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SCREENING THE WEEKDAYS/WEEKEND PATTERNS OF AIR POLLUTANT CONCENTRATIONS RECORDED IN SOUTHEASTERN ROMANIA

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Abstract

Some of the major stressors of air quality in the urban areas are nitrogen oxides, ozone and suspended particles. The effect of air pollution on respiratory diseases can increase considerably at high levels of pollution and might trigger asthma symptoms. Long-term exposure can increase the rate of respiratory infections and symptoms at population level, but particularly in children. The goal was to analyze with statistical techniques the pollutant concentrations (NO, NO_2, and SO_2) recorded by 15 automated monitoring stations, to establish weekdays-weekend trends in various towns of the South Muntenia Region during cold months when residential heating contributes to the overall emissions. Raw data of the monitored parameters were acquired from 7 stations for NO and NO_2, and 14 stations for SO_2. Data acquisition and processing were performed between November 15, 2013 and February 28, 2014 and hourly-recorded time series were characterized for central tendency, dispersion and distribution. The statistical analysis determined the degree of differentiation between different sites and time intervals of the monitored pollutants using the screening of air quality trends based on hourly concentrations of each weekday using a specific grouping of data. The results support the characterization of weekday/weekend patterns in air pollutant concentrations in several urban areas of Southern Romania, where air pollution data were available: 4 cities (NO, NO_2) i.e., Ploiesti, Slobozia, Turnu Magurele, and Giurgiu, respectively 6 cities (SO_2), i.e., Ploiesti, Pitesti, Cimpulung, Giurgiu, Alexandria and Turnu Magurele.

Key words: automated monitoring station, nitrogen oxides, sulfur dioxide, time series analysis

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1. Introduction

In the last decades, air pollution became one of the most important environmental issues, having negative effects on the human health and surrounding ecosystems (Budianu et al., 2010; Iordache and Dunea, 2013; Sandu et al., 2012). The latest predictions related to the air pollution trends (OECD, 2014) state that in the following decades, improper air quality due to high concentrations of airborne contaminants and population increasing in urban areas would be the main environmentally-driven factors of morbidity and mortality. The air pollution issue is expected to have higher social and environmental impacts than other factors such as improper drinking water or natural hazards, e.g., floods, earthquakes, fires etc. Many epidemiological studies have demonstrated a clear association

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between air pollution and adverse health effects (Briggs, 2003; Henschel et al., 2012; Schwartz, 1994). Long-term exposure can increase the rate of respiratory infections and symptoms at population level, but particularly in children (Neuberger et al., 2004). The effect of air pollution on respiratory disease can increase considerably at high levels of pollution and might trigger asthma symptoms (Landrigan and Etzel, 2013). Some of the major stressors of air quality in the urban areas are nitrogen oxides, ozone and suspended particles originating from industrial sources, heavy traffic and domestic heating being significantly influenced by the local weather conditions (Dunea, 2014). In the last years, the authorities' interest in finding new approaches to diminish the impact of air pollution on the health of inner-city residents by limiting the exposure through early warnings during high concentrations episodes has increased considerably. Many research projects, e.g., *MESSAGE*, *Citi-Sense-MOB*, *OpenSense* (Castell et al., 2014; Liu et al., 2013) were developed or are currently underway in Europe by implying public participation and by using new emerged monitoring technologies and forecasting algorithms. The outcomes are supplementing already existing monitoring networks and official infrastructures of air pollution surveillance (e.g., Airbase EIONET - EEA, 2014; national monitoring networks, and local urban infrastructures).

In this context, the *ROKIDAIR* project has started recently in Romania funded by **Economic European Area** grants, aiming to improve the urban air quality monitoring and forecasting activities, focusing on the critical areas spatial delimitation based on the receptors' vulnerability, and their detailed characterization in terms of $PM_{2.5}$ effects on children's health, in two towns of Romania, i.e., Targoviste and Ploiesti. These urban agglomerations will serve as pilot areas in order to develop and deploy a monitoring network system and adjacent information-decisional structure, which will provide synthesized data concerning $PM_{2.5}$ levels obtained from reliable monitoring micro-stations and artificial intelligence forecasting algorithms developed within the project.

The present paper shows a part of the preliminary analyses and tests required to establish trends and patterns of air pollutants in the urban areas of Southeastern Romania during cold months when residential heating has a major contribution to the total emissions. Previous studies (Blanchard et al., 2008; Motallebi et al., 2003) pointed out the importance of the weekdays – weekend patterns characterization in urban agglomerations, as well as the observation of seasonal influence on daily evolution of various airborne pollutant species.

The goal of the experiments was to analyze the trend of pollutant concentrations (NO, NO_2 and SO_2) with statistical techniques, regarding the finding of potential differences between weekdays and weekend levels recorded at 15 automated monitoring stations in various urban areas of South Muntenia Region between November, 2013 and February, 2014. The results will support the selection and configuring of the data analysis algorithms to be used within the *ROKIDAIR* project, e.g., wavelet-neural network (Dunea et al., 2014), fuzzy logic (Dunea et al., 2011), predictive data mining (Oprea and Iliadis, 2011), statistical or mathematical models (Iordache and Dunea, 2013; Smaranda and Gavrilescu, 2008) etc.

2. Experimental

In this experiment, the recorded raw values of pollutant concentrations were extracted from November 15, 2013 to February 28, 2014, at one-hour sampling rate from 15 fixed stations of the National Air Quality Monitoring Network (RNMCA) using the collected historical database.

