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INTEGRATED WATER RESOURCES MANAGEMENT OF THE YERTIS RIVER BASED ON GEOINFORMATION TECHNOLOGIES

This article examines the current state of the Yertis River and the water crisis in Kazakhstan. The main causes of the water crisis are the lack of clear management of water resources, inconsistency in the actions of stakeholders and insufficient funding. Integration of geoinformation technologies is necessary to provide an information and analytical component in water resources management. One of the significant geographic information systems (GIS) in water resources management is the WEAP (Water Evaluation and Planning) system. This article discusses examples of using the WEAP system in foreign countries and analyzes the possibilities of its applicability to the Yertis River. The WEAP system can be used to assess the impact of climate change on river runoff and anthropogenic activities on the Yertis River. Also, this system has functionality for planning the integrated use of river water resources and compiling analytical scenarios on the development of river flow. One of the key results of the article was the successful application of the WEAP platform for modeling the current and future development of the Ertis River flow by creating two scenarios. The analysis of independent scenarios, "Population growth" and "Increase in irrigated areas by 2030", revealed a significant impact of demographic and agricultural changes on water consumption in the Yertis River basin, which underlines the need for effective and rational water resources management.

Key words: hydrology, water resources, integrated water resources management, GIS, water crisis, climate change, water use.

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Геоақпараттық технологиялар негізінде Ертіс өзенінің су ресурстарын интеграциялы басқару

Мақалада Ертіс өзенінің жағдайы мен Қазақстандағы су дағдарысы қарастырылған. Су ресурстарын нақты қолданудың жоқтығы, мүдделі тараптардың іс-әрекеттерінің келісімге келмеуі және жеткіліксіз қаржыландыру дағдарыстың негізгі себептері болып табылады. Су ресурстарын басқаруда ақпаратты-аналитикалық құрамдас бөлікпен қамтамасыз ету үшін геоақпараттық технологияларды біріктіру қажет. Су ресурстарын басқаруда маңызды геоақпараттық технологиялардың бірі WEAP (Water Evaluation and Planning) болып табылады. Шет елдерде WEAP жүйесін қолдану мысалдары қарастырылды және бұл жүйе Ертіс өзеніне қолдануға болады деген қорытынды жасалды. WEAP платформасы Ертіс өзенінің ағындысына климаттың өзгеру және антропогендік әсерін бағалау үшін және өзеннің су ресурстарын кешенді пайдалану мақсатында қолданылуы мүмкін. Зерттеудің негізгі нәтижелерінің бірі Weap платформасын екі сценарий жасау арқылы Ертіс өзенінің ағынының ағымдағы және перспективалық дамуын модельдеу үшін сәтті қолдану болды. Бір-біріне тәуелсіз әзірленген «Халықтың өсуі» және «2030 жылға қарай суармалы алқаптардың ұлғаюы» сценарийлерін талдау демографиялық және ауылшаруашылық өзгерістерінің Ертіс өзенінің бассейніндегі суды тұтынуға айтарлықтай әсерін көрсетті, бұл суды ұтымды басқарудың маңыздылығын көрсетеді.

Түйін сөздер: гидрология, су ресурстары, интеграцияланған суды басқару, ГАЖ, су дағдарысы, климаттың өзгеруі, суды пайдалану.

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Интегрированное управление водными ресурсами реки Ертис на основе геоинформационных технологий

В статье рассматривается текущее состояние реки Ертис в условиях водного кризиса в Казахстане. Основными причинами данного кризиса являются недостаточное планирование и неэффективное управление водными ресурсами, а также несогласованность действий заинтересованных сторон. Внедрение геоинформационных технологий в систему управления водными ресурсами необходимо для обеспечения эффективного информационно-аналитического сопровождения. Особое внимание в статье уделяется применению платформы WEAP (Water Evaluation and Planning) как инструмента географических информационных систем (ГИС) в зарубежных странах и анализируются перспективы ее адаптации к условиям реки Ертис. Данная система позволяет оценивать влияние климатических изменений и антропогенной деятельности на речной сток, а также обладает функционалом для планирования комплексного использования водных ресурсов и моделирования различных сценариев их развития. Одним из ключевых результатов статьи выступает успешное применение платформы WEAP в моделировании текущего и будущего развития стока реки Ертис при помощи создания двух сценариев. Анализ сценариев «Рост населения» и «Увеличение орошаемых площадей к 2030 году», разработанных независимо друг от друга, выявил значительное влияние демографических и сельскохозяйственных изменений на водопотребление в бассейне реки Ертис, что подчеркивает необходимость рационального управления водными ресурсами.

Ключевые слова: гидрология, водные ресурсы, интегрированное управление водными ресурсами, ГИС, водный кризис, изменение климата, водопользование.

Introduction

The Yertis River is the largest river in Kazakhstan (Fedorov 2008). This river has a crucial significance in regional hydrological system and environmental spheres of life of the local population. In turn, anthropogenic activity also has considerable effect in the state of Yertis River, leading to pollution and depletion of river flow (Chistyakova, Kochurov and Ovchinnikova 2022). Climate change already have a significant impact on river flow in the world. In Kazakhstan, climate change also leads to a decrease in river flow. In particular, the decrease in runoff along the Yertis River began in 1996 and from 2006 to 2012. The runoff continued to decrease by an average of 3,12 km^3/year on the border with China because of water abstraction on its territory (Shivareva et al. 2014). The Yertis River uses water for various purposes, including irrigation, water supply and energy.

Integrated water resources Management (IWRM) of the Yertis River is an integral element of modern water management, which considers the interests of water users and the ecological state of the water body. Balanced management of the water fund is the main component in fully promoting balanced progress in the economic and environmental components of the region. Today, one of the most pressing problems in Kazakhstan is the water crisis caused by the lack of balanced water resources management and inconsistency of actions between stakeholders. The insufficient level of financial support from the State also has a significant impact on the deterioration of the situation. In this regard, there is a need to develop and implement new innovative methods to solve water problems both in Kazakhstan and at the global level. In this research we considered the possibility of using geoinformation technologies in IWRM on the Yertis River and analyzed the use of such technologies in foreign research.

