Pavement Carbon Monoxide Concentration Prediction: a Prediction Model from Traffic Flow, Fleet Velocity and Sound Pressure

Case study of Tirana, Albania

Gledis Guri

Degree Thesis for Bachelor of Natural Resources

Degree Programme in Sustainable Coastal Management

Ekenäs Raseborg 2016

BACHELOR'S THESIS

Author: Gledis Guri

Degree Programme: Sustainable Coastal Management

Supervisors: Patrik Byholm

Title: Pavement Carbon Monoxide Concentration Prediction: A Prediction Model from Traffic Flow, Fleet Velocity and Sound Pressure

---

Date: May 19, 2016 Number of pages: 30 Appendices: 0

Summary

Carbon monoxide is a poisonous gas which is dangerous for human health due to the fact that it is colorless, odorless and tasteless. These features minimize the possibility for humans to detect and therefore avoid carbon monoxide. Noise is a disturbance from basically every unwanted sound in human ears and its physical feature is waves which makes it invisible by the naked eye in the air. Both pollutants are harmful for human health and occur in high concentration in urban cities since most of the mobility and thus economic activity are located there. Long term exposure to relatively high amounts of noise and CO causes severe short and long term health damages depending on the level of pollutants. Due to human inability to detect these pollutants rises a need for an understanding of pollutant behavior and pollutant sources. Therefore, this study attempts to explain the behavior of CO and noise pollutants, at breathing zone on the pavements in the urban areas of Tirana, Albania caused by automobiles passing on the road beside the pavements. The study shows a strong dependency of pollutants from fleet velocity and traffic flow and low amounts of pollutants when the road is wide and located in an open area with no barriers alongside it. Meanwhile when the road is narrow and located in a sheltered place with building barriers aside it, pollutants do not have a dependency with fleet velocity but only with traffic flow and the concentration amount of pollutants is high.

Language: English Key words: CO roadside pollution, noise pollution, human health, fleet velocity, traffic flow

---

Table of contents

Abbreviations

EIA – Environmental Impact Assessment

NTA – National Tourism Agency

MoT – Municipality of Tirana

ECAT – Environmental Center for Administration & Technology Tirana

GHE – Greenhouse effect

CO – Carbon monoxide

COHb – Carbon monoxide binding in hemoglobin

Ppm – Parts per million

TTS – Temporarily threshold shift

PTS – Permanent threshold shifts

1. Introduction

Carbon monoxide has been present ever since the human existence as a natural gas mainly generated from methane oxidation in the atmosphere but always in low concentrations until the industrialization age. During the industrialization age the coal production increased significantly together with its use and therefore the concentration of CO shifted upward following the trends of the industrialization development. This high concentration increased rapidly when more fossil fuels were discovered and introduced to the general public. Along with this development CO-emissions started to affect human health and soon researchers presented studies which showed a connection between certain diseases and exposure to high CO concentrations. Limits and regulations were set by environmental agencies to maintain good health conditions of the citizens and especially of workers who were exposed to CO gas.

Noise disturbance follows the same attributes except that noise has a wave physical nature instead of gas and therefore different rules and regulations are set but with the same aim: maintaining good health conditions. Both CO and noise disturbances have an anthropogenic source with a high correlation with the development of humankind in general and especially the urban development.

2. The purpose of this study

The main reason for conducting this research is the Albanians' thinking "Roads bring development" and personally I wanted to test and see if there is only development (economically) or more than just that. The purpose of this study is to build a correlation matrix that could show dependencies of CO concentration in the air depending on traffic, average velocity and sound pressure. The purpose could be extended by using it in different fields e.g. when dealing with health care or municipality issues.

Nowadays, vehicle dependency is increasing rapidly and the cost for owning a car in Albania is decreasing. The total number of vehicles reached 981,798 in 2014 for a population of around 2.8 million (Instat, 2015). This pollution should not pass unnoticed by EIA reporters even though it is not mentioned in any national law or national/local recommendation.

G&G Group institute is a leader institute in Environmental Impact Assessment and they provide highly detailed EIA reports. G&G Group & I concluded that in any EIA in Albania the roadside pollution is not monitored nor added to the final report of the development as an outer source of pollution. Therefore, it has been agreed to build a model which could predict the roadside CO concentration depending on traffic, velocity and category of car. With the help of this model the EIA made by G&G Group will become more precise and detailed, and it will consider more factors which otherwise will require more field workers.

This model predicts a high correlation between CO concentration and traffic, average velocity and sound pressure. If this proves to be true, with the help of G&G group and more extensive research on the field, this study has the potential to influence law makers and be included as roadside pollution to EIA.

3. Albania and Tirana

3.1 Introduction of Albania

The Republic of Albania is located in the south-east of Europe on the western part of Balkan Peninsula with the coordinates 39 38’ south and 42 39’ north, (Meçaj, 1999, p. 8). It has a surface of 28,748 sq. km and a population of 2,893,005 inhabitants. (Instat, 2015, p. 1). Albania is one of the smallest countries in Europe according to its surface but it has an outstanding strategic importance on Mediterranean Sea (Dida, 2004, p. 5).

Figure 1. Physical Map of Albania (Qiriazi, et al., 2007)

Generally, it has a high terrain and it is classified as a mountain relief with an average altitude of 708 m. The mountains are located in the Eastern part of Albania where also the highest peak is located on the Korabi mountain, 2751 m, and then continuing in the north with the Albanian Alps where the next highest peaks are located. The rest of Albania (western part) consists of valleys and arable land where most of the agriculture products come from. Due to this geography all the rivers come from the north and east and flow toward the sea in the western part

(Dida, 2004, p. 11). Albania is very rich in hydrology with 133 rivers in its hydrography network, 247 natural lakes and 700 artificial lakes with a total surface of 1100 sq. km, and 200 main springs that produce 200 liters of water per second. It is washed by two ecologically diverse seas, the Adriatic Sea and the Ionian Sea that consist of a 472 km coastline (Meçaj, 1999, p. 18).

Albania has a Mediterranean climate which means hot dry summers and warm winters. Albania is well-known for its diverse microclimate all over the territory due to its diverse terrain relief. In the mountain areas the microclimate creates rainfalls and cold temperatures while in the lowlands the microclimate creates draught and hot temperatures. The reservoirs and springs are filled with water from the mountains in the mountain areas and then passed through the groundwater, rivers and channels all over the territory.

