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Measurement of Ambient Air Pollution with SO_2 Applying Lichens and Passive Samplers

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1. Introduction

Ambient air pollution is a complex mixture composed of both solid particles and gaseous pollutants (Kan et al. 2012). Air pollution has many negative effects on the natural environment, from changes in plant growth patterns to loss of ecosystem function (Chaiazzo et al. 2013). In support of this observation, the World Health Organization estimates that the every year, 2.4 million people die because of the effects of air pollution on health (Sierra-Vargas et al. 2012). About 400 000 premature adult deaths attributable to air pollution occur each year in Europe (Amato et al. 2014). Monitoring air quality by using living organisms as biomonitors has received increasing attention in recent years (Gerdol et al. 2014). It is hard to establish a region-wide monitoring system to reveal environmental risk assessment levels. Increasing awareness of the potential hazards of large-scale contamination of ecosystems by pollutants has highlighted the need for continuous monitoring of the levels of contaminants in the environment (Giordani et al. 2002).

Lichens are used in environmental monitoring of industrial pollution (Oksanon 2006). Changes in lichen diversity are used as indicators of environmental conditions and have been widely applied in air quality assessments and monitoring programs around the world (Landis et al. 2012).

The bio monitoring of pollution by the atmospheric aerosol most commonly utilizes lichens and mosses, which have no root parts and collect nutrients and pollutants through the entire body surface. Analysis of trace elements accumulated in lichens and mosses provides much information on the emission of pollutants into the environment, enables the assessment of a changing quality of the environment, and allows the determination of directions in which the pollutants propagate (Kłos et al. 2011).

Lichens in particular have been widely used as trace element atmospheric bio-monitors as they are widespread and capable of absorbing elements directly from the atmosphere and accumulating them in their tissues. Lichen bio-monitoring is often used as receptor based method in air quality studies. It can be useful in risk assessment for human health.

There are no enough scientific data about comparison of two different methods for air quality evaluation – application of passive sampling method and bio indication method with lichens. The idea was to apply two different methods for air pollution with SO_2 evaluation – passive samplers and bioindication (with lichens) and this idea was realised in the chemical laboratory of Environmental protection department at Vilnius Gediminas Technical University.

In terrestrial environments, probably epiphytic lichens are the most widely used biomonitors, which can detect and monitor numerous pollutants such as SO_2, HF, various metals, nitrogen deposits and radionuclides. They can be used as bio indicators, bio accumulators and ecological indicators, where the approaches vary in terms of biological organization from individual species-to-species associations and lichen communities (Attanayaka et al. 2013). The major effects of pollutants on lichens (especially SO_2) are summarized as follow (Pescott et al. 2015): reproductive potential, changes in morphology, changes in ultrastructure, membrane integrity, photosynthesis and respiration, loss of biodiversity and changes in lichen communities and other effects (inhibition of nitrogen fixation in lichens).

SO_2-levels greater than 40 $\mu g/m^3$ determine the disappearance of sensitive lichen species. Mean sulphur dioxide levels higher than 150 $\mu g/m^3$ cause lichen deserts. Lichen zones correspond to certain SO_2 concentrations in the exploratory ambient air. Zoning of lichens in the cities has been known long, it is based on the resistance degree of different groups and species of lichens to harmful substances (toxic tolerance) (Stravinskienė 2009). This principle was applied in article.

The passive sampler method is widely used in order to quantify ambient gaseous air pollutant concentrations (Pekey and Yılmaz 2011, López-Aparicio and Hak 2013, Caballero et al. 2012, Hien et al. 2014, Zielinska et al. 2014, Šerevičienė et al. 2014, Król et al. 2012, Adema et al. 2012, Byanju et al. 2012, Estellano et al. 2012, Fridh et al. 2014, Přibylová et al. 2012). Passive diffusion samplers provide a cost-effective way to monitor air-pollutant species at both local and regional scales. Compared with conventional methods, they can be deployed unattended for extended periods and do not require power supply (Adema et al. 2012).

Applying lichens average concentration of ambient air pollution during long period (growing of lichens on tree surface) can be found. Applying passive sampler's concentration of ambient air pollution during short period (typically 2-4 weeks) can be found. Hypothesis – approximate evaluation of ambient air pollution with sulphur dioxide can be found applying lichens. This hypothesis was tested applying certificated method – passive samplers.

Aim of research – comparison of two different methods for air quality (air pollution with SO_2) evaluation in Raseiniai district (Lithuania) – applying passive sampling method and bioindication method with lichens.

