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ANALYZING GLOBAL ENVIRONMENT QUALITY STATE AND EVOLUTION BASED ON A MULTI-CRITERIA APPROACH

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Abstract

The paper is focused on the integrated modelling of environmental quality. It shows how we can use multi-criteria decision analysis to study some aspects about the environmental quality status in a region and its evolution during a certain period of time. The global analysis is created by taking into account the concurrent contributions of different factors such as air quality, drinking-water quality and noise pollution, on the quality of the environment people live in. We propose an indicator, named environmental quality index, which can reflect the global quality of the environment. It can be considered a tool which can be used by decision-makers involved in environmental management issues for deciding if the current actions and strategies are going in right directions. The study is carried out through a multi-criteria decision model in case of certainty, namely the Simple Additive Weighting (SAW) method, because it is based on real and basic defined indicators which have certain values. We have applied this tool for a case study. We chose as our case study a city from south west Romania and a period of 7 years, namely 2012-2018. Based on this environmental quality index we have ranked the 7 years showing in which of them the level of the quality of the environment was the best.

Keywords: air pollution, drinking-water quality, environmental management, multi-criteria decisions, noise pollution

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1. Introduction

When we think about the environment, we refer especially to the air we breathe, the water we drink, the food we eat and the noise around us and of course to some basic aspects about social and economic life. There are many papers which analyzed the quality of the environment based on multiple criteria decision models. For example, application of multiple criteria decision methods in water quality analysis provided interesting results (Akter et. al, 2016; Kavurmaci, 2016; Mladenović-Ranisavljevi et al, 2018). Herva and Roca (2013), in a review paper, provided bibliographic references to papers in which multiple criteria decision models were used in problems regarding different environmental aspects. Other studies which regard air quality like (Büke and Köne, 2016; Hacıoğlu et al. 2016), were also performed using such methods. A weighted linear combination of two normalized indexes (one for air and other for noise) was used in (Silva and Mendes, 2012) to develop an approach in the assessment of the quality of the environment based on air quality and noise pollution.

An approach based on multi-criteria decision models enables us to combine different indicators, to find a measure that can be considered a global response to the level of the environmental quality, a response influenced by all the aspects that are taken into account. Our proposed environmental quality index represents an innovative point of view because in its evaluation we take into account different aspects related to the quality of the environment. The paper is focused on the integrated modelling of the quality of the environment, including here aspects about air pollution, drinking-water quality and noise pollution.

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The proposed instrument can be used to assess the quality of the environment and thus gives the possibility to take informed decisions. The implementation of environmental policies, in order to achieve an efficient environmental management, can be supported by its use. It can also be used by governmental authorities, with concerns in the field of environmental protection, in order to plan the environmental strategy. For the environmental management is necessary to know if the undertaken actions reached their goal. The indicator we propose can help decision makers to continue some actions or to decide that necessary improvements must be done.

A polluted environment can negatively affect the quality of life, leading to stress, to deterioration of the health of the population and implicitly to the decrease of the indicator of life satisfaction. Environmental factors: air quality, drinking-water quality, noise pollution are all considered in this paper because they all influence the state of health and wellbeing of the population.

Multi-criteria decision models as ELECTRE, PROMETHEE, AHP, TOPSIS, VIKOR, SAW, COPRAS, are widely used in problems regarding environmental sciences as mentioned for example in Huang et al. (2011) and there are many authors who present in their papers different aspects related to environmental management, as for example Khalili and Duecker (2013), Mardani et al., (2017) and Oltean-Dumbrava et al. (2016), or aspects related to air quality, as for example Borza et al. (2018) and Arı et al. (2016), to green supplier selection Gurel et al., (2015) and Nikolić et al. (2010), to sustainability development as for example Zolfani and Saparauskas (2013) and other. This paper is focused on some aspects regarding the quality of the environment, especially aspects about air pollution, drinking-water quality and noise pollution in a region and their evolution during a certain period of time.

2. Material and methods

2.1. A multi-criteria assessment for environment quality

Many authors are dealing with multi-criteria decision models and their importance is pointed out in many papers, as for example in (Figueira et al., 2005; Steuer, 1986; Vaduva, 2012). Different types of multi-criteria methods are used to solve problems from a wide area of domains: (Demian et al., 2016; Demian et al., 2018). In (Grecu, 2018) TOPSIS method is applied for aspects regarding environmental quality, in (Grecu, 2015) Onicescu method for studying air quality and in (Grecu, 2012) different regions are ranked by using ELECTRE method, but only from the point of view of air quality.