The selection of hourly time series for analysis was performed based on the data availability that depended mainly on the pollutant analyzer functioning. The main criteria were the consistency and continuity of time series. Consequently, only 15 stations provided useful data for the analysis from 24 stations that are located in the South Muntenia Region (Fig.1). Seven automatic stations situated in four towns i.e., Giurgiu, Slobozia, Ploiesti, and Turnu Magurele, provided complete data records for NO and NO_2 (GR-1, GR-2, GR-3, IL-1, PH-1, PH-6, and TR-2). There were also 14 stations, which have recorded sulfur dioxide concentrations (AG-2, AG-6, GR-1, GR-2, GR-3, GR-4, PH-1, PH-2, PH-3, PH-4, PH-5, PH-6, TR-1, and TR-2). These stations are located in six cities i.e., Pitesti, Cimpulung, Giurgiu, Ploiesti, Alexandria, and Turnu Magurele. Overall, there were 4 traffic, 4 industrial and 7 urban/ suburban stations having various areas of representativity (± 20 % of the recorded concentration at station location). The dataset for weekdays/weekend analysis contained 71,232 hourly values i.e., 7 × 2544 for NO, 7 × 2544 for NO_2, and 14 × 2544 for SO_2.

The statistical indicators that explain central tendency and dispersion were computed for weekdays (Monday to Friday), as well as for weekends (Saturday and Sunday) for each month of the monitored interval i.e., November 2013 to February 2014. Median and quartiles values were preferred for presentation, being indicators that are more robust in evaluating pollution trends. Minimum and maximum showed the amplitude of the hourly time series, and maximum values pointed out the critical thresholds recorded in a specific area of the analyzed cities, which were useful for ranking the pollutant concentrations by site.

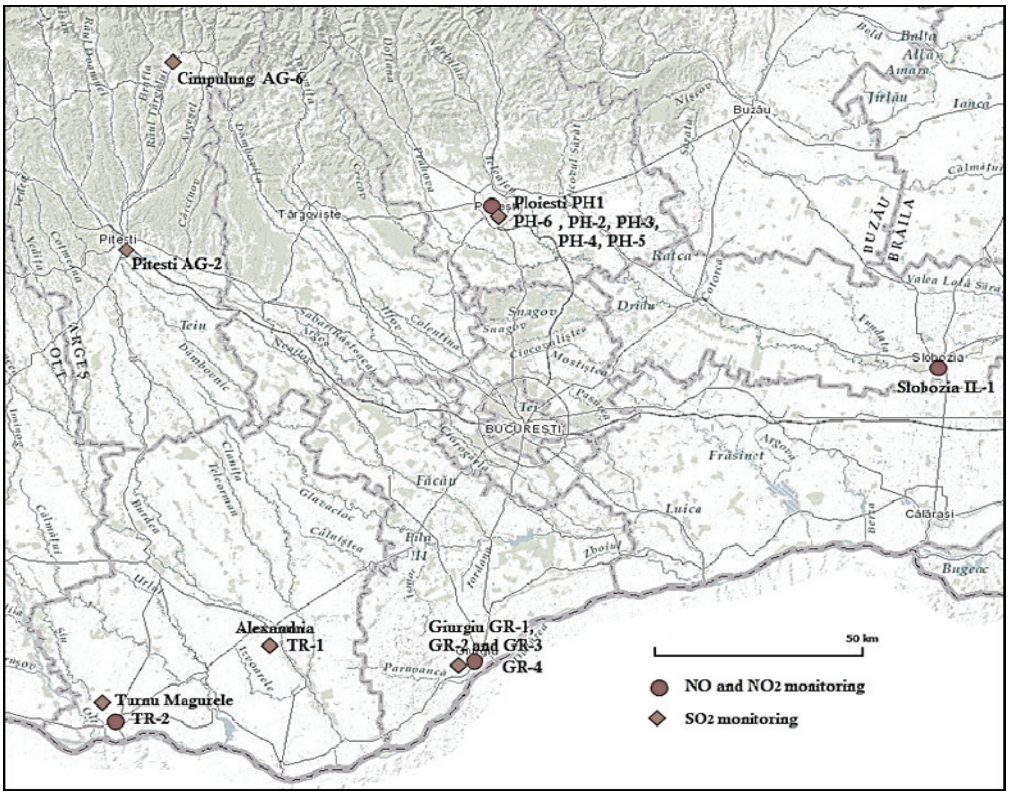
In the first step, the daily median of each weekday (Sunday to Monday) was computed using continuous hourly values recorded during a day. Then, the median of subsequent weekday medians was calculated to describe the general pattern of each day of the week during a month. For example, in January 2014 there were 5 Mondays resulting 5 daily medians for computing the median of Monday for January. Later on, the monthly median values of each weekday were grouped in two: Monday-Friday and Saturday-Sunday to compute the weekday, respectively weekend synthetic medians for each month (Table 1 to 4).

3. Results and discussion

The quantitative knowledge about emission sources, emission levels, and the trends in emissions of primary particles and precursor compounds detains an important role in finding the most appropriate control strategy for reducing risks at population level in various urban areas (Dunea, 2014). It is helpful to know the pollutant loads during "working" days as well as for "free" days to assess exposure.

The current approach took into account all the days of the week as follows: Monday to Friday to characterize weekdays, and Saturday and Sunday to characterize weekends by using medians.

Blanchard et al. (2008) considered a different approach using comparisons for the differences between Wednesday mean concentrations and Sunday mean concentrations, and for the differences between Wednesday and Saturday mean concentrations. They elected to use Wednesdays because they are equally separated in time from both Saturdays and Sundays, to diminish the carryover effect from other days of the week. In the present study, the focus was to separate the week into conventional working/free periods analyzing the time series in a continuous manner, without considering the interday carryover influence.



