Location impact on particulate matter (PM) concentration reduction during COVID-19 pandemic

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***Abstract*—Significant topic of interest in many European countries is monitoring the air pollution, especially particulate matter (PM) concentrations, mostly because of its harmful effects on the human health. Measurement of the particulate matter concentrations can be done in a different ways, one of the possible solutions is by using low-cost and energy-efficient monitoring system using sensor network. The main goal of this paper is to analyze the influence of the green areas on particulate matter mitigation, analyzing the period of pandemic COVID-19 restrictions. The paper analyze the connection among the impact of the location of the sensor nodes and green areas and other objects to the particulate matter concentrations using various statistical tools and hypothesis testing. The tests are based on the data collected during summer 2020 at the technical campus of the Ss Cyril and Methodius University. This is the period when the World Health Organization (WHO) declared COVID-19 pandemic, and the universities were closed. In this research it can be confirmed that green areas at the Faculty pacio, reduced traffic vehicles and not having presence of the faculty staff in this period have a high impact in the reduction of particulate matter.**

***Index Terms*—air pollution reduction, particulate matter, sensor network**

I. Introduction

Air pollution is a major cause of death in many European countries, responsible for more than 400000 premature deaths [6], [8] . In most of the countries, traffic-generated pollution has been identified as a major contributor to particulate matter. Many research findings have analyzed the impact of human health of those people who spend many hours near the major roads [9]. There are various methods to deal with the air pollution mitigation. Implementing green walls, green facades, green buildings on air quality measurement systems have been applied for some time as an extremely innovative and simple solution for improving the air quality. Such measurement systems have been successfully implemented in many countries such as: Switzerland, Spain, Sweden, UK, USA and Australia [1]. The experiences from these application projects are our motive for implementing such systems in our country, considering the problems with the air quality in the urban areas of the country. The benefits of implementing vertical green walls and green roof surfaces applied on the facades of the buildings include improving the thermal characteristics of the objects where they are installed, reducing the energy requirements of the facilities, reducing the level of noise and improving the air quality. Some of these benefits are analyzed in detail as presented in [12]. Studies presented in [13] show the reduction of the temperature up to 20^oC, absorb about 60% of solar radiation and reduce the cooling requirements between 25% and 80% by implementing the green roof surfaces. The ambient air temperature could be reduced from 0.3^oC to 3^oC by implementing the green roof surfaces [3]. Green wall structures can reduce the temperature of the objects by 6.1^oC in sunny or 4^oC on cloudy days [4]. These systems enable money savings because of the reduced energy requirements for cooling and heating [1], taking into account that the required financial investment of the implemented green walls and surfaces are relatively low, i.e between $400\text{EUR}/m^2$ to $1200\text{EUR}/m^2$. In particular interest of this project is the influence of the green wall in air quality improvement especially PM10 and PM2.5 concentration reduction. Study presented in [11] shows that trees can reduce PM2.5 and PM10 concentration up to 9%. Other research [7] shows that green surfaces (trees and enclosures) contribute for CO_2 emission reduction between 1.7% and 2.8%. According to [12] green walls and green facades can reduce the NO_2 and PM10 concentrations up to 15%, even up to 23% in specific conditions (urban canyons). PM2.5 concentration can be reduced between 45.3% and 74.1% under specific type of vegetation and specific conditions [14]. Meteorological factors such as wind speed, wind direction, humidity and temperature may affect on air quality parameters. In study presented by [5] the highest impact on PM10 mitigation has relative humidity, followed by wind speed and temperature. The research presented by [17] shows that the green area mitigates the PM of 2.5 or less micrometers (PM2.5) on average by 25% and PM of 10 or less micrometers (PM10) on average by 37% compared to the neighboring non-green areas. The results show a strong correlation between PM2.5 and PM10, while the combination of low temperatures, high humidity and no, or low wind speed lead to high PM concentrations. In the results presented in [2] show that the weather information for wind, temperature and humidity is correlated with the air pollution, which allows to train a machine learning model that predicts the air pollution based on the weather data and the historical data about the pollution. New generation of sensor nodes are developed as wireless sensor networks (WSNs), with nodes comprising of a battery powered unit, sensors, a microprocessor and a transceiver. These sensor networks are widely used in various types of applications. The results from measurement of the PM concentrations obtained with an air quality monitoring system which uses WSNs are presented in [15]. It is a low cost, efficient and easily replicable system, as confirmed in the analyses of the costs associated with its implementation, replication and the consumption of the WSN equipment [16].

