Original scientific papers

UDK 504.4.06:[005.96:330.15
DOI 10.7251/COMEN2201028S

INTERDISCIPLINARY RESEARCH ON RESOURCES MANAGEMENT BASED ON THE SUSTAINABLE PREDICTION METHOD

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Abstract: The subject of this paper is interdisciplinary research on resource management based on a sustainable method for the prediction of the availability of resources. The method is developed and tested in the water resources case study because water is one of the most important substances on the planet. The motivation for this research lies in numerous conflicting interests regarding different resource usage. In the case of water use, conflicting interests are especially highlighted due to a deteriorated environment, deficiency of water, deficiency of data and deficiency of proper methodologies for sustainable solutions. Different researches are done using artificial intelligence applications to analyze various models of water management optimization in conditions of conflicting interests relating to water use. This research aims to interdisciplinary investigate water management methods from the aspect of sustainability, under the condition of incomplete and uncertain information. This paper analyses the model for predicting the availability of water resources from the aspect of different impacts.

Keywords: interdisciplinarity, resources management, water, sustainability, availability, uncertainty, information system.

1. INTRODUCTION AND BACKGROUND

The resources on the earth are limited. The future of all generations depends on our prediction of resource availability, our resources management methods and resource usage. That is why the subject of this paper is interdisciplinary research on resources management. The main focus is on the prediction of the availability of the resources, considering numerous interest groups and different influences in a complex environment.

Water management is one of the most important and one of the most conflicting areas, regarding the prediction of the availability, usage and planning. That is why the proposed method is developed and tested on the prediction of the availability of the water resources management research area. Water as an essential substance on the Earth, within a deteriorated environment, with many conflicting interests and imperative for sustainable use, is a subject of different research. It is undoubtedly one of the necessary conditions for living on the planet Earth including humans. It is also one of the necessary elements for civilization development and economic growth. Civilization development is based on the supply of sufficient water for human needs at the required level 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 the civilization 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 decrease its availability, quality and quantity. Also, certain redistribution of flows and disturbance of natural behavior of water will occur as a result of water management and its utilization to satisfy civilization needs and industrial processes.

Water, especially fresh water, is considered a limited resource. 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%) [1]. 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 [2]. In the same paper [2], the following question was formulated: "Can human water demand be fully met by using only circulating renewable freshwater resources?" To answer this question, the authors based their consideration on circulation rate and natural recycling of water. "Even though renewable freshwater resources (RFWR) 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 the future." Answer and perspectives for human society would be very optimistic if the part saying "if the water cycle is managed wisely" was omitted. "Wise" management of the water cycle requires a lot of resources including huge knowledge and other rare resources as well as careful consideration of different group interests [3].

Water management is a broad and developing discipline recognized as a necessary tool for solving different problems in water utilization. Dealing with the complex issue of water over the past five to six decades: "water planning and management have become increasingly complex and difficult task all over the world" [4]. Complexity and difficulties in water resources planning and management are consequences of increasing and unpredictable demands, scarcity of water resources, need for their efficient utilization, and difficulties in water resources behavior prediction. Different approaches to water management were introduced to solve the problem of efficient water supply under the condition of increased demands, water pollution, and water scarcity. To cope with the complexity of water resources, different concepts of water management have been developed – from comprehensive, integrated, interdisciplinary, long-term and cumulative to adaptive [5]. The concept of total water management contains stewardship and management of water on a sustainable-use basis [6].

Water management is inseparably and interdisciplinary connected with the financial aspect. 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 [7]. Different approaches were developed [8] 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., geographic information system (GIS) [9], which is deemed to be imperfect, time-lagged and incomplete. Utilization of contemporary GIS in water resources is necessary because of a huge amount of information needed for their effective and efficient management.

