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# Changes in Intra-Annual River Runoff in the Ile and Zhetysu Alatau Mountains Under Climate Change Conditions

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**Abstract**

This paper presents the results of studies on intra-annual runoff changes in the Ile River basin based on data from gauging stations up to 2021. Changes in climatic characteristics that determine runoff formation in the mountainous and foothill areas of the river catchment have led to alterations in the water regime of the watercourses. The analysis of the temporal and spatial patterns of river flow formation in the basin, as well as its distribution by seasons and months, is essential for solving applied water management problems and assessing the risks of hazardous hydrological phenomena, such as high floods and low water levels. The statistical analysis of annual and monthly river runoff fluctuations enabled the identification of relatively homogeneous estimation periods during stationary observations under varying climatic conditions. The obtained characteristics of annual and intra-annual river runoff in the Ile River basin for the modern period provide insights into changes in average monthly water discharge and, more broadly, runoff volume during different phases of the water regime. In the future, these characteristics are expected to guide the design of hydraulic structures and the rational use of surface runoff in this intensively developing region of Kazakhstan.

**Keywords:** climate change; hydrometeorological characteristics; time series; homogeneity; annual runoff; design period; intra-annual runoff; water economy; reservoirs; hydropower industry

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Academic Editor: Rui Manuel Vitor Cortes

Received: 14 June 2025
Revised: 12 July 2025
Accepted: 17 July 2025
Published: 21 July 2025

**Citation:** Abdrakhimov, R.G.; Blagovechshenskiy, V.P.; Ranova, S.U.; Akzharkynova, A.N.; Gülbaz, S.; Aldabergen, U.R.; Kamalbekova, A.N. Changes in Intra-Annual River Runoff in the Ile and Zhetysu Alatau Mountains Under Climate Change Conditions. *Water* **2025**, *17*, 2165. https://doi.org/10.3390/w17142165

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## 1. Introduction

It is well known that Kazakhstan is among the countries with poor water resources. On average, the river runoff in the Republic amounts to about 100 km$^3$ per year. At the same time, about 50% of river runoff originates in neighboring countries. The rational use of surface runoff under conditions of sustainable economic development and nature-conserving technologies is one of the key tasks in ensuring water supply for various water consumers. In this regard, the Government of the Republic of Kazakhstan adopted the "General Scheme for the Integrated Use and Protection of Water Resources," dated 8 April 2016, No. 200 [1]. The resolution outlines measures for assessing water resource availability and conducting water management calculations across eight water basins, including the Ile-Balkhash region, with a planning horizon extending to 2030–2050. During this period,

the use of surface water in this region is projected to reach approximately 3.500 million cubic meters for various sectors of the economy.

The Ili-Balkhash basin is one of the most water-rich areas in the country. The volume of water resources of the Balkash-Alakol Water Basin (BAB) is 18.8 km$^3$, of which 14.7 km$^3$ falls on the Ile-Balkash basin and 4.11 km$^3$ on the Alakol Lake basin. The main river of the basin is the Ile River, whose headwaters are located in the People's Republic of China. Runoff is formed by the Ile River (in the Kaiyrilgan tract area) with a volume of 14.6 km$^3$ and the Emel River (in the Akshi area) with a volume of 0.29 km$^3$. Water outflow from the basin occurs through the Tekes River (VCU 02.01.02.01) in the volume of 1.04 km$^3$, which flows into the Ile River on the territory of China and is accounted for in the hydrographic point of the Kaiyrilgan tract [2,3].

Overall, this water management basin accounts for approximately 12–15% of the country's surface runoff. The area hosts economic, historical, and cultural centers and settlements of great importance in the life of the country. In addition, this area has great potential for further development and, in the future, there are plans to increase the energy capacity of Kapchagai Hydroelectric Power Plant (HPP) [3]. As part of the transition to a "green economy," the share of renewable energy sources should reach 10% of total electricity production by 2030, and 50% by 2050, taking into account alternative energy and small diversion (HPP) hydropower plants (Figure 1).

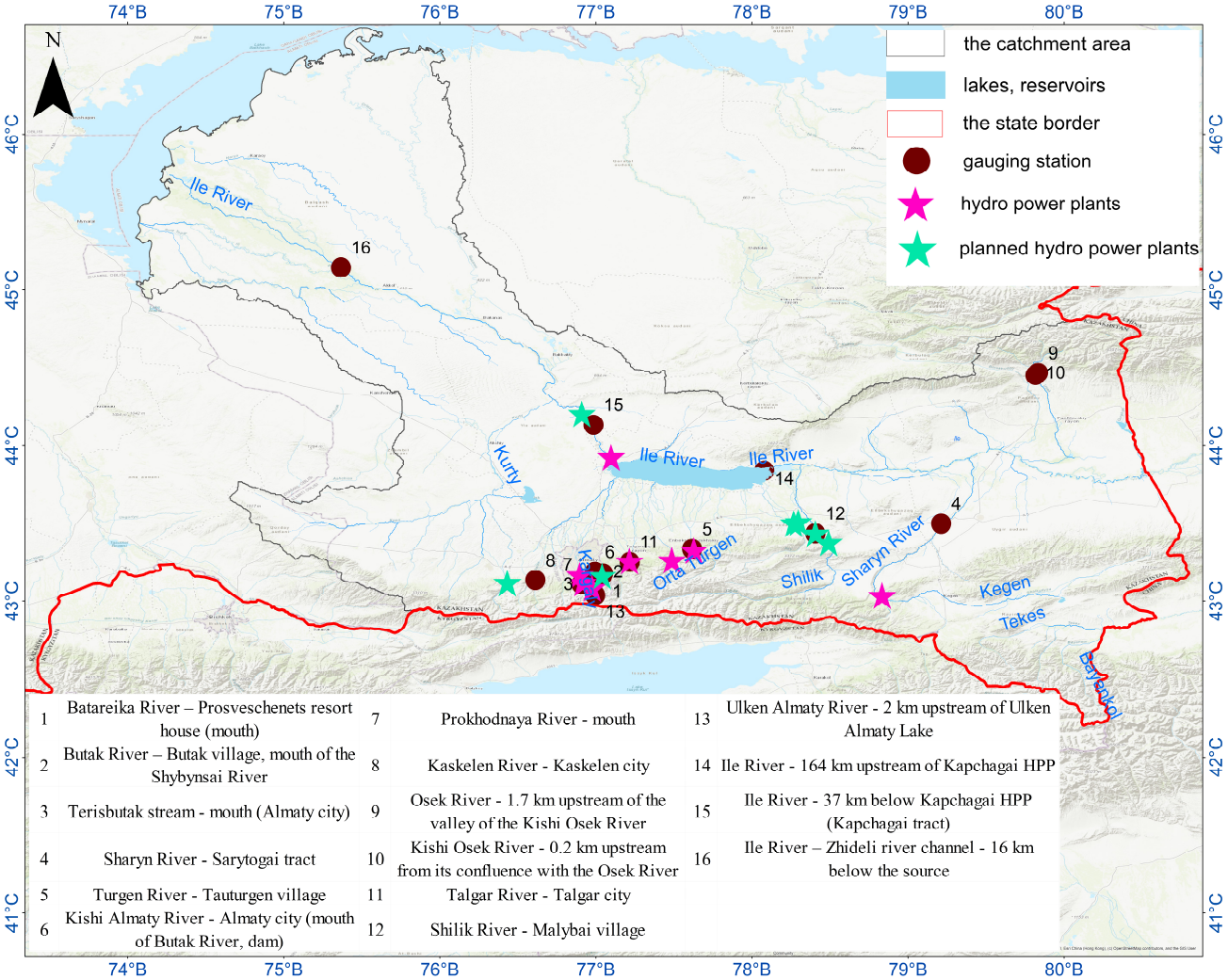



**Figure 1.** Locations of hydrological posts and hydropower plants in the Ile River basin.

Agriculture is the largest consumer of water, and most of the agricultural land in the region requires irrigation. In the region under consideration, agricultural land covers an area of 275.9, which is 14.2% of the total territory of the country [4].

Consuming more than half of all water resources used in the region, agriculture remains the most 'uneconomical' consumer: irrigation water losses for filtration and evaporation in arid areas are known to be quite significant. In the Ile River basin, particularly in its lower reaches, the Akdaly Canal and rice check irrigation system operate as one of the main irrigation complexes. Overall, water intake from the river averages around 0.5 $km^3$ per year [5,6].

The hydrotechnical infrastructure in the study region continues to evolve toward improved functional efficiency and sustainability. Modern challenges in water resource management require the integration of scientific approaches, the enhancement of design solutions, and the adoption of innovative technologies in the operation of hydraulic structures. This is especially relevant in the context of the growing need to adapt to climate change and ensure the sustainable use of water resources in the region.

Irrigation canals are unconcreted and mostly damaged; water losses in them reach 50–70% of the incoming water volume [7]. As part of the roadmaps for the introduction of water-saving technologies [8], work on the reconstruction of canals and construction of reservoirs in the studied region are underway to ensure the rehabilitation of irrigated lands. Currently, in the Ile River basin, a new modern city called Alatau is being developed between the metropolis of Almaty and the city of Konaev, and is based on the integration of several settlements. This development is expected to place additional pressure on water resources [9]. In this context, the relevance of research on the intra-annual regime of rivers, which is currently undergoing changes due to climate warming, is unquestionable.

## 2. Materials and Methods

### *2.1. Observation Data, Research Object, and Prospects for Reservoir Use*

The Ile River basin includes a large number of small mountain watercourses (2306 watercourses) and larger rivers (38 rivers 10 km long and more), with the main river—the Ile—flowing into Lake Balkhash [10].

