ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology
No. 4/2023

doi: 10.2478/ACEE-2023-0060

APPLICATION OF THE SIMPLE ADDITIVE WEIGHTING METHOD IN THE ASSESSMENT PROCESS OF AIR POLLUTION ON THE CAMPUS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY

Elwira ZAJUSZ-ZUBEK [a*], Zygmunt KORBAN [b]

[a] Associate Prof., DSc Eng.; Silesian University of Technology, Faculty of Energy and Environmental Engineering (Department of Air Protection), Konarskiego 20B, 44-100 Gliwice, Poland
*Corresponding author. E-mail address: *elwira.zajusz-zubek@polsl.pl*

[b] Associate Prof., DSc Eng.; Silesian University of Technology, Faculty of Mining, Safety Engineering and Industrial Automation (Department of Safety Engineering), Akademicka 2, 44-100 Gliwice, Poland

Received: 14.09.2023; Revised: 28.10.2023; Accepted: 31.10.2023

Abstract
The article presents the measurement results of the concentration of dust PM_{10} and $PM_{2.5}$ as well as SO_2, NO, NO_2 and NO_X based on a mobile laboratory located on the campus of the Silesian University of Technology (Poland, Gliwice, Konarskiego 20B, 50.292934N, 18.682164E), in the so-called "winter period" in 2020 (from 01/01/2020 to 31/03/2020 and from 01/10/2020 to 31/12/2020). The obtained results were used to carry out a synthetic (aggregated) assessment of the threat to the anthropogenic environment, the so-called "objects", i.e. days on which the measurements were made, interpreted as points in the multidimensional space with coordinates corresponding to the measurement results of the concentration of dust pollutants: PM_{10} and $PM_{2.5}$ and gaseous pollutants: SO_2, NO, NO_2 and NO_X. The determined synthetic values additionally allowed for ordering (creating rankings) of the examined "objects" in terms of air quality. For the calculations, the Simple Additive Weighting method (SAW) was used, which belongs to the group of single-criteria synthesis methods.

Keywords: **Environmental monitoring; Hazardous substances; Single-criteria synthesis method; Ordering (creating rankings) of the examined "objects".**

1. INTRODUCTION

The main pollutants emitted to the atmosphere as a result of anthropogenic human activity include: sulfur dioxide, nitrogen oxides, dust, volatile organic compounds (VOCs), persistent organic pollutants (POPs), heavy metals, greenhouse gases and odours. The enormous impact of air quality on the environment, but above all on human health and life, is the reason why it is so important to constantly monitor air quality and strive to minimize pollution and improve air quality. Epidemiological studies show that negative health effects in humans occur not only in the case of exposure to increased mass concentrations of various fractions of atmospheric dust, but also result from its chemical, physical and biological properties [1-2]. The incidence of asthma and chronic obstructive pulmonary disease (COPD) as well as increased exacerbation of these diseases is correlated with an increased concentration of harmful substances in the atmosphere, which implies a significant share of air pollution in the course of obstructive pulmonary diseases [3]. It is believed that children's bodies are more exposed to pollution than adults. This is because organisms in the growing phase are more susceptible to damage than organisms that are already developed. Moreover, children inhale more air in relation to their body weight than adults, and they also display greater

physical activity, which in turn translates into greater exposure to air pollutants [4].

Research results prove the huge impact of broadly understood air pollution on the biological condition, the regularity of growth and development processes, and the general psychophysical condition of people at all stages of ontogenesis, up to the quality and length of life. Environmental factors in each phase of ontogenetic development modify all aspects of the psychophysical condition. Organisms in the prenatal period of progressive development are particularly sensitive to environmental factors, when air pollution causes: 1/ fetal hypoxia (hypoxia), reducing birth weight, and 2/ through epiegenetic activities, it will change genetically programmed developmental pathways. For example, the diversity of the living environment in Poland determines up to 8 cm difference in the final body height of young men [5].