Knowledge about resources and their management is based on the theoretical and experimental results. Methods and models for decision-making and support resources management are primarily based on different mathematical optimization methods [10] and the utilization of information technology [7, 11, 12]. Let us only mention a few approaches such as dynamic simulation [13], the hybrid genetic algorithm in water resources planning and management [14], the genetic algorithm for the least-cost design of water distribution networks, and discriminant analysis and classification (DAC) method in pipe networks risk analysis under the condition of survival [15], 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 were developed [16-21] but none of them could be treated as an ultimate solution.

Interdisciplinary research is needed. Variations in conditions of exploitation of water resources, their scarcity and the tendency to provide the 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 characteristic of water resources. It may be said that experts who possess general knowledge about water resources could not be familiar with the specific situation as an operative who works in a certain water resource system and *vice versa*, an operative burdened with solving real problems could hardly master general knowledge.

Consideration of water resources must be interdisciplinary [22]. It is indivisible from interests and groups representing them. The relevant literature [23] recognises three groups of people and calls them the "environmentalists", the "water managers" and "citizens". Water resources are distinct in this interdisciplinary consideration 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 [23], all groups are environmentalists at a certain level but "environmentalists" predominantly keep 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 lead to the tragedy of the commons [24]. In addition, 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 great to be understood well by all introduced groups.

Bearing in mind that population growth in the period from approximately 1400 to 1970 was faster than exponential [25] and, according to the Population Division of the United Nations until 2050, this growth will almost certainly keep the exponential trend [26], it suggests that in a global analysis of water availability exponential curves could be used. Two possible extreme scenarios are given for the period from 2050 to 2100:

− According to the first scenario, the population will be reduced in time to the level it was in 2015, and

− According to the second scenario, the population will be more than doubled.

The Median is estimated at 11.5 billion people of the world population in the year 2100. Figure 1 shows the population growth prediction,as per both scenarios. The median is visible.

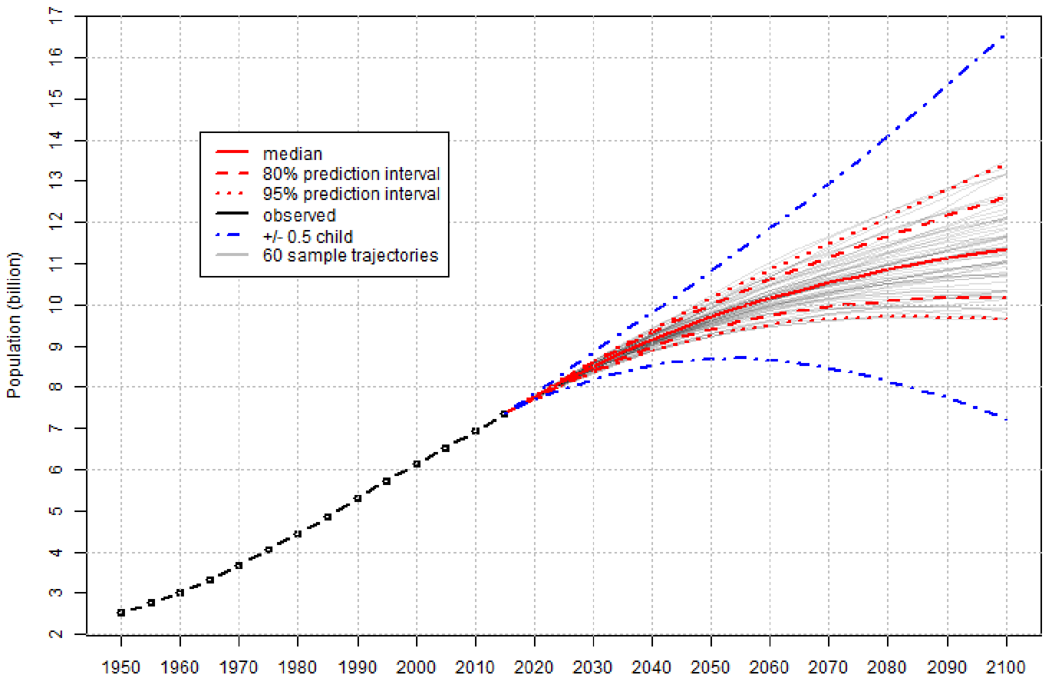

Figure 1. *Total population growth prediction, Source: United Nations Department of Economic and Social Affairs, Population Division (2015), World Population Prospects / The 2015 Revision, http://esa.un.org/unpd/wpp*

The financial dimension is an indivisible part of every management and hence of water management as well. 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 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, this will be considered a part of the influence of certain interest groups on water resources.