Large hydropower plants in the region are typically equipped with reservoirs for the seasonal or perennial regulation of river flow. These reservoirs play a critical role in maintaining the water–energy balance, helping to meet peak energy demand and ensuring a stable power supply to industrial centers and cities.

Figure 1 shows the hydrological stations of the network of the Hydrometeorological Service of the Republic of Kazakhstan and the main hydraulic structures of the study basin are shown in Figure 2 [11].

The region under study is characterized by a high density and diversity of hydraulic structures (Figure 2), differing in type, design features, and functional purpose. A significant number of these facilities are integrated into water management complexes that support the comprehensive use of water resources for water supply, irrigation, hydropower, water transport, and fisheries, as well as for recreational and other economic purposes.

Figure 3 provides information on operating reservoirs with a capacity of more than 1 million $m^3$. In addition to the reservoirs shown in Figure 3, the Kapchagai reservoir, a multi-year regulation reservoir with a capacity of 28.140 million $m^3$, operates on the Ile River.

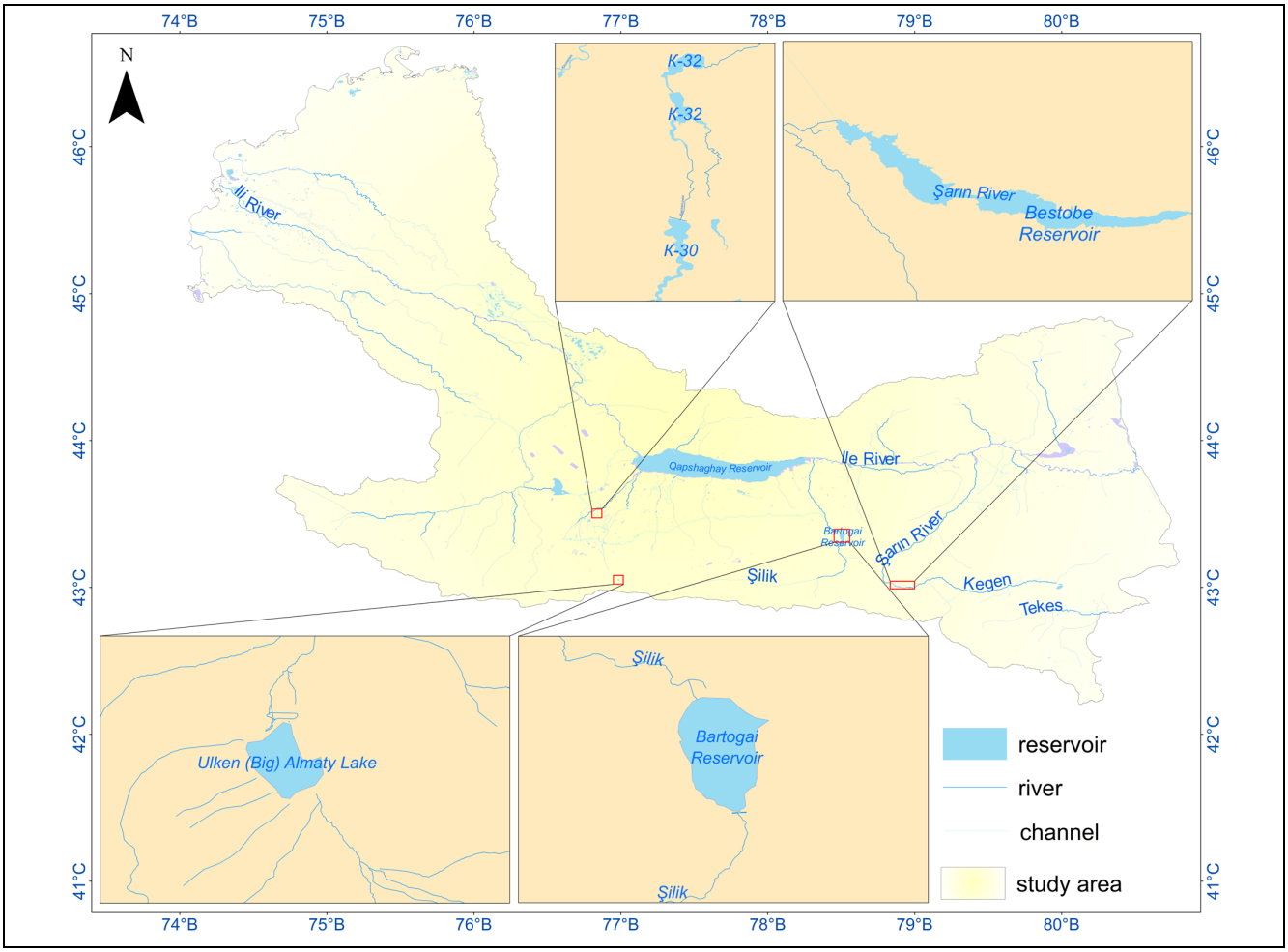



**Figure 2.** Hydraulic structures of the study region.

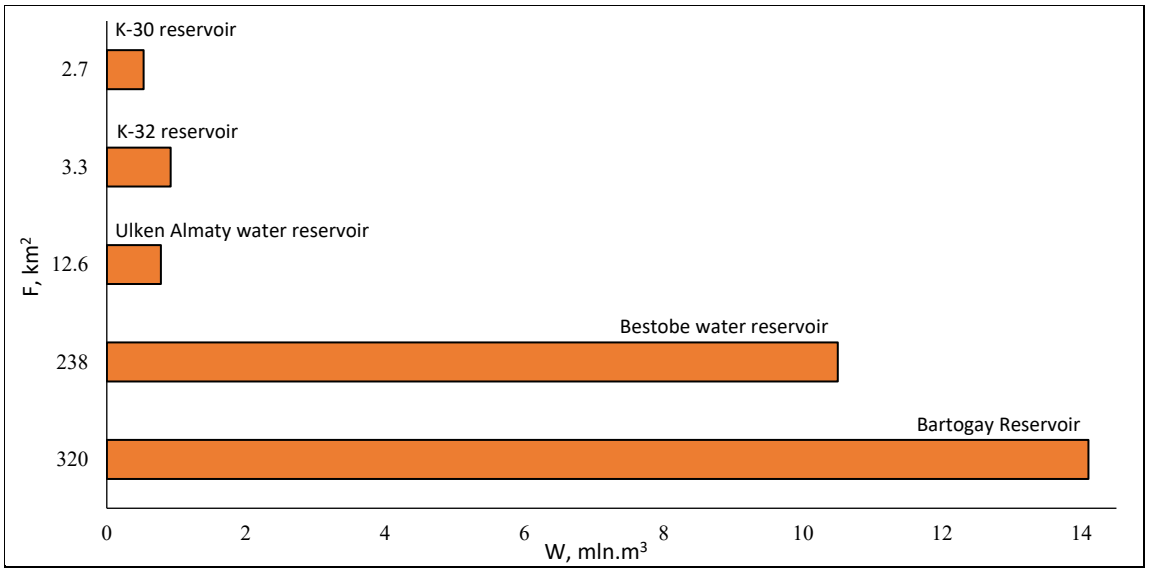



**Figure 3.** Graph of dependence on area and volume of reservoirs in the Ile River basin. F—reservoir area, W—reservoir volume.

Regular irrigation is developed in the Ile River basin and its tributaries, covering approximately 457 thousand ha [12]. The waters of the left tributaries of the Ile River—Shilik, Turgen, Yesik, Talgar, and Kaskelen, along with the Big (Ulken) and Small (Kishi) Almaty

rivers—are widely used for irrigation, power generation, and the water supply of settlements. At the expense of the Shilik river flow, there is a plan to increase the area of irrigated lands in the foothill zone of Ile Alatau.

To utilize the water and energy resources of the Ile River, there are current plans to increase the capacity of the Kapchagai Hydropower Plant to 434 MW, according to the "Plan of development of the hydropower industry of the Republic of Kazakhstan for 2020–2030". It is also planned to build a counter-regulator on the Ile River and small HPPs on its tributaries, which, in the future, will allow for an increase in the area of irrigated agricultural land and pastures [13].

### 2.2. Research Methods

The analysis of long-term changes in river runoff in the Ile River basin was based on observations from 16 hydrological stations located in the basin and its main tributaries. The database was collected using materials from the following reference books: Main Hydrological Characteristics, Long-term Data on the Regime and Resources of Surface Waters of the Land, and Annual Data on the Regime and Resources of Surface Waters of the Land for the corresponding time periods (Annual Data on the Regime and Resources of Surface Waters of the Land), published by RSE "Kazhydromet" [14–17].

The database of seasonal and monthly river runoff in the study basin was used. Observations of runoff characteristics at the gauging stations used for calculations contain data gaps. The missing values in the monthly and annual runoff series, as well as the conditionally natural runoff data, were reconstructed using the method of hydrological analogy (Figure 4).

