https://doi.org/10.14669/AM/176958

IDENTIFICATION OF PLACES WITH DETERIORATED AIR QUALITY IN CITY OF ŽILINA IN RELATION TO ROAD TRANSPORT

BRANISLAV ŠARKAN[1], MICHAL LOMAN[2], VERONIKA HARANTOVÁ[3]

Abstract

The aim of the research is to identify places with deteriorated air quality in the city of Žilina. After an analytical analysis of the data, it is possible to propose steps that can be used to actively contribute to the reduction of air pollution, especially due to road traffic. Places where deteriorated air quality was found were identified on the basis of practical measurements. Given that the measurement route was designed in a built-up area of Žilina with a large number of pedestrians, the research was primarily focused on the identification of particulate matters (PM) and the concentration of carbon monoxide CO. The measurements were repeatedly performed on a pre-defined route during the morning rush hour when traffic was congested on the roads. Based on the processing and evaluation of the measurements, the sections where increased values of individual emissions were recorded were identified. In this way, it was possible to precisely identify places where air quality deteriorates. The research conclusions provide support for planning the optimisation of air quality management policies towards the creation of sustainable cities. The research results present the possibilities of identifying problematic sections from the point of view of emissions production. Critical places with regard to the production of emissions can be connected to places where a permanently increased movement of vehicles is observed.

Keywords: emissions; air quality; vehicles; particulate matter; carbon monoxide

[1] Faculty of Operation and Economics of Transport and Communications,, University of Žilina, Slovakia, Univerzitna 8215/1, 010 26, Žilina, Slovak Republic, e-mail: branislav.sarkan@uniza.sk, ORCID: 0000-0002-5036-9223.

[2] Faculty of Operation and Economics of Transport and Communications,, University of Žilina, Slovakia, Univerzitna 8215/1, 010 26, Žilina, Slovak Republic, e-mail: michal.loman@uniza.sk, ORCID: 0000-0003-4300-3802.

[3] Faculty of Operation and Economics of Transport and Communications,, University of Žilina, Slovakia, Univerzitna 8215/1, 010 26, Žilina, Slovak Republic, e-mail: veronika.harantova@uniza.sk, ORCID: 0000-0002-0223-4244.

https://doi.org/10.14669/AM/176958

1. Introduction

In recent years, it has been found that air quality in cities has deteriorated due to the increasing concentration of human activities that produce polluting emissions [11]. The main cause of current air pollution is mainly emissions from household heating and emissions from transport. Studies [2, 20] have shown that particulate matters and nitrogen oxides contribute to excessive pollution. Their increased concentration is particularly observable in metropolitan areas with an extreme number of cars. Residents in such conditions have difficulty breathing.

Heavy pollution also promotes stable, cool and windless weather. In such weather conditions, pollutants start to accumulate, especially solid dust particles PM_{10} and $PM_{2.5}$ [12]. These are very small particles that are hardly visible to the naked eye. Solid substances from urban roads contain toxic metals and act as carriers of PTEs and carcinogens, which pose a potential risk to human health. [4, 54].

The main contributors to non-exhaust emissions are the emissions of substances that are released into the air due to road wear, and the swirling of particles accumulated on the surface. Fine and coarse particles are mostly caused by tire and brake wear [19, 21]. Particulate air pollution, which is largely the result of burning fossil fuels, is considered the deadliest form of air pollution worldwide. The AQLI study shows that, averaged among all women, men, and children worldwide, particulate air pollution shortens global life expectancy by nearly 2.2 years compared to if particulate matter concentrations were everywhere at the level that the World Health Organization (WHO) considers to be safe [14]. According to Professor Greenstone, particulate air pollution shortens lives worldwide, even more than cigarettes. there is currently no greater risk to human health [13].

When investigating the production of particulate matters, their size is important. A study by Schneider et al. points to the formation and impact of particles smaller than 1 μm in metropolitan areas [41]. The smaller the fine dust particles, the more insidious their inhalation is for our organism. Much also depends on their chemical composition. PM is composed of particulate matters and liquid droplets that have the ability to remain suspended in the air for long periods of time. Particles that are larger than PM_{10} are already filtered out in the nasal cavity and do not pose a significant risk. However, smaller particles (PM_{10}) penetrate the larynx and the lower respiratory tract. $PM_{2.5}$ particles settle in the bronchi. Because of their small size, $PM_{2.5}$ particles can remain in the air for days after being emitted or formed in the atmosphere and can be transported long distances from their source areas [1, 34, 50].

According to the World Health Organization, PMs were responsible for 3 million premature deaths worldwide in 2016 [7]. In a study [16] they declared that a decrease in $PM_{2.5}$ level by 10 $\mu g/m^3$ increased life expectancy by 0.61 years. Several studies have found a significant positive association between $PM_{2.5}$ in road dust and hospitalization due to cardiovascular and respiratory complications [3, 28].

https://doi.org/10.14669/AM/176958

Young children, the elderly, and also people suffering from allergies or asthma are a sensitive group when it comes to air pollution. The biggest air quality problem in Slovakia is air pollution with dust particles (PM_{10}). PM also causes the greatest damage to human health in Europe [33, 42, 44].

Air pollution is hard to escape, no matter where one is. Particulate matters in general can come from very diverse sources – both natural and anthropogenic. Natural resources include processes that normally occur in nature (forest fires, erosion processes, etc.). Anthropogenic sources include emissions from combustion processes – household heating, transport, electricity generation, heating plants, waste incinerators and various other production processes. To a lesser extent, the increased dustiness is also contributed by dust from the roads – residues from brake and tire wear, winter dust, and road pollution. The harmfulness of particulate matters to human health depends not only on the size of the particles but also on their composition, which is conditioned by the source from which they come [46, 47]. In the studies of Tomar et al. and also Chianese et al., the amount of production of particulate matters depending on the road surface is characterized. The research results show that in the rural-urban landscape, the main source of $PM_{2.5}$ is automobile activity. Suspended particulate matter accounts for 89% and 75% of total $PM_{2.5}$ on rural and urban roads, respectively. The proportion is higher in rural areas due to the poor condition of roads. In addition, vehicles driving on rural roads contribute to emissions in a similar proportion to the length of rural roads. it seriously affects human health as well as the environment [8, 30, 49].

A number of studies have been conducted to investigate the state of PM pollution, which in most cases exceeds global air quality guidelines [22, 40]. Therefore, in densely populated cities and industrial areas, air quality has become an important measure of quality of life. Air quality control is currently highly desirable to improve the sustainability of cities and the quality of life [26, 55].

Legislative air quality standards and emission control policies control the emissions of harmful substances into the atmosphere and regulate concentrations of air pollutants such as $PM_{2.5}$, PM_{10}, NO_x and O_3 [40, 48].

For the effective prevention of air pollution, it is necessary to monitor and forecast air quality. Several studies have been conducted focusing on different method selection strategies for effective PM concentration mapping [18, 56]. The relationship between the number of vehicles and production was addressed by several authors who declared uneven results. They found that increasing PM levels in urban areas can be caused by increasing traffic [5, 17, 27], while research by others has shown very weak or zero [5, 24, 35] correlations between variables. The Covid-19 pandemic also had an impact on the improvement of air quality, when there was a huge restriction on human activities, which led to changes in air pollution in many regions around the world [23, 37, 43]. The primary goal of the research activity is the collection and assessment of air quality data. Based on the obtained data, it is possible to identify with certainty the places where the deteriorated air quality was recorded. To collect data on quality, a methodology of research activity was created according to which the implementation of the research will be governed. Based on the data, it will be possible to introduce tools that will serve to permanently reduce emissions and thereby overall increase air quality in the territory of cities.

