

HOW TO IDENTIFY RISK IN INTEGRATED WATER RESOURCES MANAGEMENT?

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ABSTRACT

The EU Water Framework Directive 2000/60/EC (WFD) introduces new and different approaches towards water management, both for the members who recently joined the EU as well as for the older EU-member states. It is noted that social participation is essential for better water management. However, it has not been easy to ensure active social participation in water management processes. Sometimes different interest groups have attempted to capture the water management processes to promote their own agenda's. Integrated Water Resources Management (IWRM) is a participatory planning and implementation process, based on sound science, that brings stakeholders together to determine how to meet society's long-term needs for water and coastal resources while maintaining essential ecological services and economic benefits.

Possible failures in water management are mainly caused by inappropriate administration and water resources management. They are also connected with credibility of actual status diagnosis and uncertainty of forecasting changes. Proper assessment of size and spatial distribution of risk in water management, at the present time and in the future, has an essential significance in decisions concerning elimination or limitation of risk reasons.

The objective of this publication is to present the method based on Multidimensional Comparison Analysis enabling quantification of risk in integrated water resources management. It was assumed that proposed method should allow to:

- create the hierarchy of problems from the field of water management in particular area
- identification of factors in the measures used in determination of risk, responsible for its size
- spatial and quantitative diversification of activities limiting the influence of particular factors for the risk size.

The accepted objectives may be achieved only with actual participation of authorities and local communities. As a consequence, fundamental for risk assessment is evaluation of the range of this participation, its form and both technical and matter-of-fact preparation. It is also necessary for this analysis to include natural and social-economical conditions of the locality as well as issues connected with spatial management.

1 INTRODUCTION

The possible failures in water management have its cause mainly in inappropriate administration of water resources. It is also connected with credibility of existing condition diagnosis and uncertainty in forecasting the changes. The ability of assessing

the size of risk and its spatial location in water management (now and in the future) is essential in the process of making decision concerning the actions that should eliminate or limit the cause of its occurrence.

Modern water management is based on the rules of Integrated Water Resources Management (IWRM). The risk determination may be fundamental for elimination of threats which make it impossible to achieve accepted goals. It also allows to hierarchize the problems in analyzed area, diversify the intensity of actions which limit the influence of specified factors for the size of risk, together with optimization of necessary financial costs.

In this article, for the first time, we present the method which allows to determine the risk in Integrated Water Resources Management for any particular area which comply with conditions mentioned above. Quantification of risk in Integrated Water Resources Management is strictly connected with the risk of not obtaining the proper state of waters defined in Water Framework Directive, which is the basis of water policy for European Union countries. This method may also be used for planning the actions leading to its attainment.

The paper is the result of long-term research carried out by main author. It mainly consists of studies concerning optimization of water management process and methodical research on implementation of the rules of integrated water resources management, especially methods of Multidimensional Comparative Analysis. The main author also used his practical experience from the time of employment in water administration, as well as, the results of research and development realized by Institute of Meteorology and Water Management. The research indicates that established goals in water resources management may be achieved only together with significant participation of authorities and local community. As a consequence, for risk determination it is very important to assess the range of this participation, its forms, as well as, both technical and substantial preparation of those two groups. Moreover, for the analysis it is necessary to take into account local environmental and socio-economic conditions and issues connected with spatial management.

The result of research presented in the following paper, proves that its established goal was achieved and presented method may find wide range of application in risk determination which is always one of the most substantial elements of development planning, including the development of water management.

2 RISK IN IWRM - DEFINITIONS

Because of planning actions and making decisions, for people who administer water management on the level of sub-basin or river basin it is important to know what is the division of risk in IWRM in space and time. Risk is the measure which indicates possible failures in IWRM. Quantification of this determined risk allows the people who make decisions for proper hierarchization and concentration of actions in the areas where the risk may occur. Those areas require special support because of the pressures occurring there, which are the result of economic activity and local conditions. This is the reason for which it has been proposed to introduce the concept of risk in IWRM together with the method of its quantification. For risk in IWRM an influence has the intensity and scale of economic activity and other factors such as physical, environmental, economic and social. The risk determined in this way has complex

character because by using one measure all the main elements that have an influence for IWRM are included. Factors of risk in IWRM have their base in following fields:

- technical
- economic
- financial
- social
- organizational
- legal
- climatic.