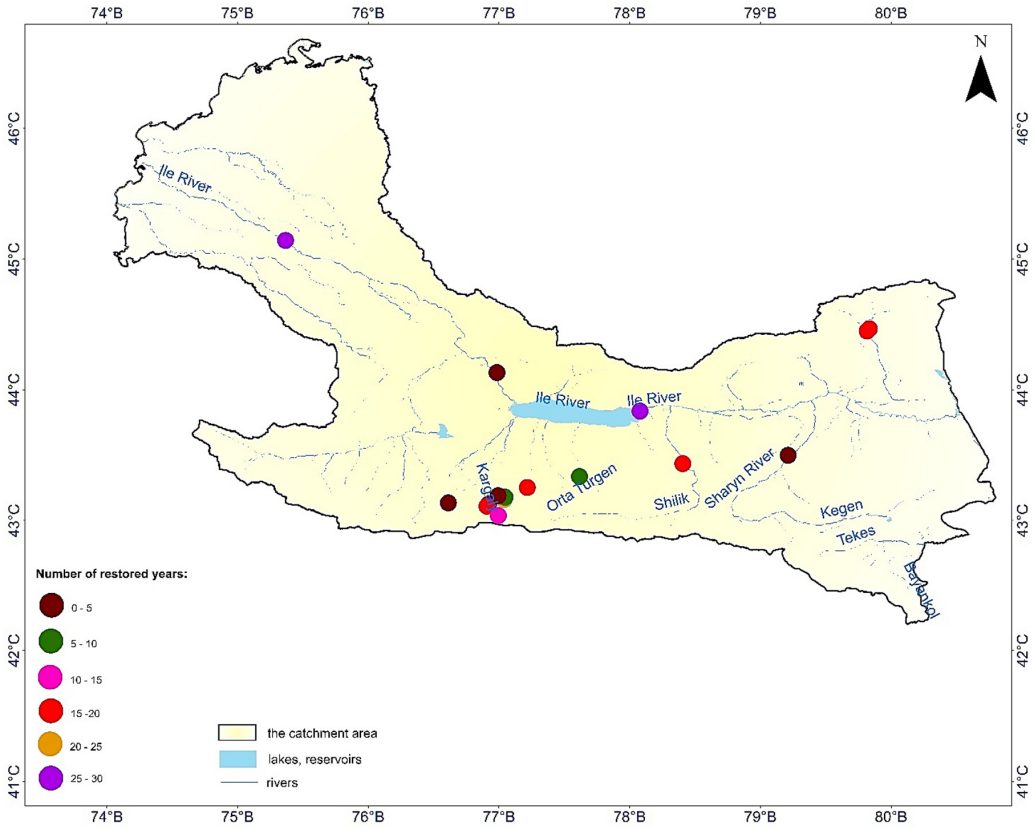



**Figure 4.** Reconstructed time series of river runoff in the Ile River basin.

When selecting a point analogue for the purpose of transferring hydrological characteristics and parameters, the main criterion is the synchrony of river flow fluctuations between

the reference gauging station and the analogous stations, which is expressed through the coefficient of pair or multiple correlation. Accordingly, the following conditions should be met [18]:

$$n/ \geq (6\text{–}10), \quad R \geq R\kappa p; \quad R/\sigma R \geq A\kappa p; K/\sigma\kappa \geq B\kappa p, \tag{1}$$

where $n/$ is the number of joint years of observations at the given point and its analogues ($n/ \geq 6$ at one analogue, $n/ \geq 10$ at two or more analogues); $R$ is the coefficient of pair or multiple correlation between the flow values of the investigated river and those at the analogue stations; $K$ is the regression equation coefficient; $\sigma\kappa$ is the root mean square error of the regression coefficient; $R\kappa p$ is the critical value of the pair or multiple correlation coefficient (usually $set \geq 0.70$); $A\kappa p$ and $B\kappa p$ are the critical values of the ratios of $R/\sigma R$ and $K/\sigma\kappa$, respectively (usually $set \geq 2.0$).

In poorly hydrologically explored areas, Rκp, Aκp, and Bκp can be reduced; in particular, $R$ values up to 0.6 are considered acceptable.

To restore annual runoff values using a single analogue station, the following regression equation [19] was applied.

$$Q = K_1 Qa + K_0, \tag{2}$$

When using two analogues, a three-variable regression equation was applied.

$$Q = K_1 Qa_1 + KQa_2 K_2 + K_0 \tag{3}$$

To exclude systematic underestimation of the variance in the reconstructed data, the following correction formula is used:

$$Q_i' = \frac{(Q - \overline{Q}n\prime)}{r} + \overline{Q}_n \tag{4}$$

where $Q_i'$ are the yearly values of the hydrological characteristic calculated by the regression equation and $\overline{Q}n'$ is the average value of the hydrological characteristic for the joint observation period.

For the stations on the Usek River—1.7 km upstream from the valley of the Kishi Usek River for 1998–2005—the series of annual runoff was reconstructed based on the regression relation (multiple correlation) between runoff and precipitation for warm and cold periods.

The multiple regression equation is written in the following form:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_p x_p + \delta \tag{5}$$

or

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_p x_p \tag{6}$$

where $b_1, b_2, \ldots, b_p$ are unknown parameters, $b_0$ is the intercept of the equation, and $\delta$ is the error of approximation of y by regression function.

The linear multiple regression function is written in the following form:

$$\hat{y} = b_0 + b_1 x_1 + b_2 X_2 \tag{7}$$

where

$$b_0 = \overline{y} - b_1 \overline{x}_1 - b_2 \overline{x}_2 \tag{8}$$

$$\mathrm{y} = \mathrm{y} + \mathrm{b}_1(\mathrm{x}_1 - \overline{\mathrm{x}}1) + \mathrm{b}_2(\mathrm{x}_2 - \overline{\mathrm{x}}_2) \tag{9}$$

Studies based on the statistical analysis of runoff characteristic series require sufficiently reliable data characterizing natural and conditionally natural (calculated) runoff. Under conditions of anthropogenic activity, some analyzed water discharge series were

reconstructed based on their correlation with similar values from calculation periods of rivers with natural runoff. To reconstruct the flow of Prokhodnaya River–mouth and Kaskelen River–Kaskelen city, data from the upstream gauging station Big (Ulken) Almaty 262 River, 2 km upstream of Big Almaty Lake, located upstream of Ulken Almaty Lake, where water withdrawal is not carried out and the hydrological regime remains in a relatively natural state, were used. This approach allowed for the minimizing of the influence of external factors and for an increase in the reliability of the reconstructed time series. Such relations for filling gaps in observations and reconstructing conditionally natural runoff were accepted when pair correlation coefficients ranged from 0.71 to 0.97.

Figure 2 shows the rivers with the longest observation periods, which have been systematically monitored since the 1930s and are included, as noted earlier, in the network of the Hydrometeorological Service of Kazakhstan: Rivers with spring–summer floods: Sharyn River—Sarytogai tract; Turgen River—Tauturgen village; Small (Kishi) Almaty River—Almaty city (mouth of Butak River, dam); Kaskelen River—Kaskelen city. Rivers with summer floods: Shilik River—Malybai village; Talgar River—Talgar city; Big (Ulken) Almaty River—2 km upstream of Big Almaty Lake; Usek River—1.7 km upstream of the valley of the Kishi Usek River; Kishi Usek River—0.2 km upstream from its confluence with the Usek River. Rivers with spring–summer floods: Ile River—37 km below Kapchagai HPP (Kapchagai tract) [8].

An analysis of changes in river flow over a long period allows for the most reliable identification of periods with a relatively stable long-term average as the norm. Flow fluctuations over time are manifested as successive changes between high-water periods (periods with increasing water content) and low-water periods (periods with a consistent decrease in water content). These cycles can be more reliably identified using difference integral curves (also known as cumulative curves of deviations of annual runoff values from their average over the entire period). The cumulative runoff curve is a variation of the total runoff curve. It characterizes the sequence of river runoff increases from a certain initial point in time. Unlike the cumulative runoff curve, the difference integral curve considers runoff fluctuations over short individual periods. It is constructed by summing the deviations of modular coefficients from the mean, i.e., its ordinates are calculated as follows:

$$\sum_1^i (K-1) \quad (10)$$

where $K = Qi/\overline{Q}$. Thus, the ordinates of the curve show, at the end of each i-th year, the cumulative magnitude of deviations of annual modular coefficients K from the norm or the multi-year average (K = 1). Qi is the average monthly or average annual water discharge for a particular year; $\overline{Q}$ is the average value of water discharge averaged over the calculation period of observations.

In order to compare multi-year variations in the runoff of different rivers, the temporal variability of runoff, reflected by the coefficient of variation ($Cv$), of several observations is taken into account.

$$\sum K - 1/Cv \quad (11)$$

The difference integral curves allow for the determination of the magnitude of runoff (relative to the average value) for individual periods; therefore, they can be used when selecting river analogues [20].

As noted in a number of studies [21–24], climatic changes lead to changes in the river regime and require a revision of water use norms and a more careful attitude toward the use of water resources.

Alongside the noted increase in average annual air temperatures and the trend of increasing annual precipitation totals [25] observed across all regions of Kazakhstan, the

mountainous areas of the Ile River basin are distinguished by a greater variety of changes in these climatic indicators. The altitude of the area, the orientation of ridges relative to moisture-carrying air masses, the internal and peripheral sections of mountain ranges, slope exposure, and other factors also influence runoff formation [26]. In contrast, the Pribalkhashie is mostly a semi-desert territory with insignificant precipitation [27,28].

Two studies presented the results of the statistical analysis of average annual air temperatures and annual precipitation totals based on data from meteorological stations (MSs) over a long observation period in the region [29,30]. An increase in temperature and overall precipitation has been observed across most of the basin over the past 30–50 years, except at elevations above 2000 m. An increase in the mean annual temperature norm leads to both a rise in moisture deficit and an expansion of snowmelt areas due to the upward shift of the climatic snow line and its involvement in the runoff formation process within the annual cycle [31,32]. The growth of annual precipitation norms—by an average of 5–8% at altitudes below 2000 m in the main runoff formation areas—contributes to both an increase in annual river runoff values and a redistribution of intra-annual seasonal and average monthly water discharge norms [32,33].

