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"Gheorghe Asachi" Technical University of Iasi, Romania

APPLYING THE TOPSIS-F METHOD TO ASSESS AIR POLLUTION IN VILNIUS

Edmundas Kazimieras Zavadskas[1]*, Artūras Kaklauskas[2], Darius Kalibatas[1], Zenonas Turskis[1], Mindaugas Krutinis[2], Lina Bartkienė[2]

[1]Department of Construction Technology and Management, Faculty of Civil Engineering,
[2]Department of Construction Economics and Property Management, Faculty of Civil Engineering,
Vilnius Gediminas Technical University, Saulėtekio al. 11, Vilnius, LT – 10223, Lithuania

Abstract

These days many works analyse air pollution, sources of air pollution, the impact of air pollution on human health, and ways to reduce air pollution. Since air pollution is affected by many factors, this paper presents a multi-attribute decision-making approach to assess air pollution. The proposed approach comprises four steps: selecting the attributes for the assessment, applying the TOPSIS-F method (the Technique for Order of Preference by Similarity to Ideal Solution with fuzzy sets) in the evaluation, measuring the selected attributes of air pollution in Vilnius, Lithuania, and evaluating air pollution levels. The TOPSIS-F method was applied to assess, from the above perspective, ten areas in Vilnius, outside several houses in Antakalnio Street and Žirmūnų Street. The experiment shows that House 5(35) in Žirmūnų Street and House 8(28) in Antakalnio Street exposed to the lowest levels of air pollution, compared to other selected houses. Air pollution dramatically depends on the distance from the main road and the presence of a barrier.

Key words: multi-attribute assessment, MADM, TOPSIS, TOPSIS-F, air pollution, air quality, Lithuanian Hygiene Norms

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1. Introduction

Air pollution now is a hot topic. Many papers analyse air pollution, sources of air pollution, the impact of air pollution on human health, and methods to reduce air pollution. All studies presented here, however, concentrate on a particular attribute or a set of characteristics of air pollution. Moreover, their results greatly depend on the country in which the studies performed; hence they are not applicable to the situation in other countries or regions. The primary purpose of this paper is to analyse current research and define a set of attributes best suited to investigate air pollution in Lithuania, in particular outside several houses in Vilnius as the biggest city, applying the MADM method. The authors of this paper apply TOPSIS-F for the multi-attribute assessment of air pollution in Vilnius.

The paper is structured as follows: Section 2 analyses the concept of air pollution and the attributes for the analysis of air pollution; Section 3 describes the TOPSIS-F method applied by the authors; and a case study demonstrates the TOPSIS-F method in action to assess air pollution in Žirmūnų Street and Antakalnio Street in Vilnius.

2. Materials and methods

This section presents the related works on air pollution. First, air pollutants analysed to determine the attributes for the analysis of air pollution. Then, the key papers on air pollution reviewed to study the

* Author to whom all correspondence should be addressed: e-mail: edmundas.zavadskas@vgtu.lt; Phone: +37052744910

methods and approaches used in air pollution assessment.

2.1. Air pollutants

Local air quality determines how you live and breathe (Mintz, 2004). The U.S. Environmental Protection Agency (EPA) proposed the Air Quality Index (AQI) to assess outdoor air quality. The AQI based on five major air pollutants: ground-level ozone (O_3), particle pollution (PM10, PM2.5), carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). For each of these pollutants, national air quality standards are established to protect public health. They can be found in the work of Mintz (2004).

Effective management of pollution has become environmentally and economically mandatory due to the increase in environmental problems. Economic concerns are considered critical issues for decision-making and selection of air pollution management technologies and practices in a sustainable integrated pollution management system (Ghinea and Gavrilescu, 2016).

Besides, the calculation of benefits would be necessary for an integrated cost-benefit analysis, to establish the economic feasibility associated with the implementation of different pollution management scenarios. According to the European Commission (EC, 2014), humans can be adversely affected by exposure to air pollutants in ambient air. Health-based standards and objectives for many contaminants in the air summarised in the table below (Table 1). These apply over differing periods because the observed health impacts associated with the various pollutants occur over different exposure times.

Another critical pollutant is volatile organic compounds, or VOCs (VOC, 2010), emitted as gases from different solids or liquids, like paints, lacquers, paint strippers, cleaning supplies, pesticides, building materials, furnishings, etc. VOCs include a variety of chemicals and may have short- and long-term adverse health effects, usually chronic. Concentrations of many VOCs are higher up to ten times indoors than outdoors (Zavadskas et al., 2009). However, the level is generally low. Therefore, the analysis of VOCs and their effects is complicated and vital (Cairpol, 2014).

2.2. Air pollution and its assessment

High levels of air pollution have apparent effects on human health, animals, plants and the environment, causing respiratory diseases and physiological dysfunction. Therefore, it is urgent and meaningful to establish an air quality monitoring and early warning system to evaluate the degree of air pollution scientifically, and forecast air pollutant concentrations more accurately (Yang & Wang, 2017). Road transport has become one of the significant sources of air pollution and traffic jams in urban areas. Many studies, therefore, investigate the functional relationship between air quality and transport air pollution. Costabile and Allegrini (2008) analyse this relationship and aim to develop a more flexible framework to investigate its concentrations.

