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CHOICE OF THE MOST USEFUL BIOLOGICAL EARLY WARNING SYSTEM, BASED ON AHP AND REMBRANDT ANALYSIS

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ABSTRACT

In paper, the ability to use of the biological early warning systems, in tap water quality biomonitoring was analyzed, based on multiple-criteria decision analysis. Five groups of organisms (invertebrates, fishes, algae, fungi and bacteria) were analyzed for the sensitivity to disturbance, the area of use, the amount of detected components, the rate of reaction and the data interpretation. Both analyzes revealed, that invertebrates are the most sensitive bioindicators (49% AHP, 29% Rembrandt). The other organisms which are useful in BEWS systems are algae and fishes. More problematic may be systems based on fungi and bacteria.Both analysis Rembrandt, as well as analytic hierarchy process(AHP) have indicated the rate of reaction as the most important factor in BEWS. All of BEWS systems are focused on reduce the time required to obtain the information about pollution presence, because the standard monitoring of tap water quality, based on physical and chemical methods, are usually time consuming.

Key words: AHP, Rembrandt, biomonitoring, biological early warning systems

INTRODUCTION

Chemical analyzes are indispensable for the production of safe drinking water. They allow detection of biological as well as chemical pollution and in case of emergency, undertake the treatment action. A lack of continuous monitoring in time is the biggest limitation [Bae and Park 2014]. Due to the growth numbers of non-identification pollutants and in order to make an appropriate assessment of their impact to alive organisms, the biological monitoring is additionally used.

Two types of biomonitoring can be distinguished: active and passive. Passive focus on living organisms observation in their natural environment. Active, assumes putting the living organisms into the research area and observation of their behavior [Traczewska 2008]. Correct interpretation of behavior changes is significant in context of tap water quality monitoring.

The harmful for human health factors, present in water can be divided into microbiological and chemical. The chemical pollutions, in contrast to microbiological usually do not causes acute effects. Problematic is their ability to harmful effect after long period of consumption. Especially heavy metals and carcinogenic substances [Wojtyła-Buciora i Marcinkowski 2010]. Water pollutants in water supply network can be caused by sources contamination, exploitation problems, or secondary water contamination in pipes [Szpak and Tchórzewska-Cieślak 2015]. Due to that, water quality monitoring is one of the most important part of water distribution.

In paper, the ability to use of the biological early warning systems, in tap water quality biomonitor-

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ing was analyzed, based on multiple-criteria decision analysis (MCDM).

The MCDM analysis allow to take account of many factors and their interconnections. Based on them, the choice of the most favorable method of water biomonitoring is also possible.

MATERIAL AND METHODS

AHP and Rembrandt methods of multi-criteria decision

Discrete methods of multi-criteria decision support, developed rapidly in recent years can be used to analyze the decision-making in various fields of science [Trzaskalik 2014]

In the literature can be find many examples of the use of the basic method of multi-criteria AHP. In paper Vahdani et al. [2010] model has been applied to a vendor selection process of a firm working in the field of rail transportation. Triantaphyllou [2000] describes the problem of choosing the best method of multiple-choices, concentrate on methods such as WSM, WPM, AHP, revised AHP, ELECTRE, TOPSIS. Lootsma [2007] described basis analysis multiple with using SMART andAHP method. Bolloju [2001] models AHP representing employment preferences of two subjects with of the 70 AHP models revealed that a wide variety of factors.

The REMBRANDT method has been designed to address three criticized features of AHP. In this method, the scale Saaty'sis replaced by a logarithmic scale. Determining the value of their solutions by Perron-Frobenius is replaced with the logarithmic least squares estimation [Trzaskalik 2014]. The first issue described by Lootsma was the numerical scale for verbal comparative judgment Olson [1995].

