ALEXANDER V. CHEREDNICHENKO, R. I. HALPERIN, S. K. DAVLETGALIEV, ALEXEI V. CHEREDNICHENKO, V. S. CHEREDNICHENKO, R. G. ABDRAHIMOV, A. S. NYSANBAEVA

SRI of Biology and Biotechnology Problems, Almaty, Kazakhstan

IMPACT OF CLIMATE CHANGE ON RUNOFF IN THE REPUBLIC OF KAZAKHSTAN

The dynamics of surface runoff in Kazakhstan under the impact of climate change temperature and precipitation analyzed. It is shown that in the absence of synchrony and coherence in the climate changes in temperature and precipitation throughout the territory of the Republic for the forecast of climatic changes in surface runoff it is necessary to analyze the climatic changes and the dynamics of runoff for each basin separately. For example the analysis of the dynamics and the constructed scenario runoff changes for the period up to 2040 for basin Ural River (Zhaiyk) was fulfilled. The high sensitivity of surface runoff of rivers of the arid zone to climate change was received.

Introduction. The Republic of Kazakhstan is situated in the center of Eurasian continent and ranked ninth in the world in the area of its territory (about 2.72 million km^2) and approximately the sixteenth largest in terms of surface runoff on square unit only [1]. The cause of this is a significant distance from the oceans, primarily from the Atlantic (over 5000 km), and particularities of the General atmospheric circulation, promoting the removal of dry tropical air during the warm period and the influence of the Siberian anticyclone during winter, it is also not conducive to the cloud and precipitation.

Figure1 – Location of the Republic of Kazakhstan in the Northern hemisphere.

As a result, only in the extreme North-West and the North of the territory the rainfall reaches 400 mm/y or more, the some time evaporation exceeds 800 mm/y throughout all territory of the Republic. Only for the foothill and mountain areas of the South-East of the territory and the Kazakhstan Altai is characterized precipitation exceeding 400 mm/y [2]. As a result of shortage of rainfall and regular movement to the territory of the Republic of dry tropical air masses, the share of deserts and semi-deserts accounts for up to 58% of the than normal, while in the dry year is three times below the norm. In addition, there is a large intra-annual and asymmetry in the distribution of runoff. Up to 90% of runoff of steppe rivers refers to spring, while 70% of the runoff of mountain rivers - to the summer. The specific water availability in Kazakhstan is about 6 thousand m³ per one citizen per year. This is the lowest supply among all the countries on the territory of the former USSR. In fact, all branches of economic activity in the Republic lack of the water, and for some, e.g. for agriculture, water scarcity is a limit to development. Security of the population, agriculture and industry by water of required quality is a strategic priority for the state.

According to estimates made by the Russian science hydrological institute at the beginning of the nineties of the last century, average long-term runoff was estimated at 126.0 km³, of which the local runoff accounted for 66.8km³ and 59.8 km³ as cross border runoff. Consequently, surface runoff has decreased over this time by approximately 25.3 km³, of which the local flow has decreased by 10.3 km³ and transboundary – by 15.2 km³[3]. The reason for this change of flow is considered as the intensification of economic activity, especially in foreign countries, and climate change. This shows that the assessment of possible changes in runoff in the coming decades on the territory of the Republic in connection with climate change is very important. Our study problem is devoted to this problem.

Seemed most expedient to adhere to the following order of studies:

- on the example of the Ural river basin to analyze climate variability time series of temperature and precipitation over the past century and to assess the sensitivity of surface runoff to such oscillations, find the matching quantitative relationships;
-then to build a scenario of climate change temperature and precipitation for the coming decades for the basin of the Ural river, as an example of similar calculations for the other basins;
- further, to construct scenarios of changes in temperature and precipitation for the whole territory of the Republic;
- to assess in principle the possibility of predicting surface runoff for the whole territory of Kazakhstan;
- based on expected climatic changes in temperature and precipitation to draw General conclusions regarding the dynamics of surface runoff under climate change.