What needs to be emphasized is that the possibilities of risk limitation are connected with state's income level and wealth of society.

How to calculate the risk in IWRM?

The key-terms used in presented method are:

Measure of risk in IWRM – R^i – the measure of possible failure in IWRM formulated by product of measure of pressures and measure of sensitivity;

Measure of pressure – M_p^i – aggregated measure representing pressures coming from economic activity exerting on particular spatial unit calculated on the basis of pressures indicators;

Measure of sensitivity – M_w^i – aggregated measure representing sensitivity for pressures in spatial unit, taking into account physical, environmental, economic and social factors – calculated on the basis of indicators of sensitivity;

Pressure indicators – indicators which characterize pressures coming from economic activity in spatial unit, enabling calculation of the measure of pressures;

Sensitivity indicators – indicators which characterize sensitivity for pressures in spatial unit, enabling calculation of the measure of sensitivity;

Spatial unit – a unit for which we determine risk, as well as, measures of pressures and sensitivity. This unit might be an administrative unit (commune, county) or natural (sub-basin, surface water body);

For spatial unit i we have two measures which are:

M_p^i – measure of pressure in spatial unit i ,

M_w^i – measure of sensitivity in spatial unit i .

According to one of the used formulas, the risk in IWRM in particular spatial unit, which is R^i , may be defined as:

$$R^i = M_p^i \cdot M_w^i \quad (1)$$

Graphic interpretation of risk is presented in the figure 1.

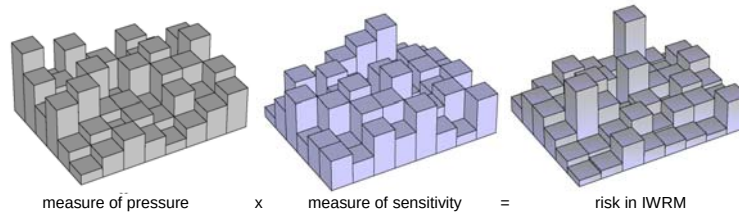


Figure 1. Risk in IWRM

According to the formula the risk in IWRM is small in those units in which:

- pressures coming from economic activity are small
- there are favourable, for small sensitivity on pressures, physical, environmental, economic and social factors.

On the other hand, the risk in IWRM is big in those units, in which pressures are big and there are favourable for big sensitivity physical, environmental, economic and social factors.

Big measure of pressure			Small measure of pressure	
M_p^i	M_p^j	M_p^k	M_p^l	M_p^m
Big measure of sensitivity			Small measure of sensitivity	
M_w^i	M_w^j	M_w^k	M_w^l	M_w^m
Big measure of risk			Small measure of risk	
R^i	R^j	R^k	R^l	R^m

Figure 2. Graphic interpretation of the value of measures

3 THE ESTABLISHED METHOD AND MULTIDIMENSIONAL COMPARATIVE ANALYSIS

As a matter of fact, the problem of risk determination and its localization in some particular area is the problem of spatial information. This is the reason for which in presented method we propose to use Multidimensional Comparative Analysis (MCA). The origin of term MCA may be found in term multidimensional object, which is used in taxonomic methods and in factor analysis. According to Mynarski (1992) this object is a statistical unit called spatial unit determined by the values of variable set. Ordering the units is done on the basis of aggregated variable, which is resultant of particular indicators.

