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Anthropogenic load on water resources of Kazakhstan

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Abstract

In the article the main factor affecting water resources – irrevocable water consumption in the main river channels and administrative regions of the Republic of Kazakhstan, the degree of its impact on water resources is considered. Quantitative assessment of water resources use was carried out on the basis of data analysis of the statistical form of the departmental statistical observation 2-TP (water farm) and basin inspections. The most complete annual data are available only since 1992. For earlier years, water consumption accounting is not systematic and data are sometimes incomplete and contradictory. In this regard, this study uses data for the period 1992-2015. Anthropogenic changes in river flow at reference points in the main river channels draining the waters of a certain water collection were determined, channel water balances were compiled, transformations of water balance elements in each section were studied and compared with real water-intake facilities, and the share of irrevocable water consumption in certain sectors of the economy was determined. Using data on water consumption, the impact of water consumption on water resources was assessed by comparing the water resources available in the region with the volume of water used according to the so-called water load criterion. It is characterized by the capacity factor of water resources C_{cap}, equal to the ratio of the percentage of total water consumption to renewable water resources. This assessment was carried out for each WMB, as well as for all administrative regions of Kazakhstan.

Keywords: water resources, anthropogenic changes, water consumption, method of hydrological analogy, method of water balance, anthropogenic load, projected estimates of water resources

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INTRODUCTION

Within large water management basins, water resources are usually affected simultaneously by many anthropogenic factors. One of the main factors affecting the quantitative characteristics of river flow is water withdrawal from water sources or water consumption. The scale of the impact of water consumption on water resources is determined by the ratio between the parameters of water consumption and the characteristics of the water body from which water is taken and where it is discharged after use. Depending on these ratios, water consumption can have a large impact on small, medium, and sometimes large river systems, while the conditions for the formation of flow in the water collection do not change much.

Water resources on the territory of the Republic of Kazakhstan are distributed very unevenly. Water resources are one of the most important components of the environment, a renewable, limited and vulnerable natural resource. They ensure the economic, social, and environmental well-being of the country's population and the existence of the region's flora and fauna.

Water resources change over time and space, fluctuations are mainly determined by climate factors, but recently, namely since the second half of the XX century, the role of anthropogenic influence is commensurate with natural influence. It is possible to divide the set of factors into natural and anthropogenic ones, which differ in the nature and consequences of their influence on water resources.

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RESEARCH METHODS

To assess the anthropogenic load, a method has been developed based on the complex application of various techniques, with a detailed study of the state of irrevocable water consumption in economic sectors, which in general can be combined into two groups (Koronkevich and Zaitseva 2003, Water resources of Russia and their use 2008, Voskresensky et al. 1974, Vodogretsky 1974, Vodogretsky 1979, Shiklomanov 1976, Shiklomanov 1989, 2004, UN/WMO/SEI 1997):

1) Statistical methods - based on a joint analysis of long-term flow fluctuations and natural factors, as well as the dynamics of economic activity in the basin;

The methods of the first group include techniques and methods for restoring natural flow for a period with a disturbed water regime using regression equations that relate the amount of flow in the range under consideration:

- with the flow of one or a group of analogous rivers whose regime is in a natural state;
- with the flow of the basin area that has not been changed by economic activity or private areas of the basin;
- with meteorological factors.

The restored series is compared with the actual ones and on the basis of this, the change in river flow caused by economic activity is detected and evaluated.

2) Water balance method - calculations are performed on the basis of data on accounting for water use and changes in water balance elements in the river basin as a result of the impact of each type of economic activity separately.

The methods of the second group include those methods and techniques of research that provide for separate accounting of each type of economic activity. This is based on the analysis of changes in the elements of the water balance under the influence of economic activity using the principle of conservation of water masses, expressed by the water balance equation.

