Water management and sustainability of water resources

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ABSTRACT

As a limited resource, especially under market conditions, water should be managed at the highest level of efficiency. This approach, however, leads to a conflict with the sustainability principle. At the basic level it could be defined as a question: ‘Is the market eager to pay the sustainability cost?’ If it is, then the cost of sustainability shall be determined and explicated in the price of water unit delivered to the customer. If not, sustainability is then jeopardized. The solution to this conflict may be a test from a responsible aspect for the current generation towards water resources. This paper aims to research the management of water resources methods from the aspect of sustainability under the conditions of uncompleted and uncertain information. In this paper, the model for water resources availability forecasting is analysed from the aspect of different influences.

Key words | GIS, management, sustainability, uncertainty, water

INTRODUCTION

Water is undoubtedly one of the necessary conditions for living on the planet Earth, as well as for humans. It is also one of the necessary elements for civilization’s development and economic growth. Civilization’s development is based on a supply of enough water for human needs at required levels of quality and quantity. Economic growth is based on the utilization of water as a necessary element of industrial and agricultural processes. Assuming that both civilization’s needs and economic growth will steadily increase, the consequence is that water demand will also steadily increase. Also, it is logical that the utilization of water will steadily reduce its availability, quality and quantity. Also, it is obvious that certain redistribution of flows and disturbance of natural behaviour of water will occur as a result of water management and its utilization to satisfy civilization’s needs and industrial processes.

In general, water is considered a limited resource, especially fresh water. Only a small amount (about 2.5%) of the total water on the Earth is of vital importance for humans, and only a small part of it is renewable (approximately 0.26%) (Gleick 2014). Stocking freshwater and its renewability are the main characteristics of its availability. Stocks of water in natural and artificial reservoirs, although helpful to increase available water resources for human society, are not the solution for water scarcity, and the flow of water should be focused on water resources assessment (Lenzen et al. 2015). In the same paper (Lenzen et al. 2015), the following question was formulated: ‘Can human demand for water be fully met by using only circulating renewable freshwater resources (RFWRs)?’ To answer this question, the authors based their considerations on the circulation rate and natural recycling of water. ‘Even though RFWRs are naturally recycled, the circulation rate is determined by the climate system, and there is an upper limit to the amount of RFWR available to the human society. On the global scale, current withdrawals are well below this limit, and if the water cycle is managed wisely, RFWR can cover human demand far into future.’ Answers and perspectives, quoted above, for human society would be very optimistic if the part saying ‘if the water cycle is managed wisely’ was omitted. The management of the water cycle ‘wisely’ requires a lot of resources, including huge
knowledge and other rare resources as well as careful consideration of different groups’ interests.

Water management is a broad and developing discipline recognized as a necessary tool for the solution of different problems in water utilization. Dealing with the complex issue of water over the past 5–6 decades: ‘water planning and management have become increasingly complex and difficult tasks all over the world’ (Schewe et al. 2014). Complexity and difficulties in water resources planning and management are consequences of increasing and unpredictable demands, scarcity of water resources, the need for their efficient utilization, and difficulties in predicting the behaviour of water resources. Different approaches to water management have been introduced in order to solve the problem of an efficient water supply under conditions of increased demands, water pollution, and water scarcity. To cope with the complexity of water resources, different concepts in water management have been developed from comprehensive, integrated, long-term and cumulative to adaptive (Giordano & Shah 2014). The concept of total water management contains regimens and management of water on a sustainable use basis (Cosgrove & Rijsberman 2014).

Water management is inseparably connected with financial aspects, and it may be said that without financial sustainability any resource, including water, could not be developed or even kept at the required level of quality and availability. Different approaches have been developed (Mirajkar & Patel 2016) in order to determine the price of water, but in this paper a comprehensive structure of costs will only be considered.

Information about water resources under contemporary conditions is considered primarily through information technology, i.e. the geographic information system (GIS) (Stevović & Nestorović 2016), which is deemed to be imperfect, time lagged and incomplete. Utilization of contemporary GIS in water resources is necessary because of the vast amount of information needed for their effective and efficient management.