For determination of measures of pressure and sensitivity it is proposed to use taxonomic method enabling for example classification and hierarchization of spatial units which are presented by Grabiński (1984). In order to do so, one should create the matrix of distance, where taxonomic distance is calculated between the points of multidimensional space, according to the rules of analytic geometry. Calculated distances enable to determine the position of each point to the others, which provides the possibility of ordering and classification. In the case of proposed method, the distances are calculated on the basis of model spatial units, independently from pressures and sensitivity. The rules of constructing model spatial units and calculating the distance are presented in the further part of this chapter.

The terms related to classification are: division, ordering, discrimination, grouping, delimitation, and regionalization.

4 DESCRIPTION OF THE METHOD

4.1 Selection of spatial units for risk analysis

Selection of spatial units for risk analysis has to ensure the possibility of comparing them regarding those features, which are the subject of consideration. In this application

we distinguish natural, pseudo-natural and artificial units. As natural units we include real objects which are separated from surroundings, among them following might be distinguished: economic units, morphology units, sub-basins or households. Regarded as pseudo-natural are aggregated natural units such as villages, communes, counties, districts, states etc. Their trait is irregularity and diversification in respect of shape and size. In their case, it is necessary to look at them in relation to basic variables, which are surface and population. As artificial units we include geometrical figures filling studied area – the description of those objects may be done without relativization of traits. For risk analysis in IWRM proper are natural units (possibly pseudo-natural) which are sub-basins or their parts, Surface Water Body (SWB) or possibly administrative units.

4.2 Selection of indicators for determination of measures of pressure and sensitivity in spatial units

After the selection of spatial units for the analysis, it is necessary to define indicators for determination of measures of pressures and sensitivity. The base for their determination are enumerated factors of risk.

In the case of measure of pressure, the possible indicators are divided into following groups:

- public utilities factors;
- industry factors;
- agriculture factors.

Indicators included in the groups mentioned above should be characterized by pressures in spatial units coming from public utilities (water usage, sewage), industry (water usage, sewage including cooling liquids), agriculture (water usage, fertilization, number of cattle). Those are potential sources of problems, requiring proper preparation and support from local structures responsible for water management in spatial units.

Remaining factors: physical, environmental, economic and social, occurring in spatial units, having connection with water management and having influence on condition of management or preparation of local authorities, as well as, local conditions showing the activity of local population in the terms of environmental protection, they all determine the level of sensitivity in spatial unit. This level is defined as the measure of sensitivity.

In the case of measures of sensitivity, the factors for analysis might be divided into following groups:

- indicators of water resources management concerning coordinated process of making decision – they characterize cooperation in the field of water management of local administration in spatial unit and sub-basin administration;
- indicators of water resources management concerning flexibility in process of making decision and implementation of new technologies – they characterize utilization of best practice and technology in water resources management in spatial unit;
- indicators of goals identification in water management – they tell us how legible are goals in water management on local level and if they correspond with local needs;
- indicators of economic and financial aspects – they characterize legibility of financial sources of water management on local level, the assessment of

- implementation of repayment rule for water services in spatial unit, possibility of trainings for specialists;
- indicators of organizational and legal frames – they characterize existence of local strategy in solving problems of water management which consists in phase approach, as well as, existence of proper legal personnel to its implementation;
 - indicators of trainings – they characterize quantitatively existence of training programs in spatial unit and functioning interdisciplinary personnel for IWRM;
 - indicators of information and research – they characterize existence of information systems for water management in spatial unit and its participation in current researches;
 - indicators of monitoring and importance of public sector – they inform about access of local authorities to monitored information and importance of public sector in the process of integrated planning;
 - indicators of natural potential coming from resources and natural conditions in spatial unit – they characterize existence of natural conditions for implementation of IWRM rules in relation to population in spatial unit;
 - indicators of economic potential – they indicate for financial potential of spatial units, initial state of environment, possibilities of financing environment protection investments, wealth of society and its life standard;
 - indicators of education potential – they indicate for possibilities of forming ecological attitudes through existence of proper infrastructure and age structure of spatial unit's population;
 - indicators of land use planning and protected areas - they indicate for rationalization of activities in space management which allows integrated planning of water management in spatial units;
 - indicators of local social organization, activity and representation - they reflect the existence of local structures taking care of environmental protection, having plans and programs and which are potential partners for sub-basin administration in spatial units and also which reflect their representation in front of sub-basin administration;
 - indicators of informatics and communication - they reflect usage of electronic communication channels in spatial units, which facilitates running water policy and information policy connected with it;
 - indicators of structures in water management administration on local level in SWB - they indicate for the state of organizational preparation for implementation of integrated water resources management rules in spatial unit.

