Sustainable development in the Esil River basin in the context of water, food and energy security

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Abstract

The geographical basin of the Esil River is located in the northern and central parts of the Republic of Kazakhstan. In its natural state, the Esil River basin is characterized by high variability of annual runoff and a marked unevenness in its intra-annual distribution. The study area is regarded as one of the most significant industrial and agricultural regions of the Republic, with agriculture representing the dominant economic sector. The water factor is of paramount importance for the sustainable production of agricultural commodities.

The development of economic sectors in this region is hampered by growing water scarcity, surface and groundwater pollution, excessive water losses in water management systems, aggravating problems of supplying the population with quality drinking water, problems of interstate water distribution.

As one of the measures aimed at providing sufficient water supply to water-scarce regions, the study considers the method of territorial redistribution of river flows. The comprehensive nature of the study highlights the interrelationships and complementarities that exist between different aspects of sustainable development in the Esil River Basin.

Water scarcity affects food security. Agriculture in the basin, primarily focused on grain production and livestock, requires substantial water resources and is heavily influenced by climatic conditions.

The sustainable development of the region requires an adequate energy supply. The studied area is energy deficient and imports electricity from other regions of the country. In order ensure energy sustainability while taking into account the norms of the Paris Climate Agreement, it is crucial to develop alternative energy sources, such as small hydro plants, suitable for the local community and industry, as well as to facilitate the distributed generation of electricity in the regional power grid.

1. INTRODUCTION

The Esil geographical basin is located in the Northern and Central parts of the Republic of Kazakhstan, administratively it includes Akmola and North Kazakhstan regions with the region centers of Kokshetau and Petropavlovsk. The territory under consideration is considered to be one of the main industrial-agrarian regions of the Republic, where agriculture is the prevailing branch of the economy. For sustainable agricultural production, the water factor is of significant importance.

The water availability of the catchment area is 11.8 thousand m^3/year per 1 km^2. This figure represents a relatively low average availability of water in comparison to the national average, which stands at 20.6 thousand m^3/year per 1 km^2. North-Kazakhstan and Akmola provinces are the least provided with water resources. Thus, the development of the region is constrained by limited water resources.

The tenets of sustainable development, often referred to as “the world model of the future civilization”, are the most sought-after methods of economic advancement.

In order to analyze the sustainable development of the Esil River Basin in detail, this study will focus on the nexus between water, food and energy security. An integrated approach, which crosses sectoral boundaries, is essential for achieving sustainable development in the region's most important areas of the economy. The integrated nature of the study emphasizes the interconnections and complementarities that exist between the different aspects of sustainable development in the Esil River Basin.

The materials used in this paper included historical data on precipitation, air temperature, water use in the Esil River, hydrological maps of the region, data on soil cover and irrigated land shares, as well as irrigation rates and gross yields of durum wheat. Economic data included market prices for wheat. Infrastructural data covered existing water infrastructure and plans for new water facilities and an inter-basin water transfer project.

This paper assesses the feasibility of this project using statistical analysis and forecasting methods, and presents aggregated calculations of gross wheat production, and aggregated calculations of the capacity of the proposed small hydropower plant in the study region.

2. LITERATURE BACKGROUND

The geographical basin of the Esil River is characterized by a sharply continental and arid climate. The warm months are characterized by high temperatures, low precipitation and high air dryness. The distribution of precipitation in the Esil River basin is strongly influenced by orography and altitude. The difference in annual precipitation at different Esil stations reaches 75 mm (Petropavlovsk meteorological station – 351 mm, Esil meteorological station – 276 mm). The primary source of water for the basin's rivers, 60-75% of the yearly precipitation occurs during the warm season and 25-40% falls during the cold season. In arid climates, a significant portion of precipitation (300 to 325 mm) evaporates from the land surface.

The Esil River originates on the northern edge of the Kazakh Lawlands and discharges into the Ertis River in the neighboring territory of the Russian Federation. The total length of the river is 2 450 km and the catchment area is 155 000 km^2.

