AIR QUALITY ASSESSMENT AS AN ENVIRONMENTAL FACTOR OF THE QUALITY OF LIFE

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Abstract
This paper proposes a tool for air quality assessment that could be used among environmental factors in the studies of quality of life. It also demonstrates performance of a set of air quality related questions that might be considered part of questionnaire surveys for the subjective dimension of the quality of life. A measure of relative risk of exposure to particulate matter is proposed for quantification of adverse health effects of air pollution on the general population, on children under 5 years of age or on persons over 30 years of age. The city of Ostrava was selected as a study area for its long-term issues with air pollution in order to test the proposed instruments in a location where air quality is the most likely to affect the quality of life in the Czech Republic.

Key words: air quality, quality of life, relative risk, questionnaire survey, Ostrava.

INTRODUCTION

Quality of life has become a frequently researched topic in geography owing to its strong spatiotemporal aspect and its interdisciplinary complexity. Although originally based on economic and social indicators, it has later incorporated environmental dimension into the overall assessment (Andráško 2009). This inclusion dates back to the 1980s and is marked by demands for multidimensional quantitative analysis, pointing out that welfare and quality of life are determined by a varied set of factors, which cannot all be monetized (Maasoumi 1986). The development of research methods and concepts has been described e.g. by Slottje (1991), Maasoumi (1999), van Kamp et al. (2003), Pacione (2003), Pissourios (2013) and others; in the Czech and Slovak context e.g. by Vaďurová and Mühlpachr (2005), Payne et al. (2005), Ira and Andráško (2007) or Kladivo et al. (2009).

Quality of life may be assessed in its objective dimension, based on quantitative data describing external factors (usually social, economic and environmental), or in its subjective dimension, based on qualitative indices of individual's views, perceptions and feelings (Ira and Andráško 2007). The environmental factors range from urban green, noise levels or waste management to water and air pollution, each of them being a rather complex field of study on its own. The application of environmental indices is therefore inevitably selective even in multivariable analyses.

Objective quality-of-life studies are usually based on selection of input data ready-available from statistical surveys and continuous monitoring. In the case of air pollution, emission inventories and data sets on concentration levels of various air pollutants are used the most commonly. Data on volumes of substances emitted from air pollution sources are

derived from statistics on fuel use, production volumes etc. using 'emission factors', which means that they are estimates, carrying a certain level of inaccuracy or incompleteness. Nonetheless, if carried out systematically and thoroughly, emission inventories represent a reliable source of air pollution data (Braniš and Hůnová eds. 2009). Utilization of this type of data is proposed by e.g. Hirschberg et al. (2001). Their study examines two air pollution indices, 'population per ton SO2 emitted' and 'population per NOx emitted', and use cluster analysis to justify their applicability as components in quality-of-life assessments.

Another common approach is to analyze air quality monitoring data, providing information on instantaneous, daily, monthly, annual or long-term pollutant concentration levels in ambient air. A wider range of substances is usually monitored, which means that either a representative selection must be made, or a synthetic indicator needs to be applied for the assessment. The most often monitored air pollutants world-wide are sulphur dioxide (SO_2), nitrous oxides (NO_x) and particulate matter (PM). For the purposes of synthetic assessment, various air quality indices have been developed, differing mutually in the assessment algorithm applied and in the pollutants concerned. The best-known and frequently applied (often with local modifications) is the US EPA air quality index (US EPA 2009); its local adjustment is used by the Czech Hydrometeorological Institute for indication of overall air quality in the Czech Republic.

A limiting factor in the use of air pollution data for quality-of-life assessment is that they are usually compared against legally accepted limit values of ambient air pollution levels (and the construction of air quality indices often follows the same pattern). It must be noted here that national air quality standards are defined as a result of legislative debate between experts and policymakers, therefore legal limits for air pollution levels represent a compromised guideline, not necessarily health-safe thresholds. This is unfortunately a case of even recently suggested indices – e. g. Silva and Mendes (2012) propose an urban environmental quality index based on noise levels and air quality, where the air quality component is quantified both against legal limits and WHO guidelines. An alternative approach to overcome this limitation builds on the results of exposure-based studies of the environmental burden of disease (Milovantseva and Ogunseitan 2011). Also Pascal et al. (2013) base their assessment urban air pollution in public health impacts, studying gains in life expectancy from potential reduction of air pollutant levels.

