IN DEPTH EVALUATION OF CUMULATIVE AIR POLLUTION FORMING FACTORS IN LIEPAJA AND RIGA WITH CUMULATIVE POLLUTION INDEX METHOD

Viesturs Kalnins[1], Inga Straupe[2], Ritvars Sudars[2]
[1]Liepaja University, Latvia; [2]Latvia University of Agriculture
k.viesturs@inbox.lv

Abstract. Evaluation of the cumulative effect – synergy of multiple pollutants is one of the most topical problems in environmental quality monitoring due to lack of appropriate methodology. In 2013, the new cumulative effect evaluation method Cumulative Pollution Index (CPI) for the first time was tested in field research by doing cumulative air pollution evaluation in two cities of Latvia – Liepaja and Riga. By the use of this method, the cumulative effect is calculated from simultaneous air quality measurements and bioindication research. Due to this approach, CPI results are difficult to compare with similar research and there is a risk that explanation can be pure biological. Therefore, the aim of this research was to validate the year 2013 results by use of statistical analysis methods. The results show that these detections were adequate, because they can be justified statistically and comply with similar research by other authors.

Keywords: cumulative effect, air pollution, Cumulative Pollution Index, bioindication.

Introduction

Evaluation of the cumulative effect – synergy of multiple pollutants is one of the most topical problems in environmental quality monitoring due to lack of appropriate methodology. Cumulative risk assessment to real-world mixtures is hindered by a lack of verified analytical frameworks [1]. Therefore, methods in this field are relatively simple and use statistical models with small fixed number of pollutants in association with different factors.

Alternative is the use of new approaches as it is done in one of the recent methods for cumulative effect evaluation in the air quality monitoring field – Cumulative Pollution Index [2]. In this method, the cumulative effect is calculated as the difference between air quality measurements done by automated measurement stations and bioindication results in the form of analysis of chlorophyll-pheophytin ratio in lichen samples placed on the same measurement stations. The resulting index (1) is calculated with the following equation [3]:

$$CPI = \frac{\left[\left(\sum_1^{ns} P\right) / \left(\sum_1^{ns} C\right)\right] \times 100}{\left[\left(\sum_1^{np} C_p\right) / \left(\sum_1^{np} BP_p\right)\right] \times 100}, \qquad (1)$$

where CPI – cumulative pollution index (greater value – greater cumulative effect);
BP_p – breakpoint for pollutant p (units according to normative);
C_p – concentration of pollutant p (same units as BP_p);
np – number of pollutants;
ns – number of lichen samples;
C – initial chlorophyll amount in the sample (either in optical density or units of mass);
P – pheophytin amount in the sample (same units as C).

The Cumulative Pollution Index method is completely new and is used only in one study when cumulative air pollution was evaluated in Liepaja and Riga in 2013 [3]. Due to this, and the fact that the CPI method uses a new approach – bioindication and air quality measurements merged in one method, these results are difficult to compare with similar research. As the part of CPI calculation is two biochemical indicators in lichen samples, it is not possible to completely exclude biological explanation of CPI values. Therefore, additional validation of the first results by the CPI method is necessary to determine if the CPI method can be used in air quality evaluation in the current form or it needs some revisions. The aim of this research was to find it out by the use of statistical analysis methods.

Materials and methods

As the data source for this research, tables of CPI and measured pollutants from 2013 study in Liepaja and Riga were used (merged in Table 1) and all data were analyzed according to places where year 2013 evaluation was done – Liepaja Kalpaka Str. 34; Riga Brivibas Str. 73 and Riga Kr. Valdemara Str. 18.