The Esil River's main feeding area is located within the territory of the Akmola region, where it receives its principal tributaries: Kalkutan, Zhabai, and Tersakkan. Additionally, the river's course is influenced by the Akkanburlyk and Imanburlyk tributaries within the North Kazakhstan region. Below the confluence of Imanburlyk, the river flows westward into the Siberian lowland. At the point of the river's confluence with Imanburlyk, no further tributaries flow into the river until it reaches the lower reaches. During the summer months, the Esil River above the Astana (Vyacheslav) reservoir is in a state of drought, whereas the river below the reservoir maintains a constant flow.

The location map of the Esil water management basin is shown in Figure 1.

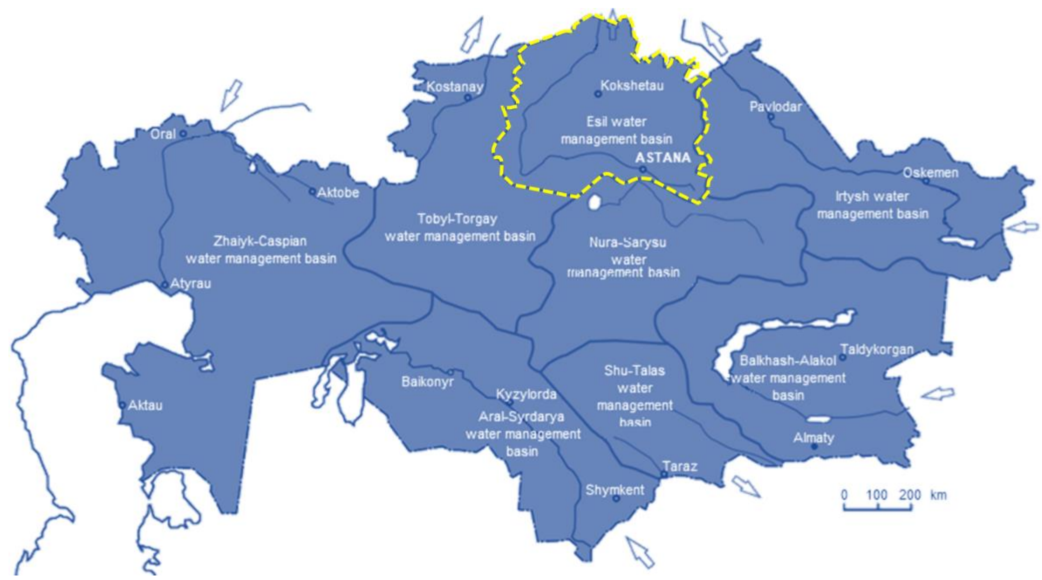

FIGURE 1. The Esil water management basin location.

On the territory of Republic of Kazakhstan, the Esil River traverses a valley that ranges in width from 2 to 12 kilometers. The river has a distinct floodplain that increases mostly downstream for almost its whole course. The water regime of rivers in the Esil River basin is characterized by a high degree of variability in annual runoff. The highest average annual discharge exceeds the average perennial discharge by a considerable margin, with extreme irregularity in the intra-annual distribution of runoff (85-98% of the annual runoff occurring in the spring). In the steppe part of the basin, very low minimum water discharges are observed, with river drying being a common phenomenon.

One of the peculiarities of multi-year flow of the Esil River and its tributaries is the tendency to grouping of high-water and low-water years, which complicates its use in economic sectors. According to available data, the duration of low-water years can be up to eight years.

Total surface water resources in the Esil River basin amount to 2.46 km^3 and decrease in low-water years with a frequency of once in 4 years (P=75%) to 1.16 km^3, with a frequency of once in 20 years (P=95%) – to 0.49 km^3.

The main water sources in the basin are the surface runoff of the Esil River and its tributaries. Underground waters of fresh and slightly brackish deposits are used mainly for domestic and drinking water supply, sometimes for irrigation and industrial and technical purposes, but they are characterized by relatively small operational reserves. Re-used treated wastewater is practically not involved in covering the needs of the economy due to the lack of necessary legislative, methodological and technical tools.

At the same time, in the Esil water basin there is a high pressure on local water resources, 96% of which are used for domestic needs.

The water supply of the city of Astana, the capital of Kazakhstan, is an acute problem due to the constant growth of the population. Until 2020, the water consumption of the capital's residents was 269 thousand m^3 per day, in 2022 – 311 thousand m^3 per day. According to forecasts, due to the active development of the city with residential neighborhoods, water consumption will reach 340 thousand m^3 per day by 2026.