As a limited resource, especially under market conditions, water should be managed at the highest level of efficiency. This commercial 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 the water unit delivered to the customer. Otherwise, sustainability is jeopardized. The solution to this conflict may be one of the challenges of responsibility of current generation attestation.

In this paper, the interdisciplinary model for the deterioration rate of water resources is investigated from the aspects of time and errors of initial values determination. If the deterioration rate of water resources is considered a constant, the availability of water resources in future could be predicted. Prediction of the 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 the availability and quality of water resources in future above the threshold providing development.

2. MATERIALS AND METHODS

The methodology is based on comprehensive interdisciplinary consideration of interest groups, real costs of produced water unit and expressing it concerning necessary efforts to reset it in 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.

In this paper, the sustainability of water will be considered through the common definition of sustainability (economic approach) expressing sustained economic development as development without compromising the existing resources for future generations [27]. A strict interpretation of this approach means that resources, after utilization for development, shall be returned to their original state. Since this is impossible, at least due to energy spent in activities of development processes, this strict approach shall be reformulated to recognise 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 the water resource is expressed by power function dependent on time;

− The negative influence of interest groups is additional and it is a negative multiplier of time in the exponent.

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

− "Observers" – a group of people, usually experts, who possess knowledge about complex mechanisms in nature about water resources utilization and consequences both at present and in 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 on water resources and

− "Customers" – all people who use water resources.

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

$$W_a(t) = W_o\left[1 + \begin{pmatrix} g_{ob} + g_{st} \\ + g_{su} + g_{co} + g_{re} \end{pmatrix}\right]^{-t} \quad (1)$$

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

$$W_a(t) = W_o(1 + \Sigma)^{-t} \quad (3)$$

whereby:

− $W_a(t)$ – available water resources in a 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;
− Σ – the 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 turn them back to their initial state.

The influence of the consumers' group could be quantified by an increase of its member, i.e., by the increase in population and aiming to obtain water at a minimum price.

The influence of regulators could be expressed by favor groups (stakeholders or costumers), which maximize their interests instead of maximizing the sustainability of water resources.

Those influences are denoted in relative units, the sum of which gives the rate of water resources deterioration.

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

$$TWP = TWI - W_L \tag{4}$$

− TWP – Total Water Production;
− TWI – Total amount of water influenced by its production and
− W_L- Water losses.

Total water costs are a sum of all elements involved in water production, and are interdisciplinary researched and given in the following formula:

$$TWC = C_{UC} + C_{UM} + C_{UD} + C_{UEK} + C_{UMNG} + C_W + C_{WR} + C_L + C_S + C_I + C_{WReg} + L \tag{5}$$

− TWC- Total Water Costs;
− C_{UC}- costs of water utility;
− C_{UM} - costs of water utility maintenance;
− C_{UD} - costs of water utility development;
− C_{UMNG} – costs of water utility management;
− C_{WR} – costs of water recycling;
− C_L – the cost of water losses;
− C_S – the cost of sustainability and
− C_I – the cost of an interest conflict influence
− C_{WReg} – the cost of water resources regulation and
− L – losses caused by the impossibility to optimize other resources because of (in)efficient water utilization.

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

$$C_{WUN} = \frac{TWC}{TWP} \tag{6}$$

where C_{WUN} is the cost per water unit.

Including the marketing principle that the price of 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 freshwater resources, the price will unpredictably grow even in the case of fixed and/or reduced costs per produced water unit.

