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Optimization of water resources use in agriculture of Yenbekshi-Kazakh District through artificial groundwater recharge

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Abstract. In the context of increasing water resource scarcity, the search for alternative irrigation sources has become a key factor in the sustainable development of agriculture. One of the effective solutions is the reconstruction and creation of cascades of water accumulation ponds, which significantly improve the reliability of the water reuse system. The implementation of this practice has notably enhanced irrigated farming conditions, especially during drought periods. In the villages of Baiterek, Alga, and Koishibek, the water supply issue has been largely mitigated, leading to the return of 1420 hectares of previously abandoned land to agricultural use. These lands are now actively used for growing crops, ensuring stable production. Over 300 farms now have access to a dependable irrigation water supply, which contributes to the development of the agricultural sector and reduces drought-related risks. Thus, the use of water accumulation systems demonstrates high efficiency and significance for food security and the resilience of agriculture in a changing climate.

Keywords: *meltwater, aquifers, irrigation system, water supply system, irrigation.*

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1. Introduction

Existing uncertainties in water resource forecasts and the long-term (century-scale) accumulation of fresh water in aquifer reservoirs play an important role in setting and achieving sustainable development goals.

Climate change affects water management at all levels, including hydropower, drainage and irrigation systems, water supply, and wastewater management. This impact is primarily reflected in operational costs, which increase significantly [1]. During the transition from a planned to a market economy, investments in water management were nearly nonexistent, resulting in the deterioration of irrigation and drainage systems and the worsening of the ecological and reclamation conditions of lands [1-3]. Given the deterioration and decommissioning of these facilities, there is a risk of failing to maintain even the existing volumes of irrigated agriculture in the medium term. Rising water temperatures, combined with increased frequency of extreme weather events (such as floods and droughts), are expected to negatively impact water quality and increase contamination (e.g., higher concentrations of biogenic substances, dissolved organic carbon, pathogens, pesticides, salts, and thermal pollution), which will harm ecosystems [4] (Figures 1 and 2).

Research on water supply issues and the effective use of natural water resources has been conducted by scientists from the Institute of Hydrogeology and Geoecology of U.M. Akhmedsafin, as well as by structural units of the Ministry of Agriculture of Kazakhstan. Technologies for using groundwater have been developed [5, 6].

The current state of irrigated agriculture and the growing water demand of rural producers highlight the need to use floodwaters, viewing them as a natural water resource for the agricultural sector. Floods in Kazakhstan are inevitable because rivers are primarily fed by precipitation. Thus, there is an urgent need to include the construction of reservoirs for river flow regulation in flood prevention measures, alongside the construction of protective ditches, dams, bypass channels, and other structures [7]. Ponds for collecting meltwater can subsequently be used for agriculture, energy production, and other industries. Additionally, extreme rainfall events, such as those that recently occurred in Astana and Atyrau, must be managed effectively. According to Deputy of the Mazhilis Andrey Begeneev, creating such lakes could significantly improve the operations of emergency services and other water-related organizations. The text was also signed by Mazhilis deputies A. Milyutin, Sh. Utemisov, N. Ashim, T. Berdongarov, Zh. Dyusengaliev, V. Kiyansky, A. Pepenin, A. Samakova, I. Umurzakov, O. Shishigina, A. Bazarbayev, M. Begentaev, A. Kozhakhmetov, E. Kappel, A. Muradov, B. Sorokin, and A. Turtaev.

Dostay Zh.D. et al. [8] clearly substantiated the priorities for ensuring the environmental safety of water bodies in transboundary basins and the foundations for interstate use of transboundary rivers based on the principles of integrated water resources management.

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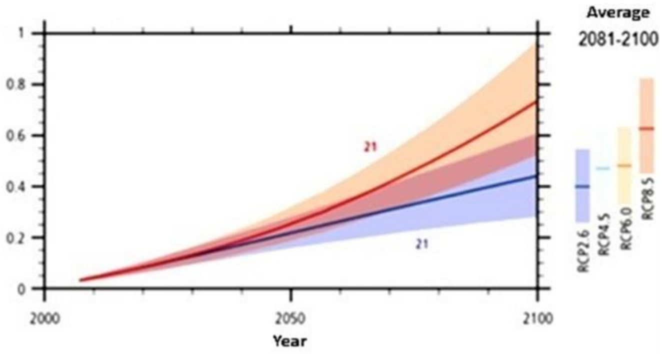
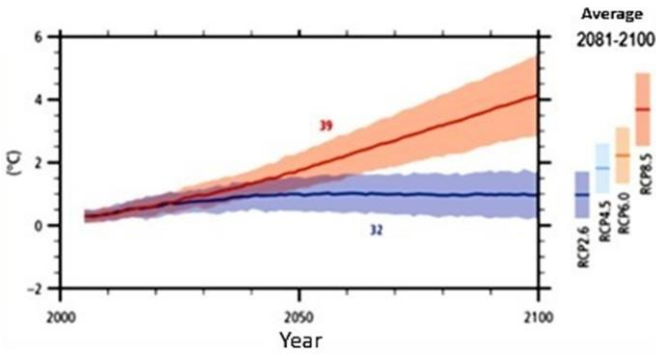