The natural and climatic peculiarities of the zone determine its grain and cattle breeding specialization. However, given that the moisture regime is very severe, the sustainability of grain crop yields depends on the observance of agrotechnical practices aimed at accumulating and conserving soil moisture. The zone has high potential for production of durum wheat varieties.

The following negative climatic factors have been identified as affecting the growth of crops collectively: insufficient precipitation, very low relative humidity, late spring and early autumn frosts, low winter temperatures with strong winds and low snow cover. These factors result in droughts, freezing and the blowing out of crops, which have a negative effect on crop development. Consequently, farming in the study region will only be profitable if irrigation is provided.

Within the basin under consideration, the total area of irrigated lands is 116.11 thousand hectares, including 54.7 thousand hectares of regular irrigation lands and 61.41 thousand hectares of firth irrigation. The share of irrigated land is 0.55% of the total area of agricultural land, irrigated arable land occupies 0.27% of the total arable land. At the same time, it should be noted that, as can be seen on the map below (Figure 2), in the context of the regions of the republic, these indicators for the region can be considered minimal.

In the river basin, cereal crops predominate, occupying 86.58% of the cropped area structure, followed by forage crops (11.96%), industrial crops (0.69%) and potatoes, vegetables and melons (0.77%). On irrigated lands, the main part of the cultivated area is occupied by forage crops (68.28%), while on irregularly irrigated plots potatoes, vegetables and melons account for 31.72%, according to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan.

The territory under consideration is considered one of the leading industrial-agricultural regions of the republic, where agriculture is the dominant branch of the economy, being a large consumer of water resources.

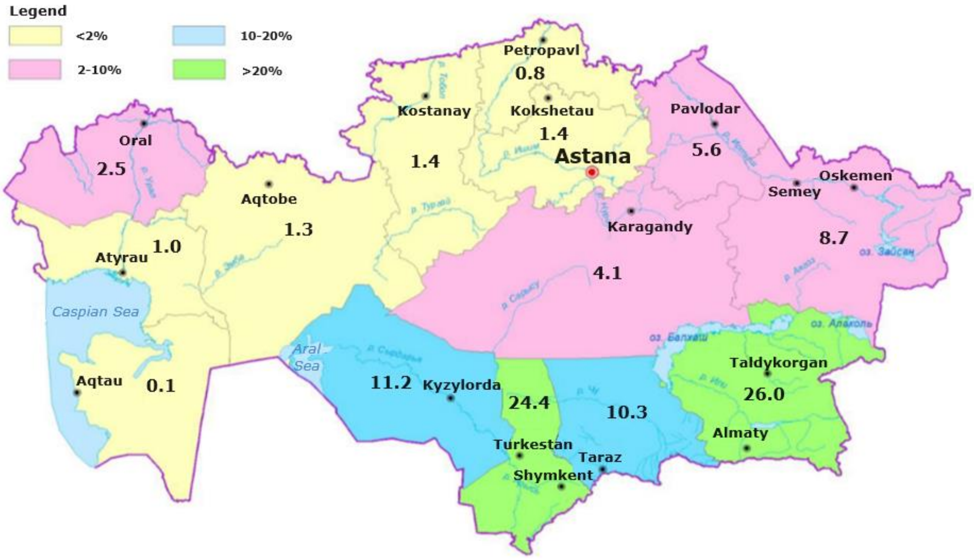

FIGURE 2. The share of irrigated land by region from their total area.

The primary water supply for a variety of economic sectors is derived from surface water resources. Up to 45% of all consumed water is directed to the needs of agriculture, approximately 30-35% is used in public utilities, while approximately 20% of water resources in the basin are used for industry. Table 1 below indicates that agriculture is a sector with a tendency to increase its water consumption.

TABLE 1. Aggregated calculations of water consumption in the Esil River basin for the period 2020-2025.