The geographic information system (GIS) of water resources, even though incomplete, time-lagged and containing imperfect information, is one of the most stable components of water resources management. The incompleteness of GIS is caused by the lack of information needed for efficient interdisciplinary water resources management (especially 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 a certain phenomenon is collected continually. Imperfectness of information is caused by unavoidable errors during the processes of their collection. Despite 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.

3. RESULTS AND DISCUSSION

According to the proposed interdisciplinary 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 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 of the negative influences increases another one or the rest of them must be reduced till equation (2) fulfils the condition

$$\Sigma = g_{ob} + g_{st} + g_{su} + g_{co} + g_{re} \leq \varepsilon \qquad (7)$$

where ε is the acceptable level of rate of water resources deterioration 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 the formulae (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 identification of every single influence on water resources, an analysis of possible total influence will only be made. Figure 2 shows the available water resources as a function of time obtained by formula (3) on the different rates of water resource deterioration based on their availability in 2015.

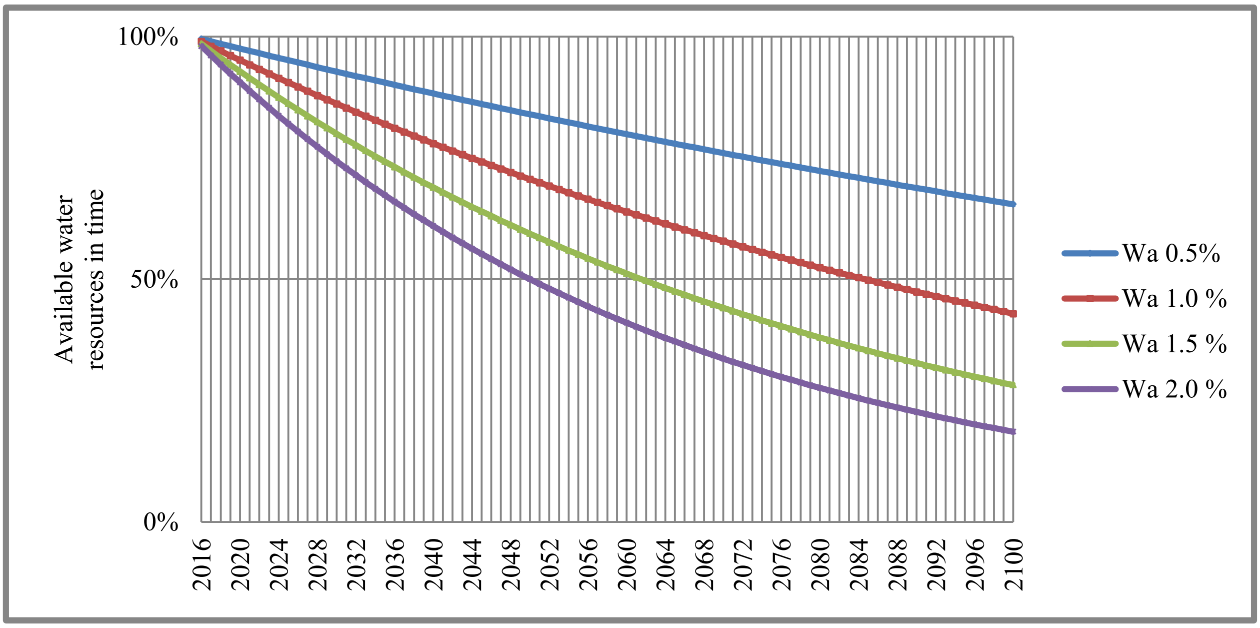

Figure 2. *Available water resources from 2016 to 2100 on the different total rates of their deterioration*

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

GIS of water resources shall be concepttualized in a way to contain information about the contribution of each interest group to the rate of water resource deterioration. If it is not possible, which is much more probable, it shall contain information about the total rate of water resources deterioration denoted by symbol Σ in the formulae (3) and (7). Also, the GIS of water resources shall contain independent information for controlling parameters in the model (7). It 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 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 formula (3), it is possible to estimate an error as a function of the uncertainty of their arguments:

$$\Delta W_a = \Delta W_o(1+\Sigma)^{-t} + W_o[-(1+\Sigma)^{-t-1}]\Delta\Sigma \tag{8}$$

