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Landscape pattern as an indicator of urban air pollution of particulate matter in Poland

Damian Łowicki

Adam Mickiewicz University in Poznan, Faculty of Geographical and Geological Sciences, ul. B. Krygowskiego 10, 61-680 Poznan, Poland

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ABSTRACT

Air pollution is the single largest environmental health risk. It significantly impacts human life and the condition of ecosystems. One type of dangerous pollutant is particulate matter (PM). All EU countries, especially Poland, should take intensive actions to achieve the necessary standards of air quality. These actions should be aimed at reducing emissions on the one hand, and on the other, at reducing the PM concentrations in the air. To achieve this, identification of the factors influencing air pollution is needed. In this study, the landscape pattern, climate and emissions around PM monitoring points were recognized. Climate factors, particularly wind speed, prove to be most important for PM pollution. In addition, the landscape pattern modifies the concentration significantly, especially in the case of PM2.5. The presence in the landscape of green areas with a large surface and complex shape is connected to the lesser concentration of PM. The importance of emissions, although statistically significant, was rather small. In particular, the relationship between the distance to large point sources and PM concentration was not demonstrated, meaning that the pollution from high chimneys is strongly dispersed and does not affect the concentrations of PM in their vicinity. It is concluded that the landscape indicators provide new information to explain the PM concentration and that it is very important to shape the landscape with consideration of green areas as a pollutant filter. Taking into account the green areas together with pollution sources in spatial planning can significantly support the effectiveness of air protection, and at the same time, can increase the comfort of life by providing a whole range of ecosystem services, both regulating and cultural. The landscape approach best suits the needs of spatial planning, especially in cities where the highest anthropogenic pressure and increased demand for ecosystem services are evident.

1. Introduction

Air quality significantly impacts human life and the condition of ecosystems, both directly and through processes related to climate change. As the WHO (2014) reports, air pollution is the single largest environmental health risk. The number of deaths per 100,000 capita attributable to ambient air pollution in the world was 53 in 2012. The most common reasons for premature death caused by air pollution are ischaemic heart diseases and strokes, as well as lung diseases and lung cancer (WHO, 2014). The International Agency for Research on Cancer has classified air pollution in general, as well as particulate matter (PM) as a separate component of air pollution mixtures, as carcinogenic (IARC, 2013). Exposure to elevated levels of PM significantly influences life expectancy. Studies conducted for six U.S. cities indicate that mortality was most strongly associated with air pollution with fine particulates. (e.g. Dockery et al., 1993). Analyses conducted in Wrocław, Poland, showed that the estimated number of cases of mortality per 100,000 relating to PM2.5 concentration amounted to 150–166 cases in 2014 (Sówka et al., 2016).

To decrease the negative impacts of PM on, and risks to, human health and the environment, the EU created legislation using a twin-track approach of implementing both emission mitigation controls and air-quality standards. The first approach is represented by the directive on the limitation of emissions of certain pollutants into the air from medium combustion plants (EU, 2015). The second approach is implemented by a directive on ambient air quality (EC, 2008). The air quality limit given in this directive for PM10 is 40 $\mu g/m^3$ (annual) and 50 $\mu g/m^3$ (daily), and for PM2.5 is 25 $\mu g/m^3$ (annual). Despite the actions taken under these directives, high concentrations of PM still remain an unresolved problem in Europe. PM10 concentrations above the EU daily limit value were registered in 21 of the 28 EU member states in 2014. Poland, next to Bulgaria, is the country where the concentration of PM is the highest, contributing to almost 50,000 premature deaths in 2013. The vast majority of monitoring stations showing concentrations above the PM annual limit were located in urban areas (93% for PM10) in 2014. In Poland, the population-weighted concentrations of PM10 and PM2.5 to

E-mail address: damek@amu.edu.pl.

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which the urban population is potentially exposed were, respectively, 56% and 72% higher than average for the EU-28 in 2014 (Eurostat, 2014). According to the classification of WHO (2016), six for PM10 and ten for PM2.5 among the ten most polluted cities in the region (European high income countries) are located in Poland. Fine particles in urban areas are more dangerous for people as they contain more metals and toxic organic compounds, like PAHs (Langner et al., 2011), especially for people living in street canyons. However, a study for Poland proved that the cities vary significantly in terms of concentrations and chemical composition of PM (Rogula-Kozłowska et al., 2014).

There are many studies identifying the influence of different factors on PM concentration. They usually concern the separate roles of climatic conditions (Baklanov et al., 2009; Salizzoni et al., 2009), economic factors (Jiang et al., 2018; Cheng et al., 2017) and vegetation (Jeanjean et al., 2016; McDonald et al., 2007). Less often, studies show the significance of green areas by analysis of landscape structure (Wu et al., 2015; Weber et al., 2014). This study covers all of these factors and distinguishes the role each of them by comparing together 26 Polish agglomerations. The research objective of this study is to assess the influence of landscape pattern, emissions and climate on PM pollution on a regional scale. This is the voice in the discussion regarding the role of vegetation in cities, which has taken place between scientists from various fields for a long time. The practical objective is to give a basis to the spatial planners for such space design to use green areas as a filter for PM. The detailed questions to be answered are as follows: 1. How do Polish cities differ in respect to PM pollution? 2. What is the place of landscape structure, among other factors, such as climate and emissions, in influencing particle concentration? 3. What features of green areas decide their efficiency in pollutant capturing? 4. In what season is the effect of green areas strongest? 5. What are the differences between the effects of green areas on PM2.5 and PM10 pollution?