From the wide breadth of existing multi-criteria decision analysis models, in the herein paper we have used the Simple Additive Weighting (SAW) method for making the assessment, because it is easy to apply and to understand. It is a method which uses a weighted aggregation function for making an overall judgment, which represents the response to a certain variant of decision to all criteria involved. Based on it an indicator for the environmental quality is built. The indicator we propose in this paper must not replace the others that exist, each of them referring to a certain aspect, as for example air quality index, but rather complete them. It shows a global result of the consequences of all considered factors taken together and it can reflect the natural environment status at a certain moment and of course it can be used to study its evolution during a certain period of time. It can be used by all authorities who deal with problems regarding the environmental management because it can reflect both positive and negative consequences of certain policies or measures.

Our proposed indicator is built using measured data from different institutions which are designated to process and collect such data, certified by the local governments or authorities, so it is based on reliable data. In order to show how this indicator can be evaluated and used we will apply it for our case study, in which we choose a Romania county seat from south west region, namely Drobeta Turnu Severin (DTS) and the last 7 years, namely 2012-2018, for which we could find statistical data on official sites. By applying this method, we can obtain the indicator value for each of the mentioned years and finally, based on these values, a hierarchy of them. The environmental approach is so realized by analyzing air pollutants emissions, parameters of drinking-water quality and noise pollution in the area.

2.2. Basic concepts in applying SAW method

The importance of SAW method is pointed out in many papers, as for example in (Kaliszewski and Podkopaev, 2016) and it can be used not only in case of certainty but under fuzzy environment as well as in (Wang, 2015). Before applying the mentioned method, we consider that is important to make it a briefly presentation in the following paragraphs.

When applying SAW method, we first have to establish the criteria according to which we make the decision and which are the decision variants we have to analyse. The criteria used are the above mentioned factors that influence environmental quality and the variants are represented by the years that we want to prioritize. SAW method, or the global utility method, is based on the concept of global utility (in fact the aggregation function) which represents the global satisfaction degree of all criteria involved and is evaluated taking into account how important each of them is, with respect to the others. Based on this method the downward hierarchy of the variants is given by the downward order of the global utilities.

Suppose that we have m variants and n criteria to do the global evaluation. Denoting by a_{ij} the value which represents the satisfaction degree of C_{ij} criterion, $j = 1,...,n$, in case of variant, v_i, $i = 1,...,m$, we have a matrix, noted (Eq. 1):

$$A = (a_{ij}),\ 1 \le i \le m\ ,\ 1 \le j \le n \qquad (1)$$

Not all criteria influence in the same manner the performance of the decision variant. Sometimes a higher satisfaction degree of the respective criterion is obtained when higher value for its corresponding attribute is obtained and the criterion is said to be a max-criterion and other times a higher satisfaction degree is obtained when a lower value is obtained and the criterion is said to be a min-criterion.

Because we have different types of criteria and attributes, with different size orders, we have to homogenize the data collected in matrix A, in order to get the normalized values of the responses. In this paper there is used for normalization a linear interpolation scheme which takes into account criterion type, as in papers Figueira et al. (2005), Vaduva (2012).

Denoting by u_{ij} the normalized values they are obtained using the following relations (Eqs. 2-3):

$$u_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}\text{, in case of min-criterion} \qquad (2)$$

$$u_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}\text{, in case of max-criterion} \qquad (3)$$

Elements of the normalized matrix (Eq. 4):

$$U = (u_{ij}), 1 \le i \le m\ ,\ 1 \le j \le n \qquad (4)$$

are named utilities. It is obvious that an ascendant ordering of the elements in column number *j* gives us an analogue order for the performances of all elements according to criterion number *j*, so all criteria can be considered after this normalization as being of max-type.

In order to obtain the prioritization of the considered variants one needs a hierarchy for the criteria involved and so we need to establish the coefficients of importance for each of the involved criterion. Using the coefficients of importance, as weights, we can evaluate the global utilities for each element, in our case, for each year, through an additive weighted formula. Denoting by p_j, $j = 1,...,n$ the coefficients of importance (considering as weights) the global utilities, denoted gu_i, are evaluated using relation (Eq. 5):

$$u_{ij} = \sum_{j=1}^{n} p_j u_{ij}\ , i = 1,...,m \qquad (5)$$

Years are ranked according to their global utilities. Obviously the highest value of the global utility corresponds to the year when environment quality had its highest level.

