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Influence of Traffic Flow and Meteorological Conditions on Air Pollution – A Case Study

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ABSTRACT

In this paper, the influence of traffic flow volume and meteorological conditions on carbon monoxide (CO), particulate matter (PM), ozone (O3) and sulphur dioxide (SO2) concertation is determined based on the measurements conducted at a selected location over a 784-hour period. Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA) were applied to the data set. Regression analysis was also used to determine trends in pollutant concentrations as a function of traffic flow and meteorological parameters. Analysis of the obtained data indicates a statistically significant relationship between traffic volume and meteorological parameters on the one hand and pollutants on the other. However, increase in the value of certain input variables does not necessarily result in the increase in pollutant concentration. CO and O3 showed a significant dependence on the number of vehicles, while for SO2 the influence of commercial vehicles was greater than that of passenger cars. The relationship between the number of vehicles and PM was not evident at the study site.

KEYWORDS

traffic flow; meteorological parameters; carbon monoxide; particulate matter; ozone; sulphur dioxide.

1. INTRODUCTION

For many decades, human activities have induced excessive air pollution with adverse impacts on both the environment and human health. Global emission levels are rising rapidly and are expected to increase by more than 100% by 2050 [1, 2]. Although pollutant emissions arise from diverse sources, transport remains a highly dominant contributor to air pollution and is the only sector in which emissions have continued to rise since 1990 [3]. During 2016, in the European Union (EU), almost 27% of the total greenhouse gas (GHG) emissions was attributed to the transport sector, marking an increase of 26% and 3% compared to 1990 and 2015, respectively [4]. This issue is further exacerbated by the continued increase in the number of vehicles, although the growth rate is slower than in the past. According to the estimates provided by Keller [5], the number of passenger and freight vehicles in 2035 will be 20% greater than in 2010.

Although CO2 comprises the greatest amount of vehicle emissions, other air pollutants such as carbon monoxide (CO), hydrocarbons (HCS), nitrogen oxides (NOk), sulphur dioxide (SO2), etc. are also harmful, as they are precursors of the secondary formations of ozone (O3) and particulate matter (PM2.5) in the air [6]. Thus, PM, O3, CO, SOx, NOk and lead are recognised by the World Health Organisation (WHO) as the six main pollutants [7], which coincides with the results published by Kim [8]. It can be noticed that the pollutants isolated by the WHO are precisely those that occur as a result of vehicle emissions.

On the other hand, pollutants such as PM, CO, SOx, NOk, occur as a consequence of incomplete combustion of different fuels of heating devices in residential buildings and other facilities [9, 10]. Heating in residential buildings is one of the key sources of harmful pollutants in urban areas, especially in the winter period [11]. Solid fuels, which include wood and coal, and which are used for heating, are distinguished as the most dangerous pollutants [12–14].

As strategies aimed at reducing air pollution need to target the main sources of pollutants, EU has already published regulations on the acceptable concentrations of air pollutants which have been adopted both within the EU and nationally [15]. At the same time, every country can independently determine the permissible pollutant levels, which must not exceed the stipulated global framework. Therefore, continuous monitoring of the pollutant concentration in the air is required.

Based on these principles, the present study measured the concentrations of certain pollutants (CO, PM, O3 and SO2) and established a relationship between the measured values of the pollutants, the volume of traffic and the meteorological conditions. The aim of this paper was to follow the concentration of pollutants during the winter period, i.e. the heating season, because the effect of heating on air pollution is also expected. By establishing the relationship between pollutants and traffic, and taking into account the meteorological conditions during this period, it will be possible to determine whether traffic in the area under study has a primary influence on the emission of pollutants.

2. LITERATURE REVIEW

The main air pollutants (CO, PM, O_3 and SO_2) are caused to a greater or lesser extent by vehicle emissions [16] and have been linked to a variety of diseases. For example, O_3 and PM concentration in many cities in developed countries are sufficiently high to evoke certain health risks [6]. According to the WHO report, 4.2 million premature deaths occurred in 2016 across the globe due to exposure to air pollution [17]. However, even prolonged exposure to lower concentrations of pollutants exerts a number of negative effects on the population's health [18, 19]. While the association between different pollutants and the increased number of hospitalisations and mortality has been established, such epidemiological studies are usually conducted in urban areas where vehicles are the primary air pollution sources [7, 20]. Indeed, research conducted in seven Brazilian cities has shown that approximately 5% of the annual deaths from respiratory diseases in individuals aged over 65 and under 5 years can be linked to traffic-related pollutants [20, 21]. The significant influence of air pollution on respiratory problems was also established in other parts of the world [22, 23]. In particular, exposure to traffic has been shown to compromise the lung function in children [24, 25]. In a number of epidemiological studies, pollutants were also linked to cardiovascular disease [26−28]. For example, Khajavi et al. [29] demonstrated a significant influence of air pollutants on cardiovascular disease-related deaths in Iran, while Zhao et al. [30] reported a positive connection between pollution and mortality due to cardiovascular causes in China. Moreover, Yang et al. [31] established a connection between harmful PM levels and hypertension in Chinese adults. It is also noteworthy that the International Agency for Research on Cancer (IARC) has estimated that certain air pollutants, especially emissions from diesel and petrol vehicle engines, are carcinogenic to humans [8], and that evidence linking certain airborne pollutants to human cancer is growing [7, 32]. Air contamination can also affect the central nervous system and lead to skin diseases, eye irritation and allergies [7].

