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F. Zh. Akiyanova[1], N. L. Frolova[2],
A. M. Shaimerdenova[1], Ye. M. Karakulov[1], A. B. Oleshko[1]

[1]«International Science Complex «Astana», Nur-Sultan, Kazakhstan,
[2]M. V. Lomonosov Moscow State University, Russia.
E-mail: akiyanovaf@mail.ru, frolova_nl@mail.ru, altynay_sh@mail.ru,
ergali_1992@mail.ru, goodwin1996@mail.ru

IMPACT OF ANTHROPOGENIC TRANSFORMATION OF RIVERBEDS ON THE WATER RESOURCES OF ARID REGIONS (THE YESIL AND NURA RIVERS CASE, NORTH KAZAKHSTAN)

Abstract. Kazakhstan belongs to countries with limited surface water resources, the total indicators of household effluent of 50% probability level amount to 91.3 km^3 per year [1]. The region under study falls within the Yesil (Yesil river) and Nura-Sarysu (Nura river) water-management basins. 3.1% of the river runoff of the country is formed here [1]. The main rivers of these basins – Yesil (the old name - Ishim) and Nura were studied. The annual flow of these rivers in a high-water year can exceed the flow of low-water year more than a hundred times [2]. At the same time, these figures do not take into account theirretrievable loss of water resources associated with an increase in evaporation from the water surface due to anthropogenic transformation of the beds and floodplain terraces of the rivers. The article assesses the changes in main morphological elements of the river valleys, associated with the development of the fields of building materials. The loss is estimated based on the analysis of different-time data of remote sensing and hydrological calculations with determining the evaporation discharge from the water surface.

Keywords: water resources, anthropogenic transformation, evaporation from an open water surface, irretrievable losses of water, water consumption, suburban area, Yesil river, Nura river.

Introduction. The surface water resources of Kazakhstan are limited and extremely unevenly distributed throughout the territory. This significantly affects the processes of population settlement and the sustainable organization of the country's territory. According to the Institute of Geography of the Ministry of Education and Science of the Republic of Kazakhstan, the total indicators of household effluent of 50% probability level amount to 91.3 km^3 per year [1]. 48.5% of them are transboundary and come from neighboring countries: the Russian Federation, the Republic of Uzbekistan, the Kyrgyz Republic and the People's Republic of China. The region under study falls within the Yesil and Nura-Sarysu water-management basins (figure 1). Less than 6% of the river runoff of Kazakhstan is formed here [1].

The Yesil water-management basin is transboundary and belongs to the basin of the Kara Sea. The Nura-Sarysu basin is the only inland water-management basin in Kazakhstan, and it is an inland drainage basin. 3.1% of the river runoff of Kazakhstan is formed in these two basins [1]. The vulnerability of the supply of the population and the economy with water resources is enhanced due to the expected decrease in precipitation in the region [3].

The issues of conservation and sustainable use of water resources become relevant under these conditions. One of the aspects of water resources conservation is reducing unproductive losses [4]. Unproductive non-recoverable losses of water resources in the study area are associated with anthropogenic multiple widening of riverbeds for the development of stocks of building materials by reducing the areas of floodplain terraces of the Yesil and Nura rivers. During the period of active construction of Nur-Sultan (1998-2017), more than 50 quarries for the extraction of building materials operated only within the suburban zone.

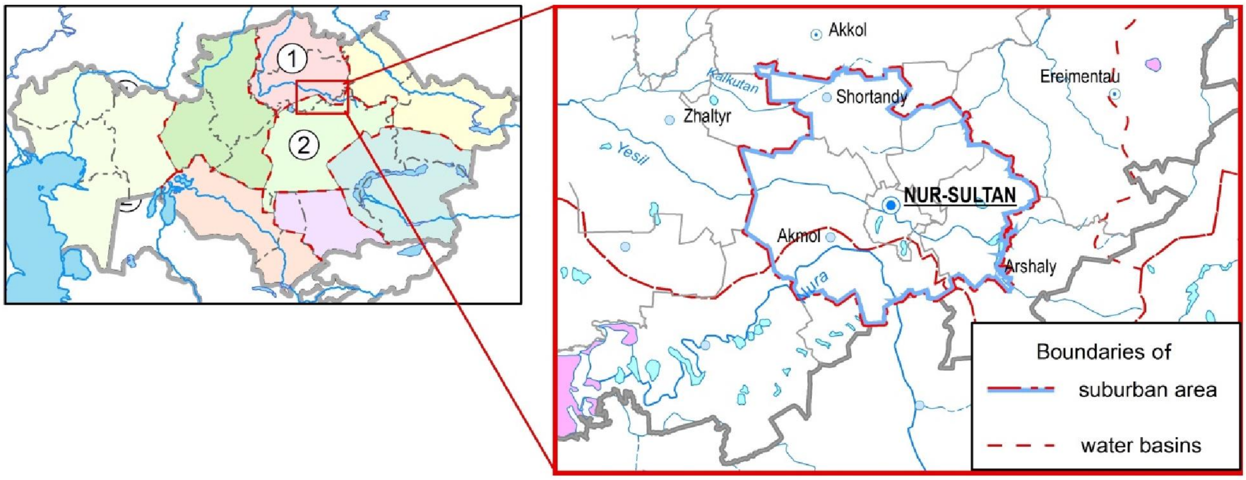

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Figure 1 – The location of the territory under study in the system of water-management division of the Kazakhstan's territory:
a) Water-management basins of Kazakhstan: 1 – Yesil, 2 – Nura-Sarysu;
b) The Yesil and Nura river valleys within the suburban zone of the city of Nur-Sultan

The purpose of the studies was the assessment of the current state and the anthropogenic transformation of the river network sections located on the borders of the suburban zone of Nur-Sultan. The territories of the suburban zone are intended for the development of the city, the placement of engineering and transport infrastructure, as well as the formation of a natural-ecological framework. In the future, the suburban zone should form a single social, natural and economic territory with the city.