Keogh et al. (2009) examined particle emissions of motor vehicle tailpipe and their effects on health. They found that heavy-duty vehicles in the study region were significant particle emitters pollution (or particulate matter) (>50%). Buses contributed approximately to 1–2% of regional particle emissions.

Baltrėnas et al. (2008, 2009) showed that the most significant amounts of pollutants emitted during the morning and afternoon hours when traffic is the heaviest. Numerical modelling of the transfer processes of these pollutants shows that 1−2 m away from lanes the amounts of the emitted gaseous pollutants are high, but 4–6 m away, the values of exhaust gasses plummet.

Table 1. EU Air Quality Standards (EU, 2014)

Pollutant	***Concentration***	***Averaging period***	***Permissible overrun each year***
Fine particles (PM2.5)	25 µg/m^3	1 year	n/a
Sulphur dioxide (SO_2)	350 µg/m^3	1 hour	24
	125 µg/m^3	24 hours	3
Nitrogen dioxide (NO_2)	200 µg/m^3	1 hour	18
	40 µg/m^3	1 year	n/a
PM10	50 µg/m^3	24 hours	35
	40 µg/m^3	1 year	n/a
Lead (Pb)	0.5 µg/m^3	1 year	n/a
Carbon monoxide (CO)	10 mg/m^3	Maximum daily 8 hour mean	n/a
Benzene	5 µg/m^3	1 year	n/a
Ozone	120 µg/m^3	Maximum daily 8 hour mean	25 days averaged over 3 years
Arsenic (As)	6 ng/m^3	1 year	n/a
Cadmium (Cd)	5 ng/m^3	1 year	n/a
Nickel (Ni)	20 ng/m^3	1 year	n/a
Polycyclic Aromatic Hydrocarbons	1 ng/m^3 (expressed as concentration of Benzo(a)pyrene)	1 year	n/a

Matuliauskaitė et al. (2008) presented an assessment of PM10 and PM2.5 in Vilnius, describing their influence on the quality of life.

The measurements of particle pollution performed by the Seimas, in collaboration with the Environmental Protection Agency, show that around the Seimas in Vilnius, the average daily concentration of PM10 exceeds the specified limit value of 40 μg/m^3, and ~26% of the city's population live in highly polluted areas. Studies, however, show that residential indoor air is often more polluted than outdoor air.

Laurinavičienė (2009) analyses air pollution by ground-level ozone in Vilnius. The results of her study show that the annual mean concentration of ground-level ozone in Vilnius is 30.3 μgm^{-3}, well within the specified value (120.0 μgm^{-3}). The highest ground-level ozone concentration was in Viršuliškės district (43.1 μgm^{-3}), while the lowest at Eišiškių Highway (17.9 μgm^{-3}).

Zavadskas et al. (2007) present a model of rational and sustainable development in Vilnius, with an emphasis on air pollution. They propose to make a multi-criteria analysis of sustainable urban development critical components and select the most efficient version of the life cycle of sustainable urban development, with an emphasis on pollution (SUD-P) in Vilnius. For a more detailed description, the multi-criteria analysis is, therefore, needed. Zavadskas et al. (2010) identify and describe the main trends of E-development in Vilnius.

Salcedo-Sanz et al. (2009) discuss the performance of Radial Basis Function networks (RBF) in solving the problem of spatial regression of NOx and O_3 pollutants in Madrid. The entire surface of the contaminants in the city obtained.

Trompetter et al. (2010) investigated how motor vehicle emissions and biomass burning for home heating impacts on PM concentration in air in ten New Zealand cities. The authors found that PM concentration from these two primary sources only rarely correlated with the population and source activity.

Uygur et al. (2010) measured significant (Na, K, Al, Ca and Mg) and trace (Pb, Ni, Fe, Cu, Cr, Co, and V) elements in 43 rain samples and statistically analysed their concentrations. The results show that a significant amount of the measured pollutants comes to the studied area from source regions in Europe, Russia, southern and northern Mediterranean countries and industrial zones west of Turkey.

Mayera et al. (2008) apply the air quality index LAQx (Long-term Air Quality Index), which has been developed to evaluate the long-term integral air quality related to well-being and health of people, to analyse the evolution of air pollution from 1985 to 2005 at different urban and rural sites in SW Germany. The results show decreasing LAQx values at urban locations, e.g. improvement of the essential air quality.

Zhanga et al. (2010) established the link between energy use, air pollution, and its public health impacts in Taiyuan for 2000, and for 2010 and 2015 under alternative scenarios. The authors found that, in the year 2000, more than 2,200 excess deaths might be caused by PM pollution.

Paulauskienė et al. (2011) examine the impact of VOCs in an oil terminal on air pollution. They investigate the dependency of VOC concentration in the air on the wind speed and oil loading intensity during shorter time intervals, when the fluctuations of ambient temperature are minimal (1−3) °C. An analysis of the experimental study shows that VOC concentration depends on the number and type of loading operations in oil terminals. The multifactor analysis of variance was applied to analyse VOC concentration during different seasons, and it determined that it depends on wind velocity when wind force exceeds 4 m/s.

