

Features of the Sediment Runoff Regime Downstream the Ile River

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ABSTRACT

This paper is devoted to study on the sediment runoff of the Ile River downstream. The article analyses the Kapshagai reservoir impact on the regime and characteristics of the sediment runoff in the Ile River downstream before and after construction of the reservoir in 1970. Along with the calculation of characteristics of sediment runoff, an assessment of the amount of the suspended sediment, which is in the bowl of the reservoir, was shown. Furthermore, the impact reservoir on the granulometric composition of the suspended and bed sediment of Ile River was calculated.

Keywords: sediment transport, sediment runoff characteristics, suspended load, bed load, granulometric composition

INTRODUCTION

The Ile River is one of the largest transboundary rivers located in the South-East of Kazakhstan (Fig. 1). Currently, the water resources of the Ile River play an important role for both the Balkash-Alakol basin and for the economy of the Republic of Kazakhstan as well as for China. Realization of the plans for sustainable use and preservation of the water resources of the Ile River is possible only on the basis of reliable data of all hydrological characteristics. Above all, the quality of water, as well as the characteristics of liquid and solid river runoff, refer to the main hydrological characteristics of the Ile river in its lower reaches [1–6].

For perennial control of Ile River runoff, the Kapshagai reservoir with area surface of 1.847 km² and a length of 180 km was build, its project capacity was equal to 28.1 km³. The main goal of building the Kapshagai reservoir on the Ile River was the development of irrigated lands in the river's downstream with an area of 430 thousand hectares and to provide the region with necessary electricity [7].

The filling of the Kapshagai reservoir was started in 1969, and by 1985 the filled water

volume was 13.99 km³, which is just 50% of the planned project volume.

Since the moment when the Kapshagai reservoir started operation, a number of negative consequences started to appear in the river basin, especially in the downstream. For instance, high daily deviations of flow in the tail-water of the Kapshagai reservoir led to a disturbance of the natural hydroecological regime. As a result of water evacuation to tail-water, waves, which reach the boundaries of the modern delta of the Ile River and increase erosion of the river in the tail-water of reservoir, are formed. According to the measurements of the Kazakh Scientific-Research institute of Ecology and Climate, another negative factor of creating the reservoir is the irrecoverable loss of the water runoff – from the water area of the reservoir. According to the experts' assessment, this value reaches 1.5–2 km³ per year [8].

The delta of the Ile River occupies about 20 km² of Pre-Balkash Lake region are. Out of them, 8 km² is the area of modern delta, the Akdala-Bakanas river mouth is located in the remaining part (compare Fig. 1). In this figure, a view of the Ile River's modern delta is similar to an

isosceles triangle with the base of 210 km (along the coastal line of Balkash Lake) and the length in a straight line of 125 km (Fig. 2).

The Ile River's delta begins 140 km from Lake Balkash, near the village of Akkol. At this place, the river channel branches into three inflows: the north-east – arm Zhideli, central – Ile, south – arm Topar. The eastern boundary of the delta is sand Saryesik constituting an ancient delta of river and the southern boundary of the sand Taukum. The significant volumes of sediment transport, which are formed as a result of

that reduce the conveyance capacity of the river arms while moving to the river delta and sharply decrease the transportation capacity of the water-courses of the delta and the channel of the river itself [9, 10].

MATERIALS

The main part of the sediment load transported by inflows of the Ile River's delta (66–99% of annual runoff) passes in the spring and summer



Fig. 1. The map-scheme of delta of Ile River



Fig. 2. Balkash-Alakol basin

periods of year. The highest value of the suspended sediment load discharge is observed in these times of year. Currently, the amounts of suspended sediments load in the composition of liquid runoff of Ile River are 164 mg/l in autumn and 1300 mg/l in spring (Fig. 3).

For this study, the volume of sediment entering the reservoir at the gauging station located above the Kapshagai reservoir basin was determined (Table 1)

METHODOLOGY

Granulometric composition and sediment regime

The sediment regime largely determines not only the conveyance capacity of the delta water-courses but also the ecological conditions of both delta itself, and its water objects [11].