Emissions from vehicles are particularly harmful because they are emitted at the ground layer, facilitating their direct inhalation. As the traffic network is an indispensable part of urban planning, research is increasingly focusing on the measures to control and reduce the level of emissions [33, 34]. Habermann et al. [20] drew a general conclusion that there is a significant relationship between pollutant concentration and traffic. At the same time, it was not specified between which pollutants and traffic a connection was found. As a part of research conducted in the city of Bangalore, India, during 1998, Harish [35] identified traffic as the main source of CO. During several months of research in the Nigerian city of Benin, traffic was also identified as the main CO generator [36]. Kho et al. [37] found a strong relationship between CO levels and the number of vehicles at all research locations. Researchers in Delhi have shown that passenger cars and two-wheelers are the most significant contributors to CO concentrations [38]. Hama et al. [39] found that about 80−90% of NO_x and CO concentrations in Delhi come from the transport sector. As a part of their work, Abbass et al. [40] investigated car commuters' exposure to PM, NO_2 and CO while Yang et al. [41] examined PM and CO concentrations in an urban area in China. Kim and Guldmann [42] similarly analysed the influence of traffic flows on CO, SO_2, NO_2, O_3 and PM concentrations in Seoul, Korea.

On the other hand, several researchers focused on the meteorological conditions and demonstrated their significant impact on pollutant concentrations. According to Li et al., who conducted their research in northeast

China, while the temperature was the main factor influencing air pollution, it was also affected by wind direction [43]. Reiminger et al. [44] examined the effect of wind speed and temperature variation on the pollutant levels behind noise barriers. The influence of wind on air pollution was also examined by other researchers [42, 45–49]. According to Kalisa et al., temperature variation exerts a significant influence of the O_3, PM and NO_2 levels in different urban and rural Birmingham locations [49]. Influence of relative humidity and temperature on air pollutant concentrations was the subject of Jayamurugan et al.'s study [50], whereas Vujić et al. [51] developed a model for predicting mean daily PM concentrations based on meteorological parameters and other pertinent data.

Similar to the research in this paper, Azharia et al. took into account traffic and certain meteorological parameters in their research in Malaysia [52]. The results of their research showed that the concentration of pollutants increases with the number of vehicles, while the influence of relative humidity, wind speed and temperature on the concentration of pollutants is noticeable. Quang Ngo et al. determined the concentration of CO and PM as a function of traffic volume in the area of Hanoi, Vietnam, taking into account wind speed, wind direction and temperature [53]. In contrast to these studies, Akinosho et al. developed a model to predict PM concentration using meteorological parameters and traffic flow as input data [54]. As a part of their investigation, Zalakeviciute et al. [55] examined the impact of air humidity on daily average PM concentrations in urban locations in Quito characterised by intensive traffic.

On the other hand, the expected influence of the traffic flow on the pollutant emission in certain meteorological conditions may be absent, due to the strong influence of some other sources of emission at the research location.

Research conducted by Kubica et al. in Austria showed that the concentration of certain pollutants is dominantly influenced by stationary combustion [56]. In rural China, as a consequence of reliance on solid fuels for heating and cooking [10, 57], emissions of harmful pollutants, PM in particular, is high [58]. Mahmoud et al. [10] similarly found in their research that where coal and wood are mostly used in heating systems, their combustion emits most CO. According to the data published by Hua et al. [9], the highest PM emissions result from the use of coal. As a result of burning primarily coal, PM, CO, SO_2, NO_x and O_3 emissions in China are well above the global average [59, 60]. The influence of residential heating on the emission of pollutants was also examined by many other researchers [61–65].

In sum, extant evidence points to the adverse influence of traffic and meteorological conditions on air pollution. However, most of the research in this domain is based on the average annual daily traffic, rather than on the real traffic load for the researched period, and the total traffic flow is rarely segregated into passenger cars and trucks [20]. These shortcomings have motivated the present study as a part of which passenger cars and commercial vehicles were precisely recorded as a part of the traffic flow measurement at a particular location, at which meteorological conditions and CO, O_3, PM and SO_2 emissions were also captured simultaneously.

3. METHODOLOGY

During the continuous 784-hour research period which spanned from 6:00 p.m. on 5 November to 6:00 p.m. on 8 December, traffic flow, the basic meteorological parameters – temperature (TEMP), atmospheric pressure (AP), the intensity of solar radiation (ISR), relative humidity (RH), wind speed (WiSp) and wind direction (WiDi) – and the concentration of individual pollutants (CO, O_3, PM and SO_2) were recorded in digital form. SO_2 concentration was not recorded in the 784-hour interval, but the data were obtained for a 597-hour interval. Meteorological parameters and pollutants were measured by a mobile measuring station, owned by the Government of the Brčko District of Bosnia and Herzegovina, the Department for Spatial Planning and Property Legal Affairs. The mobile measuring station consists of an analyser (APMA-370, APNA-370, APSA-370, APOA-370 and F-701-20) and auxiliary units. These devices enable the measurement of all meteorological parameters (AP, ISR, RH, TEMP, WiDi and WiSp) and pollutant (CO, O_3, PM and SO_2) concentrations of interest for the present investigation.

When recording the daily traffic flows, a digital camera was utilised, aiming to establish its intensity and structure, as well as any unevenness. Vehicles were divided into passenger cars and commercial vehicles (light, medium and heavy commercial vehicles, road train and buses).

MANOVA (Multivariate Analysis of Variance) and ANOVA (Analysis of Variance) were used to determine the pollutant concentration trends depending on the traffic flow volume and meteorological parameters. MANOVA was also used to test the dependence of PC, CV, AP, ISR, RH, TEMP, WiDi, and WiSp (V_i, i=1,2,3,4,5,6,7,8) as a group on CO, O_3, PM and SO_2 as the output variables. The resulting dependence indicates the global influence of all input variables, while it is unknown what influence each individual variable has on the observed criterion output variable. The output variables were categorised, that is, their values were divided into intervals (*Table 1*). The lowest and highest measured values of each variable were taken into account and, in relation to these values, the division was made into three equal intervals. The lowest measured pollutant concentrations are in the first interval. The middle values of the pollutant concentrations are in the second interval, while the highest measured values are in the third interval. In the subsequent analyses, the aim was to ascertain whether there is a statistically significant difference between the three value intervals of input variables V_i in relation to the group of output variables.

