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Cumulative Impact Evaluation in Central Part of Liepaja with Comulative Pollution Index Method and Air Pollution Dispersion Modelling

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Abstract. Cumulative impact evaluation is one of the most actual problems in air quality monitoring. At the same time, it is also the most problematic factor to evaluate due to lack of appropriate methodology. The aim of this study was to assess the opportunity to use a new method – Cumulative Pollution Index (CPI) in cumulative impact calculation from two different sets of data – bioindication survey with Index of Atmospheric Purity method and air pollution dispersion modelling. Results show that the usage of modelling data, instead of measurements, in cumulative impact evaluation can be quite difficult due to the fact that dispersion models not always give sufficiently accurate data. Despite the issues with modelling specifics, the use of dispersion modelling in CPI calculation shows that the use of this approach not only gives plausible data – obtained values correlate with pollution level and forming strong clustering in spatial distribution, but also reveals new facts about cumulative impact – demonstrates the city microclimate importance in forming of cumulative effect due to geometry of street canyons.
Key words: cumulative impact, air pollution, cumulative risk assessment, dispersion modelling, lichenoindication.

Introduction

Evaluation of cumulative effect – synergy between different pollutants and environmental factors is one of the most actual problems in the air quality monitoring field due to lack of appropriate methodology, because the cumulative risk assessment to real-world mixtures is hindered by a lack of verified analytical frameworks (Callahan and Sexton, 2007).

There are only a few methods available for cumulative risk assessment. They are relatively simple and use statistical models with a small fixed number of pollutants in association with different factors (Meek et al., 2011; Monosson, 2005). For example, Bell, Peng and Dominici (2006) use combined effect of ozone exposure and particle pollution (PM10); Cumulative Environmental Hazard Inequality Index (CEHII) method (Su et al., 2009) was used to evaluate exposure to multiple air pollutants within different racial-ethnic groups and socioeconomic positions in Los Angeles, etc. Such cumulative risk assessments are not only done with measurements approach, but also by using air pollution dispersion modelling (Davies and Whyatt, 2014; Krzyzanowski, 2011). However, like similar measurements, these studies are based more on dose additivity than evaluation of cumulative effect forming factors – interactions between pollutants and environmental factors.

One of the recent methods – Cumulative Pollution Index (CPI) uses a completely different approach – cumulative effect is calculated from simultaneous bioindication and air quality measurements (Kalniņš, 2012). In this way, theoretically, it is possible to use unlimited number of pollutants and interactions, because cumulative impact is derived from the vitality of indicator organisms instead of evaluation of separate interactions among pollutants.

CPI method is completely new and has been used only in one study of air quality – cumulative pollution evaluation in Riga and Liepaja in 2013 when cumulative impact was calculated from measurements done by automated air quality monitoring stations and biochemical analysis of lichen samples, placed on these stations. (Kalniņš et al., 2014). Due to this fact, it was unclear, if CPI method can be effectively used only in measurements based studies or it can also be used to calculate cumulative impact in air pollution dispersion modelling. Therefore, the aim of this study was to find it out by evaluating with CPI method the cumulative impact in the central part of Liepaja, as information basis for calculations using data from the latest pollution dispersion modelling done by municipality of Liepaja.

Materials and Methods

Calculation of Cumulative Impact

The place of study – Liepaja was chosen due to information availability. In the use of CPI method, bioindication results and pollution concentrations

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are needed, both for the same time period, and for Liepaja such data was available – the evaluation of traffic impact on air quality in the central part of Liepaja in 2007 with dispersion modelling method and bioindication data – accounting of lichen flora at different locations, collected in the same year for preparation of bachelor thesis (Kalniņš, 2009).

To use these bioindication data in CPI calculation, they were summarized with Index of Atmospheric Purity, developed by LeBlanc and De Sloover (1970):

$$IAP = \sum_{1}^{n} \frac{(Q \times f)}{10}$$

where:
n = number of lichen species presented at a site;
f = frequency (cover) of the lichen species (scale of 1 to 5);
Q = ecological index of each lichen species i.e. the mean number of other lichen species growing with the species under study in the surveyed area.

According to these data, lichen flora in the central part of Liepaja can be divided in two zones – medium pollution level (IAP range from 54.9 to 110.2) where 4-5 species of lichen were found (*Lepraria incana, Xanthoria parietina, Lecanora conizaeoides, Hypogymnia physodes, Parmeliopsis ambigua*) and medium low pollution (IAP range from 111.9 to 200.7) – 5-8 species of lichen (in addition to species of medium pollution zone, also *Lecanora chlarotera, Platismatia glauca, Parmelia sulcata Taylor*).