Air pollutant, instrumentation and analysis method			*Monitoring stations*
Nitrogen oxides (NO_X), ML9841B analyzer (SR EN 14211/2005- chemiluminiscence)			GR-1 GR-2 GR-3 IL-1 PH-1 PH-6 TR-2
Sulfur dioxide (SO_2), ML9850B analyzer (SR EN 14212 / 2005- UV fluorescence)			AG-2 AG-6 GR-1 GR-2 GR-3 GR-4 PH-1 PH-2 PH-3 PH-4 PH-5 PH-6 TR-1 TR-2
Type of station	*Traffic*	*Industrial*	*Urban/Suburban*
Monitoring Stations	GR-1, PH-1, PH-5, and TR-2	AG-6, GR-3, PH-4, and PH-6	AG-2, GR-2, GR-4, IL-1, PH-2, PH3, and TR-1
Area of representativity (± 20%)	10-100 m	100 m-1 km	1-5 km

Fig. 1. Location and particularities of the 15 automated stations for NO, NO_2 and SO_2 monitoring in Southeastern Romania considered in the present study

The rationale for this separation was to obtain a preliminary outlook of the potential outdoor exposure of children that attend the schools and kindergartens located in the representativity area of the stations during weekdays, as well as for weekends when they play outdoors in playgrounds.

Two groups of pollutants presented data available for this type of analysis i.e., nitrogen oxides (NO and NO_2) and sulfur dioxides (SO_2). Nitrogen oxides (NO_x) form ground-level ozone in combination with volatile organic compounds and in the presence of sunlight.

They are generated by various combustion processes but especially from vehicles engines and thermal power plants. Nitrogen oxides and sulfur dioxide may react with water vapors, oxygen, and other substances in the atmosphere to form acid rain. Both pollutants categories aggravate directly or as precursors of secondary pollutants, the respiratory illnesses, and can cause adverse effects depending on exposure, such as damage to lung tissue and reduction in lung function mostly in vulnerable category of populations (children, elders, and asthmatics).

3.1. Monthly patterns of nitrogen oxide during cold months

The statistical indicators of nitrogen oxide (NO) time series recorded at each monitoring station from 4 cities in Southeastern Romania, showed that the calculated medians of the weekdays was lower than the medians of weekends in many sites and depended on the month of recordings (Table 1). In November, significant differences between weekdays-weekend medians were observed at GR-1, due to the heavy traffic – Giurgiu is a border town with Bulgaria being transited by many heavy trucks and vehicles, and GR-1 is located near the main street to Bucharest, and IL-1 due to residential heating – a station that is located in a residential area near Slobozia Emergency Hospital.

The other stations showed almost constant values between weekdays and weekends medians. Maximum values were higher for weekdays at all stations. In December, the medians of weekdays were superior than weekend ones at all stations, but only GR-1, PH-1 and PH-6 showed significant values, the rest of stations showing almost similar values of weekdays-weekend medians. Several significant ($p<0.01$) values of maximum were observed for weekends as compared to weekdays at GR-1, PH-1 (traffic stations) and PH-6 (industrial station near Teleajen eastern refinery of Ploiesti). In January, significant values of weekend medians were observed at GR-1, PH-1 and PH-6. At these stations, the maximum values of weekends were significantly higher than weekdays' maximums, as in December. February month was characterized by medians almost constants between weekdays and weekend, and just one maximum significant value recorded in weekend at GR-1.

3.2. Monthly patterns of nitrogen dioxide during cold months

Nitrogen dioxide data were available at 7 stations from Giurgiu, Slobozia, Ploiesti, and Turnu Magurele cities (Table 2). Medians of November month were higher for weekend than weekdays at all stations excepting PH-1. The most significant differences were observed at GR-1 (traffic station), GR-2 and IL-1 (urban stations). In December, only one station had a superior median in weekend as compared to weekdays' synthetic value at GR-1 station.

The peak values of medians were observed at PH-1 (traffic station) in December for the entire interval of analysis both for weekend and for weekdays. Superior median values resulted at all traffic stations i.e., GR-1 (near national road DN 5C), PH-1 (near Gr. Gh. Cantacuzino street – a much transited road), and TR-2 (near national road DN 51A). One explanation is that NO_2 emissions are often the result of intense traffic. In January, NO_2 medians of weekend were significantly higher only at PH-6 probably due to the emissions from surrounding furnaces, and TR-2 due to traffic. In February, the comparison of medians showed the superiority of weekend values at GR-1 and GR-2, stations that are monitoring the traffic and urban air quality influenced by traffic and residential heating. Concerning the nitrogen oxides, the results presented in Table 1 and Table 2, confirmed that in many situations, medians of weekend values were close to weekdays ones and several times significantly higher at GR-1, PH-1, PH-6, and TR-2 stations.

3.3. Monthly patterns of sulfur dioxide during cold months

Along with the common major sources of SO_2, which are the burning of coal and naphtha at electric and thermal power plants, other sources in Southeastern Romanian urban areas are petroleum refineries (Ploiesti and Pitesti), cement manufacturing (Cimpulung), metal processing (Targoviste), and transportation with **diesel engines** (Giurgiu) that burn enriched sulfur fuel. In the last decade, many thermal electric plants and centralized heating systems have been closed in this region, which lowered significantly the SO_2 concentrations.

The improvement resulted also from gas desulfurization in power plants and sulfur removal from fuels in refineries using specific processes. Many residential areas rely now mainly on individual gas heating boilers during cold months, but there are cities that still have centralized systems with large combustion facilities i.e., Ploiesti, Pitesti, and Giurgiu.

Table 1. Statistical indicators of nitrogen oxide (NO) hourly time series recorded at each corresponding monitoring station from Giurgiu, Slobozia, Ploiesti, and Turnu Magurele cities, which showed complete data records by site and pollutant species (values in μg m^{-3}; * - $p < 0.01$)