2. Materials and methods

2.1. Study area

Using lichens as bio-indicators, air pollution studies were carried out in Raseiniai town and its surroundings (Fig. 1). Raseiniai district municipality is located in the western part of Lithuania, 76 km north-west of Kaunas city. Raseiniai district area covers 157.3 thousand ha, of which 113.206 thousand hectares are agricultural areas, 23% – forests, 4.3% – towns and settlements, 2.8% – industrial enterprises and roads, 3.8 thousand ha – water, 13.4 thousand ha – areas intended for other purposes (Raseinių rajono... 2008). Raseiniai district includes twelve elderships (Figure 1), its population is 33 520 (at the beginning of 2017), two towns (Raseiniai – population is 10 256, Ariogala – population is 3208). There are seven small towns, three railway stations, 597 villages (Raseinių seniūnijos... 2009).

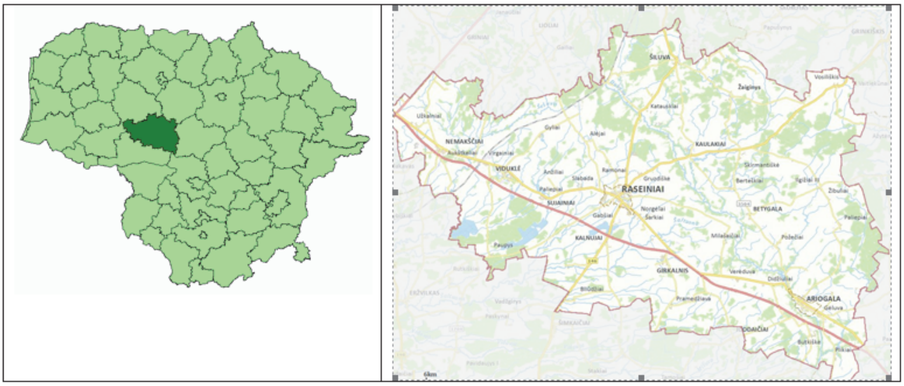

Fig. 1. Location of the study area
Rys. 1. Lokalizacja badanego obszaru

In the Raseiniai district municipality, pollutants to the ambient air come from stationary sources of pollution (energy, industrial and economic objects, as well as individual residential buildings) and from mobile sources of pollution (road transport). Many pollutants come from the large boiler-houses located in Raseiniai, Ariogala and Viduklė, and individual homes. The amount of the main air pollutants (SO_2 and other pollutants) emitted into the atmosphere from the stationary sources in Raseiniai district municipality, are presented in Figure 2.

The emissions of sulphur dioxide in the Raseiniai district municipality, as compared to previous years, have significantly decreased, as energy companies use clean fuel – biofuel instead of sulphury heavy fuel oil from approximately 2011 year. After installing of biofuel boilers, the emission of sulphur dioxide into the atmosphere remained almost unchanged.

Emissions from individual housing especially increase during the cold season, when boilers are being heated intensively, and weather conditions for the pollution dispersion are adverse; in addition to this, the increase in pollution also depends on the type of fuel used, its quality, and sometimes on the waste fired.

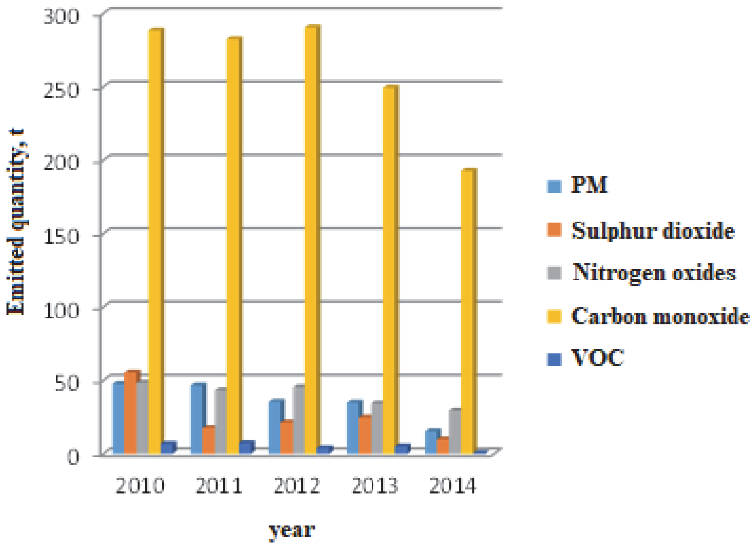

Fig. 2. Quantity of particulate matter, sulphur dioxide, nitrogen oxides, carbon monoxide and volatile organic compounds (t/y) emitted into the atmosphere from stationary sources in Raseiniai district municipality
(Data from the Lithuanian Department of Statistics)
Rys. 2. Emisja cząstek stałych, dwutlenku siarki, tlenków azotu, tlenku węgla i lotnych związków organicznych (t/rok) do atmosfery ze źródeł stacjonarnych w gminie powiatowej Raseiniai
(Dane z litewskiego departamentu statystyki)

