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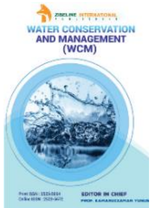

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RESEARCH ARTICLE

INTRA-ANNUAL FLOW DISTRIBUTION OF THE RIVERS IN THE YESIL RIVER BASIN

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ABSTRACT

Climate change and intensive economic activity in the river basins lead to a restructuring of the water regime. Therefore, this study aims to study the current intra-annual flow distribution in the plain rivers of the Yesil river basin, and to determine the estimated intra-annual distribution for different time periods. The results showed that the decrease in spring runoff is most noticeable in the upper stream of the Yesil river, in the lower stream of the river the spring runoff for the period with the disturbed regime is much higher than the spring runoff for the natural period, there is an increase in seasonal runoff. These findings indicate that as a result of an increase in the coefficient of natural flow regulation, the winter runoff of the Yesil river in the middle stream has increased by two or three times.

KEYWORDS

climate change, intra-annual flow distribution, coefficient of natural flow regulation, water regime, flow hydrograph

1. INTRODUCTION

The study of the patterns of intra-annual river flow distribution is one of the most essential issues for the rational and integrated use of water resources. The intra-annual flow distribution primarily determines the basic parameters of water management facilities: the guaranteed return of water from reservoirs, the capacity of regulation, the nature of flow regulation from reservoirs and, therefore, the economic efficiency of water management measures and facilities (Lisetskii, 2021). The intra-annual flow distribution varies constantly from year to year due to differences in the values of water discharge during the same phases of the water regime (peaks of high water, floods, low water level) and due to shifts in the time of occurrence of single-valued phases of the regime in different years (Christodoulou et al., 2020). Data on the intra-annual flow distribution is used in the development of flood control measures, in irrigation, in the development of industrial and economic water supply projects (He et al., 2019; Komilova et al., 2021).

The intra-annual river flow distribution is influenced by various factors. These include climatic conditions (amount and regime of precipitation, air temperature during the melting of seasonal snow and glaciers, evaporation from the surface of basins), topography, type of river feeding, hydrogeology, etc. (Cui et al., 2020; Korneychuk and Kirichuk, 2018). It is critical that methods and techniques for calculating intra-annual flow distribution must be analyzed both in terms of their correct reflection of existing natural patterns of intra-annual flow and meeting design requirements. The purpose of this research is to study the current intra-annual flow distribution in the plain rivers of the Yesil river basin, to determine the estimated intra-annual distribution for different time periods, and to study the coefficient of natural flow regulation.

2. LITERATURE REVIEW

The intra-annual river flow distribution varies significantly across the territory in accordance with changes in climatic conditions (Thakur et al., 2020). In addition to climatic factors, local conditions have a great impact on the flow distribution within the year. By the nature of the distribution of natural flow, the rivers of the Yesil river basin belong to the group of rivers with spring floods. During the spring period, 90-95 % of the annual runoff occurs within one to two months, and on small rivers up to 100 %.

According to H. Tan et al. (2021) classification, the rivers of the Yesil river basin belong to the Kazakhstani type, and according to A. Azarisamani et al. (2020) classification to the area of exclusively snow feeding: hence, the annual runoff of rivers in the concerned area is formed exclusively during spring floods (spring runoff makes up 90-95 % of the annual runoff). Spring floods in the Yesil river basin usually start in the second half of March – early April. In the first days of flooding, the intensity of water level rise is insignificant and reaches up to 5-10 cm per day, but then the intensity sharply increases and in years with average water content reaches up to 200 cm per day. In high-water years with smooth snowmelt (Moldakhmetov et al., 2019), the floods in the rivers of the Yesil river basin are very intense. Spring floods end in the small and medium-sized rivers of the concerned area by the end of April/early May and in the large rivers – by the end of May/June.

After the end of the spring high water, the rivers enter a summer-autumn low water season, characterized by consistently low levels. In June-July most of the rivers dry up and the water remains only in the individual reach holes, which are disintegrated with drying cross-overs. Low summer levels in the middle-size rivers occur mostly in July-August, and in the

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larger rivers, due to the late fall of the floodwaters, in September. Their fluctuations in small rivers do not exceed 15-30 cm and in large rivers – 50 cm (Blum et al., 2020).

Variations in winter river levels are generally insignificant, as they reflect only changes in the river reaches; cross-overs remain dry during this period. The duration of the summer-autumn and winter low-water periods is from 9 (July-March) to 11 (May-March) months. Winter low-water levels in most rivers occur in November, and in January-February in watercourses with little groundwater feed when groundwater runs out and the river reaches freeze over to the bottom. Winter levels are usually 20-40 cm higher than summer levels (De Niel and Willems, 2019). The annual amplitude of water level fluctuations in the rivers of the concerned area varies within considerable limits.

Due to the dryness of the climate, rainfall rarely forms floods. Only the most significant rains or series of rains with a rainfall amount of 30-50 mm or more can do this. Rainfall floods occur on average once every 3-5 years. This happens usually in June-July, and the duration of the flood usually does not exceed 5-10 days (Morri and Soualmia, 2020). If the flooding is low, the discharge at the peak of the rainfall flood can be higher on the small rivers than the maximum spring flood. In general, the proportion of rainfall runoff in the annual volume is usually insignificant.

3. Materials and Methods

Data from hydrological yearbooks and funds of Republican state enterprise "Kazhydromet" (Surface water resources…, 1977; 1980; State Water Cadastre, 1987; 2002; 2004) were used for calculations of intra-annual river flow distribution. Data processing was conducted for the following periods: 1933-1973, 1974-2014, and the entire observation period 1933-2014. The choice of the boundaries of the estimated periods is based on the results of the previously performed analysis of multi-year fluctuations of monthly river flow in the Yesil river basin and the authors' own studies (Moldakhmetov and Makhmudova, 2018). Hydrological calculations and statistical analysis were carried out using standard Excel and Statistica packages, maps were created using ArcGIS 10.6 software (spatial analysis method).

