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Impacts of some meteorological parameters on the SO_2 concentrations in the City of Obrenovac, Serbia

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Abstract: In this paper, the impacts of some meteorological parameters on the SO_2 concentrations in the City of Obrenovac are presented. The City of Obrenovac is located in the north-west part of Serbia on the banks of the River Sava. The observed source emission, the power plants TENT A and B are situated on the bank of the Sava River in the vicinity of Obrenovac. During the period from January to November 2006, the concentrations of sulfur dioxide in the air at 4 monitoring sites in Obrenovac were measured. It was noticed that the maximal measured daily concentrations of sulfur dioxide ranged from 1 μg m^{-3} (16th November, 2006) to 98 μg m^{-3} (29th January 2006) and lie under the maximal allowed concentration value according to the Serbian Law on Environmental Protection. The measured sulfur dioxide concentrations mostly showed characteristics usual for a daily acidification sulfur dioxide cycle, excluding the specificities influenced by the measuring site itself. Sulfur dioxide transport was recorded at increased wind speeds, primarily from the southeast direction. Based on the impact of meteorological parameters on the sulfur dioxide concentration, a validation of the monitoring sites was also performed from the aspect of their representivity.

Keywords: sulfur dioxide; correlation; meteorological data; thermal power plant; environment.

INTRODUCTION

Sulfur dioxide (SO_2) is an important trace species in the atmosphere, both under background conditions and in polluted areas.[1] The present concern on the

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increasing level of SO_2 in the troposphere is essentially due to its role in causing environmental issues and posing detrimental effects on human health.[2–8] For instance, sulfate aerosols, through processes of scavenging and acid rain, lead to serious degradation of terrestrial and aquatic ecosystems.[5–10] It can be released into the troposphere as a result of anthropogenic and natural phenomena. The emitted SO_2 is chemically converted to sulfuric acid in the atmosphere, both in the gaseous and aqueous phase.[1] Thus, SO_2 is a major acid rain precursor, and its oxidation product, sulfate, plays an important role in radiative forcing of the climate.[5–10] When these acid rains precipitate, damage is caused to both ecosystems and the environment. The related formation of sulfuric acid aerosols can cause human respiratory morbidity and mortality. Sulfate aerosols have a cooling effect on the Earth's surface (Intergovernmental Panel on Climate Change (IPCC), 2001). These sulfate particles reflect energy coming from the sun, thereby decreasing the amount of sunlight reaching and heating the Earth's surface. The contribution of SO_2 to acidic deposition on terrestrial ecosystems by dry deposition and by precipitation in dissolved forms, such as fogs and clouds, is also clear. When converted into aerosols, it also has an impact on visibility.[9]

Natural sources of air pollution include gaseous emissions, animals and lightning, and gaseous and particulate emissions from volcanic eruptions, soil erosion, wind-blown dust and forest fires.[11]. Anthropogenic sources of air pollution involve combustion of fossil fuels (thermoelectric power plants, motor vehicles, communal and household heating installations), mining operations (sources of fugitive dust emissions), manufacturing processes (metallurgical plants, chemical plants, oil refineries), agricultural activities (crop spraying, burning of crop-residue), *etc*. Anthropogenic emissions of SO_2 occur predominantly at the continental surface and chemical conversion and loss processes occur during transport. Air pollutants are transported in the atmosphere *via* advection and turbulent diffusion processes.

According to Serbian Law on Environmental Protection (Official Gazette of the Republic of Serbia No. 135/04), the emission limit value of the SO_2 concentration into the air is 150 μg m^{-3}.

EXPERIMENTAL

Topological data of the City of Obrenovac and the monitoring sites

The City of Obrenovac is located in the north-west part of Serbia on the banks of the River Sava. The observed sources of pollution, power plants TENT A and B are situated on the bank of the Sava River, 42 km upstream from the Serbian capital Belgrade. They were built in 1970 and produce between 2.2 and 2.5×10^9 kg of coal ash per annum.[1] Approximately 70 % of the total energy production in Serbia is obtained from seven power plants situated near Obrenovac, in the vicinity of coal mines, having a combined installed power of 5766 MW.[1] The coal ash is transported to the dump after being suspended in the water taken from the Sava River, in an approximate ratio 1:10. Hitherto, TENT A has shown itself to be one of the most reliable parts of the Serbian power system, as it provided over 6000 h of work with the full power connected to the power grid. This activity produces air contamination, so a constant control of the pollutants is required.