2. Measurement methodology

The practical part of the research was focused on measuring the amount of carbon monoxide and particulate matters in the air. Each measurement took place on the same, predetermined route. The route was compiled in such a way as to include places with higher traffic intensity and at the same time places where a larger number of people move. The measurements were taken at a time that captured the morning peak. Individual measurements took between 120 minutes and 150 minutes. In order to implement the research task, three measurements were made. During the execution of individual measurements, the exact position of the measuring device was monitored. The exact position of the particulate matters analyser was recorded using a GPS locator. This is due to the merging of the results from the gas analyser and the place where the given measurement was performed. GPS coordinates were used to identify sections with possible increased pollution values. There is also an air quality monitoring station on the territory of the city, managed by the Slovak Hydrometeorological Institute. It regularly publishes the measured values on its website. A direct comparison between the values measured by us and the values measured by the measuring station was not made because the station is located at a relatively distant place from the planned measuring route. A comparison of the obtained results would have no informative value since the planned route was focused on sections with high traffic intensity and at the same time on sections with a potentially higher concentration of residents. The measurements are primarily intended to point out the negative impact of traffic on the air quality in the given area. In the images, we can monitor the traffic load on individual sections of the road within the assessed city.

https://doi.org/10.14669/AM/176958

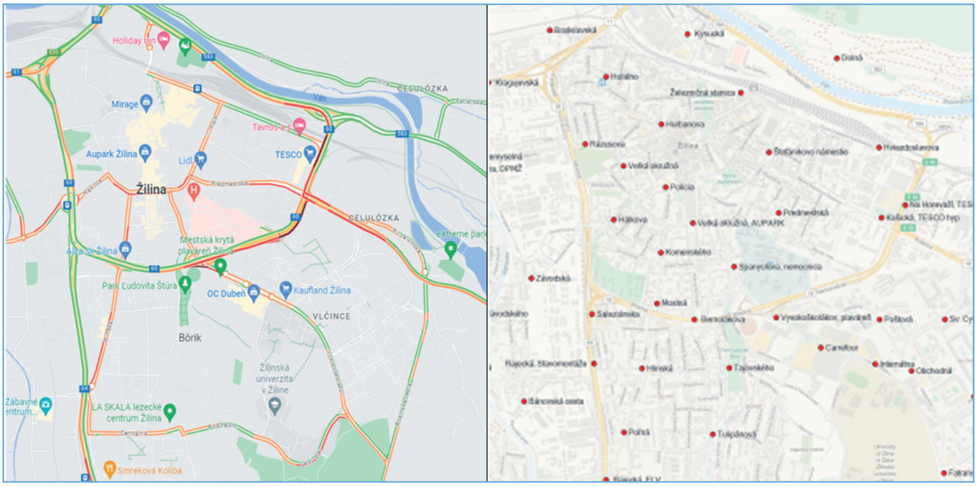

Fig. 1. Traffic load in the urban environment compared to public transport stops [author]

Figure 1 shows the usual (regular) intensity of traffic on individual sections of the road network within the assessed city. On the right part of the picture, we can observe that the traffic intensity reaches critical values in certain parts (red colour on the left part of the picture). These locations represent critical points from the traffic engineering assessment. A high incidence of conventions can be expected in these places. In connection with road transport, it is assumed that there will be an increased production of exhaust gas emissions in these places, this is also confirmed by studies [9, 51]. In the right part of the picture, you can see the location of public transport stops within the city. In this way, it is possible to point out the negative impact of emissions from transport directly on people. Bus stops are often located in places where there is increased traffic, so passengers waiting for a connection are exposed to adverse effects in the form of increased emissions (polluted air).

https://doi.org/10.14669/AM/176958

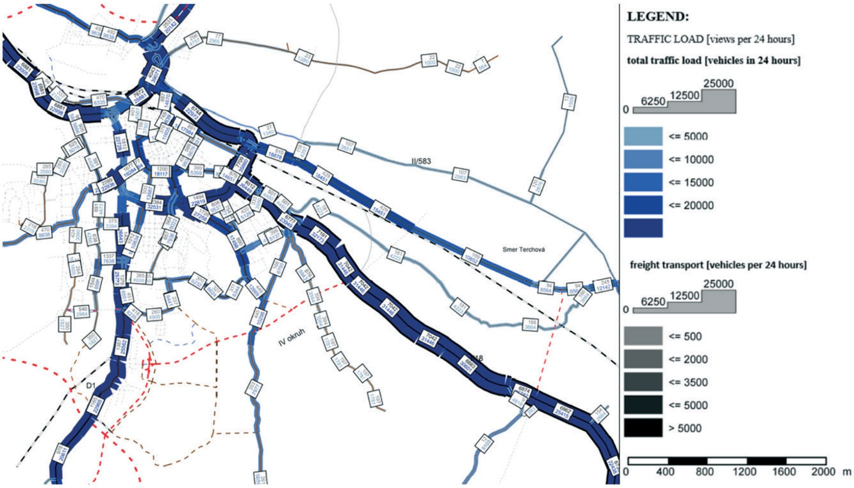

Fig. 2. Road infrastructure load in the selected city [author based on the city's spatial plan]

Figure 2 shows the load on the road network in the form of a cartogram. This is concerned with rendering the load of individual roads within the city on a map basis. In comparison with the previous images, it is possible to observe a close connection between the places where the frequent occurrence of traffic congestion is identified (red places) and the places where the traffic intensity is the highest (thickest lines in the cartogram).

2.1. Measurement route

The measurement route was determined based on previous analysis results. Measurements were carried out in places where high traffic intensity was identified due to the high intensity of pedestrians. The measurement started at the Hliny dormitories, and continued along Antona Bernolák Street, past the Aupark shopping center, towards Marián´s Square. The measurement continued past the Mirage shopping center on Andrej Hlinka Square, in the direction of the bus station. From the bus station, we proceeded past the railway station to Andrej Hlinka Square, from where we continued past the Mirage again, along J.M. Hurbana Street to the intersection of Veľká Okružná and Komenského streets. From there, we continued past the Aupark shopping center towards Vojtecha Spanyana Street and then Vysokoškolákov Street. The route went past the Veľký Diel dormitories and ended at the University of Žilina. It should be noted that the measurement of particulate matters PM was carried out at thirty-three points that were chosen on the given route. The nature of the meter does not allow continuous data collection. For proper data collection recording, each measurement was performed three times. This is due to cleaning the data from extreme values. The plotted measurement points as well as the route itself can be viewed in Figure 3.

https://doi.org/10.14669/AM/176958

The individual measurement points on the route were set up so that they were approximately the same distance from each other. The measurement of carbon monoxide took place at the same time as the measurement of solid particles. Carbon monoxide was measured continuously. The nature of the measuring device enables continuous measurements. In the following Figure 3, it is possible to follow the direction of the measuring route with the drawing of measuring points

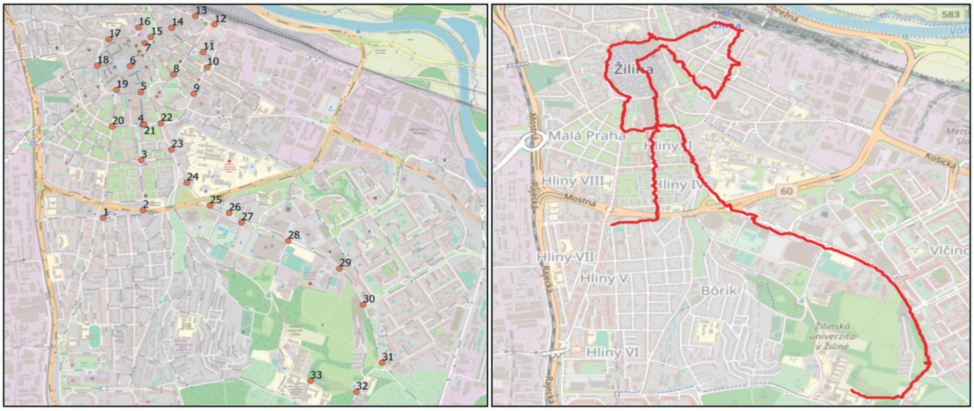

Fig. 3. Measurement route with plotting of measurement points [author based on GPS visualizer]

Due to the distribution of the road infrastructure in the city, a measuring route was established, which primarily captures places associated with high traffic intensity and high pedestrian intensity. In connection with the load on the road network, there are several sections in the city that are more heavily loaded with traffic, but from the point of view of pedestrian traffic, these places are unattractive.