Time of week	*Station ID*	*GR-1*	*GR-2*	*GR-3*	*IL-1*	*PH-1*	*PH-6*	*TR-2*
	Station type	*traffic*	*urban*	*industrial*	*urban*	*traffic*	*industrial*	*traffic*
	Town	*Giurgiu*	*Giurgiu*	*Giurgiu*	*Slobozia*	*Ploiesti*	*Ploiesti*	*Turnu Magurele*
November								
Weekdays	Median	**16.84**	**11.47**	**9.03**	**3.30**	**11.23**	**9.52**	**4.34**
	25th Quartile	14.46	10.68	8.65	3.19	8.58	7.37	3.16
	75th Quartile	31.44	12.41	10.45	6.18	14.84	12.06	7.36
	Minimum	6.08	5.64	5.97	0.00	5.43	4.97	1.35
	Maximum	*156.09*	*21.10*	*14.97*	*11.10*	*37.38*	*47.91*	*14.03*
Weekend	Median	**20.16***	**11.51**	**8.98**	**6.51***	**9.87**	**9.33**	**5.18**
	25th Quartile	15.64	10.92	8.68	6.33	8.19	7.20	3.50
	75th Quartile	28.73	12.24	10.24	6.25	14.08	11.94	7.37
	Minimum	10.33	10.29	8.39	6.00	6.61	5.86	1.88
	Maximum	*68.42*	*17.90*	*12.45*	*7.16*	*32.29*	*24.62*	*13.72*
December								
Weekdays	Median	**32.47**	**10.87**	**8.89**	**6.90**	**16.58**	**12.94**	**4.37**
	25th Quartile	24.04	10.51	8.50	6.54	10.28	10.95	3.06
	75th Quartile	40.34	11.81	9.19	7.14	20.63	16.99	6.52
	Minimum	10.19	10.06	8.10	6.12	6.10	6.74	2.10
	Maximum	*164.98*	*24.52*	*10.91*	*7.87*	*36.22*	*53.64*	*15.66*
Weekend	Median	**28.52**	**10.57**	**8.79**	**6.69**	**14.21**	**8.88**	**4.24**
	25th Quartile	22.41	10.41	8.54	6.50	9.95	7.46	3.17
	75th Quartile	64.31	11.11	9.37	7.13	25.35	18.20	6.76
	Minimum	18.94	10.00	8.19	6.11	6.71	6.18	2.44
	Maximum	*212.27*	*12.10*	*11.15*	*8.99*	*61.15*	*77.17*	*16.47*
January								
Weekdays	Median	**22.82**	**11.18**	**8.92**	**6.35**	**8.46**	**6.74**	**3.89**
	25th Quartile	21.76	10.76	8.79	6.16	6.83	6.16	2.83
	75th Quartile	24.65	11.59	9.34	6.42	9.90	7.51	5.39
	Minimum	17.38	10.16	8.10	3.25	5.88	5.20	0.64
	Maximum	*85.60*	*15.76*	*13.86*	*6.69*	*32.50*	*23.90*	*11.42*
Weekend	Median	**28.07***	**11.00**	**8.96**	**5.93**	**9.77**	**8.07***	**2.50**
	25th Quartile	20.56	10.57	8.78	5.76	8.44	6.55	1.58
	75th Quartile	40.82	13.23	9.64	6.17	12.60	10.14	4.66
	Minimum	17.52	10.02	8.47	2.97	5.29	5.48	0.13
	Maximum	*179.81*	*42.58*	*16.27*	*6.49*	*27.65*	*40.27*	*10.00*
February								
Weekdays	Median	**23.49**	**10.40**	**8.42**	**6.28**	**8.40**	**6.17**	**10.70**
	25th Quartile	20.97	10.31	8.23	6.19	6.97	5.86	10.18
	75th Quartile	25.23	10.89	8.78	6.42	9.43	6.58	11.64
	Minimum	17.33	9.63	7.85	5.38	1.47	5.34	8.67
	Maximum	*53.95*	*14.03*	*11.89*	*6.90*	*13.51*	*39.70*	*15.88*
Weekend	Median	**22.98**	**10.77**	**8.50**	**6.27**	**7.25**	**6.04**	**11.29**
	25th Quartile	20.46	10.51	8.28	6.21	6.63	5.80	10.75
	75th Quartile	27.91	10.97	8.91	6.41	8.78	6.52	12.03
	Minimum	17.79	10.22	8.05	6.03	5.43	5.33	10.11
	Maximum	*104.92*	*12.20*	*9.84*	*6.67*	*14.74*	*15.56*	*14.35*

Data of SO_2 concentrations showed weekdays/weekend medians that varied from 8.38/8.11 μg m^{-3} at AG-2 to 24.72/25.71 at GR-1 in November, 9.58/8.94 at AG-2 to 28.99/28.59 at GR-1 in December, 8.81/6.84 at PH-5 to 28.89/29.24 at GR-1 in January, and 8.00/8.16 at PH-2 to 29.52/29.67 at GR-1 in February

The highest medians were observed for Giurgiu city at three stations, Cimpulung and Alexandria stations during all 4 months and for Ploiesti (PH-5) in February (Table 3 and Table 4). There was some superiority of the median weekend values as compared to weekdays at GR-1, GR-4, PH-2, and PH-5 in November, GR-2, GR-3, GR-4, PH-4, and TR-1 in December, GR-1, GR-2, GR-4, and PH-6 in January, and AG-2, AG-6, GR-1, GR-2, GR-3, GR-4, PH-2, PH-3, PH-4, TR-1 and TR-2 in February. The only significant differences ($p < 0.05$) were determined at GR-2 in December and January, as well as for PH-4 in December and February. For the other pairs, the values of medians at the same site were almost constant both for weekdays and for weekend, and between months with few exceptions.

