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A SPATIAL EVALUATION OF THE IMPACT OF AIR POLLUTION: A GIS-BASED APPROACH

VREDNOTENJE PROSTORSKIH VPLIVOV ONESNAŽENJA ZRAKA NA PODLAGI GIS-OV

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Keywords: air quality indicators, Bosnia and Herzegovina, living environment, Montenegro, Slovenia, spatial evaluation

Abstract

The common denominator of the three areas discussed in this paper is basin-type terrain; all areas of the research were thoroughly transformed by human activities (mining, production of energy, industry, settlements and associated infrastructure) in the second half of the 20th century:

1) the wider area of Plevlja Community in Montenegro; air quality indicators were monitored at 19 sampling places;

2) Tuzla basin in Bosnia and Herzegovina as a heavily polluted landscape (industry, energy production, heating of private furnace); 20 monitoring sites were placed there. The anthropogenic environmental pressures have not been reduced;

3) Šalek Valley (Slovenia) as an example with an entire range of well-established technological environmental solutions and measures in the manufacturing sector with 34 measuring points.

In all three cases, very active transport activity caused by different users represents significant environmental pressure.

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The evaluation of the quality of the living environment was made indirectly, using the environmental indicator method. The basis of the survey was carried out during the winter heating period, since we intended to determine the presence of some air pollutants and their effects (especially spatial ones) on the quality of the living environment. Principally, the researched areas are more delicate in the winter period, because private heating system fossil fuels are used. We monitored sulphur dioxide and nitrogen dioxide. In the survey, the method of measurement with diffusion tubes placed at various outdoor locations of the living environment was used, with locations in rural and urban area.

We wanted to add an applied value to the preliminary results of measurements, so these results were used for the spatial presentation below. Both can play an important role in the municipal spatial planning of socio-economic activities, e.g. settlement, educational and medical institutions, manufacturing facilities.

Furthermore, we intend to show the obtained results of the air quality level in relation to the data on morbidity in the treated areas, i.e. cardiorespiratory diseases.

Povzetek

Območja raziskave so v 2. polovici 20. stoletja močno preoblikovale in obremenile človekove dejavnosti: rudarstvo, energetika, industrija, poselitev in pripadajoča infrastruktura. V prispevku obravnavamo tri območja s še enim skupnim imenovalcem - kotlinski pokrajinski tip:

1) širše območje občine Plevlja v Črni gori, kjer smo antropogene pritiske na kakovost zraka spremljali na 19 merilnih mestih;

2) Tuzlanska kotlina v Bosni in Hercegovini, 20 merilnih mest, okoljsko obremenjevanje ne pojenjuje (kemična industrija, termoenergetika);

3) Šaleška dolina s celim nizom uvedenih dobrih tehnoloških okoljskih rešitev in ukrepov v proizvodnih dejavnostih, kjer smo izpostavili 34 merilnih mest.

Kakovost bivalnega okolja smo vrednotili posredno, z merjenjem kazalcev za zrak v zimskem (kurilnem) obdobju. Tako smo se odločili predvsem zaradi tujih območij, kjer v hladnem delu leta zasebna kurišča zaradi rabe fosilnih goriv močno vplivajo na kakovost zraka. Ugotavljali smo prisotnost nekaterih zračnih onesnažil ter njihovo prostorsko razporeditev in vpliv na kakovost bivalnega okolja. Spremljali smo vsebnost žveplovega dioksida in dušikovega dioksida v zunanjem zraku. Na terenu je bila uporabljena metoda merjenja s pasivnimi difuzivnimi vzorčevalniki, nameščenimi na lokacije s funkcijo bivalnega okolja.

Rezultatom meritev smo želeli dodati aplikativno vrednost in jih prikazali tudi prostorsko. Imajo lahko pomembno vlogo pri nadaljnjem umeščanju posameznih dejavnosti, npr. poselitev, izobraževalne in zdravstvene ustanove, ter proizvodni obrati v preučevanih območjih.

V nadaljevanju raziskave želimo prikazati dobljene rezultate kakovosti zraka v razmerju do podatkov o obolevnosti, predvsem kardiorespiratornih bolezni, na obravnavanih območjih.