Table 1 – Categorical variables

Interval	CO	PM	O_3	SO_2
a	[1.22–2.00)	[0.40; 61.70)	[2.40; 19.40)	[7.90; 81.80)
b	[2.00–2.78)	[61.7–123)	[19.40; 36.30)	[81.80; 155.60)
c	[2.78–3.57]	[123–184.3]	[36.30; 53.30]	[155.60; 229.50]

In the next stage of analysis, ANOVA was performed to determine the individual influence of each input variable on each output variable. Tukey HSD multiple comparison test with 95% confidence interval (CI) was used to determine whether each individual variable belongs to a specific interval.

Regression analysis also showed a correlation between the hourly average values of vehicle numbers (PC and CV) and air pollutants (CO, PM, O_3 and SO_2).

3.1 Study location

The research described here was conducted in a specific area of the City of Brčko, Bosnia and Herzegovina, for the purposes of a doctoral dissertation [66]. Brčko is located in the northeaster, lowland part of Bosnia and Herzegovina, on the banks of the Sava River. This city is characterised by an extremely favourable geographical position because it represents an important land, river and railway connection between Bosnia and Herzegovina and Croatia, i.e. the junction to the EU. Its design is monocentric, whereby almost all administrative, trading and major attractions are located at the city centre. The position of the border crossing with the Republic of Croatia and the position of the international port on the Sava River and the railway belonging to the wider central zone further complicate the traffic situation. During the survey period, the transit traffic was routed through the main roads of the city.

The Fifth Primary School (44°52’24.8”N, 18°47’26.3”E) was chosen as the research location as it is situated in the residential zone of Brčko intended exclusively for individual single-storey housing, and is characterised by intensive traffic flows during the day. Thus, not only is pollutant dispersion unhindered, all households rely on coal and wood for heating, which also contributes to the emission of harmful pollutants in the winter period. The emissions, which are the consequence of household heating systems, result in a high concentration of harmful pollutants on the ground level [56], which also relates to traffic.

4. RESULTS

The statistical data related to the measured meteorological parameters, traffic flows and pollutant concentrations are shown in *Table 2*.

The traffic flow in the studied area can be broadly segregated into daily and night periods, with peak and non-peak. Moreover, discrepancies between Sunday and other days of the week can be noted. When the recorded traffic flow was examined by vehicle type, the participation of passenger cars emerged as dominant, ranging from 90% to 97%. Meteorological parameters also varied throughout the day as well as week. For example, temperature was the highest on Thursdays and Fridays, and between 12:00 p.m. and 6:00 p.m. Unexpectedly, variations in atmospheric pressure did not follow temperature trends, while RH was inversely related to temperature. There was a markedly high variability in daily as well as hourly wind speed. The traffic flow values (PC and CV) in relation to the concentration of each individual pollutant are shown in *Figures 1–4*. *Figure 4* clearly shows the period in which no SO_2 data was recorded.

Table 2 – Descriptive statistics of input and output variables

Variable	*n*	Mean	Sd	Median	Trimmed	MAD	Min	Max	Range	Skew	Kurtosis	SE
PC	784	406.8	302.9	395.0	393.0	307.0	7.0	962.0	955.0	0.1	-1.6	10.82
CV	784	31.7	25.9	22.0	22.9	16.0	0	106.0	106.0	0.8	-0.5	0.93
AP	784	1,007.1	5.8	1,0	1,006.3	4.0	996.4	1,020	23.6	0.4	-0.7	0.21
ISR	784	42.8	72.2	6.9	6.9	0.9	5.2	409.9	404.7	2.6	6.8	2.58
RH	784	92.3	10.7	98.4	98.3	1.5	42.9	99.9	57.0	-1.7	2.5	0.38
TEMP	784	7.3	5.0	6.4	6.4	3.2	-2.1	22.8	25.0	0.5	-0.2	0.18
WiDi	784	164.7	91.9	116.6	117.3	43.7	6.9	358.5	351.6	0.5	-1.3	3.28
WiSp	784	1.2	0.7	1	1.0	0.5	0.2	3.6	3.5	0.7	-0.2	0.02
CO	784	1.7	0.4	1.6	1.6	0.2	1.2	3.6	2.4	1.9	3.5	0.01
PM	784	47.5	30.9	39.5	39.7	16.2	0.7	184.3	183.6	1.4	2.0	1.10
O_3	784	16.8	12.1	12.2	12.2	5.6	2.4	53.3	50.9	1.1	0.3	0.43
SO_2	597	30.3	25.4	21.6	21.6	8.2	7.9	229.5	221.6	2.7	9.5	1.04