ASSESSMENT OF ANTHROPOGENIC LOADS ON WATER RESOURCES

Reliable quantitative assessment of anthropogenic changes in river flow is one of the most difficult tasks of modern hydrology. The problem is particularly relevant for our country with a weak network of observations of river flow, and unreliable data on water-intake facilities and discharges into natural water bodies. There are often cases when there is even a complete lack of such data, not to mention information describing the time, scale and intensity of economic activities carried out within water collections.

In our study, we aimed at an approximate assessment of irrevocable water consumption, to differentiate them by individual regions and sectors of the economy, which would allow to obtain relatively reliable scenarios for the long-term impact of anthropogenic loads on water resources in the future.

At the first stage, an assessment of anthropogenic changes in river flow was made for the main reference points of observations based on the method of hydrological analogy (**Table 1**). The method gives quite reliable results, although they are integral values of changes and are limited for evaluating the role of individual industries or types of economic activity. These results, as the most reliable, will be used as control materials for further detailing of anthropogenic changes. According to the results of **Table 1**, the largest changes occurred in the Aral-Syrdarya, Balkash-Alakol, Ertis, Shu-Talas, the smallest - in the Esil, Nura-Sarysu water management basins (hereinafter WMB), which is quite consistent with the level of water resources development in Kazakhstan.

According to **Table 1**, the total anthropogenic impacts of the main river in the basin are recorded in each WMB in the final AC.

Fig. 1 graphically shows the anthropogenic load on water resources relative to total and local water resources in different by water content years for 8 WMB. Local resources here refer to river flow and annually renewable river flow in the territory, while the total resource also includes tributaries from neighboring countries and actual inter-basin transfers of river flow.

For all the main rivers of the RK WMB within the water resources region (hereinafter WRR), channel water balances have been compiled in natural and actual conditions. The most significant components of the water balance are taken into account, such as river flow, precipitation, evaporation from the water surface, the relationship of surface and ground water, and lateral inflow.

The results provide a clear picture of the transformations of all the main elements of the water balance in terms of economic activity. Here it is possible to clearly define the role of channel changes and changes in water flow (lateral inflow) from the site. Thus, having estimates for the reference stream gauges on the one hand, and estimates obtained on the basis of channel water balance on the other, have a more complete picture of anthropogenic transformation of the flow of WRR and WMB of the RK.

Comparison of available data on water-intake facilities and the results of anthropogenic changes in river flow in the WRR makes it possible to approximate the values of irrevocable water consumption in each region and the ratio between the volumes of irrevocable and total water consumption. As already mentioned above, the data obtained in this way on the values of irrevocable water consumption is very approximate, however, some regularities in the values of these ratios can be noted, which vary very much by region depending on the structure of water consumption and climatic conditions.