Exposure to air pollutants is highly dependent on their concentration. According to a report by the World Health Organization, nine out of ten people breathe polluted air, and this causes around seven million deaths worldwide each year. The current state of air quality in Poland is mainly caused by the so-called low emissions, mainly from the household and municipal sectors. The factors that negatively affect air quality, especially in the case of low-emission sources, include unfavourable meteorological conditions, such as: weak wind, low air temperature or fog. However, high wind speeds and heavy rainfall result in a significant reduction in the level of pollutant concentrations. The problem contributing to poor air quality in Poland is the use of outdated motor vehicles, especially those with diesel engines, which are important sources, e.g. of dust emissions. The exceedance of air quality standards for dusts PM_{10} and $PM_{2.5}$ is caused not only by their emission, but also by their gaseous precursors commonly emitted into the atmosphere, e.g. SO_2, NO_X, and hydrocarbons.

Air protection is one of the priority directions of Poland's policy. Considering the improvement in air quality, the need to replace coal with other energy carriers becomes more and more clearly visible. This problem affects all countries where energy policy is based on coal, such as China, India and North America. The key activities in the field of air protection include the reduction of air pollutant emissions, allowing for the improvement of its quality and compliance with the air quality standards in force in Polish law.

At the end of 2018, the Silesian University of Technology in Poland acquired a mobile laboratory built on the Ford Transit chassis, and the obtained measurement results are used in the area of low emissions forecasting and serve as a tool to fight smog. The mobile air pollution emission laboratory is equipped with: SO_2 – T100/Teledyne API analyzer, NO_X – T200/Teledyne API analyzer, suspended dust meter $PM_{10}/PM_{2.5}$ BAM1020, WS 500 Lufft meteo set, Envimet intake Services, Envimet Services calibration system, Envimet Services datalogger with a display and Envimet Services power system. The laboratory allows to measure the concentration of:

SO_2 – continuous automatic measurement using the fluorescence method in accordance with PN-EN 14212: 2013-02/AC:2014-06E (PN-EN 14212:2013-02/AC:2014-06E Ambient air quality – Standard method for the measurement of the concentration of sulfur dioxide by ultraviolet fluorescence [6]);

NO_x – continuous automatic measurement using the chemiluminescence method in accordance with PN-EN 14211:2013-02 (PN-EN 14211:2013-02 Ambient air quality-Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence [7]);

PM_{10} – continuous automatic measurement with the method for which equivalence with the reference method has been demonstrated according to PN-EN 12341:2014-07 (PN-EN 12341:2014-07 Ambient air - Standard gravimetric measurement method for the determination of PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter [8]);

$PM_{2.5}$ – continuous automatic measurement with the method for which equivalence with the reference method has been demonstrated according to PN-EN 12341:2014-07 (PN-EN 12341:2014-07 Ambient air - Standard gravimetric measurement method for the determination of PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter [8]).

Owing to the co-financing granted by the Voivodship Fund for Environmental Protection and Water Management in Katowice and by the Silesian University of Technology in Poland, the launched mobile laboratory allows to carry out measurements of air pollution concentrations in the vicinity of selected emission sources, e.g. energy facilities, municipal sources, or sources of fugitive emissions. It allows to supplement and expand the spectrum of information on air quality in places not covered by systematic monitoring. Therefore, the use of the simple additive weighting method in the assessment process of air pollution may be of particular importance in interdisciplinary research on public health and its determinants.

2. SIMPLE ADDITIVE WEIGHTING (SAW) – DESCRIPTION OF THE METHOD

Monitoring the phenomenon of smog, which generates high concentrations of substances in the air, hazardous to human life and health, is one of the platforms of broadly understood pro-ecological activities. In recent years, in the processing of large amounts of data and information describing the extent of air pollution, the so-called synthetic measures have become more and more important. They are determined on the basis of multivariate statistical methods, and although these methods differ in the approach to the criteria which are taken into account (setting correlation thresholds, unifying the field of compared criteria), by their application, we can replace the entire set of features describing the object with one aggregated variable.