Decision, based on comparative judgement of C_j to C_k was captured on a category scale to restrict the range of possible verbal responses. This is converted into an integer-valued gradation index d_{jkd} according to the scale in table 1 [Van den Honert and Lootsma 2000]:

The ratio matrix in REMBRANDT for criteria is transformed through the operator $e^{y \cdot \delta(jk)}$ to generate the set of values transformed to the logarithmic scale. Lootsma considers two alternative scales y to express preferences. For calculating the weight of criteria, $y = \ln 2 \approx 0.347$ is used. For calculating the weight of alternatives on each criterion, $y = \ln 2 \approx 0.693$ is used.Notes that the geometric means of row elements of such a matrix yields the solution minimizing the sum of squared errors.This solution is normalized by product. It is a simple matter to normalize by sum, simply dividing eachelement by the total [Olson et al. 1995, Van den Honert and Lootsma 2000, Modiri et al. 2010].

Table 1. Comparative judgment hierarchy (Van den Honert, Lootsma, 2000)
Tabela 1. Oceny w metodach analizy hierarchinej (Van den Honert, Lootsma, 2000)

No.	Comparative judgment	Gradation index d_{jkd}	Saaty ratio
1.	Very strong preference for C_k over C_j	–8	1/9
2.	Strong preference for C_k over C_j	–6	1/7
3.	Definite preferences for C_k over C_j	–4	1/5
4.	Weak preference for C_k over C_j	–2	1/3
5.	Indifference between for C_k over C_j	0	1
6.	Weak preference for C_k over C_j	2	3
7.	Definite preferences for C_k over C_j	4	5
8.	Strong preference for C_k over C_j	6	7
9.	Very strong preference for C_k over C_j	8	9

Living organisms used in biotests

Water quality biomonitoring based onbioindication is applied for many years [Bea and Park, 2014]. Precise diagnosis of specific behavior represents an organism's responses to environmental changes, contributed to increase the popularity of biological early warning systems (BEWSs).

Systems are more sensitive and precise than physicochemical sensors. They allow to obtain information about various pollution in real-time (heavy metal, organic and inorganic components, pesticide, herbicide and antibiotics) [Kramer and Foekema 2000, Gu et al. 2004, Zurita et al. 2007, Storey et al. 2011, Traczewska 2011, Woutersen et al. 2011, Bea and Park 2014, Jia i Ionescu 2015, Häder and Erzinger 2017]. The tools used to evaluate behavior are inexpensive, that makes them both more practical and economical than chemical methods.

Continuous monitoring of tap water quality resulted the development of commercial systems based on bioindicators. Biological early warning systems evaluate the quality of water based on the reaction of invertebrates [Kramer and Foekema 2000, Gu et al. 2004, Storey et al. 2011, Traczewska 2011, Bea and Park 2014, Häder and Erzinger 2017], algae [Stevenson and Smol 2003, Gu et al. 2004, Allan et al. 2006, Zurita et al. 2007, Zhou et al. 2008, Storeyet al. 2011, Traczewska 2011], fish [Van der Schalie et al. 2001, Gu et al. 2004, Allan et al. 2006, Gerhardt et al. 2006, Storey et al. 2011, Traczewska 2011, Bea and Park 2014], fungi [Välimaa et al. 2008, Traczewska 2011, Rumlova and Dolezalova 2012, Wachowska and Stasiulewicz-Paluch 2016] and bacteria [Zurita et al. 2007, Storey et al. 2011, Traczewska 2011, Woutersen et al. 2011, Jia and Ionescu 2015].

Invertebrates

The most popular invertebrates used in those systems are Daphnia, Gammarus, Rotifers as well as Gastropods and Clams. Impact of pollutants on to the species is evaluated for mortality, reproduction, swimming behavior, valve opening/closing etc.Possibility to adaptation to the various environments allow to assess quality of fresh water (including tap water), saltwater and wastewater [Kramer and Foekema 2000, Traczewska 2011]. Real-time monitoring systems based usually on behavioral reaction of Daphne (DaphTox II, Multi-DaphTrack, Daphniatox etc.) or bivalves (The Mooselmonitor, The Dreissena Monitor, Symbio etc.). Reaction rate depends on concentration and kind of substance. The minimum time to obtain the changes of behavior is 2 minutes [Häder and Erzinger 2017]. High sensitivity of invertebrates can result the reaction on the other factors like changes of temperature, pH, salinity or chlorine, which are not danger for human health. Predisposition to detect heavy metals, pesticides, herbicides, chemical, organic and inorganic substances, as well as uncomplicated interpretation of reactions makes invertebrates more effective bioindicators than other organisms [Gu et al. 2004, Storey et al. 2011).