Types of water consumption	**Total water withdrawal, mln m^3**	
	2020	**2025**
Utilities	151,399	199,854
Industry	86,344	103,389
Agriculture, including:	193,692	242,372
regular irrigation	71,300	90,0
limanic irrigation	60,740	87,0
agricultural water supply	49,85	52,750
pasture watering	11,802	12,622
Fishery	3,60	4,500
Recreation and other needs	3,99	4,460
TOTAL	439,025	554,575

Source: Own elaboration based on the data of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan

In this regard, it is worth noting that limited access to water resources constrains the development potential of the region's economy, including agriculture, utilities and industry. At the same time, energy stability is necessary to ensure the sustainability of the region even in the context of sufficient water resources.

The energy sector in the study region is based on hydrocarbon fuels, particularly natural coal combustion.

The energy sector in the study region is primarily reliant on hydrocarbon fuels, with natural coal combustion representing the predominant energy source.

In parallel, Kazakhstan is implementing a decarbonization strategy in alignment with the Paris Agreement. Kazakhstan has declared its objective of achieving zero CO_2 emissions by 2060. Nevertheless, the country continues to face significant challenges in reducing CO_2 emissions, with levels remaining high and reaching 271 Mt CO_2 in 2022. This places Kazakhstan in 24th place in the ranking of CO_2 emitting countries, according to the Global Carbon Atlas. The goal of achieving carbon neutrality will be accomplished through the incorporation of alternative energy sources; nevertheless, the necessity for significant financial investments and the relatively short payback period have resulted in a relatively slow rate of implementation.

3. DISCUSSION AND RESULTS

3.1. Water security

The development of economic sectors in the studied region is hindered by growing water deficit, surface and groundwater pollution, excessive water losses in water management systems, aggravating problems of providing the population with quality drinking water, and problems of interstate water distribution.

The vulnerability of Astana, the capital of Kazakhstan, and the Esil River basin as a whole has also been identified. In this regard, attention should be paid to the ecological condition of the Esil River, the hydrological regime of which was changed as a result of the construction of the Astana (formerly Vyacheslav) reservoir. In fact, as part of the capital's territory improvement, a dam was built and the riverbed was significantly widened. At the same time, in order to maintain the water level, the river was divided into sections separated by a number of spillway-type dams, which significantly reduced the speed of water movement and, consequently, worsened the ecological condition of the Esil River.

Thus, at present there are real threats to sustainable development and environmental sustainability of the territory of the study region.

There are also problems with water supply to the residents of the capital city due to the increase in water consumption associated with population growth. Today water supply of the capital is carried out from the only source – Astana water reservoir, built in 1969 and designed for 500 thousand people. Due to the growth of the city's population (1.3 million people), the need to create a reserve source of drinking water for the city of Astana is becoming more acute. Therefore, in order to achieve sustainable development of the region, the priority task of the study is to develop recommendations to reduce water deficit in the Esil River basin.

In areas experiencing a deficit of water resources, it becomes necessary to employ a range of water management measures. The sequence of implementation of these measures is determined, firstly, by economic indicators, and secondly, by their environmental friendliness – that is to say, by the degree to which they result in adverse effects on the environment.

The study will consider the method of territorial redistribution of river flow as one of the measures aimed at ensuring adequate water supply to water-stressed regions. It is also a holistic, interconnected approach that transcends sectoral boundaries and promotes sustainable development of the most important sectors of the economy. The comprehensive nature of the study emphasizes the interconnections and complementarities that exist between the different aspects of sustainable development in the Esil River Basin.

Water resources redistribution can be defined as the complex of hydraulic and other structures that provide water withdrawal from regions with excessive water supply and its delivery through the watershed to low-water or remote catchments. The tasks of redistribution are associated with the solution of a wide range of environmental problems relevant for both the source and receiving areas.

The categorization of transfer systems is contingent upon the geographical features of the territory and the distances over which water is delivered. There are three main categories: intra-basin, or local, where the transfer system does not go beyond the basin of a given river that has an independent outlet to the sea, ocean or inland water body; inter-basin, linking river basins that have an independent outlet to the sea, ocean or inland water body; and interregional, or interzonal, linking river systems belonging to different physiographic regions.

In addition to territorial classification, it is reasonable to divide flow transfer systems according to the scale of water resources involved. The main criterion in this case should be the average annual volume of transfer. To a first approximation, complexes with an annual volume of transferred flow up to 1 km^3 can be referred to small transfers, medium – from 1 to 5 km^3, and large – over 5 km^3. The watercourse from which a part of runoff is withdrawn is usually referred to as the donor, and the river to which runoff is added is referred to as the recipient.