The Simple Additive Weighting (SAW) method belongs to the group of single criteria synthesis methods, which rank the examined objects on the basis of a linear combination of the weight vector W [k×1] and the decision matrix D [m×k] (m – object, k – criterion) [9–26]. The weight vector W can be filled arbitrarily (subjective weights) or using mathematical methods (objective weights), and regardless of the determination method of the weights of the values of the coefficients defining the degree of influence of the k-th criterion on the final decision, it should be within the range ⟨0;1⟩. The SAW method requires the determination of the nature of each of the criteria: cost criterion or qualitative criterion (in the case of the first one, it is desirable to minimize the obtained values, and in the case of the second one – to maximize the obtained values). In turn, the decision matrix D consists of real numbers d_{ij} corresponding to the numerical value adopted by a given criterion for the selected object. In order to ensure the comparability of the values obtained by the objects under criterion k, the decision matrix D should be linearly re-scaled [27]:

- in the case of the so-called cost criterion:

$$v_{ij} = \frac{d_j^{max} - d_{ij}}{d_j^{max} - d_j^{min}} \tag{1}$$

- in the case of the so-called qualitative criterion:

$$v_{ij} = \frac{d_{ij} - d_j^{min}}{d_j^{max} - d_j^{min}} \tag{2}$$

Figure 1.
Location of the measurement point (50.292934N, 18.682164E) [28]

which gives a new decision matrix V [m×k]. By multiplying this matrix and the weight vector W [k×1], we can determine the ranking vector R [m×1]: the best object is the one that reaches the highest value of the ranking coefficient.

3. RESULTS OF THE RESEARCH

As part of the article, the measurements results of the concentration of PM_{10} [μg/m^3] and $PM_{2.5}$ [μg/m^3] as well as the concentrations of SO_2 [μg/m^3], NO [μg/m^3], NO_2 [μg/m^3] and NO_x [μg/m^3] were used. They were made in the so-called "winter period" of the year 2020, i.e. from 1/01/2020 to 31/03/2020 and from 01/10/2020 to 31/12/2020 on the campus of the Silesian University of Technology in Poland (sampling point PP (Fig. 1): Gliwice, Konarskiego 20B, 50.292934N, 18.682164E).

The distance of the sampling point from the nearest building development was about 12 m, and it was greater than the distance required for the place of air sampling [29]. The following communication routes are located in the vicinity of PP:

- from the north-east, at a distance of approximately 500 m – road DW902,
- in the north-west direction at a distance of about 450 m – road DW901,
- towards the west, at a distance of approximately 600 m – road DK78.

In addition, to the north, at a distance of about 600 m, there is a well-developed railway infrastructure (Gliwice railway station).

In the immediate vicinity of the PP, there is a typical urban development including public utility buildings, a shopping centre and multi-family residential buildings.

The compilation of the measured values of the above-mentioned substances is presented in Table 1.

The ranges of variability of the measured parameters are presented in Table 2.

Additionally, the following were also measured: air temperature, air humidity, air pressure, as well as wind speed and direction (Table 3).

The scaled decision matrix V is presented in Table 4.

The weight of features (parameters) w_j were determined on the basis of a survey of experts' opinions. The compiled list of weights of the features (parameters) w_j is presented in Table 5.

The ranking vector R [m×1] is presented in Table 6.

Partial rankings of "objects" according to concentration of dusts: PM_{10} and $PM_{2.5}$ and chemical compounds: SO_2, NO, NO_2 and NO_X are presented in Tables 7–8.