3. Quality of environment

In this section we have applied SAW method and have obtained first the air quality index. Using this index a hierarchy of the last 7 years has been made. In the same manner an index for drinking-water quality in this region and for noise pollution are obtained and similar hierarchies for the mentioned years have been made.

3.1. Air quality

Continuous monitoring of atmospheric pollution is one of the essential requirements of a performant environmental management. In Romania, this monitoring is done through Environmental Agencies, government structures, which use automatic stations to measure the concentrations of various atmospheric pollutants.

Our study is based on data from the National Environmental Protection Agency in Drobeta Turnu Severin. From the set of pollutants measured at the city level we have considered only some (SO_2, CO, PM-10 and PM-2.5), because they are considered the most important parameters which influence air quality in the region, but the study can be extended to deal with many others. The index we evaluate based on the mentioned pollutants, is used to establish a hierarchy of the mentioned seven years according to air quality. In order to apply SAW method, we consider as alternatives (variants), so as lines in matrix A (Eq.1), years from 2012-2018, in a descending order (first line corresponds to 2018). The criteria according which we make the hierarchy represents the mean annual values of the most important pollutants in the region, namely: sulphur dioxide (SO_2)-first column of matrix A, carbon monoxide (CO)- the second column, particulate matter (PM-10)- the third column, particulate matter (PM-2.5)- the fourth column. Matrix A is presented in Table 1. Data used in this approach are obtained directly from the environment reports for this region in the mentioned years, see http://www.anpm.ro/web/apm-mehedinti.

Other dangerous pollutants as nitrogen dioxide (NO_2) for example, have not been considered in this paper as they have not been monitored continuously during this seven-year span, so data regarding them were not complete. It must be mentioned here that for a complete study NO_2 represents a pollutant that must be considered, due to its impact on human life. However, since what we present here is just an example of how we can use the mentioned technique to make an overall judgment, we can omit it.

All pollutants have dangerous consequences regarding human health and that's why we consider equal influences for them in our study, so we consider the same values for the importance coefficients. Other studies can be made and, depending on their degree of involvement regarding the desired goal, their influences can be changed.

If for example we want to analyze aspects about the impact of the air pollution on a population regarding a certain malady we can take into account with higher weights those pollutants that have major influence on that illness. SAW method applied in this case offers us an indicator which we refer to as air quality index. It is obvious that the lower the average value of the concentration of a certain pollution is, the better is the rank of the specific period, namely the year for which the air pollution is lower (we want to obtain an indicator which points out the best period with respect to air quality). So, we consider all the above criteria as being of min type.

Using Eq. 2 we first get the values for elements of normalized matrix U (Eq. 4), in fact for the utilities, matrix presented in Table 2.

Based on the following importance coefficients: $p_1 = 0.25$, $p_2 = 0.25$, $p_3 = 0.25$, $p_4 = 0.25$, we can evaluate the global utility for each year, using the additive weighted formula (Eq. 5), in fact the values of the air quality index. The results, and the rank of the years, according to air quality, are presented in the last two columns of Table 2.

Fig. 1 provides so a comparison of the situation between 2012 and 2018 concerning the potential exposure of urban population to air pollution. So, after applying SAW method to study air quality evolution, we can say that 2016 is the best year, the year with the highest air quality level. Comparable values for air quality index can be noticed in 2018 and 2017.

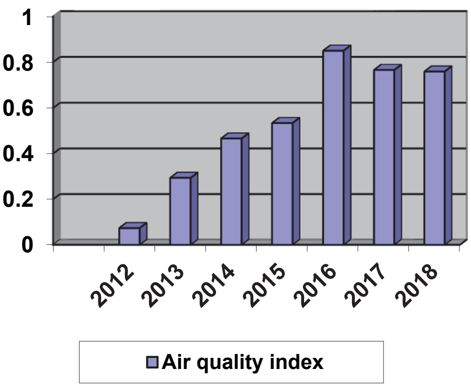

Fig. 1. Air quality index (2012-2018)

3.2. Drinking-water quality

Regarding the assessment made to drinking-water quality in Drobeta Turnu Severin, we have examined the data from SECOM S.A. reports, SECOM being the institution that is responsible for the delivery of drinking-water to the city. The annual average of the most important parameters, parameters specified by Law 458/2002 republished with modifications in 2011 which establishes Romanian regulations for drinking-water, are presented in these reports. Because some parameters were identically, or did not show a large variation during this period of time, we have considered only six of them, namely those presented in Table 3.

