ASSESSMENT OF DETECTED *IN SITU* AND MODELED $PM_{10/2.5}$ CONCENTRATION LEVELS DURING THE URBAN TRANSFORMATION PROCESS IN NOVI SAD, SERBIA

by

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Ambient air pollution is a very considerable and complex physicochemical and environmental issue. Particulate matter (PM) is one of the fundamental pollutants constituted in ambient air. Rapidly expanding urban transformations in city of Novi Sad, Serbia, produces high concentrations of PM. The vast and growing number of construction sites as pollution emission hotspots induce constant nuisance for the people, build surrounding and environment in total. Serbian legislation has set PM pollution limit values for daily emissions, but the air pollutant registry still does not recognize construction sites as severe sources of PM emergence. Understanding the importance and the effects of PM emission from construction sites is crucial in environmental preservation. For the preparation and application of methods and techniques for prevention and mitigation, suitable environmental pollution modeling needs to be achieved. The aim of the research is to assess and determine the utility of Tier 1 prediction model designed by Environmental Protection Agency and environmental modeling software ADMS URBAN on observed construction sites in Novi Sad, Serbia. Assessing monitoring data confirms construction sites as significant PM_{10} and $PM_{2.5}$ pollution sources. Two sets of correction coefficients were calculated for PM_{10} and $PM_{2.5}$, using average and median values, 2.56-2.54 and 1.03-0.97 respectively. The research study was for the first time conducted in Novi Sad, Serbia in the case of construction sites.

Key words*: assessment, air pollution, LRT, urban transformation, construction sites, PM_{10}, $PM_{2.5}$, sensors, prediction model*

Introduction

The 21[st] century at the global level, particularly in developed and developing countries, brings the environmental challenges in the first plan, whereas the key issue of air pollution is conveyed in the focus, after being neglected in previous decades. The PM air pollution can be observed as a global pandemic phenomenon, similarly causing harmful and hazardous

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effects on the environment and human health. Numerous studies [1-5] have shown a high correlation between ambient air pollution with public health, biocenosis status, regional and global climate. Suspended particles also known as Particulate Matter, are recognized as the basic omnipresent factors of air pollution. Fine suspended particles with a diameter of less than or equal to 10 μm have a direct and partially unknown impact on the environment. High concentrations of suspended particles can be manifested in the environment by the degradation of atmospheric visibility.

The beginning of the new millennium in its initial years is characterized by globalization processes that stimulate increased anthropogenic activities, resulting in a high level of urbanization. The need for constant development and urbanization is characterized by the emphasized migration from rural to urban areas, creating the need and demand for residential housing and accompanying content, noticeable in the number of active construction sites. During architectural processes on construction sites, a large number of pollutants are released into the surrounding environment. Suspended particles, which have the ability to sorb chemical and microbiological pollutants on their surface, have been identified as a fundamental polluting matter [6]. Numerous studies have shown that suspended particles due to their size, with special emphasis on PM_{10} and $PM_{2.5}$ (particles smaller than 10 μm and 2.5 μm), can cause severe health problems and damage the built environment (techno sphere) [7].

Frequent occurrences of high PM concentrations of architectural origin in the ambient air initiated pressure on governments in developed countries of Europe and the world to develop mitigation measures and models [8-14]. In order to ensure the efficiency of PM mitigation measures and models created during the architectural space transformations, regulations have been prepared with the accompanying legal measures. Researches [5-8] have shown that building generates PM throughout the whole construction cycle. Various architectural activities typical for building construction are important sources of PM in the ambient air:

- Site preparation (land clearing and demolition of existing buildings).
- Earth excavation and transport.
- Moving equipment and moving machines.
- Transport and storage processes (loading, unloading, transfer and storage).
- Specific activities in accordance with the position being performed.
- Final activities

Understanding the background, behavior and transport mechanisms of the particle pollution express prediction models. Appling effective prediction models, potential pollution hotspots could be spotted before they occur and preventive measures can be operated. Many different models have been assessed and the Environmental Protection Agency (EPA) Tier I prediction model has shown the best compatibility with detected measures. Environmental modeling software ADMS-URBAN has been selected for this research, with the goal to show the air quality of affected areas alongside the PM dispersion.

