GEOGRAPHICAL SCIENCES

FORECASTING THE RUNOFF ON RIVERS OF THE DNISTER RIVER BASIN ACCORDING TO THE REMO NUMERIC CLIMATIC MODEL

Vasyl Grebin, *Professor, doctor of geographic sciences*
Kateryna Mudra, *post-graduate student*

Ukraine, Kyiv, Taras Shevchenko National University of Kyiv

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ABSTRACT

This article presents the results of forecasting of future changes in water runoff in the basin of the Dnister River. The forecast is made until the year 2100 in 30-year periods. For forecasting, the data from the network of hydrological stations at Dnister and its affluents. After conducting the verification (testing) of the selected REMO climatic model, an adjustment coefficient was developed and its use was proposed when forecasting the runoff. The results of the forecast have shown the decrease in the value of the runoff modulus for each of the forecasted periods. The deviation of forecasted runoff rates from the control period (1970-2000) with the use of the coefficient for the period 2011-2040 was (in average for the basin) 0.81 l/s*km2 (9%); for the period 2041-2070 it was 0.96 l/s*km2 (11%); for the period 2071-2100 it was 0.88 l/s*km2 (10%).

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Introduction. As of today, the climate change is a confirmed fact, in consequence of which a question arises how the quantity and the quality of water in resources will change in years to come. The level of availability of water resources in Ukraine is insufficient and is determined by the formation of the river runoff rate, the availability of underground and sea waters [1]. Because of that, the forecast of the quantity of water which will be available in Ukraine in the future is an important issue for today's researchers. One of the main issues is to valuate the changes in the hydrological regime in vulnerable flood hazard regions and in result of the climate change [2, 3]. The basin of the Dnister River is characterized by formation of rain floods which have a destructive effect on the economies of two countries: Ukraine and Moldova [4, 5].

Results of Studies. For forecasting the runoff rate in the future, the REMO regional numeric model was used in our study. It was developed in Max Plank Meteorology Institute (Hamburg) [6]. REMO unites the former EUROPA-MODELL numeric model for weather forecasting for calculation of thermodynamic characteristics and the block of ECHAM5 global climatic model, using which the processes of clouds and precipitation formation, of the movement of flows of sun radiation in the atmosphere, the influence of the underlying terrain on heat flows with taking into account the albedo and the type of the terrain are calculated [7].

Before the forecasting itself it is necessary to ascertain how plausible and accurate the selected model can provide the forecast of the characteristic necessary for us: the runoff modulus. Because of that, the first task was the verification (testing) the results of the REMO numeric modeling [8] in respect of quantitative runoff indicators in the territory of Ukraine. The testing was conducted through the comparison of the results of the model with the data of observation of the hydrological network in corresponding period [9].

For the research, we used the data of observations at 17 affluent rivers of Dnister (19 hydrological stations) and at the Dnister River itself (9 hydrological stations). The selected network of hydrological stations fully covers the basin of Dnister and characterizes the conditions of formation of the water runoff of rivers in the entire basin territory in a good way [10].

Table 1 shows the comparison of values of the water runoff modulus averaged over the research period (1971-2000) separately for each studied hydrological station, as well as the percentage deviation of values of the both sets of data.

Table 1. Runoff Modulus (l/s·km^2) of Dnister Basin Rivers (averaged over 1971 – 2000)