The calculation of intra-annual runoff characteristics under new climatic conditions has thus become an essential task for understanding the prevailing trends in the water regime of rivers in the basin, assessing seasonal and phase-based average water discharge characteristics, and evaluating prospects for rational water use under changing climatic conditions.

## 3. Results

*Analysis of Changes in Annual River Runoff Series*

The evaluation of the timing of changes in hydrometeorological indicators (air temperature, precipitation, water discharge), characterizing the processes that determine their formation and the statistical homogeneity of the series, in mountainous regions is complicated by several factors, including altitude, slope exposure, and the relationship to moisture-bearing air masses. In general, the water regime of rivers in the region exhibits several distinct characteristics and is typically classified as follows: (a) rivers with spring floods and floods in the warm season; (b) rivers with spring–summer floods; (c) rivers with summer floods; and (d) large rivers. In this context, climatic changes and their impacts on river flow are observed during different time periods (Table 1) [32].

In fact, the series of intra-annual runoff characteristics in the upper reaches of the studied rivers are not subject to anthropogenic influences, and changes in their statistical parameters are caused solely by climatic conditions [33]. As previously noted, in the study region, runoff characteristics have changed due to warming and shifts in temperature and precipitation norms. The normative regime indicators of intra-annual runoff are also changing, as they are derivatives of evaporation and precipitation.

The relatively stable long-term norms of the basin's water balance elements undergo changes; consequently, the series of water discharges for the year and its phases cannot be considered homogeneous. An assessment of the homogeneity of the studied runoff series based on average annual water discharges allows for the identification of multi-year periods that are representative and characterized by sufficiently stable average values, i.e., norms.

**Table 1.** Estimated groups of rivers with floods in different periods of the year.

| River Point | Season | | |
|---|---|---|---|
| Rivers with spring flood | | | |
| Butak River—Butak village<br>Big (Ulken) Almaty—Terisbutak<br>Batareika River—Prosveschenets resort house | spring–summer III–VI | summer–autumn VII–XI | winter XII–II |
| Rivers with spring–summer floods | | | |
| Sharyn River—Sarytogai tract<br>Turgen River—Turgen village<br>Kaskelen River—Kaskelen city<br>Small (Kishi) Almaty River—Almaty city<br>Prokhodnaya River—mouth | spring–summer III–IX | autumn X, XI | winter XII–II |
| Rivers with summer floods | | | |
| Usek River—1.7 km upstream of the valley of the Kishi Usek River<br>Kishi Usek River—0.2 km upstream from its confluence with the Usek River<br>Yesik River-Yesik city<br>Big (Ulken) Almaty—upstream of Big Almaty Lake<br>Talgar River—Talgar city<br>Shelek River—Malybai village | summer V–IX | autumn–winter X–II | spring III, IV |
| Rivers with spring–summer floods | | | |
| Ile River—Kapchagai tract<br>Ile River—164 km upstram of Kapchagai<br>Ile River—Zhideli river channel | spring II–VI | autumn–winter X–I | summer VII–IX |

Based on the graphs of the cumulative integral curves of average annual water discharge of the studied rivers [30], it can be observed that, starting from around the mid-1990s, there is a shift in homogeneous periods towards an increase in flow (Figure 5).

The increase in normative indicators of annual runoff is observed across all rivers in the region. Figure 5 presents selected examples illustrating changes in the average annual runoff of rivers in the Ile River basin.

Moreover, a clear upward trend in the average annual water discharge norm is evident when analyzing the dynamics of these values over the study period (Figure 6).

Based on the analysis of annual river runoff fluctuations, distinct periods characterized by relatively stable long-term average water discharges—referred to as norms—have been identified. On average, a significant shift in runoff dynamics associated with climate warming has been observed since 1997. This year is considered the baseline for the statistical assessment of runoff indicators under new climatic conditions.

The homogeneity of the selected periods was assessed using well-known parametric criteria, Student's *t*-test and Fisher's *F*-test, conducted in the "Statistics for Hydrology" software, StokStat 1.2, based on binomial distribution curves with Cs = 2Cv. The results confirm the heterogeneity of the series of average annual water discharges over the full observation period. However, when the periods before and after 1997 are analyzed separately, each can be considered statistically homogeneous. It should be noted, however, that such statistical assessments based on relatively short hydrological data series should be interpreted with some caution.

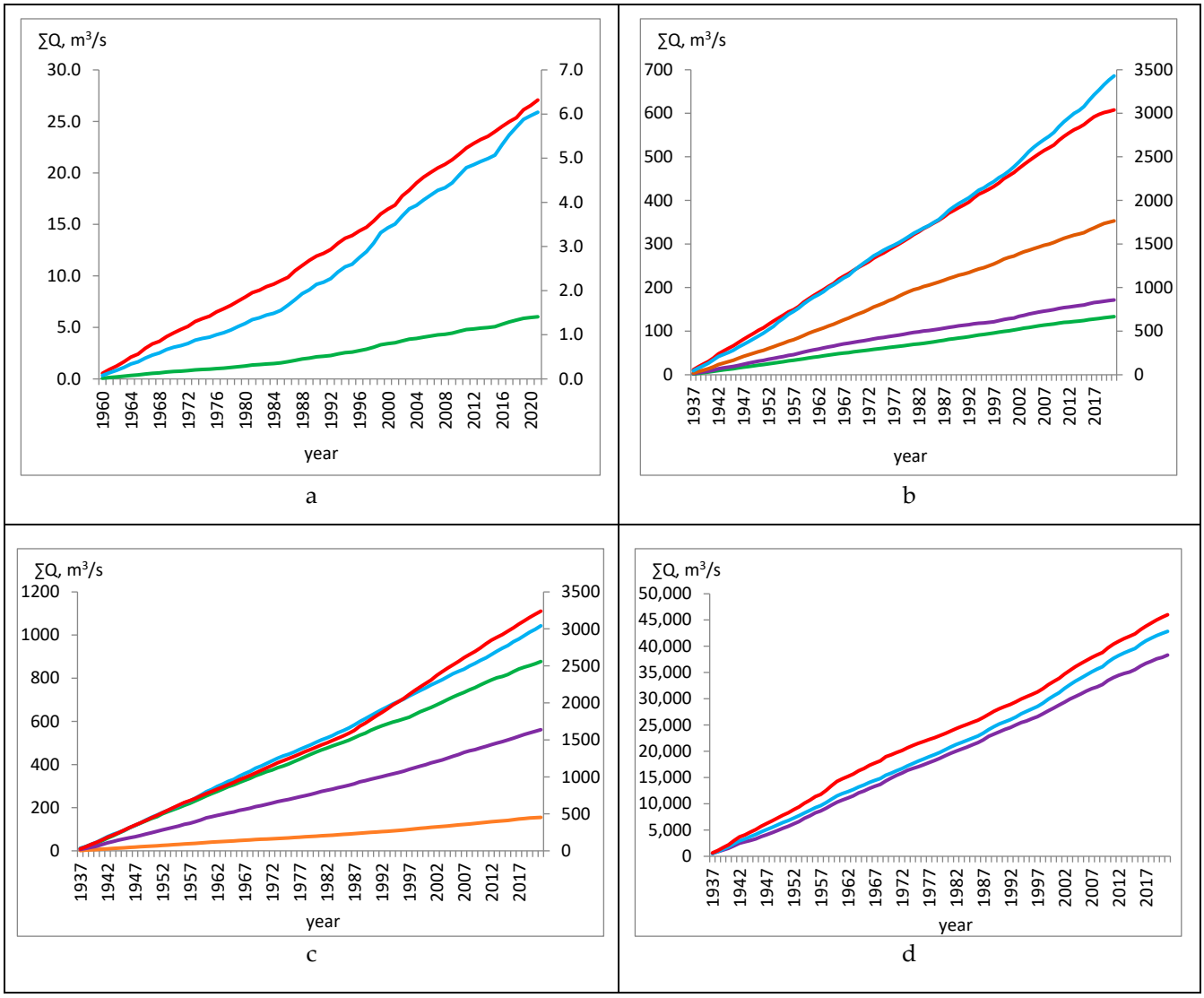



**Figure 5.** Cumulative integral curves of average annual water discharge in the Ile River basin. Integral curves by stations: ***(a)*** *Rivers with spring floods (▲ Butak River—Butak village, mouth of Shybynsai River; ▲ Batareika River—Prosveschenets resort house (mouth); ▲ Terisbutak stream—mouth (Almaty city)).* ***(b)*** *Rivers with spring–summer floods (▲ Sharyn River—Sarytogai tract; ▲ Turgen River—Tauturgen village; ▲ Small (Kishi) Almaty River—Almaty city (mouth of Butak River, dam); ▲ Prokhodnaya River—mouth; ▲ Kaskelen River—Kaskelen city).* ***(c)*** *Rivers with summer floods (▲ Shilik River—Malybai village; ▲ Talgar River—Talgar city; ▲ Big (Ulken) Almaty River—2* km *upstream of Big Almaty Lake; ▲ Usek River—1.7* km *upstream of the valley of the Kishi Usek River; ▲ Kishi Usek River—0.2* km *upstream from its confluence with the Usek River).* ***(d)*** *Rivers with spring–summer floods (▲ Ile River—164* km *upstream of Kapchagai HPP; ▲ Ile River—37* km *below Kapchagai HPP (Kapchagai tract); ▲ Ile River—Zhideli river channel, 16* km *below the source).*

The results of testing for the homogeneity of the considered statistical series of annual runoff by the sign of norm (t) for the calculation period since 1997 confirm the hypothesis of homogeneity in 95% of cases. Additionally, the homogeneity of the series by the variance (F) characteristic was shown in 92% of the considered cases. The non-parametric Wilcoxon criterion (U) also allows for the characterization of the selected design period as homogeneous, thus indicating the possibility of applying mathematical statistics methods to these hydrological series [34].