In this paper we study the effect of the location on the PM concentrations. In March 2020 the World Health Organisation (WHO) declared Covid-19 pandemic. The start and the development of the pandemic drastically change people's habits all over the world. The first anti Covid-19 restrictions in Macedonia were introduced in March 2020. Kindergartens, schools and universities were closed. Many sectors (if possible) were transferred to online work, while others did not work with full capacity. There were also lock-downs and curfew. This study is based on the data collected during summer 2020 at the technical campus of the Ss Cyril and Methodius University in Skopje. In this period the university staff was mainly working online, except a dozen exams held offline. No other restrictions were implemented at that time. This implies that the traffic in the campus was drastically reduced compared to the years before. In this study we are evaluating the effect of the location, and meteorological factors on the PM concentration using different statistical tools.

II. Method

A. Sensors

The experiment was set up on a location close to the Faculty of Electrical Engineering and Information Technologies in Skopje. Near the location of the sensor nodes there is a small green area (as a part of the building pacio), one small building as a part of the Faculty complex and a parking lot. The location was chosen to capture the effects of green areas as well as the influence of movement of vehicles and people, especially in the period of the COVID pandemic restrictions when the traffic and the presence of people at the campus were drastically reduced. As depicted in Fig. 1, the sensor node 1 is nearest to the pedestrian pavement, the sensor node 2 is located near the green area (Faculty pacio) and the node 3 is located close to the Faculty parking place.

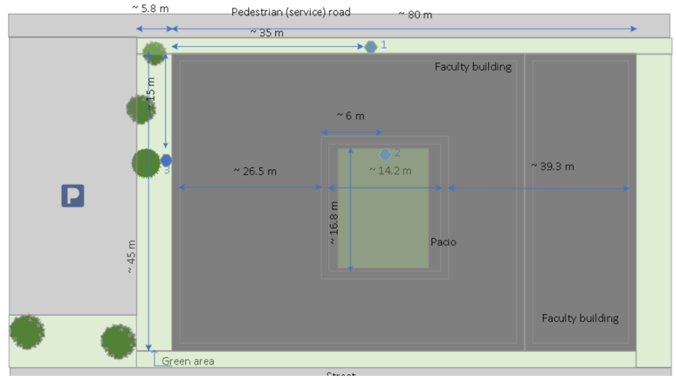

Fig. 1. Overview of the location with the disposition of the sensor nodes.

The Wireless sensor network (WSN) monitoring system consists of three nodes, each of them containing four sensors and a Wi-Fi module integrated on a single-board controller. Measurement of the sensors include aggregation of the concentrations of PM2.5, PM10, carbon monoxide (CO) and nitrogen dioxide (NO_2). The measurement of the PM concentrations are integrated in one sensor using a direct technique. PM concentration can be measured in the range of $0.3 - 10\mu m$. Resistance sensing is the method for measuring the concentrations of CO and NO_2, which means that OX (oxygen) sensor resistance in the presence of NO_2 is increasing, while the RED (reduced) sensor resistance in the presence of CO and hydrocarbons is decreasing. The controller is responsible for processing the data before they are transmitted to the network. The integrated Wi-Fi modules in each sensor nodes send data to the closest routers in the Faculty building. The collected data is uploaded on an open platform (Internet of Things open platform, 2020) and can be monitored on-line or downloaded for additional analyses. The system is designed to have low power consumption and overall low costs. The details of the hardware used for the described setup are available in [18].