All calculations have been made in accordance with Code of practice SP 33-101-2003 "Determination of design hydrological performance" and the Methodological recommendations for determining estimated hydrological characteristics in cases of available, insufficient or missing hydrometric observation data and for assessment of uniformity of hydrological characteristics and determination of their estimated values from irregular data.

Several methods are available for the calculation of intra-annual distributions. The well-known methods are arithmetic mean (dummy) hydrograph, the hydrograph of a real year (characteristic year), equilibrium hydrograph, application of special indicators for calculation of intra-annual flow distribution, use of daily discharge duration curves to describe intra-annual flow distribution, compilation method.

The arithmetic mean method (dummy) hydrograph for the calculation of the intra-annual flow distribution is widely used in practice. This method has the advantage that atypical features of the flow regime of individual years are excluded, and the resulting characteristics are more stable and change insignificantly with the addition of new years of observation. The limitation of the method is that it results in a more aligned intra-annual distribution than in individual actual years, so this distribution is known in practice as the "dummy average" and can be used only for an approximate estimate.

When calculating by method of "equilibrium hydrograph", empirical probability curves of average monthly discharges for each month are constructed. They are used to derive values of average monthly discharges of different water probability (25, 50, 75, and 90 %). In practice, this method is not applied, since a real year does not consist of monthly discharges of the same probability. The essence of applying special indicators for calculating the intra-annual flow distribution is that special indicators are used to calculate the intra-annual flow distribution. These indicators mainly provide a general characteristic of intra-annual flow distribution. Several dozens of indicators are known: coefficient of natural flow regulation, intra-annual irregularity, etc.

V.G. Andreyanov (1960) considered this shortcoming and developed a method of calculation of the intra-annual flow distribution, which is suitable for any design problems and any physical-geographical conditions, for any type of intra-annual flow. This scheme assumes the same flow probability for the year, for the limiting period of the year, and within the limiting season. The probability is assumed to be a given.

The intra-annual distribution is calculated for several gradations of water content. Seasonal and intra-seasonal flow distributions are considered separately. The limiting period and season are selected depending on the prevailing economic use. This methodology is included in the Code of standards and rules 2.01.14-83 as the basic one recommended for the calculation of the intra-annual flow distribution. The calculation time intervals are usually months and seasons, less frequently decades and weeks. If observation materials are available, the calculation is based on series with duration of at least 15 years. This method is adopted for the calculation of the intra-annual flow distribution in the Yesil river basin.

4. Results and Discussion

The method of V.G. Andreyanov (1960) gives the best results for those rivers, on which dependence of the intra-annual flow distribution on the water content of the year is observed – these are plain rivers, which have snow feeding. The method is based on the assumption of the equality of flow probability for a year, limiting period and season. Calculation of annual, limiting period and limiting season runoff values is usually carried out according to the following four gradations of water content: high-water (P=25 %), medium (P=50 %), low-water (P=75 %) and very low-water (P=95 %). The hydrological justification of projects should select one design combination (in special cases two or three) out of the many possible flow combinations for individual seasons and parts thereof, which meets the design requirements for the proposed water use scheme. The design combination should be chosen as possible unfavourable, but not too rare frequency, which provides a given degree of guarantee of trouble-free and uninterrupted operation of the water consumer under consideration. In this regard, during the calculation, attention should be paid not only to the water content of the year but also to the water content of those periods and seasons, which are limiting (Andreyanov, 1960).

According to A.V. Rozhdestvensky et al. (2010), the intra-annual flow distribution is calculated using three methods: compilation; real (characteristic) year; average annual flow distribution of characteristic water content gradation. The boundaries of hydrological seasons and calculations of the intra-annual flow distribution were made based on observation data at 14 major gauging stations using the compilation method. The time frames of hydrological seasons for the rivers of the Yesil river basin are presented in Table 1.

Table 1: Time frames of hydrological seasons for the rivers of the Yesil basin

Basin	Season		
	Spring	Summer-Autumn	Winter
Yesil river basin	IV-V	VI-X	XI-III

In recent decades, the water regime of the rivers in the Yesil river basin and the nature of their intra-annual flow distribution have changed significantly. Let us consider in more detail the current peculiarities of intra-annual flow distribution and water regime for individual gauging stations. Under conditions of economic activity, a special role in changing intra-annual river flow distribution is played by channel storage, irrigation, industrial water supply, municipal economy and land and forest reclamation (Garibli et al., 2021).

The main factors of economic activity influencing the intra-annual river flow distribution in the basin under consideration are channel storage – multi-annual and seasonal regulation reservoirs (Astana, Sergeevsky, Petropavlovsk), numerous ponds, various water intakes, wastewater discharges, as well as ploughing of catchments. Reservoirs, on the other hand, have the dominant impact on runoff among the above-mentioned economic activities.

At present, there are 45 water reservoirs in the basin of Yesil river: 3 multi-purpose reservoirs with a capacity of more than 100 million m^3; 6 – with a capacity of more than 10 million m^3; and 36 reservoirs for special purposes with capacity from 1 to 10 million m^3. The total full capacity of multi-purpose and special purpose reservoirs under the project is 1584 million m^3, total usable capacity is 1446 million m^3, which makes 80 % of the annual volume of the basin's flow in the Yesil river basin. The water surface area of the reservoirs is 312 km^2 (Moldakhmetov et al., 2007) (Table 2).

