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Research Article

Generalized Net Model of the Water Resources Assessment Process and Water Use Management

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ABSTRACT:

The assessment of water resources and the determination of the water balance is one of the main tasks of water management, and in view of climate change, water security is becoming of increasing concern. To support decision-making, this article presents an original model for assessing water resources and the respective water management process. The model is realized through a generalized net with four transitions and allows to determine the estimates of the individual characteristics by using fuzzy and intuitionist fuzzy values.

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Introduction

Nowadays, climate change is having an increasing impact on the availability and the opportunities for the use of natural resources, especially for the provision of drinking water to the population. The assessment of water resources and their proper distribution is especially important for meeting drinking and household needs, for providing water to industry, agriculture and others. This is one of the main tasks for determining the water balance and for increasing the efficiency of water management. In view of climate change the issue of water security is of increasing importance.[1, 2, 21]

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Water management involves widespread use of information and communication technologies and software applications. They are used for modelling, for processing big data and the related need to ensure reliable protection of information resources. An attractive opportunity is to build on the experience of modelling information systems,[4, 14] creating models in the field of cybersecurity [6, 15, 20] and the communication environment.[5, 18]

To support the process of water management, a common decision-making model for water use management is proposed here. The model is designed on the basis of a Generalized net (GN).

The generalized nets, proposed by K. Atanasov in 1982,[7] are increasingly used to describe complex processes and allow the presentation of individual elements in varying degrees of detail, achieving the modelling of a wide variety of interactions. So far, generalized nets have found application in fields such as: medicine, economics, transport, industry, computer technology and various methods of database creation.[3, 10, 19] A number of models have been developed to analyse the processes of handling large volumes of data and extracting knowledge from them,[8, 9] and represent elements of neural nets [12, 13] and expert systems.[11] There are also some generalized net models that describe the decision-making process for water quality management.[16, 17]

Description of the GN-model

The scheme of the model of the process of water resources management and the needs for water use, realized with a generalized net, is shown in Fig. 1, and the description is as follows:

$$E = \{Z_1, Z_2, Z_3, Z_4\}, \text{ where}$$

Z_1 – assessment of water resources,

Z_2 – water needs assessment (water consumption),

Z_3 – water balance (comparative analysis of the water needs and the available water resources),

Z_4 – water supply management.

The tokens used in generalized net E are:

α – water resources (rivers, dams, wells, springs, etc.);

β – water needs (need of water consumption for drinking and household needs, for industry, for agriculture, etc.);

γ – procedures (regulations);

ι – information related to the requirements for water consumption, water reserves, forecasts, data for water management, etc.;

δ – hidden states of the water system management (possible deviations from the anticipated, unexpected problems, impact of climate change, etc.).