Materials and methods

During the study, we conducted an extensive analysis of relevant literature sources. This analysis included research of scientific publications, statistical data, reports and expert opinions about the application of the WEAP system in IWRM of Kazakhstan. This study also included an analysis of the experience of foreign researchers in the application of this system. This approach has provided us with the opportunity to identify advanced techniques and approaches applicable to the context of Kazakhstan.

One of the applied research methods is the case study method. It was used to study in detail specific situations where the WEAP system was used to solve water management problems, both in foreign countries and in Kazakhstan. This research methodology allowed us to identify effective practices and methods of applying the system under study that can be adapted to the local conditions of our country.

The comparative analysis provided an opportunity to conduct a detailed comparison of the international experience of using the WEAP system with the features and specific needs of water management in Kazakhstan. This made it possible to identify the most promising areas for further development and adaptation of this system in accordance with local conditions.

In this study was used the regional research for assessment of the impact of local factors and conditions on the effective application of the WEAP system in IWRM on Kazakhstan. With this approach, the features of the climate of the studied territory, geographical and economic factors were revealed. The identified features will be useful for making recommendations and strategies for the development of water resources in the region.

The inconsistency of the actions of water users leads to significant losses and difficulties in managing the studied area. There is a low level of interaction between stakeholders in coordinating the use of water resources. Now there are restrictions on public and scientific figures' access to information. In the current legislation, non-working mechanisms for managing the water sector are also observed. The combination of these problems creates a cumulative effect, increasing the negative consequences in IWRM, which can be described as a snowball effect.

The underdevelopment of modern water management tools leads to inefficient use of water and pollution of water bodies. The level of public participation in management decisions remains low. In the water sector, not only ecosystem constraints are ignored, but also economic and environmental requirements are not considered, which leads to crisis situations in the river basins of Kazakhstan (National Plan for Integrated Water Resources Management and Improvement of Water Use Efficiency of the Republic of Kazakhstan for 2009-2025 2009).

Data on average annual water consumption from 1942 to 2021 were collected using the time series analysis method. We processed data from the "Annual data on the regime and resources of land surface waters" using a Hydrological Database, which allowed us to systematize and analyze information on the hydrological post on the Yertis River at the Ustkamenogorskaya HPP (Gidrologicheskaja baza dannyh 2021). The methodology included data standardization, checking for omissions and anomalies, as well as the use of statistical methods to identify long-term trends in water consumption.

The cumulative integral curve provides insight into the dynamics of river discharge over time, allowing for the identification of periods of flow increase or decrease. Additionally, the differential integral curve helps assess the impact of human activities on river flow by comparing it with data from literature sources and actual measurements. The construction of such a curve relies on the following two formulas:

$$CQS_i = \sum \frac{K_i - 1}{C_v}, \tag{1}$$

$$K_i = \frac{E_i}{E_m}, \tag{2}$$

where:

C_v – coefficient of variation,

E_i – the value of the element in the i-th year,

E_m – the long-term mean value of the element,

K_i – modular coefficient of the element,

CQS_i – values of the accumulated sum of standardized element values.

Based on the formula, the differential integral curve represents the cumulative sum of deviations from the runoff norm and the studied hydrological characteristic over a given period. To facilitate comparison and analysis of long-term variations, these deviations are normalized using the coefficient of variation (Andreyanov 1959).

An essential tool for tracking changes in the water regime is the autocorrelation function, which reflects the relationship between the values of a time series and its adjacent elements with a one-step shift. This shift is referred to as the lag (L). When constructing the autocorrelation function, lags ranging from 1 to 15 are typically used.

If expressed in numerical form, the autocorrelation function represents a sequence of correlation coefficients between the original time series and its shifted copy at a given lag. The autocorrelation coefficient is calculated using formula (3):

$$r(1) = \frac{\sum_{i=1}^{n-1}(Q_i - \bar{Q}_1)\cdot(Q_{i+1} - \bar{Q}_2)}{\sqrt{\sum_{i=1}^{n}(Q_i - \bar{Q}_1)^2 \cdot \sum_{i=1}^{n-1}(Q_{i+1} - \bar{Q}_2)^2}}; \quad (3)$$

where:

$$\bar{Q}_1 = \frac{\sum_{i=1}^{n-1} Q_i}{n-1} \text{ и } \bar{Q}_2 = \frac{\sum_{i=2}^{n} Q_i}{n-1}.$$

For shifts with a larger lag L, a similar formula is used, where the term n-1 is replaced with the corresponding value. The formula is expressed as follows:

$$r(1) = \frac{\sum_{i=1}^{n-L}(Q_i - \bar{Q}_1)\cdot(Q_{i+L} - \bar{Q}_2)}{\sqrt{\sum_{i=1}^{n}(Q_i - \bar{Q}_1)^2 \cdot \sum_{i=1}^{n-L}(Q_{i+L} - \bar{Q}_2)^2}}; \quad (4)$$

where:

L – the specified lag value.

The autocorrelation function helps identify seasonality and fluctuations in river discharge, as well as trends and patterns within the analyzed data. Additionally, it reveals hidden periodicity in runoff variations, as significant deviations in the autocorrelation coefficient indicate the presence of a recurring cycle.

When the distribution asymmetry is positive, rhythmic fluctuations do not follow a sinusoidal pattern. Instead, the data exhibit numerous minor negative deviations, punctuated by occasional but substantial positive anomalies.

Modeling of the Yertis River basin using the WEAP software package was used to conduct the study. The model was developed considering key input data reflecting the socio-economic and hydrological characteristics of the river basin in Kazakhstan. Based on these data, two scenarios of water use and development of the Ertis River water flow for the period from 2023 to 2030 were created. 2022 has been adopted as the base year for the analysis.