The daily average values of SO_2 in Obrenovac were calculated using arithmetic averages of the data obtained from four monitoring points. The meteorological data was provided by the Republic Hydro-Meteorological Service of Serbia. Eighty percent of the measured values were used in this study. A map of the monitoring points near TENT A and B is given in Fig. 1.

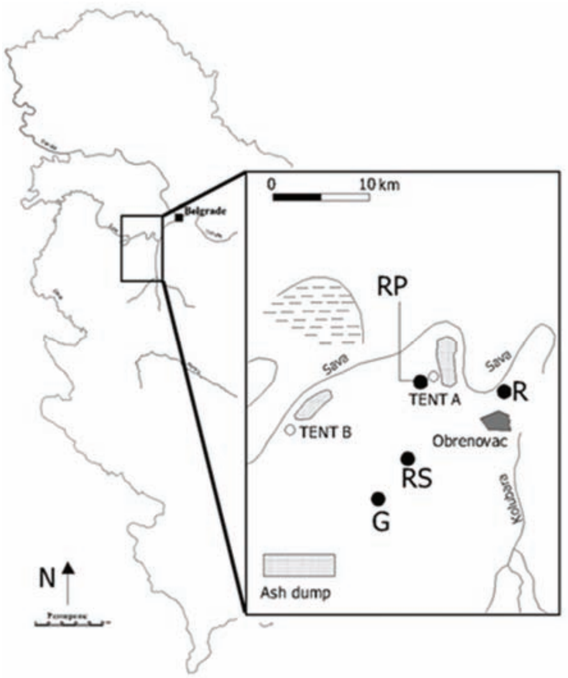


Fig. 1. Monitoring points of sulfur dioxide concentration: R, RS, RP and G located in the vicinity of the power plants TENT A and B. The exact distances are given in Table I. As can be seen, the monitoring points RS and G are located south from TENT A and southeast from TENT B; RP and R are situated east from TENT B while RP is located west from TENT A, R is located east from TENT A.

TABLE I. Distances of the monitoring sites from the SO_2 sources, monitoring method and equipment

Monitoring site	Method of monitoring	Equipment	Distance, km	
			TENT A	TENT B
R	JUS ISO 6767	Ultramat 23-Simens	3.0	–
RS		Biolafite SF8	3.6	–
RP		Ultramat 23-Simens	1.0	–
G		Biolafite SF8	–	9.5

The main factor which defines the weather and climate in Obrenovac is its geographic location. Obrenovac is located near the confluence of the Rivers Kolubara and Sava, 80 m above sea level, 20° 11' 40" east of Greenwich Time at latitude of 44° 39' 34" north. As mentioned before, Obrenovac is situated in the northwest part of Serbia where two regions, Srpska Posavina and Podrinje with Podgorina emerge. Srpska Posavina has a moderate continental climate with appreciable micro-climate differences, mostly arising from the junction between a Mediterranean Climate (a climate of the bank of the Adriatic Sea) and a Carpathian climate. The primary characteristics of a moderate continental climate are warm summers and cold winters. Obrenovac is open in the north and northwest directions as there are no orographic barriers; hence the cold air current has an easy breakthrough to the south. It can be said that Obrenovac is under the influence of a Pannonian-continental climate. In any case, the Fruška Gora Mountain, which is located around 60 km northwest of Obrenovac (538 m height above sea level), is the only orographic barricade from the north. The mountains Cer (689 m), Povlen (1347 m), Maljen (1104 m), Rudnik (1132 m) are located west and south of the City, while Kosmaj (696 m) and Avala (506 m) are located east of Obrenovac. From both the orographic viewpoint and the atmospheric dynamics process, these mountains play an important role in the development of the weather.