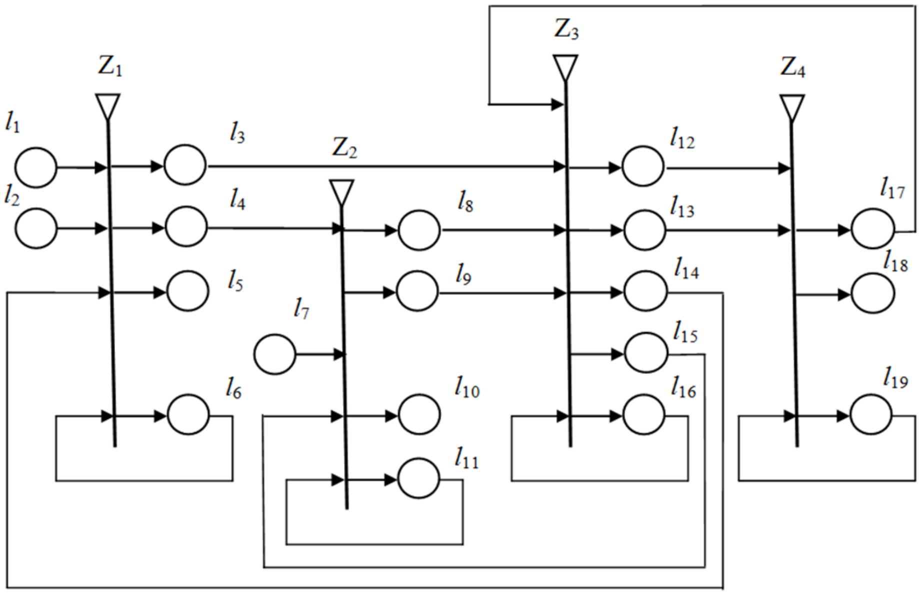

Figure 1. GN-model of the water resources management process and the water consumption needs.

The description of the transitions is as follows:

$$Z_1 = < \{l_1, l_2, l_6, l_{14}\}, \{l_3, l_4, l_5, l_6\}, r_1, M_1, \vee(l_1, l_2, l_6, l_{14}) >,$$

where

l_1 – place in which tokens α enter, characteristics X_α ($e^\alpha_{p,1}$, $e^\alpha_{p,2}$, …, $e^\alpha_{p,i}$, …, $e^\alpha_{p,k}$), where $e^\alpha_{p,i}$ is the evaluation of the i-th parameter from p_i ($i \leq k$) evaluation parameters (quantity and quality of the water, delivery price, etc.);

l_2 – place in which γ and ι tokens enter, with the following characteristics:

- X_γ ($e^\gamma_{w,1}$, $e^\gamma_{w,2}$, …, $e^\gamma_{w,i}$, …, $e^\gamma_{w,n}$), where $e^\gamma_{w,i}$ is the evaluation of the i-th procedure of w_i ($i \leq n$) evaluation parameters (laws, regulations, regulations for water use, water resources management, etc.);

- $X\iota$ ($e^\iota_{v,1}$, $e^\iota_{v,2}$, … $e^\iota_{v,i}$, …, $e^\iota_{v,m}$), where $e^\iota_{v,i}$ may be an evaluation of the usefulness of the information v_i ($i \leq m$) in terms of expertise, heuristics, evaluation criteria, research results, experiments, etc., related to water management;

l_3 – place in which only these tokens α enter that meet the requirements (after evaluation);

l_4 – place in which the tokens γ, ι (with characteristics that refer to the next transitions) and δ – with acquired in the process of analysis values of characteristics X_δ ($e^{\delta}_{r,1}$, $e^{\delta}_{r,2}$, … $e^{\delta}_{r,i}$,…, $e^{\delta}_{r,d}$), where $e^{\delta}_{r,i}$ is an evaluation of the i-th latent state of r_i ($i \leq d$), regarding a given water management situation;

l_5 – place in which the dropping α and β tokens enter (that do not meet the requirements);

l_6 – place in which α, γ and ι tokens enter that are involved in the water resources assessment process;

l_{14} – place in which tokens α enter (with a need for updating or those that do not meet the requirements of the water balance)

r_1 =		l_3	l_4	l_5	l_6
	l_1	F	F	F	T
	l_2	F	$W_{2,4}$	F	$W_{2,6}$
	l_6	$W_{6,3}$	$W_{6,4}$	$W_{6,5}$	$W_{6,6}$
	l_{14}	F	F	F	$W_{14,6}$

T – true (transfer is possible), F – false (transfer is not possible)

$W_{2,4}$ = "there are tokens involved in other transitions" (ι-tokens or γ-tokens)

$W_{2,6}$ = "there is an active token evaluation process α" (the water resources)

$W_{6,3}$ = "there are tokens α that meet the requirements" (after an evaluation is made)

$W_{6,4}$ = "there are tokens γ and ι with updated parameters after the evaluation process"

$W_{6.5} = \neg W_{6.3}$

$W_{6,6}$ = "α -tokens evaluation process in progress"

$W_{14,6}$ = "there are α -tokens that need updating"