The article presents the results of studies of the anthropogenic transformation of individual sections of the Yesil and Nura river valleys. New data were obtained during field studies and office processing of the data using geo-information technologies. Quantitative parameters for changes in the structure of the riverbeds and floodplain terraces of the Yesil and Nura rivers, which influenced the resource potential of the rivers, were received.

Materials and methods. The published climatic and hydrological materials [5-7], data acquired through grant funding from the Republican State Enterprise "Kazhydromet"[8], monitoring and statistical data [9-11], data on commonly occurring mineral resources [12] and the remote sensing data [13-15] were used for conducting the study.

The quantitative parameters of the transformation of the riverbeds and floodplain terraces of Yesil and Nura were studied and determined on the basis of field and desktop study methods. They included the survey of river valleys by an unmanned aerial vehicle (UAV) Phantom 4, a comparative analysis of different-time digital Sentinel and Landsat satellite images [13-16], an analysis of topographic maps of the Yesil and Nura river valleys. The processes of natural-anthropogenic transformation in the river valleys were studiedand mapped on the basis of the application of quantitative assessment methods in the ArcGIS 10.1 software modules. The quantitative parameters of the valleys were determined in field conditions on the basis of aerial surveying from the UAV on key sections of the Yesil and Nura rivers,with a total length of 5.29 km. To obtain the images of high resolution, the following parameters of surveying were applied: the degree of overlap of 70%, the flight height of 150 m, the capture bandwidth of up to 200 m, and the average motion speed from 7 to 10 m/s. The coordinates and absolute elevations were clarified using GNNS of a Trimble R8 receiver with the creation of a reference network. The main reference stations were objects located near the riverbeds and ledges of the floodplain terraces, which were clearly distinguished on the ground and in the images. The obtained images were processed in the AgisoftPhotoScan Professional 1.4.4 specialized program.

The changes in the main parameters of the riverbed and floodplain terraces of Yesil and Nura were assessed on the basis of the application of geo-information mapping methods for materials of Sentinel and Landsat satellite images of different periods, detailed aerial surveying of the beds and floodplain terraces of the rivers. Based on the use of satellite images and orthophotomaps obtained from the UAV, the boundaries of water surfaces were determined using the classification taught by ArcGIS 10.1 tools. According to the results of processing, a comparative analysis of the open water surface areas of the Yesil and Nura rivers within the suburban zone and key areas was carried out.

To assess the losses of water resources of the Yesil and Nura rivers, the losses of runoff for evaporation were determined. The volume of evaporation was calculated using the formula previously obtained for the territory of the northern part of Kazakhstan [17]. In accordance with this approach, the monthly values of evaporation from the water surface are to a greater extent dependent on the air temperature in the warm season (1):

$$E = 8.28 \cdot t + 11.3, \quad (1)$$

where t is the average monthly air temperature [10].

The volume of evaporated water (Ev) is calculated by multiplying the evaporation layer (E) by the open water surface area (S).

Results. The modern river network of the suburban zone of Nur-Sultan is represented by the sections of transit of the Yesil and Nura river runoffs. The density of the river network does not exceed 0.05-0.10 km/km². At the same time, due to the peculiarities of the lithology of the rocks, the density of the ravine network of drainless depressions reaches 0.2-0.3 km/km^2 [1]. Within the suburban zone, there is a watershed between the Yesil and Nura-Sarysu water-management basins of Kazakhstan. This boundary is rather conditional due to a number of reasons. The main are the geological-geomorphological structure of the valleys, as well as the peculiarities of regime and feeding of the rivers.

The river Yesil (the name is Ishim on the territory of Russia) originates in the Niyaz mountains, at an absolute altitude of 561 m. The length of the river is 2450 km (of which 1400 km - within Kazakhstan), the catchment area is 177 thous. km^2 (of which 147 thous. km^2 - within Kazakhstan) (figure 2) [5]. Before Nur-Sultan, the mean basin height is 460 m, and the river goes to the plain lower the city of Nur-Sultan. The studied section of Yesil is located in the upper reaches, in the latitudinal segment. The main tributaries (Koluton, Zhabai, Terisakkan, Akkanburlyk, Iman-Burlyk) flow into Yesil downstream of the city of Nur-Sultan and do not affect the regime of the study area [6].

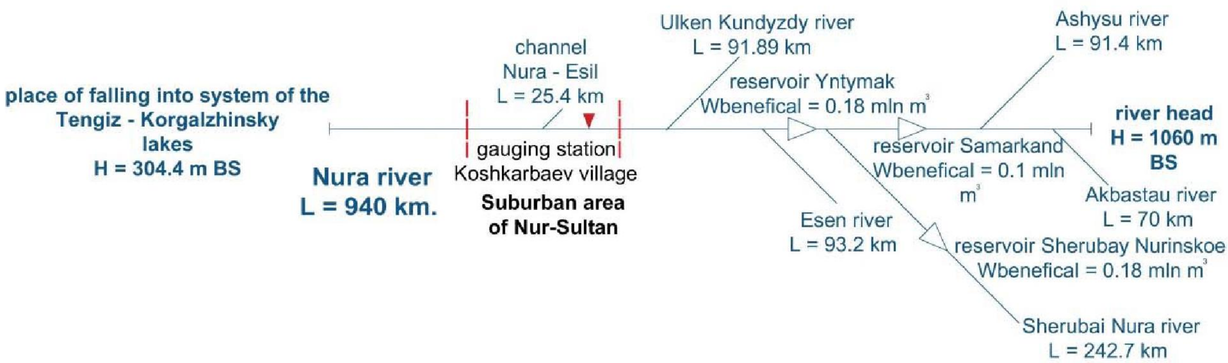

Figure 2 – Linear diagram of the river Yesil with main tributaries

The river Nura originates in the north-western spurs of the Otrar mountain massif, at absolute altitudes of 1060 m. It falls into Lake Teniz with an absolute elevation mark of 304.4 m (figure 3). The length of the river is 978 km, the catchment area – 60 800 km^2. The main tributaries of Nura (Akbastau, Ashchisu, Shcherubai-Nura, Yesen, Ulken-Kunyzdy) fall in the upper part of the basin. In the flat part, within the study area, the river has no tributaries, and the runoff is diverted and dispersed [7].