Table 2. Statistical indicators of nitrogen dioxide (NO_2) hourly time series recorded at each corresponding monitoring station from Giurgiu, Slobozia, Ploiesti, and Turnu Magurele cities, which showed complete data records by site and pollutant species (values in μg m^{-3}; * - $p < 0.01$)

Time of week	*Station ID*	*GR-1*	*GR-2*	*GR-3*	*IL-1*	*PH-1*	*PH-6*	*TR-2*
	Station type	*traffic*	*urban*	*industrial*	*urban*	*traffic*	*industrial*	*traffic*
	Town	*Giurgiu*	*Giurgiu*	*Giurgiu*	*Slobozia*	*Ploiesti*	*Ploiesti*	*Turnu Magurele*
November								
Weekdays	Median	**28.90**	**13.13**	**5.66**	**11.00**	**41.14**	**22.72**	**16.94**
	25th Quartile	25.57	11.96	4.79	7.90	20.61	16.96	13.68
	75th Quartile	35.27	14.71	6.50	18.43	48.98	25.98	25.43
	Minimum	18.67	6.72	3.49	0.00	9.64	9.58	8.69
	Maximum	*72.26*	*26.15*	*12.16*	*133.59*	*68.84*	*49.98*	*102.34*
Weekend	Median	**35.01***	**16.40***	**6.02**	**19.57***	**25.16**	**22.85**	**18.56**
	25th Quartile	31.57	14.35	4.86	14.07	20.71	17.67	14.52
	75th Quartile	43.63	18.87	7.20	24.54	35.83	25.55	25.31
	Minimum	26.18	10.69	3.87	4.43	10.69	11.98	10.65
	Maximum	*81.12*	*25.94*	*9.40*	*43.36*	*49.82*	*29.57*	*129.91*
December								
Weekdays	Median	**36.32**	**13.63**	**7.43**	**15.28**	**45.87**	**30.27**	**27.87**
	25th Quartile	30.33	10.45	6.22	10.48	35.13	27.74	25.78
	75th Quartile	51.27	16.35	9.44	16.78	53.64	35.49	32.04
	Minimum	14.10	4.20	4.60	6.27	13.95	22.20	15.21
	Maximum	*129.61*	*25.81*	*13.72*	*53.52*	*69.21*	*48.64*	*44.41*
Weekend	Median	**43.37***	**10.37**	**6.90**	**13.67**	**45.29**	**28.23**	**28.12**
	25th Quartile	33.52	9.33	5.55	11.42	35.79	24.55	25.12
	75th Quartile	50.19	11.01	9.05	16.64	59.22	37.03	31.76
	Minimum	23.52	4.08	4.41	8.23	23.97	17.22	19.08
	Maximum	*66.05*	*22.42*	*12.95*	*24.57*	*87.80*	*54.08*	*65.43*
January								
Weekdays	Median	**25.38**	**14.62**	**6.75**	**8.77**	**25.41**	**29.12**	**17.26**
	25th Quartile	23.03	13.35	6.23	7.72	15.49	20.05	15.57
	75th Quartile	26.91	15.79	8.21	10.69	29.31	32.19	19.11
	Minimum	12.85	10.80	3.88	4.90	7.97	12.95	9.69
	Maximum	*64.52*	*23.33*	*10.43*	*16.44*	*49.72*	*64.65*	*38.82*
Weekend	Median	**21.33**	**14.65**	**5.71**	**7.08**	**25.89**	**32.50***	**20.55***
	25th Quartile	18.71	13.09	4.52	5.88	21.77	27.91	16.66
	75th Quartile	28.05	18.85	7.41	9.44	29.90	36.58	26.82
	Minimum	15.35	9.11	2.75	4.73	13.64	18.77	8.65
	Maximum	*52.82*	*51.66*	*9.75*	*18.14*	*42.63*	*49.60*	*58.51*
February								
Weekdays	Median	**27.99**	**14.76**	**7.70**	**14.93**	**23.71**	**29.16**	**20.91**
	25th Quartile	24.88	13.44	6.70	11.83	20.32	24.71	20.16
	75th Quartile	42.17	15.81	9.28	17.03	26.88	34.41	24.70
	Minimum	16.60	9.41	3.63	5.87	8.35	15.11	15.57
	Maximum	*78.49*	*27.27*	*20.62*	*33.76*	*43.27*	*61.54*	*35.90*
Weekend	Median	**35.30***	**16.82**	**7.59**	**10.91**	**22.56**	**24.32**	**20.65**
	25th Quartile	31.68	14.75	6.48	9.04	16.96	21.29	18.80
	75th Quartile	45.40	19.53	9.95	15.57	28.54	33.36	24.06
	Minimum	22.21	12.60	4.52	6.84	11.18	16.66	15.29
	Maximum	*69.90*	*33.56*	*13.29*	*36.97*	*43.02*	*49.37*	*28.23*

Several significant maximum values of medians were observed at Ploiesti industrial stations PH-4 (December and February – near Brazi refinery) and PH-6 (January - near Teleajen refinery), but the peak value (362.3 μg m^{-3} – hourly value) was recorded at PH-3 (February – near Blejoi refinery).

The goal of the second part of the experiment was to analyze the hourly evolution of medians corresponding to weekdays in comparison with weekend. The synthetic results are useful in establishing the intervals of maximum exposure during the day.

3.4. Hourly distribution of nitrogen oxide during cold months in Ploiesti urban area

Blanchard and Tanenbaum (2006) suggested that weekend declines of ambient NO, NO_x, and CO concentrations could result from decreased emissions from gasoline vehicles, on-road and off-road diesel vehicles, stationary sources, or a combination of source types. Fig. 2 shows the results for NO at two stations of Ploiesti that provided valid data for analysis. Both stations i.e., PH-1 (traffic) and PH-6 (industrial) are placed on the horizontal axis that crosses Ploiesti city from West to East. The most relevant peaks of weekdays were located between 7 and 9 a.m. with the rising starting from 6 a.m. and the declining from 10 a.m. There was also another interval with rising medians between 4 and 6 p.m. These intervals were related with the high traffic periods. The highest NO medians were observed in December and the lowest in February. A different pattern was observed in February for PH-1 during weekdays suggesting intense traffic from 11 a.m. to 8 p.m. The results of weekend time series showed peak intervals between 8 and 10 a.m., and 6 and 8 p.m. An interesting observation was that starting from December, the weekend time series of medians were higher than weekdays, especially between 6 and 8 p.m. This might suggest that the recorded values of emissions were resulted from a combination of source types, with contributions from industrial sources. The LSD test showed only two significant differences ($p < 0.01$) between the means of weekdays and weekend series in January (PH-1 and PH-6).