As lichen species show long term pollution effects (Falla et al., 2000; Nimis et al., 2002; Tiwari, 2008), to align both types of data – bioindication and dispersion modelling, the time frame for CPI calculations was chosen for one calendar year (2007.), respectively, also units from dispersion modelling data were chosen – year average values.

Dispersion modelling was done by Ltd. Estonian, Latvian & Lithuanian Environment on contract by the Municipality of Liepaja with ADMS Roads 2.2 model. It shows dispersion of nitrogen oxides (NO_X). According to modelling survey authors, traffic is the only significant pollution source in the central part of Liepaja and NO_X takes the largest part in composition of car exhaust gases (Estonian, Latvian and Lithuanian Environment, 2007). According to these data, the air pollution level in most of the central part of Liepaja is medium to low (10-20 to 2-5 µg m^{-3})

To evaluate cumulative pollution in the central part of Liepaja, 12 points were selected according to bioindication data availability. The locations, coordinates and spatial distribution of these points are shown in Table 1 and Figure 1. For cumulative effect calculation, modified version of CPI equation was used:

$$CPI = \frac{\left\{\left[\left(IAP_C - IAP\right) / \left(IAP_C - 1\right)\right] \times 100\right\}}{\left\{\left[\left(\sum_1^{np} MC_p\right) / \left(\sum_1^{np} BP_p\right)\right] \times 100\right\}}$$

where:
CPI – Cumulative Pollution Index (unitless value – greater number, greater cumulative impact);
MCp – modelled concentration of pollutant p;
BPp – breakpoint of pollutant p concentration (according to normative);
np – number of pollutants;
IAP – IAP value;
IAPc – IAP value in control site.

As the control site (IAPc), small urban forest, near the ruins of South fortification of Liepaja, was used – coordinates: 56.480955; 21.001331, IAP value – 345 which, according to LeBlanc and De Sloover (1970), is considered as an indicator of clean urban air (IAP >200).

Statistical Analysis of Cumulative Impact Evaluation Results

To determine whether there is a correlation between obtained CPI values and pollution level, correlation analysis was done by using Microsoft Excel built-in Analysis ToolPak. In result, the correlation coefficient (r) for two factors – NO_X pollution and CPI values were calculated. Since the result of this study consists of CPI values and their spatial distribution, to determine if there are any spatial patterns in cumulative effect detections, spatial autocorrelation in the form of Moran's I index was calculated using an online tool, developed by the University of Tartu for statistical analysis of spatial data (available at http://digiarhiiv.ut.ee/kalkulaator/). For Moran's I calculations, the following specification was used: area borders – 56.50631 E min; 56.51399 E max; 21.01018 N min; 21.02341 N max, the number of intervals – 10, the interval size 10, p=0.05).

Results and Discussion

In this study, as a cumulative effect possible interaction between the following factors – NO_X, temperature, humidity and pollutants created in combustion of fuel, but not used in specific modelling – O_3, SO_2, CO and volatile organic compounds (VOCs) was assumed. Results are shown in Table 1 as CPI values.

Table 1

Cumulative Impact Evaluation in Liepaja with CPI Method as Data Source Using Air Pollution Dispersion Modelling and IAP Bioindication Survey

Point Nr.	Coordinates	Place	NO_X µg m^{-3}	IAP value	CPI value
1	56.507034; 21.010184	Tirgonu, Kungu st. crossing	15	110.2	1.82
2	56.506490; 21.013304	Malkas, Kungu st. crossing	20	62.9	1.65
3	56.506313; 21.019863	Kungu, Ganibu st. crossing	15	130.2	1.66
4	56.508299; 21.011569	Rozu sq.	10	177.6	1.94
5	56.508835; 21.015131	Baznicas st.	10	183	1.88
6	56.508299; 21.022196	Baznīcas, Ganibu st. crossing	15	112.6	1.81
7	56.510092; 21.013163	Liela st.	15	109.1	1.82
8	56.510269; 21.017835	Barinu st.	10	200.7	1.67
9	56.509618; 21.023411	Jaunā st.	15	132.9	1.65
10	56.511765; 21.015265	K. Zales sq.	15	111.9	1.80
11	56.513992; 21.015157	Jauna ostmala	30	54.9	1.36
12	56.513966; 21.022977	Ganibu, Ezermalas st. crossing	25	57.8	1.36

