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ScientEvents

ProScience 1 (2014) 387-392

ProScience

Conference Proceedings

1st International Conference on Atmospheric Dust - DUST2014

The concentration of PM_{10} in a rural area during episodes of tropospheric inversion occurring in the cool months

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Abstract

The article presents the results of research on the concentration of particulate matter (PM_{10}) in a compact settlement village. Measurements were taken in four cold season (December to February) experiments, which included observations of air quality within the two separate zones of the village of Kotórz Mały (Poland).

It was found that the character of (degree of emission) sources plays a key role in local air quality (the average concentration of PM_{10} in the area S1 was twice as high as that in S2). The permanent presence of temperature inversion and the stable state of the atmosphere cause the inhibition of pollution propagation processes and significant local changes, exceeding the permissible daily PM_{10} concentrations. Enhanced by an anticyclone, the three-day period of temperature inversion occurrence caused a situation in which local air emission levels did not meet the standards required for the protection of human health. Simultaneously, this study proved the unstable state of the atmosphere and the horizontal movement of air masses >2.5 m/s, resulting in a noticeable improvement of the aerosanitary conditions in one day. It was found that in the cold seasons the average concentration of PM_{10} in the area of rural compact settlement is around three times greater than during the summer months. The results can be analysed in the supra-local dimension to furnish confirmation of areas with similar characteristics of emission and climatic-meteorological conditions. For the considered terms and the period of observation, conducting meteorological measurements can be considered sufficient for estimation of the occurrence of alarming conditions.

Keywords: Gravimetric method; temperature inverse; PM_{10}; rural area.

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ISSN: 2283-5954
Selection and peer-review under responsibility of DUST2014 Scientific Committee
DOI:10.14644/dust.2014.063

1. Introduction

Publications dealing with the issue of air pollution are mainly focused on presenting data on air quality in urban and industrialised areas (Mijić et al., 2010) and areas exposed to major road transport impact (Ho & Clappier, 2011). By comparison, papers discussing the results of research on air quality in rural areas are scarce and usually cover rural areas located in the vicinity of industrial zones and large metropolitan areas (Monn et al., 1999; Gomiscek et al., 2004; Ragosta et al., 2006). Given the key criterion determining the necessity of air quality monitoring, i.e., that of population density, this approach is fully justifiable. However, the toxic influence of the compounds enriching the atmosphere of the Earth also negatively affects humans, flora, fauna and material goods within rural areas (Nam et al., 2010).

International literature includes information on the effect that particular rural emission sources have on air quality (Caseiro et al., 2009). This article discusses results of research on the concentration of particulate matter (PM_{10}) in a compact settlement village. The main purpose was to compare the PM_{10} levels in two areas of one village which differ because of the individual heating systems. The main focus is on the cold periods of the year, during the occurrence of tropospheric inversion strengthened by an anticyclone. In the research hypothesis an assumption is made that during cold seasons the average daily and hourly PM_{10} concentrations are similar on the borders of one village.

2. Materials and methods

Measurements were led by four cold season (December to February, 2010 to 2014) experiments, which included observations of air quality within the two separate zones of the village of Kotórz Mały, Poland (50^{o}43’50”N; 18^{o}02’36”E). The first zone (S1) is characterized by rural buildings, which predominantly use obsolete individual heating systems (coal, in a proportion of 91%). The second is a modern building zone (S2), where the production of heat energy mainly uses gaseous fuel (73%) and electricity (18%). The distance between S1 and S2 is 1.2 km. Table 1 presents the characteristics of individual emitters at both sites.

Table 1. Characteristic of Individual Emitters (IE) of heating system.

Site	**No of IE**	**Heating systems share [%], (number in the bracket)**				
	With r=200m from S	coal	Fuel gas	wood	electricity	RES
S1	94	91 (85)	1 (1)	6 (6)	1 (1)	1 (1)
S2	71	2 (2)	73 (51)	1 (1)	18 (13)	6 (4)

In the research, the reference gravimetric method with PNS3D15 low-volume dust meters was used. To assess the meteorological conditions at S1 and S2, two portable weather stations were used (Davis Vantage). To determine the occurrence, duration and range of temperature inversion, weather balloons equipped with radiosonde and temperature detectors were used.

At both sites PM_{10} concentration was measured at 6 h intervals; 4-10, 10-16, 16-22, 22-4 hrs (during selected temperature inversion episodes at 1 h intervals). At both sites weather balloons (2x3) connected with nylon cord were exposed on three levels; 25, 50 and 100 m above the ground.