Table 2: Information on active reservoirs in the Yesil river basin

N	Reservoir	Watercourse or reservoir formation area	Year of entry	Project capacity, million m^3		Water surface area, km^2		Type of regulation
				full	useful	at normal retaining level	at dead volume level	
Akmola region								
1	Ishimskoe	Yesil river	1958	*9.2*	8.2	2.3	-	Seasonal
2	Viacheslavskoye (Astaninskoye)	Yesil river	1971	410.9	375.4	60.9	9.94	Multiannual
3	Seletinskoe	Silety river	1966	230.0	220.0	36.3	2.1	Multiannual
4	Shaglinskoe	Shagalaly river	1970	28	27.2	9.7	4.13	Multiannual
5	Anarkul'skoe	Anarkul' lake	1946	3.48	2.8	4.05	3.02	Multiannual
6	Kara-Adyrskoe	Taldysai river	1948	2.64	2.26	1.7	0.15	Seasonal
7	Bogembajskoe	Bogembai river	1955	4.5	3.82	1.46	0.2	Multiannual
8	Bersuatskoe	Aktasty river	1960	34.0	32.5	11.0	0.12	Seasonal
9	Damsinskoe	Damsa river	1962	1.51	0.8	1.03	0.13	Seasonal
10	Ashchily-Ajryk	Ashchily-Airyk river	1963	3.71	3.04	1.3	0.5	Seasonal
11	Zhdanovskoe	Damsa river	1963	1.02	0.52	0.34	0.25	Seasonal
12	Osnovnoe	Damsa river	1967	7.5	4.0	3.0	0.14	Multiannual
13	Zhilandy-2	Zhilandy river	1971	1.51	1.33	0.6	0.14	Seasonal
14	Karabulakskoe	Aksu river	1974	12.34	11.89	5.50	0.45	Seasonal
15	Prohorovskoe	Kairakty river	1974	4.98	4.52	2.67	0.46	Seasonal
16	Gubernatorskoe	Bezymyannaya girder	1975	3.48	3.42	1.59	0.35	Seasonal
17	Ushakovskoe	Koshubai river	1975	2.17	2.10	1.37	0.03	Multiannual
18	Mat	Mat river	1976	1.45	0.35	0.90	0.18	Multiannual
19	Asyksai	Asyksai river	1977	1.47	1.41	0.84	0.10	Multiannual
20	Osychki	Osychki broad gully	1977	1.0	0.90	0.52	0.06	Multiannual
21	Uryupinskoe	Stepnaya rivver	1978	10.82	10.7	3.06	2.15	Multiannual
22	Tasmola	Tasmola river	1978	3.68	3.61	2.04	0.01	Multiannual
23	Tochim	Tochim girder	1978	1.57	1.54	0.64	0.05	Multiannual
24	Donetc	Donetc river	1979	2.04	2.01	1.15	0.08	Multiannual
25	Sarykamys	Sarykamys girder	1980	2.17	2.13	0.6	0.04	Multiannual
26	Kenetaj	Shortandy river	1980	16.41	10.0	5.22	1.66	Multiannual
27	Dal'nee	Tributary of Koluton	1981	1.19	1.17	0.88	0.02	Multiannual
28	Aksuat	Aksuat river	1982	3.41	3.24	1.82	0.03	Seasonal
29	Zimbulak	Zimbulak river	1982	2.25	2.16	0.65	0.05	Multiannual
30	Kyzylsai	Kyzylsai girder	1983	1.13	1.1	0.51	0.02	Seasonal
31	Ergol'skoe	Zholboldy river	1983	8.65	7.74	2.73	0.49	Seasonal
32	Akzharskoe	Akzhar river	1984	1.62	1.58	0.66	0.04	Seasonal
33	Sovetskoe	Tributary of Koluton	1986	2.04	2.02	0.76	0.11	Multiannual
34	Pervomajskoe	Sarykamys girder	1988	3.0	2.59	0.9	0.02	Multiannual
35	Verhnee	Shortanbai river	1988	9.95	6.69	6.5	2.64	Seasonal
36	Koyandy	Koyandy river	1989	5.79	5.16	1.78	0.04	Multiannual
37	Nizhnee	Shortanbai river	1989	2.76	1.88	1.75	0.89	Seasonal
38	Karasu	Karasu streamlet	1990	9.97	7.34	2.32	0.83	Multiannual
39	Petrovskoe	Bezymyannaya streamlet	1991	2.8	2.33	1.53	0.50	Multiannual
40	Krasnoozernoe	Zhilandy river	1993	3.05	2.44	1.01	0.24	Seasonal
41	Bel'-Agacheskoe	Zhaman-Kairakty river	1962	2.24	2.14	1.67	0.07	Multiannual
42	Svobodnoe	Solenaya balka river	1988	1.66	1.33	0.48	0.02	Seasonal
North Kazakhstan region								
43	Sergeevskoe	Yesil river	1969	693	635	116.7	19.2	Multiannual
44	Petropavlovskoe	Yesil river	1973	19.2	16.1	9.7	3.7	Seasonal
45	Sharykskoe	Sharyk river	1987	8.26	7.9	2.12	1.14	Multiannual

Analysis of average monthly precipitation and average monthly air temperatures for 30-40 years showed relative stability of their intra-annual distribution in the basins of the rivers of Yesil river basin, they cannot lead to significant shifts in the intra-annual flow distribution (Mustafaev et al., 2019).

Analysis of the intra-annual distribution of annual runoff in a multi-year section can be carried out using the moving average method, integral curves of monthly runoff, as well as by comparing the distribution of monthly runoff of different years with different level of flow regulation in the watershed, but with approximately the same meteorological conditions. Calculation methods are also used, where the regulated observed flow is compared with the restored values. However, it is difficult to retransform the monthly and decadal flows using the existing calculation methods, as the errors in flow restoration are often incompatible with the monthly flow.

The final result of the assessment of changes in the intra-annual flow distribution in a year depends not only on the methods of analysis and comparison of monthly flow and its distribution in a multi-year section with the dynamics of economic activity in the watershed but also, to a certain extent, on comparison of the natural and disturbed flow distribution. It should be noted that when describing the intra-annual flow distribution, there is obviously no, and cannot be universal methods suitable for application to all rivers.

As mentioned above, the intra-annual flow distribution under the natural regime is a fairly stable characteristic of the river catchment, and only the construction of large reservoirs leads to clearly visible shifts in the intra-annual flow distribution at the outlet. Under regulated runoff conditions, the natural hydrological regime is disturbed as soon as the reservoir is filled. Subsequently, during the operation of the reservoir, the hydrological regime in the upstream and tailwater can undergo some changes due to the introduction of new reservoirs, growth of water consumption in the river basin, and changes in the regulatory regime (Shcherbak and Korneychuk, 2006).

