

**Artur Stelegowski**

**Lodz University of Technology, Faculty of Architecture, Civil and Environmental Engineering,**  
al. Politechniki 6, 90-924 Lodz, Poland, artur.stelegowski@edu.p.lodz.pl

## CORRELATIONS BETWEEN AIR POLLUTANT CONCENTRATIONS IN SELECTED URBAN AND RURAL AREAS IN POLAND

### Abstract

Correlations between concentrations of selected air pollutants were analyzed in different areas in central Poland from 2012-2016. Three neighboring voivodeships (Lower Silesian, Lodz, and Masovian), were selected for which specific measurement locations were designated in urban and rural areas. The characteristics of the location of monitoring stations allowed to distinguish the following types of measurement stations: "urban-transport", "urban-background", "suburban-background", "town-background", and "rural-background". Therefore, using the Pearson's linear correlation coefficient, it was possible to analyze the interrelations between the occurrence of air pollution in various types of areas. It was found that the coefficient changed along with the type of area. Moreover, it turned out that the coefficient decreased in each voivodeship along with a decrease in the population density of the analyzed areas. In addition, concentrations of various air pollutants in given areas were compared. Also, it was observed that the strongest correlations occur between the results of calculations from measurement stations located in the same province.

### Key words

air pollution; statistical analysis; nitrogen dioxide; particulate matter

### Introduction

Occurrence of air pollution depends on the characteristics of the tested area. Levels of contaminants differ in urbanized and industrialized areas, and in less urbanized, or agricultural areas [1–3]. In addition, air quality varies depending on the characteristics of the region [2–4]. Generally, the level of air pollution is lower at rural sites, and higher in large cities [1, 5–6]. This is because air quality is strongly affected by emission sources of air pollution [7–9]. Therefore, it is assumed that the presence of specific pollutants in the air may indicate the activity of selected types of emission sources [10–12]. For example, an increase in the concentration of nitrogen oxides and carbon monoxide in the air near a road can be associated with an increase in traffic intensity. While presence of PM<sub>10</sub>, sulfur oxides and carbon monoxide in a residential area is often associated with the impact of individual home's fuel combustion. Also, meteorological conditions can affect the level of air quality. Nevertheless, the maximum and minimum daily concentrations at various areas could occur at a similar time (Fig. 1). For example, in Poland peak ground level ozone occurred usually at 15:00, nitrogen dioxide at 7:00-9:00 and 19:00-21:00, sulphur dioxide at 10:00-12:00, carbon monoxide at 6:00-8:00 and 20:00-22:00, PM<sub>10</sub> at 7:00-9:00 and 20:00-22:00 [6].

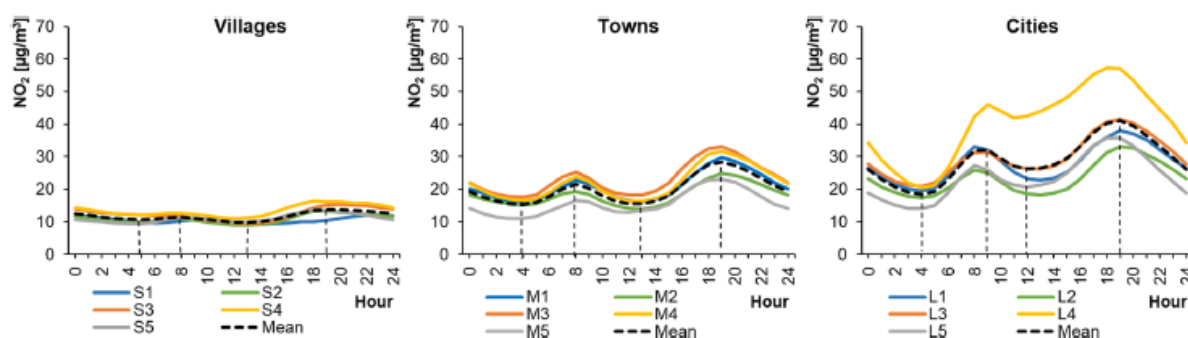


Fig. 1. Average hourly NO<sub>2</sub> concentrations in winter periods in selected villages, towns and cities in Poland in 2012-2016.

