-IoT to a central server. By using a smartphone, the people can then monitor the existing website for the measurements of air quality. The measurements are performed in two locations: P1 and P2 in the city of Bangkok, Thailand for seven days. The AQI result of both locations was approximately the same. The air quality was good; the highest AQI was recorded the last day of the study, but it was still in the range 0-50.

In [10] researchers evaluated the Air Quality Index (AQI) by measuring the average concentration of four pollutants (NO2, SO2, PM2.5 and PM10). These measurements were used to determine the prevailing ambient air quality in the location of study. The results of seasonal and daily readings of the AQI ranged from good, to moderate, acceptable, and unsatisfactory in different AQI computations according to the guidelines from CPCB. The results of this study deduced that PM10 is mainly responsible for pollution in this location and was causing serious public health problems.

In [11], the study employed the IoT to detect vehicle-produced pollution in real time. There are two sensors which are used to detect two important types of toxic gases produced by gasoline powered vehicles: CO and SO2. Moreover, this study utilized a Radio Frequency Identification (RFID) reader system to count the passing cars on the road. In the experiment, the Arduino board is used as a controller system to receive data from sensors, and the RFID reader is used to track, detect, and find the location of the cars. The data are saved on a central server for the analysis. The user of the platform is alerted if the pollution levels exceeds prescribed threshold values.

III. EXPERIMENTAL SETUP

The purpose of this paper is to model and to analyze pollution data on the street level. The street level is considered as the best place to measure gas emissions from cars. The first step of this research is to collect data from an air quality sensor in the street. The air quality sensor was placed in close proximity to Babcock Street in Melbourne, FL USA. The second step analyzed the air pollution data. By comparing the average of the number of cars for an hour with the average of the air quality for an hour, one is able to calculate the correlation between them. Thus, an analytical model may be created that relates the AQI to the number of the cars in the street, i.e., traffic density.

A. Study Area

The experiment was conducted in the city of Melbourne, Florida, in the United States, Fig 3, on Babcock Street, as shown in Fig 4. Babcock Street is one of the main streets in the city. In Melbourne, the summers are four months long, hot, with 120 days above 24°C to 30°C, and wet, with an average rainfall of 6 inches. The winters are around two months, cool (with an average temperature of 12°C to 22°C), and windy. Over the course of the year, the temperature typically varies between 12°C and 32°C and is rarely below 4°C or above 34°C. The economic and urban developments of the area have caused negative environmental effects [12].

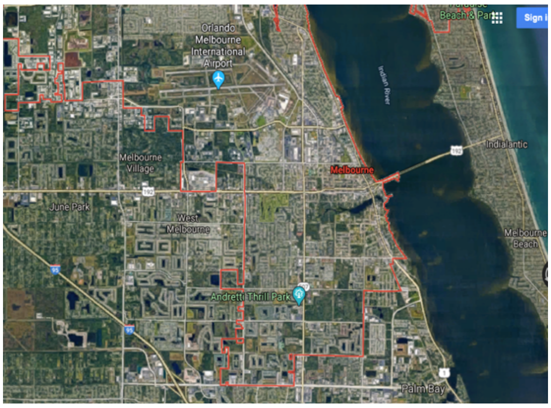

Fig. 3. Melbourne Scope

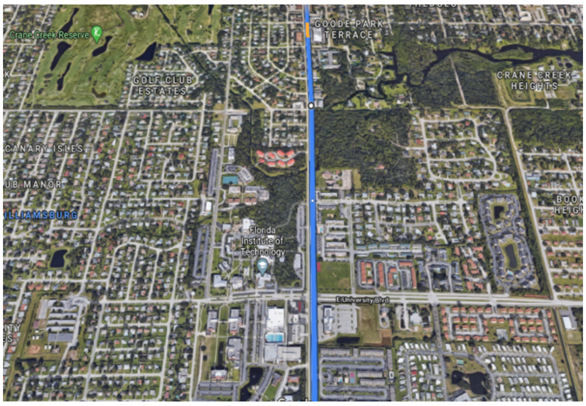

Fig. 4. Babcock Street

B. Hardware:

The IoT air quality system which was used consists of sensors that enable monitoring of the concentration of pollutants, as well as several environmental parameters such as air temperature, humidity and pressure as shown in Fig 5. Included, there are sensors for measurements of gaseous pollutants (CO, SO2, NO2, O3) and PM-Particulate Matter (PM2.5, PM10). The system collects the data and sends them via Ethernet, Wi-Fi, cellular (2G/3G/4G) or NB-IoT interface to a central server location as shown in Fig 6. The Air Quality Sensor has some additional features, such as firmware parameter management (through which update and retrieval are supported), robust casing, low power consumption, and operating range from -40 to +125 °C. For data processing and visualization, the system provides an air quality monitoring solution, the main purpose of which is to identify and monitor sources of air pollution. Table 1 shows the most important data on the sensors used in the air quality measurement system. A Hikvision camera and a Network Video Recorder (NVR) are used to record video from an IP camera pointing towards the street. The NVR camera has a hard disk to record and save a video for a long time and which could be retrieved at any time.