No.	River	Hydrological Station	Average Annual Value of the Runoff Modulus, l/s·km^2		Average Deviation for the Entire Period of Research, %
			Network of Hydrological Stations	REMO Model	
1	Dnister River	Strilky village	13.51	11.77	14.9
2		Rozdil urban-type village	8.17	6.78	20.4
3		Halych town	11.42	10.12	13.9
4		Zalishchyky town	9.46	8.17	14.3
5		Mohyliv-Podillskiy town	6.70	5.82	16.5
6		Hrushka village	6.29	5.42	16.5
7		Dubossary hydro-electric power station	5.56	5.33	16.1
8		Benedery town	4.72	4.45	5.8
9	Strviazh River	Luky village	9.74	8.88	15.4
10	Zavadka River	Rykiv village	23.60	21.60	8.7
11	Opir River	Skole town	19.23	17.15	12.0
12	Svicha River	Myslivka hamlet	27.76	24.70	12.0
13	Svizh River	Bukachivtsi urban-type village	5.67	5.14	19.7
14	Limnytsia River	Osmoloda village	35.41	32.35	8.7
15	V. Nadvirnianska River	Pasichna village	22.33	20.51	9.0
16	Zolota Lypa River	Zadariv village	12.15	10.41	18.0
17	Zolota Lypa River	Berezhany town	5.26	4.57	23.0
18	Koropets River	Koropets urban-type village	5.51	4.74	20.9
19	Strypa River	Kaplyntsi hamlet	4.22	3.62	21.5
20	Seret River	V. Berezovytsia urban-type village	5.50	5.12	18.6
21	Seret River	Chortkiv town	4.04	3.60	16.4
22	Nichlava River	Strilkivtsy village	3.01	2.60	22.6
23	Zbruch River	Volochysk town	3.95	3.58	27.5
24	Zbruch River	Zavallia village	3.32	2.96	18.5
25	Smotrych River	Kupin village	3.26	2.82	17.9
26	Studenytsia River	Holozubyntsi village	3.16	2.85	22.3
27	Ushytsia River	Tymkiv village	3.06	2.69	23.1
28	Kalius River	Nova Ushytsia urban-type village	3.14	2.82	20.0

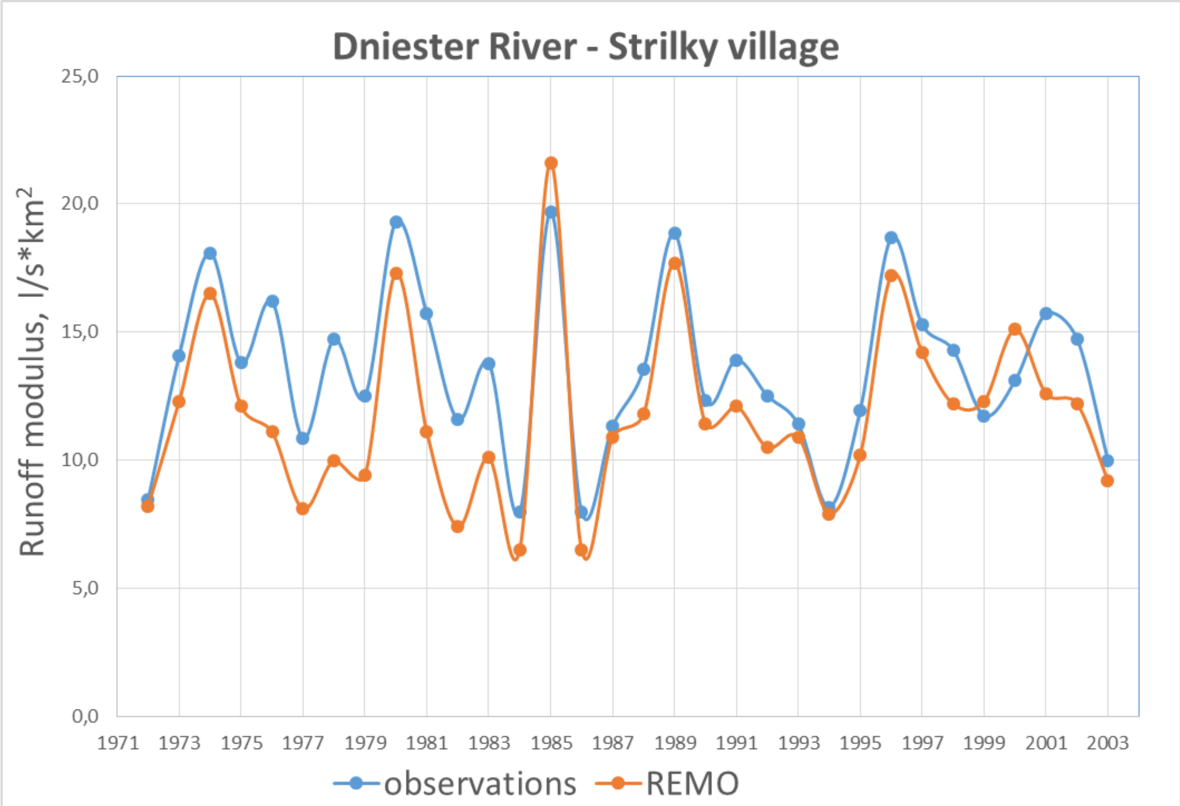

Fig. 1. shows the example of results of modeling of the value of river runoff for certain hydrological stations of the basin.

