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Anthropogenic Impacts in the Yesil River Basin

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ABSTRACT

The research aimed to assess the impact of human economic activities on the Yesil River Basin based on the observational data contained in Kazhydromet's (Republic State Enterprise, RSE) hydrometeorological periodicals of 1933-2019. The additional analysis of numerous sources - statistics digests, online data of the Bureau of National Statistics under the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (RK), monographs and scientific papers also allowed to reliably evaluate the overall water consumption in the country. The analysis of the available materials permitted identifying the indicators of irretrievable water consumption (IWC) by sectors of the national economy, including utilities, industry, and agriculture (irrigation). As the result, in terms of water use the IWC in the target watershed turned out to range between 3-29% of the total irretrievable water consumption (TIWC), with the corresponding highest value registered in 2007. It was also established that large reservoirs - Astaninskoye (Vyacheslavskoye) and Sergeyevskoye - have been exerting a regulating pressure on the long-term flow of the rivers comprising the basin. The review of the data obtained likewise indicates that, compared to the conditionally natural phase, their runoff reduction during the disturbed phase is caused not only by reservoir related but also agrotechnical and climate change impacts. The study findings can serve water management purposes, aid the design of hydraulic facilities, as well as expand regional theoretical and applied hydrological research.

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1. Introduction

A reliable and comprehensive assessment of water resources as well as current and future water availability in a basin/area requires a quantitative evaluation of its dynamics due to human economic activity.

For centuries, the anthropogenic effects on river flows were mostly local and rather insignificant. The remarkable properties of natural water, i.e. renewal and selfcleansing in the course of natural circulation, have been contributing to its relative purity, sufficient quantity and quality for a long time. As in multiple other regions and countries around the globe, the situation in Kazakhstan has radically changed in recent decades – persistent and longstanding unreasonable water use and transformation of river catchments have started yielding their bitter fruit. Small and midsized rivers became the first victims of cardinal water regime changes in multiple densely populated areas (Davletgaliyev, 2011). Starting 1950-1960's, noticeable manmade changes in river flows became more obvious, primarily in variable and insufficient moisture contexts. Mounting water shortages, especially in dry years, further aggravated ubiquitous water resource depletion.

In catchments located amidst most economically developed regions, river flows are usually exposed to many anthropogenic factors simultaneously, including the main ones affecting their quantitative parameters: channel regulation; irrigated agriculture; discharge diversion; industrial, municipal, and agricultural water supply; agroforestry; and urban development.

Whereas anthropogenic activities inevitably tamper water resources (Dalzochio, 2019), demographic and economic growth constantly bolster their role. Unlike other natural resources, water is capable of renewal in the process of its circulation in nature. Yet, water mainly in the form of surface river runoff is distributed extremely unevenly over territory and time. In many parts of the world, the available water assets do not cover the corresponding water needs, especially due to industrial pollution. The same is true for Kazakhstan's water management basins. Their runoff water resources have been shrinking by 16.0 km^3 per year due to human activities (Alimkulov, 2021).

Since 1970's, the relevance of reliable water resource assessment and projection of their potential changes due to human economic activity has grown even more against the backdrop of real changes in global and regional climate characteristics. These changes are already taking place in the Yesil Basin and may lead to largescale hydrological cycle shifts, alterations in water resources and their use, as well as modify their spatial and temporal distribution, extreme river flow features, and their variability.

The Yesil flows on the territory of Kazakhstan (50°38′05″ n.l. 73°11′41″ e.l. and 57°41′53″ n.l. 71°11′51″ e.l.), and is a leftbank tributary (2 450 km long) of the Yertis River with the catchment area of 177 000 km^2, including 141 000 km^2 of active catchment (Galperin, 2012). The watershed represents an important ecosystem both for Kazakhstan and its capital city of Astana currently undergoing brisk growth and development. The river serves as practically the only source of fresh water supply for the population, industry, and agriculture of Akmola and North Kazakhstan Oblasts (Regions) as shown in Fig. 1., as well as the key natural factor contributing to favorable living conditions in the study area. The long-term impact of the totality of anthropogenic and technogenic factors on the target basin have already manifested themselves in the changing water regime and deteriorating quality of local surface and ground water (Makhmudova, 2023).