Yesil and Nura are characterized by the meandering nature of the river beds, with pronounced stretches and shallows [18]. Downstream the river beds are expanding. It is from 15-25 m to 30-40 m for Nura and from 5-12 to 10-25 m for Yesil. The sizes of stretches increase up to 0.5-1.5 km, with the depths of 1-4.5 m [5]. The floodplains of the rivers are two-sided, from 100-200 m to 10-15 km, with numerous old riverbeds, swales and closed depressions. The height of the low floodplain reaches 1-1.2 m. The high floodplain of the Yesil and Nura rivers is clearly pronounced in the relief, and its width varies from a few meters to a kilometer. The height of the surface of the high floodplain varies between 2.5 and 3m, rarely up to 6 m. The first terrace above the floodplain is developed almost everywhere, the width varies from a

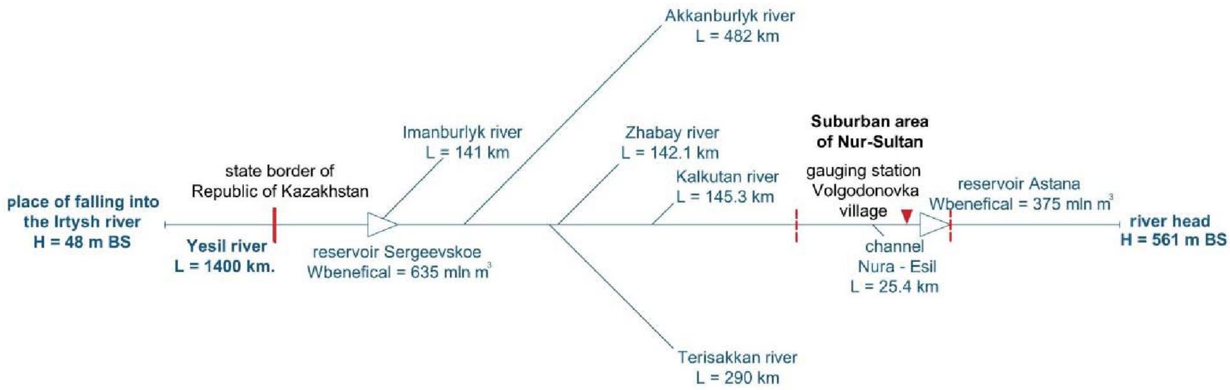

Figure 3 – Linear diagram of the river Nura with main tributaries

few hundred meters to 1.5 km, the surface is low-inclined. Above the long-term annual average water edge, it rises from 4 to 6 m, there are numerous traces of old riverbeds on the surface. The second terrace above the floodplain is developed fragmentarily, and in some areas its width reaches 3-4 km. The terrace cusp is clearly pronounced, the excess over the edge varies from 6 to 8 m [18].

The river Nura is characterized by the phenomenon of bifurcation, in the place of closest approach to the river Yesil. This is due to the uncertainty of the watersheds of the Yesil – Nura interfluve. The presence of a common incline from Nura towards Yesil (0.45 ‰) with the magnitude of the fall of 12,5 m formed a valley-like lowering with a length of 28 km and a width of 2-6 km here. Flowing of a part of water from the river Nura occurs here through 3 channels (Sarkrama, Kozgosh and Mukhor), which merge into a single riverbed 9 km to the confluence into Yesil [18].

The hydrological regime of the Yesil and Nura rivers is characterized by a strongly-pronounced short flood and almost dry low water period. According to the classification of B.D. Zaikov for river regime, it refers to the "Kazakhstan type" [19]. The main feeding of the Yesil and Nura rivers is snow (82.5% and 78%, respectively), groundwater and rainwater supply is of little significance. The spring flood begins in April and lasts from one and a half to two months. Up to 85-95% of the annual runoffs of the rivers pass during this time [6]. The hydrograph shape of the flood is mostly single-peak (figure 4). In the end of May - the beginning of June, there is low water period, which lasts 9-10 months. In summer, the minimum discharges of water are observed in July-August, in the cold period - in January-March. The smallest of the minimum discharges fall on the winter low water period. Fluctuations of the Yesil river levels over low water within the suburban zone of Nur-Sultan are 4.5-5 m, of the Nura river – 2.5-6 m [6, 20].

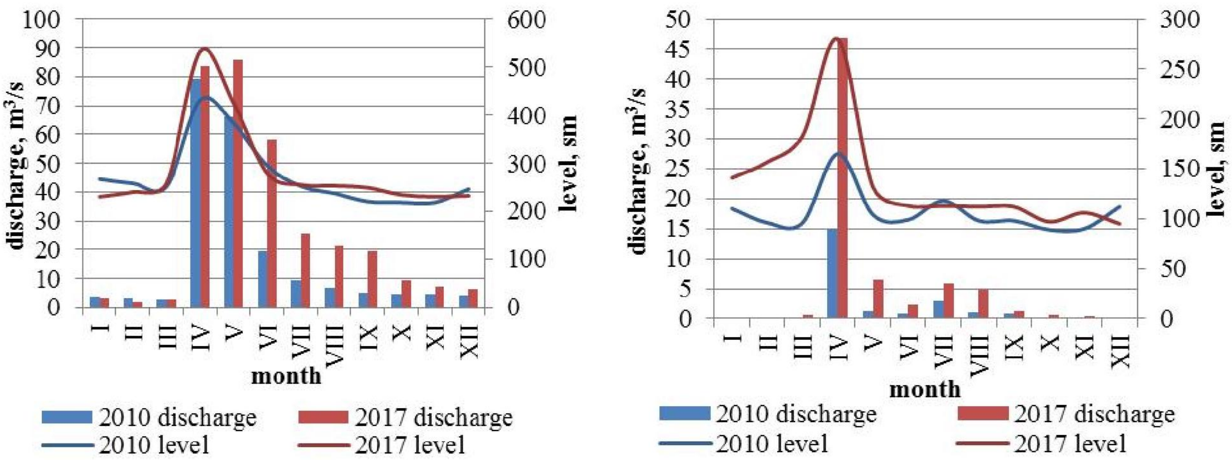

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Figure 4 – The course of average monthly water flow and water levels in 2010 and 2017 on gauging stations:
a) the river Yesil –Volgodonovka village; *b*) the river Nura – R. Koshkarbayev village

