Impact of Reservoir Construction on Flood Characteristics of the Rivers of Kazakhstan during Spring Season

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ABSTRACT

This paper investigates the influence of human activities on the runoff depth of the spring flood of the rivers Zhayyk, Ilek and Tobyl in Kazakhstan. Statistical characteristics of the runoff depth of the spring flood of these rivers before and after the construction of the reservoirs, as well as for the long-term period of supervision, are analyzed based on actual and restored data. Values of the runoff depth of the spring flood of various frequencies were calculated. Series of observations on homogeneity conducted by graphical and analytical procedures were checked. Total integrated curves of the runoff depth of flood during the spring season were developed. Series of observations of the runoff depth of the spring flood were analyzed for homogeneity by means of Student and Fischer's criteria. The analysis revealed that as a result of reservoir construction, the spring flow is not complying with the hypothesis of homogeneity.

KEYWORDS: River flood, Runoff depth of spring flood, Spring season, Reservoirs, Homogeneity assessment, Kazakhstan.

INTRODUCTION

Water resource issues and problems in developing countries present special challenges, as the development of these countries significantly depends on the utilization of water resources. Due to global warming phenomenon, it is expected that fresh water availability will decrease. This is why it is necessary to analyze the status of water resources and manage the use of water by means of reservoir construction, which will enable to meet the increasing demand for water and consequently attain a large economic efficiency (Basilashvili, 2016). On the other hand, water reservoirs (dam construction) have adverse environmental impacts that affect the natural hydrological system of rivers.

With global environmental changes and increase in human activities, steramflows of rivers gradually decreased (Milly et al., 2005). The analysis of streamflow variations and their potential impacts on ecosystems is of scientific and practical importance to help deepen the understanding of the streamflow regime and provide a basis for rational utilization of water resources by following the principles of integrated water resource management (Birsan et al., 2014).

Literature review revealed that different researchers have followed different approaches in analyzing water flow in rivers as a result of human interventions, like dam construction. For example, many investigations have been conducted to analyze the trends and aberrance points in the river streamflow (Birsan et al., 2014; Burn, 2002). Xuan Wang et al. (2015) analyzed annual and

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seasonal streamflow variations and aberrance points for Baihe and Chaohe rivers by Mann-Kendall test and F-test for the period (1963-2011). Furthermore, the double mass curve method was applied to identify human activities affecting streamflow variations (Xuan Wang et al., 2015).

The main objective of the current study is to assess the impacts of constructing reservoirs on the flood characteristics of Kazakhstan rivers during the spring season. The influence of reservoir construction was evaluated in terms of the runoff depth of the flood during spring season for the long-term period (1940-2012) for the rivers Zhayyk, Ilek (western Kazakhstan) and Tobyl (northern Kazakhstan). The method of river analogy was applied.

Study Area

Climate of the flat territory of Kazakhstan is defined as being a continental climate with harsh conditions (hot in summer and cold in winter). The conational conditions are increasing as moving from west to east of the country. These harsh conditions are changing with time. For example, during summer season, they become weak as a result of zone circulation (Baidal, 1964).

In general, the magnitude of spring flood is assessed by the amount of precipitation including both snowfall and rainfall. However, the main contributing factor to the flood in the study area is the snowmelt during spring season. On the northwestern slopes of small hills of the study area, the intensity of snowmelt reaches 50-60 mm/day.As a result, the drainage is 3-8 times more than on the eastern and southeastern slopes (Semenov, 1986).

During spring season, snowmelt increases due to rising temperature and consequently spring flood can be generated even with lower thickness of snow cover as compared to wintertime when temperature is lower. Therefore, snowmelt sometimes covers the study area (flat basins) entirely (Galperin et al., 2011).

The magnitude of spring flood in the steppe zone of the study area is accounting for 60-70% of the annual flow, while it is 98-100% of the annual flow in semi-arid and arid zones of the studied basins.