The subjective dimension of the quality of life is studied mainly using questionnaire surveys or interviews (Ira and Andráško 2007). A comparison of several questionnaire-based studies on quality of life carried out recently in the Czech Republic (Jeřábková 2011, Karoľová 2012, Kladivo 2012, Macrineanu 2012) shows that questions on air pollution mostly inquire level of contentment with or importance of air quality, or ask for general evaluation of air quality, usually asking only one question on this topic. A detailed questionnaire survey was carried out for the Czech Academy of Sciences within the "Programme Ostrava" (GAC 2010), using a whole range of questions on perception of air pollution and its relation to public health. A comparison of performance of such a wider set of questions may indicate what is to be inquired in order to obtain more specific information on perception of air quality. Kim et al. (2012) demonstrate a way of linking perceived air quality with measured air pollution data and discuss the influence of social factors on perception of air quality and public acceptance of environmental policy.

The city of Ostrava was selected as location for a case study because of its air quality issues. Ostrava and its surroundings have been regularly identified as a region with the most polluted ambient air in the Czech Republic and forming part of a wider cross-border area with one of the worst levels of air quality in Europe (Blažek et al. 2013). The Upper Silesian Region in Poland and the adjacent Moravian-Silesian Region in the Czech Republic represent a contiguous area of relatively high population density and concentration of heavy industry, both leading to significant volumes of emissions. Therefore, close attention has been paid to the research of causes and impacts of air

Figure 1 Study areas of the city of Ostrava (share of resident population in brackets).

pollution in this area. The "Programme Ostrava" (Šrám 2012) consisted of research projects AIR-GEN and AIRTOX carried out in the years 2008-2011 with the aim to assess the influence of air pollution on health of population in the Moravian-Silesian Region (genetic mutations, toxicity); it confirmed a significant health risk of exposure to fine particulate matter PM2.5 and related carcinogenic polycyclic aromatic hydrocarbons (e.g. benzo[a]pyrene). The project "Air Quality Information System in the Polish-Czech border in the Silesian and Moravian-Silesian Region" (also known as "Air Silesia") was carried out in 2010-2013 in order to create a mutual trans-border assessment and information system on air quality in the Silesian Voivodeship and Moravian-Silesian Region (Blažek et al. 2013).

METHODS

The city of Ostrava is divided into 23 administrative neighbourhoods, which we have grouped into four areas for the purpose of our study: Ostrava West, Ostrava South, Ostrava Centre and Ostrava East (Figure 1). This division respects the intra-urban features of the city (e.g. terrain, historical development of settlement, specifics of urban design etc.), provides for air pollution monitoring data in each of the four areas and is consistent with a previous study of Tomášková et al. (2011).

Air pollution data for assessing the objective dimension of the quality of life were selected as annual means of PM_{10}. Data sets from air quality monitoring stations are ready-available on-line on the

Table 1 Formulas estimating relative risk from air pollution data. Source: Ostro (2004).

Exposure metric	Health outcome	Relative risk function	Suggested β coefficient	Subgroup
PM_{10}	All-cause mortality	$RR = \exp[\beta(X - X_0)]$	0.0008 (0.0006–0.0010)	All ages
PM_{10}	Respiratory mortality	$RR = \exp[\beta(X - X_0)]$	0.00166	Age < 5 years
$PM_{2.5}$	Cardiopulmonary mortality	$RR = [(X+1)/(X_0+1)]^{\beta}$	0.15515	Age > 30 years
$PM_{2.5}$	Lung cancer	$RR = [(X+1)/(X_0+1)]^{\beta}$	0.23218	Age > 30 years

Note: X – current pollutant concentration (μg/m³), X_0 – threshold concentration of pollutant (μg/m³)

website of the Czech Hydrometeorological Institute (CHMI 2013a). Data on annual concentrations of PM_{10} and $PM_{2.5}$ for the years 2007-2011 were examined from air quality monitoring stations Ostrava-Poruba, Ostrava-Zábřeh, Ostrava-Fifejdy, Ostrava-Přívoz and Ostrava-Bartovice.