Additionally, meteorological conditions have a great influence on the generation of suspended particles, as well as on the emission from related activities. For most activities, the vital element of emission and generation of particles depends on the material, *i.e.,* the humidity of the material, since the wetter the material, the harder the particles are held together (statical tension occurs), which prevents their emission into the ambient air. The PM generated and emitted during architectural activities and urban space transformations is considered to be one of the primary sources of ambient air pollution in most countries [15]. In its annual reports, the Environment Agency of Canada estimates that constructive activities account for about 20% of total suspended particulate emissions [6]. The emission of suspended particles occurs throughout the architectural and urban transformations of the space, which endangers both workers on construction sites and residents from the surrounding area. Easy long-range transport ability (affected by particulate size) allows PM to deposit on all surfaces in the environment far from the source. High levels of deposited suspended particles can cause significant and extensive negative effects on ecosystems and the built environment.

The aim of the study is to measure PM emission during construction works for the first time in Serbia. The obtained data will be compared with modeled prediction values in order to assess the applicability of the selected model for construction sites in Serbia. The special task of the research will be to define air quality based on the obtained monitoring data and to provide PM dispersion on the city matrix.

Methods and models

Monitoring is performed by a specially designed sensor based on the OPC-N2 particle counter. Data were obtained from monitoring five selected locations in the city of Novi Sad, Serbia. Obtained data is compared with the EPA Tier I prediction model and environmental modeling software ADMS-URBAN as a comprehensive system for modeling air quality.

Prediction model

In order to be able to predict PM emission for specific architectural activities on construction sites prediction model needs to be defined. The EPA Tier I prediction model has shown the best results and is accepted by EU as the official prediction model. Tier I prediction model is dependent on PM size (10 μm and 2.5 μm) and for correction reasons it uses precalculated emission factors.

Fundamental information on the PM emission during architectural (constructive) activities derive from the USA, which first began to examine and develop emission factors for specific constructive activities – sources of generation and emissions of suspended particles. The list of emission factors is regularly improved and supplemented. Using existing factors and previous models, in 2019 a new methodology was developed to predict the concentration of suspended particulate emissions in three Tiers – levels [14], which required the availability of more field data. The USA EPA based the modern version of the Tier I prediction model on previous models and obtained research results. The basic methodology of the model was developed in the late 1990's, and since then it has been developed and improved for applications in other regions of the USA, and more recently in other parts of the world. The vital changes in the modern Model are corrective measures for meteorological factors and soil elements, which enables the application of the Tier I model effective in different locations. The advantage of the model is the ability to observe the entire affected area by the PM emission. Research conducted by Kimmel *et al*. [16] showed that the Tier I model gives high results outside the USA. In 2019, the European Environment Agency (EEA) as part of the European Monitoring and Evaluation Program published a manual in which one of the chapters is dedicated to the prediction of suspended particulate matter emissions during architectural activities [14]. The Manual recognizes construction sites as dominant PM emission and generation sources and uses a modified Tier I EPA model as a prediction algorithm. All literature [5-10] dealing with the emission of suspended particles during architectural activities – building construction, believes that predicting the actual emission can only be a quantification of the first level and that uncertainties are high, or much higher than for other sources of PM particles. The research within the paper will assess and quantify the effectiveness of the EPA Tier I and show the data overlapping of predicted and monitored values. In the selection process, many different prediction models were considered, but only the Tier I EPA model provided the required high performance, and as such is widely accepted and the most frequently applied model for reliable, swift and direct emission prediction and quantification. The model allows rough correction of meteorological conditions that affect soil moisture. The method predicts the calculation of the index based on monthly precipitation (in mm) and mean temperature (in °C) according to:

$$EM_{\mathrm{PM}x} = EF_{\mathrm{PM}x} A_{af} d(1-CE)\left(\frac{24}{PE}\right)\left(\frac{s}{9\%}\right) \tag{1}$$

where the values of x are taken as 10 μm and 2.5 μm, in proportion to the fraction of the particles for which the emission factor is calculated. The emission factor is calculated as the product of several factors:

- $EF_{\mathrm{PM}x}$ is the emission factor, adopted constant related to the fraction to be calculated,
- A_{af} is the area affected by the emission of particles,
- d is the work time – activities,
- CE is the efficiency of suspended particulate matter emission control,
- $24/PE$ is the correction for terrain humidity, and
- $s/9\%$ is the correction for fine particle content.