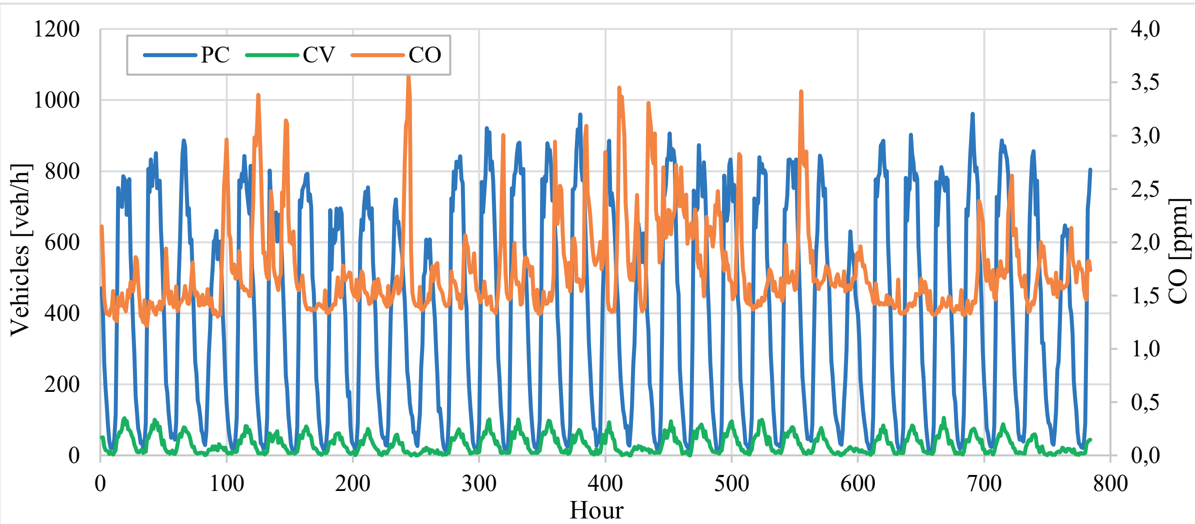

Figure 1 – The relationship between the number of vehicles (PC and CV) and CO

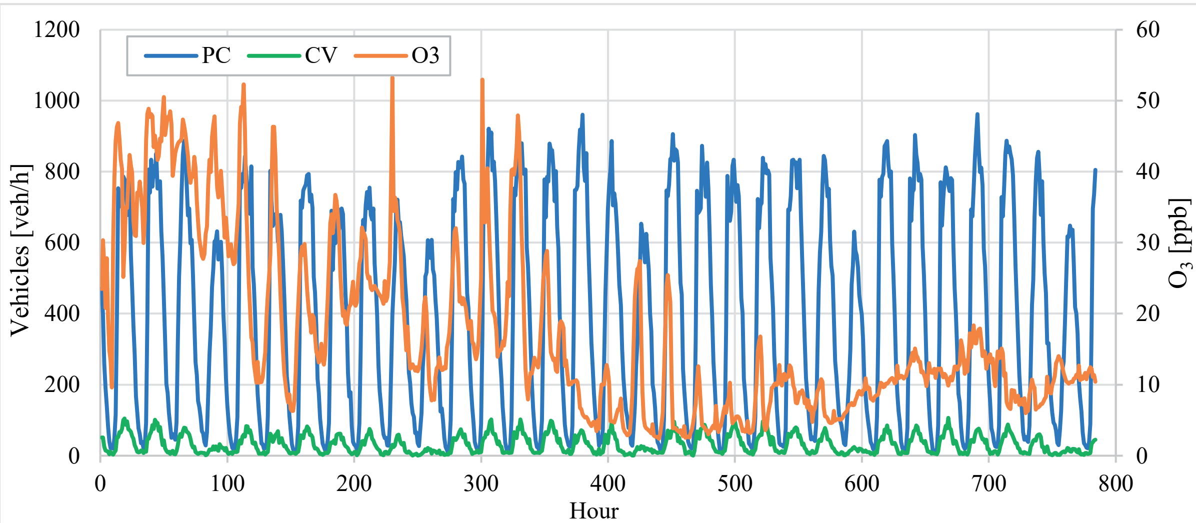

Figure 2 – The relationship between the number of vehicles (PC and CV) and O_3

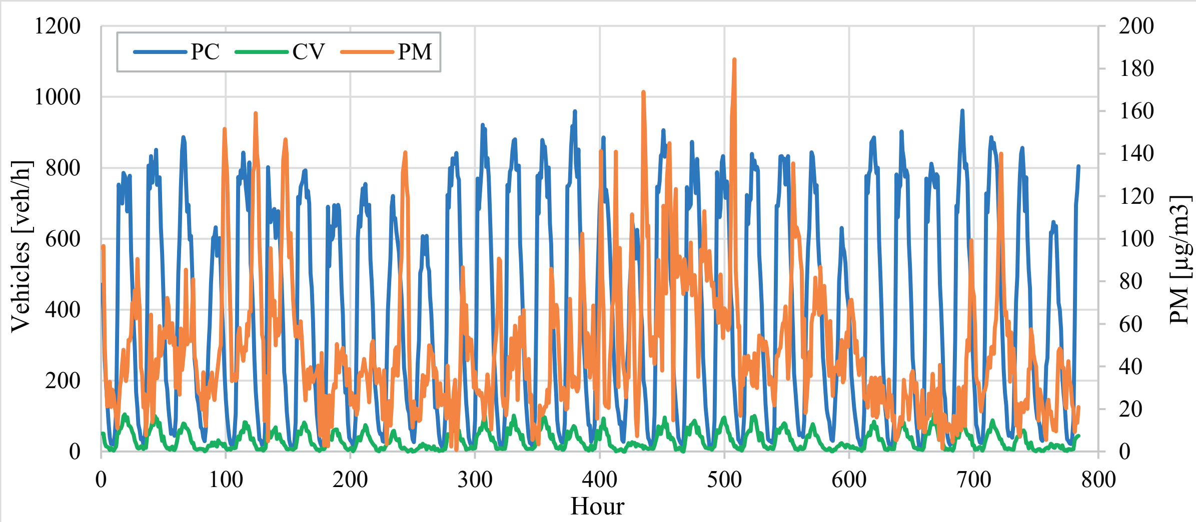

Figure 3 – The relationship between the number of vehicles (PC and CV) and PM

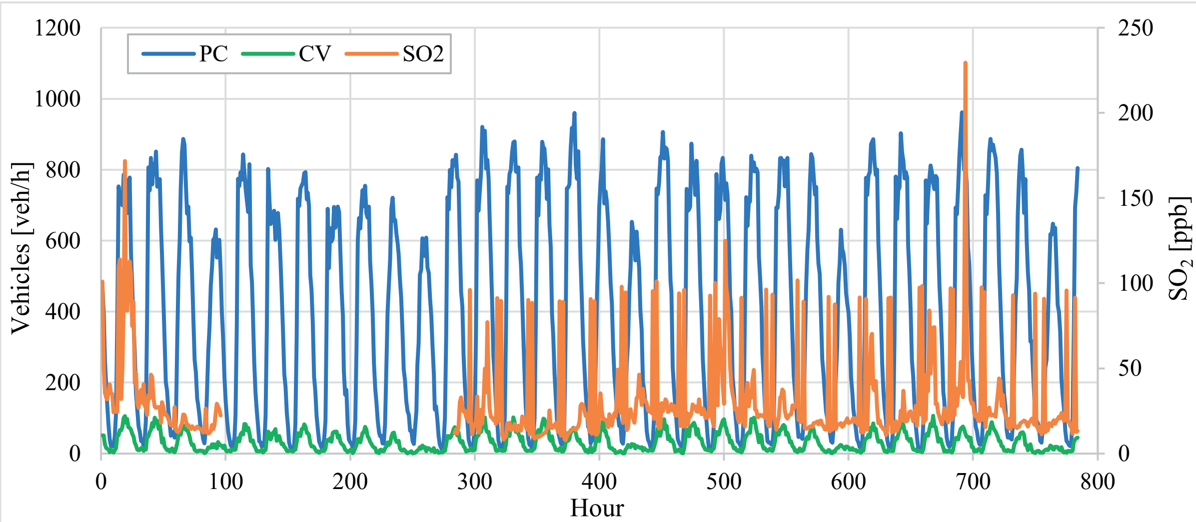

Figure 4 – The relationship between the number of vehicles (PC and CV) and SO_2

4.1 MANOVA and ANOVA results

Table 3 shows the MANOVA test results, indicating that for each output variable there is a statistically significant difference between certain intervals. The best results were obtained for the variable O_3 with F=49.80 and Pr(>F) <2.2e-16, while similar values were obtained for other variables: F=16.93 and Pr(>F)<2.2e-16 for CO; F=13.17 and Pr(>F)<2.2e-16 for PM and F=11.79 and Pr(>F)<2.2e-16 for SO_2. The most important thing to note is that there is a statistically significant difference between certain intervals for all variables with significance codes p<0.001. The MANOVA test showed that the level of each of output variable in the air differs significantly by concentration, observed in relation to the group of variables V_i.

Table 3 –MANOVA Results

MANOVA test	Df	Pillai	F value	Num df	Den df	Pr(>F)
CO	3	0.4429	16.93	24	2,346	<2.2e-16
PM	3	0.3562	13.17	24	2,346	2.2e-16
O_3	3	1.0125	49.80	24	2,346	<2.2e-16
SO_2	3	0.3229	11.79	24	2,346	<2.2e-16

Table 4 shows the ANOVA results. Unlike the MANOVA test, which looks at the dependence on a group of variables, the ANOVA uses a single dependent variable for its tests on a single continuous variable to find the difference in means. A higher F-value of the ANOVA test indicates greater variation between the sample means relative to the variation within the samples. In addition, an increase in the F-value results in a decrease in the p-value. From the