1 INTRODUCTION

The combination of environmental impact assessments (EIA) and GIS (Geographical Information System) could provide an approach to explore the scope of the evaluation of air quality.

GIS can be used to obtain the spatial information for the assessment of air pollution impact in various suburban and rural areas. Such information serves as an example to quantify the negative impacts of ambient air quality associated with any planned projects of anthropogenic origin. The approach utilized the spatial evaluation of air pollution and aids in providing critical insight to the assessment, which is not apparent while carrying out such activity in the traditional manner. That kind of study could encourage spatial planners to make wider application of the technique for an in-depth assessment of environmental impacts, [3].

The Slovenian Environment Agency has been monitoring air pollutants in the ambient air by using diffusive samplers since 2003, [7].

Slovenia has been obliged to adopt two European Directives on ambient air quality. The directives establish, [10]:

- Ambient air quality standards, in particular the target, limit, warning, critical and alert values for ambient air quality in order to avoid, prevent or reduce adverse effects on human health and the environment,
- Ways of informing the public on overcoming the threshold values for certain pollutants,
- An obligation to draw up plans and measures for maintaining and improving air quality.

Fieldwork was carried out in three areas, in different nations, but related by geophysical characteristics. All belong to the basin area type, especially sensitive in terms of the self-cleaning ability of the air. Locally, the most variable factors depending on the terrain are the wind speed and the wind direction. The direction of wind is usually dominated by the axis of the valley. The wind at the bottom of the valley is the weakest, while its speed increases with the height of the valley slopes, [8].

Winter is also unfavourable due to frequent foggy days and the occurrence of temperature inversions. Two areas of inversion have been identified: a) a terrestrial temperature inversion layer, which protects the bottom of the valley from the air pollution, as there are usually high exhaust chimneys of thermal power plants up to 230 m, and b) a higher subsidence temperature inversion layer, that closes the flue gas path from a thermal power plant. These accumulate below the top layer of the air with a temperature inversion, and then the slope winds move down towards the bottom of the valley; as a result, the terrestrial inversion is not achieved, [6].

The researched sites have inherited similar social development policies. Their appearance today is energy-intensive and industrialized (there are thermal power facilities of national significance), concentrated with settlements and associated infrastructure. Šalek Valley represents an isolated role as an example of a thoroughly improved environmental landscape, while environmental measures in the other two areas are lagging behind (both in the perception of air pollution and the implementation of remediation). Periods of exposure to diffusive samplers coincided with a cold period due to a lack of available sampling materials, and measurements were performed sequentially in Šalek Valley between the 20 November and 4 December 2009, from 27 October to

18 November 2010 in the Tuzla basin, and from 27 October to 22 November 2012 in Montenegro.

We wanted to determine the presence of certain air pollutants and their spatial distribution. To measure the quality of the living environment, we deliberately chose to use the fossil fuels most consumed in winter. Based on the results of air quality measurements and trends of urbanization, we can systematically track changes in the environment and coordinate them with the spatial needs of different socio-economic activities, [4].

1.1 Air quality indicators

The Slovene Regulation of sulphur dioxide, nitrogen oxides and particulate matter in ambient air, [12], was replaced in 2011 by the Regulation on ambient air quality, [11]. By 2005, the hourly limit value for nitrogen dioxide was 200 g/m³, which was not supposed to happen more than 18 times per calendar year. Later, the threshold value steadily decreased (in 2005 50 g/m³, in 2006 40 g/m³, in 2007 30 g/m³, in 2008 20 g/m³ and from 2009 onward 10 g/m³).

The value for the calendar year until 2005 amounted to 40 g/m³, then decreased (in 2005 10 g/m³, in 2006 8 g/m³, in 2007 6 g/m³, in 2008, 4 g/m³, and from 2009 onward 2 g/m³).