(a)



(b)

Figure 1. Projected global climate change impacts; (a) – average change in land surface temperature (compared to 1986-2005), mean for 2081-2100; (b) – mean sea level rise (relative to the 1986-2005 period), average for 2081-2100

Mirlash V.M. and Ismagulova argue that water scarcity in southeastern Kazakhstan, exacerbated by long distances from high-quality natural water sources, necessitates the combined use of surface and groundwater from local aquifers for irrigation, pasture watering, and decentralized drinking water supply for small rural settlements [9]. In arid conditions, this is the only way to prevent groundwater depletion, increase its storage capacity, and expand its natural filtration area. This approach ensures the availability of drinking water for the population [10-13].

2. Materials and methods

The natural and climatic conditions, terrain, and availability of temporary and floodwater sources in the lower parts of alluvial fans and the gently sloping erosion-denudation foothill plains of the arable lands in the Baiterek rural district enable the creation of a cascade of seasonal regulation reservoirs and offer vast prospects for their use as a primary source of irrigation. To address the main objective of the research program, extensive work has been carried out over the past several years to develop and subsequently implement the efficient utilization of local runoff and groundwater. Depending on soil, hydrological conditions, and terrain, seasonal regulation reservoirs are established to optimize water storage and use.

As a result of the project implementation, the reconstruction of the distribution irrigation canal was carried out, along with the repair of two seasonal regulation reservoirs. A unique cascade of seasonal regulation reservoirs was created, utilizing local temporary and floodwater sources.

The irrigation system incorporating accumulation ponds consists of distribution canals that follow the land's natural slope and flow into artificially created accumulation ponds. Once the water in these ponds has warmed and reached favorable irrigation conditions, it is directed into irrigation canals for watering crops. Any unused irrigation water is transported via canals to the next accumulation pond.

All irrigation canals are equipped with retention and regulation structures at their downstream ends, while the outflows of the seasonal regulation reservoirs are fitted with level regulators for the lower reach. Thus, the irrigation system ensures favorable conditions for plant growth during watering by incorporating seasonal regulation reservoirs and enables more efficient use of irrigation water through the structure of the irrigation system.

At the same time, the project tested innovative designs of sluice gates and spillways, which demonstrated positive results in water accounting and the prevention of vandalism by the local population.

The simplicity, durability, low cost, short production time, and guaranteed reliability of the proposed innovative sluice gate-featuring a manually operated movable spillway with an anti-vandal mechanism-allowed its successful implementation not only in this project but also in all hydro-melioration systems of the Yenbekshi-Kazakh district. It has been recommended for adoption in other regions of Kazakhstan.

In this regard, hydrological posts and hydrogeological wells have been installed at the site to study the quality and determine the suitability of accumulated irrigation water for cultivated agricultural crops, as well as the groundwater formed due to the backwater effect caused by infiltration between the seasonal regulation reservoirs.

During the project implementation and subsequently during the operation of the seasonal regulation reservoirs and the use of irrigated lands, regular ecological monitoring has been and will continue to be conducted to assess the hydrological regime of the local river flow and the quality of accumulated water sources-including meltwater, rainwater, floodwater, and emerging perched groundwater. The latter forms in higher-elevation areas of the terrain and is used by peasant and farming enterprises for irrigating cultivated agricultural crops.

To obtain initially crucial indicators of the quality of water accumulated in seasonal regulation reservoirs and groundwater for its subsequent use in irrigating cultivated agricultural crops, water samples were collected and analyzed in the accredited laboratory of Satbayev University.

To ensure a comprehensive assessment of irrigation water quality, we applied agronomic, technical, and environmental criteria [14-21].

Due to the absence of unified approved standards, the suitability of water for irrigation was determined based on its chemical analysis using irrigation coefficients, which were calculated by various methods (Table 1).