results presented, it can be seen that a good statistical significance was obtained between the output variable CO and the meteorological parameters, while the statistical significance was lower when observed in relation to PC and CV. An identical conclusion can be drawn for the output variable PM. It is noticeable that not all meteorological parameters have the same influence on PM, as the statistical significance obtained between PM and temperature and PM and WiDi is slightly lower than other meteorological parameters.

Table 4 –ANOVA Results

ANOVA test	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
CO vs. PC	1	1,148,318	1,148,318	12.71	0.000387
CO vs.CV	1	11,682	11,682	17.73	2.85e-05
CO vs. AP	1	3,802	3,802	133.00	<2e-16
CO vs. ISR	1	92,868	92,868	15.49	9.02e-05
CO vs. RH	3	9,871	3,290	23.47	1.43e-14
CO vs. TEMP	3	1,886	628.80	25.09	1.59e-15
CO vs. WiDi	3	378,863	126,288	15.85	5.11e-10
CO vs. WiSp	3	65.30	21.766	57.81	<2e-16
PM vs. PC	3	729,952	243,317	2.66	0.0474
PM vs.CV	3	7,234	2,411.30	3.55	0.0142
PM vs. AP	3	142,463	47,488	43.41	<2e-16
PM vs. ISR	3	238,000	79,333	12.54	5.09e-08
PM vs. RH	3	8,842	2,947.30	20.83	5.25e-13
PM vs. TEMP	3	889	296.30	11.27	3.02e-07
PM vs. WiDi	3	182,844	60,948	7.42	6.61e-05
PM vs. WiSp	3	39.80	13.28	32.54	<2e-16
O_3 vs. PC	3	1,739,547	579,849	6.42	0.000269
O_3 vs.CV	3	21,347	7,116	10.77	6.14e-07
O_3 vs. AP	3	144,267	48,089	44.05	<2e-16
O_3 vs. ISR	3	580,745	193,582	32.80	<2e-16
O_3 vs. RH	3	47,463	15,821	169.10	<2e-16
O_3 vs. TEMP	3	14,751	4,917	540.40	<2e-16
O_3 vs. WiDi	3	140,189	46,730	5.65	0.000779
O_3 vs. WiSp	3	114,096	38.03	8.70	2.469e-09
SO_2 vs. PC	3	1,612,562	537,521	5.94	0.000524
SO_2 vs.CV	3	10,846	3,615	5.36	0.00117
SO_2 vs. AP	3	14,535	4,845	3.87	0.00919
SO_2 vs. ISR	3	31,991	10,664	1.62	0.183
SO_2 vs. RH	3	2,724	908.1	6.09	0.000423
SO_2 vs. TEMP	3	2,293	764.2	31.12	<2e-16
SO_2 vs. WiDi	3	66,529	22,176	2.65	0.0476
SO_2 vs. WiSp	3	0.30	0.09	0.21	0.891