Used equipment

The equipment employed during the experiments and the precise positions of the monitoring sites are presented in detail in Table I. The JUS ISO 6767 method, which is approved by the "Regulations on the boundary levels of emission, the criteria for establishing of monitoring points and the records data" and published in the Official Gazette of RS, No. 54/92, 30/99 and 19/06, was applied to monitored the daily concentration of SO_2 in the vicinity of TENT A and B at the four monitored points. The employed method is a manual spectrophotometric method equivalent to the West Geake method.

Meteorological data for the City of Obrenovac during 2006

The meteorological data were obtained from the local meteorological station (H_s = 71 m, φ = 44°39'34" N and λ = 20°11"40" E), which is located in the city center of Obrenovac. Two seasons: summer (May–mid October) and winter (December–February), with a very short spring (March and April) and autumn (October and November) were observed during 2006. The average summer temperature was 32.8 °C, while the winter one was 8 °C, with an average temperature difference between day and night of 12 °C. This great temperature difference promotes the formation of dew as the relative humidly of the air generally becomes high, especially during the winter season. The relative humidity in the region fluctuated between 86 % in August and 39 % in January, with a visibility of about 5 km (see Fig. 2). This restricted visibility is the result of the presence of solid particles in the atmosphere.

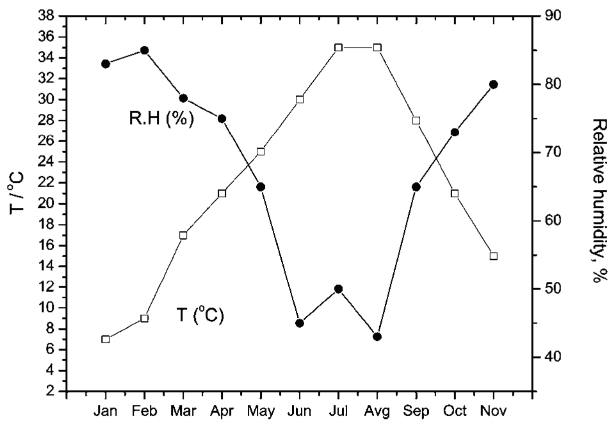


Fig. 2. Meteorological parameters in the City of Obrenovac during 2006.

As mentioned before, Obrenovac is influenced by both cold and warm air because of its geographic location. In the winter time, the penetration of cold air from north and the Carpathian region cause a significant drop in the air temperature, and windy and dry weather. During the spring, the southwestern flows are dominate, leading to an increase in air temperature, while east, northeast and southeast penetrations appear in the cold part of the year. When cold air from the northeast and southeast travels west, it encounters the serious orographic barricade of the Carpathian mountains; hence, direct northeast penetrations are very unusual. This cold air mass, called Koshava Wind, more or less also appears in Obrenovac. During the summer, the penetrations of cold air from the north onto the warm Balkans provoke phenomenon of weather disasters. The cold air warms up quickly from the ground, transforms and obtains the characteristics of continental tropical air. There are no basic differences between the cold north and cold northwest penetrations with respect to the weather development. It is very interesting to analysis the penetration of cold air from the northwest during the winter when in there is a huge accumulation of cold air in the Panonnian basin. In this case, instead of a drop in temperature, the temperature increases. Few days before the cold air incursion, the air pressure becomes reduced, and then during penetration suddenly increases. The air pressure starts to decrease on the day after the incursion and continues for several days. Then, precipitation can often be noticed (see Table II). After a precipitation period, the weather is usually clear and cold. As meteorological parameters (air pressure, air temperature, air humidity, rainfalls, cloudy conditions and wind) have a high influence on the emission of pollution materials and on the air quality in general, these parameters will be discussed individually.

TABLE II. Rainfall amount, mm, for period January–December 2006 in the City of Obrenovac

Month	Rainfall amount
January	111.9
February	133.4
March	141.2
April	112.8
May	221.6
June	108.6
July	28.6
August	222.4
September	109.6
October	97.3
November	102.5
December	98.6

Air pressure: In the City of Obrenovac and its surroundings, the average air pressure was around 1006 mbar. From January, when the average pressure attained its highest value (1010 mbar), the air pressure decreased and had the lowest value (1003 mbar) in April. Just for comparison, in October the value reached 1008 mbar.