Table 1.
Compilation of the concentration of PM_{10} [μg/m^3] and $PM_{2.5}$ [μg/m^3] and the content of SO_2 [μg/m^3], NO [μg/m^3], NO_2 [μg/m^3] and NO_X [μg/m^3] in the "winter period" of the year 2020

Measurement date	PM_{10} [μg/m^3]	$PM_{2.5}$ [μg/m^3]	SO_2 [μg/m^3]	NO [μg/m^3]	NO_2 [μg/m^3]	NO_X [μg/m^3]
1/01/2020	40.462	28.323	25.478	3.275	8.706	13.715
2/01/2020	124.902	87.432	41.503	38.821	27.195	86.583
3/01/2020	107.254	75.078	32.006	26.421	14.956	55.371
…	…	…	…	…	…	…
29/03/2020	55.676	38.973	7.273	2.754	14.338	18.552
30/03/2020	20.938	14.656	6.421	3.986	15.239	21.336
31/03/2020	39.466	27.626	8.923	5.641	20.317	28.951
1/10/2020	18.258	12.781	22.049	14.453	19.972	42.070
2/10/2020	26.515	18.560	21.959	9.113	21.565	35.493
3/10/2020	24.387	17.071	22.209	1.164	7.612	9.392
…	…	…	…	…	…	…
29/12/2020	43.747	30.623	19.279	13.790	24.309	45.409
30/12/2020	39.855	27.899	18.920	41.474	45.820	109.232
31/12/2020	54.991	38.493	37.079	13.620	34.108	54.943

Table 2.
The ranges of variability of the measured parameters

Measurement	PM_{10} [μg/m^3]	$PM_{2.5}$ [μg/m^3]	SO_2 [μg/m^3]	NO [μg/m^3]	NO_2 [μg/m^3]	NO_X [μg/m^3]
max	174.146	121.902	41.503	112.511	45.820	216.371
min	7.403	5.182	5.552	0.959	5.935	7.406

Table 3.
Measured values of air temperature, air humidity and air pressure, wind speed and direction

Measurement date	Air temperature [°C]	Air humidity [%]	Air pressure [hPa]	Wind speed [m/s]	Wind direction [°]
1/01/2020	2.626	77.801	1005.725	1.203	208.410
2/01/2020	-0.240	74.948	1003.083	0.514	151.699
3/01/2020	0.998	73.279	996.589	0.954	128.822
…	…	…	…	…	…
29/03/2020	4.583	72.266	988.835	3.349	340.415
30/03/2020	0.262	59.337	996.989	2.493	270.373
31/03/2020	0.566	65.272	999.125	1.642	272.971
1/10/2020	12.491	95.095	979.778	0.995	89.145
2/10/2020	14.304	86.464	979.089	0.946	173.747
3/10/2020	19.404	65.669	975.675	2.524	179.362
…	…	…	…	…	…
29/12/2020	4.897	78.060	968.197	1.015	148.936
30/12/2020	3.773	92.317	978.256	0.646	193.396
31/12/2020	-0.311	97.963	983.239	1.055	171.390

Table 4.
Scaled decision matrix V

Measurement date	j = 1	j = 2	j = 3	j = 4	j = 5	j = 6
1/01/2020	0.802	0.802	0.446	0.979	0.931	0.970
2/01/2020	0.295	0.295	0.000	0.661	0.467	0.621
3/01/2020	0.401	0.401	0.264	0.772	0.774	0.770
…	…	…	…	…	…	…
29/03/2020	0.710	0.710	0.952	0.984	0.789	0.947
30/03/2020	0.919	0.919	0.976	0.973	0.767	0.933
31/03/2020	0.808	0.808	0.906	0.958	0.639	0.897
1/10/2020	0.935	0.935	0.541	0.879	0.648	0.834
2/10/2020	0.885	0.885	0.544	0.927	0.608	0.866
3/10/2020	0.898	0.898	0.537	0.998	0.958	0.990
…	…	…	…	…	…	…
29/12/2020	0.782	0.782	0.618	0.885	0.539	0.818
30/12/2020	0.805	0.805	0.628	0.637	0.000	0.513
31/12/2020	0.715	0.715	0.123	0.887	0.294	0.773