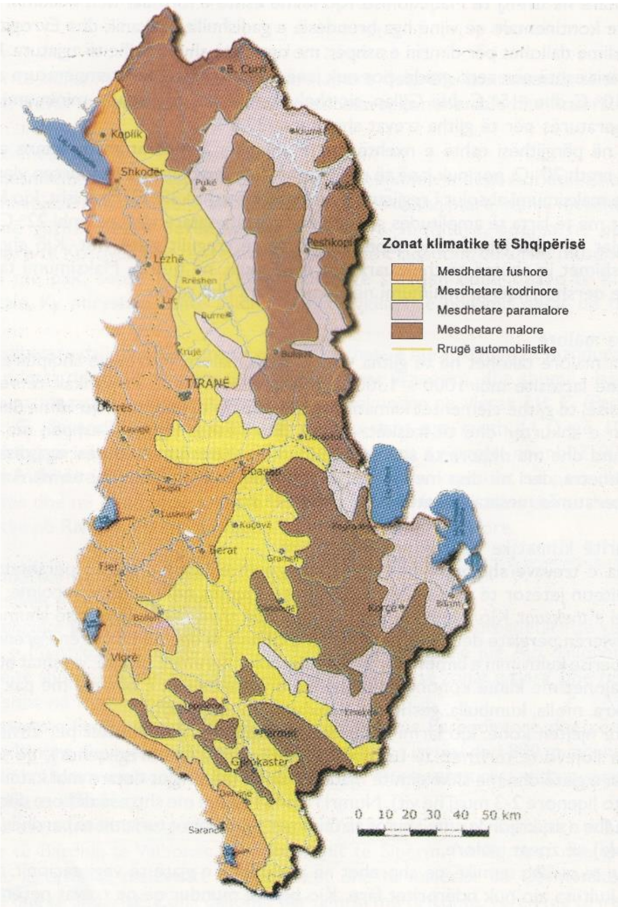

Figure 2 Map of Albanian climate zones (Qiriazi, et al., 2007, p. 38)

An important aspect of the Albanian climate is the high number of sunny days. It has an average of 300 sunny days in the lowland part (western part) and 250 sunny days in the mountain areas (eastern and northern parts). Albania is known for a high amount of precipitation with an average of 1430 mm/y but it differs a lot in different microclimates with an average of 3100 mm/y in the Albanian Alps and 600 mm/y in the lowlands. Snow is very rarely seen in the lowland of Albania while in the mountain areas it is a normal phenomenon (Qiriazi, et al., 2007, p. 32; Meçaj, 1999, pp. 1,16,17)

“In summer you can pass within a few hours from the great heat of the lowland to the characteristic coolness of highlands”. (Meçaj, 1999, p. 16)

Albania is very rich in flora, when around 36% of the Albanian territory is forested and it has a number of 3250 species, which 150 of which are native. The whole flora of Albania consists of Mediterranean plants and it makes up 29% of the entire European flora comprising of 11,500 species (Dida, 2004). Protected areas come up to 5.8% of the total area of Albania with high floral diversity in 13 National Parks (Dida, 2004, p. 11).

The Albanian economy is composed by three main chapters: agricultural, industry and tourism & infrastructure listed by their importance accordingly. The Albanians have always been known as really good farmers starting from the Illyrians (350 BC) until the end of WWII when around 80% of the entire Albanian population was working as farmers. It has been a family tradition to become a farmer and to continue this tradition over the generations. Around 18,800 km of irrigation channels where built voluntarily during 45 years of communism to protect the arable land from drought (Qiriazi, et al., 2007, pp. 77-79)

3.1. Introduction of Tirana

Tirana is the capital of Albania and the biggest city in Albania with a population of 800,986 inhabitants registered on 1st of January 2015 (Meçaj, 1999, p. 99) . The history of Tirana is not as old as that of other ancient cities in Albania and it also has little history compared with other European capital cities (Aliaj, et al., 2003, pp. 14,15). The history of Tirana as a city begins as a written name in a document of the Pope. It then starts to come into life in 1614 when Sulejman Pasha invests in building a city with oriental influences, including a mosque and a bazaar. (Meçaj, 1999, p. 99). In 1920 Tirana became the capital of Albania after a convention held at The Lushnja Congress and it remains so even today (Meçaj, 1999, p. 99).

Figure 3. Landscape of Tirana 1851 (©Edward Lear) (Lear, 2012)

Tirana is in central Albania and therefore it has different climate conditions from the lowland climate or mountain area climate. The climate of Tirana includes fresh summers and rainy or snowy winters since it is located 25 km away from the Adriatic Sea and Mount Dajti is located 7 km north of the city (Albanian green line, 2010, p. 99). The wind velocity is relatively low, it blows north-west during the summer time and it changes to a south-west direction during the winter (ECAT, 2008, p. 10). Mount Dajti also acts as a protection from the cold winds that could come from the north. (Aliaj, et al., 2003, pp. 15,16)

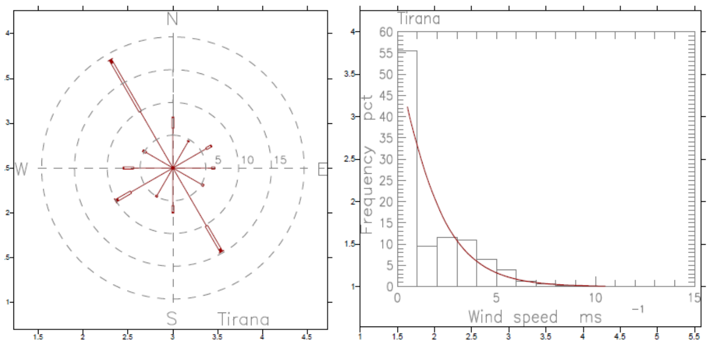

Figure 4. Wind directions (left) and the frequency of wind speed (right) in Tirana area (ECAT, 2008)

In an urban development aspect, Tirana does not have its own identity. Contrariwise, it has been mixed during different systems and invasions and all this mixed again with its antiquity. This "fuzzy" structure comes also due to its location in between a mountain and a sea, which prohibits Tirana from creating its own character in an urban aspect. Tirana represents a human civilization history within its territory shown by monuments belonging to different ages and systems. (Aliaj, et al., 2003, pp. 14,15)

"Broad and narrow, some straight but more broken and in particular curved, discontinuous and often dead ended, that due to ownership interests and informal adding start branching off into other, forming hundreds of wires that make the structure road city everything like the veins of a leaf poplar" (Aliaj, et al., 2003, p. 25). This shows the poor road infrastructure development of 18th century of Tirana.

4. Pollution

4.1. Carbon monoxide pollution

4.1.1. Carbon monoxide chemical features

Carbon monoxide is a compound combined by a Carbon atom (C) and an Oxygen atom (O). It is odorless, colorless and tasteless and it is poorly dissoluble in water. CO has a lower weight than air and therefore tends to rise up in the atmosphere. Its molar mass is 28.01 g/mol. It does not react easily with other chemicals in gas shape after polluted or emitted but instead, it is removed from the atmosphere due to sedimentation (William, 1994, p. 286).

Carbon monoxide is considered an air pollutant affecting human health rather than global warming and greenhouse effect (GHE). The anthropogenic sources of CO are simply produced from incomplete combustion of organic matter (everything that contains C) and therefore is called an organic pollutant. In other words, low amounts of oxygen in combustion for producing CO_2 would produce CO (see formula below) (Hobbs, 2000, pp. 153,154)

$$C_8H_{18} + 12.5\ O_2 \rightarrow 8CO_2 + 9\ H_2O\ (F\ 1)$$

$$C_8H_{18} + 11.25\ O_2 \rightarrow 5.5CO_2 + 9\ H_2O + 2.5\ CO\ (F\ 2)$$

Formula (1) is the ideal combustion of fossil fuel with the right amount of oxygen or otherwise called oxygen rich combustion. Formula (2) demonstrates a combustion made with 1.25 mol of O_2 less; therefore, the reaction will produce 2.5 mol of CO.

