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Mapping the supply and demand of regulating air chemical composition in Lithuania

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SUMMARY

Urban and industrial areas contribute substantially to air quality degradation. Evidence shows that the pollution released in these areas is responsible for human health problems. Therefore, it is of paramount importance to identify the areas that can contribute to air pollution mitigation (supply) and the areas where from a human standpoint, it is more needed (demand). This work maps and assesses the supply and demand for regulating air chemical composition in Lithuania. The results showed a higher supply in areas with high forest density, while the demand is high in the major urban areas. Overall, there is a mismatch between supply and demand. Further work at a high resolution in urban areas is needed since the demand for regulating air chemical composition is highly important for human well-being.

Introduction

Urban and industrial expansion is the most important causes of air quality degradation. It is estimated that approximately 7 million persons die per year due to problems related to air pollution (https://www.unep.org/explore-topics/air/about-air). Therefore, it is urgent to identify areas where the pollution needs to be mitigated and find solutions to reduce the impacts of air pollution, especially those that use nature-based solutions (Pereira et al., 2021). Mapping and assessment of ecosystem services (ES) have been widely applied to find the areas where the ecosystems have a high capacity to remove pollutants (supply), but also to identify where clean air is more needed (e.g., Raum, 2018; Zhang and Munoz Ramirez, 2019; Zhao et al., 2019). This will be key to land managers to distinguish the areas that are more vulnerable to atmospheric pollution. Green areas are recognized as areas with a high capacity to clean air, while in dense urban areas, the air quality usually is poor and has negative implications for human health (Pereira et al., 2021). From the modelling point of view, there is a need to increase the number of ES quantitative assessments to increase the reliability of the models. As some studies highlighted, still, most of the studies were focused on qualitative models (e.g., Inácio et al., 2020). This work aims to map and assess the supply and demand for regulating air chemical composition in Lithuania.

Materials and Methods

Study area: Lithuania is a country located in the Baltic Sea coast (Northeast Europe). Nowadays, it has 2.8 million inhabitants. Most of them live in urban areas. The major cities are Vilnius (580,000 inhabitants), Kaunas (330,000 inhabitants), Klaipeda (170,000 inhabitants) and Šiauliai (101,511 inhabitants) (Inacio et al., 2021). *Data and Methods:* The ES modelled were assessed following the CICES 5.1 classification (https://cices.eu/). The data applied to assess the supply for regulation of air chemical composition were from dominant leaf type and tree density (https://land.copernicus.eu/), both with 20 m resolution. The capacity of each leaf type to capture pollution was assessed according to Räsänen et al. (2013). To assess the demand for regulation of air chemical composition, we used buildings and primary and secondary roads from Lithuanian Cadastre (https://www.registrucentras.lt/); stationary pollutant sources in 20221 from Lithuanian Geological Survey (https://www.lgt.lt/) and vectorized from google maps engine; average wind speed (average 2014-2018) was extracted from worldclim database (Fick and Hijmans, 2017; http://worldclim.org/version2) with a 1000 m resolution and finally, Particulate matter (PM10) data from Copernicus database (https://www.regional.atmosphere.copernicus.eu/). The frameworks applied to assess the regulation of air chemical composition supply (Figure 1a) and regulation of air chemical composition demand (Figure 1b). The regulation of air chemical composition supply was assessed by reclassifying dominant leaf type and tree cover density. Subsequently, data were overlaid using ArcGIS 10.4 raster calculator. A Zonal statistics tool was applied to extract the mean values at the eldership level. Concerning the regulation of air chemical composition demand, the modelling step, the Euclidian distance tool, was applied to calculate the distance to the primary and secondary roads. Simultaneously, the density of stationary pollution sources and buildings were assessed using the Kernel density tool. After these data treatments, all the data was resampled at 1000 m and reclassified. Data was overlaid using a weight sum overlay method. Different weights were considered in this model since the areas with a high building density is where population density is high. Therefore, these areas are where the demand for clean air (Pereira et al., 2021). Therefore, we applied weight of 40%. All the other variables weighted 20%. The air chemical composition demand model regulation was validated using PM10 data (average 2014-2018). Similarly to the regulation of air chemical composition supply, a zonal statistics tool was applied to extract the mean values at the eldership level. Aggregating both models at the eldership level, we could compare both supply and demand dimensions. The classes were divided following the natural breaks method in the final maps (supply and demand). Validation was carried out by applying a linear regression and a Spearman correlation coefficient. The correlation between supply and demand models were also conducted with a Spearman correlation coefficient. To identify spatial autocorrelation, a Moran's I index was applied. Values close to -1 show a dispersed pattern, while values close to +1 are evidence of a clustered pattern. Values near 0 represent a random pattern. Also, a Getis Ord (GI*) hotspot was carried out to identify the clusters spatial distribution. Spatial and statistical analyses were carried out using Statistica 12.0. and ArcGIS 10.4. Scatterplots were created using online Plotly (https://chart-studio.plotly.com/).