There is a statistically significant difference between O_3 and all input variables, but the statistical significance is slightly lower for PC and WiDi. When comparing the values of SO_2 concentration with the values of the input variables, a good statistical significance was shown only for temperature. Observing the output variables in relation to each individual input variable, it can be seen that the results obtained show statistically significant differences in the concentration of pollutants CO, PM, O_3 and SO_2 between the observed intervals in relation to the variable Vi with significance codes $p<0.05$, except SO_2 vs. WiSp and SO_2 vs. ISR.

Table 5 shows the influence of the input single variables V_i on the output categorical variables.

Table 5 – Differences of values between intervals according to the corresponding categorical variable

Categorical variable	Interval	PC	CV	AP	ISR	RH	TEMP	WiDi	WiSp
O_3	b–a	+	0.21	0.30	+	+	+	+	+
	c–a	+	+	0.41	+	+	+	+	+
	c–b	0.62	+	0.99	0.09	+	+	0.75	+
CO	b–a	+	0.08	0.19	+	+	+	+	+
	c–a	+	+	0.82	+	+	+	+	+
	c–b	0.41	0.19	0.99	0.65	0.96	0.88	0.99	0.66
PM	b–a	0.29	0.60	0.35	0.89	+	+	+	+
	c–a	0.09	0.07	0.92	0.28	+	0.12	0.20	+
	c–b	0.51	0.30	0.99	0.52	0.26	0.99	0.99	0.15
SO_2	b–a	+	0.41	0.99	0.32	0.93	0.92	0.73	0.68
	c–a	0.32	+	0.99	0.88	0.06	0.17	0.93	0.46
	c–b	0.08	+	0.99	0.72	0.09	0.14	0.98	0.93

From *Table 5* it can be seen that all meteorological parameters except AP have a statistically significant influence on CO and O_3 concentrations. For CO concentration, no statistical significance was found for the difference between intervals c and b for any input variable. The results also indicate that there is no statistically significant difference between intervals c and b in the value of O_3 concentration for the variables PC, ISR and WiDi. Meteorological parameters have no influence on the level of SO_2 concentration, while statistical significance between meteorological parameters and PM concentration was shown only for some meteorological parameters and not for all groups. A statistically significant difference in PM concentration was found only between the intervals b and a in relation to the variables RH, TEMP, WiDi and WiSp, whereas there was a significant difference between the intervals c and a for the variables RH and WiSp.

In most cases, the increase in the number of vehicles (PC and CV) is accompanied by an increase in the concentrations of O_3 and CO, except in certain cases. The statistical significance between the number of PCs and the CO concentration is significantly higher than the statistical significance between the number of CVs and the CO concentration. Higher values in both groups of vehicles do not follow an increase in CO concentration. The increase in the number of PCs and CVs does not follow the increase in PM concentration for any interval. The increase in the number of commercial vehicles has a statistically significant effect on the increase in SO_2 concentration compared to passenger cars, for which a statistically significant difference was obtained only between the intervals a and b.

4.2 Regression analysis results

Figures 5–8 show the results of the regression analysis with the dependence function and the coefficient of determination. The results show a strong relationship between the number of vehicles (PC and CV) as an independent variable and the dependent variables CO and O_3 with coefficients of determination of 0.7121 and 0.6026 respectively. A moderate relationship was found between the variables number of vehicles (PC and CV) and SO_2 (R^2=0.4146), while a weak relationship was found with PM (R^2=0.2677).