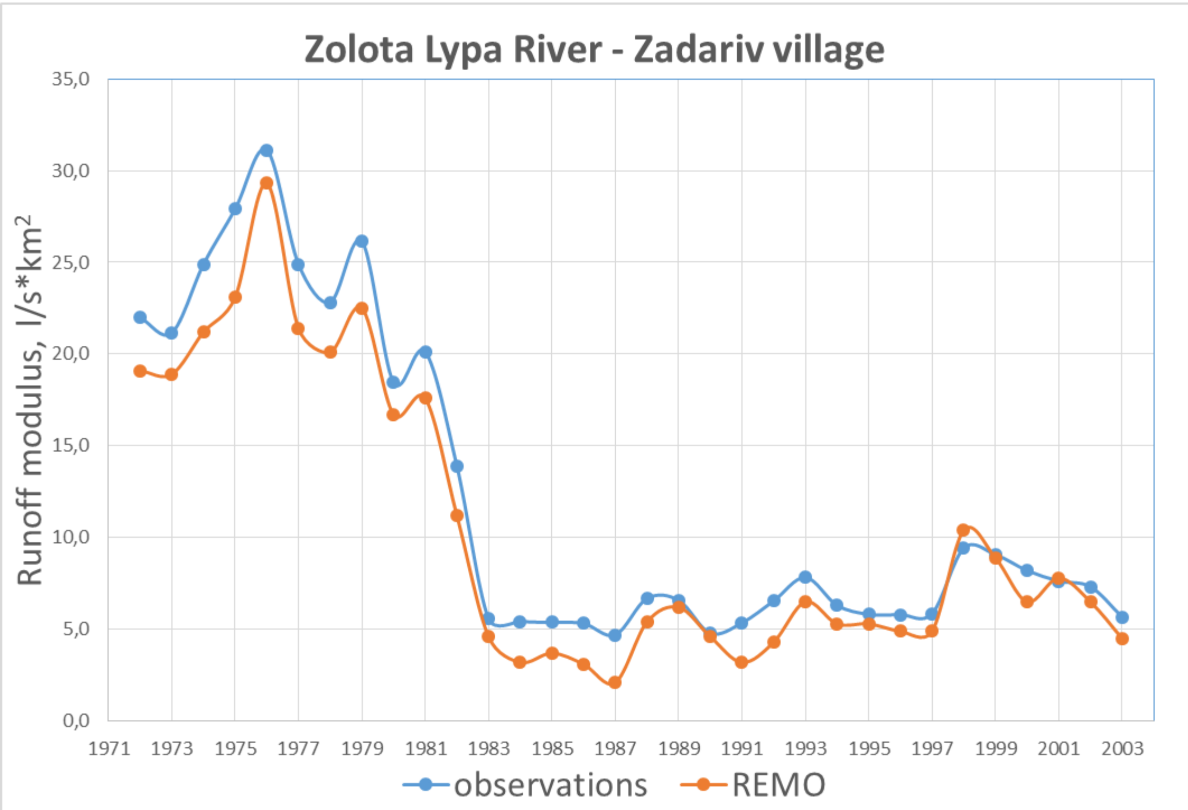

Fig. 2. Average Perennial Hydrographs of Water Runoff Obtained According to the Data of Observations and Results of REMO Modeling for the Period 1971-2000

The analysis of Fig. 1 shows that in the majority of cases the average annual value of the runoff modulus taken according to the REMO model is lower, as compared to the data of stationary hydrographical observations.

The average annual runoff modulus in the basin of Dnister averaged across the entire basin is, according to the data of the hydrometrical network, 9.25 l/s·km^2, and according to the REMO model it is 8.27 l/s·km^2. The calculation data averaged across the basin, calculated according to the REMO model are underestimated as compared to the data of observations at hydrological stations by 0.98 l/s·km^2, which amount to approximately 11% in percentage.

In the process of the verification of the veracity of obtained model values of the runoff modulus, we proposed to use an adjustment coefficient (C_a) which shows what fold the modeled monthly value of runoff has to be decreased or increased for hydrological stations in the basin of Dnister. That is needed to be done in order that the modeled value would be more corresponding to the value of the runoff modulus obtained during direct measurements at a hydrological station. The values of coefficients were calculated on the basis of deviations of modeled values for each month for the period 1971-2000.