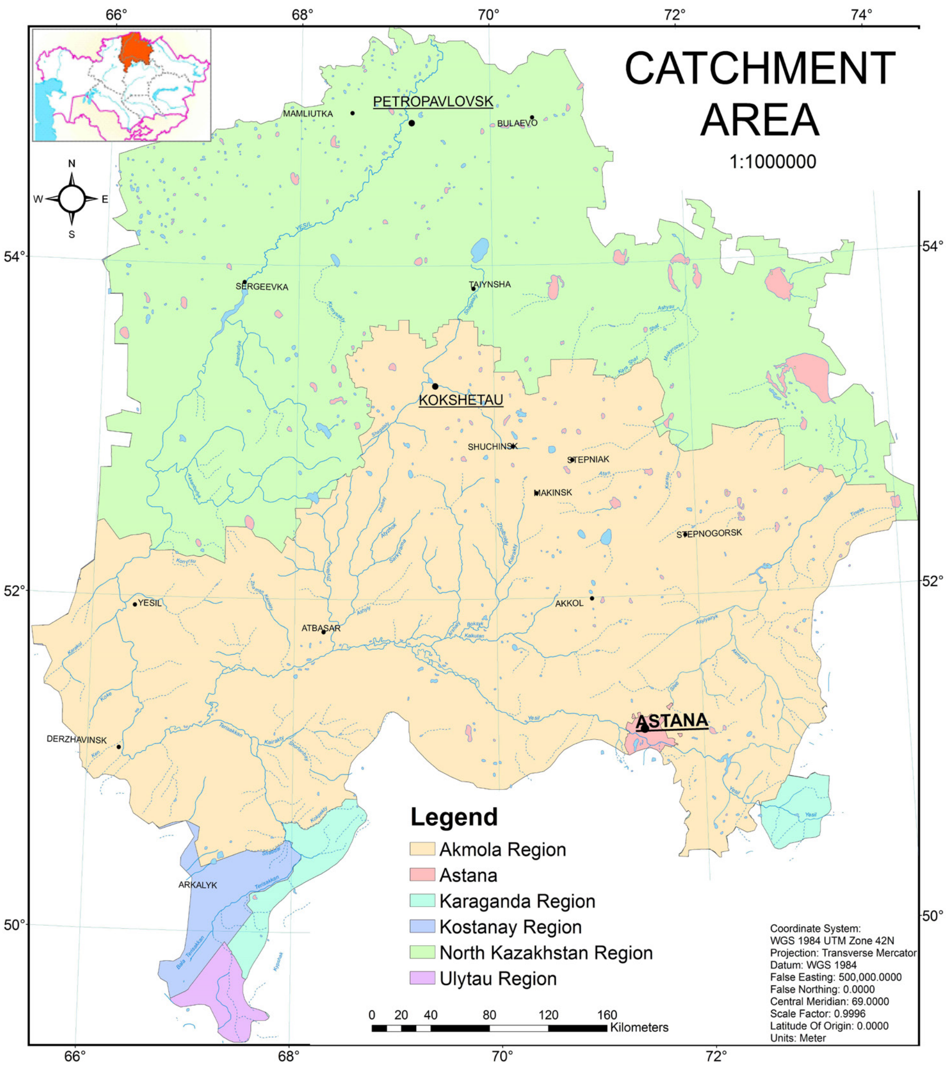

Figure 1. Study area.

The study aimed to identify the impacts of anthropogenic factors on the Yesil River Basin described in several research articles (Moldakhmetov et al., 2007; Galperin, 2001; Moldakhmetov & Makhmudova, 2008) the majority of which focus on their influence on the river's runoff formation and intra-annual distribution, but this time considering the regulatory capacity of reservoirs and ponds.

2. Materials and methods

This study utilized the published data of Kazhydromet RSE harvested by its observation networks, Hydrological Yearbooks, as well as Kazakhstan's State Water Cadastre spanning 1933 through 2019 (annual databases describing inland surface water regimes and resources) (Surface water resources of virgin and fallow lands under development, 1959; Basic hydrological characteristics, 1981; State Water Cadastre of the RK, 2004; State Water Cadastre of the RK, 2000-2017, 2017). The undertaken analysis of numerous sources like statistical digests, open-source data of the Bureau of National Statistics under the Agency for Strategic Planning and Reforms of the RK, monographs and scientific articles made it possible to reliably assess water consumption in Kazakhstan (Environmental Protection in the RK, 2011, 2015, 2020, and 2021).

The choice of the calculation periods was based on the outcomes of the earlier analyses of long-term runoff fluctuations in the rivers of the Yesil Water Management Basin (Galperin, 2012). The assessment accommodated the information on the total water usage characteristics, including the data on primary water consumers such as utilities, industry, and agriculture (irrigation water supply). Various methods were used for data processing, including multivariate statistical analysis, correlation dependencies, and geographical analogy.

The research made an attempt to evaluate the total and irretrievable water consumption, with subsequent differentiation of evaluation results by economic sectors. This approach allowed obtaining relatively reliable forecasts of the potential future anthropogenic impacts on water resources.

The two main variables in any water use accounting system include: 1) volume of water withdrawn from a water body (separately from surface and ground water bodies) often referred to as total water consumption; volume of used and then discharged water, i.e. volume of water disposal with mandatory indicators of water quality (fundamental feature of water consumption impact on the quality of natural water); 2) volume of irretrievable water consumption, i.e. difference between water intake and volume of water that came back to water bodies after use (usually, this value corresponds to the volume of water release or wastewater disposal).

The volume of IWC presented as a percentage share of the volume of total water consumption represents the core parameter of a quantitative assessment of water consumption influence on water resources. The volume of irretrievable water consumption not only in irrigation but also in industry and public utilities is more significant for dry and hot climate areas, the Yesil River Basin being one of them.

To assess the impact of municipal water consumption on the annual runoff, the research team applied the methods of the State Hydrological Institute, SHI (Russian Federal State Budgetary Organization) allowing to calculate irretrievable water losses based on total water consumption and special coefficients (indices) depending on various water consumption characteristics and climatic conditions.