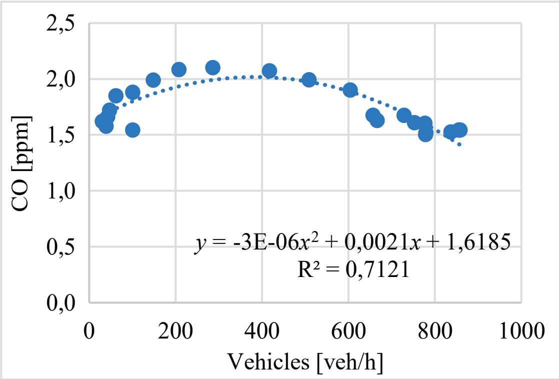

Figure 5 – The correlation between the number of vehicles (PC and CV) and CO

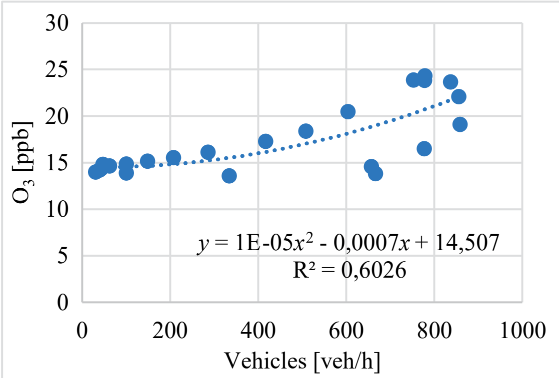

Figure 6 – The correlation between the number of vehicles (PC and CV) and O_3

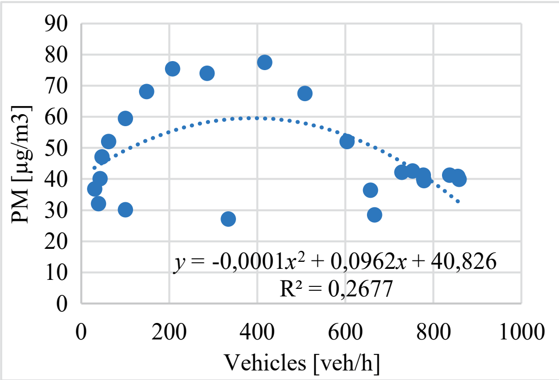

Figure 7 – The correlation between the number of vehicles (PC and CV) and PM

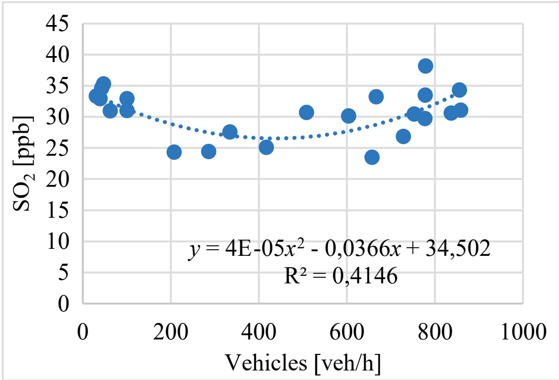

Figure 8 – The correlation between the number of vehicles (PC and CV) and SO_2

5. DISCUSSION

The ANOVA results reported in the preceding section indicate that, in certain cases, the pollutant concentration trend does not follow that observed in the input variables. While air pollution generally trends to be lower during windy weather, this was not the case at research location. In certain locations, the wind direction is dominant, because it has a significant role in the presence of pollutants. The investigated location can be significantly affected by the existence of the Ugljevik thermal power plant, which is considered the biggest PM and SO_2 polluter in the Western Balkans [67]. Similar conclusions were reached by Li et al., who demonstrated that the power plant emissions in Manaus city can travel more than a hundred kilometres southwest and west of its location [60]. Thus, it is not surprising to find that the concentration of all pollutants (except SO_2) at the research location increases with wind speed during almost all studied intervals. The research results reported here further indicate that there is a statistically significant difference between the first two PM intervals in relation to wind speed, concurring with the results obtained by Chaloulakou et al. [68]. They determined that the drop in PM concentration occurs only after the WiSp value exceeds 2 m/s, which coincides with the research in this paper. The same conclusion was reached by Yin et al. [45]. They believe that a strong wind can bring pollution from the surrounding areas because they have determined through research that with an increase in wind speed, the concentration of PM also increases. Research in Shanghai has further shown that the northerly and north-westerly winds in the winter significantly influence the increase in PM concentration [46]. Similar results were obtained by Huang et al. who found that during winter in Shenzhen, northerly and north-easterly winds transport air pollutants from neighbouring cities [69]. According to Alameddine et al., westerly winds result in greater pollutant emissions at the research locations in Beirut, Lebanon [48]. Based on their research in China, Zhang et al. have similarly concluded that wind direction has a significant impact on the CO and O_3 concentration in the air [47]. Kim and Guldmann [42] have also established a relationship between CO, SO_2, NO_2, O_3 and PM and wind direction.

In the present study, a statistically significant difference was observed between the temperature and RH and the concentrations of pollutants CO and O_3 for all intervals, except between intervals b and c for the value of the CO concentration. A direct dependence between O_3 and temperature and RH was also found by Xu et al. during their research [70]. Kayes et al. found a negative correlation between O_3 and RH, while CO is positively correlated with RH [71]. Kalisa et al. [49] showed that examined pollutants increased with increasing temperature and that the highest level of O_3 and PM concentration was during the maximum temperature. Research results by Yin et al. did not show a relationship between PM and temperature, i.e. a negative correlation was obtained between sunshine duration and PM for all seasons [45]. The relationship between PM and temperature in this study was only obtained for the first interval and it was also shown that the increase in temperature and RH had no effect on the increase in PM. On the other hand, Zalakeviciute et al. [55] showed a positive correlation between daily average PM concentration and relative humidity in urban locations of Quito with intensive traffic. The influence of meteorological parameters on SO_2 at the studied location in this paper is not statistically significant. In their research, Kayes et al. have shown that the concentration of SO_2 increases with increasing temperature [71].

Similar trends to those established in the present study were noted in other research. For example, research conducted in Tehran indicates that vehicles contribute to the total amount of CO in the air by 98.7% [72]. Likewise, Kho et al. [37] found strong relationships between CO levels and the number of vehicles at all research locations. Sahanavin et al. [73] determined the influence of heavy diesel vehicle flow (HDVF) on PM in open areas, whereby a decrease in PM concentration was recorded with the increase of these vehicles. Conversely, research on roads in Hanoi has shown that increasing the number of heavy vehicles also increases PM concentrations [53]. According to the estimates provided by Gulia et al., in the Delhi and Mumbai areas, vehicles contribute to SO2 and PM emissions by 5−12% and 3−12%, respectively [74]. In some European cities, such as Milan, Madrid and Athens, the share of traffic in PM emissions is about 39% [75]. Janssen et al. concluded that traffic flow is positively related to pollutant emissions, but they did not specify those pollutants [76]. The research in this paper shows that the increase in SO_2 concentration is accompanied by an increase in the number of heavy vehicles, which is not the case for passenger cars, while the influence of the number of vehicles on PM concentration was not shown. On the other hand, Jareemit et al. concluded that traffic has a major impact on PM concentration in the Bangkok study area [77].