3. Results and discussion

The average concentrations of PM_{10} during cold months at S1 were almost twice as high as at S2. Statistical Wilcoxon tests confirmed these differences (*p-value* = 0.032 with a test significance level of $p \geq 0.05$). In addition, the comparison of particulate levels for cold and warm seasons showed that the average concentration of PM_{10} in the area of rural compact settlement was around three times greater than during the summer months. These differences indicate that anthropogenic origins of emission play a key role and strongly influence local air quality. Of course, not only local anthropogenic sources, but also the weather conditions, specific to certain periods of the year, affect the concentration levels of PM_{10}. During the four seasons of observation the average temperature was around -0.8°C, and almost 50% of the days were characterized by low wind speed (<1 km/h). Furthermore, the mean atmospheric pressure was 1002 hPa, which was associated with the presence of a large anticyclone from Russia. Measurements indicate that over 43% of days of observations were characterized by the presence of significant temperature inversion with over 2 °C differences between 0 and 25 meters above the ground.

Fig. 1 presents the average PM_{10} concentration at S1 and S2 during days with significant temperature inversion. Considerable differences can be observed. Insignificant statistical differences in weather conditions between the two places of observations clearly show that for the local aerosanitary conditions the type of individual heating systems is responsible. According to the CAFE Directive, only 35 days per year should have an average daily concentration of PM_{10} above 50 μg/m³. During only four selected months (2010-14) at S1, 42, 17, 47 and 22 days had such a concentration. At site S2 only in 2013 was the number of days characterized by a higher than acceptable level (36).

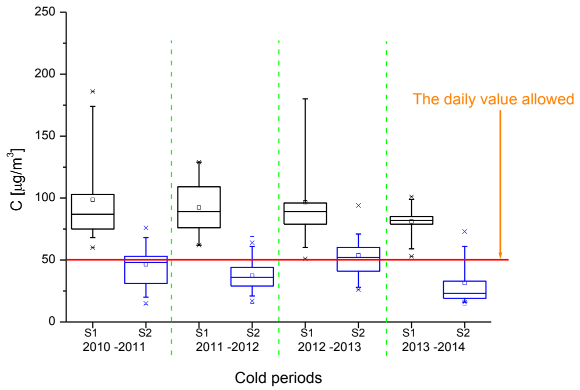

Fig. 1. Average PM_{10} concentration at S1 and S2 during days with temperature inversion only (boxes show the range between the 25th and 75th percentiles. The whiskers extend from the edge of the box to the 5th and 95th percentile of the data. The horizontal line inside indicates the median value. The small square inside indicates the average value).

The permanent presence of a temperature inversion and stable state of the atmosphere cause the inhibition of pollution propagation processes and significant local changes, exceeding the permissible daily PM_{10} concentrations. The measurements show that, enhanced by an anticyclone, the three-day period of temperature inversion occurrence only caused a situation in which local air emission levels did not meet the standards required for the protection of human health. Fig. 2 presents selected data for eight days of permanent presence of a temperature inversion. It can be seen that the inhibition of the dispersion in the atmosphere, for a similar temperature and size of local emission conditions, causes noticeable enrichment of the local atmosphere by particulate matter. On the other hand, studies proved that the appearance of the unstable state of the atmosphere and the horizontal movement of air masses >2.5 m/s resulted in a noticeable improvement of the aerosanitary conditions in one day.

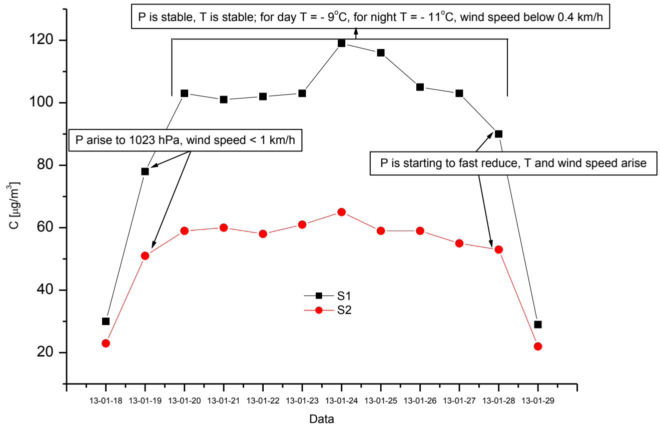

Fig. 2. Comparison of PM_{10} concentrations at S1 and S2 during permanent temperature inversion event 19.01.2013 – 28. 01.2013.