Knowledge about water resources and their management is based on theoretical and experimental results. Methods and models for decision making and support for water resources management are primarily based on different mathematical optimization methods (Stevovic et al. 2010, 2014, 2015, 2017) and utilization of information technology. Let us only mention a few approaches, such as dynamic simulation (Winz et al. 2014), the hybrid genetic algorithm in water resources planning and management (Singh 2014), the genetic algorithm for least-cost design of water distribution networks, and the discriminant analysis and classification (DAC) method in pipe networks risk analysis under the conditions of survival (Tsitsifli et al. 2011), which only illustrate a small part of the total amount of knowledge in this scientific and practical area. A large number of models and methods for water resources optimization have been developed, but none of them could be treated as an ultimate solution. Variations in conditions of exploitation of water resources, and their scarcity and tendency to provide consumers with water at a certain level of quality at the least possible level of cost need extremely precise knowledge about specific water resources. It shall be noticed here that expert knowledge about water resources is relatively rare and incomplete. Incompleteness is a consequence of the complexity and multidimensional characteristics of water resources. It may be said that experts who possess general knowledge about water resources could not have the same knowledge about specific situations as an operative who works in a certain water resource system and vice versa, an operative burdened with solving concrete problems could hardly master general knowledge.

Consideration of water resources is indivisible from the interests and groups representing them. The relevant literature (Cosgrove & Rijsberman 2014) recognises three groups of people and calls them the ‘environmentalists’, the ‘water managers’ and ‘citizens’. In this consideration, water resources are specific because all members of each group need water for survival. It means that all groups have the same interest, but in practice this is not the case. According to Cosgrove & Rijsberman (2014), all groups are environmentalists at a certain level but ‘environmentalists’ predominately pay attention to environmental issues, ‘water managers’ are focused on concrete problems, and ‘citizens’ are all environmentalists to some extent but they have different views of issues and what to do about them. It is implicitly stated in this approach that different interests in water utilization are present and, if not harmonized, they could lead to the tragedy of the commons, which means that everyone of the mentioned interest groups strives to maximize its own aim while causing significant deterioration of
availability of water resources (Hoekstra 2014). Also, the fact that all discussed groups have imperfect and incomplete knowledge is a consequence of their priorities. The complexity of water systems and water resource management is too high to be understood well by all introduced groups.

Bearing in mind that the population growth from about the year 1400 to the year 1970 has been faster than exponential (Barnett & Morse 2015) and, according to the Population Division of the United Nations, until the year 2050 this growth will almost certainly keep an exponential trend (Coale & Hoover 2015), it suggests that exponential curves could be used in global analysis of water availability. From the year 2050 to the year 2100, two possible extreme scenarios are given:

1. According to the first scenario, the population will be reduced in time to the level of the year 2015.
2. According to the second scenario the population will be more than doubled.

The median is estimated at about 11.5 billion people of world population in the year 2100. Figure 1 shows the population growth prediction.

The financial dimension is an indivisible part of every management, and also of water management. Without finance, any complex and organized activity would hardly be functional, which is also true for water resources management. Assuming that water is a necessary resource for life, it may be stated that it is not as dependent on market trends as other goods. Also, bearing in mind that financial flows under regular conditions are based on the assumption that lives are not jeopardized, it will be considered as a part of the influence of certain interest groups on water resources.

In this paper, a model for the deterioration rate of water resources is researched from the aspects of time and determination of errors of initial values. If the deterioration rate of water resources is considered a constant, the availability of water resources in the future could be predicted. Prediction of availability of water resources could be the base for managerial action in achieving goals. In water resources management, under the condition of their sustainability, the main aim is to keep availability and quality of water resources in the future above the threshold providing development.

METHODOLOGY

The methodology is based on comprehensive consideration of interest groups, the real costs of the produced water unit and expressing it in relation to the efforts necessary to reset the used water to its initial state.

In this paper, the sustainability of water resources will be considered through the negative influence of different groups on the availability of water from the aspects of their assumed interests.