2.2. Methodology of lichen sampling

During the cartography, whole Raseiniai city and its surroundings on the map were divided into separate 500 m x 500 m areas. A particular study area network was formed. With the assistance of the simulation software SelmaGIS, coordinates for mid-points of each square were determined. These coordinates were entered in the GPS device. Thus the particular location marked was known. According to LCS (Lithuanian coordinates system) coordinates, we went to each location. Using GPS technology, exact location of exploratory trees was recorded in each study area. The location of exploratory trees was indicated on the area plan (Figure 3). During the study, dominant tree species were determined and all the species of lichen on the tree trunks and branches were examined. 86 trees in 9 out of 12 Raseiniai elderships were examined in total.

In urban areas sometimes mosses and lichens are found in not sufficient quantities. In such cases, transplant techniques have been used to monitor air pollution. One of these techniques consists in exposing bags containing lichen or moss in the studied area to measure concentrations of contaminants affecting the samples (Salo et al. 2012). Tree age can be estimated by counting tree-rings in each individual tree without any additional correction (Madrigal-Gonzalez et al. 2014). Stem diameter at breast height and tree height are used also for measures of tree growth (Sumida et al. 2013). Selection of trees for research in Raseiniai district municipality were carried out after consulting with foresters, which according to archival data, selected trees of the similar age. The old trees could have lichens extant there from the times when there was no pollution in this area (Gries 2003).

Fig. 3. Topographic map of the study area
Rys. 3. Mapa topograficzna badanego obszaru

Composition of lichen species was determined on each tree of selected species dominant in that area, and coverage in percent was studied using a grid (Figure 4). To this end, a frame in the height of 130-150 cm was placed from the northern side (it was determined using a compass built in the GPS device), and the percentage of area which covered the trunk with lichens was calculated. In order to get accurate results, the same trunk test was repeated 3-4 times and the average was calculated. The study was carried out covering not only Raseiniai and Ariogala elderships and their surroundings, where main industry of Raseiniai district is situated, but also adjacent elderships: Nemakščiai, Viduklė, Paliepiai, Kalnujai, Girkalnis, Betygala and Pagojukai. Assuming that the concentration of pollutants in the ambient air starts to decrease when receding from the pollution sources, to confirm this hypothesis only a few points for the study were selected in the elderships distant from Raseiniai town. Coverage with lichens on the species of trees such as birch, oak, aspen, linden, maples and alders was measured during the study. Since the study methodology requires examination of the same species of trees, most frequently encountered species of trees – maples (*Acer platanoides*) birches (*Betula pendula*) and lindens (*Tilia cordata*) were chosen. The choice was influenced by the possibilities of comparison of results.

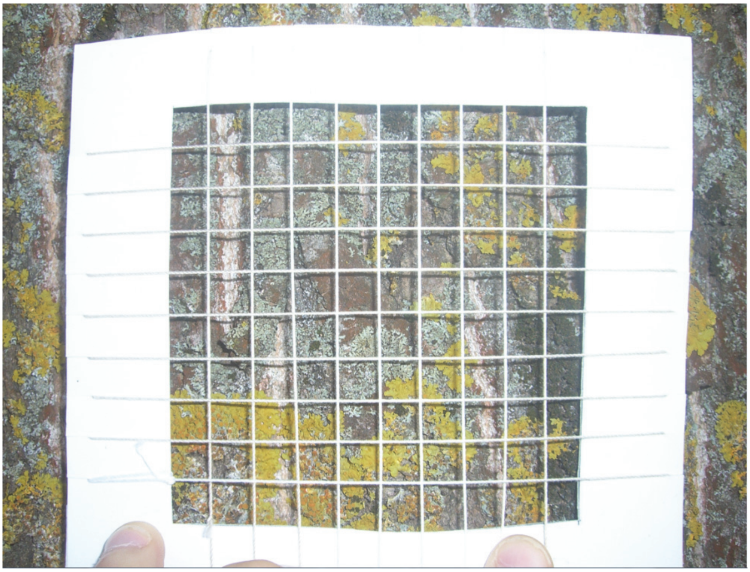

Fig. 4. Example of the sampling grid on a chestnut tree
Rys. 4. Przykład siatki do pobierania próbek na drzewie kasztanowca

According to studies, the area has been divided into zones, as it is required by the methodology (Table 1) (Stravinskienė 2010).