In order to overcome ambiguities of applying legal air pollution levels or air quality indices, a parameter called **relative risk** (*RR*) has been suggested to quantify the influence of air pollution on the quality of life. Based on epidemiological research, it relates exposition to polluted air with mortality or morbidity levels in the studied population. In general, relative risk is defined as the ratio of incidence (of disease or death) in the population exposed to the studied factor, to the incidence in an unexposed population (Holčík et al. 2002). If $RR = 1$, it means that the studied factor does not affect mortality or morbidity. A $RR > 1$ expresses an increased risk of incidence, while $RR < 1$ would indicate a protective effect of the factor (which is not expectable when studying air pollution). For air quality assessment, relative risk can be estimated using empirical formulas (Table 1) suggested by Ostro (2004) on the grounds of epidemiological studies.

The input data (X) for calculation of *RR* are concentrations of PM_{10} or $PM_{2.5}$ obtained from air pollution monitoring stations. In case $PM_{2.5}$ concentrations data are not available, the values may be estimated from PM_{10} concentrations using the formula $PM_{2.5} = 0.73\ PM_{10}$ (Ostro 2004:20). Because there is no health-safe threshold in concentrations of particulate matter, the natural background levels of 10 μg/m³ for PM_{10} and 5 μg/m³ for $PM_{2.5}$ are used as X_0.

The values of RR may range theoretically from 0 to infinity. If a parameter in the range 0 to 1 would be preferred for the overall quality-of-life assessment, a related function called **attributive fraction** (*AF*) may be calculated: $AF = (RR-1)/RR$. It expresses the fraction of all deaths or cases of disease that may be attributed to the studied risk factor. If $RR=1$ then $AF=0$, while values of AF close to 1 mean that the vast majority of all cases of death or disease result from the studied risk factor. If necessary, standardisation of the resulting values of *RR* (or *AF*) may be subsequently applied in order to incorporate them into a more complex quantitative assessment of the quality of life.

For the assessment of subjective dimension of the quality of life a questionnaire survey was carried out in the city of Ostrava in November 2012. The respondents were persons aged 15+ who live, work or study in the city of Ostrava. The survey was organised on the pattern of the four areas Ostrava West, Ostrava South, Ostrava Centre and Ostrava East. A total of 160 fully-answered questionnaires were obtained during anonymous interviews. The questionnaire contained twelve questions related to air pollution plus five questions indicating age, sex, education, place of residence and place of work of each respondent.

Table 2 Relative risk of *all-cause mortality* in the population of Ostrava as a result of exposure to PM_{10}. Source: own calculations based on data by CHMI.

Part of Ostrava	2007	2008	2009	2010	2011
East	1.045	1.031	1.031	1.042	1.032
South	1.022	1.022	1.024	1.033	1.025
Centre	1.024	1.025	1.025	1.034	1.026
West	1.007	1.010	1.013	1.015	1.011

Table 3 Relative risk of *respiratory mortality of children under 5 years of age* in Ostrava as a result of exposure to PM_{10}. Source: own calculations based on data by CHMI.

Part of Ostrava	2007	2008	2009	2010	2011
East	1.096	1.066	1.064	1.090	1.068
South	1.046	1.046	1.051	1.070	1.053
Centre	1.050	1.052	1.052	1.071	1.055
West	1.015	1.021	1.026	1.031	1.023

Table 4 Relative risk of *cardiopulmonary mortality of persons aged 30+* in Ostrava as a result of exposure to $PM_{2.5}$. Source: own calculations based on data by CHMI.

Part of Ostrava	2007	2008	2009	2010	2011
East	1.384	1.323	1.321	1.379	1.326
South	1.287	1.286	1.293	1.341	1.305
Centre	1.310	1.328	1.334	1.359	1.326
West	1.251	1.259	1.274	1.310	1.274

Table 5 Relative risk of *lung cancer mortality of persons aged 30+* in Ostrava as a result of exposure to $PM_{2.5}$. Source: own calculations based on data by CHMI.

Part of Ostrava	2007	2008	2009	2010	2011
East	1.626	1.521	1.517	1.618	1.526
South	1.459	1.458	1.469	1.552	1.489
Centre	1.498	1.528	1.539	1.583	1.526
West	1.398	1.412	1.437	1.498	1.437

RESULTS

Air quality in the objective dimension of the quality of life

The relative risk of mortality resulting from exposure to particulate matter in ambient air was calculated based on air pollution data for PM10 and PM2.5 in the years 2007-2011 in four parts of the city of Ostrava (Tables 2-5). The range of values differs based on the particulate matter fraction used, age group and type of mortality considered. The all-cause mortality values (Table 2) are the least distinguishing but even they clearly show differences between individual parts of the city of Ostrava. Respiratory mortality of children (Table 3) might be preferred in studies focused e.g. on quality of life of families, while relative risks of cardiopulmonary and lung cancer mortality of persons aged 30+ (Tables 4 and 5) are disease-specific and indicate the most pronounced relation between air pollution and adverse health effects.