The primary input data encompassed the population figures for three major cities within the basin – Semey, Ust-Kamenogorsk, and Pavlodar. As of 2022, the population of these cities was 328 782, 372 694, and 367 254, respectively (Bureau of National statistics n.d.)

Population growth forecasts based on an average annual increase in the population of Kazakhstan of 1,3%, as well as in a high-growth scenario involving an increase of 5% annually, were used for modeling. Additionally, the areas of irrigated agriculture in the Pavlodar (166 900 ha) and East Kazakhstan regions (195 900 ha) (Bureau of National statistics n.d.) were considered, as well as the average monthly water consumption of the Yertis River at a hydropost located on the border with the People's Republic of China, at the point of transition of the river from China to Kazakhstan.

To determine irrigation water demand, it is first necessary to establish the specific water consumption rates for cultivated crops and identify the natural zones within the Pavlodar region. Irrigation norms are calculated based on three runoff probability scenarios:

1) Normal year – 50% probability,
2) Moderately dry year – 75% probability,
3) Dry year – 95% probability.

To assess the probability of runoff availability for the reference year (2022), the method of moments was applied to construct a theoretical probability curve. The empirical runoff probability is calculated using the following formula:

$$P_m = \frac{m}{(n+1)} \cdot 100\%; \quad (5)$$

where:

m – the rank of a hydrological characteristic value in descending order;

n – the total number of values in the dataset.

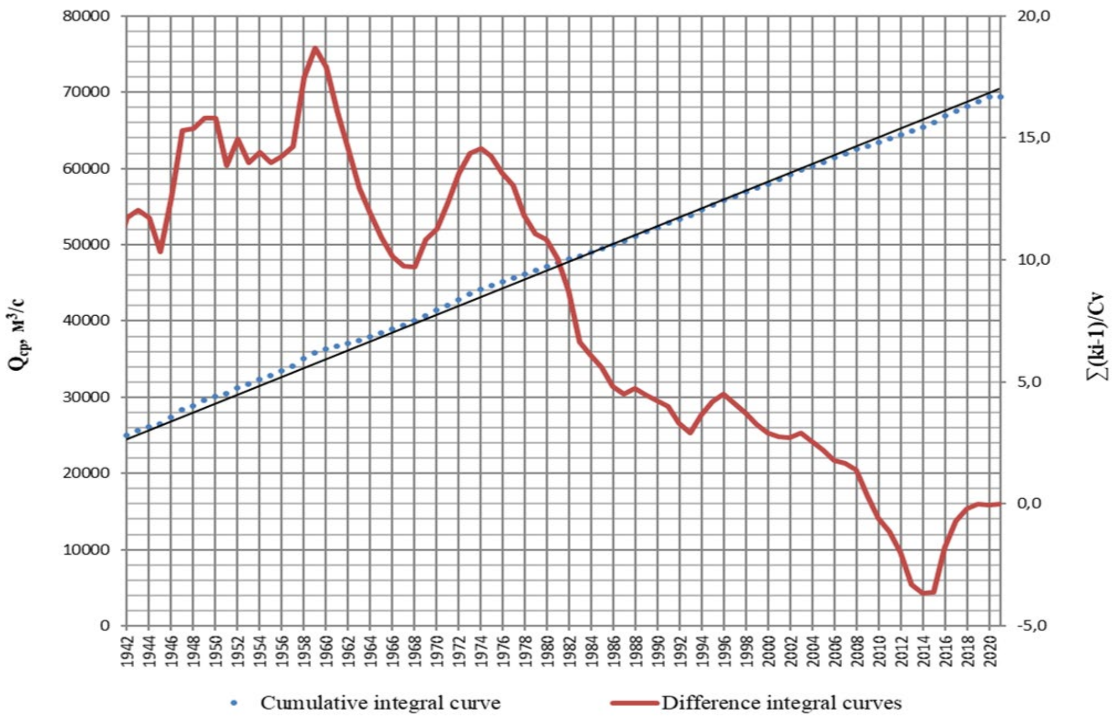
The development of analytical distribution curves and the estimation of their statistical parameters are based on the analysis of historical data of the studied hydrological characteristic. The calculation of statistical parameters of the theoretical exceedance curve is carried out in accordance with the requirements of the Interstate Set of Rules (Opredelenie osnovnyh raschetnyh gidrologicheskih harakteristik 2005). To determine the percentage of water availability for the calculation year, monthly discharge data of the Ertis River at the hydrological post near the village of Zhanabet from 1982 to 2022 were analyzed (Gidrologicheskaja baza dannyh 2021). Assessing the volume of return flows resulting from irrigation withdrawals required an estimation of the amount of return water. According to the annexes provided in the officially approved Methodology for Developing Specific Water Consumption and Disposal Standards in Kazakhstan, the return flow coefficient for irrigated fields under regular surface irrigation ranges from 0.12 to 0.15 (Ob utverzhdenii Metodiki po razrabotke udel'nyh norm vodopotrebleniya i vodootvedeniya n.d.).

Special attention in the modeling was paid to the forecast of water demand for irrigated agriculture. A gradual increase in the area of irrigated land to 300 000 hectares by 2030 has been investigated. To assess the need for water, the method of moments was used, which made it possible to calculate the availability of water resources. The study also compared the effectiveness of various irrigation technologies, including surface irrigation and drip irrigation, in order to assess their impact on water use in the long term.

Results and discussion

We have constructed the cumulative and difference integral curves of the water consumption of the Yertis River at the Ust-Kamenogorsk hydroelectric power plant (HPP). These curves were based on archival data from Kazhydromet Republican State Enterprise (RSE) and encompass cumulative and difference variations in flow deviation from the norm during the period from 1942 to 2021 (Gidrologicheskaja baza dannyh 2021). The analysis of the time series showed no missing data or anomalies, ensuring the reliability and consistency of the dataset. Graph 1 shows these curves.