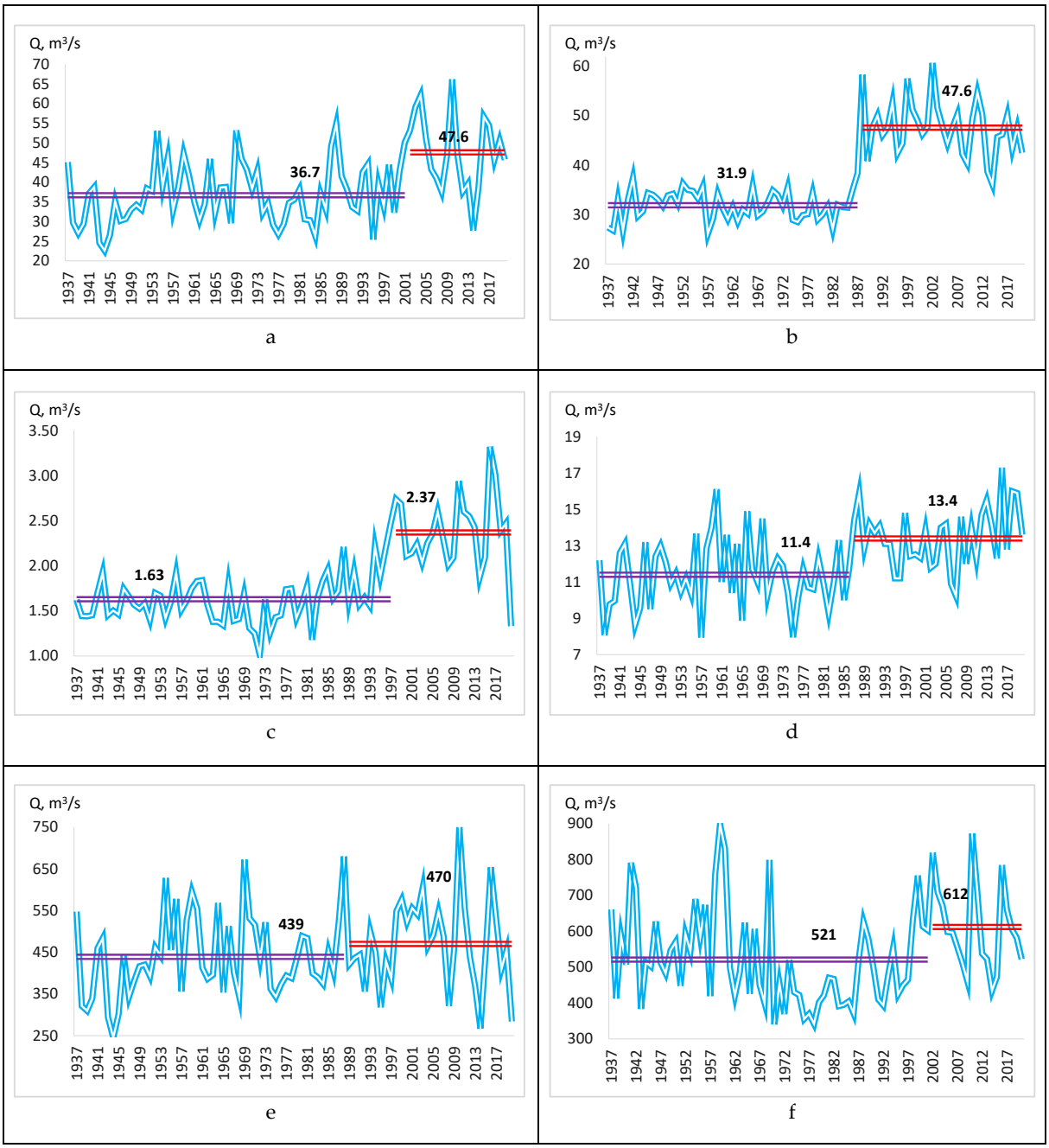



**Figure 6.** The multi-year fluctuations of average annual water discharges for selected rivers in the Ile River basin. *(**a**) Sharyn river—Sarytogai tract; (**b**) Shilik River—Malybai village; (**c**) Big (Ulken) Almaty River—2* km *upstream of Big Almaty Lake; (**d**) Usek River—1.7* km *upstream of the valley of the Kishi Usek River; (**e**) Ile River—164* km *upstream of Kapchagai HPP; (**f**) Ile River—Zhideli River channel, 16* km *below the source.*

## 4. Discussion

By calculating the distribution curve parameters and annual runoff values of rivers with different levels of availability under observed changes in climatic indicators, we assessed the current state of water availability in some tributaries of the Ile River and identified trends in the development of water balance elements in the considered territories. The distribution of the average monthly water consumption for the selected groups of rivers with different periods of high water during the calculation periods is shown in Figure 7.

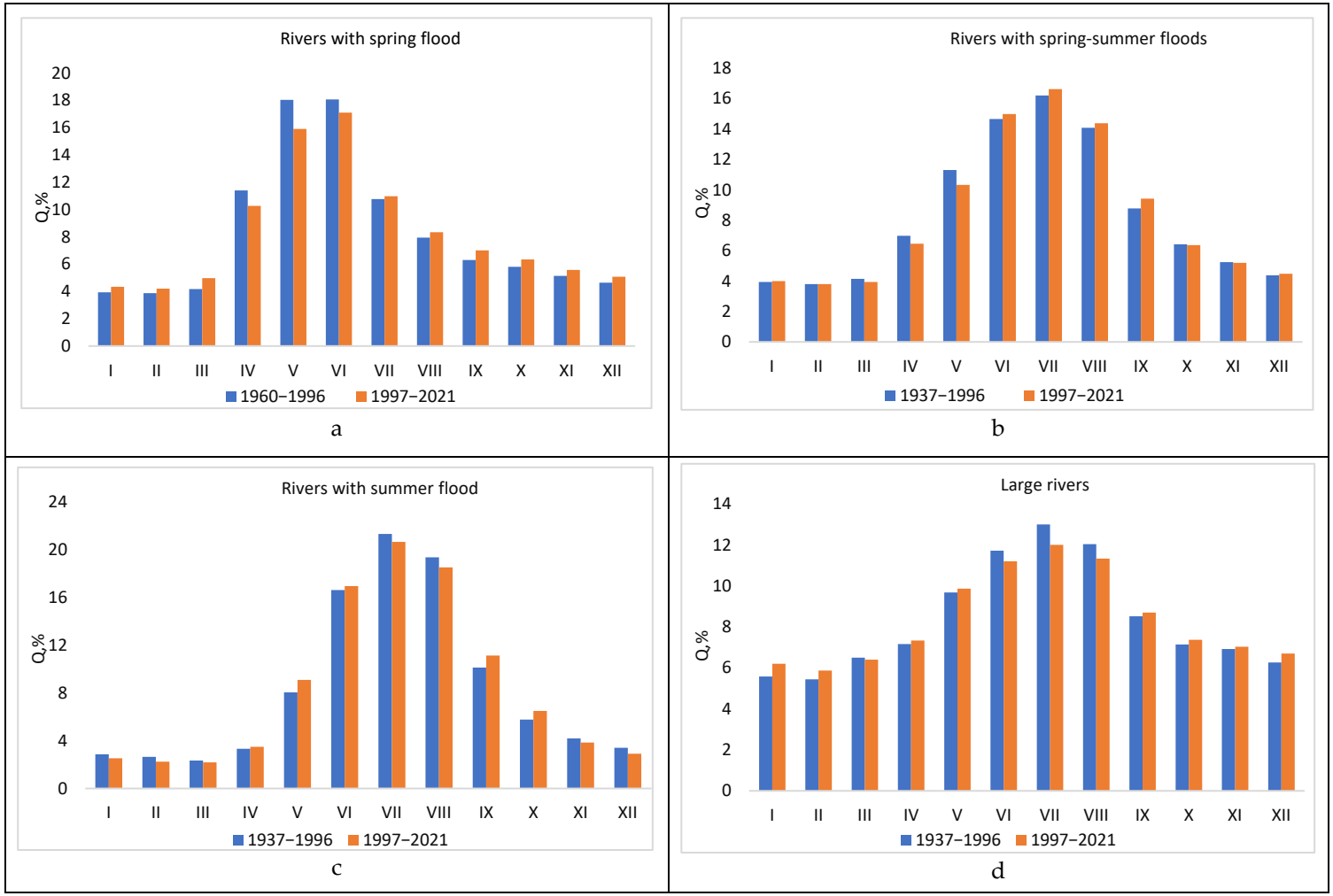



**Figure 7.** Distribution of average monthly runoff as a percentage of annual runoff for different climatic periods.

In most of the examined rivers, the increase in the average annual runoff value is due to the growth of average water discharge during the cold season months. In summer, there is a decrease in average monthly water discharge in most watercourses. Some rivers, on the contrary, are characterized by an increase in runoff during the warm period of the year. Some rivers have a small share of glacial feeding—up to 5–10% of annual runoff—and factors such as slope exposure, catchment area, and average weighted catchment elevation also contribute to changes in the intra-annual distribution of runoff. In general, however, there is a tendency toward increased river runoff in the cold period of the year, especially in the larger rivers of the region [35].

Consequently, the water content for November–March of the Sharyn River near the point at the Sarytogai tract was 5.0% of the annual runoff on average before 1996 and, since 1996, it has increased to 6% on average. At the same time, for April–July, the average monthly water discharge decreased by about 1.5% and, for August–October, the river runoff practically did not change.