Table 1. Air pollutants emission (annual average)

	C_1 (SO_2), μg/m^3	C_2 (CO), mg/m^3	C_3 (PM 10), μg/m^3	C_4 (PM 2.5), μg/m^3
2018	10.24	0.36	23.4	18.22
2017	11.36	0.29	26.7	16.8
2016	13.1	0.21	27.5	14.09
2015	17.3	0.45	31.89	13.59
2014	22	0.23	28.35	19.59
2013	20.5	0.58	26.46	19.67
2012	21.4	0.49	37.26	21.91
Type	min	min	min	min

Table 2. Normalized values, air quality index

	C_1 (SO_2)	C_2 (CO)	C_3 (PM 10)	C_4 (PM 2.5)	*Air quality index*	*Rank*
2018	1	0.594595	1	0.44351	0.759526	3
2017	0.904762	0.783784	0.761905	0.614183	0.766158	2
2016	0.756803	1	0.704185	0.939904	0.850223	1
2015	0.39966	0.351351	0.387446	1	0.534614	4
2014	0	0.945946	0.642857	0.278846	0.466912	5
2013	0.127551	0	0.779221	0.269231	0.294001	6
2012	0.05102	0.243243	0	0	0.073566	7

Table 3. Drinking-water parameters

Parameter	*Unit*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*Type*
Turbidity	*N.T.U.*	0.63	0.48	0.45	0.44	0.32	0.46	0.43	min
Water hardness	^{0}*dGH*	11.22	10.39	11.08	11.08	10.5	10.68	10.02	max
Organic substance	*mgO*$_2$*/L*	0.86	1.54	1.63	1.43	1.31	1.26	1.20	min
Residual aluminum	*μg/L*	110	103	101.13	102.13	97.78	67.34	76.82	min
Nitrates	*mg/L*	5.96	6.32	5.61	5.8	5.85	5.43	5.22	min
Electrical conductivity	*μS/cm*	390	403	402	397	418.6	415.66	412.91	min

All drinking-water parameters, with one exception, water hardness, are criteria of min-type. Water hardness is considered a max criterion because average water hardness values, from the analysed period of time, fall into the category of medium hardness water, and in such circumstances the mineral content, reflected in water hardness, must be as high as possible to provide beneficiaries with a consistent input. There are no very high values, or overtaking of the threshold that make water too hard to be harmful to human health, to pose a danger to kidney disease. When we have considered water hardness as max criteria, we have started from its definition and from the benefits of water hardness presented by WHO, (http://www.who.int/water_sanitation_health/dwq/chemicals/hardness.pdf) WHO says that calcium and magnesium are essential minerals and beneficial to human health in several respects. Inadequate intake of either nutrient can result in adverse health consequences (http://apps.who.int/iris/bitstream/handle/10665/43836/9789241563550_eng.pdf).

Drinking-water is for humans, and not only, a vital element that cannot be replaced and its quality influences human's health. Drinking-water in DTS comes largely from the Danube River. It is treated, monitored and controlled daily in the laboratory of the company that deals with its distribution, a laboratory equipped with high performance equipment, according to the European requirements, especially at the exit from the treatment plant, so that its quality is in compliance with the requirements of Law 458/2002 republished in 2011, a law which established regulations for the drinking-water in Romania (http://www.secom-mehedinti.ro/calitate-apa-potabila-analize-periodice/). According to Romanian legislation the hardness of the drinking-water must be at least 5^0dGH. Hardness of drinking-water is a property of water that influences people health but it is not a big concern because the drinking-water, and we refer here at what happens in DTS during the analyzed period of time, has a hardness situated between 10.5^0dGH and 11.22^0dGH, fact that makes it suitable for human use, and places it in the medium water category (Medium water 0 – 12^0dGH).

The utilities (the normalized values) corresponding for the values in Table 3 were evaluated with linear interpolation schemes and are presented in Table 4. Considering that they have equal influence on water quality, we set all importance coefficients as 1/6. So, their concurrent contributions on water quality can be represented by the global utility, which we refer to as water quality index. The values of water quality indexes for the considered seven years and their rank, based on them, are presented in Table 4, last two lines in the mentioned Table. As we notice in Fig.2 a great fluctuation exists, but during the last three years (2016-2018) an ascendant trend can be observed. 2018 is situated on the first place regarding drinking-water quality, fact that proves that the undertaken measures to improve the quality of drinking-water have reached their desired goal.