Table 1

Concentration of air pollutants and Cumulative Pollution Index values in Liepaja and Riga 01.02.2013- 01.01.2014 [3]

Month	SO_2 (µg·m^{-3}; 24 h)	O_3 (µg·m^{-3}; 8 h)	NO_X (µg·m^{-3}; 1 h)	CO (µg·m^{-3}; 8 h)	CPI
Riga Brivibas Street 73					
02	6.7	65.1	144.9	N/A	1.07
03	8.1	86.9	141.3	N/A	1.00
04	6.5	80.4	151.6	N/A	0.96
05	6.4	93.3	145	N/A	0.96
06	5.7	60	104	N/A	1.30
07	5.2	51.4	112.9	N/A	1.30
08	5.4	78	120.6	N/A	1.08
09	7	43	105	N/A	1.50
10	8.1	83.8	128.4	N/A	1.06
11	7.4	90.4	129.4	N/A	1.02
12	7.8	93.4	138.1	N/A	0.97
01	5.8	85	147	N/A	0.96
Riga Kr. Valdemara Street 18					
02	N/A	60.7	91.1	0.8	1.14
03	N/A	96	112.3	0.8	0.84
04	N/A	81.6	112.8	0.7	0.87
05	N/A	113.7	76	1.1	0.87
06	N/A	101	122	1.7	0.74
07	N/A	48.4	127.7	0.8	0.94
08	N/A	48.9	129.4	0.8	0.92
09	N/A	61.7	122.3	0.6	0.91
10	N/A	82.5	127.6	0.5	0.80
11	N/A	N/A	116.2	0.7	1.44
12	N/A	N/A	123.7	0.5	1.36
01	N/A	N/A	153	0.5	1.07
Liepaja Kalpaka Street 34					
02	12	87	86	N/A	1.27
03	11	114	117	N/A	1.00
04	10	108	89	N/A	1.10
05	9	128	81	N/A	1.10
06	3	102	105	N/A	1.09
07	2	94	69	N/A	1.39
08	3	110	75	N/A	1.22
09	4	107	103	N/A	1.10
10	5	97	105	N/A	1.14
11	4	91	103	N/A	1.19
12	7	86	111	N/A	1.15
01	3	81	123	N/A	1.05

As statistical methods correlation analysis (Pearson's *r*), partial correlation and factor analysis were used. The calculation of Pearson's *r* (given as coefficient of multiple correlation in MS Excel) and factor analysis were done by the use of Microsoft Excel 2013 built-in tools and Real Statistics add-in. Partial correlation was calculated with Real Statistics add-in.

Based on the previous research on cumulative effects by other authors, the following possible cumulative effect forming factors were evaluated:

- Pollutants [4; 5];
- Monthly average air temperature [6];
- Monthly relative humidity [7].

As meteorological factors – temperature and humidity, monthly average values in Liepaja and Riga were evaluated due to lack of meteorological sensors at the CPI calculation sites – Table 2.

Table 2

Air temperature and relative humidity in Liepaja and Riga during the evaluation of cumulative air pollution 01.02.2013-01.01.2014

Month	Liepaja		Riga	
	Temperature, ºC	Humidity, %	Temperature, ºC	Humidity, %
02	-0.8	87	-0.8	82
03	-3.2	68	3.8	67
04	4.2	78	4.9	74
05	13.5	75	15.7	66
06	16.4	78	19.2	65
07	17.5	80	19.1	69
08	18	77	18.3	71
09	13	81	13.1	79
10	9.6	84	8.9	80
11	6.6	84	5.3	87
12	4.2	85	2.7	86
01	-4.2	81	-5.1	79

Results and discussion

Factor analysis shows varying number of cumulative impact forming factors – 4 in Liepaja and Riga Kr. Valdemara Street, 3 in Riga Brivibas Street – Fig. 1, 2. This points to the fact that in both cities the CPI values are not a result of impact by a single pollutant or meteorological factor – they indicate complex interaction between multiple factors.