Materials and methods. *Data.* Used in the work, first of all, official data of the National hydro meteorological service of Kazakhstan on the average monthly temperatures and rainfall for the stations in Kazakhstan during the twentieth century to the present. In General when we studied problems in addition to Kazakhstan data were used data for the South of Western Siberia and the southern Urals. All inputs are passed strict technical and critical controls. Were also used data from several field studies performed in the basin of the Ural River on the territory of Kazakhstan, and kindly provided to us.

Methods. In the study of the temporal dynamics of temperature and precipitation we have approximated our ranks by a polynomial of the sixth degree, which is good on the one hand smoothes the time series, retaining, however, climatic extremes, and on the other, the polynomial is quite sensitive to the sign change of the dynamics in just several years.

Simultaneously approximating a time series by a polynomial of the sixth degree, we widely used harmonic analysis of series, which, as we know, involves the decomposition of the original time series into trigonometric functions [4].

If a sixth-degree polynomial smoothes a time series, quickly responding to trends in dynamics, harmonics characterize the internal structure of the series. Each of the harmonics, at least basic ones, usually interpreted as the result of exposure to a particular group of factors. There is no reason to believe that the factors that existed during the formation of climate before, suddenly disappears.

The coincidence of the directions of the approximating lines and the dynamics of the sums of the amplitudes of the main harmonics shows whether the approximated changes random or they are caused by the major harmonics.

The results of studies in the Ural river basin. *The hydrological regime.* In recent decades, when determining natural runoff of the Ural River and its components, the challenges are considerable, due to the influence of the magnitude of human economic activity. Therefore, the restoration of natural runoff of the Ural River on the border with the Russian Federation represents to the Republic of Kazakhstan of critical importance in addressing issues of joint use of water resources of transboundary rivers under consideration [5-7].

Restoration of the natural runoff of the Ural River in the Orenburg station was carried out by us by adding to the observed domestic flow values of water intake for economic needs in the basin, in the amount of 25 m³/s per year according to [5], etc.

The total water inflow from Russia by the Ural River is estimated as the sum of runoff of the river Ural – Orenburg, Sakmara – S. Keragala (Sakmara), Shagan and others. Average value of the discharge of these tributaries is still 8674 million m³, of which 4510 million m³ act on the Ural River and 3312 million m³ on the river Sakmara, respectively. During the period of global warming, i.e. since 1980, water resources of the study area increased to an average of 10.8 km³/year or 10% compared to the period of 1936...1977. On the territory of Russia is formed about 8.5 km³/year of runoff, and within the Republic of Kazakhstan – up to 1.6 km³/year.

The flow period of 1974...2007 is not very different from many years value. In slow runoff years 75 % probability the flow of water from the territory of Russia is reduced to 6024 million m3 respectively. In very dry years (97 % availability) these resources are at these points in time are 2349 and 3280 million m³ respectively [5, 6].

On untributary 587–kilometer strip from post Kushumto post Makhambet runoff value with probability 50% reduced 24%, i.e. on average by 4% per 100 km, and an average of 6500 million m³. In dry years, the runoff decreases with the availability of 75 % to 5456 million m³, and security 97 % –3006 million m³ [7]. On the 118-kilometer stretch from post Makhambet, to post Guryev (Atyrau) runoff decreases by only 3...4%.

In regulated river flow to establish the relationship between the amounts of precipitation falling in her watershed and runoff is very difficult. Reservoirs smooth out the natural fluctuations of the flow. Therefore, a thorough analysis was subjected to a period of not regulated flow. Over a period of runoff of the Ural River is considered to be a series until 1958, when it started filling the Irikla reservoir of long term regulation, which ended in 1966.The total reservoir capacity is about 3.26 km³ and useful is 2.8 km2. Long-term flow regulation is ensured with a guaranteed return of water to 0.5 km³/year or 15.1 m³/s. Later were built also Verkhneuralsk and Magnitogorsk reservoirs of smaller capacity. In numerous reservoirs on the territory of Russia accumulates up to 3.5 km³.

