ABSTRACT

The pandemic caused by the coronavirus COVID-19 is having a worldwide impact that affects health, economy and air pollution in cities indirectly. In Slovenia, as well as in all other countries, the number of cases of infected people increased continually in 2020, which affected the health system and caused movement restrictions, which, in turn, affected the air pollution in the country. This article presents the indirect effect produced by this pandemic on air pollution in Maribor, Slovenia. Traffic and air quality data were used to perform the evaluation, in particular PM$_{10}$ and PM$_{2.5}$ daily concentrations from the monitoring station in Maribor. By observing the detailed traffic data and particulate matter concentrations acquired in the Maribor city centre before and during the pandemic times, we show the influence of COVID-19 on particulate matter concentrations in that part of the town. The results show slightly lower particulate matter concentrations, which could be explained by the significantly lower traffic volume values in the lockdown months.

KEYWORDS
PM$_{10}$, PM$_{2.5}$, COVID-19, traffic, particulate matter.

1. INTRODUCTION

Air pollution has become a critical threat to the environment, as well as a cause of serious threats to human health. About 80% of people in urban areas are exposed to air pollution exceeding the air quality standard value set by the World Health Organization (WHO), and 98% of cities in low-middle income countries and 56% in high income countries do not meet the WHO guidelines [1]. Particulate matter with a diameter less than 10 µm (PM$_{10}$) can cause serious health problems due to its small size. Particles of this type can penetrate deep into the lungs, and impose significant risks to the respiratory and cardiovascular systems [2]. Although the sensitivity of individuals may vary with their general health and age, high concentrations of PM$_{10}$ affect the whole population. According to EU legislation [3], the concentration of PM$_{10}$ particles should not exceed 50 µg/m$^3$ more than 35 times in a year, while guidelines for protecting human health are even stricter, by recommending an annual mean value of 20 µg/m$^3$ [4]. However, despite the successful legislation, a large part of Europe’s and the world’s population is, unfortunately, still breathing air with pollution levels that exceed the Air Quality Guidelines as defined by the WHO [5].

Coronaviruses are a diverse group of viruses infecting many different animals, and they can cause mild to severe respiratory infections in humans. In 2002 and 2012, respectively, two highly pathogenic coronaviruses with zoonotic origin, Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV) and Middle East Respiratory Syndrome Coronavirus (MERS-CoV), emerged in humans, and caused fatal respiratory illness, making the emerging coronaviruses a new public health concern in the twenty-first century [6]. At the end of 2019 and at the beginning of 2020 the world was hit by the novel coronavirus, designated as Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) [7]. SARS-CoV-2 emerged in the city of Wuhan, China,
and caused an outbreak of unusual viral pneumonia. Being a highly pathogenic, transmittable and invasive pneumococcal disease, this novel coronavirus disease 2019 (COVID-19), spread all over the world fast [8, 9].

COVID-19 was first reported in Slovenia on 4 March 2020. To prevent its propagation, the Slovenian government immediately declared a state of health emergency [10]. A set of rapid and strict countermeasures were taken, including locking down cities, limiting the population’s mobility, and prohibiting almost all avoidable activities. Also, in March 2020, a world pandemic was declared by the WHO [11]. At that time, all Slovenian cities were locked down, and the majority of industrial and commercial companies were forced to stop their activities until further notice. The same restrictions were made for citizens; the authorities requested them to stay at home and not to leave it except for very specific reasons.

Due to all the mentioned restrictions, it was expected that the COVID-19 outbreak would play a significant role in air pollution. PM_{10} concentrations, in general, have an influence on the air quality. Bad air quality, especially PM_{10} particles, imposes significant risks to human health and the well-being of individuals in general [12]. In this paper, we show the influence of COVID-19 on PM_{10} concentrations in the Maribor city centre before and during the pandemic times. The acquired data were observed using the visualisation and analytics tool for multi-dimensional data presented in [13]. From the obtained results we can suggest various adjustments and modifications in that part of town to reduce PM_{10} concentrations and, thereby, improve residents’ health [14].

The remaining part of the paper is organised as follows. In Section 2, the related work is presented, while Section 3 contains a description of data capturing, data and the used methods. Section 4 presents the obtained results. After the discussion in Section 5, the paper’s conclusion is given in Section 6.