4.3 Observation matrixes

As a result, if we have determined set of spatial units Q and defined for its elements pressures and sensitivity indicators we may build two observation matrixes (Table I and Table II).

All indicators in both pressures and sensitivity matrix, which identify analysed set of spatial units, have to be quantitative features, which means that they have to present numerical values. Indicators (their set) should not be neutral and they should be connected with determined initial value (measure). There is an additional requirement, which states that each feature has to be qualified as stimulant or destimulant. Stimulant - is a feature in case of which preferred are bigger values (for example indicators of

economic potential). Destimulant - is a feature in case of which preferred are smaller values (for example indicators of water usage).

Table I. Pressure matrix – Q_p

	Indicator 1		Indicator k
Y_1 (Spacial unit 1)	P_{11}		P_{1k}
.....			
Y_m (Spacial unit m)	P_{m1}		P_{mk}

where: $i = 1, \dots, m$ – numer of units, $j = 1, \dots, k$ – numer of indicators, P_{ij} – value j -of this indicator w i -in this spatial unit.

Table II. Sensitivity matrix – Q_w

	Indicator 1		Indicator n
Y_1 (Spacial unit 1)	W_{11}		W_{1n}
.....			
Y_m (Spacial unit m)	W_{m1}		W_{mn}

where: $i = 1, \dots, m$ – numer of units, $j = 1, \dots, n$ – number of indicators, W_{ij} – value j -of this indicator w i -in this spatial unit.

For most of the indicators so-called “conversive transformation” is possible, which allows to change their character on contrary (changing stimulant into destimulant). Determination of indicators’ character should be based on essential substantial information appropriate for the goal of analysis. It is also possible to consult it with experts. Correctness of determination of particular indicators may be verified by analyzing their correlation with initial measure. It is also possible (but not used in this case) to determine weight of stimulant and destimulant. One of the methods is the expert method (individual or collective), the others are methods based on available statistic-information material. Generally, weights prefer indicators with big variation, which are those with big diagnostic value.

4.4 Standardization of indicators value

Initial scale, in which values of indicators occur in pressures and sensitivity matrix, has to be brought to reduced scale in order to eliminate specific for indicators units and equalization of variables’ values. This process is called standardization of variables. Standardization has to be done for both pressures and sensitivity matrix. As an example, the procedure of standardization is presented for sensitivity matrix Q_w . Standardization of values of features is converting values of features W_{ic} (matrix Q_w) into values X_{ic} . Values X_{ic} are interpreted as coordinates of point images of particular objects Y_i in n -dimensional space of features.

$$X_{ic} = \frac{W_{ic} - W_c}{S_c} \quad (2)$$

$$W_c = \frac{\sum_{i=1}^m W_{ic}}{m} \quad (3)$$

$$S_c = \sqrt{\frac{\sum_{i=1}^m (W_{ic} - W_c)^2}{m}} \quad (4)$$

where: X_{ic} – standard value c - of this indicator in i -in this spatial unit, W_c – arithmetic average c -of this indicator, S_c – standard deviation c -of this variable.

Similar is standardization of elements in pressure matrix Q_p .

4.5 Determination of point image coordinates of pressure and sensitivity model, which are levels of reference

The next step is ordering the set of spatial units according to the values of variables. This procedure should be done for pressures and sensitivity indicators. It is necessary to divide indicators into stimulants and destimulants. This method allows to ” put in order” analysed set of objects Q defined by using set of indicators.