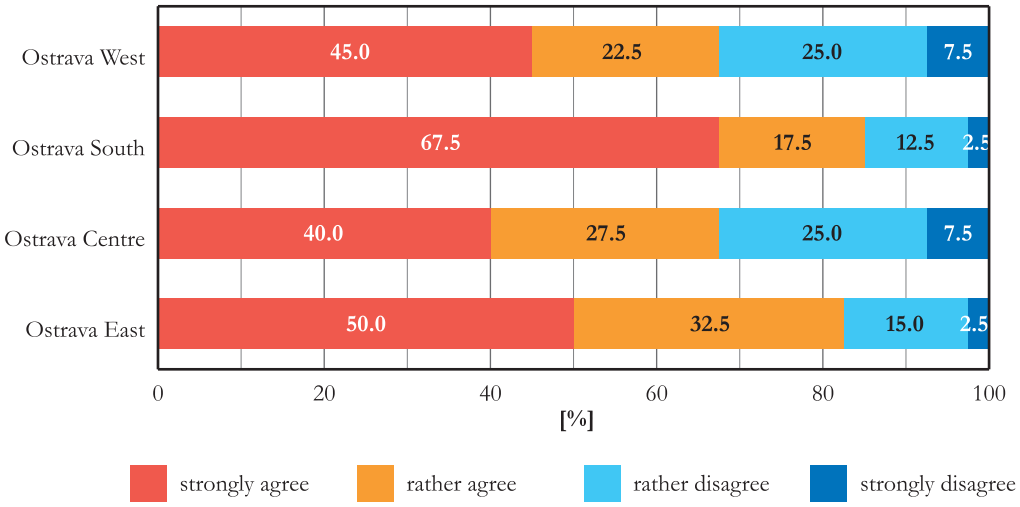

Figure 2 Share of responses to the statement *'I am worried/annoyed that I live/work/study in one of the worst polluted regions of the Czech Republic'* according to parts of the city of Ostrava. Source: own questionnaire survey.

The inter-annual differences are caused by varying meteorological conditions and volumes of pollutants emitted into ambient air, yet they are less pronounced than spatial variations within the city. Ostrava East is the most affected by adverse health effects of air pollution, which corresponds with its concentration of heavy industry and position towards the prevailing winds, while Ostrava West is the least affected.

It is important to accentuate that relative risk is not a linear function of air pollutant concentrations and should be thus preferred to direct use of air pollution levels or of their ratio towards legal air pollution limits. In addition to that, particulate matter has no safe threshold for human health; assessments based on legally set limits are therefore skewed by political compromises.

Any of the four types of relative risk could be easily customised (standardised) to fit as a component into a complex quantitative assessment of the objective dimension of the quality of life (eventually by use of the correspondent attributive fraction). Particulate matter concentrations are largely understood as a general indicator of air quality in the European realm and it is the most common cause of deteriorated air quality in municipalities and regions in the Czech Republic (CHMI 2013b). Quantification of the relative risk of mortality from exposure to particulate matter is therefore a good representation of overall air quality in relation to human health.

Air quality in the subjective dimension of the quality of life

Studies of the subjective dimension of the quality of life are based on surveys of perception, carried out using questionnaires and interviews. In our questionnaire survey we asked twelve air pollution related questions to cover a range of aspects on air quality. The answers were also analysed in subsets according to the four study areas Ostrava West, Ostrava South, Ostrava Centre and Ostrava East.