We have found that in the context of global warming there has been a marked intra-annual redistribution of runoff and increased runoff in autumn and winter, which significantly reduced the annual variability of its values. The variability of runoff in the district of Orenburg was previously estimated C_V=0.86, and now we got a value of 0.55.

In the alignment post Kushum average of the annual maximum discharges has decreased by about half, and the standard deviation is almost 2.5 times. The presence of Iriklia reservoir is not the only reason for the decrease of maximum runoff. From the middle of the seventies of the twentieth century global warming has begun and it affected the runoff of the rivers of the Ural Mountains.

With the introduction of Irikla reservoir, the transformation of the maximum water flow has become even greater. Calculations show that in the period after 1974, i.e., the filling of the reservoir, the maximum flow security 1% on the strip Kushum-Topoli is declining at a rate of approximately 11% per 100 km of channel. On the strip from the post Topoli to Atyrau (118 km) average decrease of maximum of runoff is only 3.3%.

After 1974, the maximum water levels along the river declined, in some areas the reduction is greater than 2 m, and the valley was inundated much less frequently. To estimate the width of the river was used the data of gauging stations and data of number of forwarding surveys of the floodplain. The width of the flooding depends on the morphology of the floodplain. Below Atyrau, the river-bed widens from 200 m to 300...500 m at the present time, although according to the data obtained up to the seventies, in the lower reaches, the floodplain was flooded for 6-8 km, and sometimes up to 15 km [7].

The creation of Irikla reservoir has significantly changed the maximum levels and water flows in the lower reaches of the Ural River, reducing the threat of flooding. The maximum water flow rates with decreased 1.5...2.0 times. It has also been affected by the warming climate, manifested mainly through evaporation loss and infiltration along the river, and also in increasing water intake and subsequent losses.

Analysis of climatic factors. *Temperature and precipitation.* In the study of the dependence of runoff from climatic conditions seem necessary to first try to find a link between the precipitation falling on the areas of runoff formation and runoff. For this, we tried to attract data stations of Ufa, Sverdlovsk (Yekaterinburg), Magnitogorsk, etc. located in areas of runoff formation. Such data, i.e. time series of temperature and precipitation for the twentieth century are available, but for various reasons they contain gaps. Therefore, for analysis we used data from two stations Uralsk and Kostanay, located on the territory of Kazakhstan, but close to the regions of runoff formation. Ural station is situated close to the Western catchment and the station Kostanay – to the East one. Since the station Uralsk and Kostanay are close enough to areas of the watershed, they should be good enough to reflect large-scale meteorological conditions of runoff formation to the West and East of the southern Urals. For the analysis we chose the period from 1932 to 1958, when the drain of the Ural River has not been regulated. Then calculated the annual amount of precipitation at the two stations, after which was built the correlation graph of the relationship between total rainfall and runoff of the Ural River in the area of post Kushum (Uralsk), i.e. on the territory of Kazakhstan, below the confluence of the right tributary of Sakmara (Figure 2).

From figure 2 we can see that between the curves of cumulative rainfall and runoff of the Ural River there is a good agreement, especially in the years of maximum runoff. Therefore, the selection of stations for precipitation, which we studied processes in both areas of runoff formation, was successful.

The maximum flow occurs when at both stations the greatest amount of precipitation. The rule works that after a small amount of precipitation in the basin, and their sharp growth it does not lead to the same increase of runoff because of the precipitation goes into soil moisture, the filling of lakes, depressions etc [8].

It is also noticed that the sharp decrease in precipitation after max leads to the same decrease in runoff, because accumulated earlier water supportsrun off. The linear trend of the total precipitation at the stations Uralsk and Kustanai indicates that there is a noticeable growth (regression equation shown in Figure 2). This is consistent with studies [5], according to which the drain is also increased.