Rivers with summer floods also underwent a redistribution of their water regime. The rivers Usek, Kishi Usek, and Talgar reduced their water availability during the summer months, while the values of average monthly discharges increased during the rest of the year. In contrast, the runoff of the Big (Ulken) Almaty and Shilik rivers increased during the summer period.

The main river of the basin, the Ile, shows an increase in water availability during the autumn and cold periods of the year and a decrease in monthly runoff during the summer, both in the upper parts of the catchment and in the lower reaches.

The distributions of average monthly river runoff during the year for the calculated multi-year periods are presented in Table 2.

By evaluating the changes in average monthly water discharge in percent for the calculated multi-year periods, as shown in Figure 7, it was observed that the runoff of rivers with spring floods increased by 30–35% on average during the cold period over the last 20 years, and by 10–20% during the summer months. For rivers with spring–summer floods (Turgen, Small (Kishi) Almaty), an increase in average monthly water discharge in July–September is characteristic, and the water content of the Sharyn River increases significantly in the autumn–winter period.

Rivers with summer floods, except for the highest-water Shilik River, are characterized on average by an increase in average monthly water discharge throughout the year. On the small watercourses of the Usek River and Kishi Usek River, there was an increase in water availability by 30–60% during the winter–spring period, and on the Big (Ulken) Almaty River, runoff increased to a greater extent in the summer–autumn period of the year, ranging from 37% to 63% of average monthly water discharge. On the Talgar River, the growth of monthly runoff values is most noticeable in the winter and spring seasons, while in late summer (July–August), the values of monthly water availability norms decreased. The largest river of this group, the Shilik River, is characterized by the most noticeable redistribution of runoff within the year. Significant growth of average monthly water discharge norms in the May–October period ranged from 40% to 80%. During the cold season, decreases in river water content were observed.

In the main river of the basin—the Ile River—the highest growth of average monthly discharge norms occurred in the winter months by 20–35% and in the spring months by 15% on average, while summer flow decreased in the upper reaches of the river and slightly increased by 10% in the lower reaches.

**Table 2.** Distributions of monthly values of runoff characteristics of the Ile River basin.

| Gauging Station | Periods | I | Change in % | II | Change in % | III | Change in % | IV | Change in % | V | Change in % | VI | Change in % | VII | Change in % | VIII | Change in % | IX | Change in % | X | Change in % | XI | Change in % | XII | Change in % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rivers with Spring Flood (Q, $m^3/s$)** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Butak River—Butak village, mouth of the Shybynsai River | 1960–1996 | 0.11 | | 0.11 | | 0.12 | | 0.31 | | 0.46 | | 0.4 | | 0.27 | | 0.2 | | 0.17 | | 0.15 | | 0.14 | | 0.12 | |
| | 1997–2021 | 0.14 | 22 | 0.14 | 21 | 0.17 | 28 | 0.33 | 6 | 0.48 | 3 | 0.43 | 7 | 0.29 | 8 | 0.25 | 20 | 0.22 | 21 | 0.19 | 22 | 0.17 | 20 | 0.16 | 24 |
| Terisbutak stream—river mouth (Almaty city) | 1960–1996 | 0.19 | | 0.18 | | 0.21 | | 0.40 | | 0.79 | | 0.91 | | 0.54 | | 0.38 | | 0.31 | | 0.28 | | 0.25 | | 0.22 | |
| | 1997–2021 | 0.30 | 35 | 0.29 | 37 | 0.31 | 35 | 0.53 | 25 | 0.85 | 7 | 0.99 | 8 | 0.69 | 22 | 0.50 | 25 | 0.45 | 30 | 0.42 | 35 | 0.38 | 33 | 0.34 | 36 |
| Batareika River—Prosveschenets resort house (river mouth) | 1960–1996 | 0.03 | | 0.03 | | 0.03 | | 0.12 | | 0.17 | | 0.17 | | 0.09 | | 0.07 | | 0.05 | | 0.05 | | 0.04 | | 0.04 | |
| | 1997–2021 | 0.05 | 41 | 0.05 | 37 | 0.06 | 53 | 0.17 | 29 | 0.27 | 38 | 0.32 | 46 | 0.18 | 49 | 0.13 | 45 | 0.10 | 48 | 0.08 | 41 | 0.07 | 44 | 0.07 | 39 |
| Average | | | 33 | | 32 | | 38 | | 20 | | 16 | | 20 | | 26 | | 30 | | 33 | | 32 | | 32 | | 33 |
| **Rivers with spring and summer floods (Q, $m^3/s$)** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sharyn River—Sarytogai tract | 1937–1996 | 18.3 | | 19.0 | | 26.3 | | 57.0 | | 69.1 | | 60.4 | | 44.8 | | 35.4 | | 31.2 | | 29.5 | | 25.4 | | 20.2 | |
| | 1997–2021 | 35.3 | 93 | 34.0 | 79 | 38.2 | 46 | 61.8 | 8 | 81.3 | 18 | 75.9 | 26 | 60.4 | 35 | 51.6 | 45 | 45.4 | 46 | 38.4 | 30 | 38.7 | 52 | 37.1 | 84 |
| Turgen River—Tauturgen village | 1937–1996 | 2.8 | | 2.6 | | 2.6 | | 5.2 | | 10.7 | | 13.7 | | 15.4 | | 13.3 | | 7.0 | | 4.7 | | 3.7 | | 3.1 | |
| | 1997–2021 | 2.6 | −7 | 2.5 | −4 | 2.4 | −8 | 5.1 | −2 | 9.7 | −9 | 14.9 | 9 | 16.8 | 9 | 14.0 | 5 | 8.4 | 20 | 5.4 | 15 | 4.1 | 11 | 3.0 | −3 |
| Kaskelen River—Kaskelen city | 1937–1996 | 1.90 | | 1.78 | | 1.82 | | 2.33 | | 4.19 | | 7.23 | | 9.68 | | 8.35 | | 4.75 | | 3.19 | | 2.55 | | 2.20 | |
| | 1997–2021 | 1.93 | 1 | 1.82 | 2 | 1.86 | 2 | 2.23 | −4 | 3.79 | −10 | 7.91 | 9 | 9.78 | 1 | 7.85 | −6 | 4.75 | 0 | 3.11 | −2 | 2.41 | −5 | 2.14 | −3 |
| Kishi Almaty River—Almaty city (mouth of Butakovka River, dam) | 1937–1996 | 1.04 | | 0.95 | | 0.99 | | 1.51 | | 2.65 | | 3.35 | | 3.79 | | 3.51 | | 2.21 | | 1.54 | | 1.32 | | 1.13 | |
| | 1997–2021 | 0.75 | −28 | 0.72 | −25 | 0.81 | −18 | 1.53 | 1 | 2.58 | −2 | 3.50 | 4 | 4.00 | 6 | 3.62 | 3 | 2.52 | 14 | 1.51 | −2 | 1.10 | −16 | 0.92 | −19 |
| Prokhodnaya River—river mouth | 1937–1996 | 0.78 | | 0.73 | | 0.74 | | 0.88 | | 1.66 | | 2.83 | | 3.30 | | 2.92 | | 1.89 | | 1.33 | | 1.03 | | 0.88 | |
| | 1997–2021 | 0.79 | 2 | 0.73 | 0 | 0.67 | −9 | 0.81 | −9 | 1.57 | −6 | 2.73 | −4 | 3.29 | 0 | 2.99 | 2 | 1.80 | −4 | 1.30 | −2 | 1.05 | 2 | 0.90 | 2 |
| Average | | | −8 | | −8 | | −8 | | −4 | | −6 | | 3 | | 2 | | 0 | | 3 | | −2 | | −7 | | −7 |
| **Rivers with summer flood (Q, $m^3/s$)** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Gauging station | Periods | I | Change in % | II | Change in % | III | Change in % | IV | Change in % | V | Change in % | VI | Change in % | VII | Change in % | VIII | Change in % | IX | Change in % | X | Change in % | XI | Change in % | XII | Change in % |
| Usek River—1.7 km upstream of the valley of the Kishi Usek River | 1937–1996 | 2.7 | | 2.4 | | 2.3 | | 3.6 | | 14.9 | | 32.0 | | 34.8 | | 24.9 | | 10.6 | | 5.3 | | 3.8 | | 3.2 | |
| | 1997–2021 | 4.1 | 50 | 3.9 | 62 | 3.9 | 73 | 7.8 | 113 | 18.5 | 24 | 33.6 | 5 | 35.4 | 2 | 25.6 | 3 | 13.5 | 27 | 8.7 | 63 | 6.2 | 65 | 4.9 | 54 |
| Kishi Usek River—0.2 km upstream from its confluence with the Usek River | 1937–1996 | 2.2 | | 1.9 | | 1.8 | | 2.2 | | 5.9 | | 13.7 | | 17.1 | | 13.5 | | 6.8 | | 4.1 | | 3.1 | | 2.5 | |
| | 1997–2021 | 2.9 | 35 | 2.6 | 35 | 2.4 | 34 | 3.4 | 53 | 8.6 | 46 | 17.5 | 28 | 20.0 | 17 | 15.7 | 17 | 9.0 | 32 | 7.2 | 73 | 4.0 | 30 | 3.4 | 36 |
| Ulken Almaty River—2 km upstream of Big Almaty Lake | 1937–1996 | 0.7 | | 0.6 | | 0.5 | | 0.5 | | 1.1 | | 2.7 | | 3.8 | | 3.9 | | 2.2 | | 1.4 | | 1.0 | | 0.8 | |
| | 1997–2021 | 0.8 | 19 | 0.7 | 11 | 0.5 | 5 | 0.7 | 22 | 1.5 | 37 | 3.9 | 41 | 6.2 | 63 | 6.1 | 56 | 3.5 | 55 | 1.9 | 38 | 1.3 | 24 | 1.0 | 19 |
| Talgar River—Talgar city | 1937–1996 | 4.3 | | 4.0 | | 3.8 | | 4.5 | | 8.2 | | 15.5 | | 23.3 | | 25.3 | | 14.2 | | 8.1 | | 6.1 | | 5.0 | |
| | 1997–2021 | 4.9 | 13 | 4.6 | 15 | 4.3 | 13 | 4.7 | 6 | 10.0 | 22 | 18.5 | 19 | 22.6 | −3 | 22.9 | −9 | 14.9 | 5 | 9.1 | 13 | 6.4 | 5 | 5.3 | 6 |
| Shelek River—Malybai village | 1937–1996 | 10.8 | | 11 | | 10.3 | | 19.3 | | 38.9 | | 61.1 | | 80.9 | | 82 | | 45.5 | | 23.5 | | 16 | | 12 | |
| | 1997–2021 | 2.3 | −79 | 2.48 | −77 | 4.58 | −56 | 18.2 | −6 | 70.5 | 81 | 103 | 69 | 122 | 50 | 121 | 47 | 80 | 76 | 32.7 | 39 | 9.4 | −41 | 2 | −83 |
| Average | | | −15 | | −17 | | −12 | | 7 | | 47 | | 43 | | 37 | | 31 | | 45 | | 30 | | −4 | | −19 |
| **Rivers with spring and summer floods (Q, $m^3/s$)** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ile River—164 km upstream of Kapchagai HPP | 1937–1996 | 219 | | 225 | | 346 | | 353 | | 474 | | 703 | | 868 | | 727 | | 395 | | 327 | | 326 | | 277 | |
| | 1997–2021 | 296 | 35 | 299 | 33 | 390 | 12 | 421 | 19 | 563 | 19 | 666 | −5 | 726 | −16 | 671 | −8 | 489 | 24 | 433 | 32 | 397 | 22 | 347 | 25 |
| Ile River—37 km below Kapchagai HPP (Kapchagai tract) | 1937–1996 | 279 | | 276 | | 356 | | 396 | | 551 | | 691 | | 770 | | 746 | | 485 | | 378 | | 364 | | 319 | |
| | 1997–2021 | 474 | 70 | 446 | 61 | 433 | 22 | 483 | 22 | 718 | 30 | 806 | 17 | 854 | 11 | 822 | 10 | 598 | 23 | 480 | 27 | 491 | 35 | 475 | 49 |
| Ile River—Zhideli river channel, 16 km below the source | 1937–1996 | 416 | | 398 | | 413 | | 481 | | 589 | | 606 | | 609 | | 591 | | 579 | | 519 | | 496 | | 464 | |
| | 1997–2021 | 514 | 24 | 472 | 18 | 487 | 18 | 596 | 24 | 740 | 26 | 804 | 33 | 863 | 42 | 815 | 38 | 693 | 20 | 591 | 14 | 553 | 12 | 558 | 20 |
| Average | | | 43 | | 37 | | 17 | | 22 | | 25 | | 15 | | 12 | | 13 | | 22 | | 24 | | 23 | | 31 |