Question **(1)** *'I am content with air quality in Ostrava'* indicated general discontent, with only 4% of respondents expressing contentment, while 77% were discontent and 19% rather discontent. This ratio was consistent in all four parts of the city and demonstrated a strongly negative public perception of air quality in Ostrava. A related question **(2)** *'I*

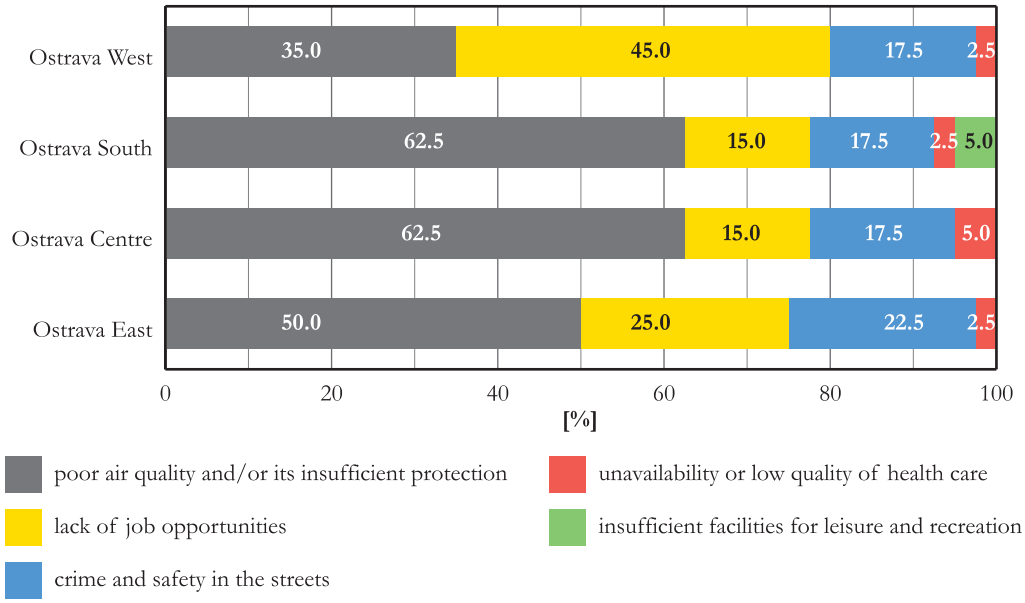

Figure 3 Share of choice from a list of issues in response to the statement *'Which of the following issues in Ostrava would you detect as the most pressing'* according to parts of the city of Ostrava. Source: own questionnaire survey.

am worried/annoyed that I live/work/study in one of the worst polluted regions of the Czech Republic' showed a less unfavourable ratio – 51% strongly agreed and 25% rather agreed, while 19% rather disagreed and 5% strongly disagreed. There was also a higher level of differences between the individual parts of the city (Figure 2).

Question **(3)** *'What is the main reason of your stay in the region'* was given to those who strongly or rather agreed at question 2. The most frequently mentioned reason was family (49), then work/study (43) and then living (40). This indicates that people are willing to compromise over air quality for job and family motives but slightly less for purely housing opportunities.

Question **(4)** *'Which of the following issues in Ostrava would you detect as the most pressing'* was framed by a fixed list of issues (Figure 3). The option 'poor air quality and/or its insufficient protection' was selected by 53% of respondents, followed by 'lack of job opportunities' (25%) and 'crime and safety in the streets' (18%). Much less selected were the issues 'unavailability or low quality of health care' (3%) and 'insufficient facilities for leisure and recreation' (1%). This result, with majority of respondents selecting air quality issues, is rather noteworthy for a region that has long been affected by a high rate of unemployment. In spatial comparison, respondents in Ostrava West were the least concerned with air quality (35%), while respondents in Ostrava Centre and Ostrava South indicated air quality as a dominant issue (62.5% in both areas) over lack of job opportunities (15%).

The second part of the questionnaire consisted of questions on compensation and active approach towards air quality issues. Question **(5)** *'I make efforts to compensate for the unfavourable situation with air quality by keeping a healthy regime and life style'* was rather included as a refocusing one. The majority of respondents (70 %) agreed to the statement. The following question **(6)** *'I support ecological organisations, citizens' associations and other activities that promote care for the environment'* showed less determination to counteract air pollution; only 41% agreed (8% strongly, 33% rather). The lowest support was expressed in