The character of the water regime of the rivers of the Toby- Torgaysky basin can be divided into three groups; namely, a) rivers of the Tobyl forest-steppe (basin of the river Uy); b) rivers of the Kostanay steppe (top part of the basin of the river Tobyl, basin of the river Obagan); c) rivers of the Torgay semi-arid plateau (basin of the rivers Yrgyz, Saryozen,… etc.).

Possessing many common natural features, the rivers of the considered basin differ in some local features, significantly and visually shown in their water regime. Surface water of the rivers of the basin is formed only during thawing of snow cover. So, for example, the rivers of all three mentioned groups have the delivery prevailing snow framing the main phase of a water regime – spring flood (high water).

In this paper, we consider the characteristics of spring flood of flat rivers of Kazakhstan and the effects of human activities (reservoir construction) on such flood.

The main factors affecting the formation of the spring flood on the rivers of the basin, as well as in other areas of the plains of Kazakhstan, are the degree of soil moisture and air temperature.

For the purpose of this study, three rivers and five hydrological gauging stations were selected as follows:

1. River Zhayyk (Ural): It begins from the slopes of the Kruglaya tops - the hill of the Uraltau ridge in Uchaly Bashkortostan region (Russia). It flows into the Caspian Sea (Kazakhstan).

The paper presents calculations at the gauging station located on river Zhayyk- Kushum village.

2. River Ilek: It is located in the Aktobe region of Kazakhstan and the Orenburg region of Russia. It is the largest left-bank inflow of river Zhayyk (Ural). In this calculation, two gauging stations located on river Ilek were selected: river Ilek in Aktobe and river Ilek in Shelek village.
3. River Tobyl (Tobol) is in Kazakhstan and Russia. It is the left and the most high-water tributary of river Irtysh. Tobyl river is formed at the confluence of river Bozbey with river Kokpektysay on the border of the eastern spurs of the southern Ural and Turgay country dining.

Two gauging stations were considered: on river Tobyl in Pridorozhnyi village and on river Tobyl in Kostanay. It is worth to mention that all three rivers considered in this study are transboundary rivers as shown in Figure 1.

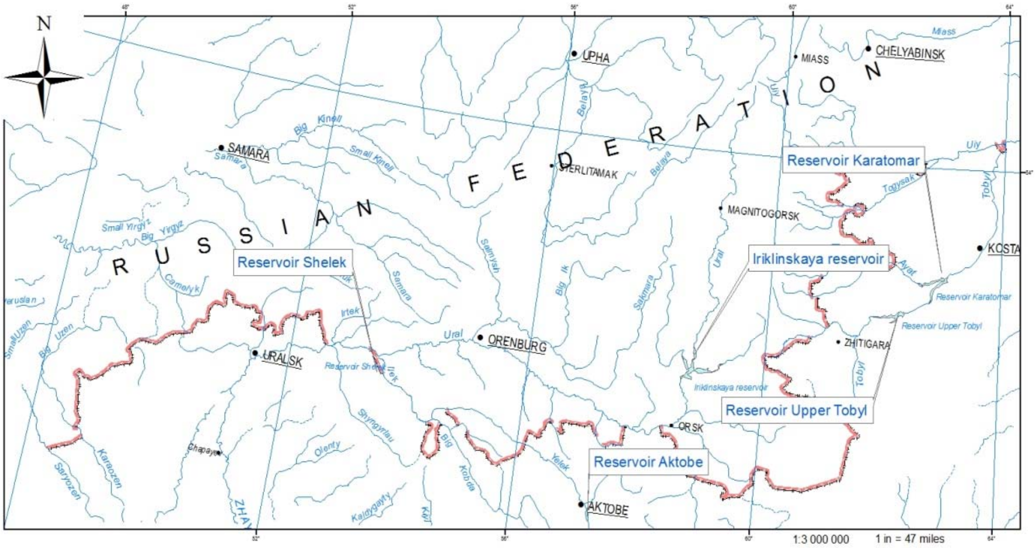

Figure (1): Map showing the location of the reservoirs on the three rivers considered in the current study

Basic data for the years (1930-1989) on the spring flow characteristics for the studied rivers of Zhayyk, Ilek and Tobyl was obtained from the database of Leningrad hydrological information system of surface water (Surface Water Resources, 1989). Data for the period (1990-2012) was obtained from Kazakhstan hydro-meteorological services (KazHydromet, 2012). The obtained data has been reviewed to make sure that it is consistent and accurate, taking into account the development and changes that took place in the study area during recent decades.