2.2. Measuring devices

A measuring device named Particle Counter PCE-PCO 2 was used to measure particulate matters– Figure 4. The device is designed to measure the exact degree of air pollution caused, for example, by industrial production, road traffic, or various other types of pollution. In addition to the measurement of particulate matters, this device also allows the recording of the current temperature and relative air humidity. The device is able to work in a temperature range of 0 °C to 50°C. The dimensions of particulate matters that the device is able to record are (0.3; 0.5; 1; 2.5; 5; 10) micrometres. The device achieves 100% measurement efficiency for particles larger than 0.45 micrometres. For the needs of our research, $PM_{2.5}$ and PM_{10} particles were recorded. Table 1 shows basic technical data about the given device [32].

https://doi.org/10.14669/AM/176958

Figure 4. PCE-PCO2 measuring device [32]

Table 1. Technical parameters of the measuring instrument [32]

Particle specifications	
Particulate matter channels	$PM_{2.5}$/PM_{10}
Particle concentrations	0 ... 2000 µg/m³
Resolution	1 µg/m³
Particle counter specifications	
Particle sizes (in micrometers)	0.3/0.5/1.0/2.5/5.0/10 µm
Flow rate	2.83 l/min
Coincidence error	< 5% at 2,000,000 particles per cubic foot
Counting efficiency	50% at 0.3 µm
Memory capacity	Stores up to 5,000 data sets
Counting modes	cumulative, differential, concentration

A CO micro-sensor manufactured by ENVEA was used to measure carbon monoxide (Figure 5). The device is characterized by high sensitivity, thanks to which it can quite accurately capture the amount of carbon monoxide in the air. The device itself does not have a built-in battery, so the device was powered from an external source. The device started measuring immediately after connecting to an external source, it measured continuously, while the output of the measurement was the average values of carbon monoxide present in the air every minute. The data was downloaded using a computer application that was supplied directly by the manufacturer. The application is called Cairsoft 5.1. The instrument recorded values in units of ppb (parts per billion), which meant that they had to be multiplied by a factor of 1.15. After multiplying by the coefficient, we obtained the presence of carbon monoxide in the

https://doi.org/10.14669/AM/176958

same units as for particulate matters, μg/m^3. Based on Table 2 (below), we can see the basic technical parameters of the given measuring device [10].

Fig. 5. CO measuring device [10]

Table 2. Technical data of the CO measuring device [10]

Sampling method	Dynamic air sampling, with a controlled micro-fan
Power supply	5VDC/500mA, USB port of a PC or Power bank type «Always on» (not provided)
Power consumption	20 mA max under 5 VDC
I/O communications	USB, UART, Modbus RTU-TTL. Modbus RS485 on request (article code A40-0219)
Lifetime duration	24 months
LCD Display	Concentration in ppb or ppm, operating status, memory available...
Control & data treatment	Internal microprocessor for data acquisition and treatment, embedded timer
Data Storage (internal)	20 days for 1 min data, 303 days for 15 min data or 1212 days for 60 min data
Weight	55 g

3. Evaluation of implemented measurement

Measured values were recorded in tables, from which graphs were subsequently processed. There are two graphs for each measurement, one for carbon monoxide and one for the concentration of particulate matters PM_{10} and $PM_{2.5}$. In the graphs, it is also possible to monitor the maximum limit value for the monitored concentration, which represents the transition between individual levels of air quality. During the measurement, the air quality level never exceeded two consecutive levels. This can be observed from the measurement results. During the measurements, the quality level decreased but never exceeded 2 levels, for that reason, the limit for determining the air quality level is indicated in the graphs as "very good".

https://doi.org/10.14669/AM/176958

In the following images, you can see the evaluation of the performed measurements. In the process of data collection, the values of particulate matters and the values of CO emissions were monitored. The first measurement as well as the other measurements were performed between 7:00 and 9:00. It is assumed that there is an increased movement of pedestrians on the streets at this time and it is known in the long term that there is an increased movement of vehicles on the roads at this time. The recorded values of particulate matter pollution within the first measurement are processed in Figure 6.

Fig. 6. PM concentration during the first measurement [author]

The results of the first measurement show that $PM_{2.5}$ emissions ranged from 0 to 5 μg/m^3, which means that their values did not change significantly. By contrast, there was a significant increase in PM_{10} emissions at point number 9 and especially at point number 10. These points are located on 1 Maja Street, in the direction of the bus station. In the next part, Figure 7, it is possible to follow the recorded values for carbon monoxide.

https://doi.org/10.14669/AM/176958

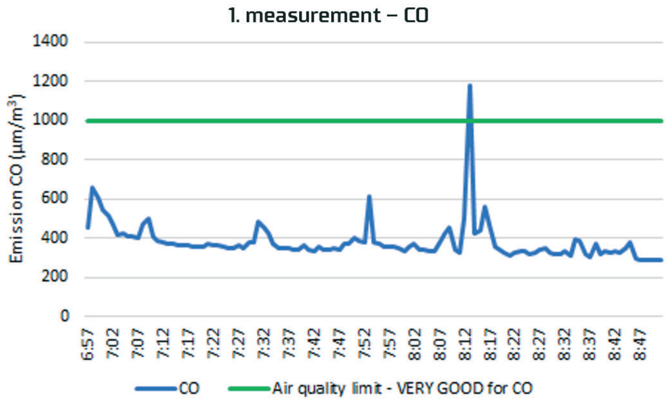

Fig. 7. CO concentration during the first measurement [author]

From the above graph of the results of measuring CO emissions, it follows that the values of carbon monoxide rose significantly at 8:13 a.m., the time at which the measurement was carried out on Vojtecha Spanyana Street, in the direction of Vysokoškolákov Street. The second measurement (Figures 8 and 9) was made in the same way as the first measurement. The processed data can be viewed in the images.