Thus, the decrease in mean annual river flow due to municipal water consumption (ΔY) equals:

$$\Delta Y = K \times Q \tag{1}$$

with Q as the volume of water intake for utility needs, and K as an index the value of which depends on climatic conditions and water intake values.

Based on SHI studies (Shiklomanov, 2008), in 1985 the coefficient value ranged between 0.10 and 0.15 for large northern river basins, and between 0.20 and 0.30 for southern ones. Considering the fact that during 1985-2005 the water withdrawal specifically for utility needs had changed insignificantly, the study team considered it reasonable to use the indicated coefficient values for presentday assessments.

To approximate the impact of industrial (as well as municipal) water consumption on river flows, SHI uses more or less reliable water withdrawal data; the rough IWC can be determined by maintaining the indices that depend on industries, adopted water supply systems and climatic conditions.

With regard to large regions and river basins hosting a wide variety of industries, the change in the annual river runoff/water resources (ΔУ) due to industrial water consumption can be approximately estimated based on the following formula:

$$\Delta У = K \times Q \tag{2}$$

with Q as total water withdrawals for industrial needs, and K as the coefficient the value of which corresponds to the level of 1980-1990 (with practically stable industrial water use), i.e. K=0.08-0.10 (for northern regions) and K=0.15-0.20 (for southern regions).

From the practical point of view, the most important aspects of irrigation impacts on hydrological regime and water balance include changes in total river flow, with their intensity depending on a broad spectrum of natural and manmade factors and, above all, the scale of irrigation, types of irrigation systems, volumes of total and irretrievable water consumption, as well as local physical and geographical conditions.

For traditional irrigation zones, where irrigated farming represents the main type of economic activity and prevailing impact on water resources, it is possible to reliably assess and forecast its influence on river discharge based on a statistical analysis of long-term runoff observations at outlet river sections featuring main runoffforming factors, meteorological conditions and dynamics of irrigated areas in the basin (Leonov, 1981).

The influence of reservoirs on the annual river runoff has been thoroughly studied (Ahn, 2014; Galperin & Vasilyev, 1979; Galperin & Moldakhmetov, 2003). However, the decisive influence of such facilities is represented, first of all, in the intra-annual runoff distribution at outlet sections, as it is exactly there where reservoirs' function is to eliminate the natural runoff unevenness, specifically an increased runoff during low periods due to decreased flood runoff (Skotselyas, 1995; Kolmogorov, 1987).

The construction of large reservoirs in the study area has led to the gradual change (leveling) of intraannual flow distribution. To investigate this change, the study team has analyzed long-term monthly runoff data series for the Yesil River along its course at several hydrostations.

It is possible to carry out the analysis of long-term intra-annual distribution of the annual runoff using the method of moving means, monthly runoff integral curves, as well as by comparing the distribution of monthly runoff in different years with various levels of runoff regulation in a catchment area, but with similar meteorological conditions. Calculation methods can be likewise applied (Makhmudova et al., 2021) for comparing the regulated observed runoff with reconstructed values. Yet, as rightly noted in (Veretennikova & Leonov, 1982; Sokolov & Popov, 1979), the retransformation of monthly and 10-day runoffs by existing mathematical methods (Andreyanov, 1960) is difficult due to reconstruction errors often commensurating with monthly runoff values.

3. Results

The research allowed estimating the irretrievable water consumption (by types of use) according to the characteristics of total water consumption in the Yesil Basin over the past 15 years, specifically that IWC for domestic and drinking purposes in the target watershed ranges from 33 to 54% of the TIWC, with the maximum value for irretrievable domestic and drinking water consumption falling on 2016; that for industrial purposes ranges between 24 and 64% of TIWC, with the maximum value corresponding to 2019; and for agriculture may reach 30%, with the maximum value observed in 2005.

Using the SHI methodology as per formula (1) to assess the impact of utility water consumption on the annual runoff, under this research the value of ΔY was calculated for the period of 2005-2019. In the target watershed, the fall in the mean annual river runoff due to utility water consumption ranged between 10 and 16%, with the maximum values observed in 2006, 2008, 2014, 2017, and 2019.

In the target catchment, against the background of a sharp TWC increase during 2017-2019, the volume of utility water consumption grew. Fig. 2. describes the dynamics of utility water consumption in the basin during 2005-2019.

Calculated as per the SHI method using formula (2), the reduction in the annual Yesil flow due to industrial water consumption is shown in Table 3. for the period from 2005 to 2019.