Table 5.
Weights of features (parameters) w_j used in the example

w_j					
j = 1	j = 2	j = 3	j = 4	j = 5	j = 6
0.163	0.163	0.121	0.286	0.095	0.173

Table 6.
Ranking vector R [m×1]

"Object"	Rank (synthetic value)	Ranking place
22/11/2020	0.976	1
25/12/2020	0.964	2
22/03/2020	0.956	3
11/02/2020	0.952	4
12/02/2020	0.945	5
02/02/2020	0.944	6
21/03/2020	0.941	7
12/03/2020	0.940	8
11/03/2020	0.938	9
18/10/2020	0.934	10
…	…	…
03/12/2020	0.586	159
18/03/2020	0.578	160
01/12/2020	0.573	161
11/12/2020	0.509	162
02/12/2020	0.455	163
02/01/2020	0.437	164
05/03/2020	0.433	165
09/11/2020	0.409	166
16/01/2020	0.300	167
17/01/2020	0.064	168

Table 7.
Partial rankings of "objects" in terms of measurement results of the concentrations of dusts: PM10 and PM2.5

Place in ranking	„Object"	Concentration of dust PM10	Place in ranking	„Object"	Concentration of dust PM2.5
1	14/10/2020	7.403	1	14/10/2020	5.182
2	23/02/2020	10.552	2	23/02/2020	7.386
3	11/03/2020	11.191	3	11/03/2020	7.834
4	12/03/2020	11.752	4	12/03/2020	8.226
…	…	…	…	…	…
166	16/01/2020	113.446	166	16/01/2020	79.413
167	02/01/2020	124.902	167	02/01/2020	87.432
168	17/01/2020	174.146	168	17/01/2020	121.902

Table 8.
Partial rankings of "objects" in terms of measurement results of the concentrations of chemical compounds: SO_2, NO, NO_2 and NO_x

Place in ranking	"Object"	Concentration of dust PM10	Place in ranking	„Object"	Concentration of dust PM2.5
1	21/03/2020	5.552	1	22/11/2020	0.959
2	22/03/2020	5.876	2	26/12/2020	1.051
3	18/02/2020	5.926	3	03/10/2020	1.164
4	12/03/2020	6.141	4	25/12/2020	1.351
…	…	…	…	…	…
166	31/12/2020	37.079	166	09/11/2020	64.873
167	14/01/2020	38.031	167	16/01/2020	96.890
168	02/01/2020	41.503	168	17/01/2020	112.511
Place in ranking	"Object"	Concentration of NO_2	Place in ranking	"Object"	Concentration of NO_x
1	22/11/2020	5.935	1	22/11/2020	7.406
2	18/10/2020	6.790	2	25/12/2020	9.094
3	25/12/2020	7.028	3	18/10/2020	9.249
4	03/10/2020	7.612	4	03/10/2020	9.392
…	…	…	…	…	…
166	27/03/2020	42.210	166	05/03/2020	129.471
167	17/01/2020	44.248	167	16/01/2020	183.417
168	30/12/2020	45.820	168	17/01/2020	216.371

4. CONCLUSIONS

The method of Simple Additive Weighting (SAW) used in the article belongs to the group of single criteria synthesis methods which creates a ranking of the examined objects on the basis of a linear combination of the weight vector W [k×1] and the decision matrix D [m×k] (m – object, k – criterion). Since the adopted criteria/measurement results of the concentration of dusts PM_{10} and $PM_{2.5}$ as well as gaseous pollutants: SO_2, NO, NO_2 and NO_X involved in this paper only one measuring point (r = s), in order to define the "objects", an additional parameter (feature) was introduced which is the time (time moments/date) of taking the measurements (sampling). Thus, the subject of the assessment involved "objects" described by the above-mentioned criteria in the successive days of the so-called "winter period" of the year 2020, i.e. on the successive days from 01/01/2020 to 31/03/2020 and from 01/10/2020 to 31/12/2020. The measurement results were used to build the decision matrix D [167×6], and all criteria had the nature of cost criteria.