Table 1. Lichen distribution in zones according to their prevalence (Stravinskienė 2010)
Tabela 1. Rozkład porostów w strefach w zależności od ich występowania (Stravinskienė 2010)

Zone number	Zone description	Lichens coverage,%	Number of species in the sample
I	*Normal zone:* Various fruticose lichens, foliose lichens and crustose lichens can be found in this zone.	70-100%	10
II	*External resistance zone:* Lower number of fruticose lichens and foliose lichens. Crustose lichens are dominating.	50-70%	5-10
III	*Internal resistance zone:* Crustose lichens are dominating. Few foliose lichens might be found.	50%	No more than 5
IV	*Desert zone:* No lichens or few crustose lichens might be found in this zone. Desert zone is usually in large industrial areas.	0-20%	0.3

According to the experience of Lithuanian (Motiejūnaitė 2007) scientists and researchers from other countries, to describe the borderline of lichen areas not only the coverage rate of tree trunk was chosen, but also such indicators as: life-zones of lichens, number of species, frequency of different species.

2.3. Methodology of evaluation of SO_2 concentration

Distribution of lichens depends on the SO_2 concentration in ambient air. Lichen zones (Table 1) correspond to certain SO_2 concentrations in the exploratory ambient air (Table 2). Zoning of lichens in the cities has been known long, it is based on the resistance degree of different groups and species of lichens to harmful substances (toxic tolerance) (Stravinskienė 2009).

Coverage rate of lichens is obtained directly through the measurements with the grid (Fig. 4). When interpolating the range of SO_2 concentration (µg/m^3) given in Table 2 according to the distribution of lichens (%), exact concentration of SO_2 in the range of each zone is calculated. The following calculations are carried out for each study area of Raseiniai district.

Table 2. Dependence of SO_2 concentration in ambient air on lichens coverage (Stravinskienė 2005)
Tabela 2. Zależność stężenia SO_2 w powietrzu od występowania porostów (Stravinskienė 2005)

Zone	Lichens coverage,%	Number of species in the sample	Concentration of SO_2, µg/m^3
I	70-100%	10	0-30
II	50-70%	5-10	30-40
III	50%	No more than 5	40-45
IV	0-20%	0.3	45-65

The concentration of SO_2 was analysed also by diffusive sampling method. In order to reduce uncertainty and the risk of data loss, three samplers were exposed in parallel at each of the sampling locations for a period of 2 weeks (August 10, 2016-August 23, 2016). A total numbers of 39 samples for SO_2 were collected. Passive samplers were exposed at 3-4 m height. The exposure time of each cartridge was 2 weeks. All samplers were placed in the special shelters to protect them from the rain and minimize the wind influence during the exposure. The places of passive samplers were selected according the principle - distance must be till 10 m from investigated trees (with lichens). The area of the samplers' exposure was open, free from buildings, trees and other objects, at least 1 m from any structures that could disrupt the airflow. During the transportation and forwarding for analysis, the passive samplers were sealed. After exposure, the diffusion samplers were analyzed in laboratory and the quantity of SO_2 was determined. According to air quality directive (2008/50/EC), the results of indicative measurements shall be taken into account for the assessment of air quality with respect to the limit values.
Statistical analysis

Descriptive statistical analysis was used (mean, standard deviations, confidence interval and Pearson coefficients). 95% confidence level was used. Data were analysed with Excel 2013.

3. Results

3.1. Lichen flora and coverage of lichens

86 trees have been studied in whole Raseiniai district. 9 different species of lichens were found onthem, 20% of which were crustose (paint-like, flat), 45% foliose (leafy) and 35% fruticose (branched). The resulting percentage of distribution of lichens is given in Figure 5.

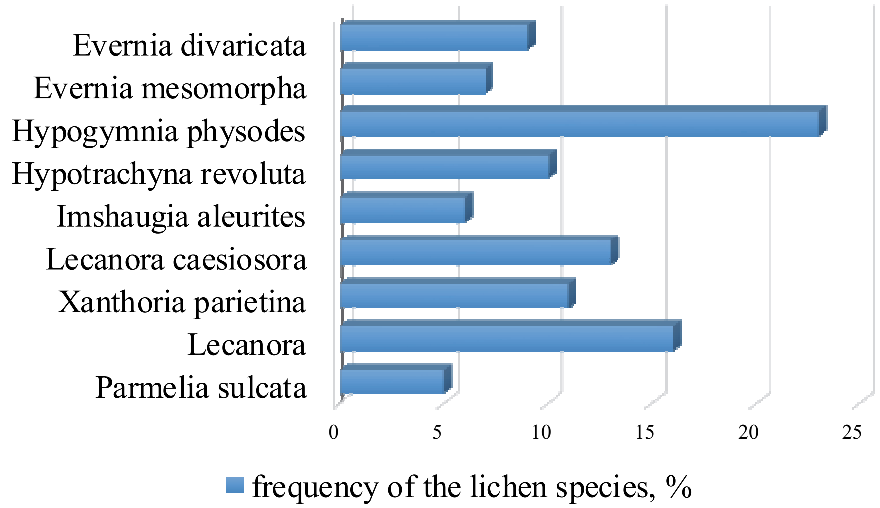

Fig. 5. List of the lichen species found on the study area
Rys. 5. Lista gatunków porostów znalezionych na badanym obszarze

Most of the trees studied were covered with lichens of type *Hypogymniarevoluta* (L.) (as much as 23%) and *Lecaora* (L.), (16%). Somewhat less *Xanthoria parietina* (L.) and *Lecanoracaesiosora* (L.) species of lichens were found on trees, respectively, they made 11% and 16% of the total amount of lichens found. Minimal amount of *Parmeliasulcata* (L.) (5%) and *Imshaugiaaleurites* (L.) (6%) species of lichens was found (Fig. 4).