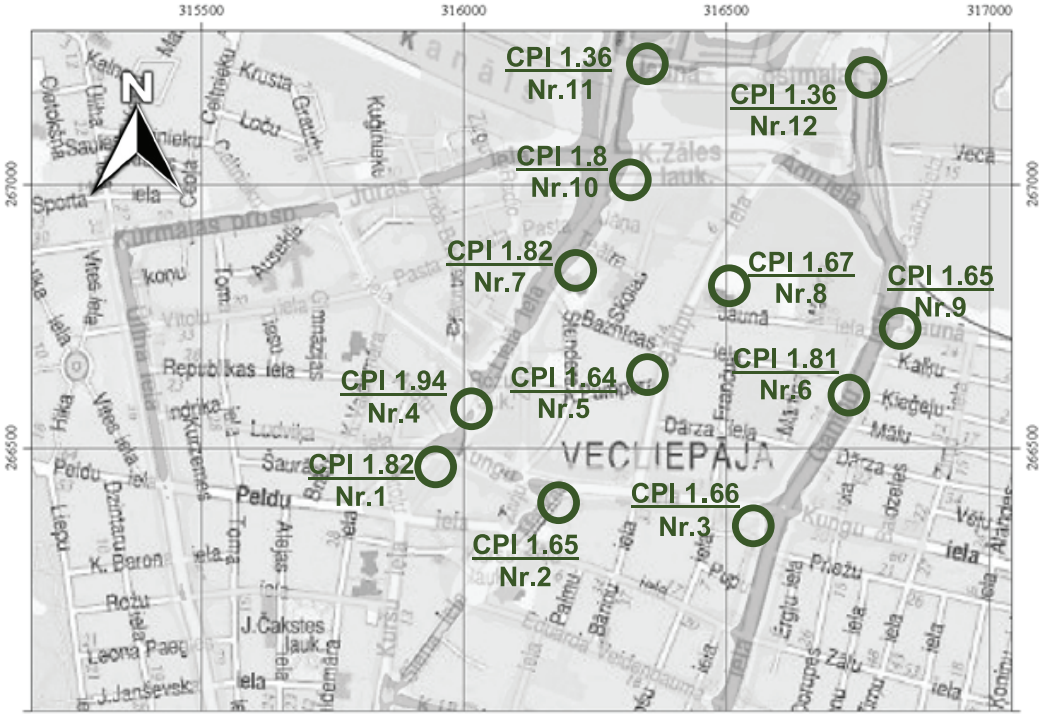


Figure 1. Spatial distribution of CPI values, bioindication survey points and pollution dispersion modelling results by Ltd. Estonian, Latvian & Lithuanian Environment in 2007. (background map).

According to obtained results (Table 1), cumulative impact in the central part of Liepaja is relatively large – CPI varies in the interval 1.36 to 1.94 – significantly higher than results obtained in a similar previous study, when in Liepaja CPI method was used to calculate cumulative impact from measurements done by air quality monitoring station. Then, CPI varied in the interval from 1 to 1.39 (Kalniņš et al., 2014).

However, these two studies cannot be easily compared – in the previous CPI evaluation, as cumulative effect was assumed interaction between 4 different pollutants – SO_2, NO_2, O_3, CO and such environmental factors as air temperature and humidity (Kalniņš et al., 2014), while, in this study, only NO_X concentrations were used due to data availability. Therefore, cumulative impact in this study also includes an impact caused by other pollutants not used in specific modelling and therefore higher CPI values cannot be automatically interpreted as higher cumulative pollution.

High cumulative impact is observed throughout the entire length of the Liela st. (1.8-1.94) while elsewhere in the central part of Liepaja CPI values are almost identical – 1.64; 1.65; 1.67, except Baznicas and Ganibu st. crossing, where cumulative impact is almost as high as in the Liela st. – 1.81 (Figure 1). The minimum of cumulative impact is in Jauna ostmala (1.36) – a wide, open place, near the Tirdzniecibas channel, while the maximum is in Rozu sq., where CPI value is 1.94 (Figure 1). There is a strong negative correlation between the modelled pollution level and obtained CPI values (r = -0.8637) which means that high pollution scores go with low CPI scores and contrary. Therefore, it is possible to make an assumption that, in many points in Liepaja, the results of this study, do not show the "real impact" on a living organism caused by cumulative effect, but the "real impact" due to non-compliance of dispersion modelling results and actual pollution level.

The fact that pollution modelling results often differ from real life situation is known from many studies (Air Quality Modelling Review Steering Group, Department for Environment, Food & Rural Affairs, 2011; Hirtl and Baumann-Stanzer, 2007). It can explain why in some places the pollution level is low while CPI values are high, for example – Rozu sq. (pollution level 10 µg m^{-3}, CPI – 1.94), there are also places where the situation is completely opposite. In Jauna ostmala, the results of dispersion modelling show high pollution (25-30 µg m-3), while CPI values there are the lowest ones in the whole central part of Liepaja – 1.36.