Global experience suggests that large-scale transfers are not always justified for a number of reasons, including significant environmental impacts, geopolitics and high project implementation costs. Nevertheless, a large number of water transfers have been designed, constructed and operated around the world. Their total global volume is about 400 km^3/year. In combination with flow regulation, they serve large regions while solving problems of energy, transport, irrigation, recreation and employment. The design and management of such systems is one of the most pressing water management issues.

As practice shows, the most feasible projects are inter-basin transfer of part of the runoff, which involve relatively small volumes of water intake. Many projects were not supported due to significant volumes of transfer, for example, the turn of the Siberian rivers to Central Asia and Kazakhstan.

A clear example of successful implementation of the of territorial redistribution of river flow is the Kanysh Satpayev Canal or Irtysh-Karaganda canal. By the end of 1940, the problems of water scarcity in Central Kazakhstan began to increase more and more often. Out of 2174 rivers flow through the territory of Kazakhstan, including the Irtysh, Syr Darya, Ili, Ural, Esil and other rivers, only 5.5% accounted for the central part of Kazakhstan. The construction of the canal was carried out more than ten years from 1962 to 1974. The problem of water scarcity in the city of Karaganda was immediately solved, and mining, chemical industry, heating and electricity, as well as irrigated agriculture began to develop rapidly. The Ekibastuz state district power plant 1 and 2 which are consuming the water of the canal, generate 50% of the electricity produced in Kazakhstan. Moreover, it is exported in Russia, and fed the largest metallurgical complex of the country in Temirtau, as well as many other industry enterprises. Both of these examples demonstrate that transferring part of the Irtysh River flow to the Nura-Sarysu and Esil river basins has been a positive experience.

The Kanysh Satpayev Canal became a key strategic water management facility, allowing for the growth and construction of new manufacturing facilities. The canal has the total length of 458 km, 272 km passes through the territory of the Pavlodar region and 186 km – through the Karaganda region. The canal contains 34 sections, 14 reservoirs and 22 pumping stations. Moreover, the canal has water outlets, duckers, storm pipes, spillways, bridges and blocking structures. The projected water supply of the canal nowadays is 1200 mil. m^3 per year. The construction of the Irtysh-Karaganda canal contributed to the active development of metallurgical production while preserving local water resources. Without the canal, it would be impossible to develop coal mining and energy in Ekibastuz, and ferrous metallurgy in Karaganda.

On the territory of Kazakhstan, the only source capable of increasing the water supply of the territory of the Esil basin is the Ertis donor River, where up to 33% of the country's total surface runoff is formed.

According to the recommendations of the Committee on Water Problems of the United Nations Economic Commission for Europe, it is considered that the intensity of water use, at which less than 10% of river runoff is withdrawn, is satisfactory, 20% – requires limiting water use and implementing measures to regulate the flow, if more than 20% – the water body will not be able to ensure the socio-economic development of the territory.

With equal water allocation of this runoff with the Russian Federation, it is possible to take water from the Irtysh River for transfer to the central region of the country up to 4.5 km^3, which is less than 15% of the runoff.

In this regard, when assessing the volume of transfers in this study, the principle of the maximum possible volume of withdrawal was adopted, taking into account the political, environmental, and economic aspects of water use. In this regard, the volume of water intake from the Irtysh River for supply to Northern and Central Kazakhstan can be 1-1.5 km^3 per year, while the volume of irrevocable withdrawal of water from the Irtysh River does not exceed the permissible 10%. The intensity of water use will be classified as moderate.

The water intake of the proposed canal will be carried out from the Shulba hydroelectric power station (hereinafter referred to as the HPP). The construction of the second stage of the Shulba HPP will increase the mark of the normal retaining level to 252.5 meters with a useful reservoir capacity of 7.5 km^3. The proposed canal to supply the Esil River basin can be laid within the Kazakh shallow-slope, which is characterized by general elevation of the territory with a range of altitudes from 200 to 1500 metres. The scheme of the proposed canal is shown in Figure 3.