Algae

Assessment of water quality based on aquatic plants entails a significant amount of time needed for their growth [Traczewska 2011]. Real-time detection of pollutants is possible solely with algae monitoring. Usually chlorophytes are used. Analogous to invertebrates, allow to assess quality of fresh water, saltwater and wastewater [Allan et al. 2006, Zhou et al. 2008]. Popular system based on chlorophytes is Algae Toximeter. The instrument compares the effects of toxins on the one part of algae to the another part kept in clean water with known parameters. The principle of operation based on the determination of the fluorescence spectrum and oxygen demand. To get the response, 10 minute time is required [Mons 2008]. Algae are sensitive to change of irradiation and substances, which are not danger for human health.In addition, the cultivation of the identical cultures of the test organisms is difficult. [Stevenson and Smol 2003, Gu et al. 2004, Zurita et al. 2007, Storey et al. 2011].

Fish

Fishes were one of the first organisms used in BEWS [Bea and Park 2014]. Rainbow trout, zebrafishes and guppies are usually used in biomonitoring systems. The individual species and their various form are able to detect pollutions in fresh water, saltwater and wastewater. [Van der Schalie et al. 2001, Allan et al. 2006]. Systems like Fish Toximeter, ToxProtect, The Bio-Sensor measures the changes of swimming speed and/or muscles activity (gill movements). Fishes are able to detect from 0,003 to 100 ppm of pollution (heavy metals, chemical compounds, pesticides) [Traczewska 2011]. To get the response, about 17 minute time is required after the toxic substances occurred. Sensitivity of fishes can result the reaction on the other factors like changes of temperature, pH, salinity or chlorine. The breeding and the development of special procedures to identify specific behavioral changes, require considerable experience. In addition, research and testing on vertebrate animals must obtain approval from The Animal Experiments Committee [Gu et al. 2004, Gerhardt et al. 2006, Storey et al. 2011].

Fungi

Fungi are rarely used in biomonitoring compared to the other organisms. Inhibition of growth and changes in cells shape of S. cerevisiae for toxic substances are usually measured [Rumlova and Dolezalova 2012, Wachowska and Stasiulewicz-Paluch 2016]. The main limitation is the possibility of using only in freshwater. Fungi are sensitive for pH and salinity changes. Pollution presence observation is possible after 2 hour of exposition [Välimaa et al. 2008]. Despite the limitations, Rumlova and Dolezalova proved that fungi are more usefull to obtain the information about presence atropine, fenitrotion and potassium cyanide in water than popular biotests based on bacteria V.fisheri or invertebrates D. magna [Rumlova and Dolezalova 2012].

Bacteria

Bacteria has been used in eco-toxicological research since 80's measuring their level of oxygen demand, nitrification process, grow and luminescence (Bea and Park, 2014).The advantage of research with V. fischeri, P. fluorescens, Spirillum sp. is their non-invasive, low cost, speed and repeatability. Bacteria are used to assessment of freshwater, tap water (excluding V. fischeri) and wastewater quality [D'souza 2001]. The wide range of applications and ease of research, lead to increased numbers of water quality control systems, based on the bacteria reaction (RODTOX 2000, Amtox, Microtox, TOXcontrol itd.). Organisms are sensitive on presence of heavy metals, organic compounds, pesticide and antibiotics in water. Reaction time, required to obtain results does not exceed 30 minute [Zurita et al. 2007, Storey et al. 2011, Woutersen et al. 2011, Jia and Ionescu 2015]. The main limitations of systems based on bacteria reaction are temperature, salinity and sensitivity to substances which are not danger for human health.

AHP and Rembrandt tree structure

The tree structure was prepared on the basis of the literature review. Based on it, the most useful of the proposed methods of water quality real-time monitoring was chosen (fig. 1). The advantage of the AHP and Rembrandt analysis is investigate the relation between the quantities and qualities parameters which are not mutually connected, at the same time.