Since many criteria can characterise air pollution, multi-criteria decision-making techniques and methods are necessary to evaluate air pollution.

The MADM techniques PROMETHEE and GAIA, as well as the report models PCA/APCS and positive matrix factorisation (PMF), are used to analyse the data from an air monitoring site located on the campus of the Queensland University of Technology in Brisbane, Australia by Friend and Ayoko (2009). The authors concluded that motor vehicle emissions, as well as the controlled burning of forests, secondary sulphate, sea salt and soil, were the most important sources of fine particulate matter on the site. A more effective approach to environmental issues related to productive activities provides many benefits for the organisation and society as a whole. When the concentration of pollutants goes out of the maximum limits, appropriate countermeasures must be taken to terminate the sources of pollution (Aramă et al., 2017). It is possible to calculate the forecast of pollutant emissions by using various available models. Approximate model models offer flexible structures and non-parametric algorithms that can show complex and non-linear relationships between input and output data sets.

Different hybrid multi-attribute decision-making methods are widely used to assess air pollution (Zavadskas et al., 2016a, 2016b).

The number of modern governments due to the increased ecological consciousness focused on reducing emissions and the environmental system has become one approach when many companies comply with eco-guidelines. The vague and ambiguous decision-making environment is a characteristic feature of decision-making models. The model must synthesise the adverse risk and cost criteria as well as the positive criteria and criteria for opportunities and benefits. Based on the above requirements, Chen et al. (2017) proposed a multi-criteria decision-making model that not only compares price but also takes into account social, ecological and technical factors. Kahraman et al. (2017) applied intuitionistic fuzzy EDAS method to solve environment protection problems. Khodadadi et al. (2017) presented

SWARA-WASPAS based model to analyse evaluate processes of environment protection.

An essential part of each land use planning methodology reported is the risk assessment of the vulnerability of all potential human and environmental objectives. Sebos et al. (2017) focus on increasing the transparency of these methodologies using the ELECTRE TRI technique, which is a well-known and structured multi-criteria methodology. A broad set of multiple and conflicting criteria are taken into account, starting with the safety of the population and the potential environmental impact to socio-economic criteria. The controversial goals of human security from land scarcity and economic development included in the assessment of vulnerability.

Teixeira (2018) presented a preliminary estimate of the inclusion of upstream life-cycle greenhouse gas emissions in concentrated feeds design using the most commonly used nonlinear optimisation algorithms to define the data presentation structure. The price of a greenhouse gas unit obtained using a genetic algorithm.

Matarazzo et al. (2018) presented a Rough Set Analysis (RSA) application, partially based on dominance concerning air micro-pollution management in an industrial place with a high environmental risk rate. This data analysis instrument has been applied to multi-attribute sorting, considering both qualitative and quantitative attributes and criteria, such as sulphur oxides (SOx), nitrogen oxides (NOx), Methane (CH4), non-methane hydrocarbons (NMCH) and some meteorological variables, such as air temperature and the relative humidity index. Heavy metals can pose health hazards to man, and air pollution in a region depends on the emission of pollutants and local meteorological conditions.

Zavadskas et al. (2010a) apply TOPSIS grey and COPRAS-G methods to assess the risk of construction projects. Jakimavičius and Burinskienė (2009; 2009a) perform multi-criteria analysis and transport system modelling for 2015 and 2025. They use the SAW (Simple Additive Weighting) multi-criteria method, to evaluate some scenarios of Vilnius development by the defined criteria of the transport system. They also apply the integrated GIS decision support system, based on the TOPSIS and SAW techniques, to analyse the transportation zones in Vilnius and determine the density of street networks in the city's zones. Ulubeyli and Kazaz (2009) apply the ELECTRE III method to select concrete pumps. Sijanec Zavrl et al. (2009) propose a way to evaluate the sustainability of a residential building. The results show that the completeness and reliability of the input data are crucial to the credibility of the proposed assessment method. They show that MOORA is a sufficiently robust tool to assess alternatives. Keršulienė et al. (2010) apply a new technique of Stepwise Weight Assessment Ratio Analysis (SWARA) that allows including experts', lawyers' or dispute parties' estimates of the significance ratio of the attributes in the process of rational decision-making. Kaklauskas and Zavadskas (2007) propose the decision support system for innovation (DSSI), based on a multi-criteria evaluation method developed by the authors. Paslawski (2008) proposed the advisory system (NOMA2) for noise management since traffic noise is considered to be one of the critical factors decreasing the quality of life of EU residents. It is, however, advisable to combine this criterion (noise) with other criteria describing adverse effects on residents. Paslawski (2009) applied a general idea of FLENOMA2 (FLExibility NOise MAnagement for A2 POZNAN BY-PASS) advisory system to determine noise sources in Poznan, Poland and found that a highway and the NATO airbase in Krzesiny were the two primary sources of noise. There are a number of researches, such as the papers of Šaparauskas et al. (2011), Hashemkhani Zolfani et al. (2013), Siozinyte et al. (2014), Zavadskas et al. (2015; 2016a) where different MADMs applied for the assessment of alternatives.