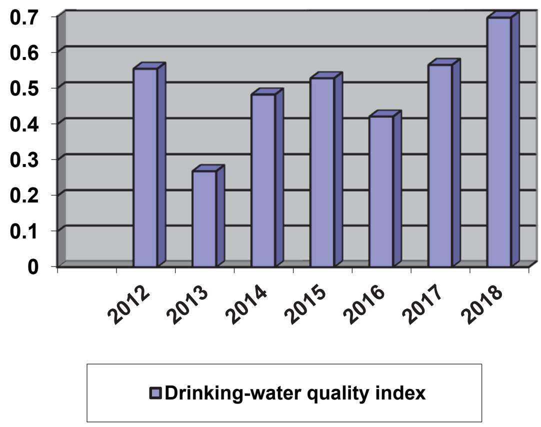

Fig. 2. Drinking-water quality index (2012-2018)

3.3. Noise pollution

Ambient noise is a serious international problem which affects the urban population. Noise is increasingly taken into account in assessing the quality of life in a city, or its neighbourhood.

The noise level is monitored by measurements at 16 fixed points in different areas of Drobeta Turnu Severin. There have been selected for study areas with high traffic, industrial areas, parks in the vicinity of educational institutions, and so on. The establishment of these noise monitoring points was made in accordance with the requirements of the national standards and the Directive 2002/49/EC on ambient noise management, transposed into national law by H.G. no. 944/2016 amending and supplementing GD 321/2005 on the assessment and management of environmental noise; so the set points provide data on road traffic noise levels, industrial activities, but also the noise level in the area of schools, gardens and recreation areas - parks. Aspects about noise pollution in this area have made the object of studies as (Demian et al., 2009; Demian and Demian, 2012).

Regarding noise pollution, the actual legislation establishes regulations for $Leq_{(A)}$, in fact sets limit values for it. The annual mean values measured in the 16 fixed points in DTS, localized as shown on the map in Fig. 3, are presented in annual environmental reports. The situation of these levels, for the mentioned period of time, is given in Table 5, where we find in the last column the limit value for this indicator too. We consider in the herein paper that the noise index for a certain year is represented by the annual average value of the values in Table 5. From Table 6 we notice that 2017 and 2018 are situated on the last two positions in the hierarchy realized by taking into account the annual average level of $Leq_{(A)}$, as a min type criterion. This situation is especially due to the road traffic and other industrial activities which have increased in the last period.

Table 4. Utilities of drinking-water parameters, water quality index

	2012	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Utilities	0	0.483871	0.580645	0.612903	1	0.548387	0.645161
	1	0.035714	0.035714	0	0.071429	0.45	1
	1	0.308333	0.883333	0.883333	0.4	0.480519	0.558442
	1	0.116883	0	0.25974	0.415584	1	1
	0	0.21097	0.26733	0.237191	0.368294	0.809091	1
	0	0.769746	0.990295	1	0	0.102797	0.198951
Water quality index	0.554545	0.269772	0.482963	0.528072	0.421551	0.565132	0.696722
Rank	3	7	5	4	6	2	1

Fig. 3. DTS map-points of noise measurements positions

Table 5. Average Values for $Leq_{(A)}$

$Leq_{(A)}$ average values / ***Nr. crt. Measurement points***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Average Value $Leq_{(A)}$***	***Limit Value $Leq_{(A)}$***
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
	2012	2013	2014	2015	2016	2017	2018	
P1	70	67.5	68.3	68.5	68.7	70.2	70.0	70
P2	69	67.5	68.7	68.5	68.9	69.5	69.4	65
P3	69	66.5	67.7	68.6	68.7	68.8	69.0	65
P4	67	67	66.2	66.4	66.3	67.4	67.5	65
P5	70	66.5	66.1	66.6	66.4	66.9	66.7	65
P6	66	65	65.9	65.7	65.4	67.1	65.1	70
P7	72	68.5	69.7	70.0	69.5	70.7	70.9	70
P8	63	64	62.8	64.1	63.8	65.1	66.3	65
P9	67	60	62.7	62.3	-	-	-	65
P10	52	50	53.3	50.9	53.0	53.8	54.5	65
P11	58	52.5	53.5	55.6	55.6	55	53.9	65
P12	62	60	62.8	59.0	61.7	62.6	62.5	75
P13	61	56	60.6	58.7	59.7	58.1	57.8	75
P14	52	55	53	50.4	51.2	52.4	49.1	50
P15	53	50	52.5	52.8	52.7	54	52.0	50
P16	52	54.5	52	50.1	49.4	51.3	51.0	50
Annual average value	62.6875	58.55556	52.5	61.1375	57.5625	62.19333	61.69553	
Rank	7	3	1	4	2	6	5	

