Investing in regional water sector development: use of digital technologies in water resources management in Kyrgyzstan

Zhyldyz Dzhylkychieva[1*], *Elnura* Kaparovna[1], *Azyk* Orozonova[1], *Nurlan* Baisalov[1], *Dinara* Cherikova[1], and *Asel* Sultanalieva[1]

[1]Kyrgyz National University named after Jusup Balasagyn, Bishkek, Kyrgyztan

Abstract. The urgent problem of the Kyrgyz Republic is water resources management. Water is used as a source of drinking water to meet the needs of agriculture, energy, industry, tourism, and residential utilities. To effectively control water consumption, regulate the cost of service provision, and develop projects to modernize the water consumption system, it is necessary to use modern digital technologies that process a large amount of data and can make recommended management decisions based on the results obtained. For this purpose, using the methods of structural analysis, synthesis, groupings, step-by-step refinement, and modeling, digital models of the water consumption system were developed using the example of a settlement in Kyrgyzstan.

1 Introduction

The total annual volume of renewable water resources in Kyrgyzstan is estimated at 46.5 km^3, and 39 reservoirs are in operation, with a total volume of 22,978 km^3 [1]. The country is considered to be endowed with significant water resources [2]. At the same time, industrial and domestic water consumption increases every year, hydraulic structures wear out, and climatic conditions change – all this leads to the problem of water resources deficit [3].

To maintain a balance between the consumption and reproduction of water resources, effective management tools are required to provide the population with potable water resources and their allocation between the sectors of agriculture, energy, industry, tourism, and housing utilities.

Information systems are actively used, based in most cases on artificial intelligence [4-6], to improve management efficiency, regardless of economic, industrial, and household activities. The operation of such systems is based on the analysis of big data, simulation models reflecting all key aspects of changing states of the problem domain, allowing interpretation of data obtained in real-time, predicting events with a certain accuracy, controlling objects and processes, etc. [5, 7, 8].

* Corresponding author: ts1179@mail.ru

Based on this, *the study aims* to develop a water resource management model. This requires performing tasks to *establish* the key entities of the problem domain and the processes between them, establish rules for their implementation, and create a simulation model.

The object of the study is the water supply system of settlements. *The subject of the study* is the process of organizing effective water resources management.

The study's theoretical significance lies in the systematization and formalization of objects and processes of the water management system under the organization of water consumption. *The study's practical significance* lies in creating a tool for real-time water resources management to ensure sustainable development of the territories of human settlements.

2 Materials and methods

The study used well-known methods that allow us to obtain a formal description of the object and subject of the study. Such methods include structural analysis, synthesis, stepwise refinement, and groupings. With their help, all quantitative and qualitative characteristics of the key elements of the object and subject of study are established, the processes arising between them are studied, and the factors of external influence that change the general state of the system under study. In studies related to the study processes of household, economic, and industrial activities, the results of the above methods are used to create digital twins or models of objects, which in virtual space simulate the processes of real systems at a given time interval [5, 9, 10].

Information, parametric, and agent-based modeling methods were used to create a digital twin simulating the processes of water resources management supplied to different consumers within a settlement. With their help, the results obtained in the research phase of the problem domain are transformed according to generally accepted modeling methodologies. This approach of using the stated methods is in line with the research conducted by other scientists in the field of ecology [11], agriculture [5, 8, 10], and sustainable economic development of territories [8, 12, 13].

3 Results

According to official data (Rossiyskaya Gazeta: https://rg.ru/2020/08/06/kakimi-zapasami-vody-obladaet-kirgiziia.html), there are 117 deposits of fresh groundwater and 39 deposits of mineral-thermal groundwater in Kyrgyzstan, and about 800 million m^3 of water is withdrawn annually from 15,000 wells (mainly for agriculture, 3.5% of which is used for drinking water supply to the population and 1.5% to meet the needs of industry). According to the State Inspectorate for Environmental and Technical Safety of the Kyrgyz Republic (Rossiyskaya Gazeta: https://rg.ru/2020/08/06/kakimi-zapasami-vody-obladaet-kirgiziia.html), there are 145 operating domestic and industrial wastewater treatment facilities in the region, which are mainly discharged into the environment (e.g., rivers and water bodies).

The water management system should include all water-consuming facilities. For example, we will show fragments of the practical results for a small settlement in which water consumers are private households engaged in private subsidiary farming and gardening.