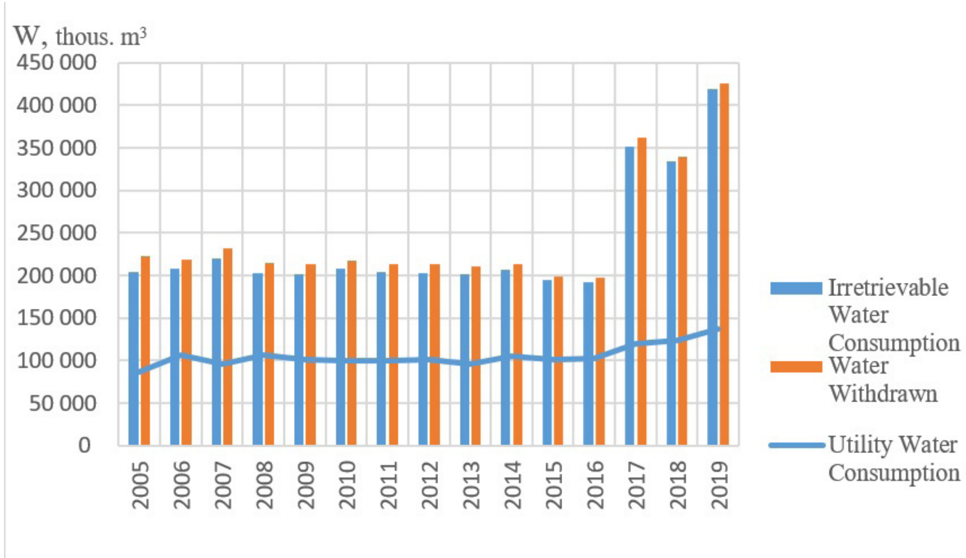

Figure 2. Utility water consumption (water withdrawal, irretrievable water consumption, utility water consumption) dynamics in the Yesil Basin.

In the Yesil Basin, the decrease in the mean annual river runoff due to industrial water consumption averaged from 5 to 10%, with the maximum values observed in 2017, 2018, and 2019. The corresponding calculated value amounted to 40 988 thous. m^3 (2019), i.e. approx. 10% of the water intake inside the watershed.

Since 2017, the target basin has been witnessing an increase in industrial production, including the construction of new enterprises based on modern water-efficient technologies. This fact made it necessary to take into account the trend of the potential growth of this index while projecting the indicator until 2030.

Fig. 2. shows IWC dynamics for irrigation and agricultural water supply in the Yesil River Basin during 2005-2019.

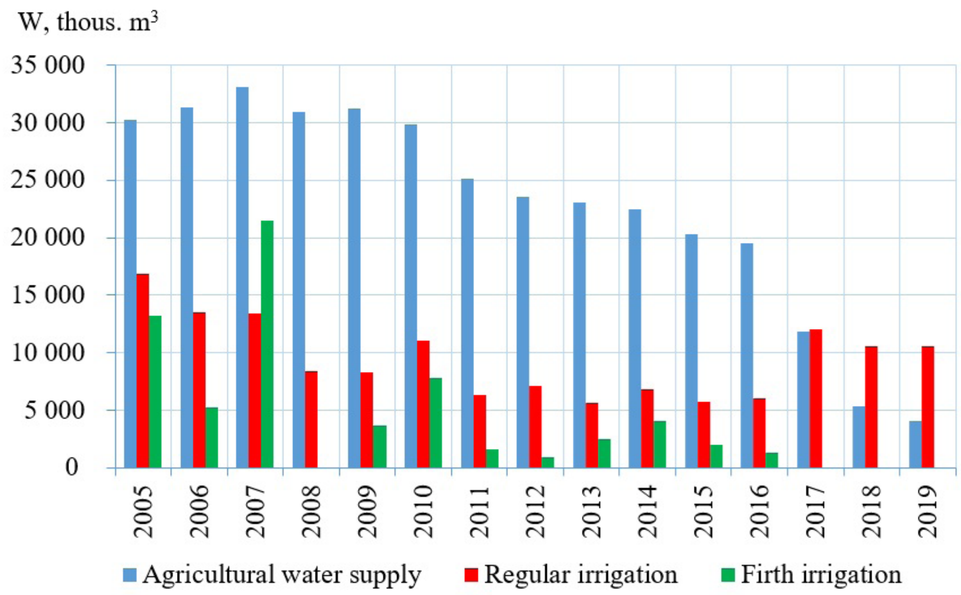

Figure 3. Dynamics of irretrievable water consumption for irrigation (regular and estuary)and agricultural water supply in the Yesil River Basin (thous. m^3).

Fig. 3. presents the maximum IWC values for irrigation and agricultural water supply in the study area for the following years: 2007 and 2009 (agricultural water supply); 2005, 2006, 2007, 2010, and 2017 (regular irrigation); as well as 2005 and 2007 (firth irrigation).

The irrigated farmland inside the target watershed is distributed unevenly with significant temporal variation, as evidenced by the data in Table I.

It is worth noting that the task of reliably estimating the irrigated acreage within river catchments is far from simple due to the lack of the necessary statistics and the need to collect long-term information about a large number of subjects. In case of the Yesil River Basin, it is especially difficult, because its certain subcatchments are shared by several constituencies (administrative units).

Table I. Irrigated land area dynamics in the Yesil Water Management Basin (thous. ha).