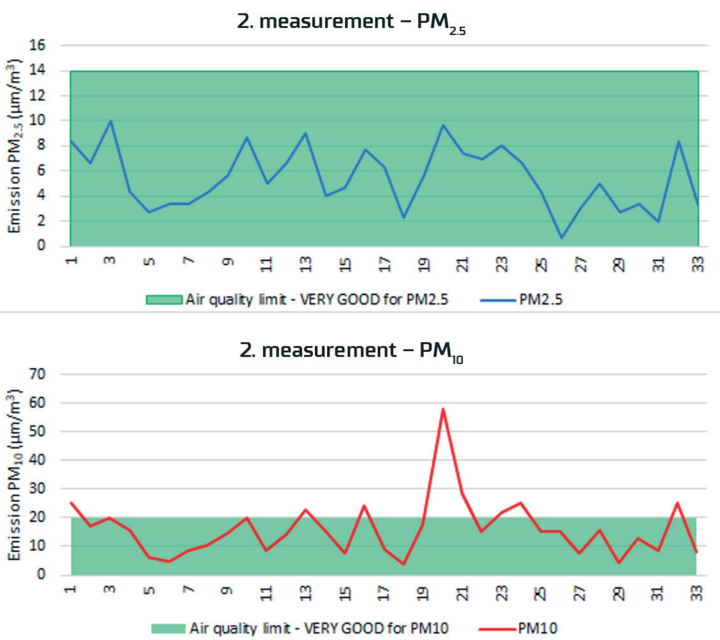

Fig. 8. PM concentration during the second measurement [author]

https://doi.org/10.14669/AM/176958

In Figure 8, it is possible to observe that, similar to the first measurement, we did not notice significant changes for $PM_{2.5}$ during the second measurement either. With PM_{10}, we can see a sudden increase again, this time the increase was recorded at a different point than in the case of the first measurement. Point number 20 is located at the intersection of Veľká Okružná and Komenského streets. More significant changes in values were not recorded. The recorded values for carbon monoxide are displayed using the graph in Figure 9. The values of CO emissions did not exceed the limit of very good air quality compared to the first measurement even once. During the measurement, two places where there was a significant increase in the values of the presence of carbon monoxide in the air were recorded.

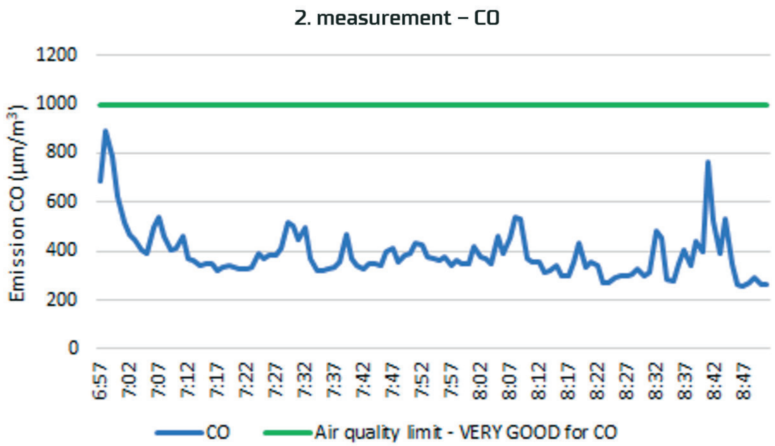

Fig. 9. CO concentration during the second measurement [author]

A significant increase in the value of carbon monoxide was recorded right at the beginning of the measurement when the measuring devices were located near the Hliny dormitories. The second increase occurred at the intersection of Vysokoškolákov and Veľký Diel streets. The values of carbon monoxide never exceeded the limit of 1000 µg/m³ during the measurement, which is the maximum limit for the "very good" air quality level. The third measurement was performed using the same procedure as the previous measurements. The start time of data collection was also the same. Air quality data is processed in the following Figure 10.

https://doi.org/10.14669/AM/176958

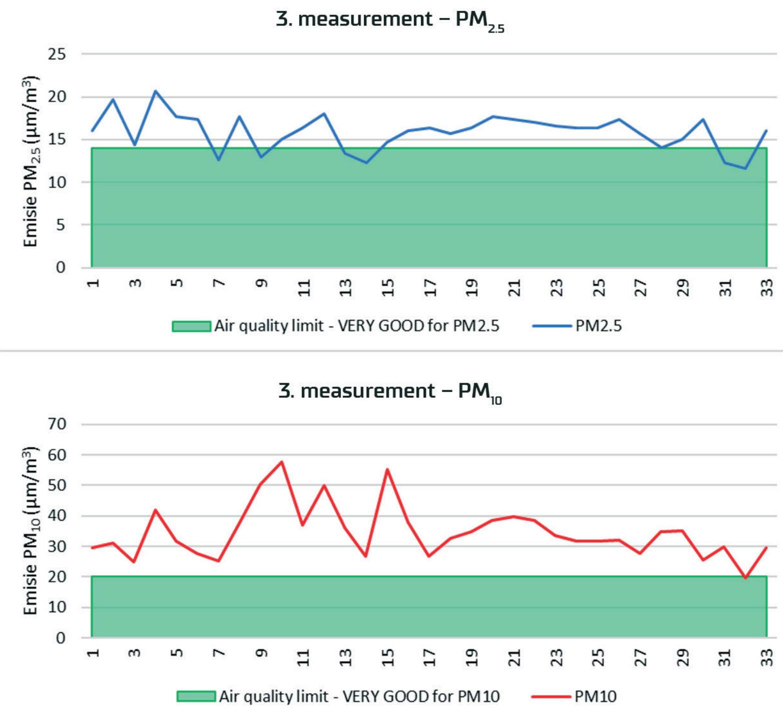

Fig. 10. PM concentration during the third measurement [author]

It can be seen from the graph (Figure 10) that the pollution values for particulate matters were generally increased compared to the first two measurements. Again, we did not notice significant changes during the measurement for $PM_{2.5}$ values, by contrast, we identified several points with increased values for PM_{10} values. Again, similar to the first measurement, the increased values were represented by points 9 and 10, and increased values were also recorded at points 12 and 15. Point 12 represents the vicinity of the bus station and point 15 represents the area of Andrej Hlinka Square. The processed values for carbon monoxide from the third measurement are shown in Figure 11.

https://doi.org/10.14669/AM/176958

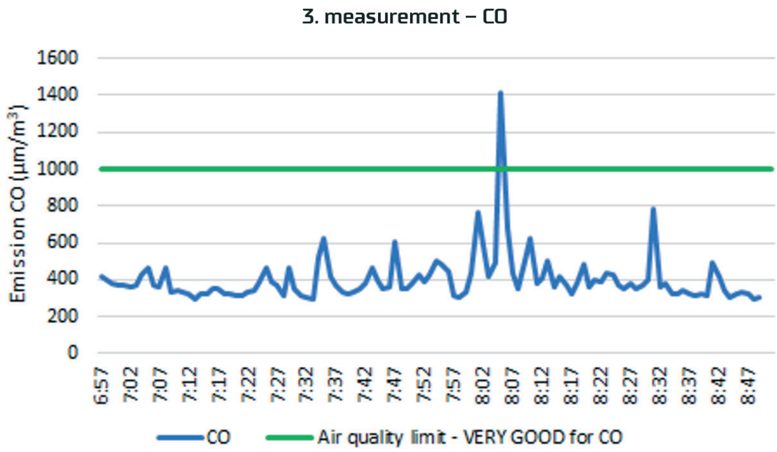

Fig. 11. CO concentration during the third measurement [author]

The results of the measurement (Figure 11) show that carbon monoxide values rose significantly at 8:13 a.m., when the measuring devices were located on Vojtecha Spanyana Street, in the direction of Vysokoškolákov Street. The maximum value defined for very good air quality was also exceeded. This place is identical to the place where significantly higher values of the presence of carbon monoxide in the air were recorded during the first measurement.