4.1.2. Anthropogenic pollution

From the beginning of the 19^{th} century the human development peaked with industrialization and that was not consequence free. During the industrialization, which mainly consisted of inventions based on fossil fuel energy, the level of anthropogenic pollution rose together with development (Spellman, 2010, p. 140). Before 1980 coal was the main source of energy and it was burned directly which lead to CO and SO_2 emissions in the air (Penny, 2000, p. 345). The anthropogenic pollution affected all three elements of the earth: land, air and water. Anthropogenic air pollution means mainly the contamination of the atmosphere from sulfur dioxide, small particulate matter in the size of 2.5µ and 10µ (PM 2.5 & PM 10), volatile organic compounds, carbon monoxide, carbon dioxide, methane, NOx etc (Spellman, 2010, p. 140).

Global background concentration of carbon monoxide is around 0.06-0.14 mg/m3 (0.05–0.12 ppm), exposure of which doesn't put humans and animals at an increased risk for adverse health effects. (WHO, 2000, p. 75). The aforementioned is belived to be generated by the voulcanic acitivies of the earth crust and the methane oxidation in the air (Fellenberg, 2000, p. 28). The main sources of CO antropogenic pollution come from combustion in coal power plants, smelters, light-heavy duty vechiles, grilling stores etc. (Hobbs, 2000, p. 153). Automobile CO pollution ranks highest in the sources of CO pollution with a contribution of 60-70% of the total antropogenic CO contamination (Fellenberg, 2000, p. 28). In urban areas this percentage rises up to 90% (Elkafoury, et al., 2015, p. 1). Automobile CO pollution was higher before the 1980's due to poor burning technologies of the fossil fuels. After the 80s, technology improvements allowed for oxygen sensors to be used in automobile engines, which kept the oxygen tightly regulated for near-complete combustion leading to an observation of lower CO concentrations (Hobbs, 2000, p. 154).

4.1.3. Carbon monoxide effects

"Carbon monoxide is responsible for more poisoning fatalities every year than any other toxic agent" (Krenzelok, et al., 1996). Carbon monoxide is a poisonous gas and it can be lethal due to its strong binding ability to hemoglobin. CO has a hemoglobin affinity around 300 times that of oxygen, leading to hypoxia as less hemoglobin is available to transport oxygen from the lungs to the rest of the body. Therefore, CO possesses a serious danger for humans even at low concentrations. An example is given to show that a CO concentration of 70 ppm (0.007%), which stimulates direct health symptoms such as headache and blurry vision, due to high affinity it results in a quantity of 10% bound in hemoglobin as described in the following formulas (Fellenberg, 2000, p. 29)

$$M \times \frac{pCO}{pO_2} = \frac{[COHb]}{[O_2Hb]} \; (1)$$

$$\frac{[COHb]}{[O_2Hb]} = 300 \times \frac{0.007\%}{20.9\%} \; (2)$$

$$\frac{[COHb]}{[O_2Hb]} = 0.1 = 10\%$$

Where M = 300 is the affinity ratio, pCO is the concentration of carbon monoxide in percentage per volume of the air, $\frac{[Hb.CO]}{[Hb.O_2]}$ *is carbon monoxide percentage bound in hemoglobin and* PO_2 *is the oxygen concentration in the air*

Table 1 Health effects of CO concentration level

CO level of pollution ppm	CO level of pollution mg/m^3	Health effects
60 ppm	74 mg/m^3	Changes in visual system such as blurry vision
130 ppm	160 mg/m^3	Headache and body pain
200 ppm	247 mg/m^3	Loss of consciousness, difficulty in breathing
660 ppm	814 mg/m^3	Inability to breathe

750 ppm	925 mg/m^3	Deadly effects

Source: (Fellenberg, 2000, p. 30)

CO intake by breathing leads to low biding capacity of oxygen in hemoglobin but that does not end here. The effect continues with changes of oxyhemoglobin concentration curve towards low concentrations, which with other words means that less oxygen is released in the tissue or cells even though hemoglobin has oxygen in it. This is otherwise expressed as the ability of oxyhemoglobin to release the oxygen in the tissue or cells. As most of other factors, there is a correlation between COHb and oxyhemoglobin curve shifting, meaning that higher COHb will bring greater shifts in oxyhemoglobin curvature. (Penny, 2000, p. 140)

The upper limits for CO concentration in hemoglobin should not exceed the levels of 2.5 % in the human body; meaning at these levels one can maintain healthy heart activity and adverse neurobehavioral should not occur (Penny, 2000, p. 11). To maintain this recommended healthy level of CO, environmental agencies in every country has set limits on CO concentrations. Directives from European Environmental Agency (EEA) entered the force in 2005 with limits shown in the table below:

Table 2 Limits for CO exposure for maintaining [COHb] at the level of 2.5%

CO concentration	Time exposed to the pollution
10 mg/m^3	8 hours
30 mg/m^3	1 hour
60 mg/m^3	30 min
100 mg/m^3	15 min

Source: (WHO, 2000, p. 77)

In addition to direct health adverse effects CO also has an effect on Photochemical smog. Other air pollutants which in high concentration contribute to photochemical smog formation include: NO_x, O_3, H_2SO_4 and hydrocarbons post sun exposure. Most of the air pollutants reacting to form the photochemical smog are derived mainly from the automobile exhaust or saying differently that high concentration required to enter in smog forming reaction are derived from automobile exhaust. Photochemical smog in the other hand serves as an indicator of very high polluted air (Hobbs, 2000, p. 158).

Similar to the Secchi depth in water, which is caused by high concentration of nutrients and microorganisms that reduce the sunlight that passes through the water, in the air this phenomenon is referred to as visibility reduction or meteorological range. In the visibility reduction phenomenon air pollution substances, composition of the photochemical smog, have the also same function as nutrient in the water, they reduce the horizon visibility by absorbing the light and preventing it from traveling further (Hobbs, 2000, p. 160)

4.2. Noise pollution

4.2.1. Sound wave features

Sound is determined as a pressure variation that is spread through waves in all 3 elements of the earth, air, water, soil. There are a lot of differences in between each element and thus sound could never be compared accounting only for pressure, speed, frequency etc. However, its physical condition as a wave is fundamental in all these elements.

Due to its wave physical condition, sound has an amplitude and a frequency or wavelength. It always has a source, a transmitter and a receiver otherwise it would not exist. By its definition it is a pressure variation done by the source which in other words is the amplitude of the wave and it is measured in Pascal (Pa) named after Blaise Pascal. A sound source produces sound in different frequencies at the same time which in other words is the number pressure variation per second and it is measured in Hertz (Hz) named after Heinrich Rudolf Hertz. Sound travels on a speed of 340 m/s in the air, 1500 m/s in the water and around 5000 m/s in solid content (Detwyler & Marcous, 1972, p. 196).

The sound pressure is very broad and it can vary from 20 µPa to 100 Pa. Due to this wide range of sound pressures, Alexander Graham Bell invented a new measurement system, decibel (dB), which is now used worldwide. The geniality of this new system goes for the logarithmic scale of the pressure in Pa, meaning that difference of 20 dB would be a difference from 200 µPa to 2000 µPa in pressure or differently saying is an increase of 10 times of the sound pressure as it is illustrated in the table 3 (Detwyler & Marcous, 1972, p. 196). Due to a high variety of units for sound measurement this study will be focused only on dB and SPL in Pa.