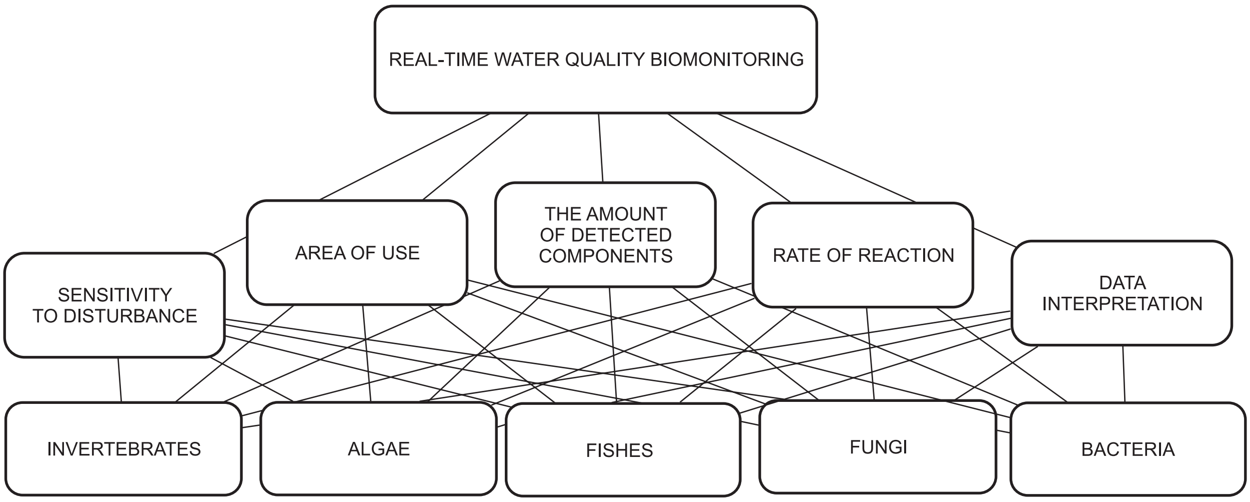

Fig. 1. Tree structure
Ryc. 1. Drzewo hierarchiczne

RESULT AND DISCUSSION

Five groups of life organisms, used in biological early warning system were analyzed.Sensitivity to disturbance, area of use, the amount of detected components, rate of reaction and data interpretation, were checked by the criteria-based assessment.

The previously mentioned information from the literature were used to comparing the differences between the groups. Both analysis Rembrandt, as well as AHP have indicated the rate of reaction as the most important factor in BEWS (fig. 2). Most of BEWS systems are focused on reduce the time required to obtain the information about pollution presence, because the standard monitoring of tap water quality, based on physical and chemical methods, are usually time consuming. The standard toxicology tests, as well as physicochemical sensors cannot provide the comprehensive water safety in real-time [Van der Schalie et al. 2001, Bea and Park 2014]. Searching for organisms or technologies which allow to minimize the rate of reaction in BEWSs is the main aim of research papers topics [Rumlova and Dolezalova 2012].

The other factor which is indispensable in BEWSs is the amount of detected components. The validity of research related to the amount of contamination is confirmed in Zhou, Van der Schalie or D'souza works [D'souza 2001, Van der Schalie et al. 2001, Zhou et al. 2008]. The standard monitoring based on chemical analyses do not allow for continuous pollution control and the water quality cannot be always guarantied. One of the biggest limitation of biological systems was the inability to distinguish pollution. However Bea and Park as well as Rumlova and Dolezalovaresearches point that used a few organisms in the same time, as one multispecies monitor make more possible detectionand recognize kind of compound [Rumlova and Dolezalova 2012, Bea and Park 2014].

For the other criteria the divergent results were obtained. The third criteria which was important in Rembrandt analysis was the sensitivity to disturbance (13%), while in the case of AHP analysis it was the area of use. In both cases, the data interpretation was the least important criterion. Possibility to create a false alarms is the second important limitation of the BEWSs [Bea and Park 2014]. Sensitivity to temperature, pH or salinity changes occur in most of analyzed organisms group. Furthermore part of organisms are more sensitive to low concentrations of the substance. Algae and fungi can detect the concentration of some substances, which are not danger for human health. Possibility to mark the response threshold in all of bioindicators groups, is required to eliminate too sensitive organisms.