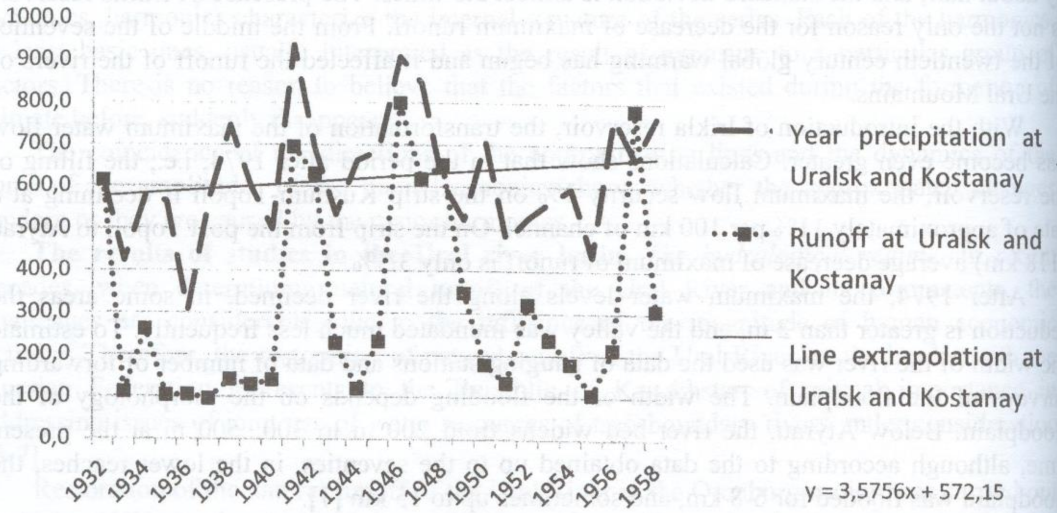
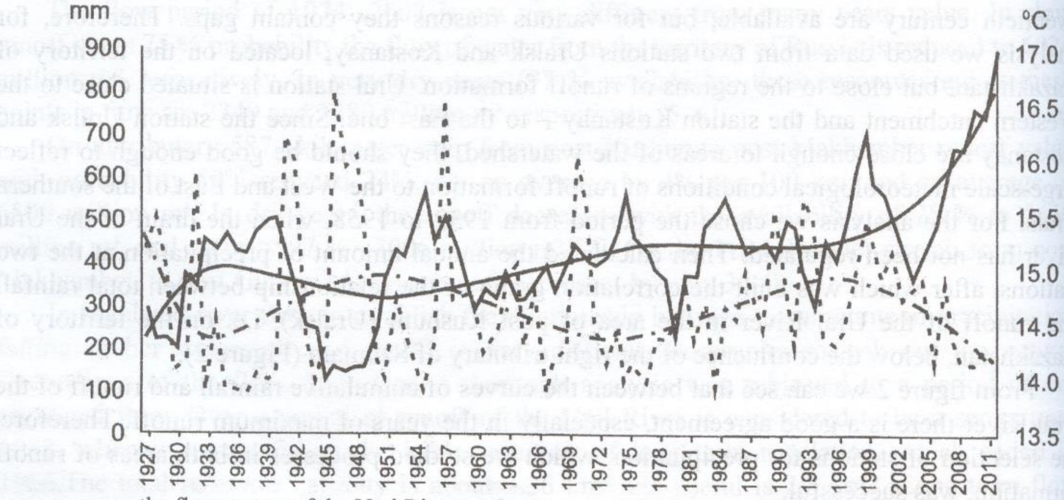


Figure 2 – Comparison of total annual precipitation values article Uralsk and Kostanay and water flow of the river Ural (Kushum post).

The dynamics of the flow It was further investigated the relationship between the time series of precipitation and temperature in the Uralsk region, on the one hand, and fluctuations of the runoff of the Ural River on the other.

The time course of water flow at the station Kushum, located almost at the entrance of the Ural River on the territory of Kazakhstan shows that during the period 1921...2007 values, the annual consumption of water varied from 89.1 to 800.0 m³/s (Figure 3 and 4).