M_1 =		l_3	l_4	l_5	l_6
	l_1	0	0	0	N
	l_2	0	$m_{2,4}$	0	$m_{2,6}$
	l_6	$m_{6,3}$	$m_{6,4}$	$m_{6,5}$	$m_{6,6}$
	l_{14}	0	0	0	$m_{14,6}$

N takes values from 0 to the maximum number of tokens that can be evaluated at a time

$m_{2,4} = m_{2,6} = m_{6,3} = m_{6,4} = m_{6,5} = m_{6,6} = m_{14,6}$ – from 0 to the maximum number of tokens for this transition.

$$Z_2 = < \{l_4, l_7, l_{11}, l_{15}\}, \{l_8, l_9, l_{10}, l_{11}\}, r_2, M_2, \vee(l_4, l_7, l_{11}, l_{15}) >, \text{ where}$$

l_7 – place of entry of tokens β, with characteristics X_β ($e^\beta{}_{q1}$, $e^\beta{}_{q,2}$, …, $e^\beta{}_{q,i}$, …, $e^\beta{}_{q,s}$), where $e^\beta{}_{q,i}$ is the evaluation of the i-th parameter by q_i ($i \leq s$) evaluation parameters (which determine the quantities of water, quality, delivery price, the cost of wastewater treatment and other parameters necessary for the respective needs for use);

l_8 – place in which tokens γ, ι and δ enter (after assessments of water resources /transition Z_1/ and water needs /transition Z_2/ have been made);

l_9 – place in which tokens β that meet the requirements enter (after an evaluation is made);

l_{10} – place in which dropping tokens β enter;

l_{11} – place in which the tokens β, γ and ι, involved in the process of water needs assessment, enter;

l_{15} – place in which tokens β enter (with a need for updating or those that do not meet the requirements of the water balance);

$r_2 =$

	l_8	l_9	l_{10}	l_{11}
l_4	$W_{4,8}$	F	F	$W_{4,11}$
l_7	F	F	F	$W_{7,11}$
l_{11}	$W_{11,8}$	$W_{11,9}$	$W_{11,10}$	$W_{11,11}$
l_{15}	F	F	F	$W_{15,11}$

$W_{4,8} = W_{2,4}$

$W_{4,11}$ = "there is an active process of β-tokens evaluation" (water use)

$W_{7,11} = W_{4,11}$

$W_{11,8} = W_{6,4}$

$W_{11,9}$ = "there are β-tokens that meet the requirements" (after an evaluation is made)

$W_{11,10} = \neg W_{11,9}$

$W_{11,11}$ = "β-tokens evaluation process in progress"

$W_{15,11}$ = "there are β-tokens that need updating"

$M_2 =$

	l_8	l_9	l_{10}	l_{11}
l_4	$m_{4,8}$	0	0	$m_{4,11}$
l_7	0	0	0	N
l_{11}	$m_{11,8}$	$m_{11,9}$	$m_{11,10}$	$m_{11,11}$
l_{15}	0	0	0	$m_{15,11}$

$m_{4,8} = m_{4,11} = m_{11,18} = m_{11,9} = m_{11,10} = m_{11,11} = m_{15,11}$ – from 0 to the maximum number of tokens for this transition.

$$Z_3 = < \{l_3, l_8, l_9, l_{16}, l_{17}\}, \{l_{12}, l_{13}, l_{14}, l_{15}, l_{16}\}, r_3, M_3, (\wedge(l_3, l_9) \vee l_8 \vee l_{16} \vee l_{17}) >,$$

where

l_{12} – place occupied by tokens γ, ι and δ (with changed parameters of some of their characteristics as a result of the completed processes in the net);

l_{13} – place occupied by α and β tokens (participating in the determination of the water balance);

l_{16} – place that can be occupied by tokens α, β, γ, ι and δ, participating in the process of determining the water balance;

l_{17} – place in which tokens α, β, γ and ι enter (for which it is necessary to update the parameters in order to regulate the water reserves);

r_3 =

	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}
l_3	F	F	F	F	T
l_8	$W_{8,12}$	F	F	F	$W_{8,16}$
l_9	F	F	F	F	T
l_{16}	$W_{16,12}$	$W_{16,13}$	$W_{16,14}$	$W_{16,15}$	$W_{16,16}$
l_{17}	F	F	F	F	$W_{17,16}$