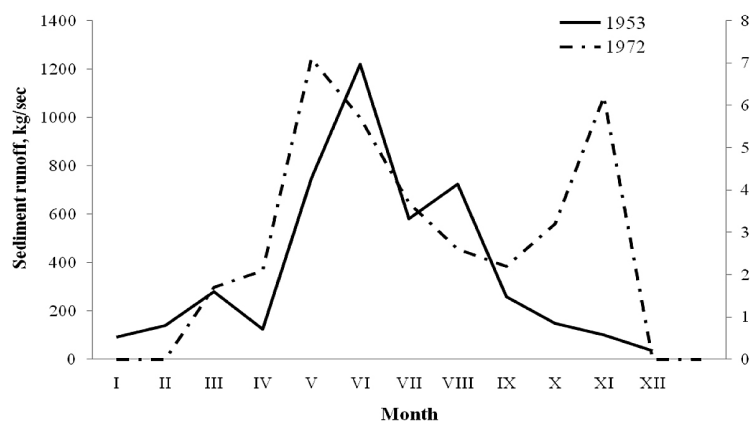


Fig. 3 Within-year distribution of average annual discharge of sediment load before and after the construction of the Kapshagai reservoir on the Ile River in the Kapshagai gauging station

Table 1. The value of the sediment runoff from the Ile River – gauging station 171 km above the Kapshagai reservoir

Years	Water discharge, (m ³ /sec)	Sediment discharge, (kg/sec)	$W_R=31,5 \cdot 10$	W (volume, ton)
1981	484	310	9765000000	9765000
1982	399	250	7875000000	7875000
1983	390	190	5985000000	5985000
1984	375	170	5355000000	5355000
1985	452	350	11025000000	11025000
1986	404	190	5985000000	5985000
1987	525	360	11340000000	11340000
1988	680	540	17010000000	17010000
1989	421	230	7245000000	7245000
1990	436	280	8820000000	8820000
1991	444	270	8505000000	8505000
1992	356	167	5260500000	5260500
1993	500	339	10678500000	10678500
1994	450	280	8820000000	8820000
1995	317	125	3937500000	3937500
1996	415	238	7497000000	7497000
1997	388	207	6520500000	6520500
1998	556	402	12663000000	12663000
1999	573	423	13324500000	13324500
2000	522	363	11434500000	11434500

In this section, the impact of the Kapshagai reservoir creation on the change of the granulometric composition of suspended sediment and load was considered.

In order to analyze the granulometric composition of the sediment, the years of 1965 (before constructing of Kapshagai Hydropower Station) and 1982 year (after constructing of Kapshagai Hydropower Station) were taken into account. The data on the granulometric composition of suspended and bed sediment were used by the results of monitoring at the Ile River in the Kapshagai gauging station [12, 13].

The average diameter and factor inhomogeneity of sediment were considered as the main characteristics of the granulometric composition of sediment. Tables 2 and 3 contain the data on the granulometric composition of suspended and bed sediment at various phases of the hydrological regime of the Ile River in the Kapshagai gauging station. The factor of inhomogeneity of sediment (η) was calculated by means of the following formula [14]:

$$\eta = \frac{d_{60}}{d_{10}} \quad (1)$$

where: d_{60} and d_{10} – diameters corresponding to 60 % and 10 % integral curve of granulometric composition.

The analysis of the content of the Tables 1 and 2 before the construction of the Kapshagai Hydropower Station shows that the size of particles of the suspended sediments (0.005/0.5 mm) varied in much wider range than the bed sediments (0.01/0.5 mm). Therewith, the factor of inhomogeneity suspended sediment was close to inhomogeneous ($\eta = 5/6$ mm), whereas the factor of heterogeneity of bed sediment did not exceeding $\eta = 1.5$, i.e. grounds were homogeneous [15].