The runoff of the rivers goes through significant fluctuations, both in the intra-annual and inter-annual context [21]. The average long-term flow rate of the river Yesil near the Volgodonovka village is 3.49 m^3/s, of the river Nura near the R. Koshkarbayev village is 21 m^3/s (1973-2015) [8, 9]. For the period of 2010-2017, a year with minimum values of discharges and levels – 2012, and with maximum values – 2015, 2017, are distinguished for both rivers (figure 5). At the same time, fluctuations of Yesil and Nura rivers levels in the flood period in a long-term section are 2-2.5 m. Such similar dynamics is explained by the regional influence of climatic factors.

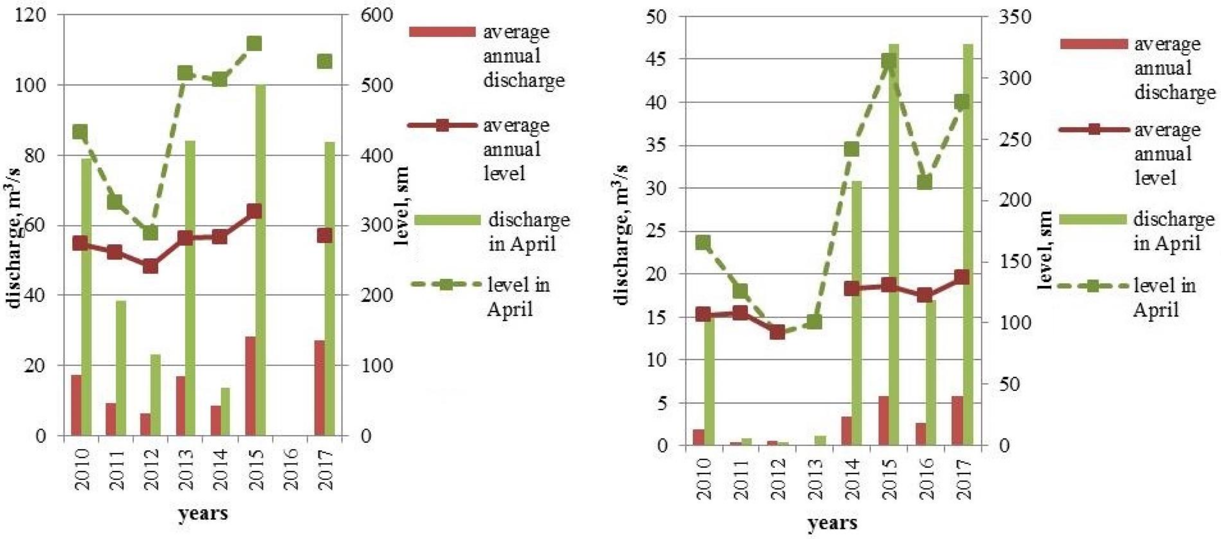

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Figure 5 – Dynamics of average annual and maximum monthly average flow rates and levels for 2010-2017 by gauging stations: *a*) the river Yesil – Volgodonovka village, *b*) the river Nura – R. Koshkarbayev village

Assessment of the anthropogenic transformation of the beds and floodplain terraces of the Yesil and Nura rivers. The boundaries of open water surfaces of riverbeds based on the measurement of the reflectivity of objects in different ranges of the spectrum on the Yesil and Nura rivers within the suburban zone of Nur-Sultan were determined [22], the changes in the main parameters of the riverbed and floodplain terraceswhere lake-shaped extensions are formed at the places of development of common minerals were assessed and evaporation volumes from these surfaces were calculated. The key section on the river Yesil with a length of 1.9 km located near the Volgodonovka village was studied in detail (figure 6). It should also be noted that the riverbed of the Yesil was blocked by a bulk bridge of stone blocks with a laid pipe. Due to the overlap of the runoff, there was a backwater level of the river above the bridge with flooding the high floodplain and floodplain tree-shrub vegetation (figure 6). The section on the river Nura with a length of 3.39 km, it is located near the Kabanbaibatyr village (figure 7). Key sections are located at a distance of 2-3 km upstream from settlements on the river Yesil – Volgodonovka village, and on the river Nura – R. Koshkarbayev village, and corresponding gauging stations.

The changes in water areas were analyzed on the basis of field works in the summer months (June-August) and according to satellite images for the same months of 2010 and 2017 [13-15]. Average water levels in July-August of 2010 and 2017 were 108-112 cm on the river Yesil – Volgodonovka village (figure 4a), as well as 244-254 cm on the river Nura – R. Koshkarbayev village (figure 4b). Only in these key river sections from 2010 to 2017, an increase in the water surface due to the expansion of the channel part with the flooding the quarries for the extraction of common minerals amounted on r. Yesil 8.4 km^2, on the river. Nura 0.4 km^2.