$W_{8,12} = W_{2,4}$

$W_{8,16}$ = "there is an active process of determining the water balance"

$W_{16,12} = W_{6,4}$

$W_{16,13}$ = "there are tokens α and β that participate in the water balance" (after an evaluation is made)

$W_{16,14}$ = "there are tokens α that cannot participate in the water balance"

$W_{16,15}$ = "there are tokens β that cannot participate in the water balance"

$W_{16,16}$ = "a process of determining the water balance is in progress"

$W_{17,16}$ = "there are tokens entered for updating the parameters in order to regulate the water reserves"

M_3 =

	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}
l_3	0	0	0	0	N
l_8	$m_{8,12}$	0	0	0	$m_{8,16}$
l_9	0	0	0	0	N
l_{16}	$m_{16,12}$	$m_{16,13}$	$m_{16,14}$	$m_{16,15}$	$m_{16,16}$
l_{17}	0	0	0	0	$m_{17,16}$

$m_{8,12} = m_{8,16} = m_{16,12} = m_{16,13} = m_{16,14} = m_{16,15} = m_{16,16} = m_{17,16}$ – from 0 to the maximum number of tokens for this transition.

$$Z_4 = \langle \{l_{12}, l_{13}, l_{19}\}, \{l_{17}, l_{18}, l_{19}\}, r_4, M_4, (l_{12} \vee l_{13} \vee l_{19}) \rangle, \text{ where}$$

l_{18} – final place occupied by tokens α, β, γ and ι for water resources management

l_{19} – place that can be occupied by tokens α, β, γ, ι and δ that are involved in the process of water reserves management

$r_4 =$

	l_{17}	l_{18}	l_{19}
l_{12}	F	F	T
l_{13}	F	F	T
l_{19}	$W_{19,17}$	$W_{19,18}$	$W_{19,19}$

$W_{19,17}$ = "water balance needs to be updated"

$W_{19,18}$ = "water management process completed"

$W_{19,19}$ = "water management process in progress"

$M_4 =$

	l_{17}	l_{18}	l_{19}
l_{12}	0	0	$m_{12,19}$
l_{13}	0	0	$m_{13,19}$
l_{19}	$m_{19,17}$	$m_{19,18}$	$m_{19,19}$

$m_{12,19} = m_{13,19} = m_{19,17} = m_{19,18} = m_{19,19}$ – from 0 to the maximum number of tokens for this transition.

Conclusion

The generalized net model of the water use management process described in the article allows to make assessments not only of water resources and water needs (water consumption), but also to determine and regulate the water balance, as well as to model the water management reserves. For a more accurate work with the model, the evaluations e^{α}_p, e^{β}_q, e^{γ}_w, e^{ι}_v and e^{δ}_r of the characteristics of the tokens and predicates ($W_{i,j}$) can be represented in the generalized net not only by whole values {0,1}, as in the classical case, but also by using fuzzy and intuitionistic fuzzy values, and can take the intervals: [0,1] – for ordinary fuzziness and [0,1] × [0,1] – for intuitionistic fuzziness and uncertainty of both types (fuzziness and randomness). This will allow us to achieve greater precision in the knowledge incorporation, taking into account the degree of hesitation of the expert in setting values of some of the tokens' parameters, for which purely human expressions are used (not determined mathematically), such as "weak," "strong," "good (water supply)," etc.

The GN-model presented here will be applied to simulate different variants of water use distribution (by changing the characteristics and the number of the individual types of tokens that pass through the network transitions), to support decision-making in critical situations (by including certain expert and heuristic knowledge in the characteristics of the tokens), for proper management of the water balance (by taking into account all the basic procedures related to water management, as well as considering the influence of the "hidden factor" caused by the lack of adequate information), etc.

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