Region	1991	2000	2018	2019
Akmola	45.2	44.5	31.6	31.6
Karaganda	96.6	89.6	93.0	93.1
Kostanay	39.8	41.6	32.3	32.3
North Kazakhstan	35.4	22.8	17.0	17.0
Total	217.0	198.5	173.9	174.0

The target basin demonstrates a significant reduction in irretrievable water consumption for agricultural water supply due to the sharp drop in livestock population; as well as a decrease in rural population and transfer of a significant share of agricultural water pipelines to domestic and utility service systems. The irretrievable losses in utility water consumption, defined as a percentage share of water withdrawal, depend primarily on the volume of water withdrawn and climatic conditions. With the water consumption of 100-200 l/day per person, the irretrievable water losses usually do not exceed 15-30% of the water intake (20-50 l/day), yet can reach 70-100% in case of small-scale water intake (20-50 l/day). The sector disaggregated irretrievable water consumption in the Yesil Basin ranges between 3-29% of TIWC, with the maximum value registered in 2007 (Table II.).

Table II. Dynamics of irretrievable water consumption by sectors in the Yesil River Basin.

Year	Water intake, thous. m^3	Utility irretrievable, %	Industrial irretrievable, %	Agricultural irretrievable, %
2005	222 825	10	4	29
2006	218 466	15	4	23
2007	232 283	12	4	29
2008	214 466	15	4	18
2009	213 072	15	4	10
2010	217 782	14	4	22
2011	213 314	15	5	15
2012	212 889	15	5	15
2013	210 625	15	5	15
2014	212 630	16	5	16
2015	198 994	16	5	14
2016	196 883	16	5	14
2017	361 610	10	9	7
2018	338 846	11	9	5
2019	425 756	10	10	3

The studies investigating IWC dynamics in river basins do not single out agricultural water supply processing the corresponding values merged with these for water consumption in irrigated agriculture.

River regimes and water resources are also significantly affected by water consumption in watersheds and operation of reservoirs. Water consumption in river basins leads to falling annual flows. In its turn, the decreased annual discharge of regulated rivers is associated with the initial filling of reservoirs, surface evaporation and water infiltration into their bed.

At present, 45 reservoirs operate in the Yesil River Basin, including: 3 mixed purpose facilities with design volume exceeding 100 mln m^3; 6 with design volume exceeding 10 mln m^3 ; and 36 special purpose reservoirs with 1-10 mln m^3 capacity.

The reservoirs in the Yesil Water Management Basin were put into operation during 1946-1993, with the maximum number (3) commissioned in 1978 and 1988), and the maximum volume commissioned in 1966 (230 mln m^3), 1969 (693 mln m^3), and 1971 (412 mln m^3). The active storage of the remaining smaller reservoirs ranges between 1.19 and 34 mln m^3 (Fig. 4.).

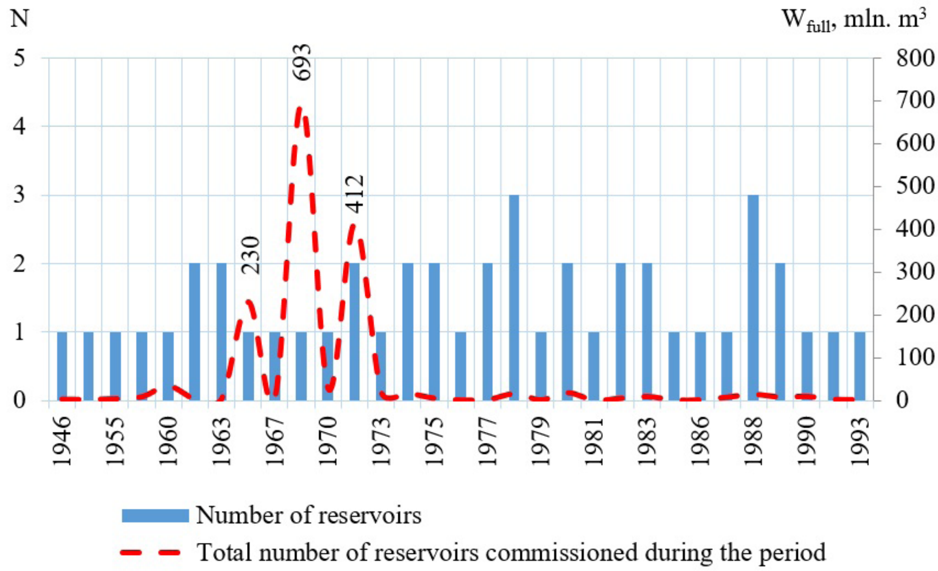

Figure 4. Reservoir commissioning dynamics in the Yesil River Basin.

To quantify the change in the intra-annual runoff distribution in the Yesil River Basin, the calculations were executed for 2 representative phases (periods):

- prior to the commissioning of the main reservoirs (1933-1973) characterized by slight economic pressure, i.e. the conditionally natural period;

- after the commissioning of the main reservoirs (1974-2018) characterized by significant hydrological regime violation due to severe long-term flow regulation by the Vyacheslavskoye and Sergeyevskoye Reservoirs (Table III.).

Flow regulation in the Yesil River Basin is carried out in the interests of industrial, domestic and agricultural water supply, estuary and regular irrigation, as well as fisheries.