The use of structural analysis, synthesis, groupings, stepwise refinement, and groupings allowed us to obtain a detailed description of the settlement's territory. Figure 1 presents a formal model of such a site, obtained using methods that formalize the results of studying the problem domain.

Fig. 1. Fragment of a digital model of a settlement showing water consumption facilities.

Figure 1 shows the boundaries of the settlement, and the gray rectangles mark the households that are water consumers, and the blue rectangles mark the pumping station that regulates the water head in the water supply network. Figure 2 shows a fragment of the agent model demonstrating the connectivity of water consumers (*fluidDispose*) to a common water supply system and pumping station (*fluidSource*).

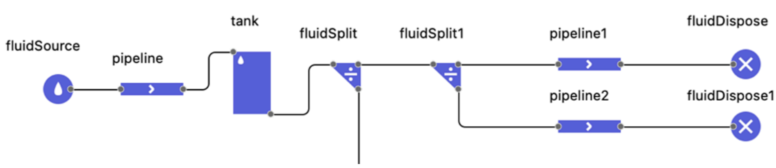

Fig. 2. Fragment of the agent-based model of water consumption by the objects of the investigated settlement.

The model considers the load and capacity of the common pipe bringing water to the household (*pipeline*) and distribution nodes (*fluidSplit*). Figure 3 shows the load on each system element under a standard water consumption scenario.

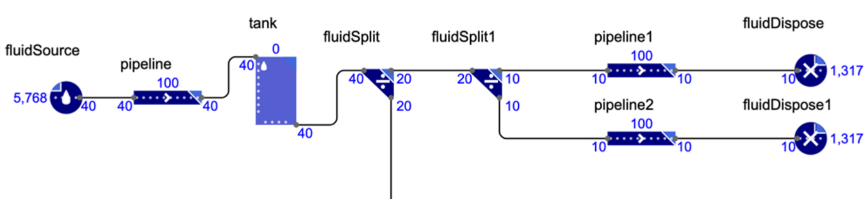

Fig. 3. Fragment of the model showing the load on the plumbing system.

To visualize the model and demonstrate the results of water consumption management scenarios, a 3D model visualization was developed, a fragment of which is shown in Figure 4.

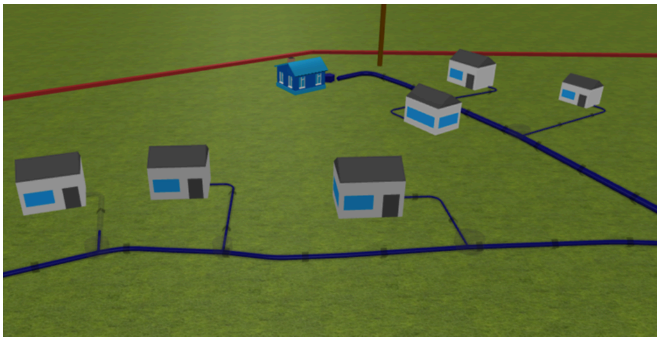

Fig. 4. Fragment of a 3D simulation model of water consumption by the objects of a settlement.

3D visualization is simplified (graphic primitives of buildings are used, road infrastructure objects are absent, etc.) to increase computational power and speed of calculations.

4 Discussion

Analysis of the obtained results (adequacy and validity of the model) showed that they reflect qualitative and quantitative characteristics of the problem domain corresponding to water resources management processes. Changes in such characteristics allow the formation of scenarios for potential changes in both the internal state of the system (e.g., changes in the number of water users, system deterioration, emergencies) and the external state (e.g., changes in climatic conditions, water source conditions, economic conditions affecting the operation and maintenance of the system). This allows you to develop methods of system maintenance and different types of work, to plan the resources required for the corresponding type of work, etc. The nature of the results and their further application correspond to those obtained in studies related to modeling complex systems and processes associated with economic and industrial human activities [4-6, 10, 11].

It should be noted that the developed simulation model can be used to train specialists engaged in state and municipal management, ecology, and logistics. Studies related to developing and implementing digital technologies in the educational process have shown positive results of using simulators based on digital models of real objects or processes of the problem domain [14-16].

5 Conclusion

In implementing projects related to water resources management in Kyrgyzstan, water supply system facilities were designed and constructed without considering the opinions of local self-government bodies, consumers, and local service providers. Some design solutions were applied without appropriate technical studies and justifications, resulting in lower quality of services, higher project costs, and complexity of management of such systems.

Creating a digital water management system allows systematizing the interaction processes between all market participants, making them transparent and accessible for designing and implementing development projects in different sectors of the state's economy.

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