Table 1: *Allowed concentration, limit values and tolerance (in mg/m³) for NO2 and SO_2, comparison between Slovenia, Montenegro and Bosnia and Herzegovina*

	SO_2 [µg/m³]		NO_2 [µg/m³]	
	hourly	**daily**	**hourly**	**annual**
Bosnia and Herzegovina	350 (alarm value 500)	125	200 (alarm value 400)	40
Montenegro	350		350 or 200 bay mass flow of 1800 g/h	
Slovenia	350 (may not be exceeded more than 24 times per calendar year)	125 (may not be exceeded more than 3 times per calendar year)	10	2

1.1.1 Nitrogen Oxides

The indicator shows the total emissions of nitrogen oxides (NOx), indicating mostly the impact of traffic. In 2011, road transport Slovenia contributed 54% of the total emissions of nitrogen oxides. The energy sector is the second largest source of these pollutants. Data for annual NOx emissions for Slovenia in the period from 1987 to 2007 showed a reduction of emissions in 2007 by almost 20% compared to 1987. The decrease happened due to higher proportion of vehicles with catalytic converters. NOx emissions in 2007 were 1% lower than the predicted target value. The level of air pollution with nitrogen dioxide in the 1992–2008 period fell below the prescribed limit average annual concentration. Only in Maribor did the annual concentration throughout the 1992–2008 period exceed the critical value of annual NOx for the protection of vegetation and ecosystems, mainly due to the influence of surrounding traffic.

1.1.2 Sulphur dioxide

In Slovenia, the level of ambient air pollution with sulphur dioxide in urban areas, according to the limits laid down in the Regulation on ambient air quality, [11], does not reach levels dangerous to human health. Moreover, critical annual concentrations for the protection of vegetation are not exceeded. Improvement of the air quality in the previous decade is attributable to the higher grade of the fuel (higher quality coal, oil, gas) plus activation of desulphurization plant of the TPP Šoštanj and Trbovlje. In the Zasavje region, a purifying plant in the Lafarge factory was installed. In Slovenia, the SO_2 emissions were reduced by 2007 to 94% compared to 1980. The decrease was primarily due to lower and controlled releases from power plants and the use of higher quality fuels. Emissions of SO_2 in 2007 were 47% lower in comparison to the predicted target value.

2 METHODS AND MATERIALS

2.1 Diffusive samplers method

As a basic material for the research fieldwork, we used the diffusive samplers. This method works on the principle of pollutant transport in the sampler by means of molecular diffusion. Samplers are tubes that stay open at one end during the time of sampling and are continuously exposed to the ambient air. At the closed end of the tube, there is a membrane with a reagent to a given substance (pollutant). Pipes should be opened just before exposure and closed immediately afterwards. The recommended exposure time is 14 to 21 days. The advantages of this method are flexibility, convenience, affordability and, therefore, the possibility of a recurrence of sampling, which increases the usefulness of the method. Due to the lower reliability of the method, it can be complemented by parallel measurements of data at automatic stations. The results provide with information about the average pollution values for the period of exposure, but not maximum, hourly and daily values, as required by legislation, [11].

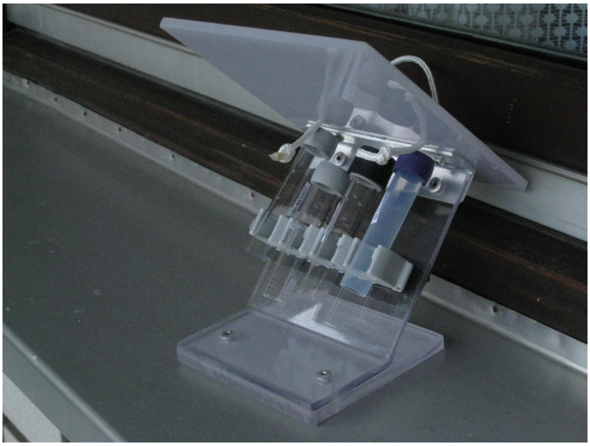


Figure 1: *Exposure of diffusive samplers*

2.2 Inverse Distance Weighted method (IDW)

Each method of interpolation determines or estimates the value of the measurements at selected locations, which lie in locations with a known monitored value. The quality of the approximated model surface depends on the measurement that is interpolated, the allocation (distribution) of sample points, and the chosen interpolation method. In principle, the denser and more homogeneous distribution of the given points leads to a credible result.