The calculation outcomes showed no significant impact of runoff regulation on the hydrological regime of the upper Yesil stream.

During the conditionally natural phase of highwater years, at the Yesil-Udarnoye Station's cross section 94.6% of the annual runoff took place in the course of the spring period (April through May), and 5.64% in the course of the summer-autumn period. During the disturbed phase, 89.8% of the annual flow passed in the spring, 6.15% during summer-autumn, and 4.06% in winter.

At the Yesil-Astana Station, natural water discharges during spring months dropped 18.6% under the influence of the Yesil and Vyacheslavskoye Reservoirs in case of high-water years, by 30.1% in case of medium water content, and by 43.0% in case of shallow years. During summer-autumn and winter periods – when the reservoirs underwent depletion – the regulated water discharges in high- and medium-water years significantly exceeded the natural ones.

Table III. Seasonal runoff distribution (as percentage share of annual runoff) at observation points in the Yesil River Basin.

№	River Station	F, km^2	Calculation period	Water content by year	Seasonal Runoff		
					Spring (IV-V)	Summer-autumn (VI-X)	Winter (XI-III)
1	Yesil-Udarnoye	202	1949-1973	high-water	94.6	4.20	1.20
				medium	91.2	6.32	2.55
				low-water	92.4	7.44	0.21
			1974-1991	high-water	89.8	6.15	4.06
				medium	91.2	6.32	2.55
				low-water	92.4	7.44	0.21
2	Yesil-Turgen	3240	1974-2018	high-water	86.5	5.01	8.52
				medium	93.2	5.64	1.16
				low-water	93.1	6.36	0.51
3	Yesil-Astana	7400	1933-1973	high-water	91.0	6.36	2.61
				medium	93.8	4.96	1.29
				low-water	95.5	4.14	0.41
			1974-2005	high-water	72.4	16.0	11.6
				medium	63.7	22.7	13.6
				low-water	52.5	31.3	16.2

4	Yesil-Petropavlovsk	106000 118000	1932-1973	high-water	76.9	19.9	3.20
				medium	68.5	26.1	5.34
				low-water	54.1	36.3	9.57
			1974-2018	high-water	69.7	22.4	7.83
				medium	64.4	24.7	11.0
				low-water	55.3	28.9	15.8
5	Zhabay-Atbasar	8530	1936-1973	high-water	68.5	30.1	1.36
				medium	67.6	31.6	0.77
				low-water	66.3	33.3	0.36
			1974-2018	high-water	88.2	8.44	3.36
				medium	87.3	8.68	4.04
				low-water	87.3	8.49	4.18
6	Imanburluk-Sokolovka	3870 4070	1950-1973	high-water	93.7	4.46	1.81
				medium	92.0	6.77	1.23
				low-water	86.8	12.3	0.86
			1974-2018	high-water	89.2	8.59	2.24
				medium	88.2	9.05	2.75
				low-water	85.1	9.86	5.05

In June-October, the regulated mean monthly discharges exceeded the amount of natural water discharges 2.5 times in high-water years, and up to 7.5 times in low-water years. In winter, the regulated runoff exceeded the natural one during high-water years 4.5 times, and in low-water years 39.5 times.

At the Yesil-Petropavlovsk River Station, the natural water discharges in April fell 10% under the influence of the Sergeyevskoye Reservoir in high-, medium, and low-water years with practically similar water content. During summer-autumn and winter periods, the regulated flow exceeded the natural flow significantly, i.e. by 7.5% and 6.5%, respectively.

The assessment of changes in the intraannual runoff distribution at the Yesil-Petropavlovsk cross section reflects the impact of 4 large reservoirs of long-term and season-al regulation (Fig. 5.).

The analysis of runoff dynamics and its intra-annual distribution points to the funda-mental hydrological regime alteration along the most part of the Yesil River. At the same time, above the Yesil-Astana Station, the flow regime transforms and balances out. In the river's lower reaches, the reservoirs exert weak pressure, i.e. the regulated hydrograph does not differ much compared to natural conditions. Whereas in the upper Yesil, the most noticeable runoff drop is observed in the spring, in its lower reaches (at the Yesil-Petropavlovsk Station), the spring runoff during the disturbed regime phase is significantly higher than that observed during the natural phase; and an increase in seasonal, especially winter, runoff is observed in dry years of 95% probability.

Calculations of the intra-annual distribution of runoff for specific years of different water content (25, 50, 75 and 95%) during conditionally natural and regulated regime phase conditions (as per Chagodayev formula) allowed assessing changes in intra-annual runoff distribution by the graphical comparison of the Yesil River's natural and disturbed hydrographs at separate cross sections (Fig. 6.).