Table 3. Statistical indicators of sulfur dioxide (SO_2) hourly time series recorded at each corresponding monitoring station from Pitesti, Cimpulung, and Giurgiu cities, which showed complete data records by site and pollutant species (values in µg m^{-3}; * - $p < 0.01$)

Time of week	***Station ID***	***AG-2***	***AG-6***	***GR-1***	***GR-2***	***GR-3***	***GR-4***
	Station type	***urban***	***industrial***	***traffic***	***urban***	***industrial***	***suburban***
	Town	***Pitesti***	***Cimpulung***	***Giurgiu***	***Giurgiu***	***Giurgiu***	***Giurgiu***
November							
Weekdays	Median	**8.38**	**17.41**	**24.72**	**15.38**	**10.17**	**14.73**
	25th Quartile	7.85	16.39	24.31	14.84	10.12	14.62
	75th Quartile	8.84	17.68	25.34	16.09	10.32	15.22
	Minimum	6.86	14.02	22.29	13.81	9.90	14.21
	Maximum	*13.87*	*18.28*	*29.35*	*51.39*	*11.19*	*20.25*
Weekend	Median	**8.11**	**15.46**	**25.71**	**14.63**	**9.99**	**15.10**
	25th Quartile	7.86	15.09	25.07	14.32	9.70	14.66
	75th Quartile	8.72	15.84	25.57	15.39	10.23	15.02
	Minimum	7.46	12.24	23.91	14.01	8.97	14.38
	Maximum	*14.26*	*17.99*	*27.91*	*19.24*	*11.46*	*17.63*
December							
Weekdays	Median	**9.58**	**18.48**	**28.99**	**18.89**	**11.95**	**16.89**
	25th Quartile	8.81	17.99	28.62	17.43	11.77	15.88
	75th Quartile	10.20	19.06	29.64	21.88	12.09	17.78
	Minimum	8.07	17.39	26.18	9.01	11.60	15.22
	Maximum	*15.14*	*21.39*	*33.22*	*43.55*	*12.87*	*24.48*
Weekend	Median	**8.94**	**18.40**	**28.59**	**21.55***	**12.07**	**17.10**
	25th Quartile	8.38	18.08	27.74	18.53	11.97	15.91
	75th Quartile	10.39	18.99	29.41	23.85	12.16	18.08
	Minimum	7.82	17.38	27.11	17.46	11.83	15.38
	Maximum	*12.05*	*19.98*	*30.58*	*34.88*	*12.51*	*21.67*
January							
Weekdays	Median	**9.33**	**19.25**	**28.89**	**19.83**	**12.60**	**17.68**
	25th Quartile	8.38	18.96	28.42	17.67	12.21	17.16
	75th Quartile	9.74	19.55	29.30	23.38	12.68	18.04
	Minimum	7.51	18.15	14.54	5.89	11.93	16.62
	Maximum	*12.59*	*22.49*	*32.20*	*29.61*	*13.82*	*28.15*
Weekend	Median	**9.17**	**18.90**	**29.24**	**21.39**	**12.27**	**18.23**
	25th Quartile	8.58	18.61	28.56	18.37	12.10	17.69
	75th Quartile	9.54	19.22	29.22	25.07	12.69	19.95
	Minimum	7.85	17.20	21.08	16.52	11.82	16.91
	Maximum	*10.20*	*20.88*	*36.53*	*32.48*	*13.19*	*29.16*
February							
Weekdays	Median	**8.14**	**19.90**	**29.52**	**18.70**	**13.16**	**18.94**
	25th Quartile	7.65	19.34	29.20	17.05	13.02	18.62
	75th Quartile	8.73	21.03	29.92	19.98	13.39	19.23
	Minimum	6.70	18.34	27.06	5.78	12.56	17.71
	Maximum	*11.38*	*24.61*	*33.92*	*34.82*	*14.37*	*21.95*
Weekend	Median	**8.78**	**20.05**	**29.67**	**21.13***	**13.43**	**19.49**
	25th Quartile	8.32	19.56	29.36	19.78	13.26	18.82
	75th Quartile	8.97	20.82	29.82	21.91	13.72	20.10
	Minimum	7.16	18.98	28.51	17.32	13.07	17.96
	Maximum	*14.20*	*26.78*	*31.63*	*26.15*	*14.68*	*23.99*

Table 4. Statistical indicators of sulfur dioxide (SO_2) hourly time series recorded at each corresponding monitoring station from Ploiesti, Alexandria, and Turnu Magurele cities, which showed complete data records by site and pollutant species (values in µg m^{-3}; * - $p < 0.01$)