Coverage of lichens (%) on the trunks of maple, birch and linden trees is shown in Figure 6. According to the average coverage area of lichens (Table 1), it was determined (Figure 6) that Raseiniai town and its surroundings (Gabšių and Andriušaičių villages) are attributed to zone III, i. e. moderate fighting zone, where the coverage rate of lichens is up to 50%, and the amount of species in each sample does not exceed 5. Ariogala and Paliepių elderships (Figure 6) are assigned to the same zone. Kalnujų, Pagojukų elderships and surroundings of Raseiniai town – Ramanava and Gruzdiškės – are attributed to zone II area, which is External (resistance) fighting zone. Percentage of fruticose (branched) lichens is decreased here, crustose (paint-like, flat) lichens begin to dominate, and amount of foliose (leafy) lichens decreases. Coverage rate of lichens on tree trunks ranges between 50-70%, and the number of species detected increases from 2-3 to 5-7. The remaining Nemakščiai, Betygala, Girkalnis and Viduklė elderships are attributed to zone I. This is a Normal zone. Various fruticose (branched), foliose (leafy) and crustose (paint-like, flat) lichens grow here. Coverage rate is up to 70-100%. Specific composition of lichens found here is the highest.

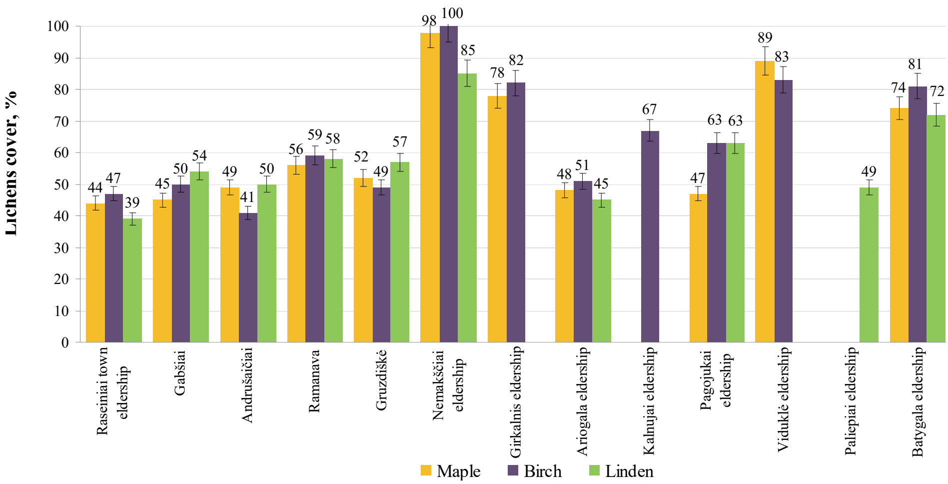

Fig. 6. Lichen ground-cover on tree stems in different investigation areas
Rys. 6. Stopień pokrycia pni drzew porostami w różnych obszarach badawczych

Amount of lichen species found on each tree trunk varies from 5 to 8. Measurement error is ±5%.

3.2. Concentration of SO_2 according to lichens coverage

SO_2 concentration in Raseiniai district municipality

SO_2 is a respiratory irritant and bronchoconstrictor that has been associated with cardiovascular abnormalities including decrease in heart rate variability (Chen et al. 2012). Therefore, ambient SO_2 concentration must be controlled. Concentration of SO_2 according to the lichens is carried out according to the procedure described (Section 2.3). Values obtained are given in Figure 7.