These results clearly indicate changes in the water regime of the rivers in the Ile basin and a redistribution of norms of average monthly water discharge in all groups of rivers. The obtained results are consistent with and complement previous studies published on this region [36].

The average hydrographs for the phases of the water regime of some rivers in the basin (Figure 8) visually represent runoff indicators for two periods with different climatic conditions.

Along with the changed norms of average monthly water discharge in the rivers of the Ile basin, the redistribution of runoff volumes during the main phases of the water regime is also an important characteristic. The amount of water flowing during different seasons and its distribution under current conditions allow for the assessment of the prospects of river runoff utilization and the planning of its regulation under water management measures, taking into account further climatic changes.

Table 3 as supplementary material shows the calculations of runoff volumes and their redistribution for different phases of the water regime for the estimated multi-year periods.

Based on the results of Table 3, it can be seen that, for the group of rivers with spring floods, the greatest increase in runoff volume on average occurs during winter (62%) and summer–autumn (48%), with an overall increase in annual runoff volume of 44% over the last 20 years.

The rivers with spring–summer floods are also characterized by a greater increase in runoff volume in winter. On average, all rivers of the group show an increase in runoff volume during winter of up to 8%, except for the Sharyn River. The winter runoff volume of the Sharyn River increased by 67%, with a total annual increase of 26%.

On rivers with summer floods, with the general growth of average long-term runoff volume by 29%, there is a more uniform growth of runoff by water availability phases in spring and summer (III–IX) by 30%, and in autumn–winter (X–II) by 24%.

The runoff volume in the upper reaches of the Ile River grows significantly in winter by 29%, and in the lower reaches by 45%, with an increase in the average multi-year volume per year of 11% and 28%, respectively.

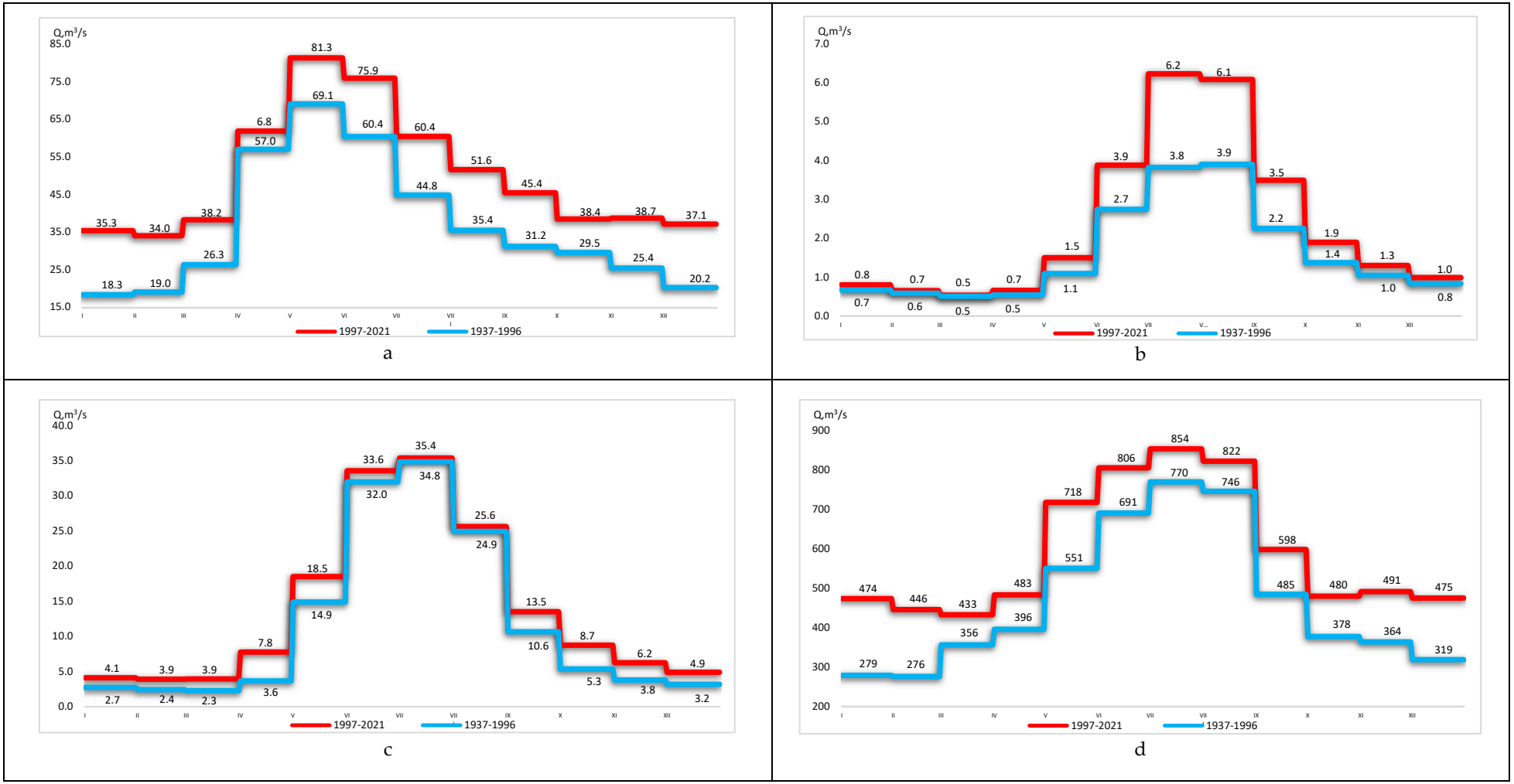



**Figure 8.** Average hydrographs by water regime phases (in Q, $m^3/s$) for major rivers in the basin. (**a**) Sharyn River—Sarytogai tract; (**b**) Big (Ulken) Almaty River—1.1 km upstream of Big Almaty Lake; (**c**) Usek River—1.7 km upstream of the valley of the Kishi Usek River; (**d**) Ile River—37 km below Kapchagai HPP (Kapchagai tract).