In terms of the aggregated values of R, the most favourable air quality conditions were reported successively as follows:

- 22/11/2020 (R = 0.976): the "object" was in the first places three times in the partial rankings (in terms of the concentration level of NO (0.959 [μg/m^3]), NO_2 (5.935 [μg/m^3]) and NO_X (7.406 [μg/m^3]), but it also took the 13th place in terms of dust concentration level (the concentration of PM_{10} dust content was 14.961 [μg/m^3], and the concentration of $PM_{2.5}$ – 10.473 [μg/m^3]) and merely the 29th place – in terms of SO_2 concentration level (8.364 [μg/m^3]).
- 25/12/2020 (R = 0.964): the "object" did not ever come first in the partial rankings: in terms of dust concentration level (PM_{10} dust concentration was 12.54 [μg/m^3], and the concentration of $PM_{2.5}$ – 8.778 [μg/m^3]), it took the 5th places, in terms of the concentration level of NO (1.351 [μg/m^3]), NO_2 (7.028 [μg/m^3]) and NO_X (9.094 [μg/m^3]) – it took the 4th, 3rd and 2nd place, respectively. Also on that day high concentration of SO_2 was recorded (11.654 [μg/m^3]), which meant that in the partial ranking the "object" took only 64th place.
- 22/03/2020 and even despite the fact that this "object" was never placed first in the partial rankings. Due to the high level of dust concentration (the concentration of the content of dust PM_{10} was 23.151 [μg/m^3], and the concentration of the content of dust $PM_{2.5}$ – 16.206 [μg/m^3]), this "object" took only the 43rd place. However, in terms of the concentration level of SO_2(5.876 [μg/m^3]), NO (1.844 [μg/m^3]), NO_2 (8.537 [μg/m^3]) and NO_X (11.355 [μg/m^3]) the "object" took respectively the 2nd, 8th, 7th and 5th place in partial rankings.

With respect to the aggregated values R, the least favourable air quality conditions were reported accordingly on 17/01/2020 (R = 0.064), 16/01/2020 (R = 0.300) and 9/11/2020 (R = 0.409). On 17/01/2020, the highest concentration of dust PM_{10} and $PM_{2.5}$ was reported (respectively 174.146 [μg/m^3] and 121.902 [μg/m^3]), and that of nitrogen oxides: NO (112.511 [μg/m^3]) and NO_X (216.371 [μg/m^3]), and on 16.01.2020 in the case of as many as four criteria (concentration of dust PM_{10} and $PM_{2.5}$) and nitrogen oxides (NO and NO_X), the reported results placed the "object" among the three most "polluted" days in the entire "winter period" in 2020.

By comparing the measurement results of the concentrations of harmful substances in the atmosphere with the observation results of atmospheric conditions (direction and speed of wind, temperature, pressure and humidity of air, etc.), it is possible to determine the level of correlation relationships between the above-mentioned elements. For example, using the Pearson linear correlation coefficient (r_{xy}), we can state that in the "winter period" of 2020, the correlation relationship (a measure of the strength of the linear relationship) between the concentration level of dusts PM_{10} and $PM_{2.5}$ and air temperature is low but clearly negative (r_{xy} = -0.393). Also, a low negative but clear correlation occurs in the case of the dependencies between the concentration level of dust PM_{10} and $PM_{2.5}$ and air pressure (r_{xy} = -0.246), and between the concentrations of nitrogen oxides: NO, NO_2 and NO_X and air speed (r_{xy} values are in the range – 0.229÷0.265). The above results can be used for the estimation of the risk of air pollution hazards, for mapping areas with a similar level of risk and for taking preventive action in the case of "objects" with "similar characteristics". However, it should be remembered that due to the introduced restrictions caused by the SARS-CoV-2 virus (from mid-March 2020, the work was done in the remote mode), the intensity of road traffic, and hence the intensity of traffic in the parking lot of the Silesian University of Technology in Poland (sampling sites) was smaller than that during the time of normal economic functioning, so it does not properly