Calculating Noise in dB from Sound Pressure Level in Pa is done according to the formula below:

$$Lp = 20\, log_{10}\left(\frac{p}{p_{ref}}\right)$$ *(Barron, 2001, p. 40)*

Where L_p is the sound in dB, p is the pressure in Pa and P_{ref} is the pressure reference in Pa (20 µPa for the air)

Table 3 Comparison of noise in dB and SPL for each activity

Activity	**Noise in dB**	**Sound pressure level in Pa**
Military jet, air raid siren	130	63245553 µPa
Train horn at 30 meters	90	632455 µPa
Busy city street, loud shout	80	200000 µPa
Highway traffic at 15 meters, train	70	63245 µPa
Predominantly industrial area	60	20000 µPa
Background noise in an office	50	6324 µPa
Public library	40	2000 µPa
Soft whisper at 5 meters	30	632 µPa
Threshold of hearing	0	20 µPa

Source: (Cowan, 1994)

4.2.2. Noise pollution

There are a lot of different definitions about noise but in this study we will accept the noise as in difference with sound, noise means the unwanted or undesired sound. Noise could lead from anything or everything that produces sound, unless is desired. The main sources of noise are outdoor activities caused by mostly everything, starting from airplanes to unwanted conversation.

Noise could be disturbing in two types of ways 1) exposure to high sound pressures or 2) exposure for an extended period of time. For this reason, different ways of measuring noise are enforced. Peak to peak (dB_{p-p}) or null to peak (dB_{0-p}) is a way to measure high sound pressure and equivalent continuous sound level-L_{eq} (dB_{Leq}) measures noise as a continuous phenomenon. These are used for different purposes or for describing different factors. Subcategories of sound measuring are seen within one type of measuring such as L_{10}, L_{50}, L_{90}, where the numbers mean the percentage of the time and the value L is the sound level in dB over the amount of time expressed in percentage and this could be measured for any kind of sampling intervals. (Hamilton & Harrison, 1991, p. 346)

Most of the outdoor peak to peak noise is caused by the large trucks or heavy-duty vehicles and by horns and engines of motorcycles. Most of the outdoor Leq noise is cause by light-duty vehicles and other factors. (Detwyler & Marcous, 1972, p. 204) The noise produced from heavy-duty vehicles varies from 70-90 dB with frequencies around 250Hz, light duty-vehicles produce noises with frequencies around 500 Hz. (Hamilton & Harrison, 1991, p. 342)

4.2.3. Noise health effects

Every specie, including humans, with a hearing system has an audiogram. An audiogram is the graphical visualization of the hearing threshold in µPa or dB for every frequency in Hz as displayed in the figure 10.

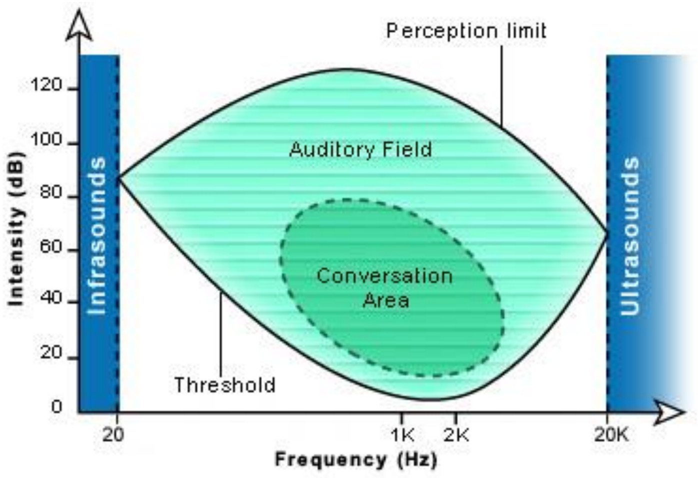

Figure 5 Human audiogram (DOSITS, 2012)

Humans hearing threshold starts from 20 Hz to 20 kHz and between that a high variation of sound intensity is experienced. Basically, 80 dB(A) above the hearing threshold would cause temporary threshold shift (TTS), meaning temporary hearing loss. Permanently threshold shifts (PTS), permanent hearing loss (with no possibility of reversibility), would be caused noise about 105 dB(A) when the subject is exposed to long time or differently saying the L_{Aeq} = 80 dB and L_{Aeq} = 105 dB respectively (Detwyler & Marcous, 1972, p. 222). These would simply be the long term effects of the noise exposure while the direct effect of hearing loss from noise would occur at pressure of 140 dB(A) (Welch, et al., 2013, p. 225). In addition to these effects, extensive noise intensity has shown correlation with cardiovascular effects and psychological effect. (Detwyler & Marcous, 1972, p. 225)

5. Methodology

5.1. CO concentration measurement

In this research the CO roadside pollution is measured at a distance 0 m from the kerbside, the part where the pedestrian and automotive lanes meet along, with a fixed electrochemical CO meter placed facing the traffic. The electrochemical CO meter measures samples of maximum CO concentration in the breathing zone (1.5 m – 4 m) in ppm for every minute in order to avoid low average values that consistently result in null. In order to provide a variability of data, samples were taken at different locations and different time periods to account for differences in traffic flow. Depending on pre-estimated traffic flow, 4 different scenarios measurements were set in which include combination of traffic flow and fleet velocity. Each group measurement, which represented one scenario, consisted of one-minute samplings for every twenty-minute interval. A total of four group measurements were done in one day. That is named “one-day sampling” and it is repeated for five days in total per each site. In total, two sites were implemented into the experiment. The first site is located in the main entrance of Tirana with coordinates (41.323° N and 19.789° E) and has a high flow of over 30,000 vehicles per day. The second site is located in a dense populated area with coordinates (41.321° N and 19.813° E) where a lower car flow is expected over the day (below 1000 vehicles per day) and mainly consisting of trucks.

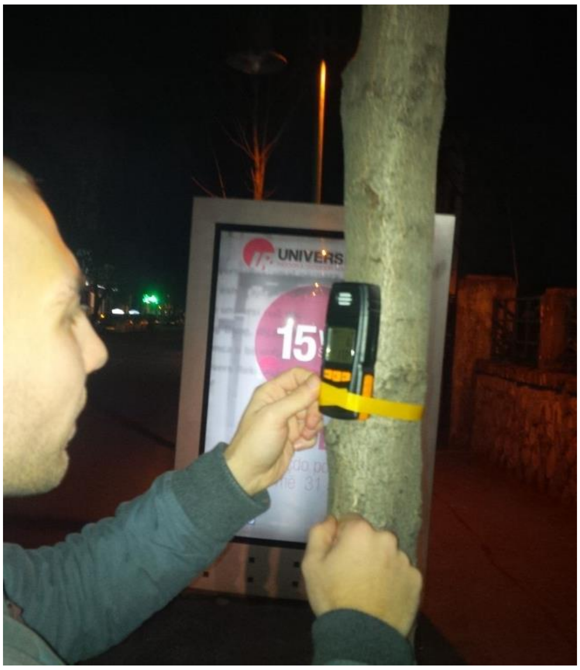

Figure 7 Roadside CO measurement in site two (photo during sampling)