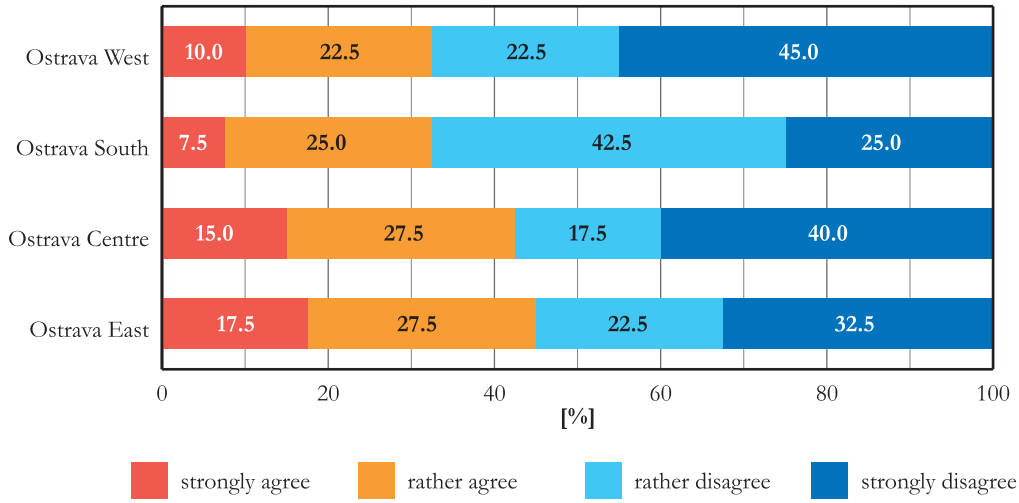

Figure 4 Share of responses to the statement *'I plan to move to a different location due to adverse situation with air quality in Ostrava'* according to parts of the city of Ostrava. Source: own questionnaire survey.

Ostrava Centre (only 32.5%), the highest in Ostrava West (55%). Question **(7)** *'It is important to me how politicians deal with air quality issues when I choose between candidates in the election poll'* was answered with a higher share of agreement; 22% strongly agreed and 38% rather agreed with this statement, while only 9% strongly disagreed. The ratios were consistent in all parts of Ostrava. Comparison of results at questions 6 and 7 indicates that people have more confidence in applying a political solution rather than making efforts through independent civic activities.

Question **(8)** *'I plan to move to a different location due to adverse situation with air quality in Ostrava'* showed a moderate level of agreement (13% strongly agreed, 25% rather agreed; 36% strongly disagreed). People were more likely to move for air quality reasons from Ostrava East and Ostrava Centre than from Ostrava South and Ostrava West (Figure 4). The willingness to move away decreased with age. However, question **(9)** *'I do not care about air quality when deciding about how to live'* showed only 29% agreement (4% strongly, 25% rather), while 28% of respondents strongly disagreed. This question also showed higher spatial variability, with more people concerned about air quality in Ostrava East and Ostrava Centre.

The third section of the questionnaire focused on perception of the influence of air quality on health. Question **(10)** *'Which of the following factors would you indicate as the least favourable for your health'* listed five indications, with the following results – 59% of respondents marked air quality, 18% individual regimen, 13% quality of food, 9% genetic predisposition and 1% provided health care. Question **(11)** *'Which of the following health complications have you recently experienced and you relate them to adverse air quality'* listed seven options (and a possibility to indicate another). In this case, 43% of respondents indicated tiredness, 38% irritation of mucous membranes, 35% headache, 33% coughing, 26% bronchitis, 11% breathlessness, 6% malaise, 8% other, 8% none.

The last question **(12)** *'What do you consider to be the biggest source of air pollution in the Ostrava region'* was open-ended. The respondents most often (41%) claimed 'industry in general', followed by a frequent mention of the company ArcelorMittal Ostrava (26%), steelworks (4%), Evraz Vítkovice Steel a.s. (3%) and chemical plants (3%). Emissions from transport were mentioned by 11% of respondents, individual heating by 9% and trans-border influence from Poland by only 2%.

CONCLUSION

Incorporating air quality as a parameter in assessing quality of life is possible through various indicators. We have suggested the use of relative risk of mortality as a result of exposure to air pollution, an indicator based on epidemiological studies that overcomes limitations of conventional air quality indices and legally set air pollution limits. Its quantification is rather simple, based on concentrations of air pollutants, yet its non-linear character allows for a more suitable assessment than direct use of concentrations data. We have tested the parameter on PM_{10} and $PM_{2.5}$ pollution data from various air pollution monitoring stations in the city of Ostrava to show its applicability in quality-of-life studies.