Table. Sensors Details.

Sensor Element Manufacturer	Specifications
Temperature (Farnell)	Operating range: -40 to 125 deg C
Humidity (Farnell)	Operating range 0 to 100% (non-condensing)
Pressure (Freescale)	Operating range: 15-115 kPa
CO, Carbon-Monoxide (Alphasense)	Range: 0-1000ppm
NO2, Nitrogen-Dioxide (Alphasense)	Range: 0-20ppm
SO2, Sulfur-Dioxide (Alphasense)	Range: 0-20 ppm
O3, Ozone (Alphasense)	Range: 0-2ppm
Particle sensor • Plantower (PM2.5, PM10)	Range 0-1000ug/m^3
Noise sensor (optional)	Range 40-111dB

Fig. 5. Installation in Babcock street

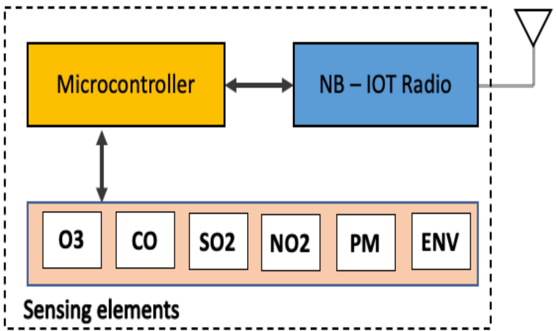

Fig. 6. Block diagram of AQ sensor

C. Calculating the Air Quality Index (AQI)

The data consists of AQI values for the different sources of air pollution as O3, CO, SO2, NO2, PM2.5 and PM10. In these data, different readings of the AQI are available for each hour, provided as an average of concentration for each hour for each of the air pollutants being measured. The AQI values for each of the gases is calculated by using the following formula from the EPA guideline:

$$AQI = Ip = \left[\left\{\frac{(I_{high} - I_{Low})}{(C_{high} - C_{Low})}\right\} * (Cp - C_{Low})\right] + I_{Low} \quad (1)$$

Where C_{high} = breakpoint concentration greater or equal to given concentration, C_{Low} = breakpoint concentration smaller or equal to given concentration, I_{high} = AQI value corresponding to C_{high}, I_{Low} = AQI value correspond to C_{Low}, Cp = the concentration of pollutant p, AQI = maximum of Ip [7].The AQI value is selected from the maximum value of all gases and particulates measured: O3, CO, SO2, NO2, PM2.5 and PM10 [13].

$$AQI = \max(O3_{AQI}, CO_{AQI}, NO2_{AQI}, SO2_{AQI}, PM2.5_{AQI}, PM10_{AQI}) \quad (2)$$

IV. EXPERIMENTAL RESULTS AND RESULTS ANALYSIS

The collected data are shown in Figs. 7 through 13. The results for the AQI of pollutants were collected for 8 hours per day from 8 AM to 5 PM over a 10-day period. In the graphs in Figs. 7 through 13, the X axis represents the time in hours and the Y axis represents the AQI associated with a pollutant. A separate chart is provided for each one of the pollutants. The AQI values for all the days on Babcock Street were at a Good level, which corresponds to the AQI value under 50 according to the EPA categories for air quality.

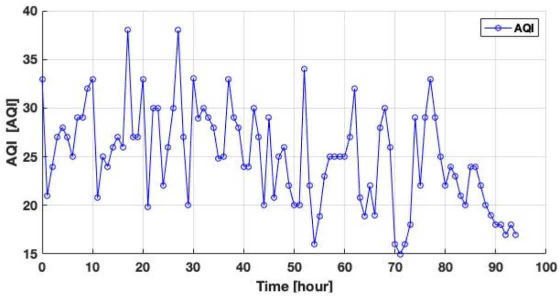

Fig. 7. AQI values calculate using (2)