2. RELATED WORK

In recent months, the interrelationship between COVID-19 and the environment has been an emerging research topic. There has been a flood of papers on the topic of COVID-19 in connection with environmental degradation, air pollution, climate/meteorological factors and temperature [15]. Wang and Su reported a significant reduction of air pollution due to the full or partial lockdown in the short run, but the study does not support the reduction of greenhouse gas emissions (GHG) in the long run [16]. In [17] the authors present the improvement of air quality, breaches and reduced noise levels because of COVID-19, and GHG reduction in a shorter time period. Saadat et al. reported the improvement of air and water quality worldwide, but, on the other hand, the generation of a large amount of medical waste [18].

The authors in [19, 20] presented the significant influence of average and minimum temperatures, as well as the air quality, on COVID-19 transmissions. Sahin presented a positive correlation between wind and COVID-19 cases in Turkey [21]. Qi et al. and Gupta et al. showed the notable negative influence of temperature and humidity on daily cases of COVID-19, while, in the US, the prediction of COVID-19 transmissions by temperature and humidity is possible [22, 23]. Sobral et al. presented that countries that have higher rainfall experienced an increase in COVID-19 transmissions [24].

Abdullah et al. found a significant influence of the movement control order in Malaysia on the reduction of particulate matters, especially PM_{2.5} [25]. Authors from Rio de Janeiro, Brazil and Barcelona, Spain, reported CO reduction during the lockdown period, and, in parallel with the mentioned reduction, there was also a decrease in NO\textsubscript{2} and PM_{10} [26]. While CO, NO\textsubscript{2} and PM_{10} have decreased, O\textsubscript{3} increased by more than 50% during the lockdown [27]. An air pollution reduction by 30% and mobility reduction by 90% during COVID-19 lockdowns have been reported by Muhammad et al. [28]. In the major cities of central China, the source of the new SARS-CoV-2, the concentrations of PM_{2.5}, PM_{10}, SO\textsubscript{2}, CO and NO\textsubscript{2} reduced by 30.1%, 40.5%, 33.4%, 27.9% and 61.4%, respectively, during the COVID-19 lockdown [29]. Moreover, Jain and Sharma stated that the maximum reduction happened in the case of PM_{2.5} in most regions in India. The concentrations of PM_{2.5}, PM_{10} and NO\textsubscript{2} declined by 41%, 52% and 28%, respectively, in six megacities in India [30]. Bacak and Toros [31] showed that, in the months with restrictions in Istanbul and Ankara, PM_{10} concentrations decreased due to the lack of use of vehicles, industrial activities and fuel consumption. The lack of car transportation in Krakow, Poland, led to the recognition that the latter is responsible for up to 20% of the PM_{10} carbon fraction concentrations [32]. The study presented in article [33] investigated the concentrations of the air.
3. METHODOLOGY

3.1 Data capturing

The data used in the presented study were acquired using a monitoring system that was established in 2013 as part of the PMinter project. The monitoring station was located in the Maribor city centre (direction west-east, as shown in Figure 1). It was around 6 m from the centre of the road (a straight one way street (no intersections), a two lane road) [14].

PM$_{10}$ concentrations were measured using laser aerosol spectrometry. A laser with a 660 nm wavelength was used according to the EN 12341 standard. The device delivered particle counts in 31 size channels, and was able to conduct measurements in the range from 0.1 to 10,000 µg/m$^3$. The data were gathered continuously from 01.01.2013, with the exception of short intervals (a maximum of 2-3 weeks per year) due to the maintenance and calibration work conducted on the sensory system. On average, the temporal resolution of the system was 1 minute [14].

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3.2 Data

In addition to particulate matter (PM$_{2.5}$ and PM$_{10}$), the sensory system measured traffic volume data simultaneously, using induction loops installed within the roadway. The presence of a vehicle and its speed were measured using inductance footprints obtained with the inductive loops, and...
the data were aggregated with a 15 min temporal resolution (i.e. by counting the number of vehicles and estimating their average speed). In each road lane there were two induction loops, and the speed of the vehicle was determined by the matching imprint of the induced voltage and the time it took the vehicle to travel from one loop to the other. Finally, the acquired data were combined with weather data using a 1 hour temporal resolution. The weather data include measurements of wind direction, atmospheric pressure, wind speed, rainfall, ambient temperature and relative humidity [14]. A description of the captured data, used units, and the ranges of collected data are presented in Table 1. In total, 78,840 hourly measurements were used in the present study (excluding leap years and maintenance). Of these, 6,864 hourly measurements were in the time of lockdown periods (the first lockdown was from 12.03.2020 to 14.05.2020 and the second one was from 18.10.2020 to 31.05.2021 [11]).