RESULTS AND DISCUSSION

To determine the statistical characteristics of the spring flow of these rivers, a calculation period from 1940 to 2012 was considered on the basis of analyzing the different integral curves (by modular ratio k) of the runoff depth of spring flood of the rivers Zhayyk, Ilek (and Tobyl) for that period (Figure 2).

Flow of river Zhayyk in 1958 was disturbed by the regulating influence of the long-term regulation reservoir Iriklinskoe and water abstraction for the needs of different economy sectors (Davletgaliev, 2011). Therefore, the characteristics of the spring flow are identified for different periods; before the reservoir construction (1940-1957) and thereafter (1958-2012), as well as for the long-term observation period (1940 – 2012), taking into account the value of recovered conditionally-natural flow.

Flow of gauging stations of river Ilek in Aktobe and river Ilek in the village Shelek in 1975 was distorted by the influence of Aktobe and Sheleksky multi-year regulation reservoirs. Regarding this, the characteristics of the spring flow are calculated for different periods; before the creation of the reservoirs (1940-1974) and after their creation (1975-2012), as well as for the long-term observation period (1940-2012), taking into account the value of recovered conditionally- natural flow.

Figure (2): Integral curve of the runoff depth of the spring flood: a - river Zhayyk in Kushum village; b - river Ilek in Aktobe

Flow of gauging stations on river Tobyl in Pridorozhnyi village in 1977 was disturbed by the influence of the Verhne (upper) Tobolsk reservoir and the river flow of Tobyl at Kostanay gauging station was disturbed by the influence of Karatomarsk reservoir in 1965. Therefore, the spring flow characteristics are determined for different periods; before the creation of reservoirs (1938-1976 and 1938-1964) and after their creation (1977-2012 and 1965-2012), as well as for the long-term observation period (1938-2012), taking into account the value of recovered conditionally-natural flow.

The results of calculating the characteristics of spring flow at these gauging stations can be seen in Table 1.

Conditionally-natural flow of river Zhayyk by Kushum village for the period (1958-2012) was restored according to natural annual flow of river Zhayyk at indicated gauging stations (SP-33-101, 2003, 2004).

Furthermore, the reservoir construction has a significant impact on the amount of runoff depth of the spring flood (Table 1). Average annual runoff depth of the spring flood for the natural period (1940-1957) on river Zhayyk in Kushum was 50.7 mm for the period (1958-2012), while after the reservoir construction it was 33.4 mm. Average annual runoff depth of the spring flood for the conditional natural period was 44.0 mm. The value of runoff depth of the spring flood after dam construction decreased by 34%.

Table 1. Characteristics of the runoff depth of the spring flood (h, mm)