4. Evaluation of processed data

Based on the processed data, it was possible to identify problematic sections with deteriorated air quality on the planned route. For a better understanding, it is possible to view the images, which are supplemented with sections where increased values were recorded. In the case of carbon monoxide (Figure 12), the representation of the problem area is clear due to the fact that the section of elevated values in the case of carbon monoxide was repeated during the measurements. The section was located on Vojtecha Spanyana Street and continued along Vysokoškolákov Street. There is a hospital very close to this place.

https://doi.org/10.14669/AM/176958

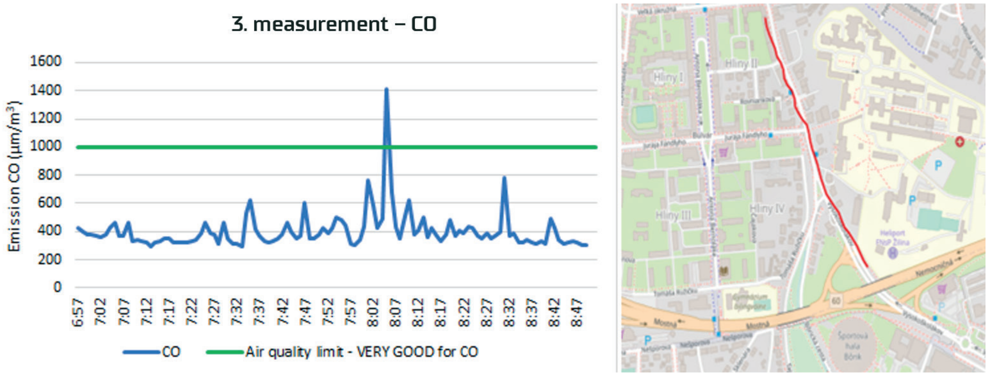

Fig. 12. Identifying the section with elevated CO values [author]

For particulate matters PM_{10} and $PM_{2.5}$, the same sections with increased values were not recorded at each measurement, similar to CO concentrations. In the following Figures 13, 14, and 15 it is possible to follow the graphic courses for each measurement together with the exact identification of the place where the given extreme value was recorded. Particulate measurements were performed at the measurement points; however, in the figures below, the measurement point locations and locations in close proximity are plotted as short sections around the measurement points for better identification.

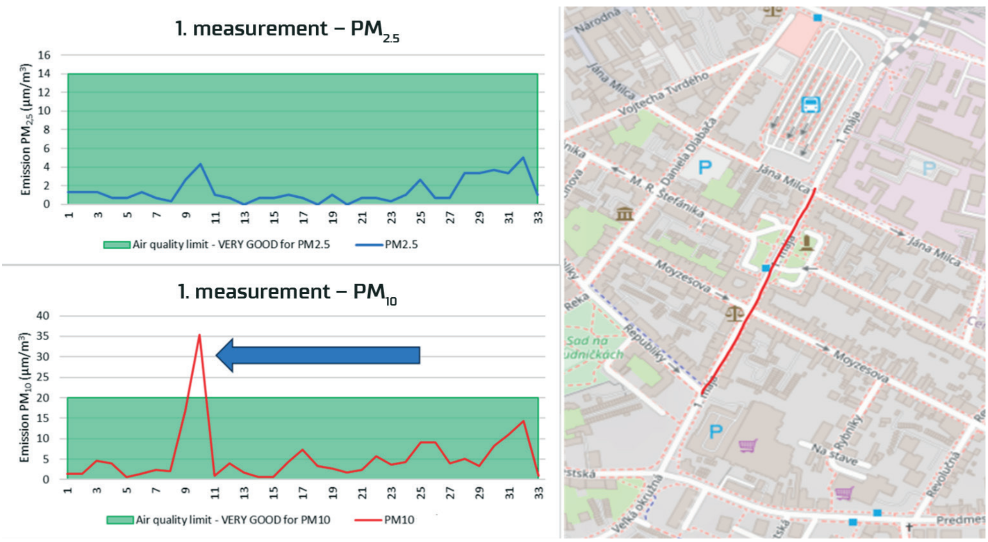

Fig. 13. Identifying the section with elevated PM values [author]

https://doi.org/10.14669/AM/176958

Based on the measurement results and GPS coordinates, it was possible to show the section where increased values of particulate matters were identified during the first measurement (Figure 13). The section is located on 1 May Street in the direction of the bus station. In the given section, an increased concentration of particulate matters PM_{10} was recorded.

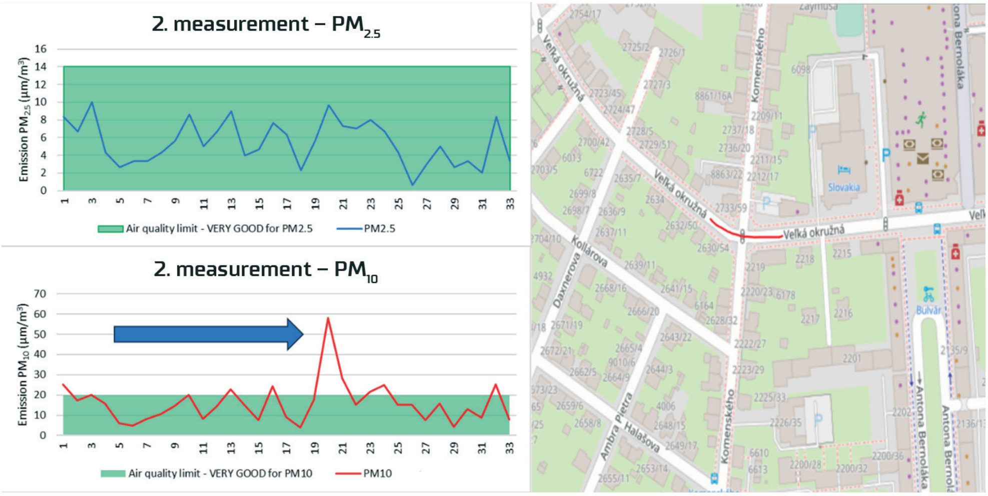

Fig. 14. Identifying the section with elevated PM values [author]

From the results of the measurement (Figure 14), it is possible to observe that during the measurement, increased values were recorded, especially PM_{10}, in the vicinity of the intersection of Veľká okružná and Komenského streets. Values for PM_{10} reached 60 µg/m³, which means a high exceedance of the air quality limit set for "very good" quality. The results and identification of the sections for the third measurement can be seen in the following image.

https://doi.org/10.14669/AM/176958

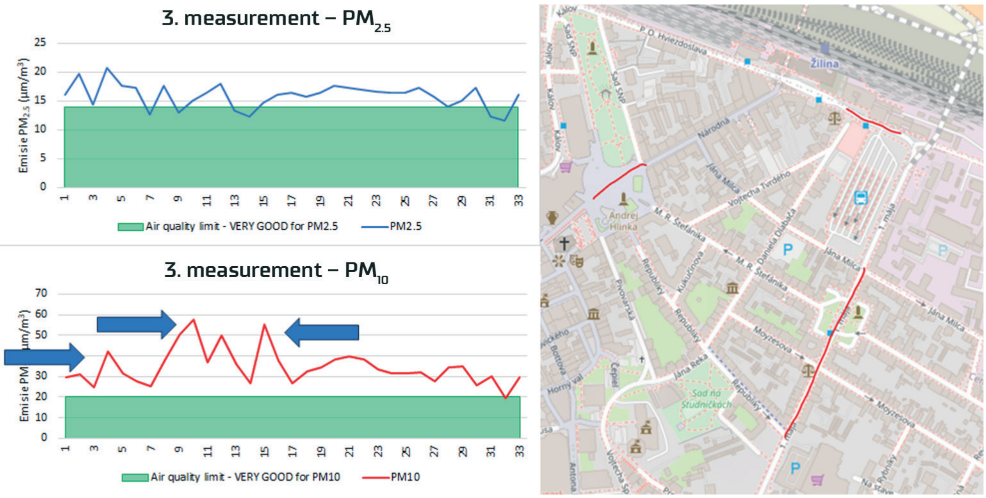

Fig. 15. Identifying the section with elevated PM values [author]

In the third measurement, three sections with increased values were identified. The first section was identical to the first, morning measurement (measuring point 9), and the second section is located near the bus and railway station (measuring points 10,11,12). The third section represents the Andreja Hlinka square (measuring point 15).