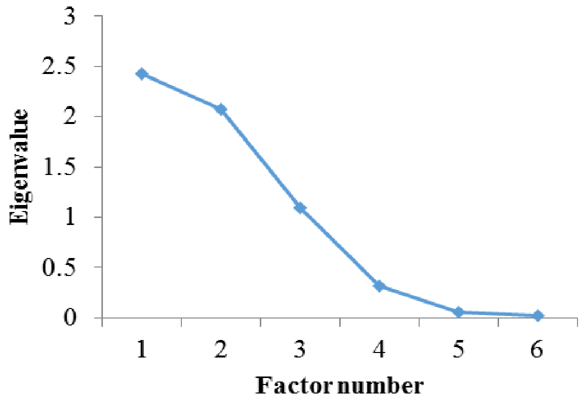
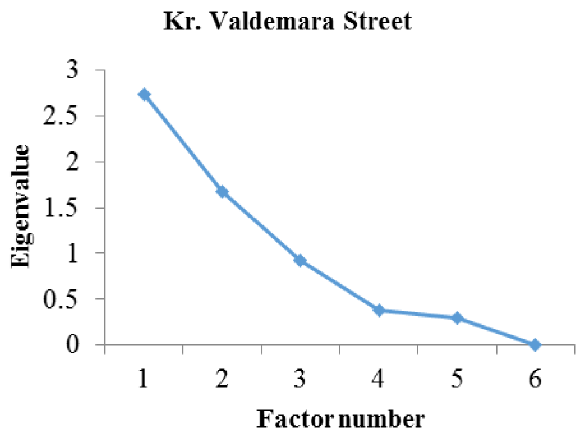


Fig. 1. **Factor analysis scree plot of cumulative pollution forming factors in Liepaja**

In Liepaja, significant impact on CPI is NO_X (r = 0.72), while in Riga Brivibas Street – O_3 (r = 0.90) and NO_X (r = 0.96) – Table 3. Despite the CPI correlation with other pollutants, for example, SO_2 in Liepaja (r = 0.54) and O_3 in Kr. Valdemara Street (r = 0.68), these results are below the level of significance – $p > 0.05$. However, $p > 0.05$ not necessarily means that the data are not valid – one of the most widespread explanations in such cases is the small sample size [8; 9], but at the same time the results with $p > 0.05$ cannot be interpreted as statistically justified cumulative effect detections.



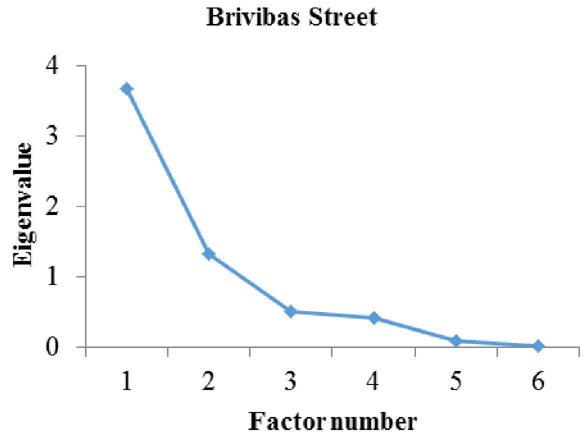


Fig. 3. **Factor analysis scree plot of cumulative pollution forming factors in Riga**

Taking into account only pollutants, statistically justified cumulative effect detection is only in Riga, Brivibas Street, because r = 0.72 for NO_X alone in Liepaja does not meet the definition of the cumulative effect – synergy of multiple pollutants. Analysis of meteorological factors impact on the CPI values – Table 3, shows significant CPI correlation with the air temperature in Liepaja (r = 0.61). Also, in Riga, Brivibas Street CPI correlates with the changes in ambient air temperature, but to a lesser extent than in Liepaja (r = 0.58). Completely different results are from the second site in Riga – Kr. Valdemara Street. In this place, significant correlation is only with relative humidity (r = 0.78). If there is any air temperature impact on CPI, it is insignificant (r = 0.37). In addition, these results are not statistically significant ($p > 0.05$). Therefore, it can be concluded that in forming of CPI values the main meteorological factor was air temperature.