The EPA Tier I emission prediction model distinguishes three different types of buildings – residential buildings (one-family and several-family dwellings), commercial buildings and road construction. Specific coefficient related to the type of object, *i.e.,* the area under the influence of emissions was obtained by multiplying the conversion factors (according to the specifics of the facility, tab. 1.) and the construction site area (expressed in m^2). Specific emission factors ($EF_{\mathrm{PM}x}$) are also shown in tab. 1, and are founded on PM_{10} emission factor studies applied in the Tier I EPA model, while the $PM_{2.5}$ particle coefficient is based on research [8] to the percentage of $PM_{2.5}$ particles in PM_{10} ranges between 5-15%, which is why the coefficient was adopted as a 1/10 of the factor for PM_{10} particles.

Table 1. The EPA Tier I factors

Conversion factor	Object type	Particulate size	
		PM_{10}	$PM_{2.5}$
2	Residential object – small	0.086	0.0086
1.3	Residential object – large	0.3	0.03
1	Commercial object	1	0.1
1	Roads	2.3	0.23

The observed key parameters required in the EPA Tier I model for the emission prediction are the work area, material moisture (soil) and fine particle concentrations.

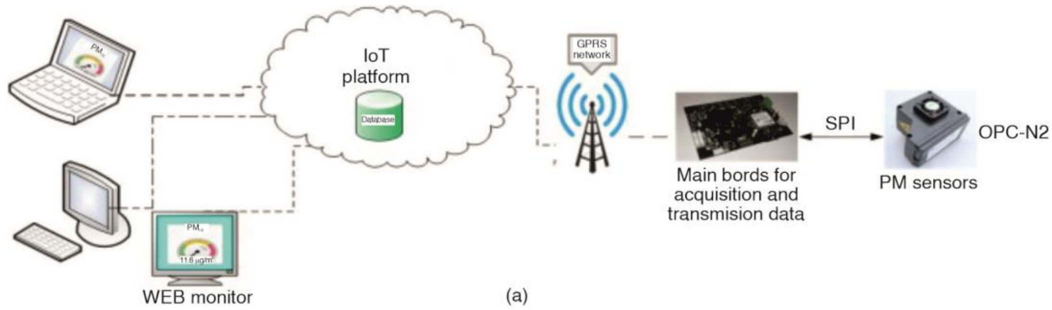
Work area, *i.e.,* the area of urban transformation space was calculated by measuring geodetic drawings available on the website of the Republic of Serbia, Republic Geodetic Authority. At each selected location, soil sampling was performed, after which the concentration of fine particles was measured in the accredited Laboratory for Landfill, Wastewater and Air Monitoring of the Faculty of Technical Sciences, University of Novi Sad. Soil moisture was determined as the Thornweight index, and the necessary data (precipitation amount and average temperature) for calculating the index were taken from the Republic Hydrometeorological Service of Serbia. For the needs of the ADMS-URBAN prediction program, in addition to the amount of precipitation and the average temperature, data on wind movement from RHMZ were also taken.

In addition to the key parameters required for prediction, suspended particles (PM_{10} to $PM_{2.5}$), air humidity and temperature were monitored at selected locations using the originally designed sensor.

Applied environmental software – ADMS-URBAN developed by CERC – Cambridge Environmental Research Consultants is a comprehensive system for air pollution modeling in large urban areas. It stands for valuable urban air quality model with the range of source types occurring in an urban area, taking into account complex urban morphology including street canyons, and provides the output of short- and long-term average pollutant concentrations from street-scale to urban-scale.

Originally designed sensor device

For the purposes of the research, monitoring of five construction sites is planned, for which a special sensor device, fig. 1, designed at the Department of Electronics, Faculty of Technical Sciences, UNS was used within the III 43008 project Development of methods, sensors and systems for monitoring water, air and soil quality. The sensor device is based on the conventional OPC-N2 (OPC- Optical Particle Counter), manufactured by Alphasense.