In accordance with the definition of open water area within the beds of the Yesil and Nura rivers in 2010 and 2017, evaporation was calculated within the suburban zone and in key areas for the period of free flowing channel (April - October) in 2010 and 2017. The values of average monthly temperatures at the weather station of Nur-Sultan in 2010 and 2017 were used for a comparative analysis [10]. To determine the volume of evaporation, the dependence of monthly values of evaporation from the water

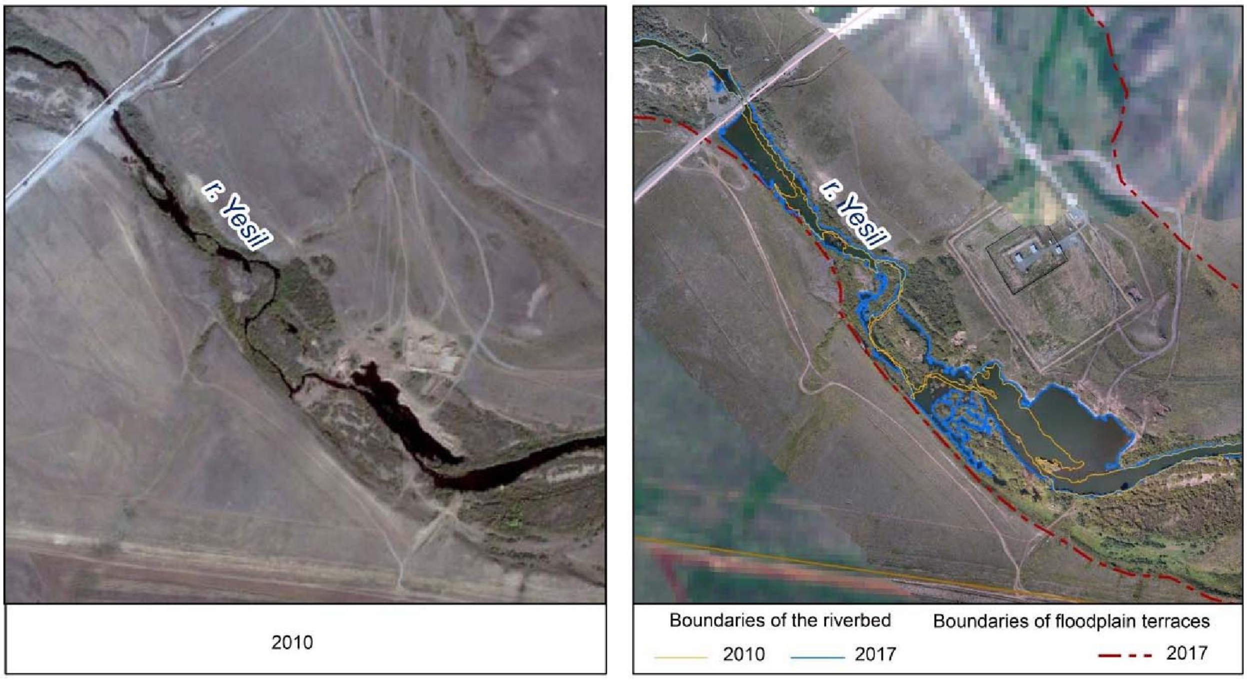

Figure 6 – Anthropogenic changes in the bed and floodplain of the river Yesil near Volgodonovka village, for 2010 and 2017 with the formation of lake-shaped extensions at the places of development of common minerals

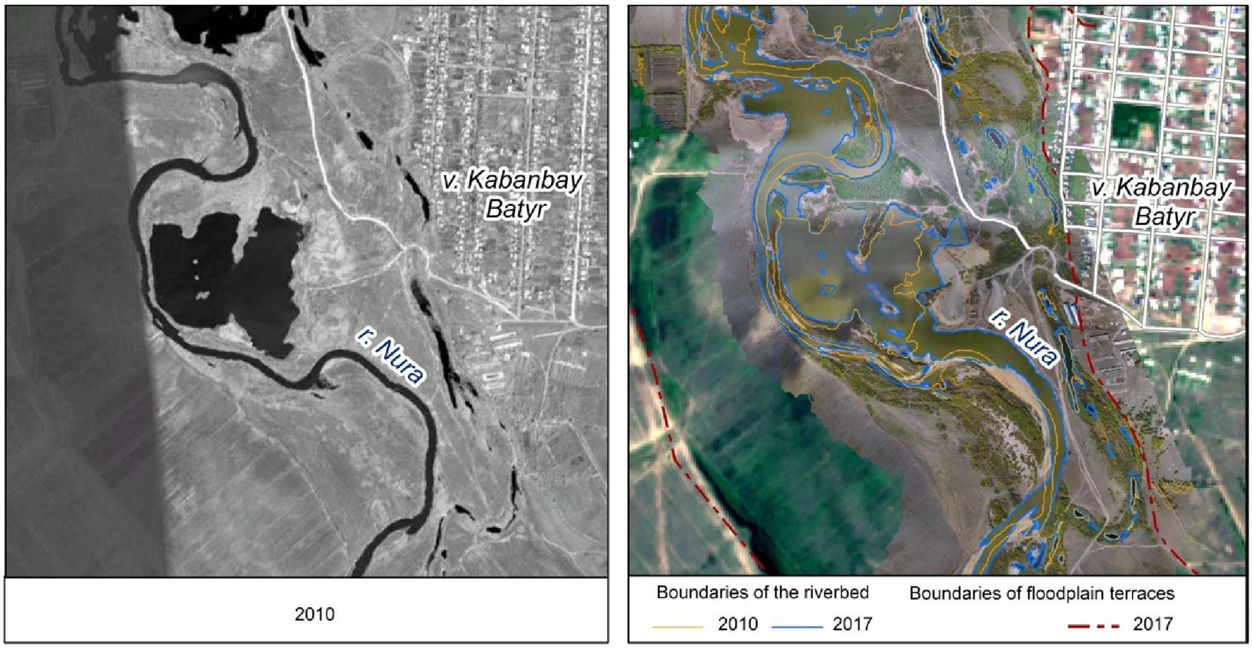

Figure 7 – Anthropogenic changes in the bed and floodplain of the river Nura near Kabanbai Batyr village for 2010 and 2017 with the merger of former waterlogged quarries with a riverbed and the formation of new lake-shaped extensions at the site of the development of common minerals

surface on air temperature in warm period of the year obtained for the territory of the northern part of Kazakhstan was used formula (1). Based on this equation, the values of the evaporation layer from the water surface (E), the volume of evaporation from the open water for the ice-free period of the year (Ev) with the open water surface area (S) were calculated (tables 1, 2).