According to Graph 1, the analysis of water flow curves of the Yertis River at the Ust-Kamenogorsk HPP for the period from 1942 to 2021 demonstrates a negative trend in deviations of the modulus coefficient. Changes in the deviation pattern are observed from 1966 to 1974, showing a tendency to increase. Since 1974, deviations from the mean flow value have mainly been negative. After 2014, deviations from the mean flow value show a tendency to increase in the positive direction, although this change is not significant.



Graph 1 – The cumulative and difference integral curves of water flow for the Yertis River at the Ust-Kamenogorsk HPP for the period from 1942 to 2021
Note – compiled by the author

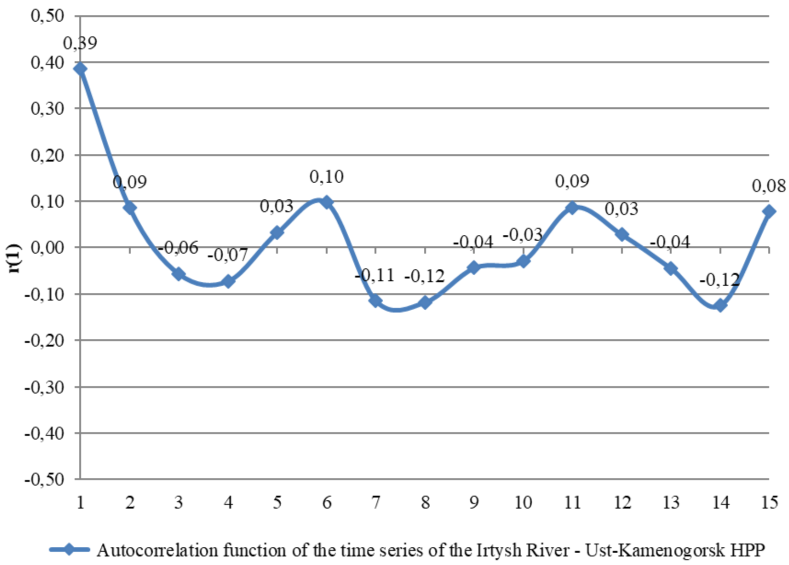
The negative deviations of the modulus coefficient from the flow norm, as shown in the above graph, indicate a decrease in water flow over the past 47 years, from 1974 to 2021.

We also have analyzed the correlation of Yertis River's water flow rates at the hydrological post Ust-Kamenogorsk HPP for the period from 1942 to 2021. For this analysis, we have used the autocorrelation coefficient with gradual shifting of time series. Table 1 below presents the data on lags and their corresponding autocorrelation coefficient values for the examined series. The time series under study from 1942 to 2021 were gradually shifted by 15 steps to check the relationship between water consumption in the first and last years of monitoring the river. These shift steps are the lags, which show time displacement between the current value and the lagged value of the time series.

Table 1 – Lags and their corresponding values of the autocorrelation coefficient for the time series of water flow rates of the Yertis River at the Ust-Kamenogorsk HPP (1942-2021)

Lag, L	Autocorrelatiom coefficient, r (1)
1	0,39
2	0,09
3	-0,06
4	-0,07
5	0,03
6	0,10
7	-0,11
8	-0,12
9	-0,04
10	-0,03
11	0,09
12	0,03
13	-0,04
14	-0,12
15	0,08
Note – compiled by the author	

Using the data from this table, an autocorrelation function was constructed for the time series of water flow rates of the Yertis River at the Ust-Kamenogorsk HPP for the period from 1942 to 2021. Based on this function, we have plotted the graph shown in Graph 2. This function represents a graph depicting the relationship between the autocorrelation coefficient and the lag.



Graph 2 – Autocorrelation function of water discharge of the Yertis River at the Ust-Kamenogorsk HPP for the period from 1942 to 2021
Note – compiled by the author

This graph allows for a visual assessment of the degree of association between the values of the time series at different time periods and helps identify possible cyclic or seasonal patterns in the data. And according to Graph 2, it can be concluded that at initial lag offsets, the function values are close to 1, indicating a strong positive correlation between adjacent series. As the lag offsets increase, the function values gradually decrease, reflecting a gradual weakening of the correlation between adjacent series. With further increases in lag offsets, the autocorrelation function (ACF) values become close to 0. This indicates that there is practically no correlation between adjacent series. In other words, the water discharge in the current year is not dependent on the water discharge a certain number of years ago.

From this, it can be inferred that the autocorrelation function demonstrates the presence of a correlation between adjacent series of water discharge of the Yertis River at the Ust-Kamenogorsk Hydroelectric Power Plant. However, this correlation weakens with increasing lag offsets, possibly due to the influence of various factors.

Changes in river flow can affect water discharge autocorrelation through several mechanisms. Climatic conditions, including precipitation changes, can disrupt natural water flow cycles and patterns, weakening the correlation between water discharges in different periods. Anthropogenic influences, such as dam construction and reservoirs, alter the natural river regime, impacting its flow and water distribution over time. Water use patterns, including changes in water intake for industrial or agricultural purposes, also affect changes in the values of water volumes in a river stream. This position for river flow means that the main flow variables will eventually lose the connection between past and future indicators.

The integration of new geoinformation technologies will provide specialists with a reliable and dynamic tool for solving hydrological problems. For example, to collect annual, monthly and daily observational data on the hydrometric parameters of the runoff of water objects. Thus, the collection of large amounts of data has a positive effect on the quality and speed of information analysis and processing. Specialists will be able to improve reports and increase the speed of response in emergency situations (Alimbekova et al. 2014).

One of the most important advantages of geoinformation technologies in hydrology is the ability to visualize data. With the help of accessible visualization, specialists can conduct a qualitative analysis of trends and anomalies, prepare reporting materials in a short time (Alimbekova et al. 2014).