FIGURE 3. Scheme of the projected canal.

The route of the canal will run mainly along the western part of the Kazakh plateau, where there are two low-lying massifs – Kokshetau Upland (947 m) and Ulytau (1133 m), separated by the vast Tengiz-Kurgaljin depression with a flat plain relief. The route is designed to use gravity transport for most of its length and to minimise the elevation of the pumping stations. This approach will undoubtedly increase construction costs, as it will require the construction of additional gravity transport structures (aqueducts, tunnels and culverts). On the other hand, it will reduce the construction costs of the pumping stations and, most importantly, the operating costs of the mechanical lift.

More than half of the cost of water supplied by the Kanysh Satpayev Canal accounts for the payment of electricity consumed by pumping stations for lifting water. Tariffs for the payment of water supply services do not contribute to the use of it for the needs of irrigated agriculture, the profit is minimal, often it brings losses. In this regard, at present, the Kanysh Satpayev Canal capacity is used by 30-40%, only about 30-40% of the design capacity is provided. The irrigated area in agriculture decreased the same way.

Furthermore, high energy costs contradict the green economy and low-carbon growth concepts. In this regard, the methods of gravity transfer and maximum use of the terrain were used when determining the canal's route.

Environmentally, economically, socially, and politically, effective water transfer schemes are widely regarded as appropriate. By using accepted principles, correct approaches and effective processes ensure that major economic, ecological, social, cultural and political issues are adequately addressed. Acceptable hydrologic, ecological, fiscal, and social values should direct water transfer planning. The majority of these are now a part of the planning and control of water supplies. The case studies demonstrate the importance of taking into account all of the principles, especially the solidarity and precautionary principles. As a result, using the proper methods and correct approaches would result in further improvements in the preparation of suitable water transfers. The case studies demonstrate how the water transfer meaning shifts over time. First, shifting from unilateral to cooperative activities presents opportunities and challenges in changing political, governance, and trade contexts. The transition from water sharing to hydro-solidarity, best joint use, and profit sharing is giving cooperative activities an additional impetus. Second, land use intensification (runoff management, and small dams) increases evapotranspiration and groundwater recharge, resulting in unintentional water transfers. Third, there is an increasing awareness of the high potential for areas experiencing water scarcity to use demand management approaches rather than depending on inter- and/or intra-basin water transfers to address water scarcity. Depending on what the recipient basin imports and exports, as well as the consequences for water demand, virtual water transfer will increase or decrease demand for water transfers.

At the moment there are two reservoirs of multi-year regulation on the Esil River within the territory of Kazakhstan – Astana (Vyacheslav) and Sergeev, in addition, there is a small reservoir of the Petropavlovsk water-engineering system, which carries out seasonal regulation of flow.

Astana (Vyacheslav) reservoir, located in the upper reaches of the Esil River, has a total volume of 419.4 million m^3 and an annual effective yield of 95 per cent of water availability equal to 72.0 million m^3. The Sergeev and Petropavl reservoirs form a single water management complex, which has a total volume of 712.2 million m^3 and an annual useful yield of 95% of security equal to 290.0 million m^3. Thus, the total annual useful yield (95% availability) of these reservoirs is 362,0 million m^3 of water per year.

In recent years, there have been cases of severe floods and droughts, the trend of growing water shortage in the region, even for municipal and drinking needs of the region and the capital. In this regard, the Government of the Republic of Kazakhstan is planning a set of measures aimed at increasing water availability in the region through additional regulation of the flow of the Esil River, in particular, the construction of the Buzuluk reservoir. The location of the proposed Buzuluk reservoir is shown below on the map below (Figure 4).

The Buzuluk reservoir construction project on the Esil River allows solving the problem of using the basin's own resources by regulating and accumulating part of the flood flow, as well as its safe passage in the lower reaches of the Esil River and stable operation of the downstream Sergeev and Petropavl reservoirs. The Government of the Republic of Kazakhstan planned to develop a project for the construction of the Buzuluk reservoir with expected commissioning by 2027.

FIGURE 4. Map-scheme of the Buzuluk reservoir location.