In 2017, compared with 2010, there was an increase by 0.22 km^2 in the area of the open water surface of the Yesil and Nura rivers within suburban zone of Nur-Sultan. Such a change leads to an increase in

Table 1 – Areas (S) and the volume of evaporation (E_v) from the open water surface on the Yesil and Nura rivers within the suburban zone of the city of Nur-Sultan for 2010 and 2017

River	Years	S, thous. m^2	E, mm	E_v, thous. m^3	Difference of E_v in 2017 compared with 2010, %
Yesil	2010	18790.55	891.9	16759.29	+52.85
	2017	27196.28	941.9	25616.18	
Nura	2010	5717.80	891.9	5099.70	+12.67
	2017	6100.16	941.9	5745.74	
Yesil and Nura together	2010	24508.35	891.9	21858.99	+43.47
	2017	33296.44	941.9	31361.92	

evaporation values. In 2017, compared with 2010, the volume of evaporation on the Yesil and Nura rivers within the suburban zone increased by 43.5 %, and larger changes are observed in the Yesil river valley – 52.9 % (table 1).

The selected key sections are located near mining, therefore, they can be considered illustrative from the point of view of the anthropogenic impact on open water areas [23]. In 2017, compared with 2010, evaporation in the key section of Yesil increased by 186 %, of Nura – by 46.2 % (table 2).

Table 2 – Areas (S) and the volume of evaporation (E_v) from the open water surface in key sections of the Yesil and Nura riverbeds within the suburban zone of the city of Nur-Sultan for 2010 and 2017

River	Length of the section, km	Year	S, thous. m^2	E, mm	E_v, thous. m^3	Difference of E_v in 2017 compared with 2010, %
Yesil	1.9	2010	31.4	891.9	28.0	+ 186.0
		2017	85.04	941.9	80.0	
Nura	3.4	2010	436.8	891.9	389.6	+ 46.2
		2017	604.8	941.9	569.6	

Conclusion and Discussion. Due to the fact that evaporation losses from the open water surface mostly depend on climatic conditions, the current climatic characteristics of the study region and trends of their changes till 2050 were considered. The Yesil and Nura river basins are located in the zone of continental and arid climate. The average temperature of the coldest month (January) varies from -17 to -15ºC, the hottest (July) - from +19 to +21ºC. The amount of sunshine in the basins increases from 2200 hours per year in the north of the Yesil river basin to 2700 hours per year in the south of the Nura river basin. Relative air humidity has a maximum (75-85%) in winter and a minimum (30-50%) – in summer. The amount of precipitation in the territory under consideration varies from 350 mm per year in the north of the Yesil river basin to 250 mm per year in the south of the Nura river basin. About 25-30% of the total annual precipitation falls on the cold period. The average height of snow cover for the basins varies from 20 to 40 mm per year. The prevailing wind direction is southwest, with an average speed of 4-6 m/s [24].

For the period of 1941-2015, there is a trend towards an increase in surface air temperatures and precipitation in the Yesil and Nura river basins [3]. The greatest temperature anomalies are observed in the spring period and are 0.33 and 0.37 ºC for 10 years (table 3).

Table 3 – Characteristics of the linear trend of the anomalies of surface air temperatures of the Yesil and Nura river basins for the period of 1941-2015 by seasons and for a year [3]

River basin	Year		Winter		Spring		Summer		Autunm	
	*a	**R^2	a	R^2	a	R^2	A	R^2	a	R^2
Yesil	0.29	32	0.29	5	0.37	17	0.18	12	0.3	15
Nura-Sarysu	0.27	28	0.3	6	0.33	17	0.16	12	0.32	20

*a – linear trend coefficient, ºC/10 years;
**R^2 – determination coefficient, %.

According to the Seventh National Communication of the Republic of Kazakhstan to the United Nations Framework Convention on Climate Change (2017), the increase in the average annual temperature may reach 2.5ºC in the Yesil and Nura river basins by 2050 compared to the long-term norm for these territories. As a result, according to the modeled data, there will be a decrease in the annual runoff in the Yesil and Nura river basins relative to the long-term norm. By 2050, the runoff of Nura will decrease by 2% (R. Koshkarbayev village), and of Yesil - by 5.9% (Turgenevka village). The increase in temperatures in the spring period will lead to an earlier onset of snowmelt processes, a decrease in the period of snow accumulation, reduced soil freezing and larger loss of moisture content [3].

Under these conditions, additional losses of runoff associated with an increase in evaporation from a larger water surface due to anthropogenic transformation of the beds and floodplain terraces of the rivers are relevant. At the same time, it should be noted that the development of deposits of sand and gravel mix and mortar sand is carried out within the suburban zone over a length of 14.5 km along the Nura river bed and 17.5 km along the Yesil river bed (figure 8). The total area of geological allotments along the Yesil and Nura rivers in the territory under consideration is 17 km^2. A number of deposits are being developed in the section of the rivers' interfluve, where the waters of Nura periodically flow into Yesil. For the period from 2010 to 2017, the extraction of sand and gravel mix from riverbed and floodplain sediments of the rivers for construction purposes began to be intensified in the territory under study along the Yesil and Nura river beds: developments at another 20 deposits with a total allotment area of more than 12 km^2 were opened [12]. In general, this is confirmed by the growth dynamics of the volume of housing put in commission within 3 administrative districts located in the suburban zone of the city of Nur-Sultan. Here it increased more than 2.5 times from 2004-2010 to 2011-2017 (figure 9).