№ №	River– gauging station	Observation period (years)	h, mm	C_v	C_s	Runoff depth (mm) of the spring flood of different provisions P, %									
						1	5	10	25	50	75	90	95	97	99
1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Zhayyk–Kushum village	1940-1957	50,7	0,76	0,73	180	126	102	69,6	41,5	22,6	11,9	7,3	5,48	2,74
		1958-2012	33,4	0,50	1,21	83,9	64,7	55,8	42,9	30,7	21,2	14,5	11,4	9,62	6,88
		1958-2012	44,0	0,42	0,49	98,0	78,1	68,8	54,9	41,4	30,5	22,6	18,8	16,3	12,5
		1940-2012	37,7	0,66	1,64	118	85,7	71,0	50,6	32,5	19,4	11,5	7,95	6,18	3,69
		1940-2012	45,6	0,54	1,03	121	92,2	78,6	59,3	41,3	27,5	18,3	14,0	11,6	8,03
2	Ilek –Aktobe city	1940-1974	48,3	0,72	1,29	165	117	95,6	65,9	40,1	22,7	12,1	7,73	5,80	2,66
		1975-2012	26,6	0,73	0,91	91,0	64,4	52,7	36,3	22,1	12,5	6,65	4,26	3,19	1,46
		1975-2012	44,2	0,50	1,34	111	85,8	73,8	56,8	40,7	27,8	19,0	15,0	12,8	9,28
		1940-2012	37,0	0,81	1,59	139	95,8	77,0	51,2	29,6	15,2	7,40	4,44	3,11	1,41
		1940-2012	46,1	0,63	1,42	139	102	84,8	61,6	40,1	24,9	15,2	10,6	8,30	5,07
3	Ilek –Shelek village	1940-1974	30,7	0,87	1,46	123	83,5	66,0	42,8	23,3	11,4	5,22	2,86	1,78	0,77
		1975-2012	20,3	0,72	1,60	68,4	48,7	39,8	27,7	17,0	9,54	5,28	3,45	2,64	1,40
		1975-2012	25,1	0,50	0,79	63,0	48,7	41,9	32,3	23,1	15,8	10,8	8,53	7,28	5,27
		1940-2012	25,3	0,87	1,84	102	68,8	54,4	35,3	19,2	9,36	4,30	2,35	1,47	0,63
		1940-2012	27,8	0,75	1,79	97,3	68,4	55,6	38,1	22,8	12,5	6,67	4,17	3,06	1,67
4	Tobyl – Pridorozhnyi village	1938-1976	14,9	1,16	2,12	78,8	49,3	36,5	20,8	9,09	3,28	0,92	0,34	0,18	0,05
		1977-2012	11,6	0,55	0,68	31,3	23,7	20,2	15,1	10,4	6,96	4,52	3,48	2,84	1,97
		1977-2012	18,7	0,49	0,42	46,4	35,9	31,0	23,9	17,2	12,0	8,42	6,55	5,61	4,11
		1938-2012	13,3	1,0	2,64	61,2	39,9	30,6	18,7	9,18	3,86	1,40	0,68	0,40	0,13
		1938-2012	16,7	0,84	1,80	65,0	44,3	35,2	23,2	13,0	6,51	3,17	1,75	1,19	0,53
5	Tobyl – Kostanay city	1938-1964	11,4	1,08	1,47	57,6	36,7	27,4	16,0	7,3	2,74	0,84	0,34	0,18	0,06
		1965-2012	5,5	1,18	1,56	30,5	18,7	13,8	7,63	3,20	1,10	0,28	0,09	0,04	0,01
		1965-2012	8,9	1,06	1,37	43,0	27,7	20,9	12,5	5,96	2,31	0,80	0,36	0,20	0,07
		1938-2012	7,6	1,23	2,01	43,9	26,6	19,3	10,5	4,2	1,3	0,3	0,09	0,05	0,01
		1938-2012	9,8	1,08	1,49	49,5	31,6	23,5	13,7	6,27	2,35	0,69	0,29	0,16	0,05

Note. The numerator shows the actual data, the denominator shows conditionally-natural values of the runoff depth of the spring flood (h, mm). C_v-variation coefficient, C_s-asymmetry coefficient.

Average annual runoff depth of the spring flood on gauging station of river Ilek in Aktobe for the natural water regime period (1940-1974) was 48.3 mm, while for the period of regulated river flow (1975-2012) it was 26.6 mm. Its value decreased by 45%. The amount of runoff depth of the spring flood for the conditionally-natural period (1975-2012) was equal to 44.2 mm. For the period (1940-2012), taking into account the value of recovered (restored) runoff depth of the spring flood, it was 46.1 mm. Average annual runoff depth of the spring flood for the natural period (1940-1974) at gauging station of Shelek village was equal to 30.7 mm, while for the period (1975-2012) after the creation of the reservoir, it was 20.3 mm. The amount of runoff depth of the spring flood decreased by 34%.