Internationally, the assessment of irrigation water for the risk of soil alkalization is conducted based on the calculation of the Sodium Adsorption Ratio (SAR, Table 1). This method is based on the principle that when sodium concentration exceeds that of divalent cations, there is a risk of sodium displacing calcium from the soil's exchange complex, replacing it with sodium. As a result, soil alkalization may occur, leading to a sharp deterioration in its water-physical properties.

Table 1. Formulas for calculating irrigation coefficients

Author	Calculation Formula
H. Stabler	$K_a = \frac{288}{5rCl^-}$, at $rNa^+ < rCl^-$
	$K_a = \frac{288}{rNa^+ + 4rCl^-}$, at $rCl^- + rSO_4^{2-} > rNa^+ > rCl^-$
	$K_a = \frac{288}{10rNa^+ - 5rCl^- - 9rSO_4^{2-}}$, at $rNa^+ > rCl^- + rSO_4^{2-}$
A.M. Mozheyko, T.K. Vorotnik	$K_a = \frac{\left(rNa^+ + rK^+\right) \cdot 100\%}{rCa^{2+} + rMg^{2+} + rNa^+ + rK^+}$
I.N. Antipov-Karataev, G.M. Kader	$K_a = \frac{rCa^{2+} + rMg^{2+}}{rNa^+ + 0.238\sum u}$
M.F. Budanov	$K_2 = \frac{rNa^+}{rCa^{2+} + rMg^{2+}}$, $K_3 = \frac{r\sum u}{rCa^{2+} + rMg^{2+}}$
SAR	$SAR = \frac{rNa^+}{\sqrt{\frac{rCa^2 rMg^{2+}}{2}}}$

3. Results and discussion

As part of the key objective of the project-focused on organizing, testing, and adapting a model site for water recycling systems under conditions of increasing river water shortages – the reconstruction and modernization of the on-farm irrigation network and two reservoirs were carried out in the Baiterek rural district of the Yenbekshi-Kazakh district in the Almaty region. This made it possible to create a unique cascade of seasonal regulation reservoirs that utilize local temporary and floodwater sources.

1. Seasonal regulation reservoir «Saimasay-1». Saimasay-1 seasonal regulation reservoir, located in the Almaty Region, Enbekshikazakh District, Baiterek Rural District, PC SPC "Margulan" (coordinates: 43°26'31" N, 77°16'42" E) (Table 2).

Table 2. Technical specifications of the «Saimasay-1» storage pond before and after reconstruction and modernization

Parameter	Saimasay-1 (before)	Saimasay-1 (after)	Change
Normal water level (NWL), m	635.0	637.0	+2.0
Maximum water level (MWL), m	635.5	637.5	+2.0
Total storage capacity, Mm³	0.912	1.482	+0.57
Usable storage capacity, Mm³	0.571	1.026	+0.455
Water surface area, ha	6.54	8.50	+1.96
Length, m	600	600	-
Width, m	380	380	-
Maximum depth, m	5.40	7.40	+2.0
Dam height, m	7.2	9.0	+2.0
Dam crest width, m	5.5	7.5	+2.0
Dam base width, m	8.5	12.5	+4.0

The dam height was increased to 9.0 m, and the crest width was expanded to 7.5 m. The normal water level (NWL) was set at an absolute elevation of 635.0 m, compared to the initial level of 637.0 m; the maximum flood level (MFL) was adjusted to 637.5 m from the previous 635.5 m.

The total storage capacity increased by +0.57 million m³, reaching 1.482 million m³ (previously 0.912 million m³). The usable storage capacity improved by +0.455 million m³, reaching 1.026 million m³, compared to the previous average of 0.571 million m³.

The surface area of open water at the usable storage capacity expanded to 8.50 ha, an increase of +1.96 ha from the previous 6.54 ha. The serviced area increased from 2,433 ha to 3,503 ha, enabling the establishment of approximately 50 to 75 new farming enterprises by utilizing previously abandoned irrigated croplands.

2. Seasonal regulation reservoir "Saimasai-3"

The completed set of maintenance and operational works at the Saimasay-3 seasonal regulation reservoir has enhanced the dam, basin, and hydraulic structures to meet the requirements for optimizing water availability for existing irrigated lands. Additionally, it has facilitated the reclamation of at least 350 hectares of previously abandoned arable land for agricultural use.