2. Study area

A total of 26 Polish large urban zones (LUZs) with more than 100,000 inhabitants, as defined by the Urban Atlas, were analysed (EEA, 2010) (Fig. 1). The study area covers 68,625 km^2, i.e., almost 22% of the area of Poland, which is inhabited by 21 million people, i.e., almost 55% of Poland's total population.

The mean area of agglomeration is 2610 km^2 (Table 1). Agricultural, semi-natural areas and wetlands cover the LUZ area by 55.6% on average, forests 31.6% and urban areas 5.3%.

3. Materials and methods

3.1. PM concentration

The first step of the study was the data collection of PM concentrations for 2014. These data for 31 stations in the case of PM2.5 and for 52 stations for PM10 for seasons, as well as annually, were gained from GIOŚ (2014). All points represent urban and suburban types and their measurement height is 1.5–4.0 m, usually 2.5 m above ground level. The PM concentration was used as a dependent value in statistical data processing including Pearson correlation and multiple regression. As independent variable indicators of emissions, dispersion and deposition were chosen.

3.2. Emissions

The total load of PM in the EU-28 is more than 3,000,000 tones annually (Eurostat, 2014). Poland, next to France, Germany and Italy is the leader in emissions (11% and 12.4% of the total EU emission for PM2.5 and PM10 in 2014, respectively). The most important source of

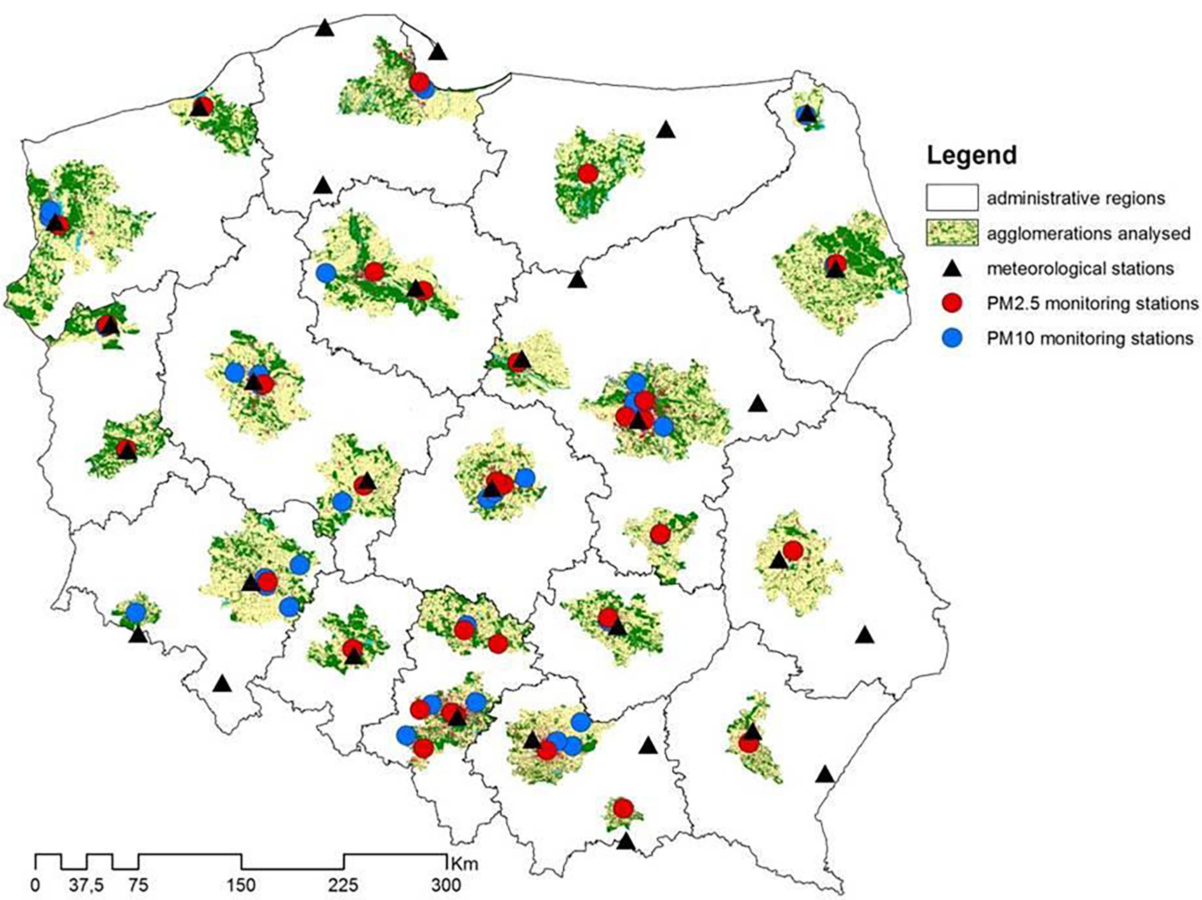

Fig. 1. LUZs, meteorological stations and air monitoring points analysed.