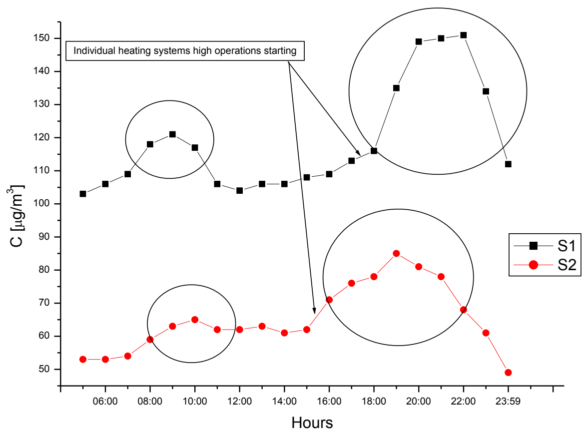

Fig. 3. PM_{10} concentrations at S1 and S2 under significant temperature inversion (2 °C at the distance from 0 to 25 m.a.g.), high atmospheric pressure (1028 hPa) and low temperature of air (-11 to -21 °C).

The effect of various sources of emissions for the hourly changes in PM_{10} concentration under the same specific weather conditions is shown in Fig. 3. Explicit differences in the concentration of PM_{10} at both places of designated measurement can also be observed for a short period of observation. Associated with increased exploitation of emission sources related to the mean, the maximum peaks are more than twice those for the older part of the village.

Table 2 presents analysis of the impact of weather conditions on PM_{10} concentrations. The data were statistically analysed (statistical significance $\alpha \leq 0.05$) and the estimated trend model adequately explains the correlation between meteorological factors and concentration of PM_{10}. A positive relationship was observed between PM_{10} concentrations, atmospheric pressure and average daily air temperature (but only during the warm period). A negative relationship, in turn, was observed between PM_{10} concentrations, the average daily wind speed and the average daily air temperature (but only during the cold period). The results of statistical analysis correspond to literature data (Hormann et al., 2005; Maraziotis et al., 2008) and show the main meteorological conditions that affect the modification process of an aerosanitary situation. In such cases, a rise in temperature and wind speed may contribute to the dispersion of particulate matter (Krynicka & Drzeniecka-Osiadacz, 2013).

Table 2. Relationship between the PM_{10} concentration and meteorological conditions.

Variables		**Correlation coefficient R (bold values significant for $\alpha \geq 0.05$)**					
		Cold season				Warm season	
		12.10-02.11	12.11-02.12	12.12-02.13	12.13-02.14	06.12-08.12	06.13-08.13
PM10	T [^{o}C]	-0.23	-0.22	-0.41	-0.37	0.09	0.14
PM10	V [m/s]	-0.39	-0.41	-0.32	-0.50	-0.33	-0.28
PM10	P [hPa]	0.43	0.29	0.26	0.31	0.04	0.03

Because distribution of measurements results was unknown for comparison of the concentrations the Wilcoxon signed-rank test was utilised. This non-parametric statistical hypothesis test was used for assessing whether one of two samples of independent observations (results of concentration measurements) tended to have larger values than the other. The two-tailed critical confidence level was considered in testing and the critical p-value was 0.05. The p-value for the two measurement sites is shown in Table 3. For considered conditions, the concentration of solid particles was determined by the local (individual heating) sources. In summary, the hypothesis with regard to dust pollutants was not upheld.

Table 3. Results of hypothesis checking.

Period of observation	**p-values S1/S2**			
	2010/11	2011/12	2012/13	2013/14
Daily avg. cold season	0.003	0.021	0.002	0.019
Hourly avg. cold season (during significant temperature inversion)	0.029	0.042	0.018	0.037

4. Conclusion

It can be stated that the source characteristics play a key role in local-rural air quality. For considered terms and the period of observation, conducting meteorological measurements can be considered sufficient for estimating the occurrence of alarm conditions. The results can be supra-local dimension and find confirmation of areas with similar characteristics of emission and climatic-meteorological conditions. At the local scale, the results of the experiment show that it is necessary to replace old heating systems with new ones that do not generate significant amounts of dust.

5. Acknowledgements

The author wishes to thank the authorities of the Mechanics Department of the Opole University of Technology for providing the necessary equipment and financial support without which it would not have been possible to carry out this research project.

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