The method of inverse distance weights (IDW) assumes that any given sample point has its local impact, which decreases with the inverse potency of the distance from the interpolated point. Points closer to the interpolated point are weighted (influential) more than more distant ones. The IDW method assesses the value of the intersection of the two profiles of the cellular network by calculating the average value of the given sample points near each intersection. This approach thus allows a greater impact of closer points than more distant ones. The method is applicable in cases in which the influence of the studied variables decreases with the distance from the sample locations. For example, the interpolation of point location of pollutants, the concentration decreases with distance from the location of contaminants, and the use of this method is logical. The disadvantage of this method is that the approximated surface can reach local extremes (minima and maxima) only in the given point, which does not reflect the situation in nature. The IDW method is suitable for the preview of the approximated surface, [2].

3 RESULTS AND DISCUSSION

The data for measured values of the monitored air quality indicators were processed with the basic statistics. Due to the low number of sample points (19–34), the most appropriate interpretation of the results was to use the mean value of the median.

Measurements revealed the highest mean (median) in the measured period for NO_2 emissions in the municipality Plevlja in Montenegro (20.22 mg NO_2/m^3). The Tuzla basin followed with 13.68 mg

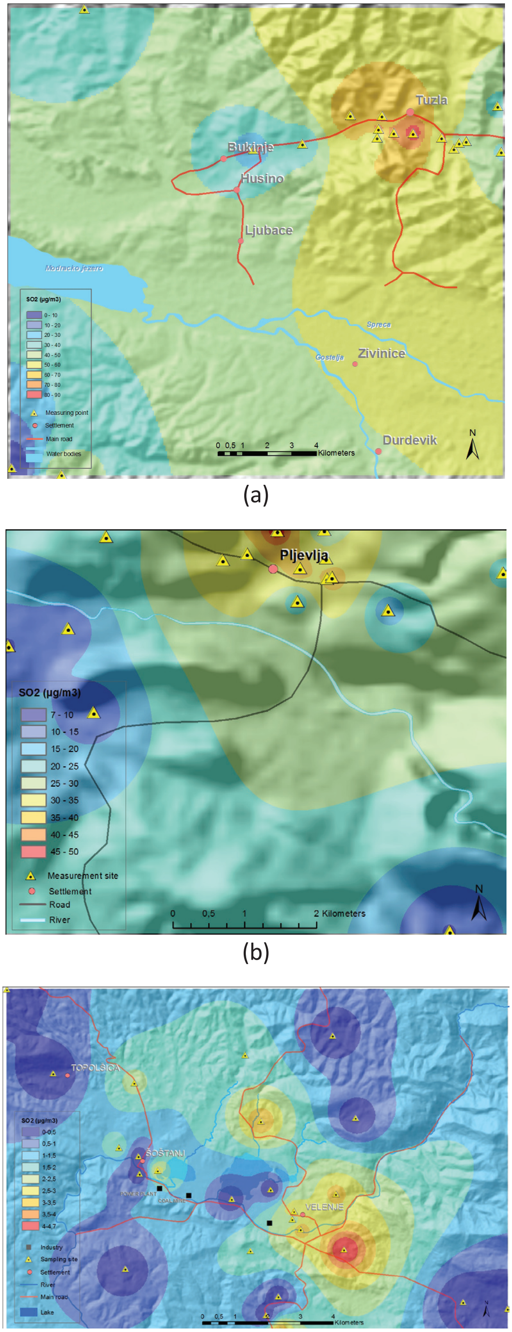
NO_2/m³, and the least burdened air with NO_2 was measured in Šalek Valley.

The indicator of sulphur dioxide in the ambient air pollution had the highest value of 45.85 mg SO_2/m³ in the area of Tuzla. The wider area of the municipality of Plevlja in Montenegro tended to have almost the half of the concentration of sulphur dioxide pollution (23.57 mg SO_2/m³), while the average value of this indicator in Šalek Valley was negligible (0.01 mg SO_2/m³).