The authors of the present paper apply the TOPSIS-F method to assess air pollution in Vilnius, Lithuania, since the technique allows determining the weight/efficiency of the compared alternatives, as it defines the profit type ('pluses') and cost type ('minuses') characteristics of the other options by calculating the utility degree of the alternatives.

Taking into account the place of the assessment (Lithuania) attributes more appropriate for the region will be selected and described in the next sections.

2.3. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) with fuzzy criteria values (TOPSIS-F)

This section outlines the fuzzy MCDM approach based on the TOPSIS method with fuzzy criteria values. Among the ranking methods, the TOPSIS has aroused most interest with those engaged in solving multi-criteria decision-making problems. The following features of the TOPSIS make it an appropriate way to solve the problem under investigation:

- Its ability to handle both tangible and intangible criteria;
- Sound logic and systematic procedure, which is relatively simple and fast;
- A set of weighting coefficients for different criteria.

The TOPSIS method proposed by Hwang and Yoon (1981) to solve multi-criteria decision-making (MCDM) problems. It rests on the idea that a satisfactory alternative should have the shortest distance from the positive ideal solution (PIS) and the longest distance from the negative ideal solution (NIS). In the method assumed that if each criterion takes a monotonically increasing or decreasing variation, then it is easy to define an ideal solution. The goal is then to propose a solution which has the shortest distance from the ideal solution in the Euclidean space (the city space and Minkovsky spaces can also be used. In the traditional TOPSIS method, the precise ratings and weights of criteria are known, but that is not always the case (Zavadskas et al.

2016c). In the Fuzzy TOPSIS method, variables described as positive triangular fuzzy numbers.

2.4. Basic definitions in TOPSIS-F

Fuzzy sets can be used to define uncertainties. A *fuzzy set* can be defined mathematically by a *membership function*, which assigns a real number in the interval [0, 1] to each element x in the universe of discourse X.

Formally, a fuzzy set A defined in space X is a set of pairs as presented in (Eq. 1):

$$A = \{(x, \mu_A(x)),\ x \in X\},\ \forall x \in X \tag{1}$$

where the fuzzy set A is characterized by its membership function μ_A : X→[0;1] that associates a real number μ_A (x) ∈ [0;1] with each element x ∈ X. The value μ_A (x) at x represents the grade of membership of x in A and is interpreted as the membership degree to which x belongs to A. So the closer the value $\mu_A(x)$ is to 1, the more x belongs to A.

A crisp or ordinary subset A of X can also be viewed as a fuzzy set in X with membership function as its characteristic function, i.e. (Eq. 2).

$$\mu_A(x) = \begin{cases} 1, x \in A; \\ 0, x \notin A. \end{cases} \tag{2}$$

The set X is called a universe of discourse and can be written $\subseteq X$. Sometimes a fuzzy set A in X is denoted by a list of ordered pairs $(x, \mu_a(x))$, where the elements with zero degree are usually not listed. Thus a fuzzy set A in X can be represented as $A = \{(x, \mu_A(x))\}$, where $x \in X$ and $\mu_A : X \to [0;1]$.

When the universe of discourse is discrete and finite with cardinality n, that is $X = \{x_1, x_1, \ldots, x_n\}$, the fuzzy set A can be represented as (Eq. 3).

$$A = \sum_{i=1}^{n} \frac{\mu_A(x_i)}{x_i} = \frac{\mu_A(x_1)}{x_1} + \frac{\mu_A(x_2)}{x_2} + \cdots + \frac{\mu_A(x_n)}{x_n}, \tag{3}$$

When the universe of discourse X is an interval of real numbers, the fuzzy set A can be expressed as (Eq. 4 and Eq. 5).

$$A = \int_X \frac{\mu_A(x)}{x}. \tag{4}$$

$$\mu_A(x) = \begin{cases} \frac{1}{\beta-\alpha}x - \frac{\alpha}{\beta-\alpha}, & if\ \ x \in [\alpha, \beta]; \\ \frac{1}{\beta-\gamma}x - \frac{\alpha}{\beta-\gamma} & , if\ \ x \in [\beta, \gamma]; \\ 0 & , otherwise. \end{cases} \tag{5}$$

A fuzzy number μ_A (x) is defined to be a *fuzzy triangular number* (α, β, γ) if its membership function is fully described by three parameters ($\alpha < \beta < \gamma$), and can be illustrated as presented in Fig. 1.

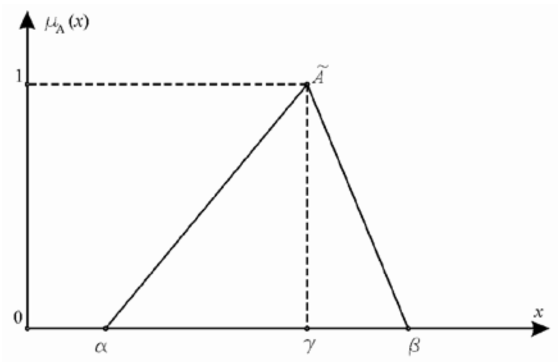

Fig. 1. Triangular membership function

The basic operations of fuzzy triangular numbers $\tilde{n}_1$ and $\tilde{n}_2$ (Van Laarhoven and Pedrycz 1983) are defined as follows (Eqs. 6–11):