Examining the spatial distribution of cumulative impact (Figure 2) on a larger scale, strong clustering of CPI values was observed (Moran's I = 0,78). It means that there is a pattern in cumulative impact spatial distribution. Taking into account the latest research on a city microclimate, it is possible to assume that one of the factors that causes cumulative impact variations in the central part of Liepaja is microclimate differences due to geometry of street canyons. The microclimate and street canyon geometry impact on air temperature and humidity is demonstrated by a number of studies (Chen et al., 2010; Idezak et al., 2007; Vardoulakis et al., 2003) – tall buildings cause a permanent shadow, thus inhibiting evaporation. They also hold wind, reducing

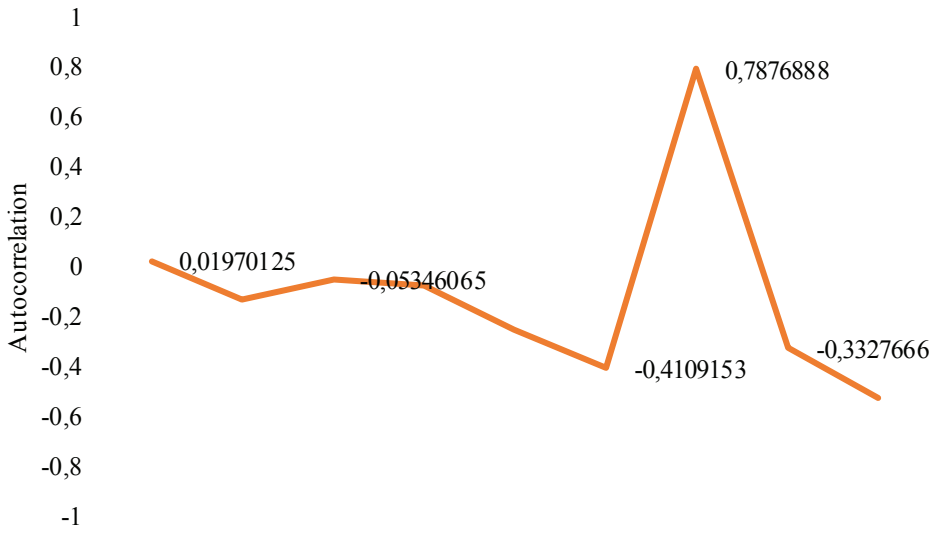


Figure 2. Spatial autocorrelation (Moran's I) of CPI distribution in the central part of Liepaja.

air exchange. Concrete, masonry and asphalt surfaces accumulate heat and ambient air temperature rises due to temperature of car exhaust gases, etc.

This can explain why the highest CPI values (1.82-19.4) are in the Liela st. which is surrounded by high stone and concrete buildings, while the lowest cumulative impact is in a wide and open space – Jauna ostmala (CPI 1.36).

Therefore, it can be concluded that CPI method can be used not only in direct measurements, but also in air pollution dispersion modelling as a tool for cumulative impact calculation. Despite the possible inaccuracy of modelling data, the obtained CPI values show plausible data – they correlate with the pollution level and forming spatial pattern. In addition, the use of this method can reveal new facts about cumulative pollution – a city microclimate as an important cumulative effect forming factor.

Conclusions

1. In this study, a high cumulative air pollution impact was detected in the central part of Liepaja – CPI values vary in the interval 1.36 to 1.94.
2. Results show that the air pollution dispersion modelling usage in a cumulative effect evaluation not always give precise data, because modelling results may differ from actual pollution dispersion. There is a strong negative correlation between the modelled pollution level and obtained CPI values (r = -0.8637) Therefore, it is possible to make an assumption that modelling by Ltd. Estonian, Latvian & Lithuanian Environment is not accurate in the whole central part of Liepaja.
3. CPI method can be effectively used to calculate a cumulative impact from air pollution dispersion modelling data, because, despite the possible inaccuracies of modelling, the obtained results are still plausible – there is a strong correlation between CPI values and pollution level (r = -0.8637) and similarly strong clustering of spatial distribution of CPI values (Moran's I = 0,78). In addition, CPI results in this study (1.36–1.94) do not differ too much from previous CPI study with the measurements approach (1–1.39).
4. This study demonstrates the city microclimate importance in forming of cumulative effects, because the highest CPI values – 1.8; 1.82 and 1.94 are in a place which is surrounded by high stone and concrete buildings (Liela st.), while the lowest CPI – 1.39 is in a wide and open area (Jauna ostmala).

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