Table 2: *The calculated mean value (median), average, standard deviation from the average and maximum measured concentrations of NO_2 and SO_2 in the discussed period and in selected areas.*

Area/Pollutant	**NO_2 [µg/m³]**	**SO_2 [µg/m³]**
TUZLA (n=20)		
median	13.68	45.85
average	14.02	44.95
st. deviation	11.56	23.22
maximum	37.99	88.49
PLEVLJA (n=19)		
median	20.22	23.57
average	19.61	23.95
st. deviation	8.69	12.47
maximum	34.08	50.14
ŠALEK VALLEY (n=34)		
median	13.29	0.01
average	14.96	1.61
st. deviation	3.99	2.65
maximum	22.21	9.42

The maximum concentration of NO_2 was measured in Tuzla (37.99 mg NO_2/m3). The data for Plevlja showed 34.08 mg NO_2/m³ and the least air pollution pressure was evident in Šalek Valley (22.21 mg NO_2/m³). Even after the measured concentrations of SO_2, as calculated by the maximum value, the outstanding result was found in the Tuzla basin (88.49 mg SO_2/m³), followed by the municipality of Plevlja (50.14 mg SO_2/m³). The least laden ambient air with sulphur dioxide was measured in Šalek Valley (9.42 mg SO_2/m³).



(a)

(b)

(c)

Figure 2: *The spatial display of the measured values for* SO_2 *in the researched areas (a) - Tuzla basin in Bosnia and Herzegovina (b) - the area of the Plevlja municipality in Montenegro and (c) - Šalek Valley in Slovenia*

The spatial distribution of the measured indicators for the quality of air produced by the GIS (Geographic Information System) approach reflects the pollution of the individual parts of the areas of research. Based on the pollution measurement of the ambient air and the appropriate number of repeated measurements with the denser (systematic) monitoring network, we could determine more detailed findings on air quality. In addition, microclimatic conditions (flow of air) and meteorological data for days of exposure of the samplers should be taken into account.

Such data on air pollutants may be an appropriate form of assistance for spatial planners in assessing and allocating activities and their potential effects on the environment. The data are also useful in the design of remedial measures and programmes.

3.1 Tuzla basin

Measurements were performed at altitudes of 221 to 326 m above sea level. They revealed a very strong contamination of the site Tuzla basin with sulphur dioxide. The highest measured values are shown in a cartographic representation for the area Mejdan in the city centre, close to the university and associated faculties, [14]. The highest measured value (88.49 mg SO_2/m^3) was also there. The lowest values were found at monitoring sites Bukinje, west of the city.

Data for NO_2 showed the lowest values in urban areas of Mejdan and Stupine, a residential (blocks of apartments) quarter, which is located south east of the city centre. Low values (up to 15 mg NO_2/m^3) were also measured south from the eastern artery into the city. Maximum values reflect the results of measurements of NO_2 in the northeast outskirts of Tuzla basin (Grabovica Donja).

3.2 Plevlja

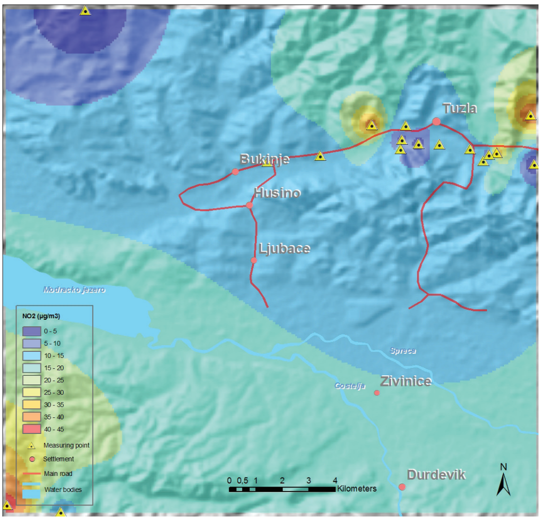
The measuring points were set at altitudes of 753 to 1017 m. The basin type of landscape has a typical spatial distribution of sulphur dioxide, i.e. heavily laden at the bottom of the depression and pollution-free edge of the basin. The highest values were measured at three urban locations (between 40 and 50 mg SO_2/m^3), the maximum at the measurement site Moćevac (50.14 mg SO_2/m^3) in the northern part of the measurement area. Values from 30 to 40 mg SO_2/m^3 were characteristic for the rest dense populated area of Plevlja. Less pollution (7-15 mg SO_2/m^3) was observed by the stations at the W and SE of the basin perimeter.