$$\tilde{n}_1 \oplus \tilde{n}_2 = (n_{1\alpha} + n_{2\alpha}, n_{1\gamma} + n_{2\gamma}, n_{1\beta} + n_{2\beta}) \text{ for addition,} \tag{6}$$

$$\tilde{n}_1 \ominus \tilde{n}_2 = (n_{1\alpha} - n_{2\beta}, n_{1\gamma} - n_{2\gamma}, n_{1\beta} - n_{2\alpha}) \text{ for subtraction,} \tag{7}$$

$$\tilde{n}_1 \otimes \tilde{n}_2 = (n_{1\alpha} \times n_{2\alpha}, n_{1\gamma} \times n_{2\gamma}, n_{1\beta} \times n_{2\beta}) \text{ for multiplication,} \tag{8}$$

$$\tilde{n}_1 \oslash \tilde{n}_2 = \left(\frac{n_{1\alpha}}{n_{2\beta}}, \frac{n_{1\gamma}}{n_{2\gamma}}, \frac{n_{1\beta}}{n_{2\alpha}}\right) \text{ for division,} \tag{9}$$

$$k\tilde{n}_1 = (kn_{1\alpha}, kn_{1\gamma}, kn_{1\beta}) \text{ for multiplication by } k, \tag{10}$$

$$\tilde{n}_1 = \left(\frac{1}{n_{1\beta}} n_{1\alpha}, \frac{1}{n_{1\gamma}} n_{1\gamma}, \frac{1}{n_{1\alpha}} n_{1\beta}\right) \ for\ inverse. \tag{11}$$

2.5. TOPSIS with fuzzy criteria values (TOPSIS-F)

The principle of the TOPSIS-F method is that if each criterion takes a monotonically increasing or decreasing variation, then it is easy to define an ideal solution.

The TOPSIS-F method was described by Mahdavi et al. (2008) and comprises the following steps:

Step 1: Compiling a fuzzy decision-making matrix (FDMM), which represents the preferred m reasonable alternatives (rows) rated on n attributes (columns) (Eq. 12):

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{13} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{23} & \cdots & \tilde{x}_{2n} \\ \tilde{x}_{31} & \tilde{x}_{32} & \tilde{x}_{33} & \cdots & \tilde{x}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x}_{m3} & \cdots & \tilde{x}_{mn} \end{bmatrix}; \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n, \tag{12}$$

where m is the number of alternatives, n is the number of attributes describing each alternative, $\tilde{x}_{ij}$ is the fuzzy value representing the performance value of the i-th alternative in terms of the j-th attribute. A tilde sign "~" above a symbol shows that the symbol represents a fuzzy set.

Step 2: Constructing the weighted normalized fuzzy decision matrix, which is shown as presented in Eq. (13) and calculated by Eqs. (14–16) (Mahdavi et al., 2008).

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \quad (13)$$

If $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}), i = 1,2,\ldots,m, j = 1,2,\ldots,n$ are triangular fuzzy numbers, then the normalization process can be performed using Eq. (14) and Eq. (15).

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), i = 1,2,\ldots,m, j \in B, \quad (14)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), i = 1,2,\ldots m, j \in C, \quad (15)$$

where B and C are the sets of benefit attributes and cost attributes, respectively, and

$c_j^* = \max_i c_{ij}, j \in B, a_j^- = \min_i c_{ij}, j \in C.$

The normalized $\tilde{r}_{ij}$ are still triangular fuzzy numbers. For trapezoidal fuzzy numbers, the normalization process can be conducted in the same way. The weighted fuzzy normalized decision matrix is shown in (Eq. 16).

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \tilde{v}_{13} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \tilde{v}_{23} & \cdots & \tilde{v}_{2n} \\ \tilde{v}_{31} & \tilde{v}_{32} & \tilde{v}_{33} & \cdots & \tilde{v}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & \tilde{v}_{m3} & \cdots & \tilde{v}_{mn} \end{bmatrix} = \begin{bmatrix} \overline{w}_1\bar{r}_{11} & \overline{w}_2\bar{r}_{12} & \overline{w}_3\bar{r}_{13} & \cdots & \overline{w}_n\bar{r}_{1n} \\ \overline{w}_1\bar{r}_{21} & \overline{w}_2\bar{r}_{22} & \overline{w}_3\bar{r}_{23} & \cdots & \overline{w}_n\bar{r}_{2n} \\ \overline{w}_1\bar{r}_{31} & \overline{w}_2\bar{r}_{32} & \overline{w}_3\bar{r}_{33} & \cdots & \overline{w}_n\bar{r}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \overline{w}_1\bar{r}_{m1} & \overline{w}_2\bar{r}_{m2} & \overline{w}_3\bar{r}_{m3} & \cdots & \overline{w}_n\bar{r}_{mn} \end{bmatrix} \quad (16)$$

Step 3: Identifying the set of positive ideal (A*) and negative ideal (A-) solutions. For the order of selecting the fuzzy positive ideal solution (FPIS; A*) and the fuzzy negative ideal solution (FPIS; A-), the following steps are used Eq. (17):