Air temperature. The year average temperature in Obrenovac was 11 °C. The highest average value of 21 °C was in July, while the lowest (–2.1 °C) was in January. The average fluctuation during the year was 25 °C, which it is one of the most important indicators of a continental climate in the Obrenovac area.

Cloudiness. The average number of clear days during the year in Obrenovac was 66 (one in December and 11 in August, for comparison). During the year, over 50 days were cloudy, while 115 (17 in December and 3.5 in August) were partially gray with a fog tendency.

Wind. In Obrenovac, northwesterly and westerly winds have the greatest influence on the air quality in the city. There is also a considerable effect of southeasterly winds, as mentioned before; hence, the positions of the measuring points were chosen taking into account the wind rose.

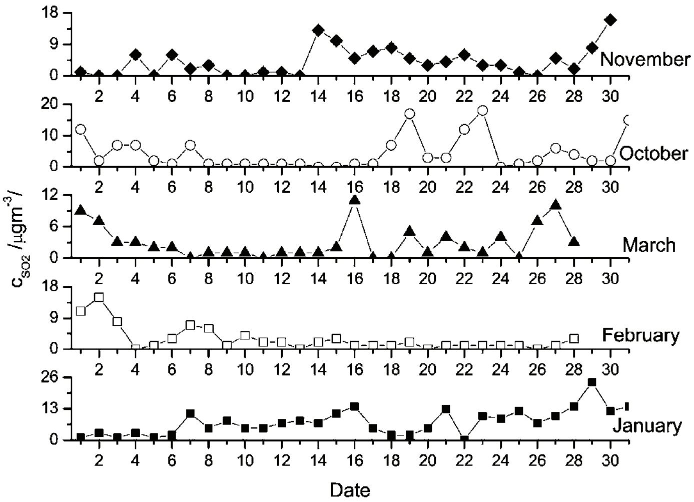
RESULTS AND DISCUSSION

As explained before, the emissions from power plants are mainly due to the type of fossil fuels burnt, which results in the discharge of various pollutants into the atmosphere. Sulfur is prevalent in most types of fossil fuels which are used for power generation, resulting in the release of large quantities of sulfur dioxide into the atmosphere. As stated already, SO_2 and NO_x are further oxidized and either deposited through wet or dry processes, resulting in sulfuric and nitric acid, respectively, or sulfate and nitrate particulates.[2–10] According to İçağa *et al*., correlations exist between SO_2 and humidity, temperature, and inversion at the 1 % significance level but no significant relationship exists between wind velocity and precipitation variables and pollutants. Based on these findings, the present measurements were divided into two periods: cold and hot and the relationships between the meteorological data and the SO_2 concentration were examined.

Monitoring of SO_2 during the cold season

The average temperature in January 2006 was lower than usual in Obrenovac and the surroundings. From the 23rd to the 28th, the temperature fell to –10 °C. Consequently, the emission of sulfur dioxide was pronounced at the monitoring point R, which is located 3 km from TENT A, as show in Fig. 3. As the monitoring point RP is located at a distance of only 1 km from TENT A, the highest emissions were at this monitoring point. The same situation was found in February, as is shown in Fig. 3b.

Due to the frequent occurrence of snow during February 2006, wet deposition of pollutants on land and the Sava River occurred. During March 2006 (see Table II), the amount of rainfalls were extremely high, two to three times greater than usual. Snow was visible on the mountains during the entire month. This metrological situation cause pronounced wet deposition on the soil and River Sava, and high emissions of SO_2 at the monitoring points located 3 and 9.5 km from the source of pollution, TENT B. At the beginning of October 2006, maximum daily temperatures were 6 to 8 °C higher than the average for this time of the year. The period of hot weather lasted for 2 weeks until the 16th October. Again, from the 21st to the 26th October, a new period with summer temperatures over the whole country arrived, with daily maximum temperatures higher than 25 °C. During October, but also during September, unusual and very small rainfalls were