Table 1. Anthropogenic changes in the flow of the main rivers of RK

№	River-point	W, million m³		Changes, million m³	In % of the nat.-res. flow
		Nat.-res.	Act.		
	Aral-Syrdarya WMB				
1	The Syrdarya river - above the mouth of the Keles river	27181	14951	-12230	-45,0
2	The Syrdarya river - NB Shardara reservoir	25759	13999	-11759	-45,7
3	The Syrdarya river - Koktobe village	24434	13356	-11077	-45,3
4	The Syrdarya river - Tomenaryk railway station	23238	11748	-11490	-49,4
5	The Syrdarya river – Kazaly city	16199	4989	-11211	-69,2
	Zhaiyk-Caspian WMB				
6	The Zhaiyk river – Yanvartsevo settlement	9833	8290	-1543	-15,7
7	The Zhaiyk river – Inderbor settlement	10348	7723	-2625	-25,4
8	The Zhaiyk river - Makhambet settlement (Topoli village)	10305	7840	-2466	-23,9
	Balkhash-Alakol WMB				
9	The Ili river – at the state border	15263	12828	-2435	-16,0
10	The Ili river - 164 km above the work settlement Ili	17032	14475	-2557	-15,0
11	The Ili river – Kapshagai	19759	13867	-5892	-29,8
12	The Ili river - Ushzharma settlement	19404	13752	-5652	-29,1
	Shu-Talas WMB				
13	The Shu river - Tasotkel settlement	2986	1925	-1061	-35,5
14	The Shu river - Amangeldy settlement	3209	1663	-1546	-48,2
15	The Talas river – Grodekovo city	937	766	-171	-18,2
16	The Talas river – Shapovalovka settlement	459	332	-127	-27,6
17	The Assy river – Maymak railway station	382	290	-92	-24,1
	Esil WMB				
18	The Esil river –Volgodonovka settlement	113	104	-9,70	-8,6
19	The Esil river - Kamenny Karier settlement	1128	1159	31,3	2,8
20	The Esil river – Dolmatovo settlement	2066	1804	-262	-12,7
	Tobyl-Torgai WMB				
21	The Tobyl river – Dzerzhinsky state farm	47,9	47,9	0	0
22	The Zhelkuar river - Mariinsky settlement	44,0	44,0	0	0
23	The Ayat river – Varvarinka settlement	200	200	0	0
24	The Tobyl river – Kostanay city	452	306	-146	-32,3
25	The Ui river – Uysky settlement	458	458	0	0
26	The Torgai river - Tosyn sands	310	309	-1,21	-0,4
	Nura-Sarysu WMB				
27	The Nura river - Sergiopol setllement (Balykty railway station)	218	297	79,50	36,5
28	The Nura river – Romanov setllement (Romanovka)	654	676	21,90	3,3
30	The Sarysu river - No.189 station	45	43	-1,48	-3,3
	Ertis WMB				
31	The Kara Ertis river - Boran village	10593	8318	-2275	-21,5
32	The Ertis river - Bukhtarminskaya HPS	20733	16574	-4159	-20,1
33	The Ertis river - Ust-Kamenogorsk city	21404	16970	-4435	-20,7
34	The Ertis river – Shulbi village	30636	27637	-2999	-9,8
35	The Ertis river – Semiyarka city	30642	26508	-4133	-13,5
36	The Ertis river – Pavlodar city, creek	30554	27231	-3323	-10,9
37	The Ertis river – Priirtyshsky village	30490	24410	-6080	-19,9

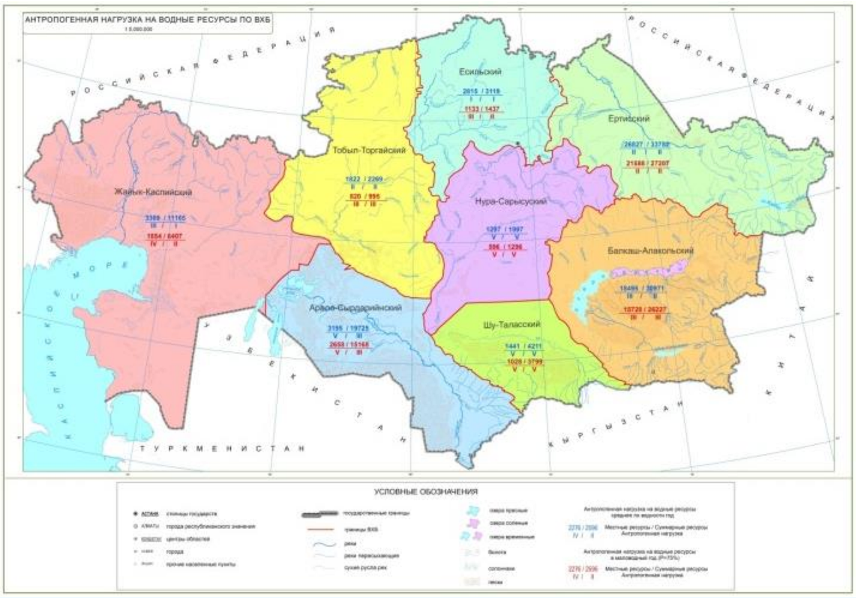

Fig. 1. Anthropogenic load on water resources relative to total and local water resources in different water content years for the WMB of the Republic of Kazakhstan