Table 4 Site one sampling scheme (above 30000 vehicles per day)

Scenario	Velocity	Traffic flow	Time of the day	Group samp. time	Sampling intervals	Repeated meas.	Total No of samples
1	High	High	Midday	20 min	1 min	5 days	100
2	High	Low	Early morning	20 min	1 min	5 days	100
3	Low	High	Morning	20 min	1 min	5 days	100
4	Low	Low	Afternoon	20 min	1 min	5 days	100

Table 5 Site two sampling scheme (below 30000 vehicles per day)

Scenario	Velocity	Traffic flow	Time of the day	Group samp. time	Sampling intervals	Repeated meas.	Total No of samples
1	High	High	Afternoon	20 min	1 min	5 days	100
2	High	Low	Morning	20 min	1 min	5 days	100
3	Low	High	Evening	20 min	1 min	5 days	100
4	Low	Low	Midday	20 min	1 min	5 days	100

The categorization of vehicles' velocity and traffic flow is made out of previous observation on both sites and defining a mean value for each factor for both sites. The mean value resulted in 20 km/h, meaning that above that limit would be classified high and below that limit would be low. The same goes for the traffic flow with a mean value of 600 vehicles per hour or 10 vehicles per minutes concluding that above that limit would be classified high and below that limit would be low.

Meanwhile, as part of CO measurements, traffic flow is measured by video recording at each spot. The video recorded result in twenty minutes' length as long as one group sampling. After recording, desk work analysis is done by counting cars for 1-min interval and synchronize the value of traffic flow with the CO concentration measured as explained above. The value measured is multiplied by 60 which gives the traffic flow in units "vehicle per hour".

Figure 8 GoPro Hero 4 equipment used for video recording during sampling

The same video recordings were used to calculate the velocity of each vehicle. On the screen, two points are marked at a distance twenty-five meters away from each other and that would be the length that the cars cross over a specific time which is counted in the video. The velocity for each car is measured by dividing the length (25 m) by the time it takes the car to pass between two marked points.

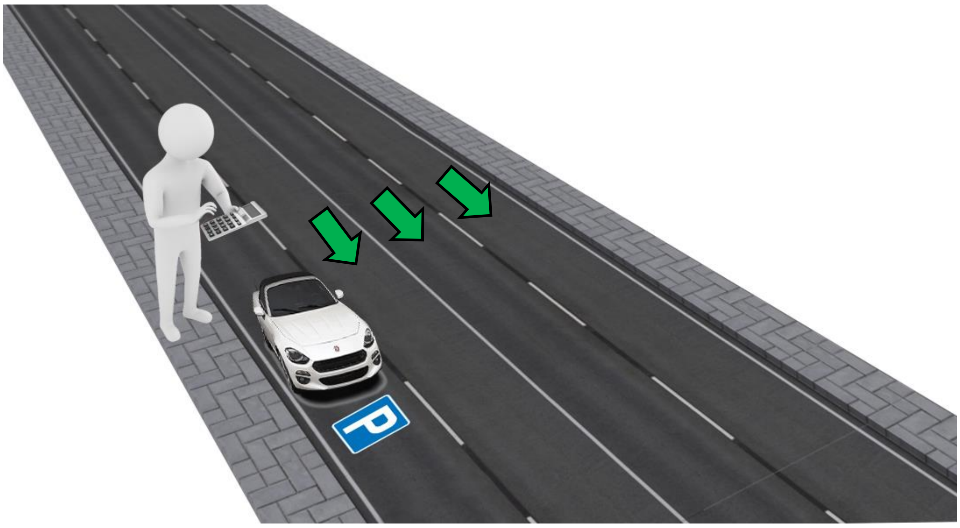

Figure 9 Sketch of Site 1 (green arrows are the line measured)

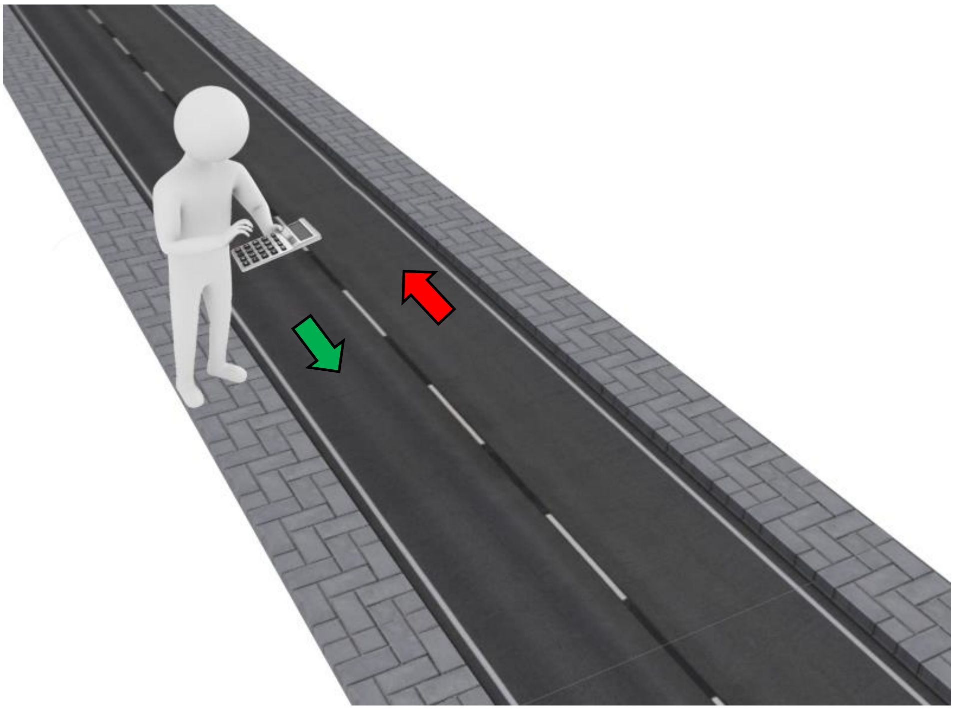

Figure 10 Sketch of Site 2 (green arrows are the line measured and red arrows are the line not measured)

Concurrently, noise levels of roadside pollution are measured with a smartphone calibrated in dB at the same location as CO measurements were gathered. Differently from CO sampling, noise sampling is done in a 4-min interval per sample and sound pressure is recorded in 3 different types, O-peak ($dB_{o\text{-}p}$), peak-peak ($dB_{p\text{-}p}$) and L_{50} (dB) and for each group sampling lasting to 20 minutes with each sample resulting to an interval of 4 min. In order to link noise pollution values with automobile velocity and traffic flow, noise pollution measurements are synchronized synchronization with CO measurement and video recordings and Pearson correlation statistical analysis was used to test a correlation between the values, so that the dataset could be inputted into statistical analysis and produce conclusion of correlation between values.