The changes in the size and uniformity of the particles of bed sediment by water regime phases, before the construction of the Kapshagai Hydropower Station were not observed. However, for the suspended sediment at the rise of flood, it differs by increasing of homogeneity and increase in the size of the particle (Fig. 4).

Upon the construction of the Kapshagai Hydropower Station for suspended load, a significant increase (more than 10 times) in the size of particles sediment (Table 4) and equally substantial increase in homogeneity were observed. An increase in the heterogeneity of particles was noted

Table 2. The granulometric composition of the suspended sediment at various phases of the hydrological regime of the Ile River in the Kapshagai gauging station for 1965

Diameter, mm	12/IV		31/V		17/VI		20/VII		08/VIII	
	%	d_{ave}	%	d_{ave}	%	d_{ave}	%	d_{ave}	%	d_{ave}
0,005	34,5	0,17	47,7	0,24	20,3	0,10	37,2	0,19	36	0,18
0,01	31,9	0,32	27,6	0,28	40,4	0,40	46,8	0,47	41,7	0,42
0,05	17,8	0,89	18,9	0,95	25,0	1,25	12,7	0,64	10,2	0,51
0,1	8,00	0,80	5,20	0,52	8,00	0,80	1,60	0,16	7,3	0,73
0,2	4,30	0,86	0,30	0,06	5,60	1,12	1,50	0,30	4,2	0,84
0,5	3,50	1,75	0,30	0,15	0,70	0,35	0,20	0,10	0,6	0,30
d_{aver}	0,05		0,02		0,04		0,02		0,03	
η	6,00		-		2,85		5,00		5,30	

Table 3. The granulometric composition of the bed sediment at various phases of the hydrological regime of the Ile River in the Kapshagai gauging station for 1965

Diameter, mm	25/II		29/III		17/VI		08/VIII		11/XI	
	%	d_{ave}	%	d_{ave}	%	d_{ave}	%	d_{ave}	%	d_{ave}
0,01	18,2	0,002	7,9	0,001	7,3	0,001	15,2	0,002	19,1	0,001
0,05	39,1	0,020	35,9	0,018	50,7	0,025	24,7	0,012	41,9	0,021
0,1	21,8	0,022	21,9	0,022	19,0	0,019	18,6	0,019	13,4	0,013
0,2	13,6	0,027	18,7	0,037	14,0	0,028	19,2	0,038	7,00	0,014
0,5	7,30	0,037	15,6	0,078	9,0	0,045	22,3	0,112	18,6	0,093
d_{aver}	0,001		0,002		0,001		0,002		0,001	
η	1,46		1,54		1,30		1,82		1,39	

by phases of the hydrological regime during the rise of flood (Fig. 5).

As for bed sediments (Table 5) after constructing of Kapshagai Hydropower Station, a manyfold increase in the particles size (more than 1000 times) and decrease of its homogeneity (almost two times) were noted. Simultaneously, significant changes either in the particles size or homogeneity of the bed load were not observed by the phases of the hydrological regime. The changes in the granulometric composition of suspended and bed sediment of Ile River identified above were caused by the following reasons.

Evaluation of the amount of suspended sediment load settling in the bowl of the Kapshagai reservoir

The distribution of the sediment load to the arms of the Ile river delta was determined for the periods before and after the Kapshagai reservoir construction. At the gauging station located below the Kapshagai reservoir, a reduction of the

considered hydrological characteristics was observed. At the Ile River in the Ushzharma gauging station, the water discharge decreased from 472 m³/sec to 382 m³/sec and the reduction of the discharge of sediment was from 442 kg/sec to 81.3 kg/sec. This means that the liquid runoff decreased for 1.24%, sediment runoff for 18.4%. These indicators are presented in Table 6.

According to the data presented in Table 6, a sharp decrease and reduction in the value of sediment runoff is observed in the periods after the construction of the Kapshagai reservoir. The main reason for this is that sediments are transported through the reservoir which is stretched for the considerable distance in the plan and has a maximum depth of 70 m. Therefore, in the first place, it is very important to know how much sediment is settling on the bottom of the basin of the reservoir.