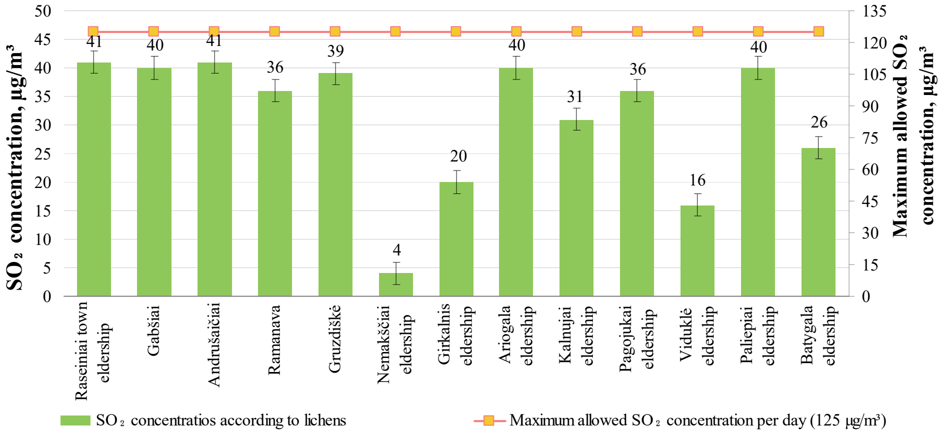

Fig. 7. Concentration of SO_2 ($\mu g/m^3$) in ambient air in Raseiniai district
Rys. 7. Stężenie SO_2 ($\mu g/m^3$) w powietrzu w rejonie Raseiniai

Figure 7 shows that SO_2 concentration in Raseiniai town and its surroundings (Gabšiai, Andrušaičiai, Gruzdiškės) is the highest compared with other study areas, and ranges from 39±2 $\mu g/m^3$ to 41±2 $\mu g/m^3$. The same SO_2 concentration is attributed to Ariogala and Paliepiai elderships. Increase in concentration can be influenced by the main industry of Raseiniai district rallied in these places. The survey also found that the concentration of SO_2 in the ambient air decreases when receding from the pollution sources (major industrial enterprises of Raseiniai district). This is affected by the distribution of pollutants in space. Lower concentration of SO_2 was determined in Kalnujų, Pagojukų elderships and the settlement Ramanava of Raseiniai town. Concentration in these areas varies between 31±2 and 36±2 μg/m^3. The lowest concentration of SO_2 is attributed to Nemakščiai and Viduklė elderships, where, respectively, SO_2 concentration is up to 4±2 and 16±2 μg/m^3. Calculation error is ±2 μg/m^3. The lowest concentration in the whole Raseiniai district is influenced by the fact that most of these elderships are distant from the major industrial enterprises most.

The studies have shown that sulphur dioxide concentrations in Raseiniai district do not exceed the limitary values for pollution. Calculations of ground-level concentration of the ambient air pollutant were compared with the limitary value of pollution, approved by the Order No 591/640 of 11 December 2001 by the Ministers of Health and Environment of the Republic of Lithuania "Relating to the determination of standards for the ambient air pollution" (Official Gazette, 2001, No. 106-3827; 2010, No 2-87), where the maximum daily limitary value of SO_2 can be up to 125 μg/m^3.

SO_2 concentrations determined in Raseiniai district applying passive samplers varied from 2.0±0.18 to 5.1±0.50 μg/m^3 with average value of 3.5 μg/m^3.

The biggest SO_2 concentrations in ambient air were recorded in Raseiniai town (5.1±0.50 μg/m^3) and the smallest concentrations – in Nemakščiai eldership (2.0±0.18 μg/m^3). In other measurement points SO_2 concentrations were within 2.7±0.26-4.5±0.41 μg/m^3.

Evaluation of ambient air quality was carried out in 2010-2011 in Lithuania and concentration of sulphur dioxide, nitrogen dioxide and benzene were measured with passive samplers in 375 places. According to data of this measurements the biggest ambient air pollution with SO_2 was measured in Stonų street 4, Raseiniai, because in this place the biggest quantity of private houses. In other places of Raseiniai district municipality average SO_2 concentration was until approximately 1 μg/m^3 (Raseiniai… 2015). The average concentration of SO_2 applying passive samplers during different seasons in the Raseiniai district municipality in 2015-2016 year was set: 0.6 μg/m^3 in winter, 1.0 μg/m^3 in spring, 0.5 μg/m^3 in summer, 0.8 μg/m^3 in autumn. The increase in SO_2 concentrations during the spring season could been caused by heating of individual homes in the cold season. Pollution from individual residential houses may depend on the type of fuel used and its quality, as well as on the distribution of pollutants under adverse meteorological conditions.

The decreasing of SO_2 concentration in the summer season can be explained by decreasing of car traffic intensity.

Similar concentrations of sulphur dioxide were measured in other urban areas of Lithuania with medium and low population applying passive samplers. The measured concentration of sulphur dioxide with passive samplers in Visaginas municipality ambient air were in range from 0.3 to 4.0 $\mu g/m^3$ in period from 2013 to 2017 year. Visaginas has 18 541 inhabitants in 2018 (Visaginas... 2017).

The concentration of sulphur dioxide measured with passive samplers in Anykščiai municipality ambient air (2017-2018) was in range from below 0.6 to 6.8 $\mu g/m^3$. Anykščiai has 8848 inhabitants in 2018 year). (Research… 2018).