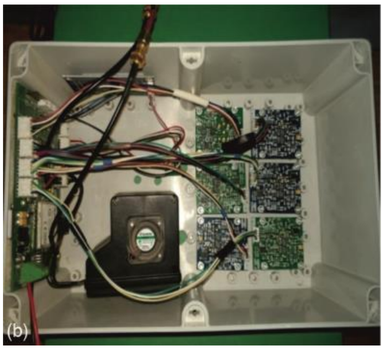


Figure 1. Designed sensor device; shematic (a) and real display (b)

Optical particle counter works on the principle of measuring the scattering of light rays by an individual particle carried in an air beam passing through an illumination laser beam (wavelength 658 nm). The intensity of light scattering was calibrated on the basis of the Mi scattering theory [17] and, in correlation with the concentration, number of the particles. The device samples with a small fan hood, elliptical mirror and two-element photo detector, creating a virtual reading zone in the center of the free space of the open light scattering chamber, with the ability to count up to 10000 p/s. The sensor has been recalibrated according to the European standard EN481 particle concentrations for fractions PM_{10} and $PM_{2.5}$ defined as particles that are regularly introduced into the body by inhalation. The ability to work for a very long period without the need for cleaning and maintenance is established by the fact that all sampled particles pass directly through the sensor without being deposited in the device itself.

External factors such as power and wind direction near the device can affect the flow of samples through the sensor, but device dynamically corrects so that the output concentration value of the suspended particles is not affected by flow variability. Based on the recorded particle histogram data, the sensor control module calculates the mass concentration of suspended particles in the air per unit volume of air, expressed in $\mu g/m^3$. The sensor can be connected as a real-time monitoring system for direct monitoring of suspended particles in selected zones.

A study by Pope *et al.* [3], confirmed that measuring PM concentrations with an OPC-N2 sensor with adequate calibrations is very practical and effective. A long-term study [18] and evaluation of airborne sensor technology in ambient conditions was conducted in Denver, Col., USA. During the test, OPC-N2 presented similar results to the reference data, emphasizing the possibility of canceling the wind effect. Testing of OPC-N2 sensors [19] points out that the sensor demonstrated high agreement between the values of measured concentrations PM_{10} and $PM_{2.5}$ with the reference device, which is proof of the accuracy and reliability of the device. The evaluation of low-budget sensors was performed by Salimifard *et al*. [20], in which the OPC-N2 sensor stood out with a high percentage of data matching. By examining the Alfasens OPC-N2 sensor, Cernicki and Kallmert [21] showed the reliability of the sensor in almost all conditions except in conditions of high humidity (over 75%). The selected Alfasens OPC-N2 sensor showed high efficiency, reliability and practicality.

Selected localities

Five representative locations, fig. 2., were selected based on the analysis of existing active construction sites in the city of Novi Sad and accessibility. Locations were marked as Construction sites C1-C5. Residential buildings were under construction at four locations, while the reconstruction of the road was selected for the fifth location. In order to achieve diversification and determine various terrain factors (primarily the percentage of fine particles in the soil on which it is built), the sites were selected to cover all parts of the city. With the

Figure 2. Location of selected building sites

same goal, the selected residential buildings are of different dimensions and levels of construction of the surrounding buildings. On construction sites concentration of PM emission was monitored by the originally designed sensor. During the monitoring period meteorological data was also tracked. Sensors were placed at a height of 1.80 m, which corresponds to the average Anthropometric Measurement Body Height Range of men in Serbia [22]. Due to the sensor's limitation and meteorological conditions (no emission of PM particles during rainy days), measurements were performed during five sunny days in a row. While the humidity does not exceed 70%.

Results and discussion

Monitoring of concentration levels of PM particles in urban transformation areas was performed on five selected locations, fig. 2. As part of the *in situ* monitoring, the concentration levels of PM_{10} and $PM_{2.5}$ particles, temperature, pressure, air humidity, precipitation, wind strength and direction were monitored, tab. 3. Software ADMS-URBAN was used for modeling particulate dispersion for PM_{10} and $PM_{2.5}$ particulates on heights of 10 m and 100 m. Particulate dispersion for location C4 is presented in fig. 3. Research assessment of detected *in situ* and modeled PM concentration levels during the urban transformation process for the first time in Serbia was conducted.