In order to check the efficacy of use of the above mentioned coefficients, the verification of the REMO model over an independent period of observations, from 2001 to 2015, was conducted. We compared annual values of the runoff modulus obtained at hydrological stations and forecasted within the model for the same period. The comparison was conducted for two scenarios: comparison of perennial values of the runoff modulus separately for each studied station, as well as comparison of average values of the runoff modulus average in the basin for each year of the independent period separately. Without using the C_a coefficient, values of the runoff modulus obtained from the REMO model quite significantly differ from the measured values. The deviations of modeled values vary within the range from 7.2% to 23.5%. While when coefficient is used, the percentage of deviation is decreased to 3.6% – 11.2%, that is, the deviation from measured values decreases twice.

The table below shows monthly adjustment coefficients (C_a), averaged by the entire basin of Dnister.

Table 2. Monthly Values of the Adjustment Coefficient Averaged by the Basin

Month	1	2	3	4	5	6	7	8	9	10	11	12	YEAR
Coefficient	1.14	1.21	1.32	1.31	1.10	1.14	1.05	1.20	1.46	1.03	1.16	1.20	1.19

The conducted verification of the correctness of the model over the independent period give the grounds to assert that the adjustment coefficient proposed by us actually provides the possibility to mitigate the percentage of deviation of modeled values, and in result of that the values of the runoff modulus obtained within the REMO model will be corresponding to the reality in a significantly more accurate way.

The data of the study show that the REMO model forecasts the changes in the runoff modulus in the basin of Dnister in a sufficiently veracious way, including regularities and local particularities of formation of the runoff in different parts of the studied basin. Significant deviations between the data can be connected with an insufficient accuracy of appropriateness of boundaries of areas demarcated in REMO and of boundaries of the river basin. However, the obtained high value of the correlation coefficient allows us to make a conclusion that the REMO model can be used for analysis of changes in the runoff of the Dnister basin in the past, at present, and forecasting that for the future with a high level of veracity. At the same time, the use of the proposed coefficient will allow to mitigate the deviation of modeled values of the runoff modulus and will provide the possibility to forecast the runoff of rivers of the Dnister basin in the future in a more accurate way. We performed the forecast of the runoff for the period until the year 2100; the forecast was made in 30-years periods: 2011-2040, 2041-2070, and 2071-2100.

The results of the forecast of the runoff in the Dnister River basin are shown below.

Table 3. Forecasted Monthly Values of the Runoff Modulus in the Dnister Basin in 30-Years Periods

