The Particulars of Territorial Distribution and Anthropogenic River Runoff Variations for the Mountainous Area of Central Asia

Veniamin Semyonov
World Data Centre of the All-Russian Research Institute of Hydrometeo-information,
6, Korolev St., Obninsk, Kaluga Reg. 249020, Russia

Abstract

The spatial distribution of runoff values for the rivers of Central Asia depends on the elevation and orientation of the locality and the extension of mountainous systems. The time variations of runoff in the second half of the 20th century depend on the relationship between feeders. Of anthropogenic factors, irrigated farming affects runoff most of all. The impact of regulated flow on the ecological conditions of water and adjacent systems is described.

Introduction

The concept 'Central Asia' in scientific publications is primarily associated with the vast drainless territory lacking sufficient water resources that is located between 40°-50° N. Latitude and 60°-120° E. Longitude

This paper deals with the regularities of river flow, their spatial distribution, river flow variations in the 20th century induced by climate and economic activities, and some ecological consequences of economic activities in the river basins of the mountainous and sub-montane regions of the Altai, Sayans, Tien Shan, Dzungarian Ala Tau, Pamir, and Alai.

Due to the different conditions of river flow formation on mountains and in regions bordering on mountains, the regularities of flow distribution and the particular uses it is put to are usually considered separately for each type of region. But the increasing use of mountain river flow in mountain hollows and on plains adjacent to mountains demands an integrated consideration of water resources and the ecological consequences of river flow use to include such plains.

Spatial Distribution of Precipitation and River Flow

The extreme inland location of the territory of Central Asia gives rise to its general relative aridity. Its long extension from north to south and west to east, one the other hand, has led to an inexhaustible variety of conditions in the formation of water resources. The elevated location of river catchments and their exposure to prevailing moisture-bearing westerly winds greatly affect the amount of atmospheric precipitation.

For instance, in the peripheral regions of the western Dzungarian Ala Tau the amount of precipitation at an elevation of about 2,500m may reach 1,700mm, while in the southern and central Altai it is 250-300mm. Affected by orography, the distribution of seasonal precipitation for the summer period of the year is similar to that of annual precipitation for all elevations. The difference lies in the absolute value of precipitation and in the fact that the largest pluviometric gradients for precipitation in the warm of the year usually occur at higher elevations than those for annual precipitation.

Conversely, pluviometric gradients for precipitation in the cold period increase with elevation more evenly than in the case of annual precipitation. But more favourable conditions for snow storage in the middle mountain and high mountain regions (the cold period is longer here), as well as in the peripheral north-western regions of mountain systems, account for considerable orographical differences in maximum snow storage and the intensity of its variation with elevation. For instance, in the peripheral regions of the western Altai, the maximum snow storage at an elevation of about 2,000m is 800-900mm and in the southern and central Altai it is 600-700mm lower.

Total evaporation in mountain and high mountain regions of northern latitudes is determined by the heat balance. At southern latitudes it is determined by the amount of precipitation. In the Altai, total evaporation decreases from 450-500mm in sub-montane regions (300-500m) to 150-200mm at elevations of 2,000-2,500m and, in the Dzungarian Ala Tau, it does not exceed 400mm even in the most humid northern areas at elevations of 1,000-1,400m (Semyonov 1990).

Due to considerable differences in the distribution of water balance elements, the spatial distribution of river flow in Central Asia depends on the latitudinal, longitudinal, and elevational location of river catchments, their orientation, and their exposure to moisture-bearing fluxes.

The joint effect of latitude-longitude location and the orientation of catchments on mean annual river flow may be inferred from data on rivers with similar basin areas (from 3,000 to 6,000km^2) and average elevations of catchments (2,000-2,500m), as given in Table 1. Table 1 shows that, even when the difference in latitude and longitude is not considerable (e.g. Dzungarian Ala Tau), variation in the mean annual flow for regions of opposite orientation is considerable (a factor of 3-4). For the Sayan-Altai mountain system, the water content of rivers decreases from north-west to south-east by a factor of 50-100.

