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TOWARDS BETTER RISK ESTIMATION FOR THE INTEGRATED WATER RESOURCES MANAGEMENT

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ABSTRACT: The aim of the paper is analysis of risk and uncertainty in water management in order to include them in a rigorous way in the decision making in water management according to the Integrated Water Resources Management (IWRM) principles. Review of scientific literature as well as case studies analysis of the European Union research on risk with regard to IWRM served for the assessment of challenges related to the risk and uncertainty estimation in water management. A novelty in the paper is a comprehensive presentation of risk analysis methods related to IWRM based on the analysis of case studies. The conclusions indicate the gaps in the current practice of risk estimation, presentation and visualization. Thus, in turn could enhance decision making in water management.

KEY WORDS: risk, uncertainty, water management

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Introduction

Risk can be considered when determining the danger or uncertainty of some phenomena. The description of uncertain consequences can be divided into two groups (IMGW, 2005): using the language of probability distributions and referring to other rules that treat these distributions as complementary.

Generally speaking, risk means a measure, an assessment of the hazard or danger resulting either from probable events that are independent of us or the possible consequences of a decision. According to Hubbard (2007) risk is a state of uncertainty, where various possible outcomes are associated with undesirable effects or significant losses. Risk can be also defined as the set of measured uncertainties, where possible results are specific losses. In the mathematical theory of decision, the risk relates to situations in which a particular decision entails certain consequences of the known probability of occurrence of each variant.

The purpose of risk analysis is to determine the likelihood of an adverse event. Risk analysis makes it possible to take appropriate measures to reduce it. There are several types of approach to risk analysis, such as a basic level approach, when standard risk mitigation measures are used, informal approach based on knowledge and experience of experts, detailed risk analysis using risk analysis techniques or mixed approach incorporating elements of the above.

The aim of the paper is to analyze risk and uncertainty in water management in order to include them in a rigorous way in the decision making in water management according to the Integrated Water Resources Management (IWRM) principles.

Risk analysis is used in the preparation of appropriate policies and management systems, including preparation of security policy and safety management systems, project management, business management, different types of business and economic analyses.

Risk management consists of planning, control and monitoring. The concept of risk is used in the analysis of decision situations, for which it is important to determine the results of the actions taken. Evaluation and graphical presentation of risk distribution allow for appropriate allocation of resources for the risk minimization.

In the paper the review of scientific literature as well as case studies analysis of the European Union research on risk with regard to IWRM served for the assessment of challenges related to the risk and uncertainty estimation in water management.

An overview of EU research on risk in water management

Uncertainty and risk are reflected in water management. Uncertainty in water management should be classified as objective uncertainty. Risks in water management are associated with hazard, exposure and vulnerability (European Commission, 2008). The risk is also usually defined through the hazard and the failure. Where the hazard is the probability of occurrence of a particular phenomenon and the failure is the resistance of a particular structure to the analyzed hazard at the assumed level. Particular emphasis has been placed on the need to conduct research on both physical processes in water management, their impact on the ecological functioning of water resources and uncertainty management approaches (European Commission, 2008) as they impact the hazard.

The risk in water management according to Judith Rees (2002) can be classified into two main categories: water supply risk and economic risk. The first category takes into account security of provision of needed quantity and quality of water, what is related with environment pollution and extreme weather and climatic events. The category of economic risk encompasses market related risk, linked to political and legal risk, imperfections in operation, financing losses, etc. Despite the apparent separation of these categories, they are closely related. For example, misrepresenting the law may pose a risk to water supply. In this case, risk management must be based on knowledge of technical conditions and technologies, and both should be taken into account in the decision-making process.

A different classification distinguishes: physical risk associated with water quality and extreme phenomena, such as floods or droughts as well as management risk that takes into account the broader social and economic context.

Particularly, flood risk is understood as a combination of probability of flooding and potential negative consequences for human health, the environment, cultural heritage and economic activity (Directive 2007/60/EC). The Water Framework Directive (Directive 2000/60/EC) introduces the notion of the risk of failing to meet its environmental objectives.