### Table 1 – Description of captured data

| Measured parameter     | Units      | Range          |
|------------------------|------------|----------------|
| PM$_{2.5}$             | µg/m$^3$   | [1.8, 128.4]   |
| PM$_{10}$              | µg/m$^3$   | [2.3, 160.5]   |
| Vehicle speed          | km/h       | [2, 69]        |
| Traffic volume         | vehicles/day | [69, 12583]  |
| Wind direction         | °          | [0, 360]       |
| Wind speed             | m/s        | [0, 8.4]       |
| Atmospheric pressure   | hPA        | [943.5, 1011.4] |
| Rainfall               | mm         | [0, 44.9]      |
| Ambient temperature    | °C         | [-15.3, 41.4]  |
| Relative humidity      | %          | [15.5, 97.9]   |

3.3 Analytics tool

Every empirical study requires proper data preparation for further examination and knowledge discovery. In the presented case, the data were structured in a spreadsheet, where each row represents an individual entry, which is treated as a multi-dimensional point, while the number of columns represents the dimension of the point [13]. As the tool serves for the observation of all kinds of data, the dimensionality of the point depends strictly on the data themselves (e.g. if the observed data have 10 different attributes, the dimensionality would be 10, whereas, on the other hand, if the data have 150 different attributes, the dimensionality of a point will be 150). In the presented article, each measured value (from PM$_{2.5}$ to relative humidity) serves as a separate dimension. In some cases it is possible that data have too many dimensions (again, it depends on the data themselves). Dimensionality reduction using principal component analysis was performed to get only a small number of important dimensions. This was achieved by mapping data to the new space, where the dimensions were arranged according to the maximal dispersion of data, from those with the largest to the smallest ones [38]. In the next, final step of data preparation, the mapped data were clustered hierarchically into clusters on different levels (see Figure 2). At the lowest level, the multi-dimensional points were compared and clustered by distance. When we determined clusters to all points, the second level of the hierarchy was created, where the clusters from the first level were grouped to the larger clusters by the same criteria as before. The highest level of hierarchy was a single cluster that contained all the data in the dataset.

![Figure 2 – a) the whole cluster hierarchy of the observed data, b) randomly selected cluster](image-url)
By clustering, similar/related data are united in individual clusters, meaning that the data captured in specific conditions (e.g., rainy weather, different seasons of the year) were gathered in one place. The statistics presented in the continuation can be applied, and new knowledge can be discovered in the clusters.

Data prepared in the described way are ready for visualisation and further analysis. In Figure 2a the visualisation of the whole cluster hierarchy is presented (a different colour means a different value of the measured particulate matter), including a box with the basic statistics, while Figure 2b shows the randomly selected cluster from the third level of the hierarchy. In both cases in Figure 2 the centre of the circular data displays the cluster at the highest level (the one that contains all the data from the input dataset). The more we move from the centre towards the edge of the circle, the lower we go in the cluster hierarchy. The individual multi-dimensional points are presented on the edge of the circle. The presented tool includes a great number of statistics and metrics (the average value, median, maximum frequency of individual value, variance, standard deviation, minimum and maximal values, Pearson and Spearman correlations, the distance correlation, the randomised dependence coefficient, the maximal information coefficient, skewness and kurtosis, the P value and the Fisher test), filtering data by individual variables or their values, and calculation of their probability density function [13]. Some of these functionalities can be seen in Figure 3, such as a network representation of the correlations between dimensions (measured values), where the dependent variable (PM$_{10}$) is coloured in yellow, while the blue nodes represent explanatory variables that are connected directly to the dependent one. The edges between the nodes indicate the correlations, where the green colour represents a positive, and red a negative correlation. The intensity of the colour (green or red) represents the value of the correlation (less intense means less correlation, and vice versa). In Table 2 some statistics/metrics about the data used in this paper are shown. All the presented metrics, such as correlations, were calculated according to the dependent variable (the dependent variable, in