GIS have great potential in integrated water resources management, as they have a number of broad opportunities for the development of water resources. These features include:

- Collection and analysis of data on the state of water bodies of various scales, watersheds, climatic conditions. This opportunity gives us a broader understanding of the water body and its potential (Amin et al. 2018).
- Visualization and its subsequent analysis with the identification of various factors that may influence a problem with the management of water resources in a region.
- Rapid emergency response in case of a flood or drought threat, which helps to take prompt measures to reduce damage.
- Ensuring maximum openness and accessibility of information for all parties interested in the state and quantity of water resources.

The above-mentioned GIS capabilities in water resources management are key factors for drawing up an effective plan to regulate problems related to the water sector of the economy. In addition, GIS and research conducted based on these technologies are also the rationale for making decisions on sustainable IWRM at the present time.

One of the significant geoinformation technologies in water resources management is the WEAP (Water Evaluation and Planning) system. This digital IWRM platform is designed to solve problems related to hydrology and water resources management. WEAP offers a powerful, versatile and comprehensive environment for developing water management strategies and planning and conducting data analysis to understand the current and possible condition of a water body. Each time, the number of professional users of the WEAP system increases, which becomes a useful addition to their set of models, databases, spreadsheets and other computer software (Why WEAP? n.d.). WEAP provides comprehensive tools for analysis, modeling and planning of water resources management. Its capabilities include the ability to integrate geospatial data, create hydrological and hydrogeological models, analyze the distribution of water resources, assess water supply and demand, and model various water management scenarios (WEAP n.d.).

The capabilities of this platform include consideration of the impact of global and local climate change and analysis of various strategic approaches to the management of water sectors not only in countries, but also in specific regions and basins. This system allows the user to build a management model through the inclusion of alternative water sources, strengthening measures for the protection and protection of the studied objects, which are necessary for the constant sustainability and effectiveness of the management strategy of water use (Yates et al. 2005).

WEAP allows you to analyze the current state of water resources based on data on the hydrological regime of the river, water needs and other factors (Ashofteh et al. 2017). The model allows you to calculate the water balance in the catchment area, identify water shortages and surpluses, as well as assess the impact of various factors on water resources.

In 2023, a group of scientists from Morocco, Spain and France conducted a study to assess the impact of climate change on water supply and water demand in an arid area on the western Hauz plain in Morocco (Abdessamad 2022), using the WEAP system to model the future water balance of the region.

The results of the study showed that climate change will lead to a significant decrease in available water resources in the region. In the RCP4.5 scenario, net precipitation in the region will decrease by an average of 36,2%, and in the RCP8.5 scenario – by 50,5% (Abdessamad 2022). By 2050, the unmet demand for water in the region may increase to 22% due to a decrease in available water resources.

The model of the future water balance of the region, created during a study in the WEAP system, showed that the main factor determining water scarcity in the region is a decrease in precipitation. Under the "business as usual" scenario, water demand in the region will increase by 30-40% by 2050 (Abdessamad 2022), which will not be offset by an increase in available water resources.

In addition, the results of the study are recommendations based on a scenario analysis of the WEAP system, on the introduction of a pressure-controlled irrigation system that can help reduce water losses and on the transition to more sustainable crops that require less water.

The study showed that the WEAP platform is an effective tool for analysis of results related to climate change on water availability and quality. Thus, we can say that this system promotes the adoption of long-term strategies that consider not only current conditions, but also projected climate changes. This allows public institutions and water management to be more prepared for potential crises, minimizing negative consequences for the population and ecosystems in the Mediterranean region.

Also, using the WEAP system, a study was conducted in 2023 on the allocation of water resources using an integrated approach to water management in the Zayenderud River basin, Iran (Zehtabian E 2023). In the course of the study, a model of water resources management in the Zayenderud River basin in Iran was developed, including the development and ranking of management scenarios using a multi-criteria decision-making method. To do this, the WEAP system was used, which includes six stages. At the first stage, an inventory of water resources and an analysis of water use were carried out. At the second stage, the ecological runoff was calculated using hydraulic techniques and analytical tools developed by the Center for Hydrological Engineering. At the third stage, the obtained data on environmental consumption were integrated into an integrated water resources management system through the application of a water resources assessment and planning model. At the fourth stage, seven possible management scenarios were created in the model of assessment and planning of water resources, which were applied in the period up to 2041:

I. Changing the priority of water supply.

II. Changing the population growth trend.

III. Changing the use of backflow and water loss management.

IV. Changing the amount of water transferred to the Gavhuni basin.

V. Changing demand management (consumption reduction per capita).

VI. Changing agricultural conditions.

These scenarios are ranked at the fifth stage using a multi-criteria decision-making method. At the sixth stage, the management scenario is applied, which is considered the most appropriate for the current situation in the region under study.

The results of the study show an increase in the need for drinking water, water for industry and agriculture, as well as an increase in unmet needs in these areas. Scenarios for changing the priorities of water supply and the volume of water transferred to the Gavhuni basin were recognized as the highest priorities. The main conclusion is the need to improve approaches to water resources management, considering the expected increase in needs over the coming decades. This highlights the importance of developing and implementing adaptive strategies that will consider dynamic changes in demand and ensure sustainable use of water resources in the long term.

In 2003, as part of the ADAPT project aimed at developing strategies for adaptation to climate change, a study of the water balance of the Syr Darya River was conducted (Water, Climate, Food, and Environment in the Syr Darya Basin 2003). The study used the results of water balance modeling using the WEAP platform, which made it possible to analyze various scenarios for water resources management. Four adaptation strategies were considered:

- ecological, focused on the conservation of natural aquatic ecosystems;
- food, aimed at meeting the needs of agriculture and food security;
- industrial, focused on supporting water supply for industrial facilities;
- mixed, combining elements of all previous approaches to achieve a more balanced regulation of water resources. The modeling revealed the advantages and disadvantages of each strategy in the context of climate change and instability of water systems.