According to the Statistics Committee of the Republic of Kazakhstan, household water consumption per capita in Kazakhstan was 29.5 m^3 per year in 2017 [11]. The difference in volumes of runoff losses for evaporation from the open water of the Yesil and Nura rivers within the suburban zone between 2010 and 2017 is equal to the annual water consumption of 322 thousand people. This can provide the water

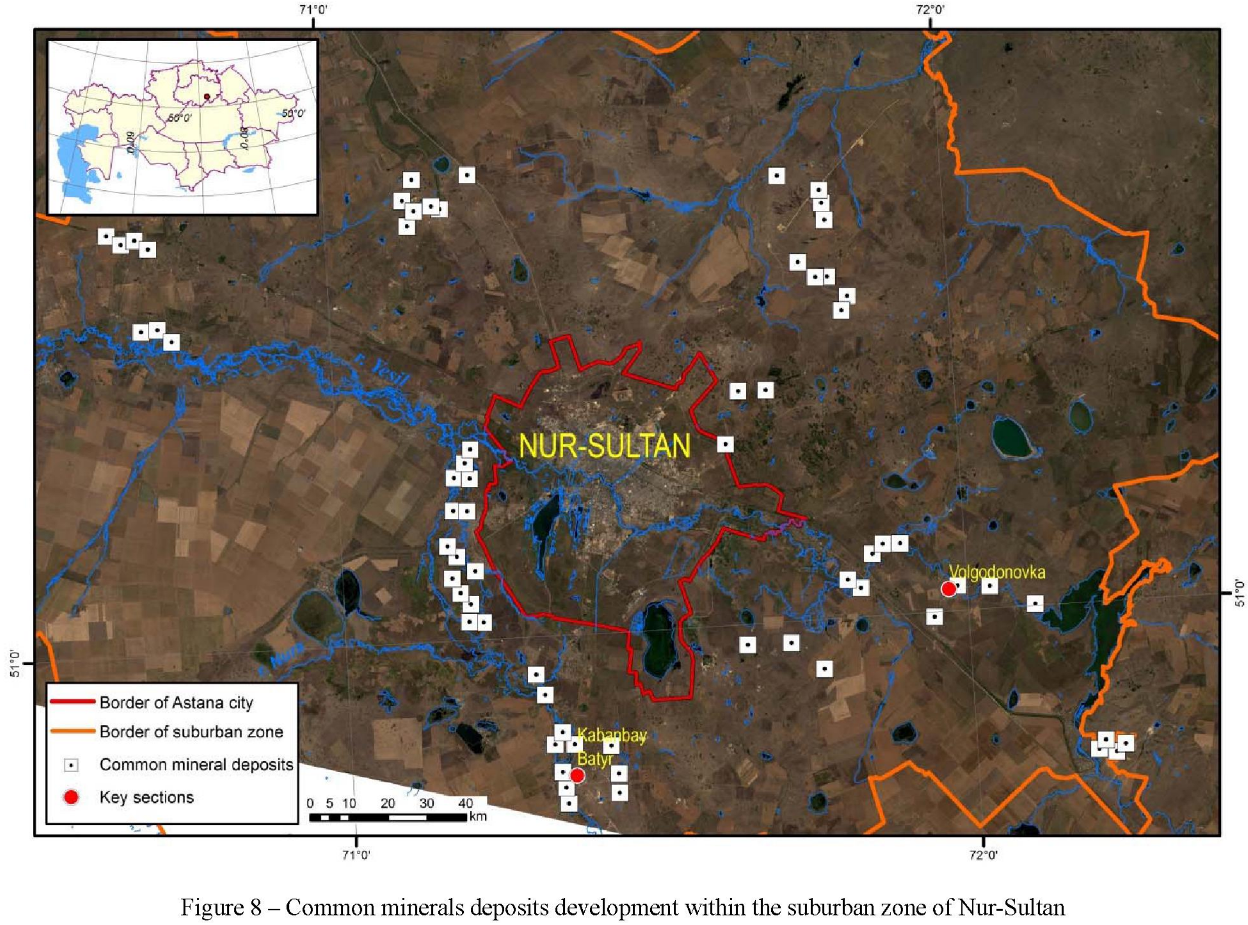

Figure 8 – Common minerals deposits development within the suburban zone of Nur-Sultan

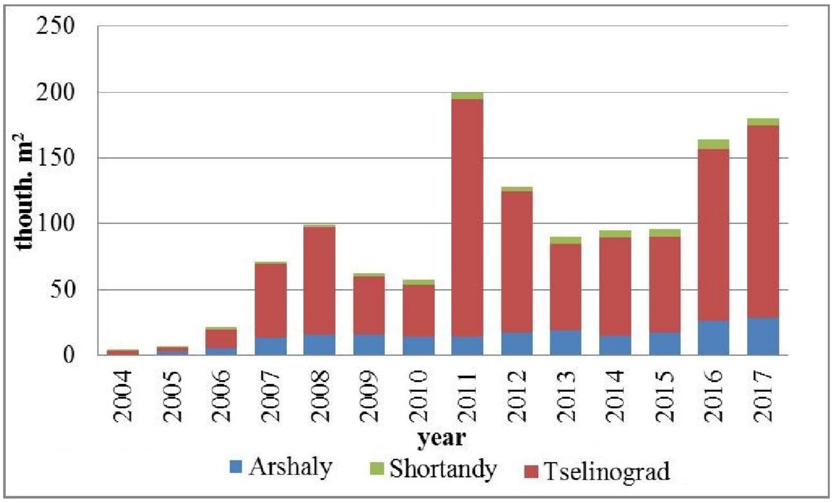

Figure 9 – Dynamics of housing commissioning by the districts of the Akmola region
that are part of the suburban zone of Nur-Sultan over the period of 2004-2017, in thousands of square meters [11]

consumption of the population of the suburban zone of Nur-Sultan for 3 years and 9 months. The studied key sections of the rivers are only 1.6% for Yesil and 2.9% for Nura of their length on the territory of the suburban zone of Nur-Sultan. In 2017, 232 thousand m^3 more water was non-recoverably lost for evaporation than in 2010 in these small sections. This difference is equal to water consumption of almost 7.7 thousand people. In the future, the intensification of the anthropogenic transformation of the riverbeds through the development of new deposits along rivers can lead to even more significant changes and losses of water resources.