In the NeWater project (New Approaches to Adaptive Water Management under Uncertainty (New Approaches…, 2009)) a concept of water management that also takes into account local conditions and climate change was developed. The project looked for common factors determining the level of preparation for Integrated Water Resources Management in the selected pilot catchments. It was observed that sectoral segmentation with regard to risk management does not adequately inform the analysis in other areas of the economy, leading to ineffectiveness and inadequacy of measures taken to reduce the occurrence of unfavourable events. Therefore the need for implementation of a comprehensive approach in the risk reduction process and in planning in water management was highlighted. The important project contribution was the conceptualization of the Adaptive Integrated Water Resources Management that found its application in the next generation studies on risk (e.g. IIASA and Zurich Insurance, 2015) and led to the development of the risk assessment and mapping guidelines (European Commission, 2010) and the risk assessment framework (IPCC, 2014).

Risk and its allocation are affected by a wide range of operational decisions and practices, which are not always closely and directly related to the threats posed by direct water management (New Approaches…, 2009). These include, inter alia, local environmental, social and economic conditions, legal aspects, fees and funding, and the structure and condition of organizations responsible for water management. So, risk management in water management is a problem that cannot be analyzed and solved in a mere technical way. Planning and management in water management, despite improvements in techniques and tools, is still subject to a high level of uncertainty and risk (Walczykiewicz, 2006). This is primarily due to the complexity of these processes and the need to take into account not only the environmental aspects, but also social and economic issues.

Research methods

The paper presents review of scientific papers on risk and risk management as well as it presents the results of the various studies analysis on the risk estimation approaches in the scope of the European Union research. Based on that the risk and uncertainty in water management are analysed and the results show the risk estimation approach that allows to include them in a rigorous way in the decision making in water management according to the Integrated Water Resources Management (IWRM) principles.

Results of risk studies review

Water resources are in close relation with global change factors, which include climate, spatial development and population with its growing needs. By analyzing the research conducted in this field, studies on risk can be classified into two main groups corresponding to one of the risk classifications:

- studies on physical risks associated with extreme occurrences, such as: floods and droughts, water scarcity and water quality hazards,

- research on the risk of management taking into account the social and economic context.

In the first group of physical risk studies aspects of potential climate change (Wilby et al., 2009) and the need to include them in risk analysis are particularly highlighted. In this case, threats to the water management objectives and variants of climate scenarios are assessed. Particular importance in such studies has the definition of good hydromorphological status of waters, where quantitative aspects are closely related to climate change. Many Member States of the European Union, while implementing the provisions of the Water Framework Directive, simultaneously consider the possibility of revising the previously established reference conditions for surface water. This is primarily due to the deterioration of their quantitative status as a result of climate change and as a consequence of the increased risk of failing to meet the objectives of the Directive. Research is being conducted examining the uncertainties surrounding the relationship between hydromorphological status and the quality of water-dependent ecosystems. The challenges for this kind of analysis include the availability and use of appropriate quality forecasts from different sectors and levels of development as well as integration of the available forecast results due to the different methods of development, different time horizons, various spatial scales of studies and transfer of forecasts for specific catchment areas. An important aspect is the search for solutions that allow for the broadest range of factors to be taken into account in the conducted analyzes. Hence there is a need to build databases that take them into account.

The second group of research studies on management risk in the context of this paper is of particular importance, because now water management goes far beyond technical considerations and includes social and economic development and forecasting in these areas. Studies in this group concern, among others, factors affecting good management, such as: water resources and water-dependent ecosystems, the legal responsibility for allocating resources, technical infrastructure related to existing water infrastructure and effective hazard management (Pegram et al., 2009). Moreover, also good governance is in focus of the social studies, which highlight: predictable, open and transparent water policy, professional and adequate to the public interest activities of the water management services as well as strong social support and participation in the management process.

An example of research on uncertainties and risks in water management provides the Texas Water Development Board. The Texas Plan includes 4,500 local water management strategies to meet water needs in the next 50 years (TWDB, 2008). In connection with the plan, a decision has also been made by the Board to carry out risk research, which should take into account the uncertainties associated with climate change, the financing of tasks, the dynamics of population change and the variability of water needs.

The NeWater project (New Approaches…, 2009) also discussed the issue of uncertainty and risk and it made classification of three types of uncertainty in water management: the unpredictability of certain phenomena, incomplete knowledge and different interpretations of phenomena. In the concept of Adaptive Water Management for each type of uncertainty, specific impact strategies should be proposed. For example, the uncertainty associated with incomplete knowledge should be limited by: establishing confidence thresholds and uncertainty intervals, conducting research that broadens the knowledge of specific problems, using models designed for this purpose, consulting experts, improving communication and cooperation between researchers and decision-makers.