Using the data from Table 6, the volume of sediment value deposited on the Kapshagai reservoir basin was determined (Table 7). Total quantitative volume of the settled sediment in the

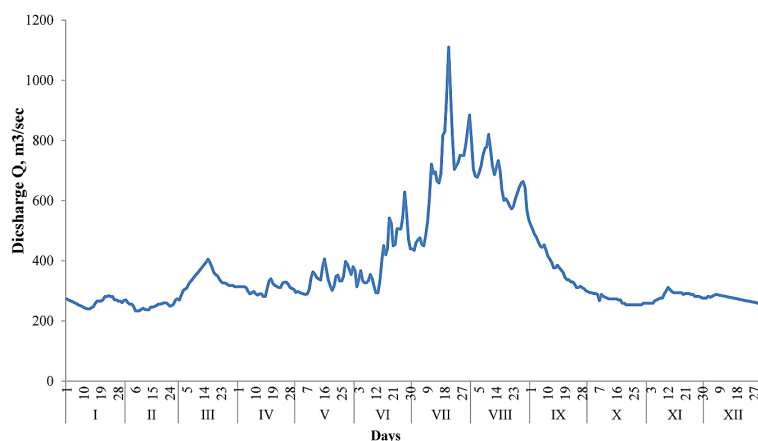


Fig. 4. Hydrograph of water discharge before construction of the Kapshagai Hydropower Station for 1965

Table 4. Granulometric composition of the suspended sediment at various phases of the hydrological regime of the Ile River in the Kapshagai gauging station for 1982

Diameter, mm	30/IV		31/VI		30/VII	
	%	d _{ave}	%	d _{ave}	%	d _{ave}
0,001	25,2	0,03	14,7	0,01	2,30	0,002
0,005	12,6	0,06	7,40	0,04	6,90	0,035
0,01	18,9	0,19	14,7	0,15	19,7	0,197
0,05	3,20	0,16	35,6	1,78	59,8	2,990
0,1	32,4	3,24	16,9	1,69	6,30	0,630
0,2	6,90	1,38	9,30	1,86	1,20	0,240
0,5	0,80	0,40	1,4	0,70	3,80	1,900
d _{aver}	0,055		0,062		0,060	
η	-		-		1,71	

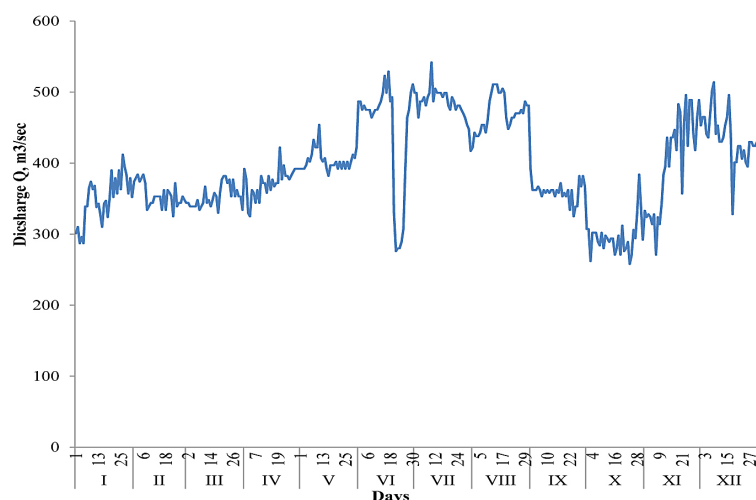


Fig. 5. Hydrograph of water discharge after the construction of the Kapshagai Hydropower Station for 1982

Table 5. The granulometric composition of bed sediment at various phases of the hydrological regime of the Ile River in the Kapshagai gauging station for 1982