Table 1: Dependence of Mountain Rivers' Water Content upon Orientation of Catchment

River basin	Coordinates		General orientation	Module of annual mean runoff, l/s/km^2
	N	W		
Dzungarian Ala Tau Caratal	45	78-80	west	15.2
Tentek, Lepsy	46	80-81	north	11.5
Usek, Khorgos	44	80-81	south	4.0
Altai and Mongolian Altai Ulyba, Uba	51	82-84	south-west	52.0
Cobdo	49	88-90	south-west	1.1
Sayany-Khangai Maly Yenisei	51	98-100	west	2.80
Ider	49	97-99	north-west	2.50
Ongi	47	103-104	south-west	0.35

Variation in the mean annual flow according to the elevation of river catchments also depends on orography: its maximum gradients are observed in peripheral northern regions and its minimum gradients in central and southern regions, with a tendency to increase in high mountain regions.

Similar regularities of spatial distribution are typical for river flow during high-water and low-water periods of the year.

Climate Flow Variations

The results of complex statistical analysis performed in accordance with methods offered by the World Meteorological Organisation and the test trend method developed with the participation of the author were used to identify tendencies of flow variation induced by climate and economic activities (WMO 1988; Semyonov and Alexseeva 1989).

The complex statistical analysis of river flow variation in zones of its formation (flow undisturbed by economic activities) indicates that, in the second half of the 20th century, regional differences of mean annual flow variation and flow variation during high-water and low-water periods are due to climate change. Negative trends prevail for mean annual flow variation and flow variation during flooding for the rivers of inland regions of Central Asia. The trends are positive for rivers substantially fed by glaciers (more than 20%) and rivers fed by snowmelt or snowmelt and rainfall (peripheral northwestern regions of the Altai, Sayans, Dzungarian Ala Tau, Pamir, and Alai).

Figure 1 shows the long-term flow of rivers located in inland regions of the Central Tien Shan (the Bolshoi Naryn River) and fed by glaciers and snowmelt. Its trend for the period from April-September is negative. This figure also shows the long-term flow of rivers located in peripheral regions of the western Tien Shan (the Maidantal River) and western Pamir and Alai (the Bartang, Lyangar, and Pasrut rivers). Its trend is positive. The difference can be explained by the amount of precipitation and the depth of glaciation.

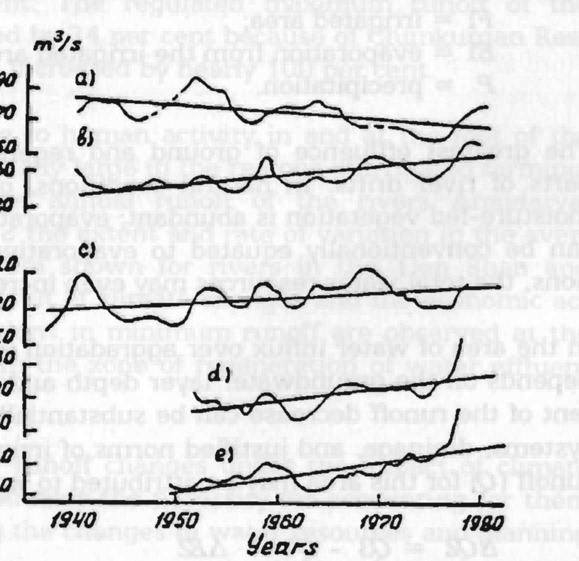

Fig. 1 Smoothed Long-term Runoff for Glacier- and Snowmelt-fed Rivers for April-September

a-r. Bolshoi Naryn – outlet
b-r. Maidantal – outlet
c-r. Pasrut-Pinnon
d-r. Bartang-Jindzhang
e-r. Jyngar - outlet

The flow variation of the Naryn River and other rivers of inland mountain regions of the Tien Shan, Pamir, Alai, and western Sayans during low-water periods also has a negative trend. The minimum river flow in peripheral northwestern regions of the western Sayans, Altai, and Dzungarian Ala Tau has a positive trend.

The Impact of Economic Activity of Man on Runoff

Among the different human activities influencing the runoff of mountain rivers, agricultural irrigation is the most significant one in the depressions between or at the foot of mountains as well as creating water storage basins.

Using the test trend method, it has been found that water losses during the irrigation period in the northern Tien Shan Pamirs and in the Altai resulted in an average annual decrease of runoff of up to 0.01-0.05 l/sec/sq km/year for 1951-1990. The greatest losses in the surface runoff were found in the irrigated areas in the upper part of the mountain river drifts where filtration and irrevocable water losses by evaporation sharply increase due to the irrigation process.