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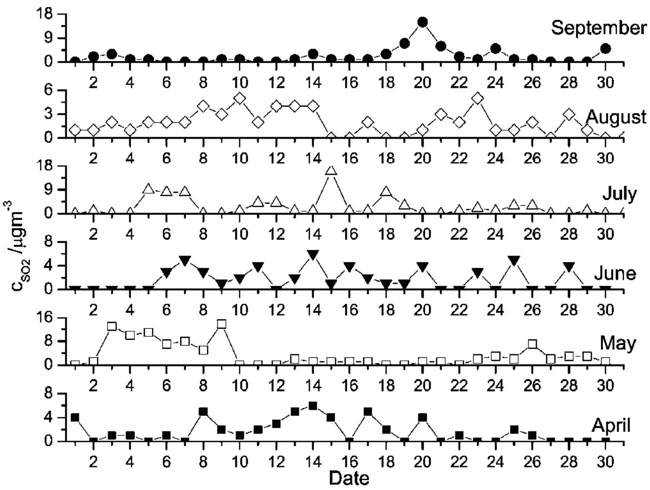


(b)

Fig. 3. Emission of SO_2 (μg m^{-3}) in the atmosphere at the monitoring point R during a) the cold season and b) the hot season. The exact distance from TENT A and B are given in Table I.

registered over the entire country. As can be seen from Figs. 3a–6a, which represent the cold (winter) period, the occurrence of the "warm wave" phenolmena had a great influence on the migration in environment of the emitted SO_2. The temperature curve in November 2006 showed unusual behavior: at the beginning of the month, the average temperature was lower than normal, while in the second and third decades, the temperature was unusually high (see Table II). The maximum emission of SO_2 (26 μg m^{-3} monitoring point R) was observed in November when the "warm wave" phenomenon was registered in two periods: from the 14th to the 21st and the 24th to the 29th. As in the previous months, there was a lack of rainfall and the autumn in 2006 was warmer than average. The observation of a high peak (24 μg m^{-3}) in the SO_2 concentrations between January and February, as show in Figure 4b, at the RP monitoring point, however, was not consistent with the occurrence of the observed health impact (the sensation of an unusual smell and the onset of symptoms generally occurred between October and November at the RS measuring point). Nevertheless, the lag of several hours between the first onset of symptoms and a peak in the SO_2 readings may not violate the relationship between symptoms and air pollution. The maximum SO_2 concentrations at the monitoring sites G and RS were 11 and 15 μg m^{-3}, respectively, which was expected since these monitoring sites are distant form TENT A and B.

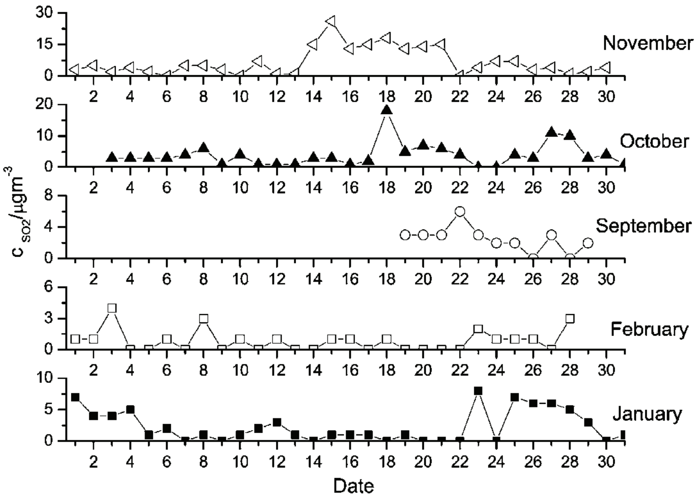
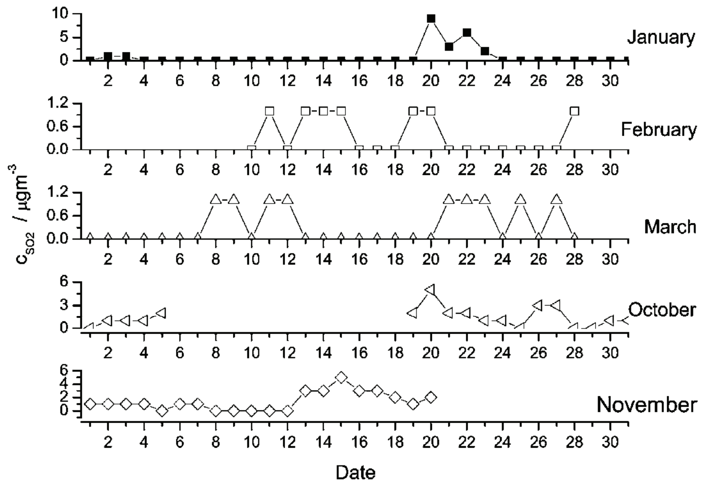