When assessing changes in the intra-annual flow distribution under the influence of reservoirs, it should be kept in mind that the water management systems of a particular river basin are in constant development, so in addition to the average flow characteristics it is important to have a flow distribution for each particular year.

The Ishim reservoir of seasonal flow regulation with a total volume of 9.2 million m^3 and a usable volume of 8.2 million m^3 was constructed in the upper stream of the Yesil river. The small usable capacity of the Ishim reservoir transforms the flow in the lower stream of the river very insignificantly. The main flow regulator of the Upper Yesil is the Astana (Vyacheslav) reservoir of multi-year regulation with a total volume of 411 million m^3 and a usable volume of 378 million m^3. The main regulators of Lower Yesil are Sergeevsky reservoir with a total volume of 693 million m^3 and a usable volume of 635 million m^3. The closing reservoir of the Yesil cascade in the Republic of Kazakhstan is the Petropavlovsk reservoir, which has a total volume of 19.2 million m^3 and a usable volume of 16.1 million m^3, carries out seasonal regulation of the flow. Due to the commissioning of reservoirs, the intra-annual distribution of the Yesil river flow in the site of Nur-Sultan city and the outlet of Petropavlovsk city has changed dramatically. Changes in the intra-annual flow distribution at different sites are manifested in various manners.

Calculations were made for two characteristic periods to quantify changes in the intra-annual flow distribution in the Yesil river basin:

- before the creation of the main reservoirs (1933-1973), characterized by little influence of economic activities – the conditionally natural period;
- the second period (1974-2014), distinguished from the first by significant disruption of the hydrological regime resulting from profound long-term flow regulation by Vyacheslav and Sergeevsky reservoirs.

To confirm the aforementioned, the data on the intra-annual flow distribution for the Yesil river basin in the context of a conditionally natural regime and disturbed regime as the result of the construction of large reservoirs in the watershed is presented (Table 3).

Table 3: Intra-annual flow distribution in the Yesil river (m3/s) for the conditionally natural (1933-1973) and disturbed (1974-2014) periods and its change

Water content of the year	Flow characteristics	Months											
		IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III
Yesil river – Nur-Sultan city													
High-water	Natural	82.9	8.08	2.53	1.22	0.88	0.66	1.07	1.42	0.58	0.36	0.15	0.10
	Disturbed	65.2	7.17	4.11	3.43	3.25	2.81	2.38	2.60	1.85	0.96	0.78	5.46
	Change	17.7	0.91	-1.58	-2.21	-2.37	-2.15	-1.31	-1.18	-1.27	-0.60	-0.63	-5.36
Medium-water	Natural	79.0	14.8	2.40	0.91	0.40	0.56	0.69	0.84	0.33	0.08	0.03	0.01
	Disturbed	51.0	12.7	7.07	5.77	4.34	3.20	2.27	3.49	2.39	1.60	1.14	4.99
	Change	28.0	2.10	-4.67	-4.86	-3.94	-2.64	-1.58	-2.65	-2.06	-1.52	-1.11	-4.98
Low-water	Natural	51.7	43.7	2.22	0.81	0.23	0.34	0.54	0.32	0.08	0.00	0.00	0.00
	Disturbed	35.6	16.9	11.3	7.44	6.09	3.92	2.54	6.61	4.33	2.41	1.58	1.29
	Change	16.1	26.8	-9.08	-6.63	-5.86	-3.58	-2.00	-6.29	-4.25	-2.41	-1.58	-1.29
Yesil river – Petropavlovsk city													
High-water	Natural	17.6	59.3	13.3	3.24	1.51	1.01	0.85	1.00	0.76	0.53	0.48	0.43
	Disturbed	21.2	48.5	13.2	3.96	2.23	1.66	1.37	1.58	1.25	1.70	1.43	1.88
	Change	-3.60	10.8	0.10	-0.72	-0.72	-0.65	-0.52	-0.58	-0.49	-1.17	-0.95	-1.45
Medium-water	Natural	26.0	42.5	12.9	4.50	3.55	2.65	2.50	1.90	1.51	0.74	0.64	0.55
	Disturbed	13.6	50.8	11.0	4.53	3.34	2.99	2.78	1.78	2.23	1.51	2.51	2.95
	Change	12.4	-8.30	1.90	-0.03	0.21	-0.34	-0.28	0.12	-0.72	-0.77	-1.87	-2.40
Low-water	Natural	26.4	27.8	17.9	7.48	4.65	3.39	2.89	3.07	2.21	1.75	1.07	1.48
	Disturbed	20.6	34.7	12.6	5.53	4.11	3.61	3.09	3.59	2.22	3.13	2.60	4.23
	Change	5.80	-6.90	5.30	1.95	0.54	-0.22	-0.2	-0.52	-0.01	-1.38	-1.53	-2.75

*The " - " sign indicates a runoff increasing

Flow regulation in the Yesil river basin is carried out for the benefit of industrial, municipal and agricultural water supply, inundative and regular irrigation and fisheries. The results of calculations of the intra-annual flow distribution by the compilation method for two periods in the Yesil river Basin are summarized in Table 4.

Table 4: Intra-annual flow distribution (as a percentage of the annual flow) of the rivers of the Yesil river basin in years of different water content