Source: [6]

Although the air quality, at a specific site, depend on many factors, some common characteristics of changes could be determined using statistical methods. Therefore, in literature, the correlation coefficient is often used as a statistical tool to analyze the nature of changes in air pollution [13–16]. Pearson's linear correlation coefficient is widely used, inter alia to analyze the dependencies between the presence of pollutants in the air, and various types of ailments and diseases occurring in the groups of people exposed to these pollutants [4,17]. By definition, this coefficient is used to determine the similarity of objects /variables and their linear interdependence [18–19]. When  $x$  and  $y$  are variables, the Pearson's linear correlation coefficient  $R$  can be calculated as follows (1):

$$R = \frac{\sum_{i=1}^n [(x_i - \bar{x}) \times (y_i - \bar{y})]}{\sqrt{(x_i - \bar{x})^2} \times \sqrt{(y_i - \bar{y})^2}} \quad (1)$$

Interpretation of the calculated coefficient depends on its value. The "stronger" are the interdependencies between variables, the higher is the coefficient. Therefore, specific ranges of the coefficient are determined, depending on the field of knowledge, to describe the "strength" of the interdependencies [19–20]. In this analysis, the interpretation of the  $R$  coefficient was adopted according to Table 1.

Table 1. Interpretation of  $R$  linear correlation coefficient.

R (-)	Interpretation
0.90–1.00	Very high correlation
0.70–0.89	High correlation
0.50–0.69	Moderate correlation
0.30–0.49	Low correlation
0.00–0.29	Little, if any, correlation

Source: [19]

The analysis was aimed at demonstrating the interdependence (or lack thereof) between the occurrence of air pollution in various types of areas, especially urban and rural areas within the same region. However, in the literature, usually only the correlations between various pollutants and their dependence on meteorological conditions are calculated [16, 21]. Unfortunately, there is a lack of comparative calculations, regarding relationships between different urban and rural areas. Therefore, in the analysis, Pearson's linear correlation coefficients were determined between the concentrations of the selected pollutant in the air in areas with different characteristics, i.e. in urban and rural areas in three voivodships in central Poland. The pollutants analyzed were: nitrogen dioxide ( $\text{NO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ), ground-level ozone ( $\text{O}_3$ ), and  $\text{PM}_{10}$ . Additionally, in selected locations, correlation coefficients between concentrations of different air pollutants were compared.

### Method description

Interdependencies between hourly air pollutants concentrations in various areas were analyzed by determining the Pearson's linear correlation coefficient  $R$ . Occurrence of pollutants was compared in three voivodeships (Lower Silesian, Lodz, and Mazovian) in central Poland, at selected areas: "urban traffic" - UT, "city background" - CB, "suburb background" - SB, "town background" – TB, and "rural background" – RB (Table 2). The occurrence of  $\text{NO}_2$ ,  $\text{SO}_2$ ,  $\text{O}_3$ ,  $\text{CO}$ , and  $\text{PM}_{10}$ , was analyzed. The parts of data used in the analysis were obtained from 15 selected automatic air quality monitoring stations in Poland, during 2012–2016. Therefore, around 43,000 measurements of a given air pollutant were obtained from a single monitoring station. However, as technical and maintenance breaks occurred in operation of measuring stations, only the parts of data with at least 75% completeness for a particular year and station, were used in the analysis.

Table 2. Location of measuring stations in selected voivodeships in Poland (where: UT – urban traffic, CB – city background, SB – suburb background, TB – town background, RB – rural background)

Province	Name of settlement	Type of settlement	Type of monitoring station
Lower Silesia	Wrocław	City	UT, CB, SB
	Kłodzko	Town	TB
	Osieczów	Village	RB
Lodz	Lodz	City	UT, CB, SB
	Piotrków Tryb.	Town	TB
	Gajew	Village	RB
Mazovia	Warsaw	City	UT, CB, SB
	Piastów	Town	TB
	Belsk Duży	Village	RB

Source: Author's

## Results

Changes in concentrations of air pollutants in a given area often correlated with changes in concentrations in other areas. For example, such a relationship is presented in Fig. 2, where the increase in NO<sub>2</sub> concentration in the city's downtown (CB area) is associated with an increase in this pollutant concentration outside the city center (SB area).