According to the results of NO_2 measurements, three locations in the N and NW part of the studied area were outstanding. Again, as the most polluted areas there were three urban sites with the highest value of NO_2 at the location Moćevac NO_2 (34.08 mg NO_2/m^3). The lowest values were measured in the western part of the area, outside the dense populated town Plevlja.

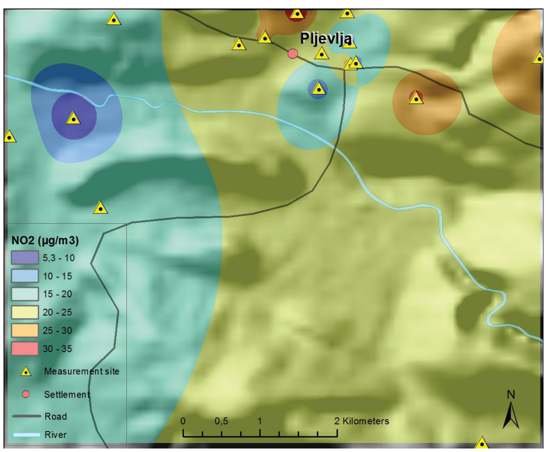
3.3 Šalek Valley

Diffusive samplers were exposed between 352 and 772 m above the sea level. Despite the very low concentrations of burdening ambient air in the valley with SO_2, peak values occurred on the SE edge of the Velenje basin (category 4 to 4.7 mg SO_2/m^3). Values were reduced to the NW in the town of Velenje with the wider hinterland, where we measured values between 2 and 3.5 mg SO_2/m^3. The lowest values were evidenced at all other measuring points of the basin periphery (0 to 0.5 mg SO_2/m^3).

Maximum values for NO2 were measured at the very southern edge of the basin. The sites of the researched area mostly expressed very low levels, with the exception of a mountain location: Graška Gora (category 20 to 25 mg NO_2/m^3).



(a)



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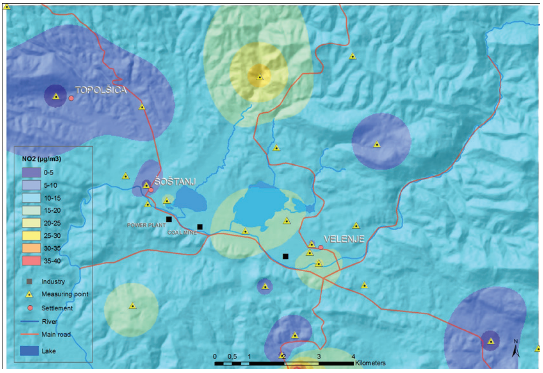

(c)

Figure 3: *The spatial display of the measured values for NO_2 in the researched areas (a) Tuzla basin in Bosnia and Herzegovina, (b) the area of Plevlja municipality in Montenegro and (c) Šalek Valley in Slovenia.*

3.4 Air Quality Index (AQI)

The AQI (of the Environmental Protection Agency (EPA)) is an index for reporting daily air quality. It explains how clean or polluted the monitored air is and what associated health effects might be of concern. The higher the AQI value, the greater the level of air pollution and the greater the health concern. For example, an AQI value of 50 represents good air quality with little potential to affect public health, while an AQI value over 300 represents hazardous air quality. The purpose of the AQI is to aid in understanding what local air quality means to peoples' health.

Each category corresponds to a different level of health concern. The six levels of health concern and what they mean are, [5]:

Table 3: *AQI categories and Health Concern*

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

The highest AQI SO_2 concentration results were in the Tuzla area. The third category (AQI index: 146) evidenced an increased vulnerability for the people with respiratory illnesses. There are also warnings relevant to inhabitants subject to asthma in other two researched areas, but with no health effects and cautionary statements. The air quality state in the Bosnian fieldwork area required urgent sanitation measures.