![Figure 3 – Network representation of the correlations between variables](image)

| Attribute name       | Mean   | Median | Mode | Variance | Std.  | Min   | Max   | Pearson | Spearman | dCor |
|----------------------|--------|--------|------|----------|-------|-------|-------|---------|----------|------|
| Traffic              | 340.41 | 380.19 | 415.5 | 9522.3   | 97.58 | 17.25 | 519.71 | 0.05    | 0.03     | 0.08 |
| Speed                | 32.58  | 30.42  | 28.92 | 21.82    | 4.67  | 18.63 | 43.0  | -0.01   | 0.0      | 0.06 |
| Wind speed           | 1.26   | 1.2    | 1.03  | 0.25     | 0.5   | 0.08  | 3.56  | -0.37   | -0.37    | 0.38 |
| Wind direction       | 209.48 | 209.06 | 216.54 | 2172.74 | 46.61 | 42.17 | 336.38 | -0.34   | -0.33    | 0.32 |
| Ambient temperature  | 11.64  | 12.26  | 6.67  | 63.9     | 7.99  | -7.2  | 30.63 | -0.41   | -0.36    | 0.46 |
| Relative humidity    | 73.8   | 74.19  | 66.79 | 173.41   | 13.17 | 35.48 | 101.75| 0.21    | 0.17     | 0.24 |
| Rainfall             | 0.12   | 0.0    | 0.0   | 0.1      | 0.31  | 0.0   | 3.61  | -0.21   | -0.29    | 0.26 |
| Atmospheric pressure | 985.48 | 985.44 | 984.4 | 53.7     | 7.33  | 948.18 | 1007.05| 0.19    | 0.16     | 0.22 |
two lockdown periods occurred in Maribor, and in Slovenia in general. The first lockdown period was from 12.03.2020 to 14.05.2020, and the second one started on 18.10.2020 and continued into 2021, where, on 31.05.2021, the pandemic was suspended.

Figures 6 and 7 show the PM$_{10}$ and PM$_{2.5}$ concentrations only in the lockdown months. For the period from 2013 to 2019 the average value of the average monthly concentrations was used, while the monthly average values were used for the years 2020 and 2021 (when both lockdowns occurred). In all the observed lockdown months, the particulate matter concentrations were lower than the seven-year average. Months such as March, April and May in 2020 are the period of the first lockdown, while other months (October, November and December in 2020 and January, February, March, April and May in 2021) are the months of the second lockdown.

Figure 8 represents the comparison of yearly average values of PM$_{10}$ and PM$_{2.5}$ from 01.01.2013 to 31.12.2021.

![Figure 4](image-url)  
*Figure 4 – Average monthly PM$_{10}$ concentrations from 01.01.2013 until 31.12.2021*

![Figure 5](image-url)  
*Figure 5 – Average monthly PM$_{2.5}$ concentrations from 01.01.2013 until 31.12.2021*
Figure 6 – Average monthly PM$_{10}$ concentrations during the lockdown months (in 2020 and 2021) in comparison to the average monthly concentrations for the period from 2013 to 2019

Figure 7 – Average monthly PM$_{2.5}$ concentrations during the lockdown months (in 2020 and 2021) in comparison to the average monthly concentrations for the period from 2013 to 2019

Figure 8 – Comparison of the yearly average PM$_{2.5}$ and PM$_{10}$ concentrations
assume that the reason behind this is global warming (higher winter temperatures), as presented by Scheinhardt et al. [50], and another one is the more frequent use of electric cars and cars with lower exhaust emissions [51]. Another assumption is that there are also more and more houses with new/better thermal insulation and more efficient heating systems (also minor use due to better insulation) [52]. Additionally, the graphs in Figures 6 and 7 also confirm the already mentioned findings from Figures 4, 5 and 8, that there was a descending trend of particulate matter concentrations in the city of Maribor, Slovenia.