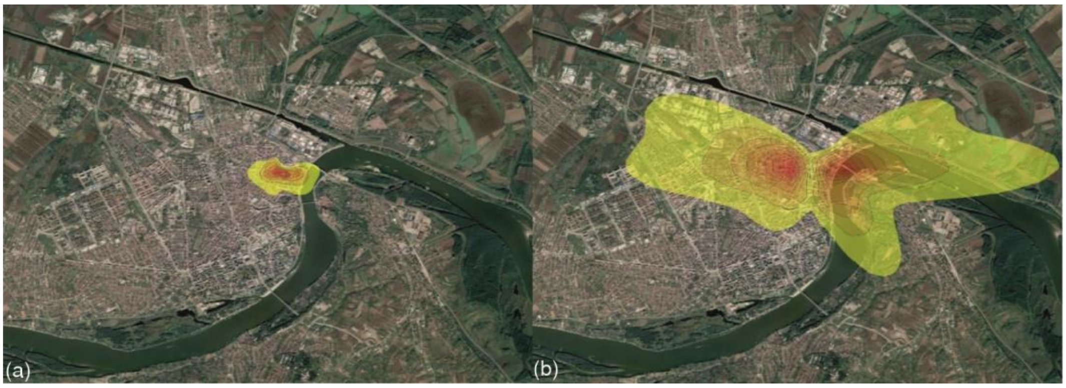


Figure 3. Particulate dispersion on location C4; (a) hight 10 m and (b) hight 100 m (PM concentrations: red to yellow – high to low)

In laboratory conditions in the accredited Laboratory for Landfill, Wastewater and Air Monitoring, Faculty of Technical Sciences, University of Novi Sad, silt content analyzes of fine particles in soil samples were performed for samples taken at selected monitoring sites, fig. 2.

The results of monitoring and sampling are shown in tab. 3. The data shown in tab. 3. represents the average daily values of sampling PM_{10} and $PM_{2.5}$ particles, humidity, temperature, percentage of fine particles, predicted values according to EPA Tier I model, active surfaces and emission factors and values modeled by software ADMS-URBAN.

Correlation analysis

The intention and objective of the research are to determine the existence of regularity and relationship between variables that did not occur completely randomly is best performed by determining the relationship – the level of relationships between the observed variables that are examined using correlation analysis.

The perceived high distinction between modeled and monitored values for $PM_{2.5}$ can be traced to the basic model and primary EPA Tier I research conclusion [8] that $PM_{2.5}$ can be considered as 1/10 of PM_{10} particulates. In determining processes of the real relation between PM_{10} and $PM_{2.5}$, correlation analysis was performed and a Scatter plot was created, fig. 4.

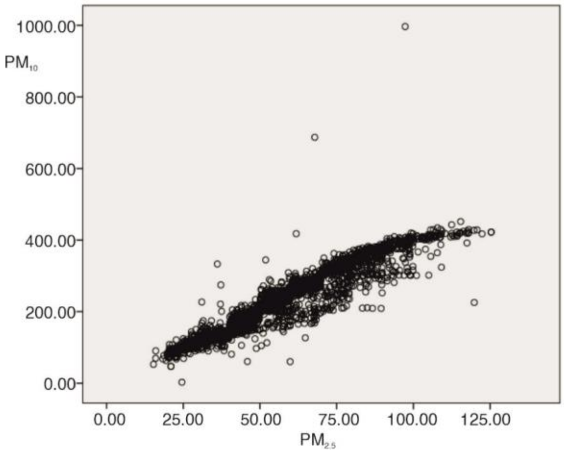


Figure 4. Scatter plot [μg/m^3]

In the conducted research the mathematical software IBM SPSS was used to calculate the Pearson correlation, tab. 2, of the detected suspended particles (PM_{10} and $PM_{2.5}$) concentration levels. Correlations at selected locations show different strengths of relations. The correlation between temperature and air humidity varies from non-existent (location C1), to low and medium, and has positive and negative connotations. Looking overall relationship, humidity is slightly negatively correlated with temperature. Suspended particles and air humidity at the observed locations have a constantly negative and low correlation except at location C3 where the ratio is medium. Software analysis of all locations shows a very low, almost non-existent level of negative correlation, which leads to the conclusion that humidity affects individual areas of urban transformation, while the overall observed has no impact. As the humidity in the air increases, the concentration levels of the suspended particles should lose value. PM_{10} and $PM_{2.5}$ particles show a high positive correlation at all locations. The high level of correlation can be explained by the fact that the $PM_{2.5}$ particle fraction is contained in the PM10 particle fraction, fig. 4.