Table 4: *Air Quality Index (AQI) in the discussed areas after calculation of SO_2 concentration*

Area	AQI	AQI Category	Sensitive Groups	Health Effects Statements	Cautionary Statements
Tuzla	146	Unhealthy for Sensitive Groups	People with asthma are the group most at risk.	Increasing likelihood of respiratory symptoms, such as chest tightness and breathing discomfort, in people with asthma.	People with asthma should consider limiting outdoor exertion.
Plevlja	9	Good	People with asthma are the group most at risk.	None	none
Šalek Valley	6	Good	People with asthma are the group most at risk.	None	none

(AQI calculation accessed at http://airnow.gov/index.cfm?action=resources.conc_aqi_calc)

Measurements of NO_2 concentrations revealed the Plevlja area to be the most polluted with nitrogen oxides. An AQI of 102 indicated unhealthy environment for people with increased likelihood of respiratory diseases, breathing discomfort and lung disease. Šalek Valley and the Tuzla basin area also seemed to be risky living environments for children and elderly with respiratory illnesses. Due to the moderate AQI category, prolonged and heavy outdoor exposure should be avoided.

Table 5: *Air Quality Index (AQI) in the discussed areas after calculation of NO_2 concentration*

Area	AQI	AQI Category	Sensitive Groups	Health Effects Statements	Cautionary Statements
Tuzla	71	Moderate	People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk.	Unusually sensitive individuals may experience respiratory symptoms.	Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion.
Plevlja	102	Unhealthy for Sensitive Groups	People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk.	Increasing likelihood of respiratory symptoms and breathing discomfort in active children, the elderly, and people with lung disease, such as asthma.	Active children, the elderly, and people with lung disease, such as asthma, should reduce prolonged or heavy outdoor exertion.
Šalek Valley	69	Moderate	People with asthma or other respiratory diseases, the elderly, and children are the groups most at risk.	Unusually sensitive individuals may experience respiratory symptoms.	Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion.

(AQI calculation accessed at http://airnow.gov/index.cfm?action=resources.conc_aqi_calc)

4 CONCLUSIONS

Monitoring of ambient air quality is a key activity in evaluating the state of the living environment or assessing and planning additional burdens in a selected area. Data on air pollution in Slovenian cities suggest high levels of pollution with NO_2. In addition, Slovenian urban areas have been increasingly more polluted with particulates of <PM10 microns. In 2010, the European Commission initiated proceedings against Slovenia at the European Court of Justice for failure to comply with environmental legislation.

Measurements and calculated data indicate the Tuzla basin to be the most polluted area. Considering the basic statistical parameters, the indicators of SO_2 and NO_2 were recorded as the highest (88.49 mg SO_2/m^3 and 37.99 mg NO_2/m^3), as well as mean values for the indicator SO_2

(45.85 mg SO_2/m3). The highest calculation of the mean values of NO_2 was measured in the wider area of the municipality Plevlja in Montenegro (20.11 µg NO_2/m^3) and is almost identical to the maximum measured value for the Šalek Valley (22.21 µg NO_2/m^3). At the same time, there are less stringent legal requirements for the limit thresholds of the indicator considered, which means that they have not been moving towards more radical action in relation to the quality of air.

Therefore, the results for the Šalek Valley are a wide disparity in the positive sense. The mean values for SO_2 concentrations are low (0.01 mg SO_2/m^3), while the maximum measured value of the same indicator was 9-42 mg SO_2/m^3. The results for nitrogen oxides are the most favourable for the Šalek Valley compared to the other two areas. Taking into account the legal provisions for the air quality, the results dictate a need for further reducing of NO_2 emissions.

The method of diffusive samplers is suitable for ambient air quality monitoring. For a relatively low cost, it offers results on the spatial distribution of air pollutants, and the resulting data are a welcome help to land-use planners in the assessment and planning of new activities in the area. The relevance of method could be supported by the denser network of monitoring sites, repeated measurements and simultaneous use of other planning methods. An appropriate amendment would provide the data on the local terrestrial air circulation.

The acquired results are just one of the models that examined the links between urbanization and the quality of environmental resources and they proposed continuation of the work. Environmental pressures have not been reduced, nor have energy needs. The trend of space burdening has been intensified by dense settlements.

Environmental capacity of the area, not just urban, should be considered broadly because of its scarcity and mainly due to overburdening. There are many factors that affect the quality of the environment. Moreover, studies similar to this one should consider more of them (weather, microclimate characteristics, demographic data, etc.) to enable more definitive conclusions about the air quality in the mentioned areas with the help of the results obtained. In general, we designed a framework for the systematic assessment monitoring of changes in air quality.

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