Calculating δ-index (δ_I) in weighted fuzzy normalized decision matrix ($\tilde{V}$) using Eq. (17):

$$\delta_I = (\min a_{ij}, \min b_{ij}, \min c_{ij},), \quad (17)$$

where

$$\tilde{V} = \left\{\bar{v}_{ij} \middle| \begin{matrix} \bar{v}_{ij} = (a_{ij}, b_{ij}, c_{ij}); \\ i = 1,2,\ldots,m; j = 1,2,\ldots,n \end{matrix}\right\}.$$

Calculating the distance between δ-index and $\bar{v}_{ij}$ in weighted fuzzy normalized decision matrix ($\tilde{V}$) using Eqs. (18-20).

$$D_{p,q}(\tilde{a},\tilde{b}) = \begin{cases} \left[(1-q)\int_0^1 |a_\alpha^- - b_\alpha^-|^p d\alpha + q\int_0^1 |a_\alpha^+ - b_\alpha^+|^p d\alpha\right]^{\frac{1}{p}}, p < \infty; \\ (1-q)\mathrm{Sup}_{0<\alpha\le 1}(|a_\alpha^- - b_\alpha^-|) + q \inf_{0<\alpha\le 1}(|a_\alpha^+ - b_\alpha^+|), p = \infty. \end{cases}$$

$$D_{2,\frac{1}{2}}(\tilde{a},\tilde{b}) = \left(\frac{1}{6}\left(\sum_{i=1}^{3}(b_i - a_i)^2 + (b_2 - a_2)^2 + \sum_{i\in 1,2}\left((b_i - a_i)\right)(b_{i+1} - a_{i+1})\right)\right)^{0.5}; D_{2,\frac{1}{2}}(\tilde{a},\tilde{b}) = \left(\frac{1}{6}\left(\sum_{i=1}^{3}(b_i - a_i)^2 + (b_2 - a_2)^2 + \sum_{i\in 1,2}\left((b_i - a_i)\right)(b_{i+1} - a_{i+1})\right)\right)^{0.5};$$

$$D_{2,\frac{1}{2}}(\tilde{a},\tilde{b}) = \left(\frac{1}{6}\left(\sum_{i=1}^{4}(b_i - a_i)^2 + \sum_{i\in 3}(b_i - a_i)(b_{i+1} - a_{i+1})\right)\right)^{0.5}; \quad (18)$$

Then,

$$u_{rj}^* = \max_i u_{ij}, i = 1,2,\ldots,m; j = 1,2,\ldots,n,$$
$$u_{sj}^- = \min_i u_{ij}, i = 1,2,\ldots,m; j = 1,2,\ldots,n,$$
$$\tilde{v}_j^* = \tilde{v}_{rj}^-, j = 1,2,\ldots,n,$$
$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) = \left\{\left(\max_i \tilde{v}_{ij} \middle| i = 1,2,\ldots,m\right), j = 1,2,\ldots,n\right\}. \quad (19)$$

$$\tilde{v}_j^- = \tilde{v}_{sj}^-, j = 1,2,\ldots,n,$$
$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) = \left\{\left(\min_i \tilde{v}_{ij} \middle| i = 1,2,\ldots,m\right), j = 1,2,\ldots,n\right\}. \quad (20)$$

Step 4: ***Calculating the similarity degree of each alternative*** from A^* and A^- as S^* and S^- using Eq. (21).

$$S(\tilde{a},\tilde{b}) = \frac{1}{1 + D_{2,\frac{1}{2}}(\tilde{a},\tilde{b})}. \quad (21)$$

Step 5: ***Calculating similarities to the ideal solution*** using Eq. (22).

$$CC_i = \frac{S_i^-}{S_i^- + S_i^*} \quad (22)$$

Step 6: ***Ranking the preferred order***, e.g. choosing an alternative with the minimum or maximum CC_i.

3. Calculations and the results

3.1. Selecting the attributes for the assessment of air pollution

Based on the related works presented above, we selected the following attributes and their weights to evaluate air pollution as given in Table 2.

Thirty seven experts, environmental researchers and practitioners were interviewed to determine the importance of the above attributes. The results of these interviews were processed according to Kendall, (1970), Keršulienė and Turskis (2011). Table 2 lists the attributes and their weight, which equals the sum of the weights of a particular attribute divided by the sum of the weights of all attributes.

As seen above, carbon monoxide (CO) and the distance from the main road are the critical attributes that have the strongest impact on the assessment of air pollution. In the case of Lithuania, the six attributes and their weights are mostly the same. The situation, however, may differ by country or region, especially if some factories or other sources of pollution are nearby.

The optimal values of some attributes 0 (opt) are taken from the EPA, the Lithuanian Hygiene Norm HN 42:2004, and legal acts. For example, a noise of 26–27 dB does not disturb. Humans start to detect smell (VOCs and NO_2) when the concentration exceeds the limit values by 10%. The limit concentration value of VOCs in the air is 4 mg/m^3 (or 0.4 ppm), while the limit concentration value of nitrogen dioxide (NO_2) in the air is 0.068 mg/m^3 (or 0.03614 ppm).