Fig. 4. Emission of SO_2 (μg m^{-3}) in the atmosphere at the monitoring point RP during the cold season. The exact distance from TENT A and B are given in Table I.

Monitoring of SO_2 during the hot season

During April, the average temperature values deviated from the normal ones by 0.5 to 1.9 °C. In the second half of the month, summer temperatures were registered, often accompanied by raining, hence, the monthly rain quantities were higher than usual. The higher temperatures caused marked changes in the sulfur dioxide concentrations. As can be seen in Fig. 3b, the emission from the sources TENT A and B attained maximum values at the monitoring point R.

A completely different weather situation was found throughout May. It was very cold during the first half of the month, with frost phenomena in the mountains, and in the second half, the temperatures reached tropical ones. As the weather conditions were changing, the emission of SO_2 changed. This trend is shown in Fig. 3b. The highest values were measured 3 km from the source TENT A at the monitoring point R.



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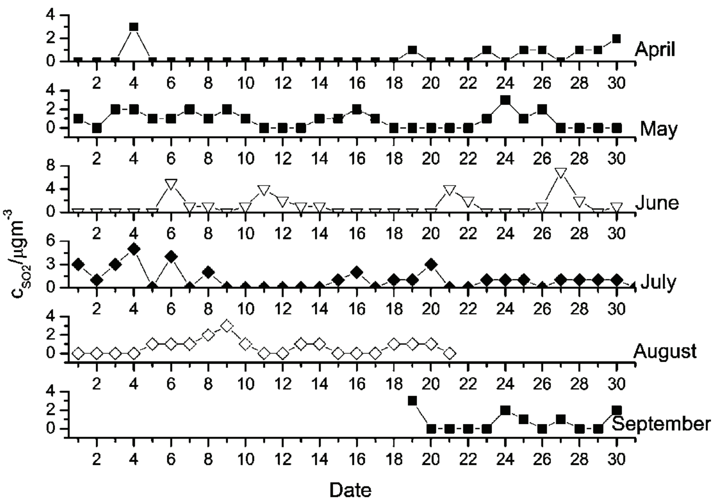
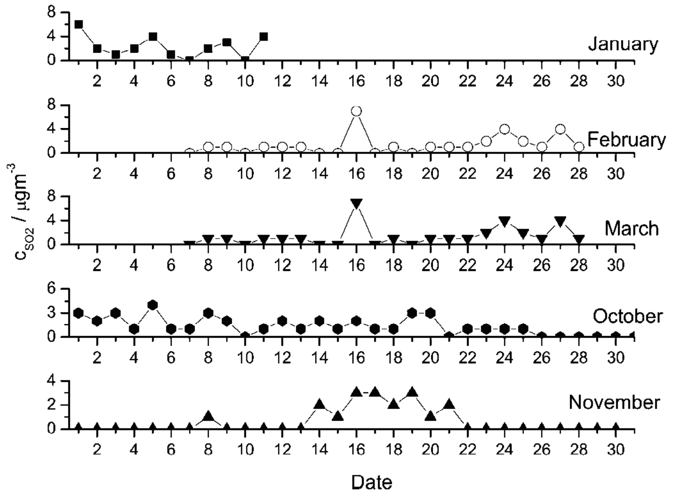


(b)

Fig. 5. Emission of SO_2 (μg m^{-3}) in the atmosphere at the monitoring point RS during a) the cold season and b) the hot season. The exact distance from TENT A and B are given in Table I.