For the subjective dimension of the quality of life, usually studied by questionnaire surveys and interviews, a set of questions was tested to show that seemingly alternating questions may lead to differing results. While the usual question on the contentment with air quality was met with overall disagreement, responses to the statement *'I am worried/annoyed that I live/work/study in one of the worst polluted regions of the Czech Republic'* showed a more varied distribution, indicating differences between the four study areas of the city of Ostrava. Such a statement could also be used in regions less polluted than Ostrava when modified into residence in 'a region with deteriorated air quality' od 'in a location where ambient air is burdened with pollution'. A good level of resolution between the four study areas of Ostrava was obtained with the question on the most pressing local issue, listing options of air quality, lack of job opportunities, crime, health care and facilities for leisure and recreation. A third question suggested for use in further quality of life questionnaires is on the level of agreement with the statement *'I plan to move to a different location due to adverse situation with air quality in Ostrava'*. This inquiry also led to diversified outputs and it can be easily modified for use in other locations.

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Résumé

Hodnocení kvality ovzduší jako environmentálního faktoru kvality života

Studie hodnotící kvalitu života včetně environmentálních faktorů obvykle zahrnují i parametr kvality ovzduší, většinou kvantifikovaný vzhledem k legislativně stanoveným limitům koncentrací vybraných znečišťujících látek nebo s využitím souhrnného indexu kvality ovzduší. Zákonné imisní limity jsou ovšem u řady znečišťujících látek politickým kompromisem mezi zdravotně nezávadnými optimy a ekonomickými zájmy emitorů škodlivin (indexy kvality ovzduší jsou od těchto zákonných limitů také odvozovány). Pro adekvátní hodnocení objektivní dimenze kvality života lze alternativně navrhnout parametr založený na epidemiologických výzkumech dopadu znečištění na lidské zdraví. Z dat o naměřených koncentracích suspendovaných částic frakcí PM_{10} nebo $PM_{2,5}$ je možné s pomocí empiricky stanovených vzorců určit relativní riziko (*RR*) úmrtnosti při expozici této škodlivině, a to buď jako vliv na celkovou úmrtnost v populaci, nebo specificky jako vliv na úmrtnost v důsledku respiračních chorob u dětí do 5 let věku nebo jako vliv na úmrtnost v důsledku kardiopulmonálních onemocnění nebo rakoviny plic u osob nad 30 let věku. Závislost hodnoty *RR* na koncentracích suspendovaných částic není lineární, nejedná se tedy o pouze triviální náhradu hodnot koncentrací. Znečištění ovzduší suspendovanými částicemi je přitom dominantní příčinou zhoršené kvality ovzduší na území České republiky a s ohledem na vazbu těžkých kovů a karcinogenních látek na tyto částice postihuje významnou část imisní problematiky.

Při hodnocení subjektivní dimenze kvality života se v dotazníkových šetřeních obvykle věnuje kvalitě ovzduší jeden, nanejvýše dva dotazy, zjišťující spokojenost respondentů s kvalitou ovzduší. Provedením dotazníkového šetření na území města Ostravy, kde je kvalita ovzduší vnímána jako jedna z nejhorších v České republice, byly otestovány různě formulované dotazy ke zjištění percepce kvality ovzduší. Zatímco otázka na spokojenost respondentů s kvalitou ovzduší se zde setkala s téměř všeobecným nesouhlasem, vyšší rozlišovací potenciál měla jinak formulovaná otázka na souhlas s tvrzením *„Vadí mi, že žiji/pracuji/studuji v jednom z nejvíce znečištěných regionů ČR"*. Tato otázka by mohla být modifikována pro jiné oblasti v ČR na pobyt *„v oblasti se zhoršenou kvalitou ovzduší" nebo „v lokalitě s ovzduším zatíženým škodlivinami"*. Uspokojivou rozlišovací schopnost mezi čtyřmi hodnocenými částmi města Ostravy měl také dotaz na porovnání závažnosti několika vyjmenovaných lokálních problémů – kvality ovzduší, pracovních příležitostí, kriminality, zdravotní péče a příležitostí k volnočasovým aktivitám a rekreaci. Odpovědi na souhlas s tvrzením *„Kvůli nepříznivému stavu kvality ovzduší plánuji odstěhovat se jinam"* byly rovněž v porovnání jednotlivých částí Ostravy diverzifikované. Uvedená trojice dotazů nejvýrazněji rozlišovala percepci kvality ovzduší mezi jednotlivými čtyřmi oblastmi Ostravy. Tyto typy dotazů lze přitom s vhodnou modifikací jejich znění zahrnout do dotazníkových šetření i v jiných zkoumaných lokalitách.

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