Meanwhile, it is planned that the reservoir be filled by drawing water from side streams on the Esil river – Akkanburlyk and Imanburlyk rivers, which do not provide guaranteed filling to cover all necessary water demands, especially in low-water years. In this regard, within the framework of this article it is proposed to transfer part of the flow from the Ertis River basin to the Esil River basin through part of the existing structures of the Kanysh Satpayev Canal from the water intake structure to the Hydrosystem No. 8, further – through the proposed new canal to the Astana Reservoir. At present, the capacity of the the Kanysh Satpayev Canal is used not more than 40% of the design capacity, i.e., 0.7 km^3 per year on average.

Additional volume of 1 km^3 proposed to be accumulated in Buzuluk reservoir is expedient to be used for creation of irrigated array in the studied region. Also, in the ongoing study the proposed reservoir is considered as a counter-regulator of the Sergeev reservoir. In this case, it is possible to ensure long-term sustainable operation of the planned Buzuluk complex reservoir.

The inter-basin water transfer project and optimization of the Buzuluk reservoir resource use proposed in this article can become key tools for local executive bodies and farmers in planning and developing the agricultural sector in the region.

These measures will enable more efficient water management, which is critical for sustainable farming. The implementation of these projects will help improve irrigation infrastructure, increase crop yields and ensure a stable water supply, which ultimately contributes to economic growth and food security in the region.

3.2 Food security

The region of Central Kazakhstan boasts favorable agro-climatic conditions for the cultivation of hard wheat (durum), which has higher market price than soft wheat on the global market. Durum wheat is characterized by resistance to drought and high temperatures, and also has resistance to diseases such as rust and hard heading. In addition, grain losses during cultivation are low compared to soft wheat.

International experience shows that productivity of durum wheat in the zone of risky farming can be increased 5-6 times by irrigation and competent agrotechnology. Comparison shows that durum wheat yield on irrigated lands is significantly higher both in Kazakhstan and globally. In Kazakhstan, the difference in durum wheat yield between irrigated and rainfed lands can be up to 3 times, while globally this difference can be 2-3 times. In the region under study, irrigated farming for growing durum wheat varieties will be the most profitable.

In the agro-climatic conditions of the study region under inconstant humidification autumn irrigations for accumulation of moisture in the soil are considered to be more priority, while vegetative irrigations are prescribed as necessary as additional measures. Moisture-charge irrigation rates for durum wheat varieties can vary between 600-1500 m^3/ha, irrigation rates can range from 600 to 800 m^3/ha, which is much less than required compared to other crops.

According to aggregated calculations, at the useful volume of the Buzuluk reservoir of 0.8 km^3 taking into account the attracted additional volume, which increases the guaranteed return of the reservoir, it is possible to irrigate about 200-330 thousand hectares of irrigated land, which at the projected yield per year of 4.8 t/ha gives a gross yield of wheat up to 1 million tons worth about USD 250 million.

3.3 Energy security

One of the most effective methods of utilizing small local energy resources of renewable energy sources in Kazakhstan is the use of energy from small watercourses, which have significant potential and can be used with comparative simplicity through the construction of small hydropower plants (hereinafter referred to as HPP). It should be noted that the economic potential of small hydropower exceeds the economic potential of such renewable energy sources as wind, solar and biomass combined. The value of hydropower plants is that they utilize renewable natural resources to produce electricity. Because there is no need for additional fuel for hydropower, the final cost of the electricity generated is significantly lower than with other types of power plants.

As an example, we can consider the project of a small hydropower plant on the Astana reservoir and calculate its capacity, having the data of the reservoirs.

Astana reservoir is one of the reservoirs of the Esil river basin, located in Akmola region, its length is 11 km and width is 10 km.

The reservoir was built in the upper reaches of the Esil River in 1969. The area – 61 km^2, volume – 0.411 km^3. It carries out perennial flow regulation and is used for energy and irrigation. In 2002, a water pipeline from the Irtysh-Karaganda canal, which was built in 1968 to supply water to industrial areas and agriculture in Central Kazakhstan, was laid to the reservoir to supply water to the capital of the country. Figure 5 below shows the dam on the Astana reservoir.

FIGURE 5. Spillway dam on the Astana reservoir.