Table 6 Noise sampling scheme for one site (same in both sites)

Case	Velocity	Traffic flow	Time of the day	Group samp. time	Sampling intervals	Repeated measurement	Total No of Samples
1	In the same time and place as CO measurements are done and video recording are done			20 min	4 min	5 days	25
2				20 min	4 min	5 days	25
3				20 min	4 min	5 days	25
4				20 min	4 min	5 days	25

5.2. Equipment used

To conduct this research, the items used include: one electrochemical meter, a GoPro Hero 4 camera and a smartphone noise measurement.

5.2.1. Electrochemical meter

The principal working method for CO electrochemical meter is by inducing small amount of electrical charges in the sensor area to detect the CO concentration in the air, as they are named after it. CO electrochemical meter have their accuracy up to 1ppm or ≈ 1,3 mg/m^3. These are ideal for gas measurements on gas chambers and widely used in gas stations for giving the correct gas concentration. Also another type is being developed recently, which is the urban environment gas measurement. (Penny, 2000, p. 72)

The basic work of CO electrochemical meter is through a reaction consisting on oxidizing CO through H_2O, which is done by catalytic action of platinum and therefore producing CO_2, two protons of H and two electrons. These positive protons move toward the counting electrode where the reading is made and the value is shown. (Penny, 2000, p. 72)

$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$ (1)

Thereafter this two positive protons of hydrogen react with 0.5 mole of oxygen to produce water so that the cycle will be closed and there will be still water in the electrochemical meter to work based on the equations described above. (Penny, 2000, p. 72)

$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (2)

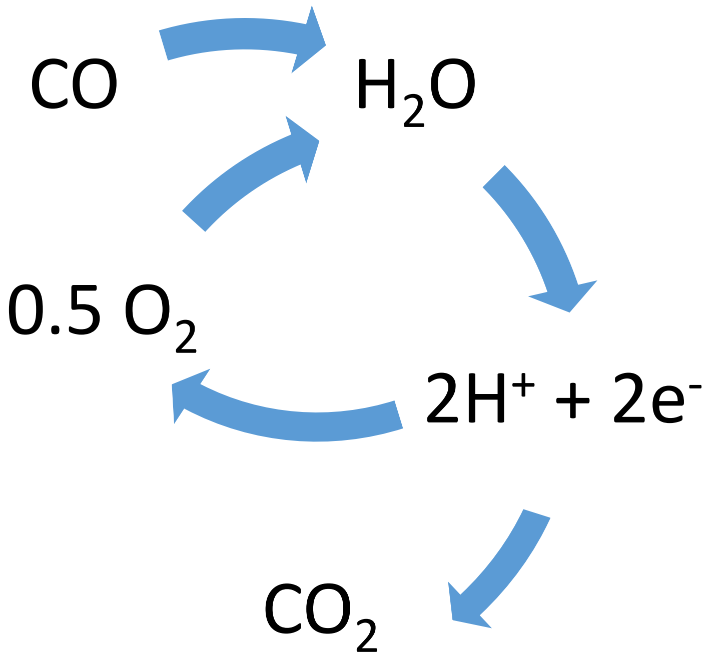

Figure 11 Scheme of chemical reaction within electrochemical meter

5.2.2. GoPro

GoPro Hero 4 Black is a very small action camera weighting 88 grams. It captures video up to 4K resolution on 30 fps and the general 1080 p on 120 fps, which can assure supper slow motion video. It has an auto low light mode that allow to capture during the night without a need for a flash light. It has a port for microSD where write the recording that could reach up to 128 GB. GoPro Hero 4 Black has a supper-wide angle that allow the camera to capture more than the traditional camera.

5.2.3. Sound Meter - Smartphone noise recorder

Sound meter app in the google play shop and through the smartphones microphone detects the levels of sound pressure in dB(A). Since the smartphones are designed for human's conversation, they have a range between 300 – 3400 Hz and 30 dB(A) – 100 dB(A) and it could not reach even 100 dB(A) or more than that. It has a high relevance for the noise of 40-80 dB(A)

6. Results

Other studies are also focused on developing correlation between mobility and CO concentration and prediction model. Elkafoury et al. (2015) developed a CO dynamic emission model depending on traffic characteristics such as traffic flow, average velocity and vehicles category (Euro 1…Euro 6). In his papers produces CO emission factors from field measurement which all of them results in curvature correlations lines with the traffic characteristics listed above. Gokhale & Khare, (2006) base their research on emission patterns and meteorological conditions and aim to develop a statistical distribution model of CO concentration from heterogeneous traffic pattern. Gokhale & Khare, (2006) compares different statistical distributional model to give the credits for the most suitable prediction model and the results show that log logistic distributional model fits the best. According to roadside barriers play an important role for CO concentration distribution patterns. Hagler, et al. (2011) states that fields studies have shown that CO concentration has a logarithmic nature on its distribution from the source toward the edges of the road or the barriers and this relation can be reached up to 300-500 m from the source.

This study is researching a correlation between CO concentration in the air beside the road, vehicles velocity, quantity of vehicles (traffic) passing in one road line and noise levels. In this study are taken a total sample of 800 samples to create multiple correlations and give a better understanding of pollutants' nature and behavior. The samples are splitted per each site, merged for both sites and averaged in 4 minutes (4 samples) depending on the interest of the hypothesis to conclude as many as possible variation and display the behavior of pollutants. For the first site, with a total fleet flow more than 30000 vehicles per day, the results show a significant correlation between CO concentration and traffic flow, meaning less traffic flow will bring less CO pollutant, **Pearson's correlation ($r=0.12$; $p=0.012$; $N=400$)** and a significant correlation between CO concentration and vehicles speed meaning faster the vehicles moves brings lower amount of CO exhausted in the air. **Pearson's correlation ($r=-0.2$; $p<0.001$; $N=400$)**

Table 7 Correlation syntax R and significance value P between CO, fleet velocity, traffic flow for Site 1

N=400	**CO**	**Velocity**	**Traffic**
CO		r= -.20; P< .001	r= .12, P= .012
Velocity			r= -.29, P< .001
Traffic			

For the second site, with a total fleet flow less than 30000 vehicles per day, the results show a significant correlation between CO concentration and traffic flow, meaning less traffic flow will bring less CO pollutant, **Pearson's correlation ($r=0.21$; $p<0.001$; $N=360$)** and no significant correlation between CO concentration and vehicles speed. **Pearson's correlation ($r=0.02$; $p=0.671$; $N=360$)**

Table 8 Correlation syntax R and significance value P between CO, fleet velocity, traffic flow for Site 2

N=360	CO	Velocity	Traffic
CO		r= .02; P= .671	r= .21, P< .001
Velocity			r= -.12, P< .021
Traffic			

For both sites together the result shows a significant correlation between CO concentration and fleet velocity, meaning that slower the vehicles move brings higher amount of CO exhausted in the air, **Pearson's correlation (r= -0.14; p<0.001; N=760)** and no correlation between CO concentration and traffic flow **Pearson's correlation (r= 0.03; p=0.393; N=760)**

Table 9 Correlation syntax R and significance value P between CO, fleet velocity, traffic flow for both sites (Site 1 & 2)

N=760	CO	Velocity	Traffic
CO		r= -.14; P< .001	r= .03, P= .393
Velocity			r= -.12, P= .001
Traffic			

Noise measurement were done at intervals of 4 minutes (see table 6) and therefore average values per 4 minutes of CO concentration, fleet velocity and traffic flow are done so that the correlation between could be done.