B. Statistical tools

For the analyses of the measured data, we use a set of statistical tools: descriptive statistics, cross-correlation, hypothesis tests [10] and appropriate post hoc tests. Descriptive statistics is used to determine mean, variance, maximums and minimums for various observed periods; hypothesis tests are used for determining distribution, regularity, and statistically significant differences between measurements. The cross-correlation measures the similarity of two random variables, but does not give a functional dependence between them. To see the functional dependence between the independent variables and the dependant variable regression is applied. The set builds coherent and appropriate methodology for assessing the influences of various factors on PM concentrations. The coefficient of variation is the ratio of the standard deviation to the mean and it "measures" the dispersion around the mean. Bigger values of this coefficient indicates that there is higher level of variability.

The aim of this paper is to determine whether the location and other conditions have significant influence on PM concentration. Therefore we use hypothesis tests. In order to perform such a test we first have to establish null-hypothesis, H_0, and the significance level α. The null hypothesis is also known as *status quo* hypothesis, i.e.,

$$H_0 : \text{There is no difference between the conditions.} \quad (1)$$

In this paper we set $\alpha = 0.05$, that indicates a 5% risk of concluding that a difference exists when there is no actual difference. Each test determines a p-value for the given data, and the obtained p-value is compared to the significance level α. The Null hypothesis H_0 (1) is rejected when p-value $\leq \alpha$, and the conclusion is that differences between the considered conditions are statistically significant. Clearly, if p-value $> \alpha$, then the Null hypothesis is confirmed, so there is no statistically significant differences between the conditions.

To determine if there is a statistically significant difference between several conditions when the variables do not have normal distribution, non-parametric tests are performed. Here we apply non-parametric version of ANOVA known as Friedman test and non-parametric version of the T-test known as Mann-Whiteney test. The first test is used for testing differences between experimental conditions (in this case locations) when there are more than two conditions, and the same participants (in our case moments) are used in all conditions. The Mann-Whitney test is used to test two conditions and different participants are used in each conditions (data collected during day-time and night-time, respectively). We use standard Kolmogorov-Smirnov test to see if the data is normally distributed. These tests report when there is a difference between the conditions, but if there are three or more conditions (as in the case of Friedman test) they do not specify where that difference is detected. Therefore a a post-hoc has to be performed. This test compares the conditions (variables) in pairs and locates the difference.

III. Results

In this research we analyze the data from the period 15th June 2020 - 14th October 2020. The whole period is during the Covid-19 pandemic, when there were no movement restrictions (lock-downs or curfew). The statistical data are calculated and analysed for the whole period, as well as for daytime and night-time. As a result, the data presented in Table I and Table II show the calculated descriptive statistics for: the whole measurement period, daytime (8 a.m. to 8 p.m.), and night-time (8 p.m. to 8 a.m.). These periods have been chosen because the period from 8 a.m. to 8 p.m. is the period of the day when there are activities within the faculty zone and thus movement is expected from both people and vehicles in the near vicinity of the experimental set up. Another reason was that the peaks in the PM concentrations were reported in the period from 8 p.m. to 8 a.m. [17].

During the studied period the temperature was between 9^oC and 36^oC, while the average temperature was 21.3^oC. The humidity, in average, was 60.6%, and the average pressure was $739\,mmHg$. The minimum wind seed was $0m/s$, the maximum $7m/s$, and the average wind seed was $1.76\,m/s$. The Pearson correlation coefficient [10] indicates very strong correlations between the PM2.5 and PM10 as well as between all three locations (in all cases Pearson coefficient is above 0.95). It is reported insignificant correlation between PM concentrations and the actual temperature, and slightly stronger correlation between the PM concentrations and the real feel temperature. Insignificant correlation is noticed between PM concentrations and the pressure, and between PM concentrations and the humidity. We detected weak negative correlation between the PM concentrations and the wind speed. A linear regression model suggests that during day-time the considered meteorological factors (temperature, humidity, pressure and wind speed) account more on the location of the Node 2 than on the other two locations. Even more, they account more on the concentration of PM2.5 than on the concentration of PM10, and more during daytime than during night-time. These results are presented in Table III.

TABLE I
Descriptive statistics for the period 15 June2020 to 15 October 2020.