Table 2. Load on water resources relative to total and local water resources in different water content years for 8 WMB

WMB	Water resources, million m³/year				Load on water resources, %							
	Medium water content year		Low water content year (P=75%)		Medium water content year				Low water content year (P=75%)			
	$W_{loc.}$	$W_{tot.}$	$W_{loc.}$	$W_{tot.}$	Local	C_{loc}	Total	C_{tot}	Local	C_{loc}	Total	C_{tot}
Aral-Syrdarya	3195	19725*	2658	15168*	226	V	22.5	III	271	V	29.3	III
Balkhash-Alakol	18495	30971*	15728	26227*	22.2	III	18.5	II	36.5	III	21.9	III
Zhaiyk-Caspian	3389	11165*	1854	6407*	28.5	III	8.64	I	52.0	IV	15.0	II
Esil	2815	3119*	1133	1437*	8.79	I	7.94	I	21.8	III	17.2	II
Tobyl-Torgai	1822	2269	820	995	15.5	II	12.5	II	34.5	III	28.4	III
Nura-Sarysu	1297	1997*	596	1296*	142	V	92	V	310	V	143	V
Ertis	26827	33782*	21588	27207*	13.6	II	10.8	II	16.9	II	13.4	II
Shu-Talas	1441	4211*	1028	3799*	184	V	62.8	V	257	V	69.6	V

*Note: * - total resources taking into account the actual inflow from neighboring countries and the actual inter-basin transfer of river flow*

The performed estimates of the load on water resources, as well as their joint analysis with data on water use, make it possible to analyze the state of water use in each administrative region. However, for objective reasons, it is not possible to assess directly which resource of the district is attributed to a particular water use. As noted (Alimkulov et al. 2019, Bissenbayeva et al. 2019, Dostay et al. 2012, 2013, Galperin 2012, Klein et al. 2014), when assessing and forecasting renewable river flow resources, it is assumed that for any administrative territory (in this case, for administrative regions of the Republic of Kazakhstan), depending on its geographical location, river flow resources consist of a set of several characteristics (local flow, water inflow, total resources, water outflow, transit flow, etc.). And in each case, the number of characteristics may differ significantly. The demand for water, despite its initial formation at the level of administrative districts, is usually distributed based on the overall water balance, at the level of the WMB, then WRR.

This problem exists in all countries where water resources management is carried out in the context of administrative-hydroeconomic territories. In such conditions, more attention is paid to the regulation of anthropogenic load, as a tool for managing demand. Currently, Kazakhstan has not sufficiently developed the issue of regulating the maximum anthropogenic load on water resources. Certain aspects of the problem, from the point of view of determining the ecological flow, are expressed in the works (Burlibayev 2014). Regulating depends on many factors, on the water resource development strategy and the principles adopted in each country. For example, on the territory of China, the load rates for river flow vary from 40 % to 80 % depending on the water content of the region, socio-economic and other conditions (Prokhorova).

Many scientists in the CIS water industry widely use the classification based on the coefficient of use of the C_{use} or the load on water resources. Thus, according to studies [2, 9], the following classification can be applied to analyze the state of anthropogenic changes in water resources in any region of the world.

Category I: C_{cap} < 10% - low load on water resources.

Category II: C_{cap} = 10-20% - moderate load on water resources.

Category III: C_{cap} = 20-40% — high load on water resources.

Category IV: C_{cap} = 40-60% — very high load on water resources.

Category V: C_{cap} > 60% - critical load.

If the water resource capacity factor is up to 20 % (I and II categories of anthropogenic load), it is possible to plan for increasing the use of water resources. Above category III, territories already have a high load on water resources and require special attention in the future development, it is recommended to introduce effective water-saving technologies everywhere, but it is best to limit non-direct water intakes from natural objects. For sustainable development, it is necessary to regulate the supply and demand for water.