As already mentioned in the previous Section, in Figure 9 we can observe some deviations in traffic volume in 2020 and 2021. We speculate that there were two main reasons for such behaviour. On the one hand it was a consequence of the lockdowns (the whole country was closed, meaning most of the industry, schools, public transport and many more) due to the COVID-19 pandemic. We can see lower values in March, April and also May for the year 2020 as an effect of the first lockdown, and decreased values in October, November and December in 2020 and January, February, March and April in 2021 due to the second lockdown. The lack of traffic due to lockdowns has also been presented by Bacak and Toros [31] and Zareba and Danek [32] in Istanbul, Ankara and Krakow. On the other hand, we have some months in 2020 with increased traffic volume, such as February, and the whole time between both lockdowns (June, July, August and September in 2020). The similar can also be observed in 2021 from May onwards. We speculated that the main reason behind those higher traffic volume values was the closure of Koroška cesta in the city centre of Maribor. Due to this closure the traffic was rearranged in the city of Maribor, and part of its traffic was directed to other streets.
it was led past the PM$_{10}$ and PM$_{2.5}$ concentrations measuring station. By taking this fact into account, closure of the road also means more traffic in lockdowns near the measuring station, and consequently, higher particulate matter values than there were without the road closure. As mentioned before, there are no outstanding average monthly values in PM$_{10}$ and PM$_{2.5}$ concentrations in Figures 4 and 5, but we observed lower traffic volumes in the lockdown months (Figure 9). The difference comes as a consequence of people staying at home during lockdowns and producing more particulate matter with heating systems (notably in the winter months).

The results also show that the closure of the Koroška cesta had an impact on the traffic past the measuring station, but it does not solve the traffic problem in the city centre. High monthly traffic volumes also indicate the need for necessary change in traffic volumes, which can be achieved by means such as restrictions for the old vehicles in the city centre and increased use of public transport.

In the case of the closure of public life due to COVID-19 restrictions we had special circumstances where traffic decreased, and we were able to observe the impact of this decrease on air quality. Usually, it is impossible to carry out such experiments in reality, but now we were offered the opportunity to observe the impact of lower traffic on air quality. The results show lower values of PM$_{10}$ and PM$_{2.5}$ due to traffic reduction, but, on the other hand, people were staying at home during the heating season, and there was more pollution from that type of pollutant. We can also observe that the limitation of the traffic on days with high pollution could not be the right solution to reduce PM$_{10}$ and PM$_{2.5}$ concentrations, as there are also other pollutant groups in Maribor centre and nearby surroundings, such as industry, heating and natural sources. This can also be observed in Table 2, as the Pearson correlation coefficient with particulate matter is only 0.05.

6. CONCLUSION

The influence of COVID-19 on air quality, especially particulate matter, in the city of Maribor, Slovenia, is presented in this paper. By processing, analysing and investigating the data captured from the beginning of 2013 until the end of 2021, we came to some general conclusions and, most importantly, conclusions that relate to the last year of observed data. We found out about the influence of COVID-19 on particulate matter concentrations in the observed city, and came to the following conclusions:

- there is the trend of decreasing particulate matter concentrations since the beginning of the measurements,
- the closure of Koroška cesta had a significant impact on the increased traffic past the measuring station,
- PM$_{10}$ and PM$_{2.5}$ concentrations decreased during the COVID-19 lockowns.

According to the results, the used visualisation and analytics tools are suitable for new in-depth research and knowledge discovery. The future directions of this work are aimed at extending the measurements used in this research with additional data, and then repeating the used approach to discover interesting new findings.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support from the Slovenian Research Agency (Research Core Funding No. P2-0041 and Project No. L2-1826). At the 19th European Transport Congress “European Green Deal Challenges and Solutions for Mobility and Logistics in Cities” held in Maribor, October 2021, by the European Platform for Transport Sciences (EPTS), the scientific chair chose the best-presented papers for publishing in extended form in the journal Promet – Traffic&Transportation.