Period, Years	*Runoff Modulus (l/s*km^2)*											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**Septembe r**	**October**	**November**	**December**
1	2	3	4	5	6	7	8	9	10	11	12	13
1971-2000	**5.61**	**5.12**	**15.04**	**14.94**	**12.88**	**11.65**	**8.05**	**7.22**	**5.31**	**5.33**	**8.53**	**6.63**
2011-2040 without the coefficient	5.01	4.56	13.15	13.34	11.03	9.95	7.17	6.33	4.74	4.72	7.38	5.79
2011-2040 with the coefficient	5.71	5.52	17.36	17.47	12.14	11.34	7.53	7.59	6.92	4.86	8.56	6.94
Difference without C_a (l/s*km^2)	**0.60**	**0.56**	**1.89**	**1.60**	**1.84**	**1.71**	**0.88**	**0.89**	**0.57**	**0.62**	**1.15**	**0.84**
Difference (%)	**10.67**	**10.96**	**12.60**	**10.70**	**14.31**	**14.64**	**10.93**	**12.37**	**10.78**	**11.57**	**13.51**	**12.66**
Difference with C_a (l/s*km^2)	**0.10**	**0.40**	**2.31**	**2.54**	**0.74**	**0.31**	**0.52**	**0.37**	**1.61**	**0.48**	**0.03**	**0.32**
Difference (%)	**1.84**	**7.73**	**15.37**	**16.98**	**5.74**	**2.69**	**6.48**	**5.16**	**30.27**	**8.91**	**0.33**	**4.80**
2041-2070 without the coefficient	4.54	4.11	11.62	12.05	9.49	8.48	6.35	5.56	4.27	4.20	6.40	5.11
2041-2070 with the coefficient	5.18	4.98	15.34	15.79	10.44	9.67	6.66	6.67	6.23	4.33	7.43	6.13
Difference without C_a (l/s*km^2)	**1.07**	**1.01**	**3.42**	**2.89**	**3.38**	**3.17**	**1.71**	**1.66**	**1.05**	**1.13**	**2.13**	**1.52**
Difference (%)	**18.99**	**19.72**	**22.74**	**19.32**	**26.27**	**27.21**	**21.21**	**22.99**	**19.71**	**21.24**	**24.94**	**22.94**
Difference with C_a (l/s*km^2)	**0.43**	**0.15**	**0.30**	**0.85**	**2.43**	**1.98**	**1.39**	**0.55**	**0.92**	**1.01**	**1.10**	**0.50**
Difference (%)	**7.65**	**2.87**	**1.98**	**5.70**	**18.90**	**17.02**	**17.27**	**7.59**	**17.22**	**18.88**	**12.93**	**7.52**
2071-2100 without coefficient	4.77	4.32	12.20	12.65	9.97	8.91	6.66	5.84	4.48	4.41	6.72	5.36
2071-2100 with the coefficient	5.44	5.23	16.11	16.58	10.97	10.15	7.00	7.01	6.54	4.54	7.80	6.43
Difference without C_a (l/s*km^2)	**0.84**	**0.81**	**2.84**	**2.28**	**2.91**	**2.75**	**1.39**	**1.38**	**0.83**	**0.92**	**1.81**	**1.26**
Difference (%)	**14.94**	**15.71**	**18.88**	**15.28**	**22.58**	**23.58**	**17.27**	**19.14**	**15.69**	**17.30**	**21.19**	**19.08**
Difference with C_a (l/s*km^2)	**0.17**	**0.10**	**1.07**	**1.64**	**1.91**	**1.50**	**1.06**	**0.21**	**1.23**	**0.79**	**0.73**	**0.19**
Difference (%)	**3.03**	**1.99**	**7.08**	**10.98**	**14.84**	**12.88**	**13.14**	**2.97**	**23.09**	**14.82**	**8.58**	**2.90**

Analyzing the table presented above, the following conclusions can be made about the tendencies of changes in the runoff in the studied basin of Dnister for the forecasted period.

For the period 2011 – 2040 without the use of the adjustment coefficient calculated by us, according to the forecast, the runoff will decrease for every month. The greatest deviations are observed for the three spring months (corresponding differences = 1.89; 1.60; 1.84 l/s*km^2) and November (the difference = l/s*km^2). The use of the adjustment coefficient will also result in the decrease of the forecasted runoff for the majority of months; the increase is observed only for February, April, September, and December.

The average annual deviation of forecasted values of runoff from the control period (1971-2000) without the use of the coefficient is l/s*km^2 which in percentage is 12%. Using the coefficient, we decrease the deviation: 0.81 l/s*km^2 (9%).

For the forecasted period 2041 – 2070, both without the use of the adjustment coefficient and with the use thereof, the runoff will decrease for each month. Sure, grater deviations are observed in the case of forecasting without the use of the coefficient: the average monthly deviation is 2.01 l/s*km^2 (22%). When using the coefficient, we obtain the averaged over a year value of the runoff: 1.07 l/s*km^2 (12%). The deviation is decreased almost twice.

If we analyze the forecast in the last forecasted period (2071-2100), without the use of the adjustment coefficient calculated by us, according to the forecast the runoff will be decreased for each month. The largest deviations are observed for the same months as in the first forecasted 30 years: three spring months (corresponding differences = 2.84; 2.28; 2.91 l/s*km^2), June (the difference = 2.75 l/s*km^2) and November (the difference = 1.81 l/s*km^2). Once again, if we compare these values with those forecasted for the period 2011-2040, the decrease of the runoff in the period 2071 – 2100 will be almost twice greater as compared to the forecast for the period 2011-2040.

The average annual difference of the forecasted values of the runoff from the control period (1970-2000) without the use of the coefficient is 1.67 l/s*km^2 (18%). Using the coefficient, the deviation is decreased: 0.73 l/s*km^2 (8%).