Average annual runoff depth of the spring flood for the natural period (1938-1976) at the gauging station of river Tobyl in Pridorozhnyi village was equal to 14.9 mm, while for the period (1977-2012) after the creation of the reservoir it was 11.6 mm. The amount of runoff depth of the spring flood decreased by 22%. In Kostanay, for the natural observation period (1938-1964), the long-term value of runoff depth of the spring flood was 11.4 mm and for the period (1965-2012) after the creation of the reservoir it was 5.5 mm, which shows a decrease in long-term norm of runoff depth of the spring flood by 52%.

Table 1 also shows values of runoff depth of the spring flood of various provisions. It can be observed that in all cases, the runoff depth of the spring flood for the calculated periods in these towns is described as Kritsky-Menkel's curve at $C_s = 2C_v$. If in the surveyed basin one or more economic activities are observed, the test of certain observations on homogeneity by statistical criteria is quite right. This is especially useful when there is no information on the rate of development of economic activities taking place in this basin (Moldakhmetov and Arystambekova, 2007). The use of statistical methods is easy and does not require a lot of time; so, it is widely used in the assessment of human-induced changes occurring in annual, spring and low flow. In C. T. Haan's work "Statistical methods in hydrology" is written about the application of statistical methods in hydrology (Haan, 1977). Some statistical tests mentioned in this work are used for homogeneity check of a row. Homogeneity analysis is based on physical analysis and statistical analysis of the studied aggregates. In some cases, it is enough to use only high-quality criteria (Davletgaliev, 2000). In the practice of hydrological calculations and scientific research, there are two types of homogeneity: temporal (in-row) and spatial- temporal (inter-row). Analysis of temporal homogeneity is performed when evaluating the characteristics of river flow, which may change as a result of the impact of human activities or climatic factors (Davletgaliev, 2000). Number of observations on runoff depth of the spring flood was examined for homogeneity (stationary) using the criteria of Student and Fisher. Student and Fisher's criteria are among the most famous and simplest methods to assess the homogeneity of average and dispersion values. The calculation results for the above mentioned points are shown in Table 2. For the different periods of duration ($n_1 \neq n_2$), the autocorrelation coefficient was taken as r = 0.2 – 0.3 and the critical value of Student and Fisher for significance level was taken as α = 5 % (Table 2).

Based on the results obtained analytically using statistical criteria, it can be concluded that the data taken from the observations contradict the hypothesis of homogeneity of the selected average values by the criteria of Student $t > t\alpha$, with the exception of data for the gauging station on river Tobol- Pridorozhnyi village. As for the hypothesis of homogeneity of variance assessment, it cannot be accepted, since the value of Fisher's statistic far exceeds its critical value: $F > F_\alpha$.

However, statistical homogeneity criterion cannot give a numerical estimation of anthropogenic flow changes. With its help, it is only possible to determine statistical heterogeneity and when it started. If the row is not homogeneous, its deviation is quite possible due to the influence of human activities. Therefore, according to the recommendation of Barisas (1981), the total integral curve method is used for determining homogeneity (Barisas, 1981).