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

Bearing in mind the statement from the literature [28] 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:

$$580\text{m}^3 = 640\text{m}^3(1+\Sigma)^{-40} \tag{9}$$

$$(1+\Sigma)^{40} = \frac{640}{580} \tag{10}$$

$$(1+\Sigma) = \sqrt[40]{\frac{640}{580}} \tag{11}$$

$$(1+\Sigma) = \sqrt[40]{\frac{640}{580}} = 1.0025 \tag{12}$$

For the period of 40 years, it is possible to estimate that the water resources deterioration rate equals 0.25%. Given 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 growth 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 provided with water resources adequately) and bearing in mind that the formula (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. Given the aspect of sustainability, the period of 40 years is too short but long enough for checking the projected decrease of water resources available per capita per year. Given that by 2100 the trends and water resources deterioration rate would remain the same (in case the assessment of the state $W_o = W_a$ (2015) = 594 m^3 year^{-1} per capita), water resources availability in the amount of approximately W_a (2100) = 480 m^3 year^{-1} per capita could be exprected.

4. CONCLUSION

The interdisciplinary 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 renewable freshwater resources by 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 (12) i.e., $(1+\Sigma) = 1.0025$ water availability will be kept at the level of 81% based on the year 2015.

Global water resources management is possible by inverse process, i.e., by determining an acceptable level of rate of water resources deterioration and control of contribution to this rate of each interest group. The characteristic of an exponential function is its low sensitivity to the change of base and high sensitivity to time, especially for a long period of prediction. However, it is also a warning that water availability could be significantly reduced in a short time in case of a change in water resources deterioration rate (especially if it rises).

Different interest groups in case of lack of information and knowledge or their incompleteness and imperfections could lead to the “tragedy of the commons” situation even if water resources are sustainable. This shall be treated as a risk and challenge for all included interest groups.

Water resources management could be implemented to keep the water resources deterioration rate at the sustainability level and to keep the model of water resources deterioration as given by formula (1). This level of water resources management will not only encompass the market parameters but also the environmental parameters in 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.

5. ACKNOWLEDGEMENTS

This research was supported by the Science Fund of the Republic of Serbia, Program DIASPORA, #GRANT No 6458003, AINIOF-SWM, Artificial Intelligence and Nature-Inspired Optimization in the Function of Sustainable Water Management.

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ИНТЕРДИСЦИПЛИНАРНО ИСТРАЖИВАЊЕ УПРАВЉАЊА РЕСУРСИМА БАЗИРАНО НА ОДРЖИВОМ МЕТОДУ ПРЕДВИЂАЊА

Сажетак: Предмет овог рада је интердисциплинарно истраживање базирано на одрживом методу за предвиђање расположивости ресурса. Метод је развијен и тестиран на примеру водних ресурса, јер је вода једна од најважнијих супстанци на планети. Мотивација за ово истраживање лежи у бројним сукобљеним интересима везано за коришћење различитих ресурса. У случају коришћења вода, конфликтни интереси су посебно изражени због нарушене животне средине, у условима недостатка вода, недостатка података и недостатка одговарајућих методологија за проналажење одрживих решења. Различита истраживања су урађена, која примењују вештачку интелигенцију и анализирају разноврсне моделе оптимизације управљања водама, у условима сукоба интереса у вези са употребом вода. Ово истраживање има за циљ да се интердисциплинарно истраже методе управљања водама са аспекта одрживости у оквиру непотпуних и непоузданих информација. У овом раду се анализира модел предвиђања расположивости водних ресурса са аспекта различитих утицаја.

Кључне речи: интердисциплинарност, управљање ресурсима, воде, одрживост, расположивост, непоузданост, информациони системи.

Paper received: 23 December 2021 *Paper accepted: 16 February 2022*