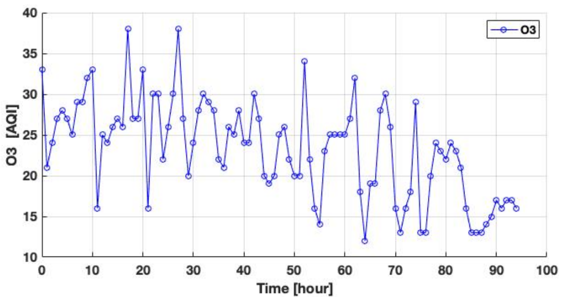

Fig. 8. AQI Measurements for O3

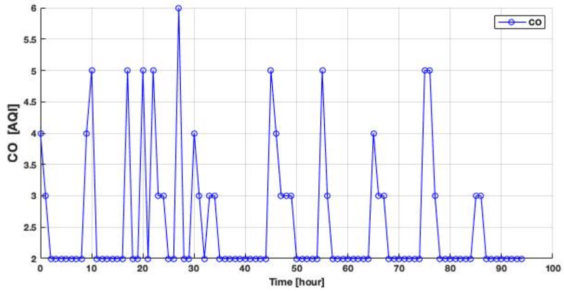

Fig. 9. AQI Measurements for CO

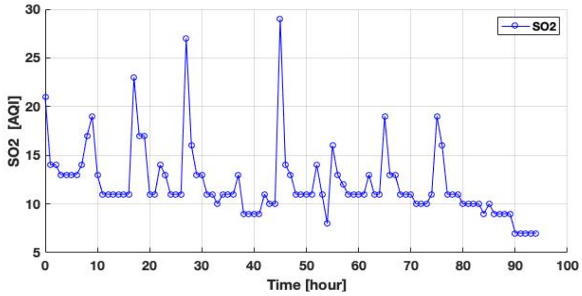

Fig. 11. AQI Measurements for SO2

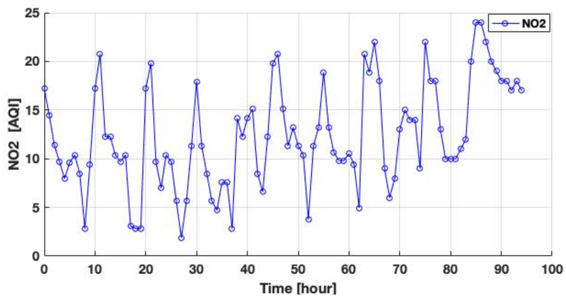

Fig. 10. AQI Measurements for NO2

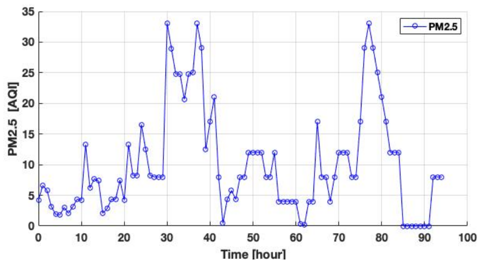

Fig. 12. AQI Measurements for PM2.5

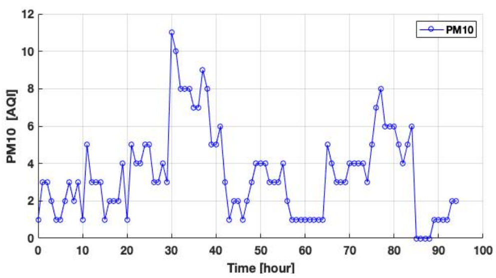

Fig. 13. AQI Measurements for PM10

A. Result Analysis

Data are analyzed to examine the relationship between the traffic density and the AQI.

A simple Linear Regression (LR) is used for model development [14]. The LR analysis is used to predict the value of a dependent variable (Traffic Density) relative to an independent variable (AQI). The linear regression equation is creating a mathematical model in order to calculate and measure the Air Quality Index of air pollution.

AQI = $a \times TrafficDensity + b$ (3)

During the 10 days of collecting the data, it can be seen that the Air Quality Index is dependent on the number of cars, as shown in Figs. 14 through 20. Table 2 presents the parameters of the LR model. In the experiment and results as shown in Figs. 14 through 16, the relationship between air pollutants and car numbers is strong for AQI, O3, and CO. The R square value tells us that there is a correlation between the number of cars and the air pollutions. The R squared value for the LR model between the total AQI and traffic density is 0.71.The R squared value for the LR model between the total ozone and the traffic density is 0.60.The R square presenting the relationship between CO and traffic density is0.50of air pollution in the street. As shown in Figs. 17through 20, the results of linear regression show that the NO2, SO2, PM2.5, and PM10 were very little effected by the number of cars.

Table 2. Results.