Time of week	Station ID	PH-1	PH-2	PH-3	PH-4	PH-5	PH-6	TR-1	TR-2
	Station type	traffic	traffic	urban	industrial	urban	traffic	industrial	traffic
	Town	Ploiesti	Ploiesti	Ploiesti	Ploiesti	Ploiesti	Ploiesti	Alexandria	Turnu Magurele
November									
Weekdays	Median	**11.42**	**10.60**	**9.39**	**10.38**	**10.60**	**9.19**	**14.35**	**12.41**
	25th Quartile	10.79	9.98	8.90	9.29	9.99	6.89	13.80	12.19
	75th Quartile	12.45	14.41	10.02	11.88	11.63	10.53	14.75	12.62
	Minimum	4.80	4.70	4.04	2.41	9.02	3.93	12.16	6.00
	Maximum	*15.80*	*16.76*	*18.81*	*27.29*	*14.30*	*56.97*	*27.65*	*19.23*
Weekend	Median	**8.11**	**10.81**	**8.18**	**9.24**	**10.68**	**8.00**	**13.16**	**12.35**
	25th Quartile	7.70	10.20	7.66	8.66	10.18	6.69	12.46	12.28
	75th Quartile	10.98	12.24	9.76	11.07	11.25	10.14	13.95	12.51
	Minimum	6.08	7.61	6.75	6.35	9.45	4.09	9.92	12.17
	Maximum	*11.51*	*13.53*	*10.20*	*20.97*	*12.61*	*13.51*	*14.79*	*12.63*
December									
Weekdays	Median	**10.78**	**17.37**	**9.74**	**12.80**	**12.29**	**15.64**	**16.54**	**12.97**
	25th Quartile	8.44	14.90	8.87	11.92	11.02	10.64	16.03	12.35
	75th Quartile	12.09	19.66	10.50	14.46	12.91	16.57	16.95	13.29
	Minimum	1.70	10.98	7.98	7.41	9.24	7.82	15.38	11.87
	Maximum	*18.09*	*24.27*	*17.33*	*27.05*	*15.36*	*49.67*	*18.54*	*15.70*
Weekend	Median	**9.24**	**14.77**	**9.42**	**16.39***	**11.27**	**10.96**	**16.77**	**12.92**
	25th Quartile	6.46	13.79	8.63	13.09	10.45	9.03	15.69	12.68
	75th Quartile	12.84	19.29	11.56	19.04	13.00	16.16	16.84	13.42
	Minimum	4.96	12.34	7.28	7.47	9.86	7.06	15.23	11.91
	Maximum	*18.39*	*22.95*	*20.78*	*43.98*	*16.50*	*25.91*	*20.78*	*17.81*
January									
Weekdays	Median	**12.97**	**8.81**	**9.02**	**9.09**	**8.81**	**14.17**	**17.62**	**9.59**
	25th Quartile	11.77	8.24	8.52	6.29	7.61	11.30	17.35	9.50
	75th Quartile	14.61	9.37	9.73	9.59	9.04	17.97	17.92	9.85
	Minimum	8.13	5.89	7.53	1.35	1.98	7.99	17.03	8.62
	Maximum	*19.65*	*12.51*	*16.97*	*25.07*	*13.19*	*30.69*	*18.83*	*12.80*
Weekend	Median	**11.03**	**8.55**	**9.15**	**8.00**	**6.84**	**14.37**	**17.54**	**9.60**
	25th Quartile	10.16	7.64	8.68	4.16	5.86	10.54	17.18	9.17
	75th Quartile	13.84	9.13	9.86	8.48	8.43	17.36	17.91	10.14
	Minimum	8.00	5.99	7.63	1.35	1.98	8.47	17.00	8.62
	Maximum	*17.76*	*12.92*	*11.04*	*25.07*	*11.90*	*51.29*	*18.33*	*12.05*
February									
Weekdays	Median	**11.88**	**8.00**	**8.20**	**17.46**	**26.42**	**9.77**	**19.65**	**8.33**
	25th Quartile	10.43	6.84	7.86	14.41	25.67	8.28	19.19	8.06
	75th Quartile	14.52	9.12	9.06	20.11	26.97	11.69	20.38	8.87
	Minimum	7.67	5.78	6.64	7.61	24.48	6.43	18.69	7.34
	Maximum	*18.89*	*19.13*	*362.39*	*43.06*	*29.59*	*22.75*	*22.57*	*10.78*
Weekend	Median	**9.55**	**8.16**	**8.97**	**24.22***	**26.09**	**9.61**	**19.80**	**9.01**
	25th Quartile	7.82	7.64	8.36	20.06	25.60	8.47	19.46	8.53
	75th Quartile	13.24	9.32	9.82	20.65	26.82	11.55	20.48	9.72
	Minimum	5.75	5.99	7.63	15.29	24.90	5.43	18.99	8.30
	Maximum	*15.54*	*12.69*	*13.13*	*75.82*	*28.66*	*15.43*	*22.30*	*11.40*

3.5. Hourly distribution of sulfur dioxide during cold months in Ploiesti urban agglomeration

The monitoring infrastructure of Ploiesti relying on 6 automated monitoring stations has provided data for SO_2 for the entire analyzed interval (Fig. 3).The peak levels of medians were noticed in February between 1 and 3 p.m. at PH-6 during weekend.This station recorded the highest peaks for each month starting from 8 to 12 p.m. As a general pattern for all the recorded time series, there was an increasing from 6 a.m. to 12 a.m. and another one from 5 to 8 p.m. both for weekdays and for weekend.

The median values depended mainly on the station location because of the proximity of refineries and other stationary sources.

High concentrations of SO_2 were also recorded from mobile sources at the stations located in the proximity of railway transportation, the city of Ploiesti being an important railway hub.

Multiple range tests (LSD) for the difference of the means of weekdays and weekend series showed three significant differences ($p < 0.01$) in November (PH-1, PH-2, and PH-3), two in December (PH-4 and PH-6), two in February (PH-1 and PH-4), and none in January.