Diameter, mm	31/I		28/II		23/III		30/IV	
	%	d _{ave}	%	d _{ave}	%	d _{ave}	%	d _{ave}
0,01	0,40	0,00	1,40	0,01	0,20	0,002	0,1	0,001
0,05	1,30	0,07	5,80	0,29	0,60	0,03	0,2	0,01
0,1	3,50	0,35	3,10	0,31	0,80	0,08	0,6	0,06
0,2	8,20	1,64	4,40	0,88	11,9	2,38	5,3	1,06
0,5	4,60	2,30	2,40	1,20	5,40	2,70	4,0	2,00
1	3,00	3,00	1,60	1,60	3,40	3,40	3,0	3,00
2	3,80	7,60	3,60	7,20	5,60	11,2	5,0	10,0
5	6,70	33,5	6,20	31,0	4,60	23,0	6,8	34,0
10	7,00	70,0	5,00	50,0	10,0	100	7,5	75,0
20	18,0	360	13,0	260	13,0	260	7,5	150
50	26,0	1300	38,5	1925	32,5	1625	37,5	1875
100	17,5	1750	15,0	1500	12,0	1200	22,5	2250
d _{aver}	35,3		37,8		32,3		44,0	
η	2,06		2,48		2,08		1,75	

Kapshagai reservoir basin can reach an average of 5 to 15 million tons per year.

As a result of the creation of the Kapshagai reservoir, practically all suspended and bed sediments of the Ile River are deposited in the bowl of the reservoir. In the tail-water of the Kapshagai Hydropower Station the treated water of the Ile River flows, which considerably increases its transporting capacity. This, in its turn, contributes to involving into transfer of the suspended sediments of larger particles downstream of the Ile River [16].

The increase in the homogeneity of the particles during this period is caused by the increase of the flow velocity in the river channel and, respectively, by the increase in its transporting capacity. A significant increase in the heterogeneity of the

bed sediment is also explained by the increase of the transport capacity of flow, wash away small particles and the form the bed material on the bed of the river [7, 9, 16].

RESULT AND DISCUSSION

The analysis of the content of the Tables 2 and 3 shows that before the construction of the Kapshagai Hydropower Station, the size of particles of the suspended sediments (0.005–0.5 mm) varied in much wider range than the bed sediments (0.01–0.5 mm). Therewith, the factor of inhomogeneity of the suspended sediment was close to inhomogeneous (5–6 mm), whereas the factor of

Table 6. The main characteristics of the liquid runoff and sediment runoff of the Ile River, before and after the construction of the Kapshagai reservoir

Inflows	Before construction				After construction			
	Water discharge, (m ³ /sec)		Sediment discharge, (kg/sec)		Water discharge, (m ³ /sec)		Sediment discharge, (kg/sec)	
	Q, m ³ /sec	Cv	R, kg/sec	Cv	Q, m ³ /sec	Cv	R, kg/sec	Cv
Ile River in gauging station Kapshagai	482	0,23	392	0,48	419	0,21	3,4	0,98
Ile River in gauging station Ushzharma	472	0,14	442	0,34	382	0,16	81,3	0,48

Table 7. The volume of the sediment deposited on the basin of the Kapshagai reservoir

Years	Water discharge, m ³ /sec	Sediment discharge, kg/sec	$W_R=31,5 \cdot 10$	W (volume, ton)	ΔW_R	$\Delta W_R \%$
1981	437	0,9	28350000	28350	9736650000	99,7
1982	392	2,0	63000000	63000	7812000000	99,2
1983	322	2,0	63000000	63000	5922000000	98,9
1984	337	2,6	81900000	81900	5273100000	98,5
1985	344	3,4	107100000	107100	10917900000	99,0

heterogeneity of bed sediment did not exceed 1.5, i.e. grounds were homogeneous.

The spring warming leads to the melting of snows, and this, in turn, exposes the basin area to intense erosion. The increase in the water discharge promotes enhancing the channel bed erosion. In the summer period the same process is repeated, and because of the wash out of the bed, sedimentation of bottom of the reservoir's basin replenished by suspended load.