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Ф. Ж. Акиянова[1], Н. Л. Фролова[2],
А. М. Шаймерденова[1], Е. М. Каракулов[1], А. Б. Олешко[1]

[1]«Астана» халықаралық ғылыми кешкні, Нұр-Сұлтан, Қазақстан,
[2]М.В . Ломоносов атындағы Мәскеумемлекеттік университеті, Ресей

АРИДТІ ӨҢІРЛЕРІНІҢ СУ РЕСУРСТАРЫНА ӨЗЕН АРНАЛАРЫНЫҢ АНТРОПОГЕНДІК ӨЗГЕРІСІНІҢ ӘСЕРІ (СОЛТҮСТІК ҚАЗАҚСТАН, ЕСІЛ ЖӘНЕ НҰРА ӨЗЕНДЕРІ МЫСАЛЫНДА)

Аннотация. Қазақстан жер үсті суларының ресурстары шектеулі елдерге жатады, тұрмыстық ағынның жиынтық көрсеткіштері 50% қамтамасыз етілуі жылына 91,3 $км^3$ құрайды [1]. Зерттелетін аймақ Есіл (Есіл өзені – Есіл ескі атауы зерттелді) және Нұра-Сарысу (Нұра өзені зерттелді) су шаруашылығы бассейндерінің шегіне кіреді. Мұнда елдің 3,1% өзен ағысынан қалыптасады [1]. Көрсетілген бассейндерінін негізгі өзендері зерттелген – Есіл (ескі атауы Ишим) және Нұра. Бұл өзендерінің жылдық ағыс көлемі су денгейі жоғары жылдары судын аздығынан жүз есе асып кетуі мүмкін [2]. Сонымен қатар бұл сандар өзендердің арналары мен жайылма террасаларының антропогендік өзгеруіне, су бетінен буланудың ұлғаюына байланысты су ресурстарының қайтарымсыз су шығынын ескермейді. Мақалада құрылыс материалдарының кен орындарын игерумен байланысты Нұр-Сұлтан қала маңы аймағының шегінде Есіл және Нұра өзендерінің (арналар мен жайылма террасалар) өзен алқаптарының негізгі морфологиялық элементтерінің өзгеруіне баға берілді. Ағынның қайтарымсыз су шығынын бағалау, соңғы 8 жылда жерді қашықтықтан зондтаудың әр түрлі кезең-дік деректерін салыстырмалы талдауды қолдана отырып және су бетінен булану көлемін анықтай отырып, гидрологиялық есептеулерді қолдану негізінде жүргізілді.

Түйін сөздер: су ресурстары, антропогендік өзгеріс, ашық су бетінен булану, қайтарымсыз су шығыны, су тұтыну, қала маңы аймағы, Есіл өзені, Нұра өзені.

Ф. Ж. Акиянова[1], Н. Л. Фролова[2],
А. М. Шаймерденова[1], Е. М. Каракулов[1], А. Б. Олешко[1]

[1]«Международный научный комплекс «Астана», Нур-Султан, Казахстан,
[2] Московский государственный университет им. М. В. Ломоносова, Россия

ВЛИЯНИЕ АНТРОПОГЕННОЙ ТРАНСФОРМАЦИИ РУСЕЛ РЕК НА ВОДНЫЕ РЕСУРСЫ АРИДНЫХ РЕГИОНОВ (НА ПРИМЕРЕ РЕК ЕСИЛЬ И НУРА, СЕВЕРНЫЙ КАЗАХСТАН)

Аннотация. Казахстан относится к странам с ограниченными ресурсами поверхностных вод, суммарные показатели бытового стока 50% обеспеченности составляют 91,3 км^3/год [1]. Исследуемый регион входит в пределы Есильского и Нура-Сарысуского водохозяйственных бассейнов, в которых формируется 3,1 % речного стока страны [1]. Изучены основные реки указанных бассейнов – Есиль (старое название Ишим) и Нура. Годовые объемы стока этих рек в многоводный год могут превышать сток маловодного более чем в сто раз [2]. При этом эти цифры не учитывают безвозвратные потери водных ресурсов, связанные с увеличением испарения с водной поверхности за счет антропогенной трансформации русел и пойменных террас рек. В статье дана оценка изменения основных морфологических элементов речных долин рек Есиль и Нура (русел и пойменных террас) в пределах пригородной зоны г. Нур-Султан, связанных с разработкой месторождений строительных материалов. Оценка безвозвратных потерь стока проведена на основе применения сравнительного анализа разновременных данных дистанционного зондирования Земли за последние 8 лет и гидрологических расчетов с определением величины испарения с водной поверхности.

Ключевые слова: водные ресурсы, антропогенная трансформация, испарение с открытой водной поверхности, безвозвратные потери воды, водопотребление, пригородная зона, река Есиль, река Нура.

Information about authors:

Akiyanova Farida Zhianshinovna, Doctor of Geographical Sciences, Professor, Director of the Institute of Geography and Environmental Research of the International Scientific Complex "Astana", Nur-Sultan, Kazakhstan; akiyanovaf@mail.ru; https://orcid.org/0000-0002-8395-8497

Frolova Natalia Leonidovna, Doctor of Geographical Sciences, Professor, Head of the Department of Hydrology of Land, Geographical Faculty of Moscow State University named after M. V. Lomonosov, Russia; frolova_nl@mail.ru; https://orcid.org/0000-0003-3576-285X

Shaimerdenova Altynay Myrzabekovna, Junior Researcher at the Institute of Geography and Nature Management of the International Scientific Complex "Astana", Nur-Sultan, Kazakhstan; altynay_sh@mail.ru; https://orcid.org/0000-0003-3572-3869

Karakulov Ergali Maratuly, Junior Researcher at the Institute of Geography and Nature Management of the Astana International Scientific Complex "Astana", Nur-Sultan, Kazakhstan; ergali_1992@mail.ru; https://orcid.org/0000-0002-8560-5097

Oleshko Anton Borisovich, Leading Engineer of the Institute of Geography and Nature Management of the International Scientific Complex "Astana", Nur-Sultan, Kazakhstan; goodwin1996@mail.ru; https://orcid.org/0000-0003-3274-3653

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