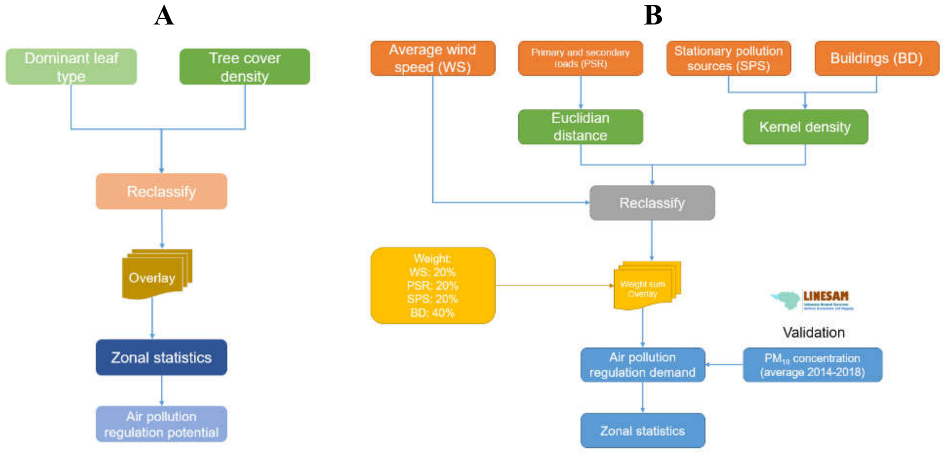

Figure 1 *Regulation of air chemical composition A) supply and B) Demand.*

Results and Discussion

On average, the regulation of air chemical composition supply had an index of 2.57 (±1.48), while the regulation of air chemical composition demand had an average of 2.80 (±0.63). The coefficient of variation was higher in the supply model (57.63%) than in demand (22.34%). This shows that the regulation of the air chemical composition supply distribution is spatially more heterogeneous. The validation of air chemical composition demand regulation was acceptable (R^2=0.49) (Figure 2) and shows that the model can assess the areas where the demand for air quality is high with some certain accuracy.

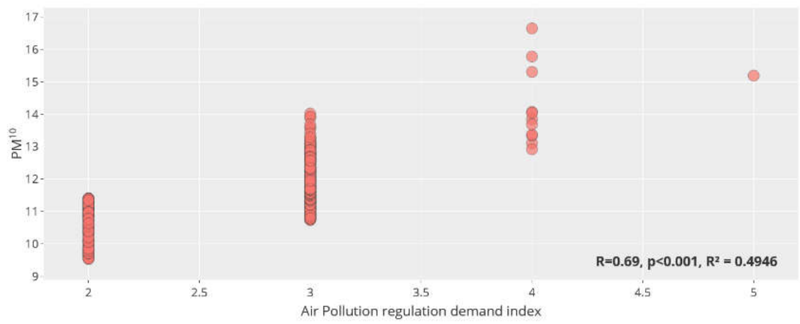

Figure 2 *Relation between Air pollution regulation demand index and PM_{10}.*

Moran's I results showed that both regulation of air chemical composition supply (z-score:13.97; p<0.001) and demand (z-score: 48.77, p<0.001) have a clustered pattern. Although both indexes have, a clustered pattern, it is clear that regulation of air chemical composition demand has a high z-score. This confirms the coefficient of variation results, and it is attributed to the fact that the areas with high demand are mainly located in urban areas, very clustered in space. Figure 3 shows the spatial distribution of air chemical composition supply and demand regulation and the respective hot-spot analysis. The highest values of air chemical composition regulation supply are in the forested areas located in the southeast part of Lithuania. The lowest were located in agricultural areas at the north and southwest of the country (Figure 3A), where forests are almost absent. Hot-spot analysis identified in the east and southeast areas as the ones with a high capacity of regulating air quality (Figure 3C). Regarding the regulation of air, chemical composition demand, the areas with the highest values correspond to the major cities (Vilnius, Kaunas, Klaipeda and Siauliai) (Figure 3B). These clusters were confirmed by the hot-spot analysis (Figure 3D). The correlation between regulation of air chemical composition supply and demand indexes showed a reduced (R=-0.33) (Figure 4) but significative negative correlation showing a substantial mismatch between the supply and the demand in some areas. For instance, urban areas have a reduced supply, and on the other hand, forest areas have reduced demand.