5. Discussion

On the basis of the processed data, it is possible to evaluate and analyse places (sections of roads) where increased values of pollution were recorded. The section in which the increased values of carbon monoxide occurred again is known for long-lasting problems with the formation of high levels of congestion, especially during the morning and afternoon traffic rush. From the results of long-term observation and practical measurements, it is possible to claim that the persistent problems with the formation of congestion have a negative impact on the production and emissions in the given area. The fact that transport has a negative impact on the creation of emissions can also be claimed on the basis of several studies that actively address these problems in their research [38, 39, 57]. But the fact remains that despite the increased values, the air quality level is still at a quality level that is rated as "very good" to "good" in the air quality assessment for carbon monoxide. The degree of "deteriorated" was not reached during the measurements at any measured location.

When analysing the results from the measurement of particulate matters PM_{10} and $PM_{2.5}$, a multiple deterioration of air quality was noted. The worst level achieved was the "deteriorated" level, specifically in the section around the Aupark shopping centre. In this case,

https://doi.org/10.14669/AM/176958

it can be argued that road transport clearly contributes to increased PM_{10} and $PM_{2.5}$ values, as these are places where cars often start and stop. This phenomenon is also associated with the use of brakes, which generate brake dust, which is practically not captured in any way and is directly released into the air. The frequent stopping and starting of means of transport is also associated with exerting pressure on the tires that rub against the road, which causes their degradation, but also the degradation of the road itself, and thus air pollution occurs. Last but not least, the resuspension of road dust contributes to pollution, especially in winter. The results of studies conducted by foreign researchers show that traffic signals at intersections create about 50% more emissions than roundabouts. Even higher production of HC emissions was detected during heavy traffic. This comparison was made with roundabouts [29]. Another similar study by Varhelyi shows that replacing a signalised intersection with a roundabout results in an average reduction of CO emissions of 29%, NO_x emissions of 21%, and fuel consumption of 28% per vehicle. Mandavilli et al. in their research found that the roundabout works better than the existing control of intersections with stop lights in reducing vehicle emissions [52].

Taking into account the results of the research part, which were mainly supported by practical air quality measurements, it is possible to characterise the monitored area. The evaluated measurements represent the underlying part for subsequent use in the creation of tools whose task will be the permanent regulation of emissions in the city. The measurement results represent the basis for further measurements that are being prepared. It is a way of assessing whether the identified places pose a threat to the health of the inhabitants in the long term or whether it is just accidental air pollution.

There are many ways to contribute to the permanent reduction of emissions. Significant emphasis is currently placed on the type of vehicle drive and also on the lowest possible amount of driving resistance [29, 36]. Similarly, it is in the studies of Skrúcaný et al. who in their research assessed the creation of greenhouse gas emissions in the process of transport services in the selected region [45]. In other studies, the authors of the research deal with reducing emissions directly at intersections [15, 31, 53]. Research results show that reducing emissions is not simply equivalent to reducing the number of vehicle stops, as delays and stops are strongly correlated in urban traffic. Based on traffic flow studies, the delay increases if there is a reduction in the number of vehicle stops. The research results of Li et al. show that a reduction in the number of stops can lead to a reduction in CO at the expense of a slight increase in CO_2 and HC, while NO_x is only slightly affected, and when there is a large reduction in stops all four measured pollutants increased [25].

Another point on how to reduce the production of emissions, especially by road transport in the selected city, is to limit or completely prevent the entry of vehicles into the selected area, which is most affected by pollution. Currently, the Slovak Republic does not have a universal tool for monitoring air quality in urban areas. Within cities or larger agglomerations, there is no study available on how to monitor and evaluate air quality in a specific section. In the

https://doi.org/10.14669/AM/176958

near future, it is planned to create measuring points in selected places that will continuously monitor air quality. One of the assessed values is the production of particulate matters. For this reason, the research is carried out in such a form. The results of the study can serve as a tool for the correct placement of measuring devices in order to permanently monitor air quality. Based on the results of the measurements and current data, specific measures can be introduced (entry ban, restricted entry for selected types of vehicles, etc.) with the aim of permanently reducing emissions in the urban environment. The research findings further provide support for planning the optimisation of air quality management policies towards the creation of sustainable cities. On the territory of the Slovak Republic, there is still no tool for preventing the movement of passenger traffic in the built-up areas of cities. To a large extent, the study could be beneficial in building a green policy and permanently reducing emissions due to traffic within cities.

6. Conclusion

The research results present the possibilities of identifying problematic sections from the point of view of emissions production. Critical places with regard to the production of emissions can be connected to places where a permanently increased movement of vehicles is observed. The results point to repeatedly increasing concentrations of carbon monoxide, which were recorded in one section. For PM_{10} and $PM_{2.5}$ particles, an analysis of each measurement was carried out, and the relevant problematic sections were marked on the map base. For particulate matters, increased values were detected especially in the vicinity of large shopping centres, buses, and railway stations. The reason for the increased values is the permanently high traffic intensity. In these sections and in their immediate surroundings, high traffic intensity is regularly recorded compared to other analysed sections. Based on the results of practical measurements, the section with increased values of carbon monoxide was identified on Vojtecha Spanyana street towards Vysokoškolákov street. In further research, it is necessary to carry out a measurement that will be connected to the measurement of traffic intensity in the given section. In the same way, air quality measurement can be expanded and continuous quality monitoring can be carried out. Only in this way is it possible to reliably set the tool necessary for the regulation of emissions in the given area. By solving the situation, it is possible to practically implement proposals that would lead to a permanent reduction of air pollution by road transport. The primary step to the permanent reduction of emissions in the chosen area is the introduction of a system that will be able to continuously measure air quality. This makes it possible to check whether specified sections suffer from long-term deterioration of air quality, or whether it is only a short-term deterioration of air quality. Control management functioning in this way is the primary tool for controlling and permanently reducing emissions in the monitored area.

https://doi.org/10.14669/AM/176958

7. Acknowledgement

This research was funded by the VEGA project. 1/0426/22 Quantification of the impact of road transport on the environment in urban areas.

This research was funded by the KEGA project. 041ŽU-4/2022 Implementation of students in the teaching process through the implementation of practical measurements in the form of driving and laboratory tests of road vehicles using multimedia tools

8. Nomenclature

CO carbon monoxide
EU European Union
PM particulate matter

9. References

[1] Ali M.U., Liu G., Yousaf B., Ullah H., Abbas Q., Munir M.A.M.: A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment. Environmental geochemistry and health, 2019, 41(3), 1131–1162, DOI: 10.1007/s10653-018-0203-z.

[2] Anjum M.S., Ali S.M., Subhani M.A., Anwar M.N., Nizami A. S., Ashraf U., et al.: An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. Journal of Hazardous Materials, 2021, 402, 123943, DOI: 10.1016/j.jhazmat.2020.123943.

[3] Bell M.L., Ebisu K., Leaderer B.P., Gent J.F., Lee H.J., Koutrakis P., et al.: Associations of PM2.5 constituents and sources with hospital admissions: analysis of four counties in Connecticut and Massachusetts (USA) for persons≥ 65 years of age. Environmental health perspectives. 2014, 122(2), 138–144, DOI: 10.1289/ehp.1306656.