The dam height has been increased to 3.5 meters, and the dam crest width has been extended to 5.0 meters. At this width, the crest of the dam will rise above both the normal water level (NWL) and the maximum water level (MWL). The dam slope steepness during its expansion, considering the physical and mechanical properties of the soil, the impact of self-weight, water influence, seismic and dynamic effects, as well as external loads on the crest and slopes, was set as follows: upstream (wet): 2.50, downstream (dry): 1.75 (Figure 3).

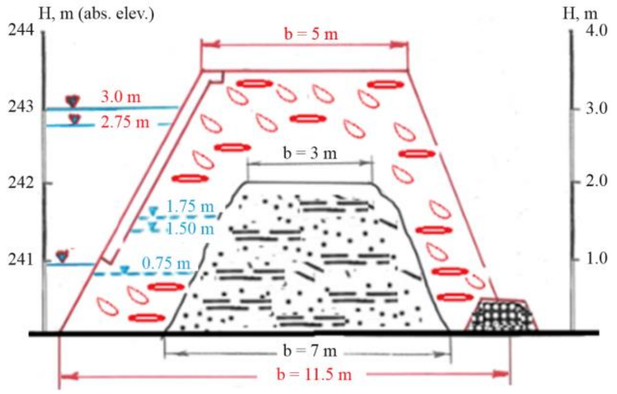


Figure 3. Schematic nomogram of the longitudinal profile of the averaged parameters of the dam of the Sai-Masai-3 seasonal regulation reservoir before and after the completed work

Saimasai-3 seasonal regulation reservoir, located in the Almaty Region, Enbekshikazakh District, Baiterek Rural District, PC "SPK Margulan" (coordinates: 43°27'40.8" N, 77°11'22.0" E), at an absolute elevation of 622 m (Table 3).

The Normal Water Level (NWL) was set at an absolute elevation of 621.0 m, compared to the initial level of 619.8 m. The Maximum Water Level (MWL) was adjusted to 621.5 m from the previous 620.2 m. The Dead Storage Level remains unchanged at 618.0 m.

Table 3. Technical characteristics of the «Saimasai-3» seasonal regulation reservoir before and after reconstruction and modernization

Parameter	Saimasay-1 (before)	Saimasay-1 (after)	Change
Normal water level (NWL), m	619.8	621.0	+1.2
Maximum water level (MWL), m	620.2	621.5	+1.3
Total storage capacity, Mm³	0.183	0.345	+0.162
Usable storage capacity, Mm³	0.153	0.305	+0.152
Water surface area, ha	7.35	11.42	+4.07
Serviced area, ha	962.9	1320	+357.1
Length, m	500	510	+10
Width, m	105	120	+15
Maximum depth, m	2.80	4.30	+1.5
Dam height, m	2.0	3.5	+1.5
Dam crest width, m	3.5	5.0	+1.5
Dam base width, m	7.0	11.5	+4.5

Total reservoir capacity increased by 0.162 million m³, reaching 0.345 million m³ (previously 0.183 million m³). Usable capacity increased by 0.152 million m³, reaching 0.305 million m³, compared to the previous average value of 0.153 million m³.

Water surface area at full usable capacity reached 11.40 ha, which is 4.05 ha more than before (7.35 ha). Irrigated area expanded from 962.9 ha to 1320 ha, enabling the potential creation of 25-30 new farming households, utilizing previously abandoned irrigated cropland.

The social impact lies in improving the social environment and enhancing the quality of life of the population. This is reflected in indicators such as the rise in educational levels due to participation in the development and implementation of new technologies in irrigated agriculture in one of the major administrative districts of Almaty Region, Republic of Kazakhstan.

The primary beneficiaries involved in the research and implementation activities were members of local rural communities, as well as farmers and agricultural enterprises. On pilot and experimental sites, local community members took an active role in implementing the very technology of water reuse systems.

In the future, the ongoing efforts to establish water reuse systems will continue, with the formation of a management and coordination council involving farmers, local elders and aksakals, representatives of local akimats, and other stakeholders.

The work and training conducted during the project have increased awareness and self-consciousness within the local community. This has fostered greater engagement among community members in adopting water reuse systems, artificial aquifer technologies, and the reuse of drainage and discharge water.

4. Conclusions

It is proposed to implement the most efficient integrated use of local runoff and groundwater, where seasonal regulation reservoirs are created based on soil, hydrological conditions, and terrain features. Additionally, agrotechnical measures are applied to retain local runoff directly in the fields.