N	Gauge station code	River – gauge station	F, km²	Calculation period	Water content of the year	Seasonal flow (%)		
						Spring (IV-V)	Spring (IV-V)	Spring (IV-V)
1	2	3	4	5	6	7	8	9
1	11272	Silety – Prirechnoe v.	1670	1961-2014	High-water	94.6	2.56	2.82
					Medium-water	97.2	2.28	0.48
					Low-water	98.2	1.78	0.00
2	11275	Silety – Izobil'noe v.	14600	1959-2014	High-water	88.7	6.02	5.24
					Medium-water	87.0	8.27	4.75
					Low-water	83.1	12.5	4.39
3	11291	Shaglinka – Pavlovka v.	1750	1939-1973	High-water	91.4	7.15	1.46
					Medium-water	91.3	7.75	0.97
					Low-water	90.5	8.93	0.60
				1974-2014	High-water	87.6	11.5	0.89
					Medium-water	86.6	12.9	0.48
					Low-water	86.8	12.9	0.27
4	11395	Yesil – Priishimskoe v.	202	1949-1973	High-water	89.8	6.15	4.06
					Medium-water	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-water	91.2	6.32	2.55
					Low-water	92.4	7.44	0.21
5	11397	Yesil – Turgenevka v.	3240	1974-2014	High-water	86.5	5.01	8.52
					Medium-water	93.2	5.64	1.16
					Low-water	93.1	6.36	0.51
6	11398	Yesil – Nur-Sultan city	7400	1933-1973	High-water	91.0	6.36	2.61
					Medium-water	93.8	4.96	1.29
					Low-water	95.5	4.14	0.41
				1974-2014	High-water	72.4	16.0	11.6
					Medium-water	63.7	22.7	13.6
					Low-water	52.5	31.3	16.2
7	11404	Yesil – Kamennyi Kar'er v.	86200	1947-1973	High-water	83.4	13.5	3.07
					Medium-water	79.0	16.7	4.20
					Low-water	72.9	20.9	6.26
				1974-2014	High-water	78.1	19.1	2.86
					Medium-water	80.4	16.1	3.47
					Low-water	81.6	13.8	4.67
8	11405	Yesil – Zapadnoe v.	90000	1974-2014	High-water	83.1	14.9	1.97
					Medium-water	84.7	13.4	1.95
					Low-water	84.9	13.6	1.52
9	11410	Yesil – Petropavlovsk city	106000 118000	1932-1973	High-water	76.9	19.9	3.20
					Medium-water	68.5	26.1	5.34
					Low-water	54.1	36.3	9.57
				1974-2014	High-water	69.7	22.4	7.83
					Medium-water	64.4	24.7	11.0
					Low-water	55.3	28.9	15.8
10	11424	Kalkutan – Kalkutan v.	16500	1937-1973	High-water	90.9	7.63	1.47
					Medium-water	91.6	7.05	1.30
					Low-water	94.1	5.84	0.09
				1974-2014	High-water	96.7	3.23	0.07
					Medium-water	97.9	2.09	0.00
					Low-water	98.4	1.62	0.00
11	11432	Zhabai – Balkashino v.	922	1960-2014	High-water	84.1	11.2	4.69
					Medium-water	84.9	11.1	3.99
					Low-water	84.5	12.1	3.44
	2	3	4	5	6	7	8	9
12	11433	Zhabai – Atbasar city	8530	1936-1973	High-water	68.5	30.1	1.36
					Medium-water	67.6	31.6	0.77
					Low-water	66.3	33.3	0.36
				1974-2014	High-water	88.2	8.44	3.36
					Medium-water	87.3	8.68	4.04
					Low-water	87.3	8.49	4.18
13	11455	Akkanburluk – Grigor'evka v.	5820 6520	1938-1973	High-water	90.6	6.28	3.08
					Medium-water	93.0	5.58	1.43
					Low-water	95.0	4.96	0.13
				1974-2014	High-water	91.7	6.37	1.93
					Medium-water	93.7	5.01	1.31
					Low-water	95.8	3.73	0.46
14	11461	Imanburluk – Sokolovka v.	3870 4070	1950-1973	High-water	93.7	4.46	1.81
					Medium-water	92.0	6.77	1.23
					Low-water	86.8	12.3	0.86
				1974-2014	High-water	89.2	8.59	2.24
					Medium-water	88.2	9.05	2.75
					Low-water	85.1	9.86	5.05

Comparison of the obtained results of calculations for two periods shows that in the upper stream of the Yesil river, flow regulation has not had a significant impact on the hydrological regime. In high-water years in the spring period from April to May in the site of Yesil river – Nur-Sultan city during the conditionally natural period 91.0 % of the annual flow occurs, and the summer-fall period – 6.36 %. In the disturbed period, 72.4 % of the annual flow occurs in the spring period, in the summer-autumn period – 16.0 %, and in the winter period – 13.6 %.

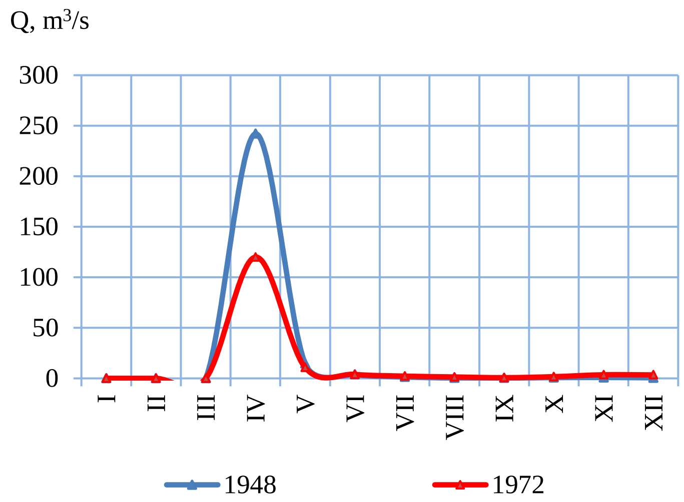
In the summer-autumn and winter periods, when the reservoirs are drawn down, the regulated water discharge in high-water and medium-water years is significantly higher than the natural water discharge. In Petropavlovsk gauging station, natural water discharge in April decreases under the influence of Sergeevsky reservoir in high-water years by 10 %, and in average and low-water years it practically does not change in water content. In the summer-autumn and winter periods, the sums of regulated water discharges exceed the natural water discharge considerably (Table 4). The assessment of changes in the intra-annual flow distribution in the site of Petropavlovsk city reflects the influence of four large reservoirs of multi-year and seasonal regulation.