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VPLIV COVID-19 NA KONCENTRACIJE PRAŠNIH DELCEV V SREDNJE VELIKEM MESTU

POVZETEK

Pandemija, ki jo je povzročil koronavirus COVID-19, ima posledice po vsem svetu in posredno vpliva na zdravje, gospodarstvo ter onesnaženost zraka v mestih. Tako v Sloveniji kot tudi v vseh ostalih državah je število primerov okaženih v letu 2020 nenahno naraščalo. Vse to je...
vplivalo na zdravstveni sistem in povzročilo omejitve gibanja ter posledično vplivalo na onesnaženost zraka v državi. Ta članek predstavlja posredni učinek omenjene pandemije na onesnaženost zraka v Mariboru, v Sloveniji. V raziskavi so bili uporabljeni podatki o prometu in kakovosti zraka, predvsem dnevne koncentracije PM$_{10}$ in PM$_{2.5}$ z merilne postaje v Mariboru. Z opazovanjem podrobnih podatkov o prometu in koncentracijah prašnih delcev, pridobljenih v središču Maribora pred in med pandemijo, prikažemo vpliv COVID-19 na koncentracije prašnih delcev v tem delu mesta. Rezultati kažejo nekoliko nižje koncentracije trdnih delcev, kar bi lahko razložili z bistveno nižjimi vrednostmi obsega prometa v mesecih popolnega zaprtja države.

**KLJUČNE BESEDE**
PM$_{10}$- PM$_{2.5}$; COVID-19; promet; prašni delci.

**REFERENCES**

1. WHO. WHO global urban ambient air pollution database. World Health Organization; 2016.
2. Loomis D, et al. The carcinogenicity of outdoor air pollution. *Lancet Oncology.* 2013;14(13): 1262-1263. doi: 10.1016/s1470-2045(13)70487-x.
3. Marco G, Bo X. Air quality legislation and standards in the European union: Background, status and public participation. *Advances in Climate Change Research.* 2013;4(1): 50-59. doi: 10.3724/SP.J.1248.2013.050.
4. WHO. Air quality guidelines: Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization; 2006.
5. Guerreiro CBB, Foltescu V, De Leeuw F. Air quality status and trends in Europe. *Atmospheric Environment.* 2014;98(1): 376-384. doi: 10.1016/j.atmosenv.2014.09.017.
6. Cui J, Li F, Shi ZL. Origin and evolution of pathogenic coronaviruses. *Nature Reviews Microbiology.* 2019;17(3): 181-192. https://www.nature.com/articles/s41579-018-0118-9.
7. Hu B, Guo H, Zhou P, Shi ZL. Characteristics of SARS-CoV-2 and COVID-19. *Nature Reviews Microbiology.* 2021;19(3): 141-154. https://www.nature.com/articles/s41579-020-00459-7.
8. Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: A modelling study. *The Lancet.* 2020;395(10225): 689-697. doi: 10.1016/S0140-6736(20)30260-9.
9. Hui DS, et al. The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health - The latest 2019 novel coronavirus outbreak in Wuhan, China. *International Journal of Infectious Diseases.* 2020;91(1): 264-266. doi: 10.1016/j.ijid.2020.01.009.
10. Vodičar PM, et al. Low prevalence of active COVID-19 in Slovenia: A nationwide population study of a probability-based sample. *Clinical Microbiology and Infection.* 2020;26(11): 1514-1519. doi: 10.1016/j.cmi.2020.07.013.
11. WHO. Coronavirus disease 2019 (COVID-19): Situation report. World Health Organization, 2020.
12. Fajersztajn L, Veras M, Barrozo LV, Saldiva P. Air pollution: A potentially modifiable risk factor for lung cancer. *Nature Reviews Cancer.* 2013;13(9): 674-678. https://www.nature.com/articles/nrc3572.
13. Jesenko D, et al. Visualization and analytics tool for multi-dimensional data. *Proceedings of the 2018 International Conference on Big Data and Education.* 2018;1(1): 1-5.
14. Lešnik U, Mongus D, Jesenko D. Predictive analytics of PM10 concentration levels using detailed traffic data. *Transportation Research Part D: Transport and Environment.* 2018;67(1): 131-141. doi: 10.1016/j.trd.2018.11.015.
15. Shakil MH, Munim ZH, Tasnia M, Sarowar S. COVID-19 and the environment: A critical review and research agenda. *Science of the Total Environment.* 2020;745(1): 138915. doi: 10.1016/j.scitotenv.2020.138915.
16. Wang Q, Su M. A preliminary assessment of the impact of COVID-19 on environment - A case study of China. *Science of the Total Environment.* 2020;728(1): 138813. doi: 10.1016/j.scitotenv.2020.138813.
17. Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L. Indirect effects of COVID-19 on the environment. *Science of the Total Environment.* 2020;728(1): 138813. doi: 10.1016/j.scitotenv.2020.138813.
18. Saadat S, Rawtani D, Hussain CM. Environmental perspective of COVID-19. *Science of the Total Environment.* 2020;728(1): 138870. doi: 10.1016/j.scitotenv.2020.138870.
19. Bashir MF, et al. Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Science of the Total Environment.* 2020;728(1): 138835. doi: 10.1016/j.scitotenv.2020.138835.
20. Tosepu R, et al. Correlation between weather and Covid-19 pandemic in Jakarta, Indonesia. *Science of the Total Environment.* 2020;725(1): 138436. doi: 10.1016/j.scitotenv.2020.138436.
21. Sahin M. Impact of weather on COVID-19 pandemic in Turkey. *Science of the Total Environment.* 2020;728(1): 138810. doi: 10.1016/j.scitotenv.2020.138810.
22. Qi H, et al. COVID-19 transmission in Mainland China is associated with temperature and humidity: A time-series analysis. *Science of the Total Environment.* 2020;728(1): 138778. doi: 10.1016/j.scitotenv.2020.138778.
23. Gupta S, Raghuwanshi GS, Chanda A. Effect of weather on COVID-19 spread in the US: A prediction model for India in 2020. *Science of the Total Environment.* 2020;728(1): 138860. doi: 10.1016/j.scitotenv.2020.138860.
24. Sobral MFF, et al. Association between climate variables and global transmission of SARS-CoV-2. *Science of the Total Environment.* 2020;729(1): 138997. doi: 10.1016/j.scitotenv.2020.138997.
25. Abdullah S, et al. Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic. *Science of the Total Environment.* 2020;729(1): 139022. doi: 10.1016/j.scitotenv.2020.139022.
[26] Dantas G, et al. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Science of the Total Environment. 2020;729(1): 139085. doi: 10.1016/j.scitotenv.2020.139085.