		PM2.5		
		whole period	daytime	night-time
Mean	Node 1	4.1	4.5	3.7
	Node 2	4.7	5.1	4.3
	Node 3	5.9	6.6	5.3
Maximum	Node 1	90.4	90.4	12.7
	Node 2	78.8	78.8	14.6
	Node 3	151.1	151.1	19.4
Variance	Node 1	1.4	1.2	1.7
	Node 2	1.5	1.4	1.7
	Node 3	1.3	1.1	1.7

TABLE II
Descriptive statistics for the period 15 June2020 to 15 October 2020.

		PM10		
		whole period	daytime	night-time
Mean	Node 1	6.3	6.8	5.8
	Node 2	5.9	6.4	5.4
	Node 3	7.4	8.3	6.7
Maximum	Node 1	162.7	162.7	29.3
	Node 2	106.9	106.9	23.4
	Node 3	218.0	218.0	35.9
Variance	Node 1	1.3	1.1	1.6
	Node 2	1.4	1.3	1.7
	Node 3	1.2	1.0	1.7

TABLE III
Account of the meteorological factors on the concentration of PM2.5 and PM10 for the period 15 June2020 to 15 October 2020 in %.

		Node 1	Node 2	Node 3
PM2.5	daytime	8.9	13.9	10.3
	night-time	7.5	11.5	9.0
PM 10	daytime	5.4	9.0	6.9
	night-time	3.8	8.1	6.5

The results presented in Table I and Table II suggest that here is a difference between the concentration of PM on these three different locations (during the whole period, daytime and night-time). These results indicate that during night-time the level of PM concentration is lower compared to the PM concentration during daytime. To evaluate whether these differences are statistically significant we do hypothesis testing. Kolmogorov-Smirnov test confirms that the data is not normally distributed, therefore we apply Fridman test and Mann-Whitney test [10], respectively. Friedman test confirms that there is a statistically significant difference between concentrations of PM2.5 on the three locations. The same result is confirmed for the concentration of PM10. We apply post-hoc Friedman test (see more details in [17]) to locate the difference. This test compares the differences in the ranking with the corresponding critical value. In this test the degree of freedom is 2 and the cardinality of the data set is $N = 2300$, so for $\alpha = 0.05$ the critical value is 0.071. If the absolute value of the ranking difference is bigger than the critical value there is a statistically significant difference. The rankings for Node 1, Node 2 and Node 3 in case of PM2.5 are 1.15, 1.89, 2.96, and for PM10 are 1.77, 1.31, and 2.92, respectively. The absolute value of the ranking difference are given in Table IV. As a result we have that all three locations report statistically significant difference.

TABLE IV
POST – HOC TEST FOR FRIEDMAN'S TEST COMPARING THE DIFFERENCE BETWEEN MEAN RANKS OF DIFFERENT GROUPS.

comparison	PM2.5 $\lvert\overline{R}_u - \overline{R}_v\rvert$	PM10 $\lvert\overline{R}_u - \overline{R}_v\rvert$
Node 1-Node 2	0.74	0.46
Node 1-Node 3	1.81	1.15
Node 2-Node 3	1.07	1.59

Applying Mann-Whitney test we confirm that there is a significant difference between the conditions during daytime and night-time at all locations for PM2.5 and PM10. The effect of these conditions is small to medium. In all cases higher concentrations of PM is detected during daytime.

IV. CONCLUDING REMARKS

The paper describes a low-cost and energy-efficient PM concentration measurement system, which has high scalability and replicability. The WSNs measurement system provides collected data that can be further analyzed with the described statistical tools to evaluate the influence of green areas on PM concentration. The results in this paper show that position of the sensor nodes plays important role when the PM concentration is concerned. The statistical results report highest concentration of PM2.5 and PM10 at the location of the Node 3, as expected. The concentration of PM2.5 is higher at the location of Node 2 (than at Node 1) but lower for PM10 (it is important to note that this sensor is locate in the building pacio). In previous analyses [17] higher concentrations of PM were detected during night-time. The source of this contamination was not located in the faculty campus, and they were not in the interest of the study. During the Covid-19 pandemic extreme pollution during the night hours were not detected. Even more, the PM concentration was significantly lower during night time.

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