reflect the pollution of the atmosphere. According to the General Directorate for National Roads and Motorways, based on the analysis of data obtained from 32 measuring stations equipped with the via Toll system, the average vehicle traffic from March 9 to May 17, 2020, amounted to approximately 16,500,000 vehicles per day, while in the same period in 2019, it was 25,300,000 vehicles, which is a decrease by approximately 35%. In the future, the author plans to use the above-mentioned method for the analysis of measurement results of air pollution recorded at various points located throughout the entire Silesian agglomeration, which will allow to better identify the concentration level of selected air pollutants in the vicinity of various emission sources and in places away from already existing monitoring stations.

ACKNOWLEDGEMENTS

This work was supported by the Faculty of Energy and Environmental Engineering, Silesian University of Technology (statutory research).

REFERENCES

[1] Francová, A., Chrastný, V., Vítková, M., Šillerová, H., Komárek M. (2020). Health risk assessment of metal(loid)s in soil and particulate matter from industrialized regions: A multidisciplinary approach. *Environmental Pollution*, 260. https://doi.org/10.1016/j.envpol.2020.114057.

[2] Świelik R., Trojanowska M. (2022). Review Chemical Fractionation in Environmental Studies of Potentially Toxic Particulate-Bound Elements in Urban Air, *Toxics; 10*(3), 124. https://doi.org/10.3390/toxics10030124

[3] Paplińska-Goryca M., Misiukiewicz-Stępień P., Proboszcz M., Nejman-Gryz P., Górska K., Zajusz-Zubek E., Krenke R. (2021). Interactions of nasal epithelium with macrophages and dendritic cells variously alter urban PM-induced inflammation in healthy, asthma and COPD. *Scientific Reports*, (art. no. 13259). 11, 1–21. DOI: 10.1038/s41598-021-92626-w.

[4] Mainka A., Zajusz-Zubek E. (2015). Indoor air quality in urban and rural preschools in Upper Silesia, Poland: particulate matter and carbon dioxide, *International Journal of Environmental Research and Public Health*, 12, 7697–7711.

[5] Lopuszanska-Dawid M., Kołodziej H., Lipowicz A., Szklarska A., Kopiczko A., Bielicki T. (2020). Social class-specific secular trends in height among 19-year old Polish men: 6th national surveys from 1965 till 2010, *Economics and Human Biology*, 37, 100832. https://pubmed.ncbi.nlm.nih.gov/31924589/.

[6] PN-EN 14212:2013-02/AC:2014-06E Ambient air quality – Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence.

[7] PN-EN 14211:2013-02 Ambient air quality - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence.

[8] PN-EN 12341:2014-07 Ambient air - Standard gravimetric measurement method for the determination of the PM**10** or PM2,5 mass concentration of suspended particulate matter.

[9] Afshari, A., Mojahed M., Yusuff R. (2010). Simple Additive Weighting approach to personnel selection problem. *International Journal of Innovation and Technology Management, 1*(5), 511–515.

[10] Alinezhad, A., Sarrafha, K., Amini, A. (2014). Sensitivity analysis of SAW technique: the impact of changing the decision making matrix elements on the final ranking of alternatives. *Iranian Journal of Operations Research, 5*(1), 82–94.

[11] Chen, T.Y. (2012). Comparative analysis of SAW and TOPSIS based on interval-valued fuzzy sets: discussions on score functions and weight constraints. *Expert Systems with Applications, 39*(2), 1848–1861.