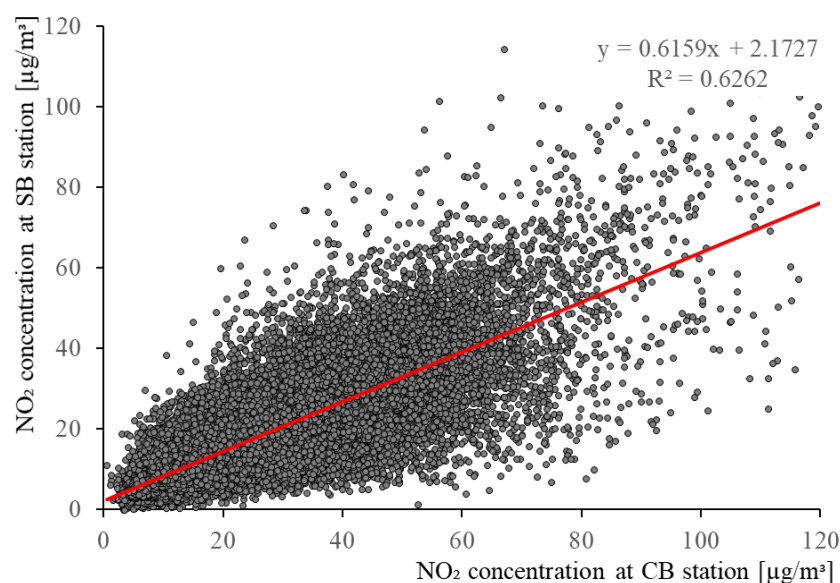


Fig. 2. Correlation between NO<sub>2</sub> concentrations at SB and CB stations in the city of Lodz.

Source: Author's

For NO<sub>2</sub>, the correlation of results was medium–high between UT and CB ( $R$  ranged from 0.61 to 0.82), as well as between CB and SB ( $R$  from 0.61 to 0.82) (Table 3). The town background and rural background were most interdependent with the suburb background areas. However, the interdependencies between NO<sub>2</sub> concentrations were most visible in the areas within the same voivodeship. The highest correlation of coefficients were in the Lodz Voivodeship ( $R$  of 0.53–0.82) which varied less than in the other two voivodeships. This could indicate the similarity of conditions, such as traffic, urban planning, concentration of emission sources, affecting the change in pollution concentration. Generally, the correlation coefficient decreased as the area changed to less urbanized areas within the same voivodeship. This indicates an increase in the changes in the conditions of air quality along with "moving away" from city centers (UT, CB). The changes in hourly concentrations differed when approaching areas characterized by a smaller number and density of inhabitants

(SB, TB, RB). This corresponded to the observation that usually air pollution level is much lower in rural areas comparing to urban areas [1, 5–6]. Unfortunately, in the literature, there is a lack of comparative calculations, regarding relationships between different urban and rural areas.

Table 3. Correlation coefficient between NO<sub>2</sub> concentrations in different areas (correlation was significant at the 0.01 level, 2-tailed). Light grey shadowing was used to underline the correlation coefficients within the same region.

-		Lower Silesia					Lodz					Masovia				
		UT	CB	SB	TB	RB	UT	CB	SB	TB	RB	UT	CB	SB	TB	RB
Lower Silesia	UT	-														
	CB	0.63	-													
	SB	0.40	0.73	-												
	TB	0.39	0.49	0.49*	-											
	RB	0.12	0.43	0.43	0.39	-										
Lodz	UT	0.55	0.54	0.39	0.37	0.19	-									
	CB	0.50	0.61	0.46	0.47	0.33	0.82	-								
	SB	0.42	0.61	0.55	0.46	0.35	0.68	0.79	-							
	TB	0.23	0.48	0.45	0.39	0.45	0.53	0.61	0.59	-						
	RB	0.48	0.60	0.52	0.51	0.29	0.69	0.76	0.72	0.60	-					
Masovia	UT	0.56*	0.34	0.22	0.15	-0.02	0.47	0.38	0.39	0.15	0.39	-				
	CB	0.58	0.38	0.20	0.27	0.07	0.58	0.55	0.39	0.28	0.45	0.61	-			
	SB	0.42	0.52	0.47	0.43	0.24	0.59	0.67	0.65	0.54	0.69	0.53	0.55	-		
	TB	0.38	0.50	0.44	0.41	0.24	0.62	0.68	0.61	0.58	0.68	0.42	0.54	0.80	-	
	RB	0.22	0.38	0.33	0.36	0.43	0.37	0.49	0.44	0.55	0.48	0.08	0.27	0.44	0.49	-