---- the flow waters of the Ural River; - the average air temperature in warm period in station Uralsk, calculated over a rolling five- year period; —— the trend line of average temperatures during the warm period; ——— the trend line of water flow.

Figure 3 – The time course of the water flow of the Ural River and the average air temperature for the warm period in meteorological station Uralsk, calculated over a rolling five-year period.

We can notice a large variability from year to year, especially before 1973, while the polynomial trend shows that about 1930 and 1977 took place the climatic minima of precipitation, and about1950 and 1998 - climatic maximums. In the period from 2003 to 2007 there was a decrease in water consumption.

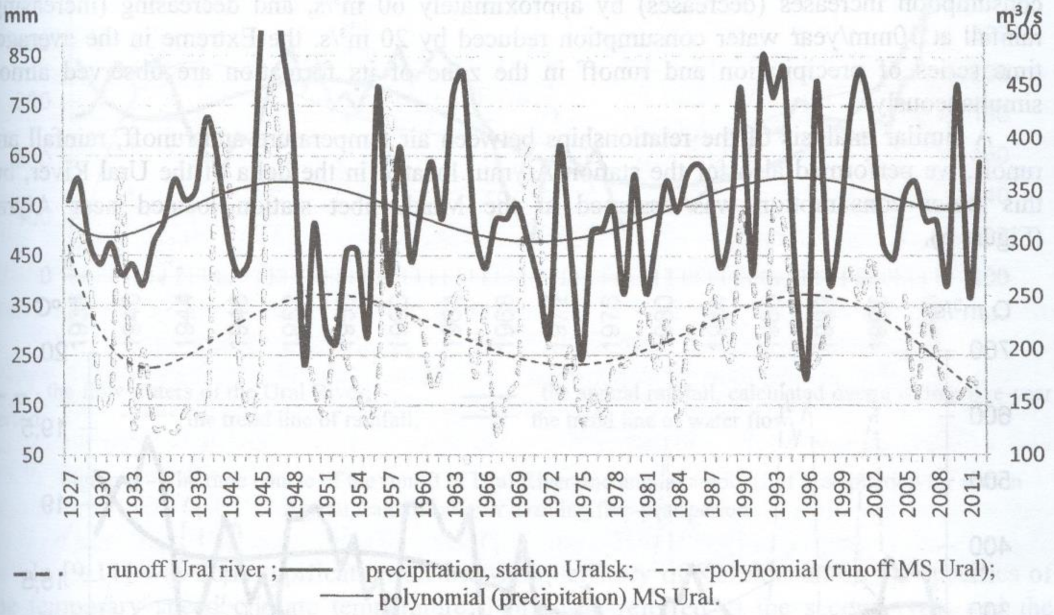


Figure 4 – The time course of the water flow of the Ural River and the annual amount of precipitation for the meteorological station Uralsk, calculated over a rolling five-year period.

Excluding the beginning and end of the rows, we can conclude that throughout the range of water flow replicates the time course of rainfall. Therefore, we can conclude that the time series of rainfall, as well as time series of temperature reflects the time course of the drain and tasks for the assessment of runoff changes under the influence of global climate change, at least at the level of General assessments, these data can be used without recourse to other information.

Purely qualitatively analyzing the time course of water flow and temperature (figure 3), as well as water flow and precipitation (figure 4), it should be noted that in the first case, there is a good negative, and the second positive connection. In this regard we tried to assess the correlation between the smoothed time series of water flow and temperature and flow of water and precipitation.