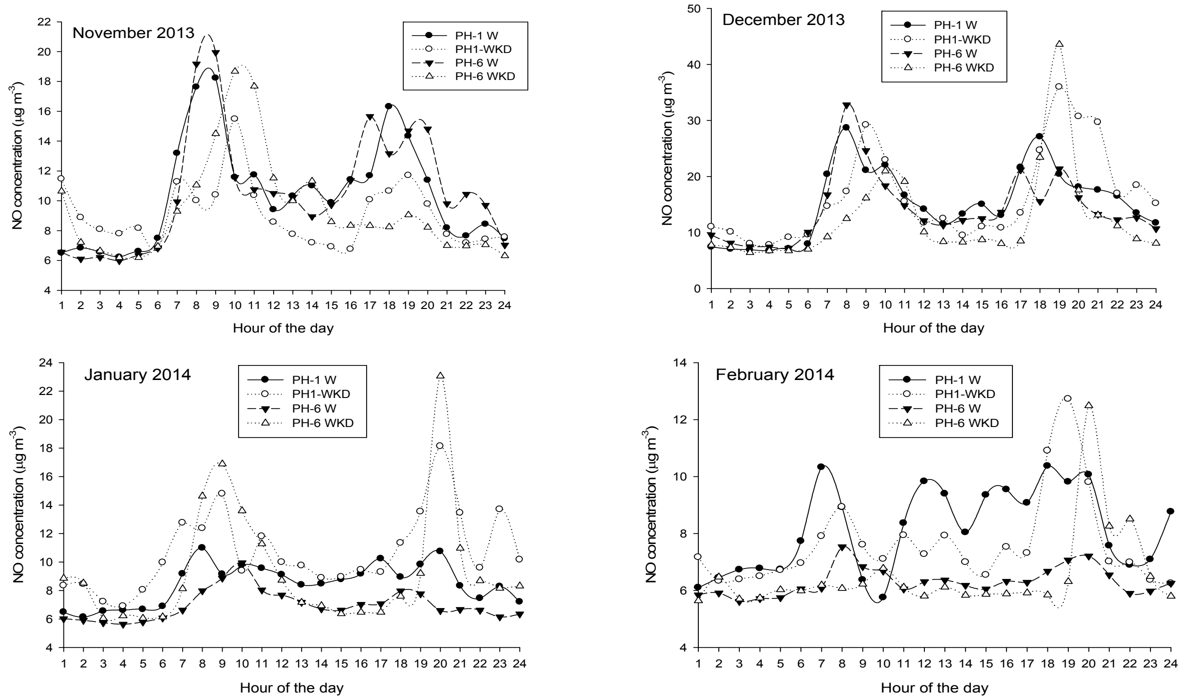


Fig. 2. Time series of nitrogen oxide (NO) medians of the hourly values recorded in Ploiesti urban area during cold months (W – weekdays' time series; WKD – weekend time series)

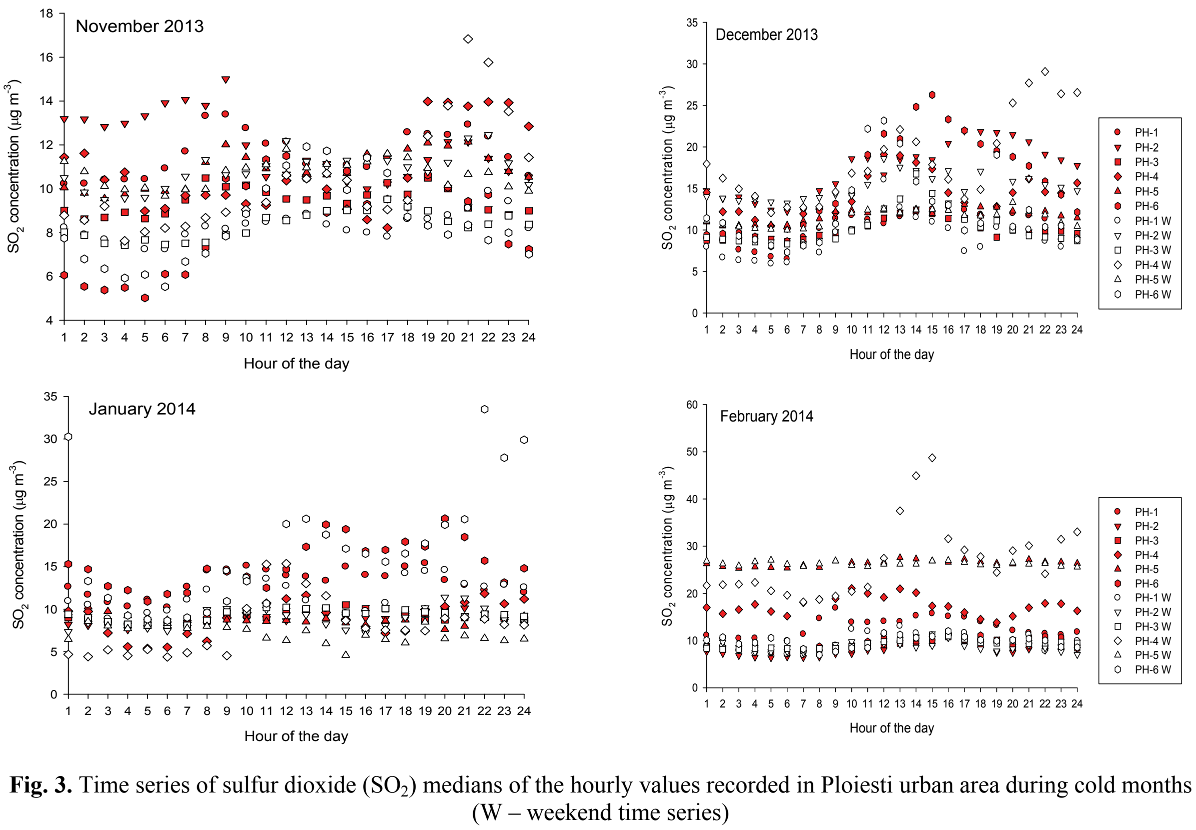


Fig. 3. Time series of sulfur dioxide (SO_2) medians of the hourly values recorded in Ploiesti urban area during cold months (W – weekend time series)

4. Conclusions

Through the review of analysis results, a random pattern was observed when comparing statistical indicators of weekdays with weekend ones depending on month of observation, pollutant species and site. In many situations, medians of weekend values were close to weekdays ones and several times significantly higher at various sites for each of the analyzed pollutants.

Many high values of medians and maximums might support the affirmation that Giurgiu and

Ploiesti were cities with higher levels of contaminants during the interval of analysis. In the future, the sites and times of day exhibiting high emission levels may vary from the sites and times that were used for the present weekdays/weekend analysis. It was noticed that weekend medians were not lower than weekdays ones in many cases.

Due to the processing activities of crude oil and transportation around Ploiesti city, which is an urban agglomeration with 197,542 permanent residents in Southeast of Romania, this area must be carefully monitored regarding air pollutants concentrations. The analysis showed that there are certain vulnerable areas under the direct impact of road traffic or industrial emissions that need to be supplemented with forecasting tasks in order to improve people's protection to the specific air pollution exposure.

The available data did not allow for the weekdays/weekend evaluation of ozone concentrations, and particulate matters presence.

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