Table 3. SO_2 concentration measured with passive samplers
Tabela 3. Stężenie SO_2 zmierzone za pomocą próbników pasywnych

Place	SO_2, $\mu g/m^3$
Raseiniai town	5.1±0.50
Gabšiai	4.0±0.39
Andrušaičiai	4.3±0.41
Ramanava	4.0±0.44
Gruzdiškė	3.5±0.32
Nemakščiai	2.0±0.18
Girkalnis	2.7±0.25
Ariogala	4.5±0.41
Kalnujai	3.3±0.30
Pagojukai	3.0±0.28
Viduklė	2.7±0.26
Paliepiai	3.5±0.33
Batygala	2.9±0.27

Correlation between concentrations of SO_2 measured with lichens and passive samplers. There were significant statistical relationships between measured SO_2 concentrations with both methods when Pearson's correlation matrix was applied to the variables at a 95% confidence interval. A strong positive correlation ($r = 0.84$) between concentrations of SO_2 measured with lichens and passive samplers indicates that lichens can be applied for approximate evaluation of SO_2 concentrations in ambient air.

4. Conclusions

1. The comparison of two different methods for air quality evaluation – application of passive sampling method and bio indication method with lichens was done. There were significant statistical relationships between measured SO_2 concentrations with both methods when Pearson's correlation matrix was applied to the variables at a 95% confidence interval. A strong positive correlation (r = 0.84) between concentrations of SO_2 measured with lichens and passive samplers suggests the application of lichens as a primary tool in determining the spatial distribution of airborne pollutant, e.g. SO_2.
2. Lichens are well suited for biomonitoring studies, since they effectively accumulate the atmospheric pollution and they can be applied to monitor temporal and spatial distribution of air pollution effects.
3. The study results show that the highest concentration of SO_2 in the ambient air determined applying bio indication method was found in Raseiniai district (41±2 $\mu g/m^3$) and its surroundings (Gabšiai (40±2 $\mu g/m^3$), Andrušaičiai (41±2 $\mu g/m^3$) and Gruzdiškės (39±2 $\mu g/m^3$). The highest concentration of SO_2 in the ambient air determined applying passive samplers was in Raseiniai district (5.1±0.50 $\mu g/m^3$) and its surroundings (Gabšiai (4.0±0.39 $\mu g/m^3$), Andrušaičiai (4.3±0.41 $\mu g/m^3$) and Gruzdiškės (3.5±0.32 $\mu g/m^3$).
4. The lowest concentration of SO_2 was determined in the Nemakščiai and Viduklė elderships where, respectively, the concentration of SO_2 was 4±2 and 16±2 $\mu g/m^3$ determined applying lichens and 2.0±0.18 and 2.7±0.26 $\mu g/m^3$ applying passive samplers. The lowest concentrations in investigated elderships are influenced by the fact that they are distant from the major industrial enterprises.
5. Applying of lichens and passive samplers indicated that road traffic and industrial activities are significant emission sources of SO_2 in region of Raseiniai district municipality, Lithuania. Study showed that concentration of SO_2 as strictly regulated air pollutant by EU Directives 2008/50/EC and 2000/69/EC did not exceed set threshold 125 $\mu g/m^3$ in the Raseiniai district municipality during the study period in August 2016. It can be assumed that air quality in the considered area is high.

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Pomiar zanieczyszczenia powietrza atmosferycznego SO_2 z zastosowaniem porostów i próbników pasywnych