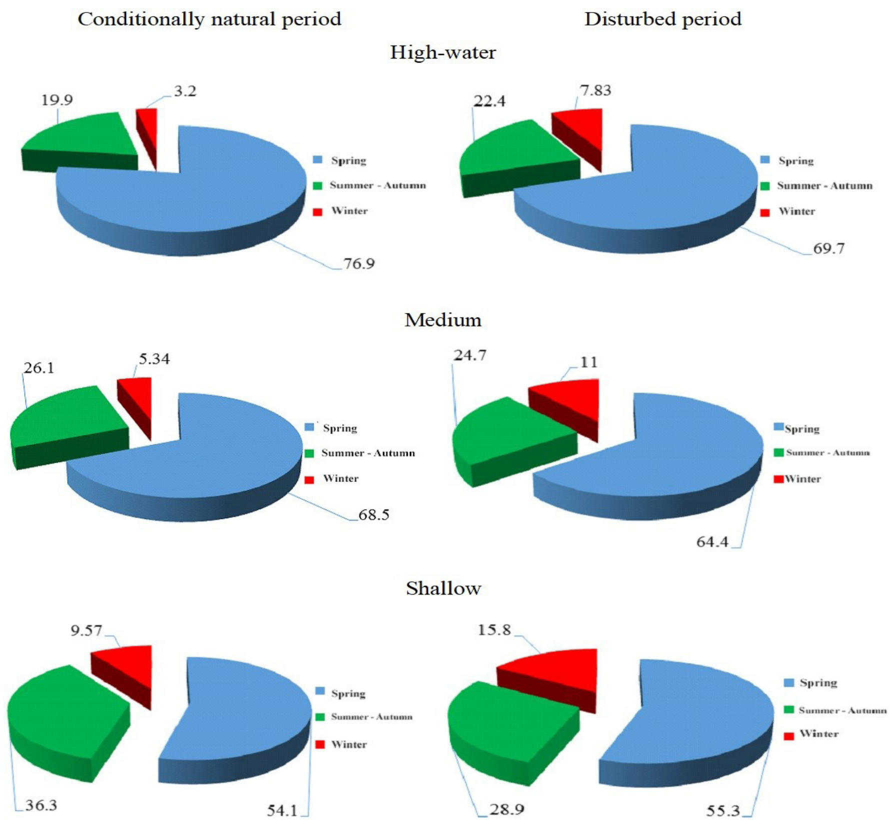

Figure 5. Seasonal runoff distribution (as percentage share of annual runoff) at the Yesil-Petropavlovsk River Station.