Firstly, it is necessary to determine:

- stimulant and destimulant for pressures indicators;
- stimulant and destimulant for sensitivity indicators.

Ordering is indicated by measure of similarity each of those objects to the model object defined by using the most favourable values of features, which occur in examined set of objects. The model objects (models) in analysis are hypothetical (not existing in reality) spatial units determined by values of indicators representing adequately the lowest pressure and the lowest sensitivity.

Below we present exemplary formulas for sensitivity matrix used for determination of model spatial unit Y_{0w} which will be the level of reference in further analysis.

$$Y_{0w} = \{X_{01}; X_{02}; \dots; X_{0n}\} \quad (5)$$

$$X_{0c} = \begin{cases} \max X_{ic} & \text{for stimulant} \\ \min X_{ic} & \text{for destimulant} \end{cases} \quad (6)$$

4.6 Calculating distance of spatial units from models of pressure and sensitivity

Afterwards, we determine, separately for pressure and sensitivity matrix, distances from model. Below, there are exemplary formulas for sensitivity matrix.

The distances between particular spatial units and Q_0 model are Euclidean distances determined according to the formula:

$$d_{i0} = \sqrt{\sum_{c=1}^n (X_{ic} - X_{0c})^2} \quad (7)$$

Obtained distances both for pressures and sensitivity indicators are the base for determination of pressure and sensitivity measures enabling settlement the risk of failure in IWRM. Distances for indicators of pressures and sensitivities should be brought to the standardized value. Below, exemplary formulas for sensitivity measure

are given, according to Hellwig (1968) and Pluta (1977):

$$d_i^* = \frac{d_{i0}}{d_0} \quad (8)$$

$$d_0 = D_{i0} + 2 \cdot S_0 \quad (9)$$

$$S_0 = \sqrt{\frac{\sum_{i=1}^m (d_{i0} - D_{i0})^2}{m}} \quad (10)$$

$$D_{i0} = \frac{\sum_{i=1}^m d_{i0}}{m} \quad (11)$$

where: d_i^* –standard distance between image i-of this spatial unit and model of sensitivity, S_0 –standard deviation of distance, d_{i0} – Euclidean distance between image i-of this spatial unit and model of sensitivity, D_{i0} – average distance in the set of objects.

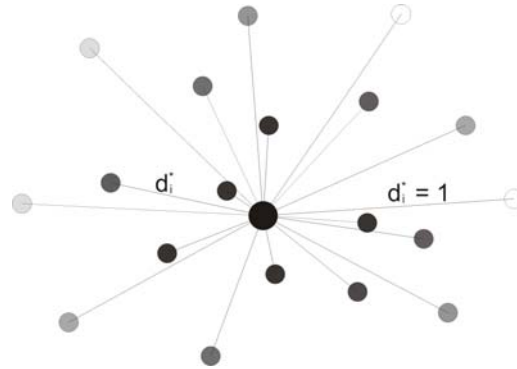


Figure 4. Standard distance between image i – of this spatial unit and the model

4.7 Determination of pressure and sensitivity measures as a similarity between each spatial unit Y_i and models of pressures and sensitivity, which are the level of reference

Values of pressures and sensitivity measures are determined on the basis of distances determined for pressures and sensitivity indicators. Indicator is determined according to the following formulas:

- for pressure measure:

$$M_p^i = e_i^* \quad (12)$$

where: M_{ip} – measure of pressure in i-in this unit, e_i^* –standard distance between image i- of this spatial unit and the model for pressure;

- for sensitivity measure:

$$M_w^i = d_i^* \quad (13)$$

where: M_{iw} – measure of sensitivity i -in this unit, d_i^* –standard distance between image i -of this spatial unit and model for sensitivity.

4.8 Risk determination in IWRM.

As we have pressures and sensitivity measures, it is possible to calculate the risk in IWRM for each analyzed area.

As a consequence, the measure of risk in spatial unit i is define according to earlier given above formula (1).

Figure 5, in next page, presents the summary of used MCA algorithm for risk determination in IWRM.