Table 6. Normalized values for quality indexes, environmental quality indexes and ranks

Year	*Normalized Air quality index*	*Normalized Water quality index*	*Normalized Noise index*	*Environmental quality index*	*Rank*
2018	0.88322129	1	0.09737129	0.660197527	2
2017	0.89176046	0.691791	0.04850748	0.544019516	4
2016	1	0.355496	0.50306748	0.619521148	3
2015	0.59363142	0.604989	0.15214724	0.450255846	5
2014	0.50646038	0.499335	1	0.668598399	1
2013	0.28382542	0	0.4055892	0.229804874	6
2012	0	0.666994	0	0.222331264	7

3.4. Environmental quality index

With the above mentioned indicators for air and water quality, together with the noise index, we propose to estimate a global indicator to reflect the environmental quality level in the region, for each of the envisaged years. The cumulative influence of these three factors on the environmental quality, in fact the environmental quality index, is obtained using the additive formula (Eq. 3), considering that all of them have the same importance. So, setting the following importance coefficients: $p_1 = p_2 = p_3 = 1/3$ we evaluate the global utility for each year. We get the results in Table 6, where not only the environmental quality index is shown (column 5), but also the positions of each year in the hierarchy made based on it (column 6).

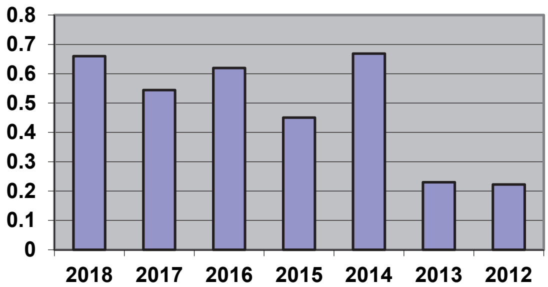

Fig. 4. Environmental quality indexes (2012-2018)

So, as one can see in Fig.4, in this case, there is no upward trend, but we notice that the highest value of this index is obtained in 2018, fact that shows that the quality of the environment is at the highest level, if we refer to the mentioned period of time.

4. Conclusions

The factors that influence environmental quality are varied and countless and an approach that takes all of them into account can be cumbersome but not impossible using multiple criteria approaches.

In the herein paper we have presented a way we can study the competitive action of various environmental factors, with contradictory developments or evolutions, over its quality, by applying a multi-decision criteria model, namely SAW method. The proposed index may be seen as an aggregate measure for the quality of the total environment. This index was used to analyze environmental quality evolution during the last 7 years.

For our case study we choose a town from south-west Romania region, namely Drobeta Turnu Severin – Mehedinti county seat, on a seven-year span: 2012-2018, the last 7 years for which we could find statistical data on official sites. SAW method has demonstrated to be a useful tool for the assessment, in fact for making the hierarchy of the quality of the environment in the mentioned years.

The results show that in 2016 air quality has reached its highest level, with respect to the pollutants taken into account in this paper, in 2018 drinking-water quality has reached its highest level, but as regarding noise pollution 2014 was the best year.

The hierarchy according to the global environmental index shows that 2014 is the best year and 2018 is situated on the second place, but very close to 2014. If we take a closer look to all indexes evaluated in the paper, we notice that 2018 is situated on the first position as regarding drinking-water index and very close to the first position as regarding air quality index but it is still on the second place globally. This result is obtained especially due to the low noise index for 2018, fact that shows that imperious and urgent actions need to be taken in order to reduce the noise level in the area.

For obtaining an upper trend with respect to the environmental quality index more efforts and coherent actions need to be taken as regarding all aspects presented in this paper.

The envisaged problem is only an example of how we can use SAW method in solving problems regarding environmental quality. The indicator we have proposed can be adapted such as to take into consideration other aspects related to the environment as: radioactivity, soil quality, even social and economic aspects about quality of life.

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