All of mentioned systems has wide area of use. Most of them are able to detect pollution in tap water after purification. It's important in case of requirement to providing good water quality, regardless of the period [Kramer and Foekema 2000, Gu et al. 2004, Storey et al. 2011, Traczewska 2011, Bea and Park 2014, Häder and Erzinger 2017]. The biggest advantage of systems is possibility to use them in surface water. It's important in the case of water contamination, to identify the pollution source. The least attention in the literature devoted to the data interpretation. It's more subjective than the other criteria [Stevenson and Smol 2003, Gu et al. 2004, Storey et al. 2011]. In paper focused on possibility to detection of contamination based on visual observation.

For all analyzed criteria, the groups of mentioned organisms were compared with each other. In case of the reaction rate as well as the detected components amount, the highest values were obtained to invertebrates. A little more time needed to observe the changes of behavior, in case of algae systems. With

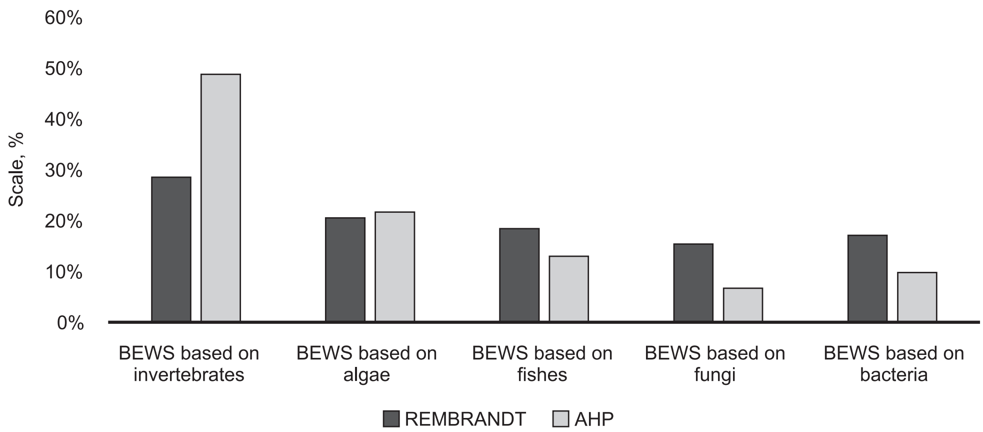

Fig. 2. Result of REMBRANDT and AHP analysis of criterial
Ryc. 2. Wyniki analizy Rembrandt I AHP dla wybranych kryteriów

the amount of detected components were demonstrated, that fishes can be also used in biomonitoring. The end result of AHP (49%) and Rembrandt (29%) analysis has demonstrated, that invertebrates are the most useful organisms in biological early warning systems. They are characterized by one of the faster response to occuring contaminants, as well as a wide range of substances detected. Invertebrates are sensitive to some disturbance, but the area of their use include the largest number of environments. Other positions went to systems based on reaction of algae (AHP 22%, Rembrandt 21%), fishes (AHP 13%, Rembrandt 18%), bacteria (AHP 10%, Rembrandt 17%) and fungi (AHP 7%, Rembrandt 15%) (fig.2).