Still, in communities that rely on wood and coal for heating, stationary combustion is the primary contributor to CO [10] and PM emissions [56, 58]. According to Huang et al., stationary sources contribute to the total SO_2 and PM emissions by 97% and 91%, respectively [61]. In China, residential heating contributed to 38% of CO and 37% of PM emissions at the national level in 2010, and these figures increased to 42% and 40% by 2017 [62]. Peng et al. found that emissions from the residential rural sector accounted for 29% of PM and 26% of CO in the total national emissions of these pollutants in China [63]. Research conducted by Bari et al. in southern Germany similarly indicates that heating residential buildings with wood in the winter is responsible for 59% of the total PM emissions [64]. On the other hand, wood burning in California's winter conditions increases PM emissions by 22% [65].

Thus, the results obtained in this study show that traffic is not the dominant source of pollutant emissions at the selected location for all the pollutants studied. There is a significant relationship between the increase in the number of vehicles and the concentration of CO and O_3, except in certain cases, while it is evident that traffic is not the main source of PM and SO_2. That is not surprising, given that research shows that the role of stationary combustion sources on the level of pollutant concentration is very significant [60]. Apart from this, this location is in an open area, where the dispersion of pollutants is unhindered. Sahanavin et al. [73] concluded in their research that in open areas all variables related to traffic flow indirectly affect PM, while the meteorological conditions have a direct influence. It is also worth noting that the influence of seasonal characteristics generally cannot be observed because the meteorological conditions in a certain region are specific and can vary from country to country [78]. The type of location also matters, as surveys along the route of the same road have shown variations in PM, CO and O3 concentrations [78]. In the study area, presence of many trees and green areas can also affect the pollution levels, given that plants serve as natural air filters (as they absorb CO and toxic substances and release oxygen), and can thus neutralise pollutants [79].

6. CONCLUSION

The analyses presented in this paper confirm the widely held view that establishing connections between the source of emission and harmful pollutants can be rather complex due to the potential influence of many factors, such as meteorological conditions, dispersion of pollutants, the source intensity, household heating, industrial activities etc. [68, 73].

Some studies considered the influence of vehicle numbers on pollutants, some included meteorological parameters, but there are very few studies that measured all parameters at the same time. Many models and simulations used estimates and pre-existing generic data rather than accurately recorded real-time data.

In this paper, the study included meteorological parameters, traffic flow data and pollution data. All data were obtained by simultaneous measurement during a 784 hour period. The aim was to determine the relationship between the number of vehicles and the meteorological conditions on the one hand and the pollutants on the other hand at the researched location. The research site is specific because it is characterised by intensive traffic flows during the day and includes an area where households are heated with wood and coal, which also affects the level of pollution. The research results obtained in this paper imply the existence of more sources of emission, i.e. that traffic is not the only pollutant at the site studied. The increase in the number of vehicles has a significant effect on the concentration of O_3 and CO, with passenger cars having a greater effect on these pollutants than commercial vehicles. Meteorological parameters also show a strong influence on the concentration of O_3 and CO, except in certain cases. Surprising results were obtained for PM, because the existence of a dependence on traffic intensity was not demonstrated. Commercial vehicles have a greater influence on the increase of SO_2 than passenger cars. No statistically significant relationship was found between SO_2 and meteorological parameters. Thus, while traffic is an important source of pollutants, complex meteorological conditions, types of heating fuel and the specific local features, as well as possible chemical reactions in ambient air, also contribute to the measured pollutant concentrations.

In order to protect the primarily human health, and also the environment, it is necessary to continually work on identifying and applying various measures that affect the reduction of emissions of harmful pollutants. First of all, it is necessary to identify the biggest polluters and allocate measures to reduce the emissions they produce. Since transport is not the only one responsible for air pollution and there are different sources of harmful gases emissions and substances, a multidisciplinary approach is requested for finding a solution that would lead to the reduction of pollution.

It would also be beneficial to conduct further studies as a part of which data would be gathered at multiple locations as well as during different seasons, as this would provide a clearer picture of the impact of traffic on the pollution levels.

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Uticaj veličine saobraćajnog toka i meteoroloških uslova na zagađenje vazduha: studija slučaja

Apstrakt

U okviru rada je utvrđen uticaj veličine saobraćajnog toka i meteoroloških uslova na koncentracije ugljen monoksida (CO), PM čestica (PM), ozona (O3) i sumpor-dioksida

(SO_2), na osnovu merenja sprovedenih na odabranoj lokaciji tokom 784-časovnog perioda. Za analizu podataka korišćene su višestruka analiza varijanse (MANOVA) i analiza varijanse (ANOVA). Za određivanje trendova koncentracija zagađujućih materija u funkciji veličine saobraćajnog toka i meteoroloških parametara korišćena je i regresiona analiza. Analiza dobijenih podataka ukazuje na statistički značajan odnos između veličine saobraćajnog toka i meteoroloških parametara sa jedne strane i zagađujućih materija sa druge strane. Međutim, povećanje vrednosti određenih ulaznih promenljivih ne dovodi uvek do povećanja koncentracije zagađivača. Polutanti CO i O_3 su pokazali značajnu zavisnost od broja vozila, dok je uticaj komercijalnih vozila bio veći od uticaja putničkih automobila na SO_2. Veza između broja vozila i PM nije utvrđena na lokaciji istraživanja.

Ključne reči

protok saobraćaja; meteorološki parametri; ugljen monoksid; PM čestice; ozon; sumpor-dioksid