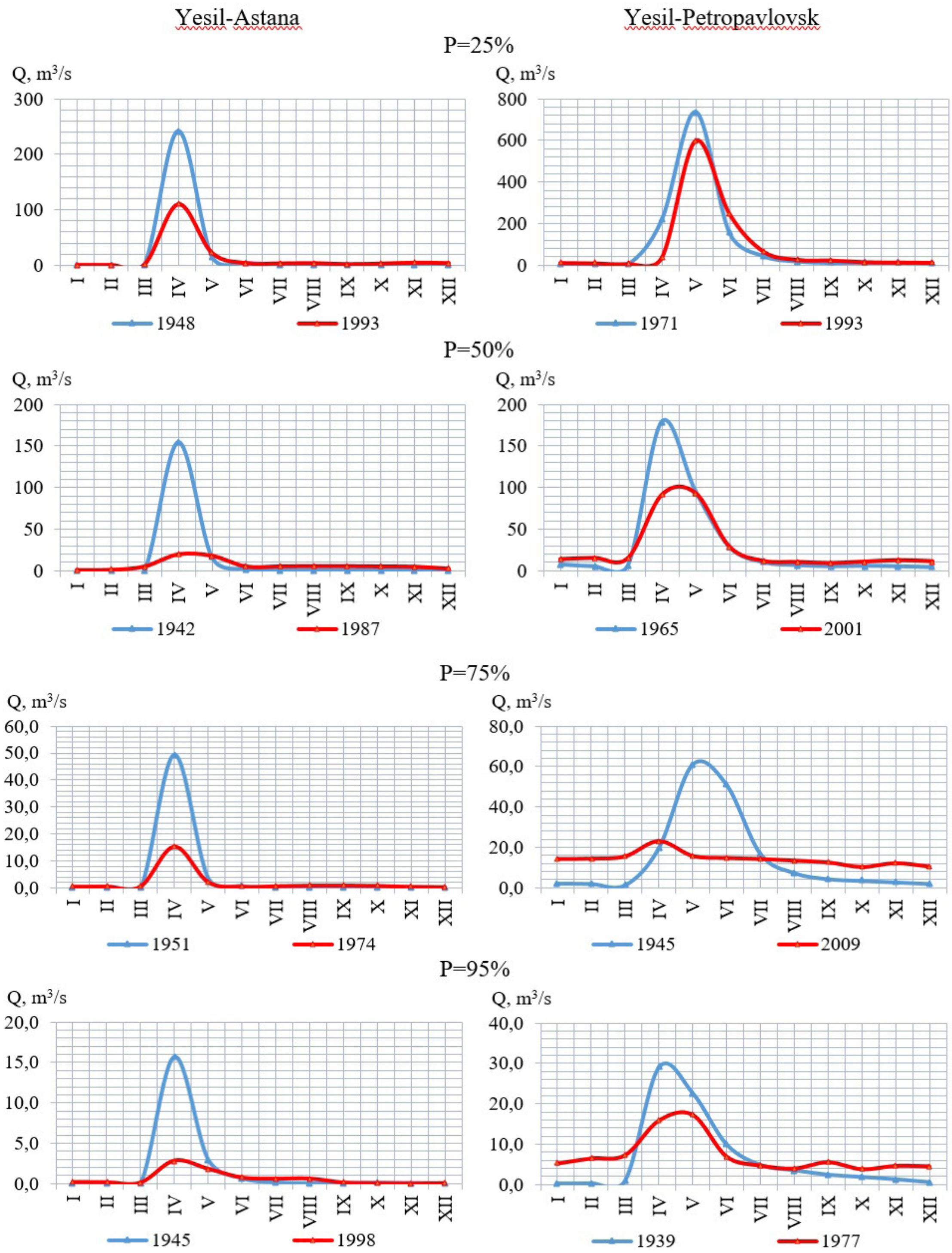

Figure 6. The Yesil River hydrographs, conditionally natural and regulated by reservoirs during years with different water availability.

Thus, under regulated flow conditions the violation of the natural hydrological regime begins after the reservoirs get filled. The quantitative analysis shows that due to the spring runoff drop during in the 2nd period (1974-2019) – distinguished from the 1st one by considerable hydrological regime violation – the summer-autumn and winter low-water runoff significantly grew as a result of deep long-term runoff regulation.

4. Discussion and concluding remarks

At the end of the 20th century, the accomplished fact of global warming began to be recognized as proven (Macklin & Rumsby, 2007; Akiyanova et al., 2019; Bernauer et al., 2012; Shiklomanov, 2004), yet the debate over the causes of the ongoing climate change remains unfinished. Many scientists associate the anthropogenically induced climate alteration with carbon dioxide accumulation in the atmosphere; others are firmly convinced that the natural cycle's energy potency is several orders of magnitude higher than human energy capabilities. The nature's rhythm and its phases exert dramatic influence over many processes occurring on Earth, including long-term river flow fluctuations as an integral climate change indicator. As for the recent man-made runoff changes, they pose quite a justified concern for the entire humanity. They do exist, yet their scale is not comparable to natural cyclic climate changes of different origin. The danger of anthropogenic changes lies in their irretrievably.

In addition, the totality of accumulating anthropogenic and cyclic natural climate changes is menacing because there are multi-year periods when both follow a similar pattern and can manifest themselves with alarming speed. For this reason, minimizing the man-induced climate change component is a safety option for humankind.

The irretrievable water consumption by sectors in the Yesil River Basin ranges from 3 to 29% of TIWC, with the maximum value registered in 2007.

Large reservoirs, such as Vyacheslavskoye and Sergeyevskoye, imposed the regulating effect on the long-term runoff in the target watershed that led to its conditional division into two phases: 1) during the period before the commissioning of the main reservoirs, and 2) during the period characterizing the current state of climate and degree of anthropogenic influences on the runoff (Makhmudova, 2022). In high-water years, the values of spring and summer-autumn runoff have shifted, spring runoff has decreased by 5% compared to the natural (1st) period, and summer-autumn runoff has increased by almost 2% due to the reservoir regulating capacity.

During medium-water content and dry years, no change in intraannual runoff is observed. The small useful capacity of the Yesil Reservoir slightly transforms the river flow in its lower section.

To track the runoff change under the influence of economic activity during the years of differing water availability, the study incorporated the calculation of natural flow dynamics.

The analysis of the calculation results shows that in wet years (10-25% supply), the runoff fell by 5% due to additional surface evaporation in artificial reservoirs. In medium water content years (50% supply), the annual runoff decreased by 18%. In dry years (80% availability), the annual runoff reduction ranged between 25 and 80%. In exceptionally dry years (95% availability), the entire annual runoff got retained in reservoirs and was irretrievably lost due to evaporation and economic use.

The analysis of the obtained data likewise shows that the comparative runoff decrease between the conditionally natural and disturbed regime phases cannot be entirely attributed to the influence of reservoirs, with an apparent anthropogenic impacts associated with agrotechnical operations and climate change.

The man- and climate-induced components of discharge reduction are determined by their adjustment (multiplication by runoff reduction indices for the conditionally natural phase). In case of no climatic trend, an approximate coincidence of the runoff of different probability and "adjusted" runoff is expected. In high-water years, these values differ apparently when the economic activity does not significantly distort the discharge, and climate change (trend) plays the main role.

The assessment of anthropogenic impact over river runoff involves justification of measures aimed at the protection and effective use of available water resources. It is clear that in each specific case, a set of actions taking account of local natural and anthropogenic peculiarities is required. Considering the falling river runoff in the study area, steps to prevent and mitigate the threat as much as possible should become a priority. The main tools to achieve these objectives are related to water saving and water-efficient technologies, as well as closed water consumption the applicability of which has been highly researched (Akhmetov, 2016; Kulkarni, 2011; Farmanov, 2020; Levidow, 2014).

The findings of this research may assist the practical tasks of executing preventive actions, efficient water management, proper design of hydraulic installations, etc., as well as scientific generalizations and forecasts on water-related matters. Further thematic research efforts may expand the theoretical and applied aspects of regional hydrological studies.

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