Taking into account the previous results, it can be concluded that the wind rise played an important role in SO_2 migration in the City of Obrenovac.

At the beginning of June, penetration of very wet air with constant precipitations occurred. The maximum temperatures in the first several days were extremely low and in the last 60 years, such low temperatures in June were not evi-



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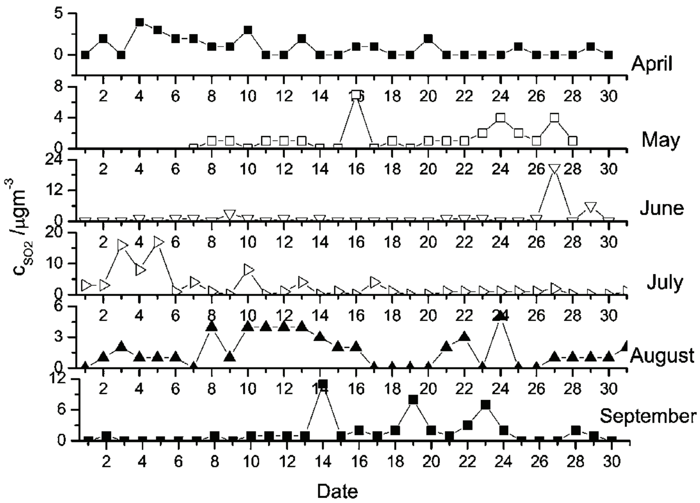

(b)

Fig. 6. Emission of SO_2 (μg m^{-3}) in the atmosphere at the monitoring point of G during a) the cold season and b) the hot season. The exact distance from TENT A and B are given in Table I.

denced. The second and third decades of June were characterized by very high temperatures (over 30 °C). In the second half of June, the phenomenon of tropical nights was evidenced. As can be seen in Fig. 6b, the SO_2 emission was dominant in the period of tropical days at the monitoring site located 9.5 km away from TENT B (this can be explained by the fact that the wind was pronounced). The main climate characteristic in July was a „warm wave" phenomenon in the second half of the mouth (from the 20th to the 29th) in many places on the territory of Serbia. Even though it rained frequently in July, the average value was at the normal level. As can be seen in Fig. 6b, the monitoring point G, which is furthermost of all measuring sites, had the most pronounced emission. As is shown in Fig. 6b, the movement of sulfur dioxide was chaotic. This unusual behavior can be explained taking into account the fact that low temperatures and the large rainfalls were observed during June. In this period, both wet and dry deposition of SO_2 was noticed. During the summer period, the minimal temperatures were higher than the average values for Serbia. There were lot of rainfalls, double the usual; the summer of 2006 was warmer than the norm, and the rainfall regime had a very marked feature. A similar situation was noticed in September, which was a relatively warm mouth. As can be seen from Table III, there was a strong correlation between the amount of rainfall and SO_2 emission since the maximum emission was observed when the rainfall amount was around 100 mm. An exception was found in July when the average amount of rainfall was 28.6 µg m^{-3} at the monitoring site R but the emission of SO_2 was pronounced. A possible reason for the summer maximum is the intense flow of south-east winds. According to information presented in the scientific literature,[11–15], the seasonal variation of the sulfur dioxide concentrations in urban and semi-urban areas is characterized by a maximum during the cold period and a minimum during the warm period of the year. However, the present findings show that the main parameter that affects the concentration of SO_2 is the amount of rainfall, since the maximum was observed during both periods when the amount of precipitation was marked.