Table 2. Attribute weights

	Attribute	*Weight* (w_j)
x_1	Carbon monoxide (CO), ***ppm*** (parts per million)	0.25
x_2	Particle pollution, ***ppm***	0.14
x_3	Noise, ***dB***	0.09
x_4	Volatile organic compounds (VOCs), ***ppm***	0.10
x_5	Nitrogen dioxide (NO_2), ***ppm***	0.20
x_6	Distance from the main road, ***m***	0.22
	Total	**1.00**

3.2. Determining air pollution in Vilnius: a case of the areas close to Žirmūnų Street and Antakalnio Street

We apply the TOPSIS-F method to assess air pollution in Vilnius, the areas close to Žirmūnų Street and Antakalnio Street. Five of the selected apartment houses are close to Žirmūnų Street and five more are close to Antakalnio Street. The selected attributes of air pollution were measured during the rush hour on a workday. The values of the attributes were measured by TSI AeroTrak 8240 (Fig. 1a) and Metrel's MI 6201 EU (Fig. 1b), devices designed for air pollution measuring and supplied with calibration certificates.

a) b)

Fig. 1. Air pollution measuring devices

Table 3 shows the data from the measurements. The optimal values are included in the assessment to determine the deviation of each alternative from the optimal one (Kalibatas et al., 2012).

Table 4 below shows the weighted normalised FDMM, the similarity degree of each alternative (S^* and S^-), the similarities to the ideal solution, and the rank. Fig. 2 shows the similarities between the houses. In Fig. 2, the last alternative (11) represents the similarity to the ideal solution; hence it equals one or is the maximum.

This case study shows that House 7(88) and House 8(28) in Antakalnio Street and House 4(67B) in Žirmūnų Street are exposed to the lowest air pollution, compared to the other houses in question. If we compare the alternatives with the best one (FPIS), however, none of the alternatives seems good enough. Furthermore, the research (Kalibatas et al., 2012) proposes to define the optimal positive solution based on regulations and hygiene norms, rather than calculate from the existing values as in TOPSIS. Such a tweak makes it possible to compare the existing solution with the optimal positive solution and see the difference. Fig. 3 shows the map of the particle pollution measured in the examined streets. The numbers on the map indicate the houses around which air pollution was measured.

The colours represent the levels of particle pollution. The brightest colour represents the areas with the highest particle pollution, while the darkest colour shows the areas with the lowest particle pollution. Similar maps drawn for the other attributes, which are carbon monoxide (CO), noise, volatile organic compounds (VOC), and nitrogen dioxide (NO_2).