**Table 3.** Distribution of conditionally natural runoff volume for different phases of water regime and climatic periods.

| Gauging station | Rivers with spring flood | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W, km$^3$ | | | | Winter XII–II | | | | Spring–Summer III–VI | | | | Summer–Autumn VII–XI | | | |
| | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % |
| 1 | 2 | 3 | 4 | 5 | 14 | 15 | 16 | 17 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Butak River—Butak village, moutn of the Shybynsai River | 0.007 | 0.008 | 0.001 | 19 | 0.003 | 0.005 | 0.001 | 36 | 0.010 | 0.01 | 0.0009 | 9 | 0.006 | 0.007 | 0.001 | 21 |
| Terisbutak stream—river mouth (Almaty city) | 0.013 | 0.016 | 0.003 | 28 | 0.006 | 0.009 | 0.003 | 50 | 0.018 | 0.02 | 0.0028 | 16 | 0.011 | 0.015 | 0.004 | 40 |
| Batareika River—Prosveschenets resort house (river mouth) | 0.002 | 0.004 | 0.002 | 86 | 0.001 | 0.002 | 0.001 | 100 | 0.004 | 0.01 | 0.0028 | 75 | 0.002 | 0.003 | 0.002 | 83 |
| Average | | | 0.002 | 44 | | | 0.002 | 62 | | | 0.002 | 33 | | | 0.002 | 48 |
| | Rivers with spring and summer floods | | | | | | | | | | | | | | | |
| Gauging station | W, km$^3$ | | | | Winter XII–II | | | | Spring–Summer III–IX | | | | Autumn X, XI | | | |
| | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % |
| 1 | 2 | 3 | 4 | 5 | 14 | 15 | 16 | 17 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Sharyn River—Sarytogai tract | 1.16 | 1.5 | 0.300 | 26 | 0.61 | 1.01 | 0.41 | 67 | 1.5 | 1.7 | 0.28 | 19 | 0.86 | 1.15 | 0.28 | 33 |
| Turgen River—Tauturgen village | 0.22 | 0.2 | 0.013 | 6 | 0.09 | 0.09 | 0.00 | −3 | 0.3 | 0.3 | 0.02 | 5 | 0.13 | 0.15 | 0.02 | 12 |
| Kaskelen River—Kaskelen city | 0.13 | 0.1 | −0.004 | −3 | 0.06 | 0.06 | 0.00 | 0 | 0.2 | 0.2 | 0.00 | 0 | 0.09 | 0.09 | 0.00 | −3 |
| Kishi Almaty River—Almaty city (mouth of Butakovka River, dam) | 0.06 | 0.1 | 0.003 | 6 | 0.03 | 0.03 | −0.01 | −23 | 0.1 | 0.1 | 0.00 | 3 | 0.04 | 0.04 | 0.00 | −7 |
| Prokhodnaya River—river mouth | 0.05 | 0.1 | 0.001 | 3 | 0.03 | 0.03 | 0.00 | 0 | 0.1 | 0.1 | 0.00 | 3 | 0.04 | 0.03 | −0.01 | −33 |
| Average | | | 0.06 | 7 | | | 0.08 | 8 | | | 0.06 | 6 | | | 0.06 | 0 |

**Table 3.** *Cont.*

| Gauging station | Rivers with summer flood | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W, km$^3$ | | | | Spring III, IV | | | | Summer V–IX | | | | Autumn–Winter X–II | | | |
| | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % |
| 1 | 2 | 3 | 4 | 5 | 14 | 15 | 16 | 17 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Usek River—1.7 km upstream of the valley of the Kishi Usek River | 0.37 | 0.43 | 0.10 | 15 | 0.09 | 0.18 | 0.09 | 93 | 0.74 | 0.80 | 0.06 | 8 | 0.11 | 0.18 | 0.07 | 60 |
| Kishi Usek River—0.2 km upstream from its confluence with the Usek River | 0.19 | 0.24 | 0.00 | 25 | 0.06 | 0.09 | 0.03 | 45 | 0.36 | 0.45 | 0.09 | 25 | 0.09 | 0.14 | 0.05 | 57 |
| Ulken Almaty River—2 km upstream of Big Almaty Lake | 0.05 | 0.08 | 0.00 | 49 | 0.02 | 0.02 | 0.00 | 6 | 0.09 | 0.14 | 0.05 | 54 | 0.03 | 0.03 | 0.01 | 22 |
| Talgar River—Talgar city | 0.32 | 0.34 | 0.00 | 5 | 0.13 | 0.14 | 0.01 | 10 | 0.55 | 0.56 | 0.02 | 3 | 0.17 | 0.19 | 0.02 | 11 |
| Shelek River—Malybai village | 1.01 | 1.50 | 0.50 | 49 | 0.47 | 0.45 | −0.01 | −3 | 1.95 | 3.14 | 1.19 | 61 | 0.46 | 0.33 | −0.14 | −29 |
| Average | | | 0.10 | 29 | | | 0.02 | 30 | | | 0.30 | 30 | | | 0.001 | 24 |
| | Rivers with spring and summer floods (Major rivers) | | | | | | | | | | | | | | | |
| Гидропост | W, km$^3$ | | | | Spring II–VI | | | | Summer VII–IX | | | | Autumn–Winter X–I | | | |
| | 1937–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % | 1960–1996 | 1997–2021 | Change in km$^3$ | Change in % |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 14 | 15 | 16 | 17 | 10 | 11 | 12 | 13 |
| Ile River—164 km upstream of Kapchagai HPP | 13.8 | 15.3 | 2 | 11 | 13.3 | 15.0 | 1.7 | 13 | 20.9 | 20.4 | −0.5 | −3 | 9.1 | 11.7 | 2.7 | 29 |
| Ile River—37 km below Kapchagai HPP (Kapchagai tract) | 14.8 | 18.9 | 4 | 28 | 14.3 | 18.5 | 4.2 | 29 | 21.0 | 24.3 | 3.2 | 15 | 10.6 | 15.3 | 4.8 | 45 |
| Ile River—Zhideli river channel, 16 km below the source | 16.2 | 19.3 | 3 | 19 | 15.7 | 19.6 | 3.9 | 25 | 18.7 | 24.6 | 5.9 | 32 | 15.0 | 17.5 | 2.6 | 17 |
| Average | | | 3 | 19 | | | 3.3 | 22 | | | 2.9 | 15 | | | 3.3 | 30 |

## 5. Conclusions

Based on the conducted research and statistical analysis of changes in the norms of average monthly water discharge and water volumes for different phases of the water regime of the rivers of the Ile River basin for the modern long-term period, the following key findings are obtained:

- due to global warming, changes in climatic norms of indicators determining the water balance of the Ile River basin entail an increase in the values of annual river runoff for a multi-year period;
- the widespread growth of average annual air temperatures in the basin leads to an increase in high mountain areas with snow reserves, from which the rivers are fed with meltwater;
- the increase in annual precipitation at altitudes up to 2000 m also contributes to the growth of average annual water discharge norms of the basin's rivers;
- warming, in turn, causes an increase in evaporation, especially in the more arid areas of the basin, such as the semi-desert areas of the lower reaches of the Ile River;
- the complex influence of climate causes noticeable changes in the water regime of the rivers under study, which, depending on the water content and weighted average height of the catchment area, are characterized by different times and periods of flooding;
- the redistribution of intra-annual runoff is generally observed with a large increase in river water content in the cold season;
- in the warm season, the values of the norms of the average monthly water discharge of rivers mainly decrease, and the insignificant growth of monthly runoff norms for this time of the year is observed in the Terisbutak, Butak, and Batareika watercourses.

Specifically, the norm of conditionally natural annual runoff of the main river of the basin—the Ile River downstream of the Kapchagai reservoir at the gauging station Kapchagai tract—increased by 28% over the last 25 years from 468 $m^3/s$ to 599 $m^3/s$. At the same time, the most noticeable increase in water availability per year was observed in the autumn–winter period (X–I) with an increase of 45%; in spring (II–IV), the runoff increased by 25% on average and, in summer months (VII–IX), by 15%.

The obtained calculated characteristics of the intra-annual runoff of the rivers in the Ile River basin, i.e., average monthly water discharge and runoff volumes for the periods of floods and low water under global warming conditions, allow for the orientation towards current trends of runoff and water regime changes in the rivers. The performed assessment of runoff values of the main rivers of the region under new conditions is believed to allow for the more informed planning of water management measures and hydraulic structure projects, supporting the sustainable and systematic development of this region of the country.

The results showed that climatic changes have a significant impact on the water regime of the Ile and Zhetysu Alatau rivers. In this regard, a more detailed analysis focusing on monthly flow values was carried out in the present study. This approach is due to the high importance of water resources for regions with developed hydropower and agriculture. The obtained data have already found practical application in a number of hydrotechnical measures, including the development of investment projects (pre-feasibility studies), the reconstruction of irrigation canals, and other areas. Thus, the results of this work can be used for thes justification and planning of water management measures under changing climate conditions.

**Author Contributions:** Conceptualization, R.G.A. and A.N.A.; methodology, R.G.A. and V.P.B.; software, A.N.A. and S.U.R.; formal analysis, R.G.A. and A.N.A.; investigation, R.G.A. and A.N.A.; resources, A.N.A. and U.R.A.; data curation, A.N.A. and A.N.K.; writing—original draft preparation, R.G.A. and A.N.A.; writing—review and editing, S.G. and A.N.A.; visualization, S.G. and A.N.A.; supervision, R.G.A. and A.N.A.; project administration, R.G.A. Funding acquisition, V.P.B. and S.U.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the program "Scientific and applied justification of debris flow, landslide, and avalanche safety in the mountainous regions of the Ile and Zhetysu Alatau of the Republic of Kazakhstan." Program-targeted funding No. BR21881982.

**Data Availability Statement:** The data used in this study were obtained from the national hydrometeorological service, the Republican State Enterprise "Kazhydromet," with the participation of the authors.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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