[12] Churchman, C.W., Ackoff, R.L. (1954). An approximate measure of value. *Journal of Operations Research Society of America, 2*(1), 172–187.

[13] Deni, W., Sudana, O., Sasmita, A. (2013). Analysis and implementation fuzzy multi-attribute decision making SAW method for selection of high achieving students in faculty level. *International Journal of Computer Science, 10*(1), 674–680.

[14] Goodridge, W. S. (2016). Sensitivity analysis using Simple Additive Weighting method. International *Journal of Intelligent Systems and Applications, 8*(5), 27–33.

[15] Huang, Y.S., Chang, W.C., Li, W.H., Lin, Z.L. (2013). Aggregation of utility-based individual preferences for group decision-making. *European Journal of Operational Research, 229*(2), 462–469.

[16] Hwang, C. L., Yoon, K. (1981). Multiple attribute decision making methods and application. Springer, United States.

[17] Janssen, R. (1996). Multiobjective decision support for environmental management. Kulwer Academic Publishers, Holland.

[18] Kobryń, A. (2014). Wielokryterialne wspomaganie decyzji w gospodarowaniu przestrzenią. Difin, Polska.

[19] Koffka, K., Goodridge, W. (2015). Fault tolerant multi-criteria multi-path routing in wireless sensor networks. *International Journal of Intelligent Systems and Applications, 7*(6), 55–63.

[20] Kumar, M., Jayaswal, P., Kushwah K. (2013). Exploring fuzzy SAW method for maintenance strategy selection problem of material handling equipment. International *Journal of Current Engineering and Technology, 3*(2), 600–605.

[21] Memariani, A., Amini, A., Alinezhad, A. (2009). Sensitivity analysis of simple additive weighting method (SAW): the results of change in the weight of one attribute on the final ranking of alternatives. *Journal of Industrial Engineering*, 4, 13–18.

[22] Mokhtari, E., Khamehchian, M., Montazer, G., Nikudel, M. (2016). Landfill site selection using Simple Additive Weighting (SAW) method and artificial neural network method; a case study from Lorestan province, Iran. *International Journal of Geography and Geology, 5*(10), 209–223.

[23] Putra, D. W. T., Punggara A. A. (2018). Comparison analysis of simple additive Weighting (SAW) and weigthed product (WP) in decision support systems. In: *MATEC Web of Conferences*. [on line] *215*(1), 1003. Available at: https://pdfs.semanticscholar.org/705b/2d3c3ba9e882f113f53c83ec185f7aef6425.pdf?_ga=2.165226936.624443085.1618500084-257788093.1618500084 [Accessed 25 Jan. 2021].

[24] Simanaviciene, R., Ustinovichius, L. (2010). Sensitivity analysis for multiple criteria decision making methods: TOPSIS and SAW. *Social and Behavioral Sciences, 2*(6), 7743–7744.

[25] Tahyudin, I., Rosyidi, R., Ahmar, A. S., Haviluddin, H. (2018). Comparison of the Simple Additive Weighting (SAW) with the Technique for Others Reference by Similarity to Ideal Solution (TOPSIS) methods. *International Journal of Engineering and Technology, 7*(2.2), 87–89.

[26] Trzaskalik, T. (2014). Wielokryterialne wspomaganie decyzji. Przegląd metod i zastosowań. *Zeszyty Naukowe Politechniki Śląskiej*, 74, 239–263.

[27] Trzaskalik, T. (red.), (2014). Wielokryterialne wspomaganie decyzji. Metody i zastosowania. Polskie Wydawnictwo Ekonomiczne, Polska.

[28] https://www.traseo.pl/mapy-turystyczne/mapa/74/gliwice-i-okolice-polska-galileos

[29] Rozporządzenie Ministra Środowiska z dnia 11 grudnia 2020 r. w sprawie dokonywania oceny poziomów substancji w powietrzu (Dz.U. z 2020 r., poz. 2279).