Table 3

CPI correlation with pollutants and meteorological factors (*$p < 0.05$)

Site	**Pearson's correlation coefficient (r)**			
	Pollutants			
	O_3	NO_X	SO_2	CO
Liepaja	0.24	0.72*	0.54	
Riga, Brivibas Street	0.90*	0.96*	0.37	
Riga, Kr.Valdemara Street	0.68	0.15		0.45
Site	**Meteorological factors**			
	Monthly average air temperature, °C		Relative humidity, %	
Liepaja	0.61*		0.38	
Riga, Brivibas Street	0.58*		0.17	
Riga, Kr.Valdemara Street	0.37		0.78*	

According to the correlation analysis – Table 3, for further validation with partial correlation analysis – Table 4, the following cumulative effect forming factors can be identified:

- NOX + air temperature (in Liepaja);
- NOX + O3 + air temperature (in Riga Brivibas Street).

The partial correlation analysis – Table 4, shows that in Liepaja exclusion of other factors results in strong CPI correlation with O_3 (-0.76) and NO_X (-0.88), but correlation with air temperature is moderate (0.40). This validates the assumption that in Liepaja the cumulative effect forming factors were NO_X + air temperature (there is strong correlation with O_3, but it is not statistically significant). Riga Brivibas Street is a different case – exclusion of other factors results in strong correlation with SO_2 (0.70), O_3 (-0.72) and NO_X (-0.94), like in Liepaja, correlation with air temperature is moderate (0.50). This validates the assumption that in Riga Brivibas Street the cumulative effect forming factors were NO_X + O_3 + air temperature. (SO_2 – not statistically significant). It is important that partial correlation with pollutants is stronger than with air temperature. This means that the air temperature most likely has acted only as a catalyzer, not as the main CPI forming factor.

Table 4

Partial correlation of CPI and cumulative effect forming factors

Liepaja						
	CPI	SO_2	O_3	NO_X	Temperature	Humidity
CPI	1	0.28	-0.76	-0.88	0.40	-0.28
SO_2	0.28	1	0.69	-0.00	-0.90	0.57
O_3	-0.76	0.69	1	-0.58	0.76	-0.74
NO_X	-0.88	-0.00	-0.58	1	0.05	-0.19
Temperature	0.40	-0.90	0.76	0.05	1	0.60
Humidity	-0.28	0.57	-0.74	-0.19	0.60	1
Riga Brivibas Street						
	CPI	SO_2	O_3	NO_X	Temperature	Humidity
CPI	1	0.70	-0.72	-0.94	0.50	-0.15
SO_2	0.70	1	0.24	0.79	-0.79	0.24
O3	-0.72	0.24	1	-0.52	-0.12	-0.20
NO_X	-0.94	0.79	-0.52	1	0.59	-0.14
Temperature	0.47	-0.79	-0.12	0.59	1	-0.09
Humidity	-0.15	0.24	-0.20	-0.14	-0.09	1

NO_X and O_3 cumulative synergy is well known from various researches done by other authors [10; 11]. Humans and animals inhale both of these pollutants and they come in contact with the respiratory tract lining fluids (RTFLs). Antioxidants in RTFLs react with NO_X and reduce respiratory tissue protection capabilities from oxidants like O_3 [12]. NO_X and O_3 synergy also occurs in biochemical level in the form of damage of various protein structures, therefore affecting not only humans and animals, but almost all living organisms [12]. Also the temperature role as a catalyzer factor in pollution impact is known from other researches – for example, it is known that O_3 causes respiratory dysfunctions in 21-23 ºC temperature diapason [13] and further increase in temperature results in even greater O_3 impact [14].

Summarizing the mentioned above, it can be concluded that during the first study with the CPI method in 2013 statistically justified cumulative effect detection which complies with similar research by other authors is only in Riga Brivibas Street. The results from other sites lack statistical significance, possibly due to the small sample size. Therefore, further research is needed – in a longer time frame and in more cities.