[4] Chalvatzaki E., Chatoutsidou S.E, Lehtomäki H., Almeida S.M, Eleftheriadis K., Hänninen O., et al.: Characterization of human health risks from particulate air pollution in selected European cities. Atmosphere. 2019, 10(2), 96, DOI: 10.3390/atmos10020096.

[5] Chang P.K., Griffith S.M., Chuang H.C., Chuang K.J., Wang Y.H., Chang K.E., et al.: Particulate matter in a motorcycle-dominated urban area: source apportionment and cancer risk of lung deposited surface area (LDSA) concentrations. Journal of Hazardous Materials. 2022, 427, 128188, DOI: 10.1016/j.jhazmat.2021.128188.

[6] Chianese E., Tirimberio G., Dinoi A., Cesari D., Contini D., Bonasoni P., et al.: Particulate Matter Ionic and Elemental Composition during the Winter Season: A Comparative Study among Rural, Urban and Remote Sites in Southern Italy. Atmosphere. 2022, 13(2), 356, DOI: 10.3390/atmos13020356.

[7] Dietrich M., Wolfe A., Burke M., Krekeler M.P.: The first pollution investigation of road sediment in Gary, Indiana: anthropogenic metals and possible health implications for a socioeconomically disadvantaged area. Environment international. 2019, 128, 175–192, DOI: 10.1016/j.envint.2019.04.042.

[8] Duque L., Relvas H., Silveira C., Ferreira J., Monteiro A., Gama C., et al.: Evaluating strategies to reduce urban air pollution. Atmospheric Environment. 2016, 127, 196–204, DOI: 10.1016/j.atmosenv.2015.12.043.

https://doi.org/10.14669/AM/176958

[9] Dyvak M., Darmorost I., Shevchuk R., Manzhula V., Kasatkina, N.: Correlation analysis traffic intensity of the motor vehicles and the air pollution by their harmful emissions. 2018 14th International Conference on Advanced Trends in Radioelecrtronics, Telecommunications and Computer Engineering (TCSET). IEEE. 2018, 855–858.

[10] ENVEA. 2023. CO micro-sensor. https://www.envea.global/s/ambient/micro-sensors/cairsens-co/ (accessed on 6.11.2023).

[11] Fenger J.: Air pollution in the last 50 years–From local to global. Atmospheric environment. 2009, 43(1), 13–22, DOI: 10.1016/j.atmosenv.2008.09.061.

[12] Graham A.M., Pringle K.J., Arnold S.R., Pope R.J., Vieno M., Butt E.W., et al.: Impact of weather types on UK ambient particulate matter concentrations. Atmospheric Environment. 2020, X(5), 100061, DOI: 10.1016/j.aeaoa.2019.100061.

[13] Greenstone M., Fan Q.: Indonesia's worsening air quality and its impact on life expectancy. Air Quality Life Index. 2019, 1–10.

[14] Grivas G., Chaloulakou A., Samara,C., Spyrellis N.: Spatial and temporal variation of PM10 mass concentrations within the greater area of Athens, Greece. Water, Air, and Soil Pollution. 2004, 158(1), 357–371, DOI: 10.1023/B:WATE.0000044859.84066.09.

[15] Harantová V., Hájnik A., Kalašová A., Figlus T.: The Effect of the COVID-19 Pandemic on Traffic Flow Characteristics, Emissions Production and Fuel Consumption at a Selected Intersection in Slovakia. Energies. 2022, 15(6), 2020, DOI: 10.3390/en15062020.

[16] Héroux M.E., Anderson H.R., Atkinson R., Brunekreef B., Cohen A., Forastiere F., et al.: Quantifying the health impacts of ambient air pollutants: recommendations of a WHO/Europe project. International journal of public health. 2015, 60(5), 619–627, DOI: 10.1007/s00038-015-0690-y.

[17] How Does Particulate Air Pollution Impact Health? https://aqli.epic.uchicago.edu/pollution-facts/ (accessed on 5. July 2022).

[18] Hutchison K.D., Smith S., Faruqui S.: The use of MODIS data and aerosol products for air quality prediction. Atmospheric Environment. 2004, 38(30), 5057–5070, DOI: 10.1016/j.atmosenv.2004.06.032.

[19] Karagulian F., Belis C.A., Dora C.F.C., Prüss-Ustün A.M., Bonjour S., Adair-Rohani H., et al.: Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. Atmospheric environment. 2015, 120, 475–483, DOI: 10.1016/j.atmosenv.2015.08.087.

[20] Kendrick C.M., Koonce P., George L.A.: Diurnal and seasonal variations of NO, NO2 and PM2. 5 mass as a function of traffic volumes alongside an urban arterial. Atmospheric Environment. 2015, 122, 133–141, DOI: 10.1016/j.atmosenv.2015.09.019.

[21] Keuken M.P., Henzing J.S., Zandveld P., Van den Elshout S., Karl M.: Dispersion of particle numbers and elemental carbon from road traffic, a harbour and an airstrip in the Netherlands. Atmospheric Environment. 2012, 54, 320–327, DOI: 10.1016/j.atmosenv.2012.01.012.

[22] Khan R.K., Strand M.A.: Road dust and its effect on human health: a literature review. Epidemiology and health. 2018, 40, DOI: 10.4178/epih.e2018013.

[23] Khan Z., Ualiyeva D., Khan A., Zaman N., Sapkota S., Khan A., et al.: A correlation among the COVID-19 spread, particulate matters, and angiotensin-converting enzyme 2: a review. Journal of Environmental and Public Health. 2021, DOI: 10.1155/2021/5524098.

[24] Kurz C., Orthofer R., Sturm P., Kaiser A., Uhrner U., Reifeltshammer R., et al.: Projection of the air quality in Vienna between 2005 and 2020 for NO2 and PM10. Urban Climate. 2014, 10, 703–719, DOI: 10.1016/j.uclim.2014.03.008.

[25] Li J. Q., Wu G., Zou N.: Investigation of the impacts of signal timing on vehicle emissions at an isolated intersection. Transportation Research Part D: Transport and Environment. 2011, 16(5), 409–414, DOI: 10.1016/j.trd.2011.03.004.

[26] Ly H-B., Le T-T., Le L.M., Tran V.Q., Le V.M., Vu H-L.T., et al.: Development of an AI model to measure traffic air pollution from multisensor and weather data. Sensors. 2019, 19(22), 4941, DOI: 10.3390/s19224941.

[27] Madrazo J., Clappier A., Cuesta O., Belalcázar L.C., González Y., Bolufé J., et al.: Evidence of traffic-generated air pollution in Havana. Atmosphere. 2019, 32(1), 15–24, DOI: 10.20937/atm.2019.32.01.02.

[28] Mar T.F., Larson T.V., Stier R.A., Claiborn C., Koenig J.Q.: An analysis of the association between respiratory symptoms in subjects with asthma and daily air pollution in Spokane, Washington. Inhalation toxicology. 2004, 16(13), 809–815, DOI: 10.1080/08958370490506646.

[29] Milojević S., Savić S., Marić D., Stopka O., Krstić B., Stojanović B.: Correlation between emission and combustion characteristics with the compression ratio and fuel injection timing in tribologically optimized diesel engine. Tehnicki Vjesnik. 2022, 29(4), 1210–1219, DOI: 10.17559/TV-20211220232130.