The main feature of the within-year distribution of the suspended sediment load is its sharp variability during the year. For instance, for the observed period, the average discharge of the suspended sediment load in the inflow of the Ile River, Iir duct in January is 4.6 kg/s, and in April it was 100 kg/s, i.e. it increased by 20 times. The within-year distribution of the sediment runoff by the inflows of the delta is also highly variable. Because of the sediment accumulation in the bowl of the reservoir, the characteristics of solid runoff in the downstream of the river decreased several times. According to the observations on the Ile River in the Kapshagai gauging station, the water discharge decreased from 482 m³/s to 419 m³/s, and at the same time, the sediment runoff reduced from 392 kg/s to 3.4 kg/s. It means that the liquid runoff decreased by 1.15%, and the sediment runoff by approximately 100%.

As a result, it was revealed that the within-year distribution of the sediment load on the arms of the river delta is sharply uneven (Fig. 6).

A sharp increase in the sediment runoff is observed in the spring months. The average monthly discharge of the suspended sediment in February is less than observable in March. A decrease in the discharge of the suspended sediment load in the following gauging stations: the Ile River in the Ushzharma gauging station – 3 times; in the inflow of the Ile River, Iir duct – a gauging station 2.5 km from delta – 6 times observed; in the gauging station in the Zhideli inflow – 16 km from the source – it decreased 10 times. Additionally, in the Ile River, in the Suminka inflow located 6 km from the source and in Zhideli inflow – 1 km below the branch, a decrease of 40 times was observed [12].

While studying the sediment mode and their within-year distribution, it was revealed that the main factor determining the variability of these characteristics is the Kapshagai reservoir. As for the periods before the construction of the Kapshagai reservoir between water runoff and sediment runoff, there is a good link; in order to restore a number of sediment runoff, a link between the sediment runoff and the water runoff was used (Fig. 6). The calculations results indicated that 99% of the incoming sediments settle in the reservoir basin can be formulated.

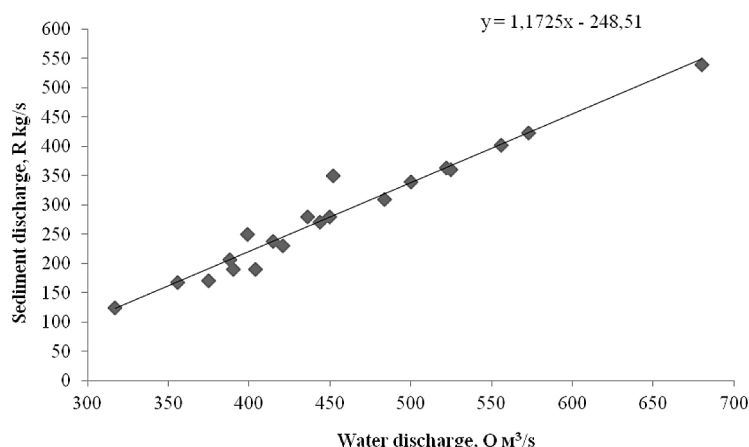


Fig. 6. Link between the water runoff and sediment runoff of the Ile River – gauging station 171 km above the Kapshagai reservoir

CONCLUSIONS

The construction of the Kapshagai reservoir led to a significant decrease of the sediment runoff and caused a considerable impact to the granulometric composition of the suspended sediment load downstream the Ile River. Downstream the reservoir, the sizes of sediment particle are increasing; simultaneously, a decrease for the suspended sediment is observed. Furthermore, for the bed sediments, an increase of heterogeneity of granulometric composition was measured.

As shown in this paper, there are from 5 to 15 million tons of sediment settled in the Kapshagai reservoir, with an average of 10 million tons per year. This is 99 % of the total volume of the sediment flowing to the basin of the reservoir.

The obtained regularities in the changes of the granulometric composition of the suspended and bed sediment loads after the construction of the Kapshagai reservoir, which were shown in this study, must be considered at planning and realization of hydroeconomic and nature conservation activities downstream and on the delta of the Ile River.

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