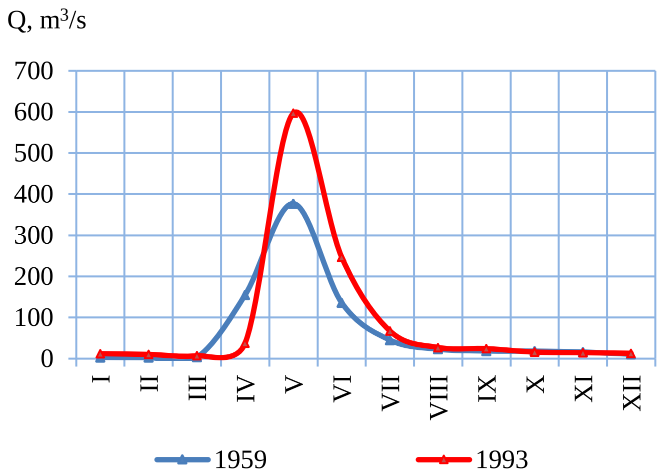
Calculations of intra-annual distribution of flow for specific years of different water content (25, 50, 75 and 95 %) in context of the conditionally natural and regulated regimes (by Chagodaev formula) allowed to estimate changes in the intra-annual flow distribution by comparing graphically natural and disturbed flow hydrographs of Yesil river on separate sites (Figure 1). The analysis of changes in the flow and its intra-annual flow distribution shows that the hydrological regime of the Yesil river has undergone serious changes in most of its territory. At the same time, in the upper stream up to Nur-Sultan city, the flow regime is leveled and transformed.

Yesil river – Nur-Sultan city

Yesil river – Petropavlovsk city

P=25 %





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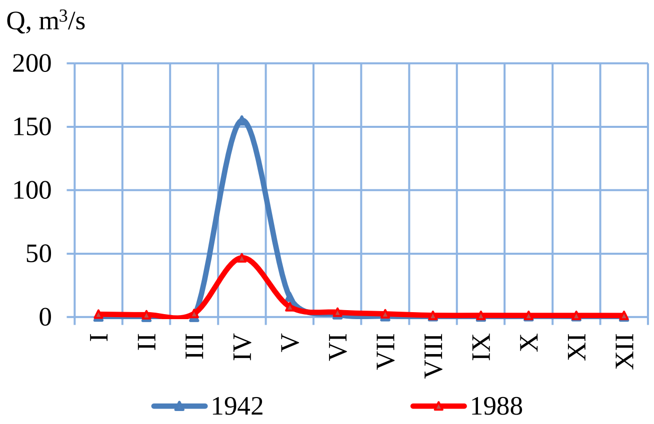

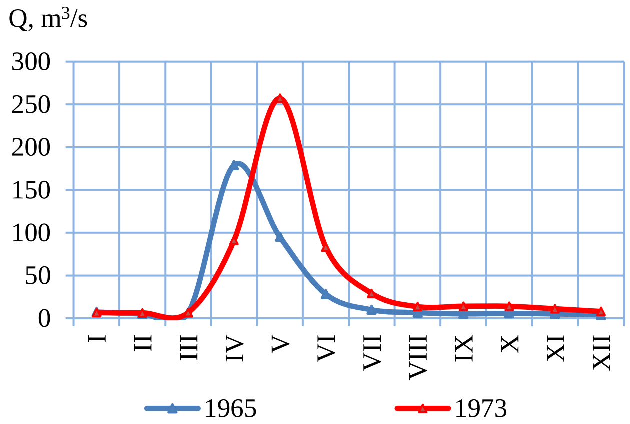

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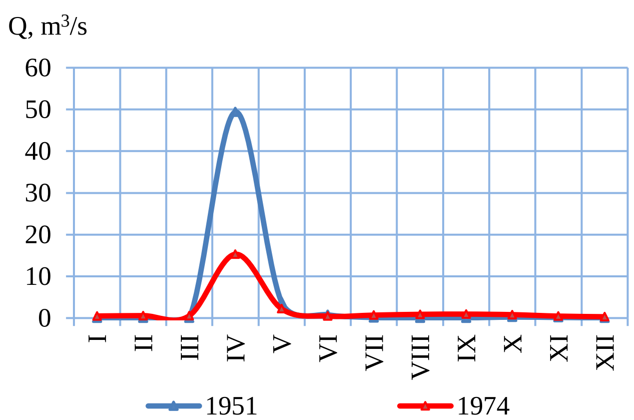

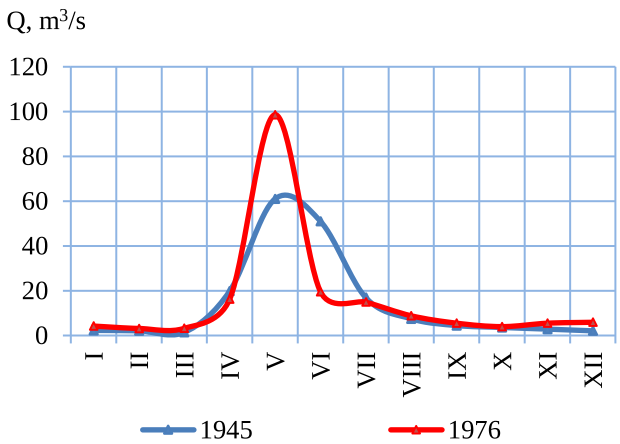

P=95 %

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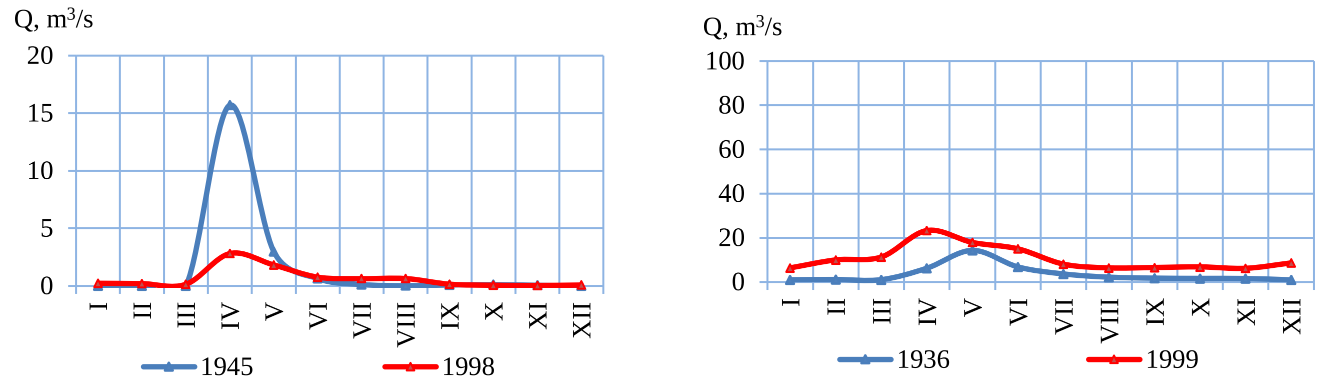