[30] Mustafa M.A., Vougias S.: Analysis of pollutant emissions and concentrations at urban intersections. Compendium of Technical Papers, ITE, 63rd Annual Meeting. Institute of Transportation Engineers (ITE). The Hague, Netherlands, 1993.

[31] Pandian S., Gokhale S., Ghoshal A.K.: Evaluating effects of traffic and vehicle characteristics on vehicular emissions near traffic intersections. Transportation Research Part D: Transport and Environment. 2009, 14(3), 180–196, DOI: 10.1016/j.trd.2008.12.001.

[32] PCE Instruments. 2023. Particle Counter PCE-PCO 2. https://www.pce-instruments.com/eu/measuring-instruments/test-meters/particle-counter-pce-instruments-particle-counter-pce-pco-2-det_5971826.htm?fbclid=IwAR1SySCoscUC1cGJcqzWQZvnZYTfTI_a3dl3DdwXG_cHKuOae-JISHBXaDoA (accessed on 6.11.2023).

[33] Pokrývková J., Jurík Ľ.: Development of emission to air in central Europe. Journal of ecological engineering. 2019, 20(2), 51–57, DOI: 10.12911/22998993/94955.

[34] Prospero J.M., Lamb P.J.: African droughts and dust transport to the Caribbean: Climate change implications. Science. 2003, 302(5647), 1024–1027, DOI: 10.1126/science.1089915.

[35] Qu H., Lu X., Liu L., Ye Y.: Effects of traffic and urban parks on PM10 and PM2. 5 mass concentrations. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2023, 45(2), 5635–5647, DOI: 10.1080/15567036.2019.1672833.

[36] Rievaj V., Stopka O., Vrabel J., Mokrickova L., Schmidt C.: The impact of air resistance on the fuel consumption in real conditions within the transport operation. Communications - Scientific Letters of the University of Zilina. 2016, 18(2), 57–61.

[37] Roorda-Knape M.C., Janssen N.A., De Hartog J.J., Van Vliet P.H., Harssema H., Brunekreef B.: Air pollution from traffic in city districts near major motorways. Atmospheric Environment. 1998, 32(11), 1921–1930, DOI: 10.1016/S1352-2310(97)00496-2.

[38] Santos G.: Road transport and CO2 emissions: What are the challenges?. Transport Policy. 2017, 59, 71–74, DOI: 10.1016/j.tranpol.2017.06.007.

[39] Shancita I., Masjuki H.H., Kalam M.A., Fattah I.R., Rashed M.M., Rashedul H.K.: A review on idling reduction strategies to improve fuel economy and reduce exhaust emissions of transport vehicles. Energy conversion and management. 2014, 88, 794–807, DOI: 10.1016/j.enconman.2014.09.036.

[40] Schibuola L., Tambani C.: Indoor environmental quality classification of school environments by monitoring PM and CO2 concentration levels. Atmospheric Pollution Research. 2020, 11(2), 332–342, DOI: 10.1016/j.apr.2019.11.006.

[41] Schneider I.L., Teixeira E.C., Dotto G.L., Pinto D., Yang C.X., Silva L.F.: Geochemical study of submicron particulate matter (PM1) in a metropolitan area. Geoscience Frontiers. 2022, 13(1), 101130, DOI: 10.1016/j.gsf.2020.12.011.

[42] Sicard P., Agathokleous E., De Marco A., Paoletti E., Calatayud V.: Urban population exposure to air pollution in Europe over the last decades. Environmental Sciences Europe. 2021, 33(1), 1–12, DOI: 10.1186/s12302-020-00450-2.

[43] Singh V., Singh S., Biswal A., Kesarkar A.P., Mor S., Ravindra K.: Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India. Environmental Pollution. 2020, 266, 115368, DOI: 10.1016/j.envpol.2020.115368.

[44] Skrúcaný T., Kendra M., Stopka O., Milojević S., Figlus,T., Csiszár C.: Impact of the electric mobility implementation on the greenhouse gases production in central European countries. Sustainability. 2019, 11(18), 4948, DOI: 10.3390/su11184948.

[45] Skrúcaný T., Kendra M., Čechovič T., Majerník F., Pečman J.: Assessing the Energy Intensity and Greenhouse Gas Emissions of the Traffic Services in a Selected Region. LOGI – Scientific Journal on Transport and Logistics. 2021, 12(1), 25–35, DOI: 10.2478/logi-2021-0003.

[46] Slovak hydrometeorological institute. https://www.shmu.sk/File/oko/vystrahy/nove/1579130025_zakladne_vseobecne_informacie_smogu_pm10_.pdf (acessed on 16.01.2023).

[47] Sun J., Huang L., Liao H., Li J., Hu J.: Impacts of regional transport on particulate matter pollution in China: a review of methods and results. Current Pollution Reports. 2017, 3(3), 182–191, DOI: 10.1007/s40726-017-0065-5.

[48] Tan Y., Wang H., Zhu B., Zhao T., Shi S., Liu A., et al.: The interaction between black carbon and planetary boundary layer in the Yangtze River Delta from 2015 to 2020: Why O3 didn't decline so significantly as PM2. 5. Environmental Research. 2022, 214, 114095, DOI: 10.1016/j.envres.2022.114095.

[49] Tomar G., Nagpure A.S., Kumar V., Jain Y.: High resolution vehicular exhaust and non-exhaust emission analysis of urban-rural district of India. Science of The Total Environment. 2022, 805, 150255, DOI: 10.1016/j.scitotenv.2021.150255.

[50] Turner M.C., Andersen Z.J., Baccarelli A., Diver W.R., Gapstur S.M., Pope III C.A., et al.: Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. CA: a cancer journal for clinicians. 2020, 70(6), 460–479, DOI: 10.3322/caac.21632.

[51] Van Fan Y., Perry S., Klemeš J.J., Lee C.T.: A review on air emissions assessment: Transportation. Journal of cleaner production. 2018, 194, 673–684, DOI: 10.1016/j.jclepro.2018.05.151.

[52] Várhelyi A.: The effects of small roundabouts on emissions and fuel consumption: a case study. Transportation Research Part D: Transport and Environment. 2002, 7(1), 65–71, DOI: 10.1016/S1361-9209(01)00011-6.

[53] Vasconcelos L., Silva A.B., Seco Á.M., Fernandes P., Coelho M.C.: Turboroundabouts: multicriterion assessment of intersection capacity, safety, and emissions. Transportation research record. 2014, 2402(1), 28–37, DOI: 10.3141/2402-04.

[54] Waked A., Afif C.: Emissions of air pollutants from road transport in Lebanon and other countries in the Middle East region. Atmospheric Environment. 2012, 61, 446–452, DOI: 10.1016/j.atmosenv.2012.07.064.

[55] Wang H., Tan Y., Zhang L., Shen L., Zhao T., Dai Q., et al.: Characteristics of air quality in different climatic zones of China during the COVID-19 lockdown. Atmospheric pollution research. 2021, 12(12), 101247, DOI: 10.1016/j.apr.2021.101247.

[56] Xu S., Zou B., Lin Y., Zhao X., Li S., Hu C.: Strategies of method selection for fine-scale PM 2.5 mapping in an intra-urban area using crowdsourced monitoring. Atmospheric measurement techniques. 2019, 12(5), 2933–2948, DOI: 10.5194/amt-12-2933-2019.

[57] Zeng Y., Bi C., Jia J., Deng L., Chen Z.: Impact of intensive land use on heavy metal concentrations and ecological risks in an urbanized river network of Shanghai. Ecological Indicators. 2020, 116, 106501, DOI: 10.1016/j.ecolind.2020.106501.