[27] Tobias A, et al. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Science of the Total Environment. 2020;726(1): 138540. doi: 10.1016/j.scitotenv.2020.138540.

[28] Muhammad S, Long X, Salman M. COVID-19 pandemic and environmental pollution: A blessing in disguise? Science of the Total Environment. 2020;728(1): 138820. doi: 10.1016/j.scitotenv.2020.138820.

[29] Xu K, et al. Impact of the COVID-19 event on air quality in Central China. Aerosol and Air Quality Research. 2020;20(5): 915-929. doi: 10.4209/aqr.2020.04.0150.

[30] Jain S, Sharma T. Social and travel lockdown impact considering coronavirus disease (COVID-19) on air quality in megacities of India: Present benefits, future challenges, and way forward. Aerosol and Air Quality Research. 2020;20(6): 1222-1236. doi: 10.4209/aqr.2020.04.0171.

[31] Bacak TN, Toros H. Impact of the COVID-19 event on PM10 air pollution in Istanbul and Ankara. Journal of Research in Atmospheric Science. 2021;3(1): 1-7.

[32] Zareba M, Danek T. Analysis of air pollution migration during COVID-19 lockdown in Krakow, Poland. Aerosol and Air Quality Research. 2022;22(3): 1-22. doi: org/10.4209/aqr.210275.

[33] Alharbi BH, Alhazmi HA, Alhafsheer ZM. Air quality of work, residential, and traffic areas during the COVID-19 lockdown with insights to improve air quality. International Journal of Environmental Research and Public Health. 2022;19(2): 727-744. doi: 10.3390/ijerph19020727.

[34] Shukla S, et al. Appraisal of COVID-19 lockdown and unlocking effects on the air quality of North India. Environmental Research. 2022;204(1): 112107. doi: 10.1016/j.envres.2021.112107.

[35] Rojano R, Arregoces H, Frias EG. Changes in ambient particulate matter during the COVID-19 and associations with biomass burning and Sahara dust in northern Colombia. Heliyon. 2021;7(12): e08595. doi: 10.1016/j.heliyon.2021.e08595.

[36] Tekin OF. Evaluation of air pollutants (PM10 and SO2) in the first year of the COVID-19: A city sample from Turkey. World Journal of Advanced Research and Reviews. 2021;10(1): 41-47. doi: 10.30574/wjarr.2021.10.0130.