Sustainability of water will be considered through the common definition of sustainability (the economic approach) expressing sustained economic development as a development without compromising the existing resources for future generations (Giacomoni et al. 2013). A strict interpretation of this approach means that resources, after utilization for development, shall be returned to their original state. Because this is impossible, at least due to the energy spent in activities of development processes, this strict approach shall be reformulated in order to recognize the irreversibility of developmental processes. In this case, the main question is: ‘Which rate of resource deterioration is acceptable from the aspect of sustainable development?’ According to the assumption that different groups of people contribute to water resource deterioration in different ways, the following approach was constructed:

- Negative influence on water resource is expressed by power function dependent on time.
- Negative influence of interest groups is additional and has a negative multiplier of time to the exponent.

In this paper, the following interest groups will be considered:

- ‘Observers’ – a group of people, mostly experts, who possess knowledge about complex mechanisms in nature regarding water resources utilization and consequences both at present and in the future.
- ‘Stakeholders’ – or investors who expect a return on invested capital from water utilities.
- ‘Suppliers’ – or a group of people responsible for water systems’ functionality and water delivery to customers.
- ‘Regulators’ – a group of people who establish regulations in water resources.
Customers – all people who use water resources.

Every group is assumed to have a negative influence on water resources from the aspect of their sustainability. The following formula expresses those influences as a function of time:

$$W_a(t) = W_o[1 + (g_{ob} + g_{st} + g_{su} + g_{co} + g_{re})]^t$$ (1)

$$\Sigma = g_{ob} + g_{st} + g_{su} + g_{co} + g_{re}$$ (2)

$$W_a(t) = W_o(1 + \Sigma)^t$$ (3)

where $W_a(t)$ = available water resources in moment of time $t$; $W_o$ = now available water resources; $g_{ob}$ = influence of observers; $g_{st}$ = influence of stakeholders; $g_{su}$ = influence of suppliers; $g_{co}$ = influence of consumers; $g_{re}$ = influence of regulators; $\Sigma$ = sum of negative influences on water resources and $t$ = time in years.

The influence of the observers’ group could be expressed by a lack of knowledge in critical phases of water resources preservation. The influence of stakeholders could be expressed by their striving to maximize the return on investments. The influence of suppliers could be expressed by a lack of knowledge and technology to recycle water resources and reset it to its initial state. The influence of the consumers’ group could be quantified by the increase in its members, i.e. by the increase of the population and aiming to obtain water at a minimum price. The influence of regulators could be expressed by favoured groups (stakeholders or customers), which maximize their interests instead of maximizing the sustainability of water resources. Those influences are denoted in relative units, which in sum give the rate of water resources deterioration.

Total water production could be expressed as the difference of total water influenced by its production and losses as given in the following formula:

$$TWP = TWI - W_L$$ (4)
where $TWP = \text{total water production; } TWI = \text{total amount of water influenced by its production; and } WL = \text{water losses.}$

Total water production is actually total water delivered to the customers generating the financial resources. In the market concept, the financial resources are the basic source for the investment cycle and they are a starting point for investment. The assumption in this paper is that only financial resources generated by delivered water are used for maintaining water sustainability. Total water influenced by water production is the total amount of water that is affected by the process of gaining suitable water for human utilization, including the influences of polluted water. Water losses shall be considered as water that is utilized in the process of water production but not delivered to consumers, for whatever reason. This approach is utilized for its simplicity and sufficiency to explain the main idea of this paper. The cycle of water sustainability maintenance from the economic aspect is given in Figure 2.