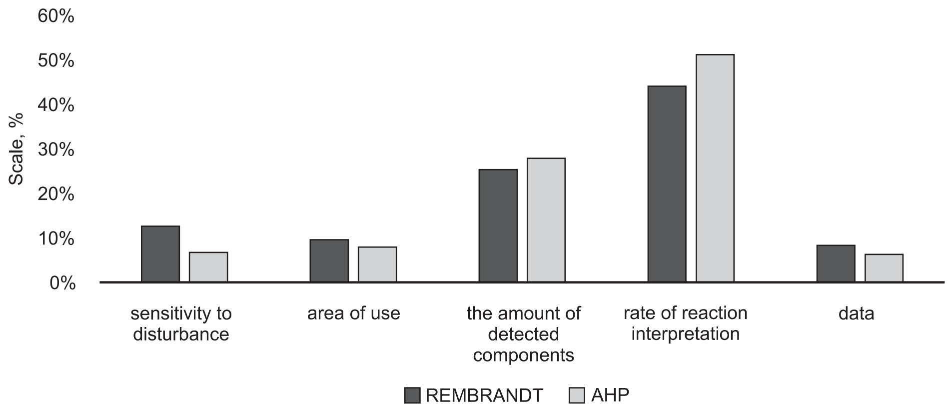

Fig. 3. Result of REMBRANDT and AHP analysis of organisms
Rys. 3. Wyniki analiz Rembrandt i AHP dla wybranych organizmów

CONCLUSION

Biomonitoring is essential to identify contaminants, protect human health, improve water quality, and prevent its degradation. Changes in behavior provide information about the individual and community-level effects caused by occurring contaminants. However behavioral monitoring it is difficult to objectively estimate and interpret behavioral data. Non-linearity of behaviors, variation in individual behavior, and the large amounts of data obtained by continuous monitoring is the biggest restrictions of these systems. Considering those restrictions, the chosen of the most useful organisms to water quality biomonitoring can be difficult.

To solve the problems in this paper compared the use of Rembrandt with AHP analysis in a group selection problem. Evaluation by these the two systems is identical, with the exception that the scale has different numerical values assigned. Rembrandt, as well as AHPis well suited to group decisions.The primary benefit are easy to identify the differences of opinions. One of the procedural difference between both methods was the calculation of impact scores.Based on the data of Rembrandt analysis (the geometric mean) and the AHP analysis (the arithmetic mean), the same recommended solution was obtained, but with different value.

Based on carried analyzes, the invertebrates organisms seemed to be one of the most sensitive bioindicators.Their behavior is easy to interpretation and observation. The response to occurring the contaminants can be measured by monitoring of valve gape or changes in shell opening. Moreover, the stress induced by organic solvents can also affect on the frequency of opening and closing. The other groups of organisms are not able to describe kind of pollutants.

In conclusion, it possible to compare only stimuli in a limited range where their perception is sensitive enough to make distinctions. The range should not be too wider. When the range is too wide some elements that are close together tend to be summarily lumped together. It is well known, that when applied to physical phenomena beyond our ability to perceive or respond to, the scale would lead to failure.

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WYBÓR NAJBARDZIEJ UŻYTECZNYCH BIOLOGICZNYCH SYSTEMÓW WCZESNEGO OSTRZEGANIA, Z WYKORZYSTANIEM METOD AHP I REMBRANDT

ABSTRAKT

W artykule analizowano możliwość wykorzystania w wodzie wodociągowej biologicznego systemu wczesnego ostrzegania, bazując na wielokryterialnej metodzie podejmowania decyzji. Sprawdzono grupę pięciu organizmów (bezkręgowców, ryb, glonów, grzybów i bakterii) pod kątem wrażliwości na zakłócenia, obszar zastosowania, ilości wykrywanych zanieczyszczeń, prędkości reakcji oraz sposobu interpretacji danych. Na podstawie przeprowadzonych analiz wykazano, że bezkręgowce są najbardziej wrażliwymi bioindykatorami (49% AHP, 29% Rembrandt). Pozostałymi organizmy użytecznymi w bilogicznych systemach wczesnego ostrzegania są ryby i glony. Bardziej problematyczne mogą być system oparte na reakcji grzybów i bakteri. Zarówno Rembrandt jak i AHP wykazały, że prędkość reakcji organizmów jest najważniejszym czynnikiem decydującym o skuteczności działania systemów. Rolą wszystkich biologicznych systemów wczesnego ostrzegania jest skrócenie czasu uzyskania informacji na temat występowania potencjalnych zagrożeń w wodzie, ponieważ standardowe metody monitoringu oparte na analizach fizycznych i chemicznych są zazwyczaj bardziej czasochłonne.

Key words: AHP, Rembrandt, biomonitoring, biologiczny system wczesnego ostrzegania,