Table 2. Pearson correlation coefficients

	Temperature	Humidity	$PM_{2.5}$	PM_{10}
Temperature	1	–0.2	0.059	–0.003
Humidity	–0.2	1	–0.002	–0.038
$PM_{2.5}$	0.059	–0.002	1	0.0941
PM_{10}	–0.003	–0.038	0.941	1

Assessment of urban transformation monitoring research results, tab. 3, have shown high PM_{10} and $PM_{2.5}$ concentration levels and potential environmental hazards. Modeled results indicate also a high number of PM. Therefore comparison results exhibited divergence between monitored and modeled results, exposing the need for corrective measures. One of the significant results of this research study was determining the Correction Coefficient (CC). Two sets of correction coefficients were calculated for PM_{10} and $PM_{2.5}$, using average and median values, 2.56-2.54 and 1.03-0.97 respectively. Calculated correctional coefficients show that Tier I model can be used for the prediction of PM_{10} emission levels in their current form, while for $PM_{2.5}$ correctional measures are required.

Ambient air quality

The results gained by monitoring, tab. 3, architectural activities in the selected areas of urban transformations for each location on a daily basis exceed the limit values. The air

quality index (AQI) is recognized and used in the world to assess air quality. The index can have values from 0 to 500, with the value of AQI increasing, the level of ambient air pollution and the potential negative impact on health and the environment escalates. The values of the index correspond to six categories of air quality assessment:
– 0-50, good, air quality is satisfactory and there is minimal or no health risk,
– 51-100, moderate, air quality is acceptable and there is a health risk for certain groups of people extremely sensitive to air pollution,
– 101-150, harmful, sensitive groups may experience health problems,
– 151-200, unhealthy, sections of the population may experience health problems and sensitive groups may have more serious health problems,
– 201-300, very unhealthy, high health risk for all, and
– 300+, hazard, health warning for emergencies, possible serious health problems for all.

Table 3. Modeling and monitoring data (PM values [μg/m^3])

	Date	Area	Fine part.	Hum.	EF $PM_{2.5}$	EF PM_{10}	$PM_{2.5}$	PM_{10}	Tier $IPM_{2.5}$	Tier IPM_{10}	A.U. $PM_{2.5}$	A.U. PM_{10}	CC $PM_{2.5}$	$CCPM_{10}$
	16.08			49			66.42	242.90						
	15.08			40			70.78	244.29						
C1	14.08	1220	35.40	41	0.23	2.3	68.58	227.95	26.92	269.17	26.92	269.17	2.54	0.91
	13.08			52			61.55	220.94						
	12.08			37			75.02	293.57						
					Average		68.47	245.93						
	23.08			27			46.96	188.94						
	22.08			44			40.15	161.79						
C2	21.08	210	19.00	39	0.0086	0.086	42.69	170.81	22.07	220.65	22.07	220.65	2.06	0.83
	20.08			22			50.32	206.75						
	19.08			28			46.78	189.68						
					Average		45.38	183.59						
	19.07			44			40.31	162.15						
	18.07			36			42.64	166.86						
C3	17.07	450	19.67	30	0.03	0.3	52.08	210.44	18.11	181.10	18.11	181.10	2.74	1.14
	16.07			29			54.78	255.69						
	15.07			25			58.37	239.18						
					Average		49.64	206.86						
	19.04			58			51.80	215.72						
	18.04			37			60.29	251.71						
C4	17.04	1050	26.30	48	0.03	0.3	55.67	229.19	24.55	245.47	24.55	245.47	2.35	0.97
	16.04			36			60.99	252.49						
	15.04			39			59.84	244.43						
					Average		57.72	238.71						
	5.07			43			56.31	226.57						
	4.07			37			63.95	262.41						
C5	3.07	840	41.25	44	0.03	0.3	55.72	233.75	19.00	190.01	19.00	190.01	3.12	1.28
	2.07			46			54.45	221.58						
	1.07			36			65.70	274.01						
					Average		59.23	243.66						