The establishment of seasonal regulation reservoirs for more effective utilization of flood runoff is both economically viable and environmentally acceptable. The project has enabled the development of irrigated agriculture in areas distant from irrigation systems.

Repair and restoration work on seasonal regulation reservoirs, including the replacement of individual structural components and bringing parameters to their design forms and dimensions, will significantly extend the standard service life of water management and hydraulic structures. This will provide a 100% guarantee of accumulating the required water volume and subsequently ensuring irrigation water supply for an area of 1,400 hectares, including 350 hectares of previously unused arable land.

The utilization of local river runoff including meltwater, rainwater, floodwaters, and emerging groundwater (perched water) formed in higher-altitude areas through accumulation in seasonal regulation reservoirs for irrigation will lead to a sharp reduction and significant conservation of scarce water resources by 45-50%.

Thus, each water user will be provided with information on the quality of the water used and its compliance with national irrigation standards.

Author contributions

Conceptualization: A.Zh.I., V.M.M.; Data curation: A.Zh.I., N.A.B.; Formal analysis: A.Zh.I., V.M.M., N.A.B.; Funding acquisition: A.ZhI..; Investigation: A.Zh.I.; Methodology: A.Zh.I., V.M.M.; Project administration: A.Zh.I., V.M.M.; Resources: A.Zh.I., V.M.M.; Software: A.Zh.I., N.A.B,; Supervision: A.Zh.I,; Validation: A.Zh.I.; Visualization: A.Zh.I., N.A.B.; Writing – original draft: A.Zh.I.; Writing – review & editing: V.M.M., N.A.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Жер асты суларын жасанды түрде толықтыру арқылы Еңбекші-Қазақ ауданының ауыл шаруашылығында су ресурстарын пайдалануды оңтайландыру

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Аңдатпа. Су тапшылығының күшеюі жағдайында балама суару көздерін іздеу ауыл шаруашылығын тұрақты дамытудың негізгі факторына айналуда. Тиімді шешімдердің бірі суды қайта өңдеу жүйесінің сенімділігін айтарлықтай арттыруға мүмкіндік беретін су қоймаларының каскадтарын қайта құру және құру болып табылады. Осы тәжірибені енгізу нәтижесінде әсіресе құрғақшылық кезеңдерінде суармалы егіншіліктің жағдайы айтарлықтай жақсарды. Бәйтерек, Алға және Қойшыбек ауылдарында сумен қамту мәселесі іс жүзінде шешіліп, бұрын қараусыз қалған 1420 гектар жер ауыл шаруашылығы айналымына қайтарылды. Бұл аумақтар тұрақты өнім өндіруді қамтамасыз ететін ауыл шаруашылығы дақылдарын өсіру үшін белсенді түрде пайдаланылады. 300-ден астам шаруа қожалығы суармалы судың сенімді көзіне қол жеткізді, бұл ауыл шаруашылығы саласының дамуына ықпал етіп, құрғақшылыққа байланысты тәуекелдерді азайтады. Осылайша, су сақтау жүйелерін пайдалану азық-түлік қауіпсіздігін қамтамасыз ету және өзгермелі климат жағдайында ауыл шаруашылығының тұрақтылығын арттыру үшін жоғары тиімділік пен маңыздылықты көрсетеді.

Негізгі сөздер: *еріген сулар, сулы горизонттар, суару жүйесі, сумен жабдықтау жүйесі, суару*.

Оптимизация использования водных ресурсов в сельском хозяйстве Енбекши-Казахского района посредством искусственного восполнения подземных вод

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Аннотация. In the context of increasing water shortages, the search for alternative irrigation sources is becoming a key factor in the sustainable development of agriculture. One effective solution is the reconstruction and creation of cascades of water storage ponds, which can significantly increase the reliability of the recycling water use system. As a result of the implementation of this practice, the conditions of irrigated agriculture have significantly improved, especially during dry periods.

In the villages of Baiterek, Alga and Koyshibek, it was possible to practically solve the water supply problem, which led to the return of 1420 hectares of previously abandoned land to agricultural circulation. These territories are actively used for growing crops, ensuring stable production. More than 300 farms have gained access to a reliable source of irrigation water, which contributes to the development of the agricultural sector and reduces the risks associated with droughts. Thus, the use of water storage systems demonstrates high efficiency and importance for ensuring food security and increasing the sustainability of agriculture in a changing climate.

Ключевые слова: *талые воды, водоносные горизонты, оросительная система, система водоснабжения, ирригация.*

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