In the first site, with average values of 4 minutes, CO builds a strong positive correlation with traffic flow, minimum, average and maximum noise level and a negative correlation with fleet velocity. **Pearson's correlation (r= 0.33; p=0.001 N=100), (r= 0.41; p<0.001 N=100), (r= 0.33; p=0.001 N=100), (r= -0.26; p=0.01 N=100).** Meanwhile minimum and average levels of noise correlate strongly negatively with fleet velocity and strongly positive with traffic flow **Pearson's correlation (r= 0.64; p<0.001 N=100), (r= 0.54; p<0.001 N=100), (r= -0.82; p<0.001 N=100), (r= 0.61; p<0.01 N=100).** Also maximum levels of noise correlate positively with fleet velocity but not with the traffic flow. **Pearson's correlation (r= 0.26; p=0.008 N=100), (r= -0.05; p=0.631 N=100).**

Table 10 Correlation syntax R and significance value P between average values of 4 minutes (4 samples) for Site 1, CO, fleet velocity, traffic flow, noise minimum, noise average, noise maximum

N=100	CO avg	Velocity avg	Traffic avg	Noise min	Noise avg	Noise max
CO avg		r= -.26 P= .01	r= .33 P= .001	r= .41 P< .001	r= .33 P= .001	r= -.01 P= .938
Velocity avg			r= -.61	r= -.82	r= .61	r= .26

			P< .001	P< .001	P< .001	P= .008
Traffic avg				r= .64 P< .001	r= .54 P< .001	r= -.05 P= .631
Noise min					R= .85 P< .001	r= .27 P= .007
Noise avg						r= .33 P= .001
Noise max						

In the second site, with average values of 4 minutes, CO builds a strong positive correlation with traffic flow, minimum, average and maximum noise level **Pearson's correlation (r= 0.28; p=0.009; N=90), (r= 0.27; p=0.010; N=90), (r= 0.32; p=0.002; N=90), (r= 0.26; p=0.014; N=90).** Also average four minutes' values of minimum, average and maximum levels of noise builds a positive correlation with traffic flow averaged for every four minutes, **Pearson's correlation (r= 0.87; p<0.001; N=90), (r= 0.86; p<0.001; N=90), (r= 0.48; p<0.001; N=90).**

According to results for averaged values for every four minutes in site 2, fleet velocity did not correlate with any of the variables such CO concentration, minimum, average and maximum noise level as an average value for every four minutes **Pearson's correlation (r= 0.02; p=0.873; N=90), (r= -0.12; p=0.256; N=90), (r= 0.08; p=0.466; N=90), (r= 0.07; p=0.517; N=90).**

Table 11 Correlation syntax R and significance value P between average values of 4 minutes (4 samples) for Site 2, CO, fleet velocity, traffic flow, noise minimum, noise average, noise maximum

N=90	**CO avg**	**Velocity avg**	**Traffic avg**	**Noise min**	**Noise avg**	**Noise max**
CO avg		r= .02 P= .873	r= .28 P= .009	r= .27 P< .010	r= .32 P< .002	r= .26 P< .014
Velocity avg			r= -.14 P= .194	r= -.12 P< .256	r= .08 P= .466	r= .07 P= .517
Traffic avg				r= .87 P< .001	r= .86 P< .001	r= .48 P< .001
Noise min					r= .93 P< .001	r= .52 P< .001
Noise avg						r= .57 P< .001

Noise max

For both sites together, with average values of 4 minutes, the result shows a significant negative correlation between CO concentration and fleet velocity, meaning that slower the vehicles move brings higher amount of CO exhausted in the air, **Pearson's correlation (r= - 0.17; p<0.001; N=190)** and no correlation between CO concentration and traffic flow **Pearson's correlation (r= 0.07; p=0.355; N=190)**. The result shows a strong positive correlation with minimum, average and maximum levels of noise **Pearson's correlation (r= 0.26; p<0.001; N=190), (r= 0.30; p<0.001; N=190), (r= 0.18; p=0.014; N=190)**

Meanwhile for the both sites, a strong negative correlation is shown between minimum, average and maximum noise levels with fleet velocity, **Pearson's correlation (r= - 0.42; p<0.001; N=190), (r= - 0.24; p=0.001; N=190), (r= - 0.25; p=0.001; N=190).**

For both sites together, minimum and average noise levels correlate strongly and positively with traffic flow, **Pearson's correlation (r= 0.64; p<0.001; N=190), (r= 0.54; p<0.001; N=190),** but not the maximum noise level with traffic flow **Pearson's correlation (r= - 0.04; p=0.562; N=190)**

Table 12 Correlation syntax R and significance value P between average values of 4 minutes (4 samples) for both sites (Site 1 and Site 2) CO, fleet velocity, traffic flow, noise minimum, noise average, noise maximum.

N=190	**CO avg**	**Velocity avg**	**Traffic avg**	**Noise min**	**Noise avg**	**Noise max**
CO avg		r= -.17 P= .017	r= .07 P= .355	r= .26 P< .001	r= .30 P< .001	r= .18 P< .014
Velocity avg			r= -.24 P= .001	r= -.42 P< .001	r= -.24 P= .001	r= -.25 P= .001
Traffic avg				r= .64 P< .001	r= .54 P< .001	r= -.04 P= .562
Noise min					r= .90 P< .001	r= .33 P< .001
Noise avg						r= .40 P< .001
Noise max						

Mean values of each site are calculated using an Independent sample t-test in order to understand if a very high total traffic flow per day in each lane changes the nature of pollutants and meanwhile changes the correlations between factors and pollution levels.

Table 13 Statistical differences between CO, traffic flow and fleet velocity of two sites

	Difference between two sites		
	t	df	p
CO	5.65	519.66	<0.001
Traffic flow	-8.33	534.95	<0.001
Fleet velocity	-12.36	570.91	<0.001

CO significantly differs between two sites (site 1 & site 2) with higher concentration in Site 2, **Independent sample t-test (t = 5.65, df = 519, p < 0.001)**. Traffic flow and fleet velocity significantly differs between two sites (site 1 & site 2) with higher amount in Site 1, **Independent sample t-test (t = -8.33, df = 534, p < 0.001) (t = -12.36, df = 570, p < 0.001)**

The same statistical test and calculation is made for the average values per 4 minutes and noise values are included as well.