Figure 1: Flow hydrographs in the context of the conditionally natural and regulated by reservoirs conditions for years of different water content

In the upper stream of the Yesil river, the decrease in spring runoff is most noticeable. In the lower stream of the river in the site of Petropavlovsk city, the spring runoff for the period with the disturbed regime is much higher than the spring runoff for the natural period and an increase in seasonal runoff, especially winter runoff, is observed in low-water years with 95% probability. Among other factors of economic activity, inundative and regular irrigation (more than 57.95 thousand hectares in the Yesil river basin) should be noted.

Influence on flow and hydrological regime of large and middle-size rivers of agro-forestry and reclamation measures (land ploughing, forestation, snow retention), industrial and municipal water supply, inundative and regular irrigation and some other types of economic activity is not beyond the accuracy of flow accounting.

The final result of the assessment of changes in the intra-annual flow distribution in a year depends not only on the methods of analysis and comparison of monthly flow and its distribution in a multi-year section with the dynamics of economic activity in the watershed but also, to a certain extent, on comparison of the natural and disturbed flow distribution (Shcherbak et al., 2007). It should be noted that when describing the intra-annual flow distribution, there is obviously no, and cannot be universal methods suitable for application to all rivers.

When studying the intra-annual flow distribution of rivers, in addition to the chronological (calendar) description of flow distribution, an analysis of its non-calendar distribution in the form of daily discharge duration curves is used. They make it possible to estimate the duration of discharges equal to or exceeding a given value.

It is more common to use the coefficient of natural flow regulation ϕ to describe the irregularity of the intra-annual water flow distribution, which corresponds to the proportion of the "base" flow in the annual volume of runoff. The coefficient of natural flow regulation φ expresses the degree of irregularity of the intra-annual flow distribution and is determined from the hydrograph, based on the ratio of the base volume of runoff to the annual volume.

The base flow reflects the natural regulation of the catchment and its storage capacity, so the value of the regulation factor decreases with decreasing lakes. This coefficient is mainly used for comparative characterization of different rivers or districts with respect to the value of the most sustainable ("baseline") water resources. For a particular river, the value of the regulation coefficient varies from year to year, depending on the characteristics of primarily the high-water phase of the water regime.

In this research, coefficients of natural flow regulation for two periods, 1933-1973 and 1974-2014, were calculated for gauging stations of the Yesil river basin, and average values for these periods were calculated. The changes in the average value of the coefficient of natural flow regulation of the rivers of the Yesil river basin are shown in Table 5.

Table 5: Coefficient of natural flow regulation of the rivers of Yesil river basin

N	Gauge station code	River – gauge station	Calculation period	ϕ
1	11272	Silety – Prirechnoe v.	1961-1973	0.30
			1974-2014	0.71
2	11275	Silety – Izobil'noe v.	1959-1973	0.57
			1974-2014	0.40
3	11291	Shaglinka – Pavlovka v.	1939-1973	0.58
			1974-2014	0.67
5	11395	Yesil – Udarnoe v.	1949-1973	0.42
			1974-1991	0.50
6	11397	Yesil – Turgenevka v.	1974-2014	0.21
7	11398	Yesil – Nur-Sultan city	1933-1973	0.43
			1974-2014	0.58
8	11404	Yesil – Kamennyi Kar'er v.	1947-1973	0.58
			1974-2014	0.64
9	11405	Yesil – Zapadnoe v.	1974-2014	0.50
10	11410	Yesil – Petropavlovsk city	1932-1973	0.56
			1974-2014	0.47
11	11424	Kalkutan – Kalkutan v.	1937-1973	0.33
			1974-2014	0.40
12	11432	Zhabai – Balkashino v.	1960-1973	0.44
			1974-2014	0.50
13	11433	Zhabai – Atbasar city	1936-1973	0.50
			1974-2014	0.58
14	11455	Akkanburluk – Grigor'evka v.	1938-1973	0.40
			1974-2014	0.63
15	11461	Imanburluk – Sokolovka v.	1950-1973	0.38
			1974-2014	0.40

The data in Table 5 shows an increase in the values of the coefficient of natural flow regulation in the second period (1974-2014), which is characterized by a significant disturbance of the hydrological regime as a result of profound long-term regulation of flow by reservoirs, compared with the first period which is the conditionally natural flow (1933-1973), characterized by little influence of economic activity. The calculated values of the coefficient of natural flow regulation of only two gauging stations (Silety – Izobilnoye village, Yesil – Petropavlovsk city) have a lower value for the second period (1974-2014) compared with the first period (1933-1973). Thus, a steady increase in the irregularity of flow for the period after 1974 has been revealed for the rivers of the Yesil river basin.