Another ingredient of the economic concept of sustainable water management is: all costs that are generated by water production. Total water costs are a sum of all the elements involved in water production given in the following formula:

$$TWC = C_{UC} + C_{UM} + C_{UD} + C_{UKE} + C_{UMNG} + CW + C_{WR} + C_L + C_S + C_I + C_{WReg} + L$$

where $TWC = \text{total water costs; } C_{UC} = \text{costs of the water utility; } C_{UM} = \text{costs of water utility maintenance; } C_{UD} = \text{costs of water utility development; } C_{UMNG} = \text{costs of water utility management; } C_{WR} = \text{costs of water recycling; } C_L = \text{cost of water losses; } C_S = \text{cost of sustainability; } C_I = \text{cost of the influence of conflicting interests; } C_{WReg} = \text{cost of water resources regulation; and } L = \text{losses caused by the impossibility of optimizing other resources because of (in)efficient water utilization.}$

The cost per water unit delivered to the customer could then be expressed as:

$$C_{WUN} = \frac{TWC}{TWP}$$

where $C_{WUN}$ is the cost per water unit. The balance between water production and its costs is obtained when total water production covers the total water costs, i.e. when $C_{WUN} = 1$. In the case of $C_{WUN} > 1$, water deterioration exists because the total water costs exceed total water production and consequently the financial sources for maintaining water resources do not exist. In the case of $C_{WUN} < 1$, the water resources deterioration shall not appear because the total water costs are smaller than the financial sources and shall cover all the activities necessary for sustainable water management. It is assumed in this paper that perfect rationality is performed, which means that water is produced only on the level that meets demands.

Including the marketing principle that the price of the lack of non-elastic resources will grow, it is possible to expect that in the scenario with a growing consumer group and fixed or decreasing renewable fresh water resources the price will grow unpredictably, even in the case of fixed and/or reduced costs per produced water unit.

The GIS of water resources, even though incomplete, time lagged and containing imperfect information, is one of the most stable components of water resources management. Incompleteness of GIS is caused by lack of the information needed for efficient water resources management (especially insufficient information describing the state of all interest groups involved in water resources deterioration). Time lag means that information about water resources could become a part of GIS only after a certain event occurred, when the information about it was properly registered. This is the case even though the information about certain phenomena is collected continually. The imperfectness of information is caused by unavoidable
errors during the processes of their collection. In spite of noted disadvantages, GIS is the most stable component of water system management because it contains information collected and registered by known methodology and, as such, is objective and comparable in time.

RESULTS AND DISCUSSION

According to the proposed approach, management of water resources from the aspect of their sustainability, the only possibility to sustain water resources is to keep the rate of their deterioration at the smallest possible level. This means that the contribution of each interest group to the deterioration of water resources shall be minimized or equated to zero. Another possibility is to make some kind of compensation, i.e. if one negative influence increases, another one, or the rest of them, must be reduced until Equation (2) fulfills the condition:

$$\Sigma = \sum_{i=1}^{n} g_{ib} + g_{st} + g_{su} + g_{co} + g_{re} \leq \varepsilon$$

(7)

where \(\varepsilon\) is the acceptable level of rate of water resources deterioration in order to consider them ‘sustainable’. This leads to thinking about new approaches in water resources management and investigating them, which exceeds the approaches of classical water management resources.

Referring to Equations (1) and (3), it is possible to calculate different scenarios with different negative influences of identified interest groups on water resources. Because of the complexity of the identification of every single influence on water resources, an analysis of the possible total influence will only be made. Figure 3 shows the available water resources as a function of time obtained by Equation (3) on the different rate of water resources deterioration on the base of their availability in the year 2015.

If the total rate of deterioration of water resources is kept at the level of 0.5\% per year in the year 2100, about 65\% of the amount of water resources will be available as in the year 2015. At a deterioration rate of 2\% per year, the available resources will be about 18\% of the amount of water resources available in the year 2015.

The GIS of water resources shall be conceptualized in such a way as to contain information about the contribution of each interest group to the rate of water resources deterioration. If this is not possible, which is much more probable, it shall contain information about the total rate of water resources deterioration denoted by the symbol \(\Sigma\) in Equations (3) and (7). Also, the GIS of water resources shall contain independent information for controlling the parameters in Equation (7). This means that the same results about water availability shall be obtained from different sources of information. Also, the obtained data shall be compared with the data obtained by the model. If a significant difference occurs, then the model shall be reconsidered or adequate investigations of inconsistencies among the collected information shall be provided.