\*Correlation was insignificant at the 0.01 level

Source: Author's

The nature of SO<sub>2</sub>, O<sub>3</sub>, CO, and PM<sub>10</sub> changes in Lodz voivodeship was similar to those of NO<sub>2</sub>. Namely, the linear correlation coefficient within the same voivodeship decreased along with the change to a less urbanized type of area (Tables 4–7). Interdependencies in various areas were high (and very high) in the case of ozone, and of carbon monoxide, but medium (and high) for particulate matters, and for SO<sub>2</sub>. This indicates a large similarity in the nature of changes in concentrations of these pollutants in the analyzed areas. Therefore, an increase of city background pollution occurred at a similar time as the increase in concentrations in other areas. The similarity was the greater, the more similar were the areas. Also, the analyzed correlations of the areas type ( $R = 0.52\text{--}0.95$ ) were higher than correlations between air pollutants and weather conditions ( $R = \pm 0.01\text{--}0.89$ ) in locations of other studies [21–22]. The calculated correlations were significant for the level 0.01, unless otherwise indicated in the tables. Unfortunately, some stations in the Lodz voivodeship did not perform measurements of SO<sub>2</sub>, O<sub>3</sub> and CO. Therefore, the corresponding cells were marked as "not applicable" (n/a).

Table 4. Correlation coefficient between SO<sub>2</sub> concentrations in Lodz Province.

SO <sub>2</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	0.67	-		
TB	n/a	0.69	0.52	-	
RB	n/a	0.62	0.56	0.58	-

Table 5. Correlation coefficient between O<sub>3</sub> concentrations in Lodz Province.

O <sub>3</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	0.95	-		
TB	n/a	0.90	0.87	-	
RB	n/a	0.86	0.84	0.88	-

Source: Author's

Table 6. Correlation coefficient between CO concentrations in Lodz Province.

CO	UT	CB	SB	TB	RB
UT	-				
CB	0.90	-			
SB	0.80	0.83	-		
TB	0.78	0.78	0.70	-	
RB	n/a	n/a	n/a	n/a	-

Table 7. Correlation coefficient between PM<sub>10</sub> concentrations in Lodz Province.

PM <sub>10</sub>	UT	CB	SB	TB	RB
UT	-				
CB	0.87	-			
SB	0.75	0.80	-		
TB	0.71	0.75	0.70	-	
RB	0.64	0.64	0.70	0.59	-

Source: Author's

The nature of air pollution changes in the Masovia voivodeship was similar to that of the Lodz voivodeship. Linear correlation coefficients decreased along with the change to a less urbanized type of area, within the same voivodeship (Tables 8–11). Interdependencies between air pollutants concentrations were high (and very high) in the case of ozone, medium (and high) for PM<sub>10</sub>, low (and medium) for SO<sub>2</sub>, and for CO. This indicated large similarities in the character of changes in the level of ozone in the analyzed areas, but much lower similarities for other analyzed pollutants. The correlations were significant for the level 0.01, unless otherwise indicated in the tables. Unfortunately, some stations in the Masovia voivodeship did not perform measurements of SO<sub>2</sub>, O<sub>3</sub>, CO and PM<sub>10</sub>. Therefore, the corresponding cells were marked as "not applicable" (n/a).

Table 8. Correlation coefficient between SO<sub>2</sub> concentrations in Masovia Province.

SO <sub>2</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	n/a	-		
TB	n/a	n/a	0.53	-	
RB	n/a	n/a	0.34	0.48	-

Table 9. Correlation coefficient between O<sub>3</sub> concentrations in Masovia Province.