These losses can be estimated from the following equation:

$$\Delta Q1 = F1 \ (E1 - P) \quad (1)$$

where,

$\Delta Q1$ - the change in surface and ground water resources due to irrigation;

$F1$ = irrigated area;

$E1$ = evaporation from the irrigated area; and

P = precipitation.

The greatest effluence of ground and regenerated water occurs in the lower parts of river drifts. In natural conditions, owing to being near groundwater, moisture-fed vegetation is abundant; evaporation reaches its maximum, and this can be conventionally equated to evaporative power. Under favourable conditions, the total water resources may even increase over this area.

In the area of water influx over aggradation plains the water lost to evaporation depends on the groundwater layer depth and the kind of irrigated crop. The extent of the runoff decrease can be substantially lowered by the chosen irrigation systems, drainage, and justified norms of irrigation. The major decrease in river runoff (Q) for this area may be attributed to water lost to evaporation:

$$\Delta Q2 = Q3 - Q4 + \Delta E2 \quad (2)$$

where,

$Q3$ = the total water intake for irrigation;

$Q4$ = the total runoff of regenerated water after irrigation; and

$\Delta E2$ = the changes in evaporation after natural vegetation is substituted for cultivated crops over the irrigation area.

The accuracy of calculations depends on an account of the specific features of irrigated plot, water supply, and consumption.

In the context of the construction of water storage basins, the variation in the volume of river runoff (ΔQ) may be attributed to the variations in water surface evaporation ($E1$); inundation areas ($E2$) as well as evaporation in water-saturated plots ($E3$) and evaporation from tailrace canals of water storage systems flooded previously during high tide ($E4$); and variations also occur at the cost of increases in groundwater resources (ΔS) during storage inundation:

$$\Delta Q = E1 + E2 + E3 + E4 + \Delta S \qquad (3)$$

Comparative tests to determine trends in the average annual, minimum, and maximum runoff of the rivers Kashkadarya and Yenisei have been made upstream and downstream from Chimkurgan and Krasnoyarsk reservoirs and to assess the joint impact of the above-mentioned factors on runoff for the period of full storage of reservoirs and their service.

Apart from the importance of reservoirs in the year-to-year storage of water resources and their use in supplying water and generating electric power, the service of these water storage basins leads to a decrease in runoff. The water losses from Chimkurgan Reservoir (south-west of Central Asia) reduced the runoff by 29 per cent and from Krasnoyarsk Reservoir (in the Nothern Central Asia mountains) by only eight per cent. The regulated maximum runoff of the Kashkadarya River has been reduced by 34 per cent because of Chimkurgan Reservoir and the minimum runoff has increased by nearly 100 per cent.

The total losses in river runoff due to human activity in and at the foot of the mountains of Central Asia are especially large in the regions of irrigated farming. Such activity reduced the average annual runoff of the rivers Amudarya, Syrdarya, and Ily (Fig. 2). In Table 2 the extent and rate of variation in the average annual and minimum runoff are shown for rivers in the Tien Shan and Dzungarian Ala Tau regions as a result of climate changes and the economic activities of man. The positive variations in minimum runoff are observed at the river sites located downstream from the zone of regeneration of water effluent after irrigation.

The existence of steady trends for runoff changes under the impact of climate and economic activities of man motivates the necessity for accounting for them in industrial design and forecasting the changes in water resources and planning their use.

If some trend is detected in runoff variations of high significance (more than 95% probability), a correction should be made to the values of calculated runoff norms according to the following formula:

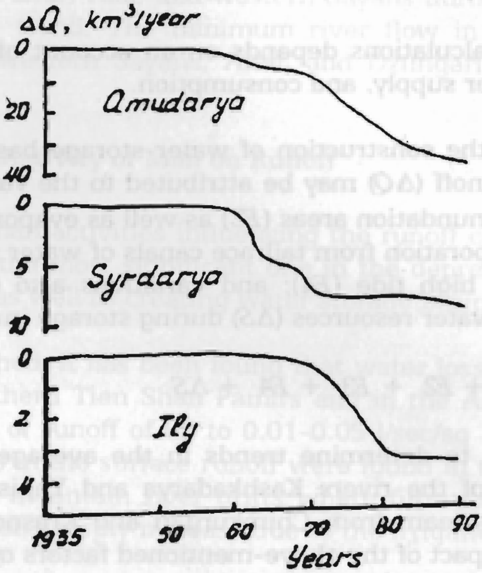

Fig.2. The Rivers' Runoff Variation under the Impact of the Economic Activities of Man