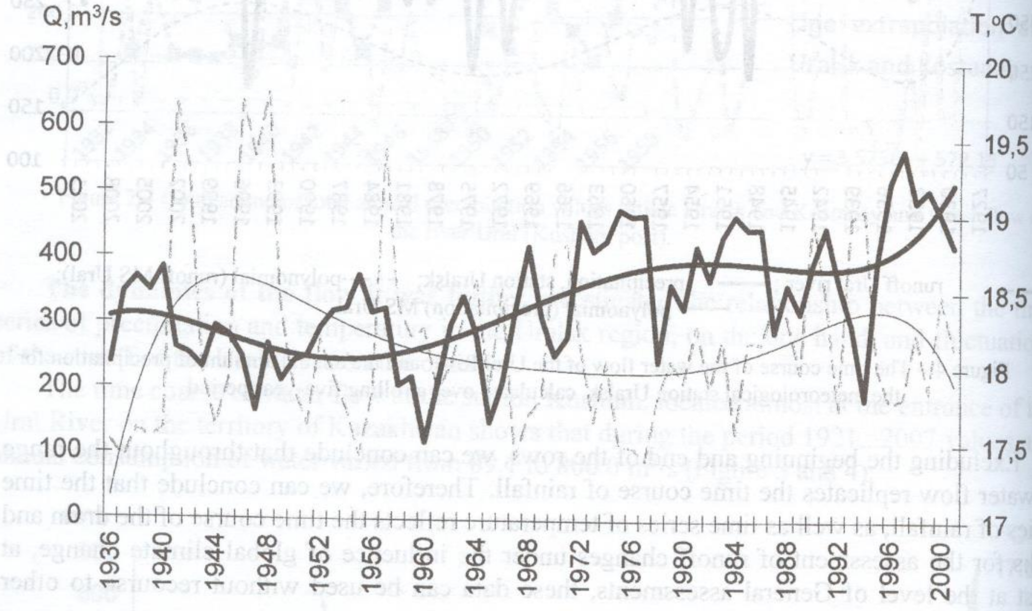
Corresponding values of parameters were taken us with smooth curves. In this case, the coefficient of negative correlation between water flow rate and temperature of the air in Uralsk increased to – 0.68, and the coefficient of positive correlation between water consumption and precipitation increased to 0.87. The coefficients of determination equal to 0.46 and 0.66, respectively. So at the decreasing (increasing) of climate temperature on 0.5°Cthe water consumption increases (decreases) by approximately 60 m3/s, and at the decreasing (increasing) rainfall at 10mm/year water consumption decreases (increases) by 20 m^3/s.

Thus, it is possible to see that, despite the relatively low correlation of annual water discharge, with annual values of air temperature and precipitation, the correlation of the smoothed speed of the water flow temperature and especially precipitation in Uralsk is high.

Since climate variations is considered to be smoothed deviations from the average within 8...10 years that we have received thus quite suitable for use in climate assessments.

Obvious, therefore, there is high sensitivity of runoff, even from weak climatic fluctuations of temperature and precipitation. It was possible to calculate quantitatively the value of communication: when decrease (increase) climate temperature 0.5°C the water consumption increases (decreases) by approximately 60 m³/s, and decreasing (increasing) rainfall at 10mm/year water consumption reduced by 20 m³/s. the Extreme in the averaged time series of precipitation and runoff in the zone of its formation are observed almost simultaneously.

A similar analysis of the relationships between air temperature and runoff, rainfall and runoff, we performed also for the station Atyrau, located in the delta of the Ural River, but this water consumption was assumed at the Makhambet station located near Atyrau (Figure 5).



– – ·the flow waters of the Ural River; —— the average air temperature, calculated over a rolling five year period; ----- the trend line of average temperature; ——the trend line of water flow.

Figure 5 – the time course of the runoff of Ural River water and average air temperature for the warm period for the Atyrau station, calculated over a rolling three year period

We can see that the time series of annual runoff in Atyrau is very similar to the course of flow in Uralsk. This confirms the thesis that in the area from Uralsk to Atyrau are only some of the flow losses through seepage and evaporation, estimated by us above, without impacting significantly on the time course of the flow.

A joint analysis of the time course of temperature and precipitation in Atyrau and Uralsk shows that the extreme they are not the same, especially precipitation (Figure 6). The maximum rainfall took place in Uralsk in 1948, 1965 and 1994. In Atyrau, the maximums barely visible ware in 1942, 1952, 1963. So in Atyrau time series of temperature and precipitation do not correlate with the magnitude of runoff. It was interesting to find out why.