O <sub>3</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	n/a	-		
TB	n/a	n/a	0.94	-	
RB	n/a	n/a	0.82	0.84	-

Source: Author's

Table 10. Correlation coefficient between CO concentrations in Masovia Province.

CO	UT	CB	SB	TB	RB
UT	-				
CB	0.53	-			
SB	n/a	n/a	-		
TB	n/a	n/a	n/a	-	
RB	0.35	0.54	n/a	n/a	-

Table 11. Correlation coefficient between PM<sub>10</sub> concentrations in Masovia Province.

PM <sub>10</sub>	UT	CB	SB	TB	RB
UT	-				
CB	0.69	-			
SB	0.72	0.87	-		
TB	n/a	n/a	n/a	-	
RB	0.59	n/a	0.67*	n/a	-

\*Correlation was significant at the 0.05 level

Source: Author's

Also, the nature of air pollution changes in the Lower Silesia voivodeship was similar to that for the Lodz and Masovia voivodeship. Linear correlation coefficients decreased along with the change of the type of area into less urbanized, within the same voivodeship (Tables 13–16). Interdependencies between air pollutants concentrations were high (and very high) in the case of ozone, but low (and medium) for SO<sub>2</sub>. This indicated large similarities in the character of changes in the level of ozone in the analyzed areas, but much lower

similarities for other analyzed pollutants. The correlations were significant for the level 0.01, unless otherwise indicated in the tables. Unfortunately, some stations in the Lower Silesia voivodship did not perform measurements of SO<sub>2</sub>, O<sub>3</sub>, CO and PM<sub>10</sub>. Therefore, the corresponding cells were marked as "not applicable" (n/a).

Table 12. Correlation coefficient between SO<sub>2</sub> concentrations in Lower Silesia.

SO <sub>2</sub>	UT	CB	SB	TB	RB
UT	-				
CB	0.69	-			
SB	n/a	n/a	-		
TB	0.46	0.48	n/a	-	
RB	0.42	0.41	n/a	0.31	-

Table 13. Correlation coefficient between O<sub>3</sub> concentrations in Lower Silesia.

O <sub>3</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	0.95	-		
TB	n/a	0.80	0.84*	-	
RB	n/a	0.82*	0.84	0.78	-

\*Correlation was insignificant at the 0.01 level

Source: Author's

Table 14. Correlation coefficient between CO concentrations in Lower Silesia.

CO	UT	CB	SB	TB	RB
UT	-				
CB	0.77	-			
SB	n/a	n/a	-		
TB	n/a	n/a	n/a	-	
RB	n/a	n/a	n/a	n/a	-

Table 15. Correlation coefficient between PM<sub>10</sub> concentrations in Lower Silesia.

PM <sub>10</sub>	UT	CB	SB	TB	RB
UT	-				
CB	n/a	-			
SB	n/a	n/a	-		
TB	n/a	0.40	n/a	-	
RB	n/a	n/a	n/a	n/a	-

Source: Author's

In addition, the occurrence of various pollutants was compared within stations containing the largest number of data, i.e. stations located in urban (CB, SB, TB) areas, and rural (RB) areas in the Lodz region. Correlation was the strongest for NO<sub>2</sub>, CO and PM<sub>10</sub> (Tables 16-19). This could indicate the impact of emissions from road transport at similar times of the day [21]. Also, the analyzed correlations ( $R = -0.61-0.87$ ) between air pollutants were comparable to other studies [21-22]. However, the O<sub>3</sub> concentrations had negative correlation with other pollutants. This was because in Poland the ground-level ozone reached the highest concentrations during early afternoon, resulting from occurrence of photo-chemical processes, while other pollutants had the highest concentrations in the morning, in the evening, or at night [6]. The calculated correlations were significant for the level 0.01, unless otherwise indicated in the tables. Unfortunately, RB station did not perform measurements of CO. Therefore, the corresponding cells were marked as "not applicable" (n/a).

Table 16. Correlation coefficient between air pollutants concentrations in CB area in Lodz Province.

City Background	NO <sub>2</sub>	O <sub>3</sub>	SO <sub>2</sub>	CO	PM <sub>10</sub>
NO <sub>2</sub>	-				
O <sub>3</sub>	-0.54	-			
SO <sub>2</sub>	0.42	-0.32	-		
CO	0.70	-0.55	0.61	-	
PM <sub>10</sub>	0.65	-0.44	0.61	0.84	-

Source: Author's

Table 17. Correlation coefficient between air pollutants concentrations in SB area in Lodz Province.