Table 4. The AQI values determined according to the monitoring data

Location identifier	C1		C2		C3		C4		C5	
Days	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Fri	156	144	129	117	111	104	141	131	150	136
Thu	158	145	111	104	116	106	152	149	154	154
Wed	157	136	116	108	141	128	150	137	150	139
Tue	153	133	136	126	146	151	153	149	146	133
Mon	160	169	126	118	151	142	152	145	156	160
Average value	157	145	124	115	133	126	150	142	151	144
Area	1220		210		450		1050		840	

Assessing and analyzing the monitoring data, the AQI was calculated by AQI Calculator – US EPA Scale convertor [23], and the results are shown in tab. 4, for all locations (C1-C5) on a daily basis. Converted PM_{10} and $PM_{2.5}$ values to AQI indicate that the air quality index increases with the area on which urban transformations are performed. Analysis of all values at selected locations confirms that urbanities marked C1, C4, and C5 are particularly exposed to particulate pollution, where there is an increased unhealthy index for $PM_{2.5}$ particles while the index for PM_{10} particles is slightly below that limit. At locations C1, C4, and C5, the air quality index for the measured concentration values of $PM_{2.5}$ particles reach high levels that are considered unhealthy in the AQI nomenclature. While the index related to PM_{10} particles on most days is below the limit of unhealthy pollution, the qualitative values of elevated harmful levels. Harmful levels can affect respiratory and cardiovascular diseases, where vulnerable groups (children and the elderly) are mostly affected. During assessment processes in the day with an unhealthy air quality index, the risk of health problems is increased, and prolonged exposure to ambient air can lead to chronic respiratory complications, and sensitive groups are advised to avoid direct exposure.

Conclusions

The application of an originally designed sensor based on OPC-N2 has proved practical for use and provided very adequate and accurate results. Obtaining real-time data allows continual monitoring of construction sites. Assessing monitoring data confirms construction sites as significant PM_{10} and $PM_{2.5}$ pollution sources. The research data (monitored and modeled) provide scientific confirmation that construction sites should be considered stationary continual pollution hot spots.

Assessment of monitored and modeled PM emission data, generated by urban transformation on construction sites in the city of Novi Sad, Serbia, exposed gaps in Tier 1 prediction model. Results unfolded the requirement for additional monitoring and modeling with the goal to adopt and improve determined correction coefficients. It can be concluded that the EPA Tier I model can be used without CC for the prediction of PM_{10} emission levels, providing sufficient reliable precision levels, while for $PM_{2.5}$ particulates use of CC is mandatory.

Data modeled by environmental modeling software ADMS-URBAN also showed requirements for additional monitoring and CC adjustment and tuning. The ADMS-URBAN provided high-quality dispersion models, showing the real potential of particulate pollution. The application of the prediction model is significant in environmental protection and the prevention of ambient air pollution.

Determination of AQI exhibited that pollution levels and air quality category in the vicinity of construction sites can be considered harmful and unhealthy affecting the population *in a continuum* with numerous health problems, while vulnerable groups may have serious health problems.

This kind of research is for the first time performed in Serbia, focused on PM pollution emitted from urban transformations in the city of Novi Sad.

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Nomenclature

EM_x – PM_x emission ($x = PM_{10}/PM_{2.5}$) [kg]
EF_{PMx} – emission factor ($x = PM_{10}/PM_{2.5}$) [kgm^{-2} per year]
A_{af} – area affected by the emission of particles [m^2]
d – work time – activities [year]
CE – efficiency of suspended PM emission control
$24/PE$ – correction for terrain humidity
$s/9\%$ – correction for fine particle content [%]

Acronyms

CC – correctional coefficient
EPA – Environmental Protection Agency
EEA – European Environment Agency
UNS – University of Novi Sad
OPC – optical particle counter
AQI – air quality index

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