Table 14 Statistical differences between 4-min average values of CO, traffic flow, fleet velocity, noise min, noise avg and noise max

	t	**df**	**Sig. (2-tailed)**
CO_avg	3.33	128.16	0.001
Velocity_avg	-4.39	122.1	<0.001
Traffic_avg	-9.68	169.49	<0.001
Noise_min	-2.1	154.64	0.049
Noise_avg	-0.75	134.66	0.457
Noise_max	3.26	182.34	0.001

Average values for four minutes of CO and minimum levels of noise, significantly differs between two sites (site 1 & site 2) with higher concentration in Site 2, **Independent sample t-test (t = 3.33, df = 128, p = 0.001), (t = 3.26, df = 182, p = 0.001)** and meanwhile average values for four minutes of fleet velocity, traffic flow, minimum levels of noise, significantly differs between two sites with higher concentration in Site 1, **Independent sample t-test (t = -4.39, df = 122, p < 0.001), (t = -9.68, df = 169, p < 0.001), (t = -2.1, df = 154, p = 0.049),**

Only average values for four minutes of average noise levels does not differs significantly between two sites meaning that those are the same in both sites. **Independent sample t-test (t = -0.75, df = 134, p = 0.457)**

7. Discussion

This study serves as an initial step to determine if CO and noise levels can be predicted by using two variables: traffic flow and fleet velocity. This study can also serve as a building block for more extensive studies in hopes to build a model. However, as this study was intended to serve as an initial study, it does lack some controlling factors. The model developed does not take into account vehicles' year of production and it does not classify vehicles into European emission standard classification of vehicles (Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6) for generating emission factors. For our purposes this limited the man power and the need to invest in advanced technology to recognize the cars' year of production.

These results can be of significance only for Albania since the cars' year of production was not taken into account. The significance can be erroneous in another country due to different percentage in the cars' model and year of production that are used in that specific country. This result could only suit could work only for Albania because in this study cars year of production is not taken into account. This could conclude into an error in another country due to a change on percentage of cars year production and therefore big calibrations are needed to conclude toward a significant result.

Gaussian dispersion model is not included and therefore wind data are not taken into account which in very unstable weather situation the CO predicting model might not result into significant levels. Also the study does not take into account acceleration and deceleration of fleet velocity but instead the average fleet velocity per sampling time.

8. Conclusion

This study concludes that infrastructures surrounding roads have an effect in CO concentration and maximum levels of noise despite the level of car traffic. When comparing narrower roads with buildings aside them have a higher concentration of CO and higher maximum level of noise even though the traffic flow is less than 30,000 vehicles per day compared with wider roads with no buildings aside them. The wider roads with no buildings aside them have a lower CO concentration as well as maximum noise even though total vehicles per day that cross there are over 30,000. Beside vehicles speed and traffic flow, road barriers should also be taken into account when predicting CO and noise pollution. However, a generalization for both sites or different types of roads cannot be made because of all the different variables.

This study concludes also that for wide roads with no barriers, CO can be predicted by all variables for every minute and for four minutes as average values. Also noise levels can be predicted for four minutes from all variables and the same way around, as all other variables can be predicted from noise levels and CO concentration. Meanwhile for the narrow roads with building barriers, CO could be predicted by all other variables (not including fleet velocity) for every minute and for four minutes as average values. Also noise levels can be predicted for every four minutes from all other variables (not including fleet velocity) and the same way around, as all other variables (not including fleet velocity) can be predicted from noise levels and CO concentration.

However, the findings in this study didn’t account for many factors; therefore, more extensive research is needed to control for these factors.

References

Albanian green line, 2010. *Tourist guide.* 4th ed. Tirana: Blue agency.

Aliaj, B., Lulo, K. & Myftiu, G., 2003. *Tirana sfida e zhvillimit urban.* Tirana: GVG.

Baçe, A. et al., 1979. *Historia arkitekturës Shqiptare.* Tiranë: Instituti i monumenteve të kulturës.

Barron, R. F., 2001. *Industrial Noise Control and Acoustics.* New York: Marcel Dekker, Inc..

Cowan, J. P., 1994. *Handbook of Environmental Acoustics.* New York: Van Nostrand Reinhold.

Detwyler, R. T. & Marcous, G. M., 1972. *Urbanization and Environment.* Belmont, California: Duxbury Press.

Dida, M., 2004. *Natural protected areas and national parks of Albania.* Tirana: Geer.

Division of Health Promotion and Disease Prevention; Institute of Medicine, 1992. *The Second Fifty Years.* Washington, D.C.: NATIONAL ACADEMY PRESS.

DOSITS, 2012. *Discovery of Sound in the Sea.* [Online] Available at: http://www.dosits.org/science/soundmeasurement/hearingmeasured/ [Accessed 4 April 2016].

ECAT, 2008. *Tirana air quality report*, Tirana: EU commission.

Elkafoury, A. et al., 2015. Develop dynamic model for predicting traffic CO emissions in urban areas. *Environmental Science and Pollution Research*, 21 March, Issue Management Of The Environment, pp. 1-12.

Fellenberg, G., 2000. *The chemistry of pollution.* 3rd ed. Chichester: John Wiley & Sons Ltd..

Gokhale, S. & Khare, M., 2006. Statistical behavior of carbon monoxide from vehicular exhaust in urban envirnments. *Environmental Modelling & Software*, 22(4), pp. 526-535.

Guri, S. etj., 2013. *Vlerësimi Strategjik Mjedisor i planit rregullues të Tiranës.* Tirane: Albanian University Press.

Hagler, G. S. et al., 2011. Model evaluation of roadside barrier impact on near-road air pollution. *Atmospheric Envirnment,* 45(15), p. 2522–2530.

Hamilton, R. S. & Harrison, R. M., 1991. *Highway pollution.* Amsterdam: Elsevier.

Hobbs, P. V., 2000. *Introduction to atmospheric chemistry.* New York: Cambridge Univeristy Press.

Instat, 2015. *ROAD VEHICLES (1993-2014)*, Tirana: Instat.

Krenzelok, E., Roth, R. & Full, R., 1996. Carbon monoxide ... the silent killer with an audible solution.. *The American jounrnal of emergency medicine*, 14 September, 14(5), pp. 484-486.

Lear, E., 2012. *Allposters.* [Online], Available at: http://www.allposters.com/
[Accessed 20 April 2016].

Meçaj, N., 1999. *Albanian Torusim Guide.* Tirane: Central for environmental education in Albania.

Municipality of Tirana, 2015. *History of Tirana.* [Online], Available at:
http://www.tirana.al/historiku-i-tiranes/
[Accessed 14 February 2016].

Penny, D. G., 2000. *Carbon monoxide toxicity.* Boca Raton: London: CRC Press.

Qiriazi, P., Doka, D. & Pushka, A., 2007. *Gjeografia 4.* Tirane: Botimet ideart.

Qiriazi, P., Hoxha, G. & Kola, B., 2007. *Gjeografia 3.* Tirana: Botimet ideart.

Schrenk, M., Popovich, V. V. & Zeile, P., 2010. *Albania in Transition: International Assistance for Roads but not Public Transport*, Viena: REAL CORP.

Spellman, F. R., 2010. *The science of environmental pollution.* 2nd ed. Boca Raton, Florida: `CRC Press.

Welch, D. et al., 2013. Road traffic noise and health-related quality of life: A cross-sectional study. *Noise and Health*, 15(65), pp. 224-230.

WHO, 2000. *Air Quality Guidelines for Europe.* 2nd ed. Copenhagen: World Health Organisation.

William, R., 1994. *Fundamentals of air pollution.* 3rd ed. San Diego: Academic Press.

World Bank, 2007. *Albania urban sector review*, Washington, DC: s.n.

Ziu, T., 2009. *Gjeografia e rregullimit të territorit.* 1st ed. Tiranë: Pegi.