[37] Al-Hemoud A, et al. PM2.5 and PM10 during COVID-19 lockdown in Kuwait: Mixed effect of dust and meteorological covariates. Environmental Challenges. 2021;5(1): 100215. doi: 10.1016/j.envch.2021.100215.

[38] Abdi H, Williams LJ. Principal component analysis. Wiley Interdisciplinary Reviews: Computational Statistics. 2010;2(4): 433-459. doi: 10.1002/wics.101.

[39] Lukač N, Žalik B. Fast approximate k-nearest neighbors search using GPGPU. GPU Computing and Applications. 2015;2(1): 221-234. doi: 10.1007/978-981-287-134-3_14.

[40] Papanastasiou DK, Melas D, Kioutsioukis I. Development and assessment of neural network and multiple regression models in order to predict PM10 levels in a medium-sized Mediterranean city. Water, Air, and Soil Pollution. 2007;182(1): 325-334. doi: 10.1007/s11270-007-9341-0.

[41] Nagendra SM, Khare M. Artificial neural network based line source models for vehicular exhaust emission predictions of an urban roadway. Transportation Research Part D: Transport and Environment. 2004;9(3): 199-208. doi: 10.1016/j.trd.2004.01.002.

[42] Cai M, Yin Y, Xie M. Prediction of hourly air pollutant concentrations near urban arterials using artificial neural network approach. Transportation Research Part D: Transport and Environment. 2009;14(1): 32-41. doi: 10.1016/j.trd.2008.10.004.

[43] Hooyberghs J, et al. A neural network forecast for daily average PM10 concentrations in Belgium. Atmospheric Environment. 2005;39(18): 3279-3289. doi: 10.1016/j.atmosenv.2005.01.050.

[44] Grivas G, Chaloulakou A. Artificial neural network models for prediction of PM10 hourly concentrations, in the Greater Area of Athens, Greece. Atmospheric Environment. 2006;40(7): 1216-1229. doi: 10.1016/j.atmosenv.2005.10.036.

[45] Stadlober E, Hörmann S, Pfeiler B. Quality and performance of a PM10 daily forecasting model. Atmospheric Environment. 2008;42(6): 1098-1109. doi: 10.1016/j.atmosenv.2007.10.073.

[46] Hörmann S, Pfeiler B, Stadlober E. Analysis and prediction of particulate matter PM10 for the winter season in Graz. Austrian Journal of Statistics. 2005;34(4): 307-326. https://graz.pure.elsevier.com/en/publications/analysis-and-prediction-of-particulate-matter-pm10-for-the-winter.

[47] Barmpadimos I, et al. Influence of meteorology on PM 10 trends and variability in Switzerland from 1991 to 2008. Atmospheric Chemistry and Physics. 2011;11(4): 1813-1835. doi: 10.5194/acp-11-1813-2011.

[48] Hoi KL, Yuen KV, Mok KM. Prediction of daily averaged PM10 concentrations by statistical time-varying model. Atmospheric Environment. 2009;43(16): 2579-2581. doi: 10.1016/j.atmosenv.2009.02.020.

[49] Schnelle-Kreis J, et al. Impact of wood combustion on urban PM10 concentration. EGU General Assembly Conference Abstracts. 2009;1(1): 2965. https://meetingorganizer.copernicus.org/EGU2009/EGU2009-2965-1.pdf.

[50] Scheinhardt S, et al. Comprehensive chemical characterisation of size-segregated PM10 in Dresden and estimation of changes due to global warming. Atmospheric Environment. 2013;75(1): 365-373. doi: 10.1016/j.atmosenv.2013.04.059.

[51] Beddows DC, Harrison RM. PM10 and PM2.5 emission factors for non-exhaust particles from road vehicles: Dependence upon vehicle mass and implications for battery electric vehicles. Atmospheric Environment. 2021;244(1): 117886. doi: 10.1016/j.atmosenv.2020.117886.

[52] Gvero P, Radić R, Kotur M, Kardaš D. Urban air pollution caused by the emission of PM10 from the small household devices and abatement measures. Thermal Science. 2018;22(6 Part A): 2325-2333. doi: 10.2298/TSCL180119152G.