The main conclusion of the study is that the mixed strategy is the most effective in terms of meeting the interests of all three main water users in the Syrdarya River basin.

A mixed strategy provides a more effective improvement in water quality than an environmental strategy. This is because this strategy provides for measures to reduce pollution of reservoirs caused by agricultural and industrial activities. In addition, it provides the best protection against desertification, as its implementation contributes to improving the efficiency of water use in agriculture and landscaping of coastal areas. By reducing the use of water for irrigation, this adaptation strategy ensures the most effective increase in outflow to the Aral Sea. Also, in comparison with other strategies, this one has advantages in food and industrial safety.

However, the relative costs of a mixed strategy are the highest among all adaptation strategies considered, as it includes measures to improve water quality, prevent desertification and increase outflow to the Aral Sea, which are more expensive than measures to increase agricultural production or hydropower.

Overall, the study showed that a mixed strategy is the most effective strategy for climate change adaptation in the Syrdarya River basin. It provides a balance between satisfying the interests of all three main water users and ensures more efficient use of water resources.

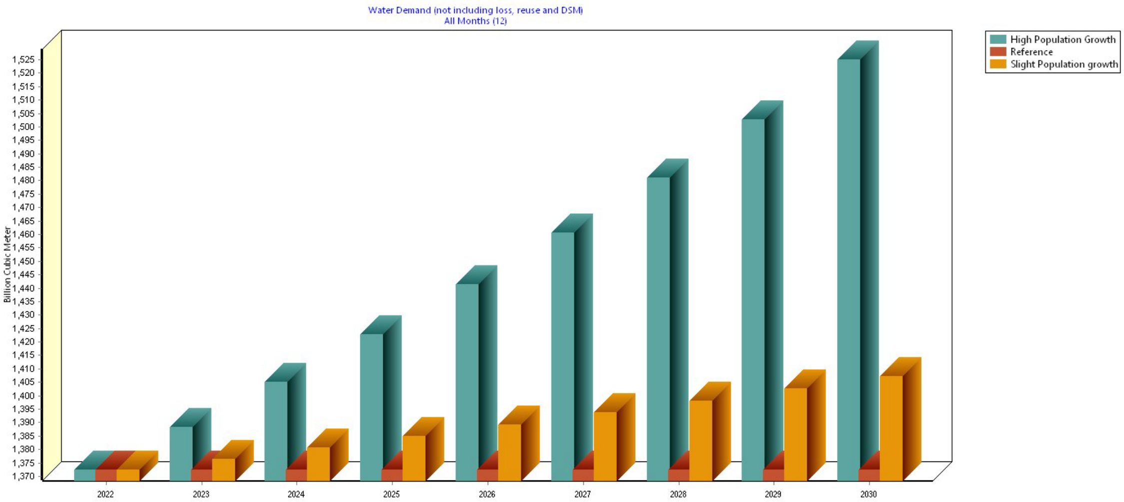
At the beginning of our research, a Reference scenario was developed that reflects the current situation without changes in the demographic component and without changes in the level of irrigated agriculture. This scenario serves as a basis for assessing future changes in water use. Two additional scenarios "Population Growth" and "Increasing Irrigated Agriculture by 2030" depart from the Reference scenario. Both developed scenarios are independent of each other, which makes it possible to flexibly model different situations and assess the impact of each factor on water use in the Yertis River basin.

The "Population Growth" scenario evaluates the impact of demographic growth on the need for water resources. Two branches have been developed under this scenario. The first branch, "Slight Population Growth", shows that with an annual increase in the population in the three major cities of the basin by 1.3% (which is the average increase in the population of Kazakhstan over the past 10 years), by 2030, the need for water increases from 1 372 million m^3 to 1 407 million m^3. This indicator was not chosen by chance, as it reflects the real demographic trend in Kazakhstan and provides a more accurate assessment of future changes. The second branch, "High Population Growth", assumes a higher population growth rate of 5% annually, as a result of which the water demand increases to 1 525 million m^3 by 2030.

Table 2 – Water demand of Yertis River (not including loss, reuse and DSM) (million, m^3)

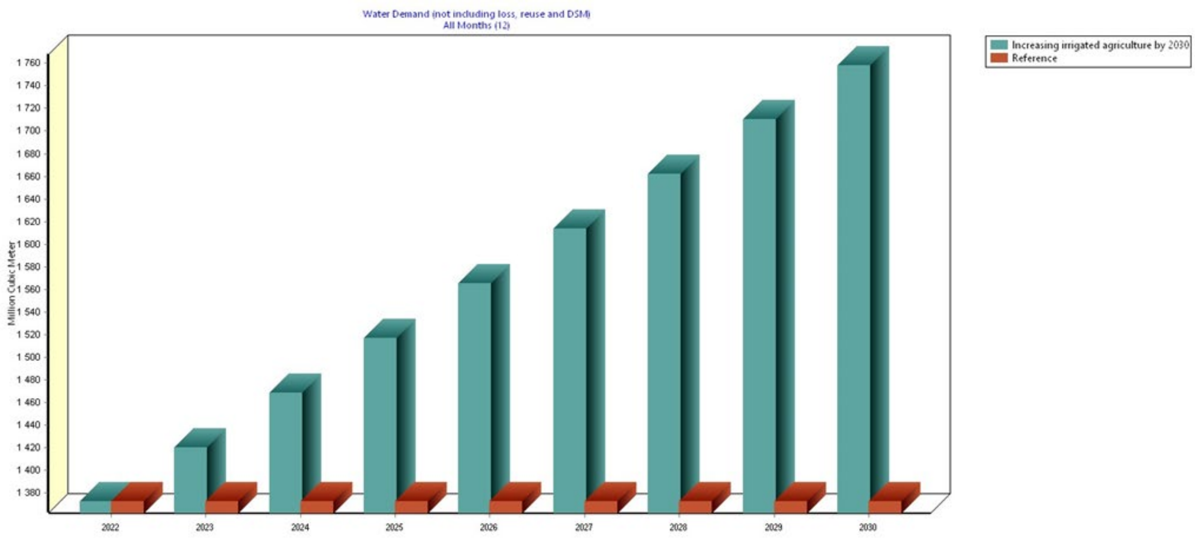
Water Demand (not including loss, reuse and DSM) (million, m^3)									
Branch: Demand Sites and Catchments, Annual Total									
Year / Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030
High Population Growth	1 372	1 388	1 405	1 422	1 441	1 460	1 481	1 502	1 525
Reference	1 372	1 372	1 372	1 372	1 372	1 372	1 372	1 372	1 372
Slight Population Growth	1 372	1 376	1 380	1 384	1 389	1 393	1 398	1 402	1 407
Note – compiled by the author									