Uncertainties are possible in the years near the base year (in this case the year 2015) because the differences could occur as a consequence of measurement errors or errors in
the estimation of the initial value of water availability. However, uncertainties will be reduced in time, and the model could be tested more reliably. Finding the first derivative of Equation (3), it is possible to estimate an error as a function of the uncertainty of their arguments:

$$\Delta W_a = \Delta W_o (1 + \Sigma)^{-t} + W_o \left[-(1 + \Sigma)^{-t-1}\right] \Delta \Sigma$$

(8)

It follows from Equation (8) that the initial error of water resources availability will be reduced in time, the error of the rate of water resources deterioration will also be reduced in time and consequently the accuracy of assessment of water resource availability will be increased in time. It also means that Equation (3) is not sensitive to errors of $\Sigma$, but is sensitive to time.

Bearing in mind the statement from the literature (Hoekstra & Mekonnen 2012) that total water use per capita is projected to decrease from 640 to 580 m$^3$ year$^{-1}$ between 1985 and 2025, it is possible to calculate the water resources deterioration rate (3) as:

$$580 \text{ m}^3 = 640 \text{ m}^3 (1 + \Sigma)^{-40}$$

(9)

$$\sqrt{\frac{640}{580}} = 1.0025$$

(10)

(11)

(12)

For the period of 40 years, it is possible to estimate that the water resources deterioration rate equals 0.25%. In view of this rate, it may be concluded that water resources are not jeopardized yet and that they could be considered sustainable. However, including the assumption that the growing rate of development will absorb more water resources (i.e. it could be expected that the water resources deterioration rate will increase in time according to the fact that a huge part of the human population is not adequately provided with water resources) and bearing in mind that Equation (3) is sensitive to time, the result (12) is considered a conservative one.

Also, the reduced water resources per capita could increase demands, and the cost of water resources per delivered unit could be expected to increase. In view of the aspect of sustainability, the period of 40 years is too short, but it is long enough for checking the projected decrease of water resources available per capita per year. Since until the year 2100 the trends and water resources deterioration rate would remain the same (in the case that states assessment $W_o = W_o (2015) = 594 \text{ m}^3 \text{ year}^{-1}$ per capita), water resources availability in the amount of approximately $W_o (2100) = 480 \text{ m}^3 \text{ year}^{-1}$ per capita could be expected.

The relationship between cost per water unit and the deterioration rate of water resources may be described by the inverse function. It means that $CWUN < 1$ causes $\Sigma > 0$ and vice versa. Consequently, considering water resources deterioration with time through this fact, it may be concluded that no adequate efforts were made in order to keep water resources at a sustainable level.

CONCLUSIONS

The approach proposed in this paper identifies a sum of negative influences of different interest groups and expresses it through the formula encompassing those interests and expressing them as a rate of water resources deterioration. The formula used shows that the availability of RFWR till the year 2100 as a function of time and different rates of deterioration (varied between 0.5% and 2%) will vary between 18% and 65%. In the case of the water resources deterioration rate obtained in Equation (12), i.e. $(1 + \Sigma) = 1.0025$, water availability will be kept at the level of 81% on the base of the year 2015.

Global water resources management is possible by an inverse process, i.e. by determination of the acceptable level of rate of water resources deterioration and control of the contribution to this rate of each interest group. The characteristic of the exponential function is its low sensitivity to the change of base and high sensitivity to time, especially for long periods of prediction. However, it is also a warning that water availability could be significantly reduced in a short time in the case of a change in the water resources deterioration rate (especially if it rises).
Different interest groups, in the case of a lack of information and knowledge or their incompleteness and imperfections could lead to the ‘tragedy of the commons’ situation even if water resources are in the domain of sustainability. This shall be treated as a risk and challenge for all included interest groups.

Water resources management could be implemented with the goal to keep the water resources deterioration rate at the sustainability level and to keep the model of water resources deterioration, as given by Equation (1). This level of water resources management will not only encompass the market parameters, but also the environmental parameters in the sense of the market and good knowledge about the negative influence of interest groups on water resources (i.e. their contribution to the water resources deterioration rate) as well as the existing mechanisms for keeping them in the domain of water sustainability.

REFERENCES


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