Table 2: Variation of Mean and Minimal Flow of Large Rivers by Economic Activities and Climate for the Period from 1941-1980

River-site	Mean annual flow variation l/sec/km²	Mean annual flow Probability %	Minimal flow variation l/sec/km²	Minimal flow Probability %
Êaratal-Ush-Tebe	-0.014	-72.9	-0.018	-98.3
Tentek-Tunkuruz	-0.012	-59.5	-0.008	99.9
Chilik-Malybai	-0.016	-93.8	-0.004	85.1
Chy-Mylyafan	-0.056	-99.9	-0.026	-99.9
Talas-Kirovskoe	-0.010	-54.8	-0.032	99.8

$$q_p = \bar{q} \pm n * \hat{q} \qquad (4)$$

where,

q_p = predetermined normal runoff;

$\bar{q}$ = normal runoff calculated for the previous long-term period;

n = period duration; and

$\hat{q}$ = magnitude of the normal runoff variation (for a year) under the impact of climatic or anthropogenic factors.

Steady runoff variations and scenarios of climate change allow one to make a prognosis of the amount of water resources at the beginning of the 20[th] century.

The Change in Ecological Conditions

The change in amount and regime of runoff affects the ecological state of water and water supply systems, thereby aggravating the negative effects of water pollution.

The almost complete depletion of water resources from the Amudarya and Syrdarya has resulted not only in the degradation of the Aral Sea but also of deltas adjacent to these rivers, which had been noted for their rich and diverse flora and fauna. The data (Bahkiev and Novikov 1986) show that the area of lakes in the delta of the Amudarya shrank from 60,000 hectares in 1960 to 10,000 in 1980, and, in the delta of the Syrdarya, the total area of lakes decreased from 14,900 to 400 hectares. The floodplain has been drained of an area of 980,000 hectares in the lower reaches of the Amudarya and 200,000 hectares in the lower reaches of the Syrdarya. As a result, trees and undergrowth suffered. Thus, the area of the Amudarya floodplain, containing rare species of vegetation, was reduced by half. The area of hayfields decreased from 420,000 hectares in 1960 to 75,000 in 1980 and the area of pastures from 726,000 to 12,000 hectares. The depletion of the delta led to a sharp transformation in the fauna: the number of species of aquatic animals and their total population went down. Over 30 thirty years, the number of musk rats in the delta of the Amudarya and Syrdarya became six to ten times smaller; foxes - seven times; jackals - four times; rush cats - two times; and badgers - 3.5 times.

The regulated runoff of the Ily River due to Kapchagai Reservoir and the increase in the use of basin river runoff for irrigation led to ecological disaster in the delta of the river and Lake Bal-khash.

The creation of Bukhtarmin Reservoir for year-round storage on the Irtysh Rover caused a sharp decrease in grass productivity over the floodplain and greatly damaged fishery resources.

These examples suggest that the changes in water content of the rivers and in their water regime are the most important ecological factors, and at times more important than water pollution. Hence, the need arises to estimate the limits in the change of water regime.

B.V. Fashchevsky (1992) has found that the highest productivity of water and water-related ecosystems is observed for large- and middle-sized rivers in which long-term flooding is close to the mean values of runoff during inundation (40-60% of occurrences).

Slightly submerged or non-flooded floodplains in the spring and summer periods result in a decrease of area for spawning and feeding fish as well as in a shortage of food resources for waterfowl. A long duration of floodplain inundation leads to inhibited plant growth and increased water turbidity, which adversely affect grass production, fish habitats, and spawning.

All aspects of the ecological control of Central Asian water resources must be based on a developed system of promptly monitoring the components of organic and inorganic nature. A scientifically-based regulation of river runoff via reservoirs and a use of runoff that conforms to the demands of water systems allow optimal conditions to be created for their operation without adverse effects on the use. Thus, for example, it is possible and expedient to reduce inundation and flood peaks by the timely draining of reservoirs during high-water years and to increase ecological dumping into tailrace canals in low-water periods, thereby averaging out the volume of river runoff, that is, approximating the runoff to that of years with average volumes of water.

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