In the WEAP model, graphs are automatically generated for scenario analysis after calculation, which allow you to visualize the data and results of the study. These graphs provide a visual representation of changes in water demand and other key indicators depending on the selected scenarios. For this scenario, Graph 3 is shown below.



Graph 3 – Water demand of water users of the Yertis River basin (not including loss, reuse and DSM) (million, m^3)
Note – compiled by the author

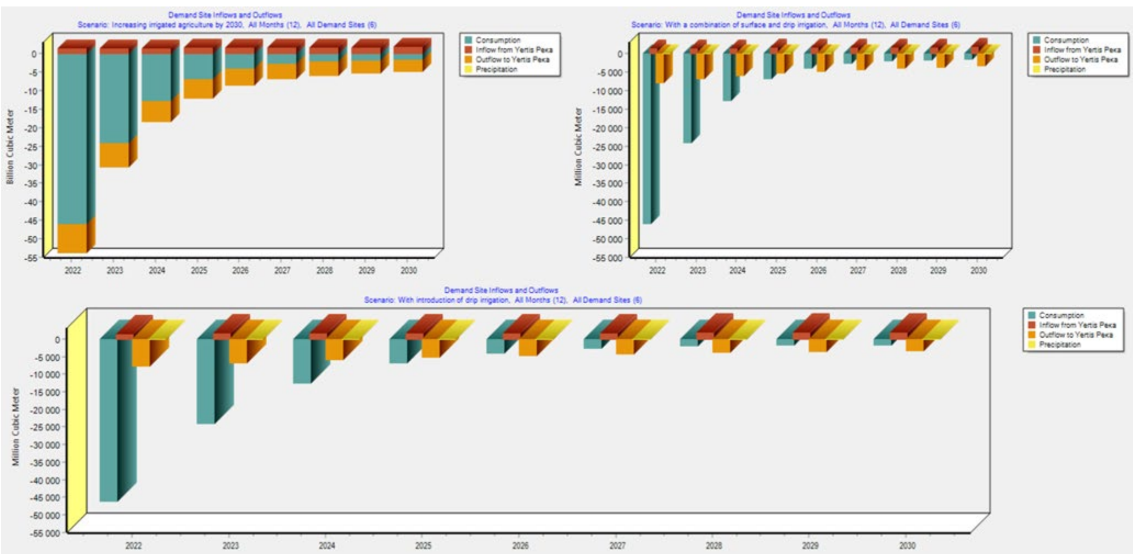
The second scenario, “Increasing Irrigated Agriculture by 2030”, explores the impact of increasing the area of irrigated agriculture in Pavlodar region to 300 000 hectares by 2030 on the need for water resources. The average net irrigation rate for agricultural crops in 2022 was 2 900 m^3/ha during the growing season. This indicator was calculated considering the estimated flow rate of 71,4% and the conditions of automorphic soil-hydrogeological areas typical of the Pavlodar region (Ob utverzhdenii Metodiki po razrabotke udel'nyh norm vodopotrebleniya i vodootvedeniya n.d.). The clear increase in water demand is shown in Graph 4.



Graph 4 – Water demand of water users of the Yertis River basin with increasing the area of irrigated agriculture in Pavlodar region to 300 000 hectares by 2030 (not including loss, reuse and DSM) (million, m^3)
Note – compiled by the author

In the first branch of the scenario, we analyze the increase in the area of irrigated agriculture without changes in irrigation methods. At the same time, the volume of non-returnable waters increases to 740 million m^3 by 2030, of which 131 million m^3 are return waters. In 2022, the volume of non-returnable water for irrigated agriculture amounted to 411 million m^3, and the volume of returnable water – 73 million m^3.

In the second branch, we modeled the transition to drip irrigation, in which the drainage coefficient is 1%. Graph 5 shows that the volume of non-returnable waters will amount to 861 million m^3 by 2030, and the volume of returnable waters will amount to 9 million m^3. This result is explained by the low coefficient of drainage with drip irrigation, which leads to a smaller volume of return water.



Graph 5 – Demand Site Inflows and Outflows in scenarios “Increasing irrigated agriculture by 2030”, “With introduction of drip irrigation” and “With a combination of surface and drip irrigation”
Note – compiled by the author

The third branch considers the combined use of surface irrigation and drip irrigation. In this case, the volume of non-returnable waters will amount to 800 million m^3, and the volume of returnable waters will amount to 70 million m^3 by 2030. The percentage of drainage with the combined approach is 8%, which is the average value between the coefficients of drainage with surface irrigation (15%) and drip irrigation (1%).

Even though with drip irrigation, the volume of return water is only 9 million m^3, and with combined irrigation – 70 million m^3, drip irrigation shows the best results in terms of water saving. With drip irrigation, all water consumed is directed directly to the roots of each individual plant, which minimizes losses on infiltration and evaporation. This makes it possible to use water resources as efficiently as possible, theoretically providing the opportunity to grow more plants on the same areas. The low volume of return flow in this case is a positive indicator, since the water is mainly used for productive irrigation.