As a result, the following maps were created for the Yesil river basin using ArcGIS 10.6 software (spatial analysis method):

1. The average value of the coefficient of natural flow regulation for 1933-1973 (Figure 2).

2. The average value of the coefficient of natural flow regulation for 1974-2014 (Figure 3).

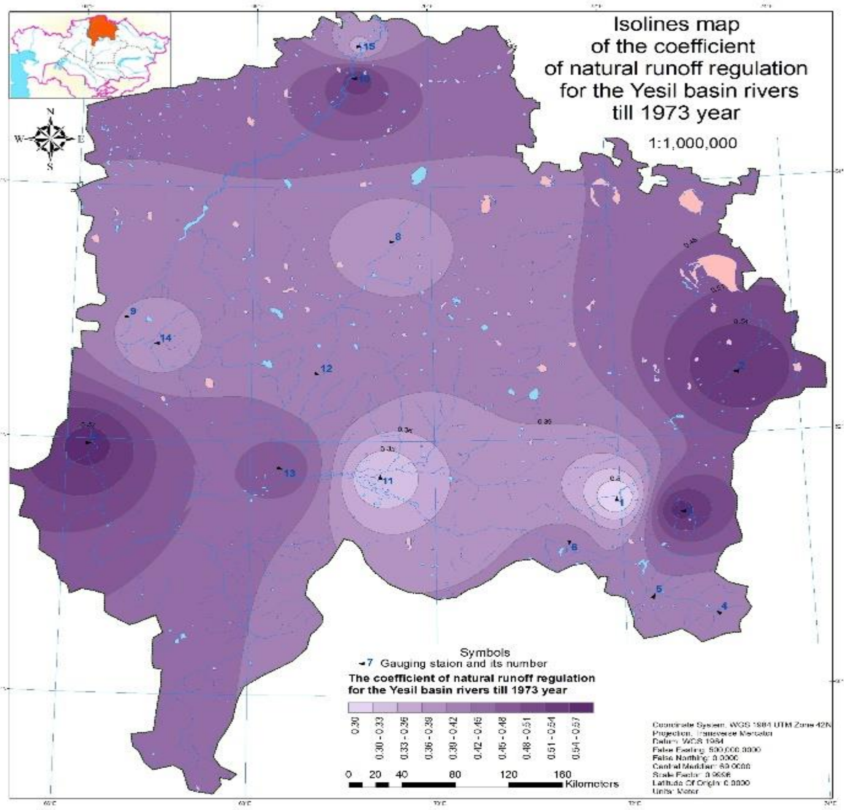

Figure 2: The average value of the coefficient of natural flow regulation for 1933-1973

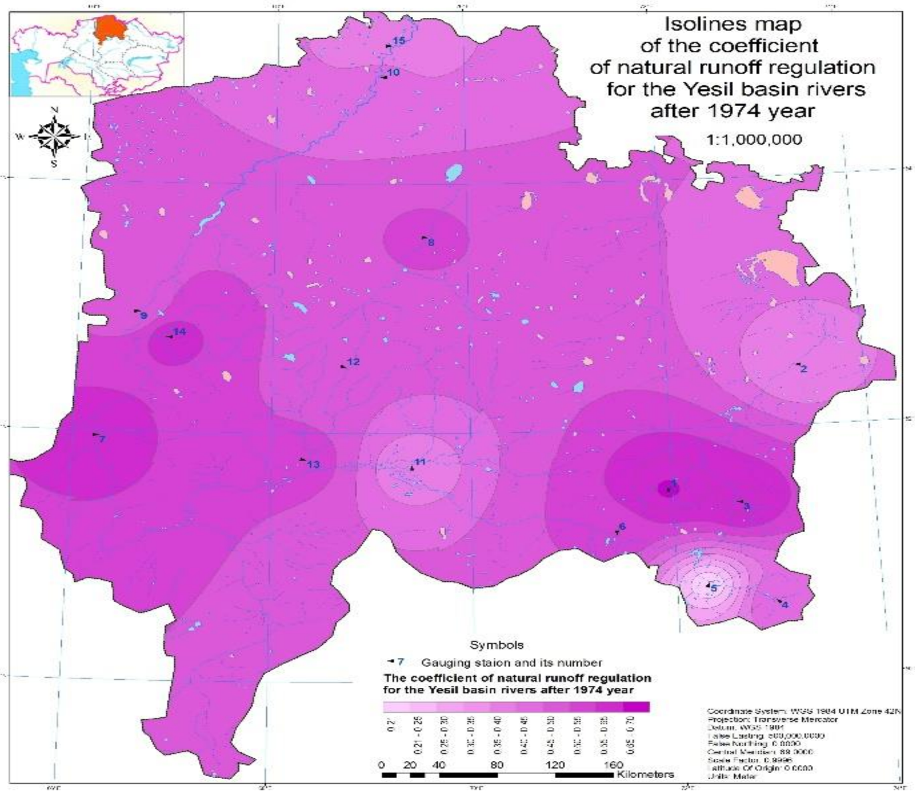

Figure 3: The average value of the coefficient of natural flow regulation for 1974-2014

The influence of the water content of the year on the degree of natural regulation of the rivers is important for economic entities and the population. Water users and consumers are mainly interested in a constant, stable flow without interruptions and abrupt rises. This means that they benefit most from the flow of rivers with a high degree of natural regulation. For example, a regulated flow during the warm (vegetation) season is crucial for irrigated agriculture. Critically, a low degree of natural flow regulation poses an enormous risk to all in the form of floods and inundations, causing destruction and even loss of life in the adjacent flooded areas. Further research should focus on the search for dependencies linking the characteristics of irregular river flow to the meteorological and hydrographic characteristics of the river basins.

5. Conclusions

Analysis of spatial and temporal patterns of flow formation of the rivers of the Yesil river basin showed that there is a significant change in the intra-annual river flow distribution in recent decades. The analysis of changes in the flow and its intra-annual flow distribution shows that the hydrological regime of the Yesil river has undergone serious changes in most of its territory. At the same time, in the upper stream up to Nur-Sultan city, the flow regime is leveled and transformed. In the upper stream of the Yesil river, the decrease in spring runoff is the most evident. In the lower stream of the river in the site of Petropavlovsk city, the spring runoff for the period with the disturbed regime is much higher than the spring runoff for the natural period and an increase in seasonal runoff, especially winter runoff, is observed in low-water years with 95% probability.

The coefficient of natural flow regulation φ in the river basin depends on the zonal factors on the one hand and the size of the catchment area determining the degree of natural flow regulation on the other hand. An increase in the coefficient of natural flow regulation φ, which expresses the complex influence of physical-geographical factors on the intra-annual flow distribution is accompanied by a substantial decrease in the flow during the flood and a significant increase in the low-water flow during the winter and summer periods. As a result of an increase in the coefficient of natural flow regulation, the winter runoff of the Yesil river in the middle reaches has increased by two or three times.

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