Special attention should be paid when developing water resources for regions where the capacity factor exceeds 40 % (IV, V). With an anthropogenic load of 40 to 60 % (IV), there is a serious water scarcity and it is strongly recommended to regulate demand and limit water consumption and attract additional sources of water supply. The water scarcity becomes a factor that hinders economic growth and increases the level of well-being of the population. If the use of 60% of available resources is exceeded (V), water scarcity becomes a critical factor in the development of the economy and life.

According to our estimates, the average values of anthropogenic load on total water resources in the WMB territories of the RK in medium water content years reach up to 62,8 %, in low water content years - up to 69,6 % (**Table 2**). In the Aral-Syrdarya, Shu-Talas and Nura-Sarysu WMB, demand exceeds local own resources. The same estimates were made for all WMB, administrative regions (**Table 3**) and districts of Kazakhstan.

Local resources mean river flow and annually renewable river flow in the territory, while the total resource also includes inflows from neighboring countries and actual inter-basin transfers of river flow.

According to the data shown in **Table 2**, in the *Aral-Syrdarya WMB*, the load on local resources in medium-water and low-water years is 226 and 271%, respectively, i.e. the demand exceeds the resources and is met only by the inflow of water from outside. The load on total resources, both in low-water and medium-water

Table 3. Anthropogenic load on water resources relative to total and local water resources in different water content years by administrative regions

Region	Water resources, million m³/year				Load on water resources, %							
	Medium water content year		Low water content year (P=75%)		Medium water content year				Low water content year (P=75%)			
	$W_{loc.}$	$W_{tot.}$	$W_{loc.}$	$W_{tot.}$	Local	C_{loc}	Total	C_{tot}	Local	C_{loc}	Total	C_{tot}
Akmola	1736	2987*	681	1369*	11.5	II	7.41	I	29.2	III	18.7	II
Aktobe	2276	2596	1163	1250	12.5	II	11.0	II	21.8	III	20.3	III
Almaty	15271	28470*	13192	24419*	22.7	III	12.2	II	26.3	III	14.2	II
Atyrau	199	8956*	23.7	5924*	106	V	2.35	I	889	V	3.55	I
East Kazakhstan	29352	33269*	23775	26963*	1.80	I	1.43	I	2.21	I	1.76	I
Zhambyl	1486	5583*	1134	4700*	160	V	43.3	III	215	V	51.9	IV
West Kazakhstan	1256	9932*	764	5845*	38.0	III	4.81	I	62.5	V	8.17	I
Karaganda	2089	2609*	1019	1539*	86.8	V	69.5	V	178	V	118	V
Kostanay	1 204	1 959	596	936	20.0	II	12.3	II	40.5	IV	25.8	III
Kyzylorda	140	13485*	93.0	10076*	3074	V	29.3	III	4293	II	39.2	II
Mangystau	27.9	29.7	0.31	0.61								
Pavlodar	291	26799*	97.5	23610*	726	V	7.89	I	2168	V	8.95	I
North Kazakhstan	912	2877	379	1180	8.47	I	2.63	I	19.9	II	6.41	I
Turkistan	3039	18018*	2367	13497*	115	V	18.1	II	138	V	24.1	III

*Note: * - total resources taking into account the actual inflow from neighboring countries and the actual inter-basin transfer of river flow*
Due to the fact that the Mangystau region takes water from the Caspian Sea for its needs, the anthropogenic load on local and total resources was not considered.

content years, is higher than 20 %, which according to the above classification is considered a high load, and requires attention to measures to regulate the supply and demand for water.

The Balkhash-Alakol WMB. The anthropogenic load on local resources here is 22.2 and 36.5 % in medium-water and low-water years, respectively. In contrast to the Aral-Syrdarya WMB, the value of load varies for certain regions of the basin. In Southern Dzungaria, in the Sharyn river basin, Ili Alatau, and the lower Ili river basin, the load on local resources is high. In low-water years, there is a water scarcity in the Ili Alatau (BAC zone) and in the Kurty river basin, which requires additional sources of water resources for water consumption.