In the conclusions, it should be noted that the choice of irrigation method depends on the type of crop and the nuances of its cultivation. For some crops, for example, for those that require precise and uniform humidification, drip irrigation is the preferred method. However, in the case of other crops, where it is important to ensure greater access of water to the roots, a combined approach can be effective.

The conducted research revealed the significant influence of demographic growth and changes in irrigated agriculture on the water demand in the Yertis River basin. Through the development of two key scenarios, "Population Growth" and "Increasing Irrigated Agriculture by 2030", it was possible to quantify the effects of population growth and the expansion of irrigated areas on water consumption, as well as to evaluate the efficiency of different irrigation methods. These findings highlight critical factors shaping the dynamics of water use in the basin under evolving socioeconomic and agricultural conditions.

Furthermore, the analysis of the total and difference curve and the autocorrelation function of the river flow demonstrated substantial deviations of the Yertis River's current hydrological state from its natural flow regime. Despite legislative measures to address these changes, the flow has continued to degrade in recent years. Without appropriate interventions, this trend poses significant risks to the region's economy and the well-being of local populations, underlining the urgent need for sustainable water resource management.

The WEAP model used in the study demonstrated its high efficiency in modeling the water resources of the Yertis River basin. This tool allows you to quickly calculate results and visualize data, which makes it valuable for making informed decisions on water management, especially in the context of climate change and demographic situation.

The analysis of the current state of water resources is an important stage in the process of managing water resources of a certain territory, which allows specialists to better understand the situation and develop effective measures for their management. WEAP allows you to develop management scenarios based on the analysis of the current state of water resources. Various parameters can be interpreted in the model, such as water needs, water efficiency, and anthropogenic impact on water resources.

Water resource management scenarios can be used to assess various options for the development of the water resources situation and make informed decisions on their management, which represent a set of possible options for the development of the water resources situation in the future. They are developed considering various factors, including climate change, population and economic growth, as well as inefficient use of water.

Conclusion

The study showed that an integrated approach is needed to effectively solve the problems of water resources management. It is important not only to strengthen the legal framework and develop new management tools, but also to ensure better coordination between the various stakeholders. Special attention should be paid to environmental aspects in order to guarantee the sustainable use of water resources in the long term. Negative deviations of the modular coefficient from the flow rate of the Yertis River over the past 47 years, from 1974 to 2021, indicate a decrease in water volume. The analysis of the autocorrelation function shows the relationship between the volumes of water at the Ust-Kamenogorsk HPP. However, this relationship weakens with an increase in time displacement, possibly due to the influence of various factors.

The use of geoinformation technologies in IWRM is an integral necessity in the allocation of water resources. GIS technologies provide powerful tools for the collection, analysis, and visualization of geospatial data, enabling accelerated modeling and simplified analysis of issues related to the management of water systems. GIS capabilities also extend to improving the quality and collection of monitoring materials. Such systems offer various variations of the development of events in the studied water bodies and, accordingly, help in making informed decisions to ensure the development of water resources and their planning. These opportunities in the modern world are especially relevant for solving hydrological problems and water supply.

The use of geoinformation technologies, such as the WEAP platform, in water resources management provides access to powerful tools for scenario modeling and comprehensive analysis of water systems. This platform has high flexibility, accuracy and ease of use, which allows experts to analyze the current state of water resources more deeply and make more informed and rational decisions for their effective management.

Based on the successful experience of using the WEAP platform in other countries, we are confident that its implementation on the Yertis River will bring significant benefits. This platform will help to improve the efficiency of water resources management in the region. On the Yertis River, this platform can be used for such purposes as analysis of results related to climate change on river flow, assessing the impact of anthropogenic activities on the river and planning the integrated use of river water resources.

Based on our research and analysis of the "Population Growth" and "Expansion of Irrigated Areas by 2030" scenarios, significant impacts of demographic and agricultural changes on water consumption have been identified. To ensure rational water resource management and mitigate water scarcity, the following measures are proposed:

1. **Optimization of Irrigation Systems.** Efficient water use in agriculture requires the adoption of advanced irrigation techniques. Drip irrigation minimizes water loss by delivering moisture directly to plant roots, while a combined irrigation approach ensures a balance between water conservation and crop needs. Additionally, upgrading existing irrigation infrastructure is crucial to reducing water losses during transportation and distribution.

2. **Water Consumption Monitoring and Management.** Effective water resource management relies on precise usage monitoring. Establishing a unified water consumption database integrated with GIS technologies will improve data accessibility. Automated control systems will enable real-time water intake monitoring, while differentiated water use standards will account for seasonal and climatic variations in the region.

3. **Promotion of Water Conservation in Agriculture.** Farmers transitioning to water-efficient technologies require additional support. Economic incentives such as subsidies and tax benefits can accelerate the adoption of modern irrigation methods. Furthermore, awareness campaigns and training programs are essential to equip agricultural producers with the knowledge needed to maximize the efficiency of water-saving technologies.

4. **Integrated Water Resource Management Approach.** Coordinated efforts among stakeholders (including government agencies, agricultural producers, industries, and local communities) are essential for achieving sustainable water use. Developing a long-term water management strategy that considers climate change will allow for proactive adaptation to emerging challenges. Strengthening regulatory frameworks and enforcing compliance will help prevent inefficient and unsustainable water use.

5. **Application of Geoinformation Technologies.** The use of the WEAP platform for water balance modeling and consumption forecasting will enable a more accurate assessment of both natural and anthropogenic factors affecting water resources. Remote sensing and GIS technologies will facilitate rapid evaluation of water bodies and irrigated land conditions, thereby enhancing the efficiency of planning and water distribution.

The proposed measures aim to promote sustainable water use in the Ertis River basin and ensure adaptation to evolving socio-economic and climatic conditions.

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