Streszczenie

Możliwe jest przeanalizowanie negatywnego wpływu na jakość powietrza w środowisku poprzez zastosowanie bio-indykatywnej reakcji żywych organizmów na zanieczyszczenia. Porosty (*Lichenes* L.) są bardzo wrażliwe na zanieczyszczenia gazowe, więc można je wykorzystać do oceny zanieczyszczenia powietrza. Trzynaście punktów w okręgu Raseiniai zostało wybranych do pomiarów stężenia dwutlenku siarki w powietrzu z użyciem porostów i próbników pasywnych dla porównania. Zmierzone wartości stężeń SO_2 porównano z wartościami granicznymi ustalonymi dla tego zanieczyszczenia w powietrzu zgodnie w dyrektywach 2008/50/WE i 2000/69/WE. Stężenia SO_2 określone za pomocą porostów porostów były wyższe niż uzyskane za pomocą próbników pasywnych, ale w obu przypadkach były one niskie i nie osiągały wartości granicznych w powietrzu. Im dalej od górnych źródeł zanieczyszczeń (główne przedsiębiorstwa przemysłowe w okręgu Raseiniai) tym wartości stężenia SO_2 w powietrzu spadały. Średnie stężenia SO_2 w powietrzu w rejonie Raseiniai nie osiągnęły dopuszczalnych wartości granicznych dla powietrza atmosferycznego (125 $\mu g/m^3$) w okresie badania (w sierpniu 2016 r.). Wyniki badań wskazują, że najwyższe stężenie SO_2 w powietrzu określone z użyciem porostów były w rejonie Raseiniai (41±2,0 $\mu g/m^3$) i jego otoczeniu (Gabsiai (40±2,0 $\mu g/m^3$), Andrušaičiai (41±2,0 $\mu g/m^3$) i Gruzdiškės (39±2,0 $\mu g/m^3$). Najwyższe stężenie SO_2 w powietrzu zmierzone próbnikami pasywnymi było w rejonie Raseiniai (5,1±0,50 $\mu g/m^3$) i jego otoczeniu (Gabšiai (4,0±0,39 $\mu g/m^3$), Andrušaičiai (4,3±0,41 $\mu g/m^3$) i Gruzdiškės (3,5 $\mu g/m^3$). Najniższe stężenie SO_2 zmierzono z zastosowaniem porostów w Nemakščiai i Viduklė (4±2,0 $\mu g/m^3$ i 16±2,0 $\mu g/m^3$) i 2,0±0,18 $\mu g/m^3$ oraz 2,7±0,26 $\mu g/m^3$ z zastosowaniem próbników pasywnych. Stwierdzono istotne zależności statystyczne między zmierzonymi stężeniami SO_2 stosując obie metody. Zastosowano macierz korelacji Pearsona dla zmiennych w przy 95% przedziale ufności. Silna dodatnia korelacja ($r = 0,84$) między stężeniami SO_2 mierzonymi za pomocą porostów i próbników pasywnych wskazuje, że porosty można stosować do oceny stężeń SO_2 w powietrzu. Najniższe stężenia w badanych starostwach spowodowane są ich odległością od głównych zakładów przemysłowych i obiektów energetycznych.

Abstract

It is possible to analyse a negative impact on environmental air quality by using living organism's bio indicative reaction to pollutants. Lichens (*Lichenes* L.) are very sensitive to gaseous pollutants so may be used to evaluate air pollution. Thirteen points in Raseiniai district were selected for measurements of sulphur dioxide concentrations in ambient air using lichens and passive samplers for comparing. Measured values of SO_2 concentrations were compared with limit values set for this pollutant in ambient air according to 2008/50/EC and 2000/69/EC directives. SO_2 concentrations determined with lichens was bigger than determined with passive samplers, but in both cases, they were low and did not reach permissible limitary values in ambient air. Further from, the main pollution sources (main industrial enterprises in Raseiniai district) values of SO_2 concentration in the ambient air gradually decreased. Average SO_2 concentrations in ambient air of Raseiniai district did not reach permissible limitary values set for ambient air (125 $\mu g/m^3$) during the study period in August 2016. The study results show that the highest concentration of SO_2 in the ambient air determined applying lichens was in Raseiniai district (41±2.0 $\mu g/m^3$) and its surroundings (Gabšiai (40±2.0 $\mu g/m^3$), Andrušaičiai (41±2.0 $\mu g/m^3$) and Gruzdiškės (39±2.0 $\mu g/m^3$). The study results show that the highest concentration of SO_2 in the ambient air determined applying passive samplers was in Raseiniai district (5.1±0.50 $\mu g/m^3$) and its surroundings (Gabšiai (4.0±0.39 $\mu g/m^3$), Andrušaičiai (4.3±0.41 $\mu g/m^3$) and Gruzdiškės (3.5 $\mu g/m^3$)). The lowest concentration of SO_2 was determined in the Nemakščiai and Viduklė elderships where, respectively, the concentration of SO_2 was 4±2.0 $\mu g/m^3$ and 16±2.0 $\mu g/m^3$ determined applying lichens and 2.0±0.18 $\mu g/m^3$ and 2.7±0.26 $\mu g/m^3$ applying passive samplers. There were significant statistical relationships between measured SO_2 concentrations with both methods when Pearson's correlation matrix was applied to the variables at a 95% confidence interval. A strong positive correlation (r = 0.84) between concentrations of SO_2 measured with lichens and passive samplers indicates that lichens can be applied for approximation evaluation of SO_2 concentrations in ambient air. The lowest concentrations in investigated elderships are influenced by the fact that they are distant from the major industrial enterprises and energetic objects.

Słowa kluczowe:
zanieczyszczenie powietrza, porosty (*Lichenes* L.), SO_2, wskaźniki biologiczne, próbniki pasywne, powiat Raseiniai

Keywords:
air pollution, lichens (*Lichenes* L.), SO_2, bio-indicators,
passive samplers, Raseiniai district