Zhaiyk-Caspian WMB. In medium water content years, the load on local resources is less than 30 %, and on total resources it is less than 10 %. In low-water years, the load increases accordingly for local flow up to 52 %, and for total - up to 15 %.

Esil WMB. According to the above data, in medium water content years, the load relative to the total water resources is less than 10 %, in low-water years (75% supply), the load increases to 22 %.

Tobyl-Torgai WMB. The load on local resources is 15.5 % in a medium-water year, and 34.5% in a low-water year. The total load in the corresponding water content years varies from 12.5 to 28.4 %.

Nura-Sarysu WMB. The load on water resources in the basin is critically high (category V). Local water resources of the basin are not sufficient for water consumption and use, which should be taken into account when planning water management activities. In different years of water content, the required amount of water is used only by transferring the flow through the Ertis-Karaganda canal to meet water needs, as evidenced by the data shown in **Table 2**.

Ertis WMB. The load on local resources is less than 20% (13.6 and 16.9 %) in both medium and low-water years, these values are reduced by 3-4% relative to total water resources.

Shu-Talas WMB. Local resources are limited, below existing demand, and even in medium years the load exceeds resources. And relative to total resources, the situation is critical - the load is more than 60 %.

According to the data provided in **Table 3**, the anthropogenic load on local and total resources of the country's regions can be estimated by administrative territories.

In general, in low-water years, there are sufficient reserves of local resources only in the East Kazakhstan region, relatively small loads are observed in the North Kazakhstan, Aktobe and Almaty regions.

While maintaining inflows of water from outside areas, reserves for the development of appear for multiple regions – Akmola, due to the transfer of water through the channel of Nura-Esil, Atyrau (transboundary inflow on the Zhaiyk river, the inflow sleeve of the Volga-Kigash river), West Kazakhstan region (transboundary inflow on the river Zhaiyk with Russian Federation), Kostanay (inflow from Russia), Pavlodar (inflow from East Kazakhstan region), Turkestan (transboundary inflow on the Syrdarya river).

CONCLUSION

The assessment of the anthropogenic load on water resources in the context of WRR and administrative regions of the Republic of Kazakhstan was performed. A method based on a complex application of methods of hydrological analogy, water balance, and a method for determining irrevocable water consumption by economic sectors was developed for the assessment. Assessment of anthropogenic load on water resources by water management and administrative divisions, using a comprehensive methodological approach and analysis for the territory of Kazakhstan is performed for the first time.

According to our estimates, the average values of anthropogenic load on total water resources in the territories of the Republic of Kazakhstan in medium water content years reach up to 62.8 %, in low-water years - up to 69.6 %. In the Aral-Syrdarya, Shu-Talas and Nura-Sarysu WMB, the demand for water exceeds the local own water resources.

In the context of administrative territories, in low-water years there are sufficient reserves of local resources only in the East Kazakhstan region, relatively small loads are observed in the North Kazakhstan, Aktobe and Almaty regions.

The difficult situation of water supply persists in Zhambyl, Karaganda and Kyzylorda regions, even taking into account the inflow (transfer) from outside the regions, the load on the total resources in these areas has reached a very high level according to the applied classification. The further development of water resources in the Atyrau, West Kazakhstan, Kostanay, and Turkestan regions is no less difficult, taking into account the uncertainty of the prospects for inflows from the territories of neighboring countries. The conditions of water supply of the territory differ somewhat in certain areas of the regions. Here, for a complete presentation of the problem on the territory of the country, attention is paid only to the state of water resources development in water management basins and regions.

For the purposes of planning further additional development of water resources or other water management plans, we consider it necessary to take into account the current state of anthropogenic influence, as well as the regulation of anthropogenic load on water resources. unfortunately, there are still no clear regulatory guidelines for the level of load on water resources in our country.

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