TABLE III. Correlation between maximum SO_2 emission and the rainfall amount

Monitoring site	Cold season		Hot season	
	Maximum SO_2 emission, mg m^{-3}	Rainfall amount mm	Maximum SO_2 emission, mg m^{-3}	Rainfall amount mm
R	24 (January)	112	15 (July)	28.6
RP	26 (November)	102	–	108
RS	15(November)	102	7(June)	–
G	11(November)	102	27(June)	108

CONCLUSIONS

This paper presents the impact of some meteorological parameters on SO_2 concentration in the City of Obrenovac. The maximum SO_2 concentrations occurred in the period from December to February. The results show that there is a strong relationship between the meteorological parameters and SO_2 migration in city center of Obrenovac, within the terms statistically analyzed. The obtained results indicated that the amount of rainfall and the concentration of SO_2 emission are positively correlated. However, all the measured values of SO_2 emission were under the limits allowed by the Serbian Law of Environmental Protection. 95 % of the measured values were less then 10 μg m^{-3}, while the other 5 % ranged between 10 and 49 μg m^{-3}. Moreover, the positions of the monitoring points were well chosen, as they represent the real situation of air pollution in the Obrenovac City and the surroundings.

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И З В О Д

УТИЦАЈ МЕТЕОРОЛОШКИХ ПАРАМЕТАРА НА КОНЦЕНТРАЦИЈУ SO_2 У ОБРЕНОВЦУ, СРБИЈА

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У раду су представљени резултати мониторинга концентрације SO_2 у ваздуху у Обреновцу који се налази на северозападу Србије на обалама реке Саве. Посматран је утицај метеоролошких параметара на концентрацију SO_2 емитованог из термоелектрана ТЕНТ А и Б који се сматрају највећим изворима емисије. У периоду од јануара до новембра 2006. године праћене су концентрације сумпор-диоксида у ваздуху на 4 мерна места локализована на различитим удаљеностима од извора емисије. Максималне измерене дневне концентрације сумпор-диоксида су се кретале од 1 μg m^{-3} (16. новембра, 2006) до 24 μg m^{-3} (29. јануара, 2006). Измерене промене концентрација сумпор-диоксида углавном показују уобичајне карактеристике дневне ацидификације циклуса уз разлике које потичу од особености мерних места. Транспорт сумпор-диоксида забележен је при појачаном ветру првенствено из југоисточног правца. На основу корелационих односа између концентрације сумпор-диоксида и одговарајућих метеролошких параметара извршена је карактеризација мерних места у погледу њихове репрезентативности за мерење сумпор-диоксида.

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REFERENCES

1. A. Canak-Nedic, M. Gavrilovic, N. Pavlovic, J. Nozinic, M. Stankovic, U. Kuzmanovic, M. Nedic, *Energy Econ. Ecol.* **2** (1997) 63
2. B. H. Chen, C. J. Hong, H. D. Kan, *Toxicology* **198** (2004) 291
3. N. A. H Janssen. P. H. N van Vliet, F. Aarts, H. Harssema, B. Brunekreef, *Atmos. Environ.* **35** (2001) 3875
4. T. Okita, H. Hara, N. Fukuzaki, *Atmos. Environ.* **30** (1996) 3733
5. J. S. Pandey, R. Kumar, S. Devotta, *Atmos. Environ.* **39** (2005) 6868
6. J. S. Pandey, S. Khan, V. Joseph, R. Kumar, *Environ. Monit. Assess.* **74** (2002) 105

7. A. Srivastava, *Atmos. Environ.* **38** (2004) 6829
8. A. Srivastava, A. E. Joseph, S. Patil, A. More, R. C. Dixit, M. Prakash, *Atmos. Environ.* **39** (2005) 59
9. M. C. Roger, *Environ. Pollut.* **126** (2003) 301
10. V. T. Wang, V. T. F. Cheung, K. S. Lam, G. L. Kok, J. M. Harris, *Atmos. Environ.* **35** (2001) 2735
11. J. An, H. Ueda, K. Matsuda, H. Hasome, M. Iwata, *Atmos. Environ.* **37** (2003) 3039
12. H. D. Kambezidis, N. S. Papanikolaou, *Atmos. Environ*. **22** (1988) 2557
13. H. D. Kambezidis, R. Tulleken, G. T. Amanatidis, A. G. Paliatsos, D. N. Asimakopoulos, *Environmetrics* **6** (1995) 349
14. A. G. Kelessis, *Fresenius Environ. Bull.* **10** (2001) 624
15. A. G. Paliatsos, *Fresenius Environ. Bull.* **6** (1997) 655
16. A. G. Paliatsos, *Fresenius Environ. Bull*. **7** (1998) 539.