In case of unpredictability of certain phenomena, an important strategy according to the authors of the NeWater project is acceptance of the state of "lack of knowledge and certainty". Consequently, Adaptive Water Management should be defined as a systematic process of improving management by analyzing the effects of implemented water strategies. The IWRM will not be realised without flexible verification conducted on their basis.

Key factors influencing adaptation to climate change should also be taken into account in the risk analysis. They include proper water management, which should be based on, inter alia, broad, well-established knowledge, active public participation, political will and the cooperation of all parties involved in the process.

To sum up, in order to take into account in the risk analysis a broad range of factors, which is necessary to properly inform the IWRM, there is a need to build extensive databases and analyse relevant future scenarios. Risk management in water management in the contemporary world is an issue that can not be analyzed and solved solely in a technical way, in isolation from other factors, including social and economic ones. Therefore, the decision-making approaches and frameworks are being developed to account for that.

Results of risk estimation approaches comparison

The analysis of spatial and temporal risk distributions is important for IWRM. The spatial and temporal cohesion are two basic components that determine risk variability (Simonovic, 2009). Depending on the nature of the analysis, the risk may be expressed by probability, membership function determined according to fuzzy set theory, or other mathematical formulas. The risk determined by the probability is used, inter alia, to assess the functioning of water supply systems. Whereas, the fuzzy sets theory can be utilised for the analysis of a flood wave control with the use of a retention reservoir, when the overlap of main river and tributary flows is considered (Żelaziński, 2000).

In the study of IMGW (IMGW, 2012) the water-economic balance models are used to quantify risk in the IWRM. Mathematical models of water balancing are an attempt to describe in detail the processes associated with the cycle of water circulation in the environment, determine the interrelationships and relationships between them, as well as determine forms of quantification of quantities characteristic for the assessment of the quantitative and qualitative status of water resources. They are tools useful in analyzes related to the assessment of water status, both in real time and in the future perspective, for instance informing the planned activities. For this reason, they can be useful in making decisions regarding the directions of development and activities in water management in a particular catchment. At present, a very large number of mathematical models related to water balancing, with varying degrees of detail (depending on the purpose) are used in the world. They are used both by entities responsible for water resources management and administration in the current statutory work, as well as by scientific units for research purposes.

Following the water-economic balance models the risk can be calculated with the use of the following formula:

$$R = R_H \times R_E \times R_V, \tag{1}$$

where:
R – risk,
R_H – measure of hazard,
R_E – measure of exposure,
R_V – measure of vulnerability, including the coping capacity.

The collection of physical, economic, social and environmental factors increase the vulnerability of certain areas and communities to the threat. The coping capacity, represents the existing resources that can be used in the event of a threat. Such approach to risk quantification is recommended by the European Commission (2010) and has been applied in several studies in Poland such as: MPA44 project, Dumieński et al. (2018).

In the case of floods, the simplified formula for calculating risk can be used as follows:

$$R = P \times S, \tag{2}$$

where:
R – risk expressed in losses per unit time,
P – probability of adverse events,
S – losses.

In the study of IMGW (IMGW, 2012) the following pilot catchments were selected with the adequate, case study related, models assigned.

- In the Orla and Sanna drainage basins that are intensively used for farming the SWAT model was used. It is a catchment model for predicting the impact of changes in the management of the basin on: water balance, degree of erosion, pollution of nitrogen and phosphorus compounds, pesticides, bacteria, and heavy metals. The model is intended mainly for typical agricultural catchments, as it has well-developed elements related to: the growth cycle of the crop and the resulting uptake of water and biogenic compounds, agricultural practices and water management (irrigation and drainage).
- In the Biała Tarnowska basin the co-existence of Natura 2000 areas with areas used for agriculture and industry located in the city of Tarnów was studied. In this case the MIKE BASIN model with the Water Quality and Load Calculator extension was used to simulate water quality. The MIKE BASIN model provides a mathematical representation of the catchment, including the configuration of main rivers and their tributaries, hydrology of the catchment in time and space, and all forms of water use existing in the basin (i.e. water abstraction, sewage discharges, water reservoirs, etc.). The model makes it possible to conduct quantitative and qualitative balance analyzes in the river basin for a period of many years. After defining the required structures and data sets, it simulates system operation based on mass balance.
- In the Wełna catchment with a lot of lakes and ponds the MIKE BASIN and MODSIM models were used. The MODSIM is a comprehensive decision support system for integrated surface and groundwater management, including water quality. Its extension GEO-MODSIM use of the GIS environment to facilitate the construction of a river network and the spatial location of objects included in the balance calculations.
- In the Supraśl case impacts related to the proximity of the city of Białystok and the water transfer from the Siemianówka reservoir were studied with the use of the MIKE BASIN and MODSIM models.
- The Koprzywianka catchment was used for comparative purposes and to test mutual data supply models MIKE SHE, MIKE BASIN–NAM and SWAT. The MIKE SHE is an integrated system modeling of the water cycle in nature, including all soil phases of the hydrological cycle. This model is widely used, among others for analysis, planning and management of water and environmental resources and for supporting solving ecological problems related to surface and underground waters. It is a three-dimensional model that allows simulation of all major processes of the hydrological cycle, including: rainfall, evapotranspiration, processes taking