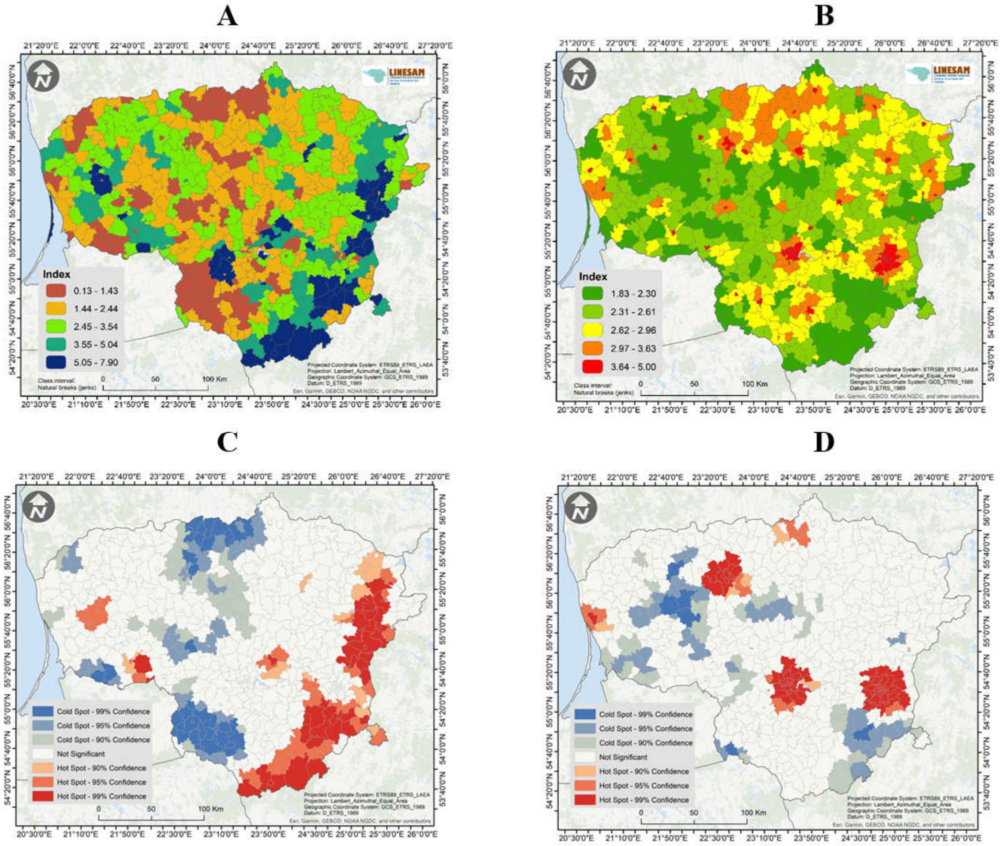

Figure 3 *Spatial distribution of regulation of air chemical composition A) supply, B) demand, C) supply Getis Ord hotspot and D) demand Getis Ord hotspot.*

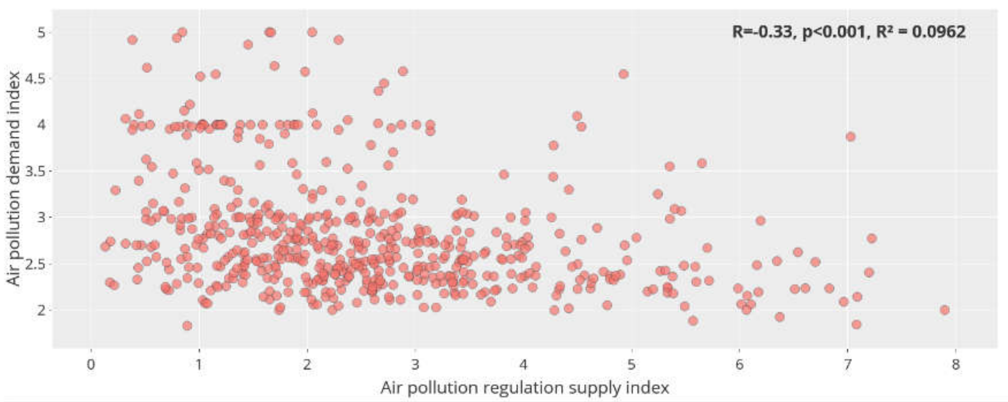

Figure 4 *Correlation between regulation of air chemical composition supply and demand.*

Modelling regulation of air chemical composition supply and demand is key to identifying areas with a high capacity to retain pollutants and where this ES is most needed. The modelling process has several limitations and uncertainties. The data we used to regulate air chemical composition demand has different data resolutions, which can produce some errors in the modelling process. This is a problem identified in other works focused on ES modelling (Hua et al., 2021). Also, we did not validate the supply model since there was no available data. The model was simple and did not consider many variables, which would make it complex. Nevertheless, model validation is crucial to ensure models credibility (Gomes et al., 2021), and further steps need to be considered in this direction. The regulation of air chemical composition demand had an acceptable validation. However, the PM10 data did not have the same resolution as the other variables used in the model. Therefore, some errors may have occurred as well. Finally, future studies are needed using quantitative methods at a better spatial resolution, mainly in urban areas where air pollution have more detrimental impacts on human health.

Conclusions

The results obtained in this work are essential to understand the spatial distribution of air chemical composition supply and demand regulation. We observed that the supply model had had a high coefficient of variation than the demand one. The values of high supply were located in the east and southeast areas of Lithuania, while the areas with high demand were located in the major urban areas.

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