The application of elaborated method for risk determination was done in Upper Vistula water region – Walczykiewicz (2010). The method was used for risk determination during current status and prognosis for year 2030. In the case of prognosis, the risk was determined exemplary for three hypothetical development scenarios, which were quantitatively characterized on the basis of proper compositions of pressures and sensitivity indicators.

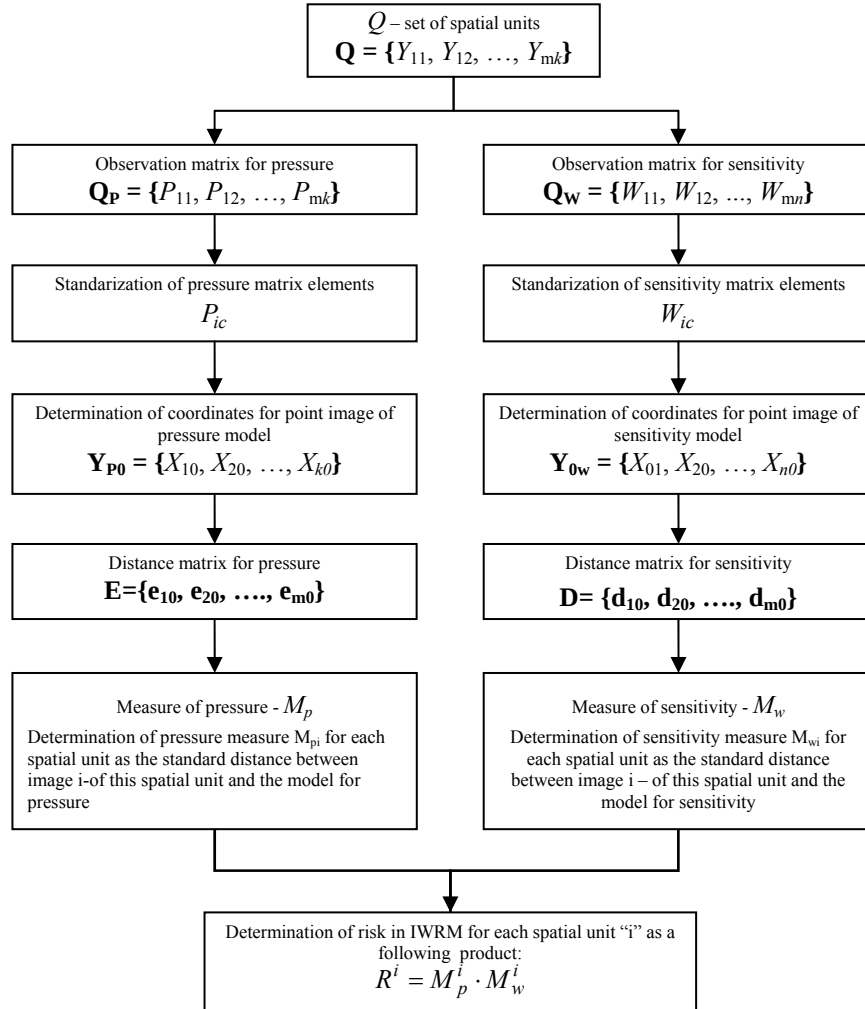


Figure 5. Algorithm MCA for risk determination in IWRM

REFERENCES

- Grabiński T. (1984). *Multidimensional Comparative Analysis in the studies of economic phenomena*, AE in Cracow, special edition: monography, nr 61, Cracow.
- Hellwig Z. (1968). *Usage of taxonomic method for typological division of countries*, Statistical Review, Warsaw.
- Mynarski S. (1992). *Scientific editorial Spatial research on market and consumption*. PWN, Warsaw.
- Pluta W. (1977). *Multidimensional Comparative Analysis in economic research*. National Economic Publishing House, Warsaw.
- Walczykiewicz T. (2010) *Risk in Integrated Water Resources Management*. Institute of Meteorology and Water Management, Warsaw.