Table 2. Results of homogeneity evaluation and assessment of average values and dispersion of rows of runoff depth of the spring flood

№	River – gauging station	Assessment of average values using Student's criteria			Assessment of dispersion using Fisher's criteria		
		t	t_{α}	result	F	F_{α}	result
1	*River Zhayyk in Kushum village*						
	runoff depth	2,59	1,72	-	5,30	1,76	-
2	*River Ilek in Aktobe*						
	runoff depth	3,28	1,76	-	3,24	2,00	-
3	*River Ilek in Shelek village*						
	runoff depth	2,06	1,88	-	3,40	2,02	-
4	*River Tobol in Pridorozhnyi village*						
	runoff depth	1,09	1,63	+	7,39	1,95	-
5	*River Tobol in Kostanay*						
	runoff depth	2,67	1,61	-	3,63	1,79	-

In the presence of observation using graphic method, the total integral of the curve is possible to determine the date of commencement of anthropogenic changes and roughly estimate the changed value of the spring flow. As an example, the total integral curve of runoff depth of the spring flood at the gauging station of river Ilek in Aktobe is shown in Figure 3.

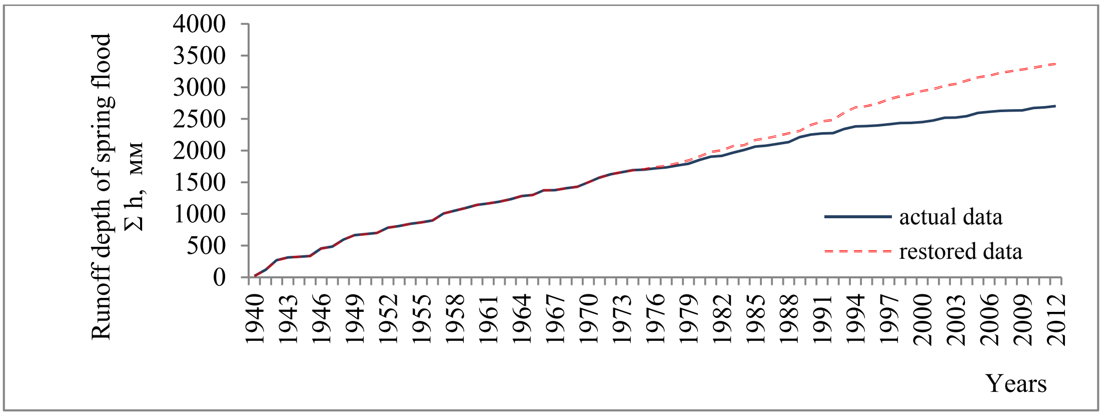

Figure (3): Total integral curve of runoff depth of the spring flood (h, mm): river Ilek in Aktobe

From Figure 3, one can see the violation of natural value of runoff depth of the spring flood of river Ilek. Violation of spring flow began nearly in 1975-1976, when Aktobe reservoir was already operated. Comparing data from the gauging station in Aktobe and actual value along with recovered (restored) value of runoff depth of the spring flood in 1976, the difference between the actual value and recovered (restored) value of runoff depth of the spring flood was 10.8 mm.

CONCLUSIONS AND RECOMMENDATIONS

Homogeneity analysis of a series of observations at the above-mentioned gauging stations was carried out by both graphical and analytical methods. Grafically, the total cumulative curve shows the significant impact of reservoirs on the spring flow.

Statistical criteria of homogeneity by Student and Fisher's method also show that the actual observations are not similar.

Analysis of results shown in Table 1 helps evaluate the effect of reservoirs on the amount of runoff depth of the spring flood. The value of runoff depth of the spring flood decreased by 22% - 52%.

The impact of human activities on river flow comes in a variety of forms, ranging from direct influence on the flow when time and space reallocation (reservoirs, water transfer,… etc.) is taking place, to indirect impact on the components of water balance equation, implemented through changes in individual physiographic basin characteristics (deforestation, afforestation, drainage of wetlands, reclamation,… etc.).

Spring flow tends to decrease due to losses in the filling capacity of reservoirs and additional evaporation from the water surface. Such a decrease may also occur because of the diversion of water for the needs of different economy sectors.

For efficient use of water resources, in the future, we need to have a reliable picture of the changes in the hydrological regime, which already took place under the influence of economic activities and of the consequences which may occur due to planned catchment events, transforming the conditions of runoff formation and climatic factors, thus affecting river flow.

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