Suburb Background	NO <sub>2</sub>	O <sub>3</sub>	SO <sub>2</sub>	CO	PM <sub>10</sub>
NO <sub>2</sub>	-				
O <sub>3</sub>	-0.56	-			
SO <sub>2</sub>	0.36	-0.21	-		
CO	0.69	-0.53	0.46	-	
PM <sub>10</sub>	0.59	-0.34	0.45	0.74	-

*Source: Author's*

Table 18. Correlation coefficient between air pollutants concentrations in TB area in Lodz Province

Town Background	NO <sub>2</sub>	O <sub>3</sub>	SO <sub>2</sub>	CO	PM <sub>10</sub>
NO <sub>2</sub>	-				
O <sub>3</sub>	-0.55	-			
SO <sub>2</sub>	0.51	-0.30	-		
CO	0.63	-0.45	0.71	-	
PM <sub>10</sub>	0.60	-0.38	0.67	0.87	-

*Source: Author's*

Table 19. Correlation coefficient between air pollutants concentrations in RB area in Lodz Province

Rural Background	NO <sub>2</sub>	O <sub>3</sub>	SO <sub>2</sub>	CO	PM <sub>10</sub>
NO <sub>2</sub>	-				
O <sub>3</sub>	-0.61	-			
SO <sub>2</sub>	0.35	-0.15	-		
CO	n/a	n/a	n/a	n/a	
PM <sub>10</sub>	0.56	-0.27	0.43	n/a	-

*Source: Author's*

## Conclusions

Calculated linear correlation coefficients for air pollutants had a similar tendency in the analyzed locations. Although the hourly concentrations of pollutants varied greatly depending on the area, some correlation between these results was observed. This was particularly visible within the same region, where the coefficients were the highest ( $R$  up to 0.82 for NO<sub>2</sub>, 0.69 for SO<sub>2</sub>, 0.95 for O<sub>3</sub>, 0.90 for CO, 0.87 for PM<sub>10</sub>). Correlation coefficient for air pollutants decreased along with the change of characteristics (UT, CB, SB, TB, RB) of the analyzed area to a less dense area. Results of measurements in the cities (UT and CB areas) were more strongly interrelated with each other, than results from a city (UT) and a village (RB). For example, PM<sub>10</sub> concentrations at urban traffic site in Lodz (Table 7) were highly correlated to city background ( $R = 0.87$ ) suburb background ( $R = 0.75$ ) and town background ( $R = 0.71$ ), and moderate correlated to rural background ( $R = 0.64$ ). However, interrelations between air pollutants in the same area were the strongest between NO<sub>2</sub>, CO and PM<sub>10</sub> (Tables 16-19). Correlation coefficient between nitrogen dioxide and carbon monoxide was 0.70 in city background, 0.69 in suburb background, and 0.63 in rural background. For NO<sub>2</sub> and PM<sub>10</sub> the coefficient was from 0.56 at RB monitoring station to 0.65 at CB station. This could indicate the impact of emissions from road transport, which generates inter alia those three pollutants. However, ground-level ozone had a negative correlation to other analyzed pollutants, as its concentration is usually increasing in the afternoon, contrary to other air pollutants [6]. This could be a result of photochemical processes, affected by solar radiation and ambient temperature [21]. Those interrelations were similar to those of other studies [21–22]. However, it should be remembered, that the correlation coefficients do not prove the existence (or absence) of dependencies between the analyzed variables [24], but may indicate the occurrence of such



interdependencies. Also, the results from air quality measuring stations might not always adequately represent the air quality conditions in large, especially highly urbanized areas [25].

Generally, *R* values decreased along with the change in the type of area into less urbanized, within the same voivodeship. Therefore, it should be further investigated if the most significant impact to this phenomenon was related to similar weather conditions in the same region, or the urban spatial structure, or hourly profiles (patterns) of human activity. However, a strong influence from all factors was very likely related.

#### Conflict of interest

There are no conflicts to declare.

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