Conclusions

1. Taking into account only pollutants, statistically justified cumulative effect detection in the first study by the CPI method was only in Riga Brivibas Street (r = 0.96 for NO_X; r = 0.90 for O_3)
2. The main meteorological factor in CPI forming was the air temperature (r = 0.61 in Riga, Brivibas Street; r = 0.58 in Liepaja)
3. During the 2013 study cumulative effect detections were adequate because the results from at least one site (Brivibas Street) can be fully justified with statistical analysis methods and comply with similar research by other authors.
4. The results from other sites lack statistical significance, possibly due to the small sample size. Therefore, further research is needed – in a longer time frame and in more cities.

References

1. Callahan M.A., Sexton K. If cumulative risk assessment is the answer, what is the question? Environmental Health Perspectives, vol. 115, 2007, pp. 799-806.
2. Kalniņš V. Bioindication based cumulative effect evaluation for air pollution monitoring in cases when monitored pollutant values do not exceed breakpoint values. Innovations and Technologies News, vol. 2, 2012, pp. 3-10.

3. Kalniņš V., Straupe I., Sudārs R. Evaluation of cumulative air pollution in Riga and Liepaja with Cumulative Pollution Index method. Research for Rural Development. Annual 20th International Scientific Conference Proceedings, vol. 2, 2014, pp. 127-132.
4. Bell M.L., Peng R.D., Dominici F. The exposure–response curve for ozone and risk of mortality and the adequacy of current ozone regulations. Environmental Health Perspectives, vol. 114, 2006, pp. 532-536.
5. Stylianou M., Nicolich M.J. Cumulative effects and threshold levels in air pollution mortality: Data analysis of nine large US cities using the NMMAPS dataset. Environmental Pollution, vol. 157, 2009, pp. 2216-2223.
6. Roberts S. Interactions between particulate air pollution and temperature in air pollution mortality time series studies. Environmental Research, vol. 96, 2004, pp. 328-337.
7. Qiu H., Yu I.T.S., Wang X. et.al. Season and humidity dependence of the effects of air pollution on COPD hospitalizations in Hong Kong. Atmospheric Environment, vol. 76, 2013, pp. 74-80.
8. du Prel J.B., Hommel G., Röhrig B. Blettner M. Confidence interval or p-value?: part 4 of a series on evaluation of scientific publications. Deutsches Ärzteblatt International, vol. 106, 2008, pp. 335-339.
9. Gail M.S., Feinn R. Using Effect Size – or Why the P Value Is Not Enough. Journal of Graduate Medical Education, vol. 4, 2012, pp. 279-282.
10. Gelzleichter T.R., Witschi H., Last J.A. Synergistic interaction of nitrogen dioxide and ozone on rat lungs: acute responses. Toxicology and Applied Pharmacology, vol. 116, 1992, pp. 1-9.
11. O’Neill C.A., van der Vliet A., Eiserich J.P. et.al. Oxidative damage by ozone and nitrogen dioxide: synergistic toxicity in vivo but no evidence of synergistic oxidative damage in an extracellular fluid. Biochemical Society Symposia, vol. 61, 1995, pp. 139-152.
12. Gamon L.F., White J.M., Wille U. Oxidative damage of aromatic dipeptides by the environmental oxidants NO2 and O3. Organic & Biomolecular Chemistry, vol. 41, 2014, pp. 8102-8355.
13. Adams W.C. Comparison of chamber 6.6-h exposures to 0.04–0.08 ppm ozone via square-wave and triangular profiles on pulmonary responses. Inhalation Toxicology, vol. 18, 2006, pp. 127-136.
14. Foster W.M, Brown R.H., Macri K., Mitchell C.S. Bronchial reactivity of healthy subjects: 18–20 h postexposure to ozone. Journal of Applied Physiology, vol. 89, 2000, pp. 1804-1810.