place on the surface (such as retention and runoff), processes occurring in surface and underground waters as well as spatial processes of groundwater flow. Imposing anthropogenic interactions on the natural cycle (e.g. water intakes, land development, drainage, drainage, pollution sources, etc.) allows for a comprehensive analysis of the water cycle in the environment.

Calculation of risk in the mentioned studies included factors stimulating risk (average rainfall and average landfall in standardized values, share of lakes and reservoirs in the SCWP area [%], share of forests in the SCWP area [%], long-term average flow in the main stream closing the SCWP section [m^3/s]) and factors de-stimulating risk (water use in industry, in agriculture, by households [dam^3/year], share of Natura 2000 sites in the total SCWP area [%], share of arable area in the total SCWP area [%], density of water network [m/ha] under the assumption that the more dense the water network the quicker the outflow from the basin and lower accumulation of underground waters).

Different needs related to risk assessment, different levels of detail and approaches to calculate and visualize risk depend on the available and needed information about risk, e.g. what information is needed, for what purposes, how fast and how frequent it is necessary, etc. For different purposes, e.g. strategic, tactic, operational planning, the different kinds of risk analyses are needed. For example tools, such as MeteoGIS, help to monitor the following meteorological values: precipitation intensity, precipitation sum, precipitation type, temperature, wind speed and direction, and atmospheric discharges, with one kilometer spatial resolution of data and temporal resolution of ten minutes. The users of the system are, for example, government administration employees (Security and Crisis Management Departments). For the development of strategies climate and weather related risks are presented on the maps, e.g. spatial distribution of flood hazard and flood risk is depicted on the maps. Graphs presenting the probability distributions are often used. Also, Average Annual Damage functions are promoted to be calculated and analyzed (KZGW, 2013).

All the mentioned approaches to the risk estimation and the modelling efforts are used to better communicate risk and support the risk management process.

Conclusions

The conducted review of scientific literature as well as case studies analysis of the European Union research on risk with regard to IWRM serves for the assessment of challenges related to the risk and uncertainty estimation in water management. The analysis that have been carried out shows that:

1) Depending on the available data and the purpose of the risk analysis different approaches to risk estimation and presentation are most adequate, so the variety of methods and approaches reflects the complexity of the matter. However, in order to take into account in the risk analysis a broad range of factors, which is necessary to properly inform the IWRM, there is a need to build extensive databases and analyse relevant future scenarios.
2) Risk management in water management in the contemporary world is an issue that can not be analyzed and solved solely in a technical way, in isolation from the socio-economic environment. Therefore, the decision-making approaches and frameworks that will be developed in the future should account for this even more precisely and rigorously then the contemporary ones.
3) The research material on risk in water management is rich, but does not contain specific proposals for risk quantification in water management, including the risk in the IWRM. Decision-makers have the right to expect specific algorithms and methods to take decisions that account for risk and its distribution over time and space.
4) From the point of view of decision makers, it is particularly important to be able to graphically present risks in the form of appropriate maps or graphs. More and more widely used Geographical Information Systems allow for the spatial classification and hierarchy of objects at risk depending on its size.
5) The visualization of risk can be improved through the application of more precise tools fed by the better quality data obtained from established wide monitoring networks and unified system of damage and loss reporting on a country-wide scale.
6) The identified knowledge gaps in risk estimation are related to the uncertainties of modelling, future climate change and socio-economic development.

The future studies need to focus on improved integration of physical and socio-economic factors to better inform decision-making processes in various scales.

The contribution of the authors

Both Authors participated equally in conception, development, literature review, acquisition of data, analysis and interpretation of data.

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