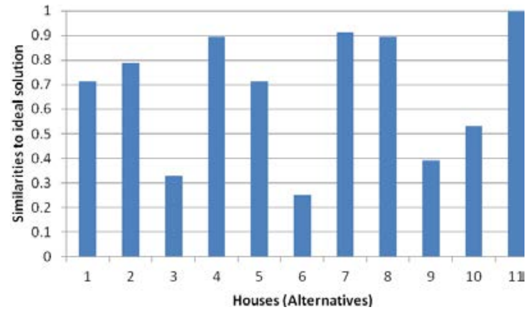

Fig. 2. The utility degree of the houses

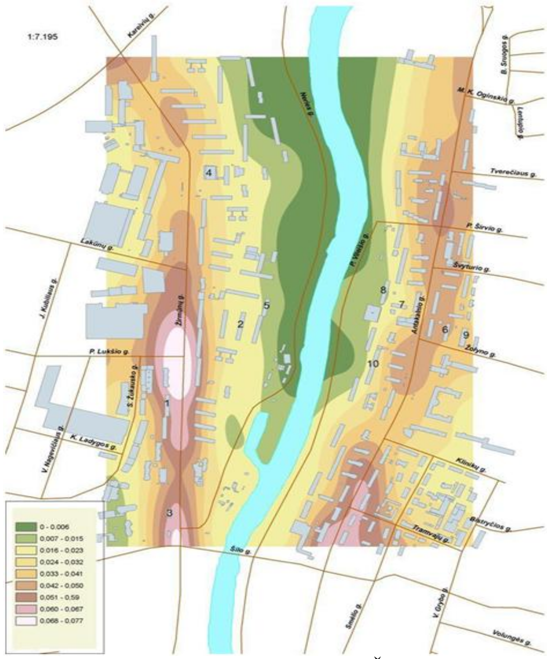

Fig. 3. Particle pollution measured in Žirmūnų Street and Antakalnio Street

Table 3. Initial decision-making matrix of TOPSIS-F

Opt	***min***			***min***			***min***			***min***			***min***			***min***
w_j	0.25			0.14			0.09			0.1			0.2			0.22
Attr./ Alt.	x_1			x_2			x_3			x_4			x_5			x_6
	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α=β=γ
Žirmūnų Street																
1	1.9	2.5	3.1	0.06	0.063	0.067	76	81	86	3.06	3.43	3.8	0.023	0.031	0.039	41
2	0.6	0.95	1.3	0.02	0.024	0.03	56	62	68	1.52	2.02	2.52	0.018	0.022	0.025	156
3	5.6	6.1	6.6	0.051	0.055	0.059	72	80	88	3.46	3.78	4.1	0.037	0.044	0.051	29
4	1.24	1.32	1.4	0.025	0.029	0.032	69	72	75	3	3.49	3.98	0.043	0.046	0.049	55
5	0.07	0.14	0.21	0.007	0.009	0.015	50	58	66	1.74	1.98	2.22	0.015	0.02	0.025	218
Antakalnio Street																
6	4.5	5.2	5.9	0.042	0.048	0.05	79	81	83	3.33	4.17	5.01	0.049	0.059	0.069	78
7	0.36	0.4	0.44	0.016	0.02	0.023	64	67	70	3.8	4.49	5.18	0.045	0.052	0.059	60
8	0.09	0.1	0.11	0.007	0.01	0.015	59	62	65	3.32	3.72	4.12	0.031	0.036	0.041	121
9	3.31	3.7	4.1	0.033	0.037	0.041	70	74	78	2.95	3.37	3.79	0.038	0.046	0.054	117
10	2.5	2.87	3.2	0.02	0.023	0.027	70	71	72	3.7	4.4	5.1	0.053	0.063	0.073	107
0 (opt)	0.0467			0.0047			26			0.4			0.01			19.33

Table 4. Weighted normalised DMM and the utility degree K_i of alternatives

Attr./ Alt.	x_1			x_2			x_3			x_4			x_5			x_1	***S****	***S⁻***	***CC***	***Rank***
	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α=β=γ				
Žirmūnų Street																				
1	0.044	0.064	0.090	0.067	0.077	0.090	0.029	0.032	0.036	0.024	0.030	0.039	0.029	0.044	0.066	0.025	0.009	0.023	0.714	5
2	0.014	0.024	0.038	0.022	0.029	0.040	0.021	0.025	0.029	0.012	0.018	0.026	0.022	0.032	0.042	0.096	0.007	0.026	0.788	4
3	0.128	0.156	0.191	0.057	0.067	0.079	0.027	0.032	0.037	0.027	0.033	0.042	0.046	0.063	0.086	0.018	0.030	0.015	0.330	9
4	0.028	0.034	0.041	0.028	0.035	0.043	0.026	0.029	0.032	0.023	0.031	0.041	0.053	0.066	0.083	0.034	0.003	0.029	0.893	3
5	0.002	0.004	0.006	0.008	0.011	0.020	0.019	0.023	0.028	0.013	0.017	0.023	0.019	0.029	0.042	0.135	0.014	0.034	0.712	6
Antakalnio Street																				
6	0.103	0.133	0.171	0.047	0.059	0.067	0.030	0.032	0.035	0.026	0.037	0.052	0.061	0.085	0.117	0.048	0.025	0.008	0.250	10
7	0.008	0.010	0.013	0.018	0.024	0.031	0.024	0.027	0.030	0.029	0.040	0.053	0.056	0.075	0.100	0.037	0.003	0.035	0.912	1
8	0.002	0.003	0.003	0.008	0.012	0.020	0.022	0.025	0.028	0.026	0.033	0.042	0.038	0.052	0.069	0.075	0.004	0.035	0.895	2
9	0.076	0.095	0.119	0.037	0.045	0.055	0.026	0.030	0.033	0.023	0.030	0.039	0.047	0.066	0.091	0.072	0.015	0.010	0.393	8
10	0.057	0.074	0.093	0.022	0.028	0.036	0.026	0.028	0.031	0.029	0.039	0.052	0.066	0.090	0.124	0.066	0.013	0.014	0.530	7
FPIS	0.002	0.003	0.003	0.008	0.011	0.020	0.019	0.023	0.028	0.012	0.017	0.023	0.019	0.029	0.042	0.018	0.000	0.048	1.000	
FNIS	0.128	0.156	0.191	0.067	0.077	0.090	0.030	0.032	0.037	0.029	0.040	0.053	0.066	0.090	0.124	0.135	0.048	0.000	0.000	

4. Conclusions

The analysis of the related works on air pollution assessment shows that scientists proposed many methods and models to measure and analyse air pollution. Since air pollution characterized by different criteria (attributes), multi-criteria decision-making methods used in the assessment. The paper presents a multi-attribute assessment of air pollution with the TOPSIS-F method applied to analyse the results obtained in the course of our investigation. Authors of the research the following attributes for the detailed study selected: carbon monoxide (CO), particle pollution, noise, volatile organic compounds

(VOC), nitrogen dioxide (NO_2), and the distance from the main road (m).
The experimental data, obtained by assessing ten areas outside several houses in Antakalnio Street and Žirmūnų Street in Vilnius, Lithuania, shows that House 5(35) in Žirmūnų Street and House 8(28) in Antakalnio Street are exposed to the lowest air pollution, compared to the other houses in question. Compared with the optimal alternative (FPIS), however, none of the alternatives is good enough in this case study. Furthermore, the distance from the main road has a strong impact on air pollution.

The results presented in this paper show that the approach based on multi-attribute decision-making, which was proposed for the assessment of air pollution, is an appropriate tool for the global evaluation of air pollution in any city or country.

The next step of the research could be to extend and verify the proposed approach and define the particular attributes in order to prove the method's validity. In future research, it would be also reasonable to join the efforts of various researchers investigating air pollution in Vilnius. An alternative approach might be to determine, using repeated measurements of air pollution, the variation of air pollution levels.

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