Air pollutions	Linear regression equation	R square (R^2)
AQI	AQI=15.62*TD+1718	**0.71**
O3	O3=10.55*TD+1862	**0.60**
CO	CO= 67.64 * TD +1936	**0.50**
SO2	SO2=14.98* TD + 1927	**0.35**
NO2	NO2=-4.453* TD + 2164	**0.064**
PM2.5	PM2.5=1.857*TD+ 2090	**0.028**
PM10	PM10= 7.946*TD+ 2081	**0.039**

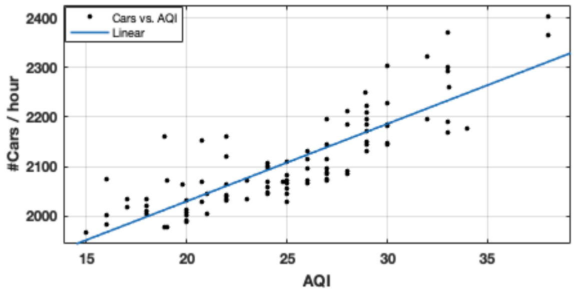

Fig. 14. Linear regression for AQI

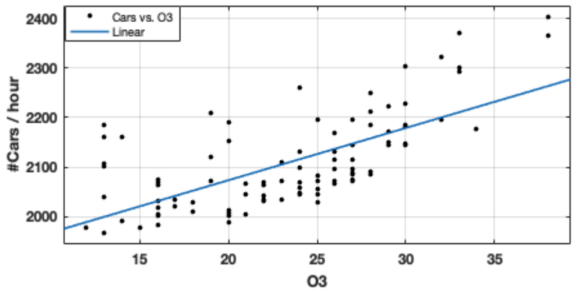

Fig. 15. Linear regression for O3

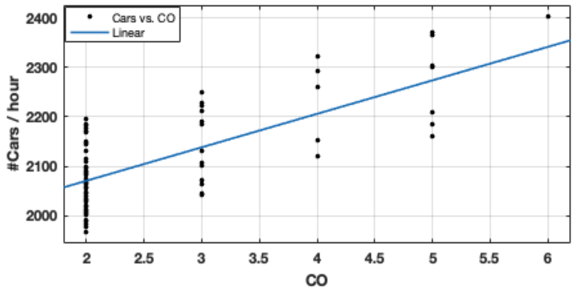

Fig. 16. Linear regression for CO

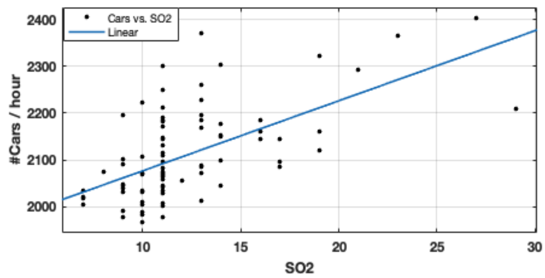

Fig. 18. Linear regression for SO2

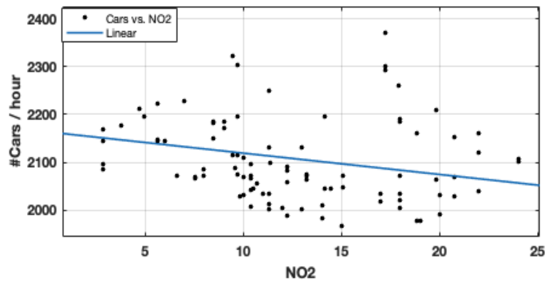

Fig. 17. Linear regression for NO2

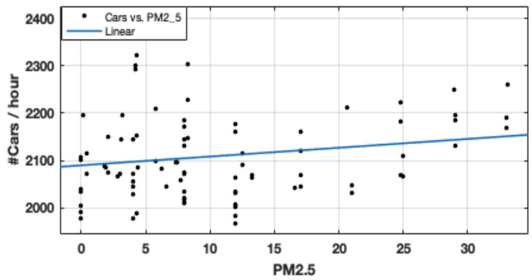

Fig. 19. Linear regression for PM2.5

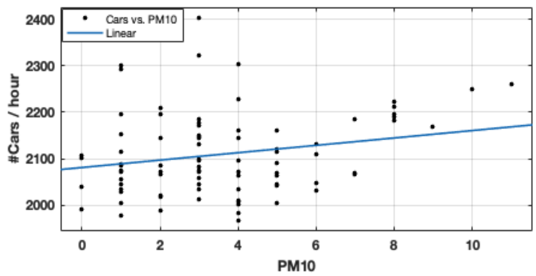

Fig. 20. Linear regression for PM10

V. CONCLUSION

The paper presents the relationship between the air quality on the street level and the density of the vehicle traffic. The evaluation of the data reveals that some of the pollutant have very high correlation with the density of the traffic. These pollutants are O3, CO and SO2.On the flip side, according to the measurements reported in this study, some pollutants show a weak correlation with the traffic density. These pollutants are NO, PM2.5 and PM10. The study considered just raw measurements and did not correct for environmental conditions (pressure, temperature and humidity). Further work will consider these additional factors.

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