Having established the water head at the Astana reservoir by means of the level difference of the reservoir embankment (H), as well as the data of the average water discharge (Q), the calculations of potential capacity of the proposed small HPP can be made. Using general formulas by A. Subbotin and V. Khaustov "Hydrotechnics and melioration" textbook (1), (2) the aggregated potential capacity of the HPP can be calculated as follows:

$$N_{HPP}=9{,}81\cdot Q\cdot H\cdot \eta_t\cdot \eta_g, \quad (1)$$

where,

N_{HPP} – the SHP generation capacity (kW);

Q – flow rate (m^3/s);

H – effective head (m);

η_t – turbine efficiency;

η_g – generator efficiency.

Then,

$$N_{HPP}=9.81\cdot 24.32\cdot 18\cdot 0.75 = 3320.8 \text{ kW}$$

The annual energy production (AEP) will be equal to:

$$AEP=(W_{HPP}\cdot H_{HPP}\cdot \eta_t\cdot \eta_g)/367{,}2 \quad (2)$$

where,

W_{HPP} – flow volume;

H_{HPP} – actual power with which the HPP operates in the time interval ΔT.

Then,

$$AEP=(767\ 000\ 000\cdot 18\cdot 0.88\cdot 0.95)/367.2 = 31\ 431\ 960.8 \text{ kW/h}$$

Construction of small HPPs has broad prospects for development in different regions of the world with transboundary river basins. Small hydropower is free from many disadvantages of large HPPs and is recognized as one of the most economical and environmentally friendly ways of generating electricity, especially when using small watercourses.

Advantages of small hydropower plants:

- mitigating the environmental impact of global climate change by reducing CO_2 emissions;
- minimal flooding and development areas;
- local and regional development;
- river basin maintenance assistance;
- rural electrification.

During the construction and operation of small hydropower plants, the natural landscape is preserved and there is practically no load on the ecosystem. The advantages of small hydropower compared to fossil fuel power plants include: low cost of electricity and operating costs, relatively inexpensive replacement of equipment, longer service life of HPPs (40-50 years), integrated use of water resources (power generation, water supply, land reclamation, water protection, fishery).

The disadvantages of small HPPs include slow return on investment, which is at the level of 5-10 years. For comparison, cogeneration plants and mini-TPPs built on their basis currently have a payback period of 2 to 4 years (depending on regional tariffs for electricity and heat, as well as gas prices).

The projected small HPP with a capacity of 3320.8 kW at the Astana reservoir will provide electricity generation of 31 431 960.8 kW/h for the neighboring settlements, which contributes to the regional development of green infrastructure.

4. CONCLUSIONS

This study analyzed in detail the sustainable development of the Esil River Basin with a focus on water, food and energy security linkages, which is in line with the principles of the NEXUS "water-food-energy-ecosystems" approach and the requirements of the

Paris Agreement. The study of historical data and economic indicators revealed significant pressure on local water resources, which necessitates the introduction of new water management facilities and effective water resources management.

Redistribution of river flow from the Ertis River basin to the Esil River basin through existing and new canals will solve the water supply problem, increasing water availability in the region and the capital city.

The increasing demand for water resources in all sectors of the economy, coupled with the negative impact of climate change, creates risks for sustainable agriculture in the region. To prevent such risks, this paper proposes a set of measures, such as an inter-basin transfer of part of the flow from the Ertis River basin to the Esil River basin, proposals for effective regulation of the flow of the Esil River, as well as proposals for rationalizing the operation of the planned Buzuluk reservoir. These measures together can ensure sustainable development of the region under study, as well as contribute to the diversification of local agricultural production aimed at growing profitable durum wheat varieties.

The region's energy sector, based on hydrocarbon fuels, requires modernization and transition to renewable energy sources. The development of small hydropower plants, such as the projected hydropower plant at the Astana reservoir, will ensure stable energy supply and reduce CO_2 emissions, which is in line with Kazakhstan's decarbonization goals and its commitments under the Paris Agreement. The introduction of alternative energy sources will help the region not only to achieve carbon neutrality, but also to support sustainable agricultural and industrial development.

In conclusion, the integration of sustainable agricultural practices, optimization of water resources uses and renewable energy development in the Esil River Basin will create the basis for long-term sustainable development of the region, improve the quality of life of the local population and minimize environmental impacts.