The change in the forecasted runoff for the period 2011-2040 averaged across the basin without the use of the C_a coefficient is 11.40 l/s*km^2, and with the use of the coefficient the value is 7.56 l/s*km^2. In the period 2041-2070, without the use of the coefficient the value is 20.24 l/s*km^2, and with the use of the coefficient the value is 10.87 l/s*km^2. For the last 30-years period, the changes are as follows: 16.93 l/s*km^2 and 9.96 l/s*km^2 accordingly.

Taking into consideration the expedience of the use of the adjustment coefficient, and generalizing the tendencies described above, we will obtain the following average annual deviations of the forecasted values of the runoff from the control period (1970-2000): for the period 2011-2040 – 0.81 l/s*km^2 (9%), for 2041-2070 – 0.96 l/s*km^2 (11%), for 2071-2100 – 0.88 l/s*km^2 (10%).

Visually, the generalization of the information set forth above can be represented in the form of a diagram, of monthly changes in the runoff modulus for each of the 30-years periods (Fig. 3).

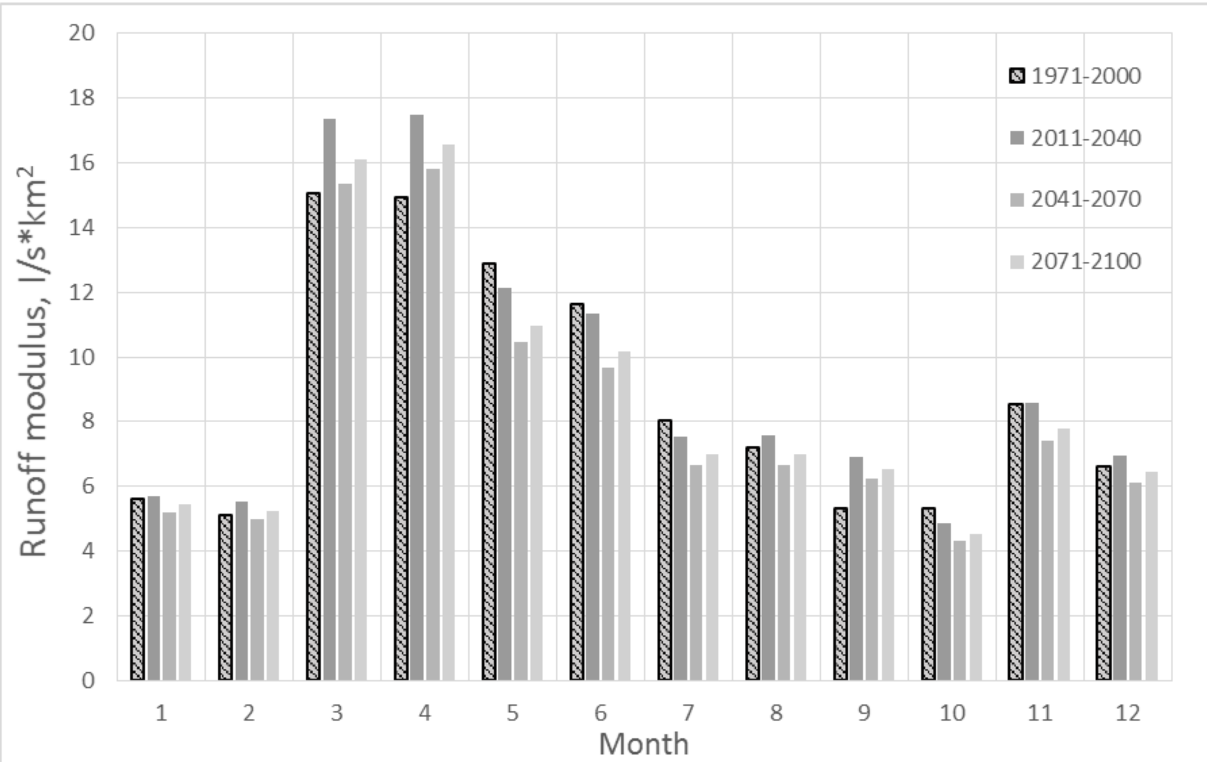

Fig. 3 Monthly Forecasted Values of the Runoff Modulus in the Dnister Basin

As to the distribution of the forecasted runoff modulus in the Dnister basin, the following values can be mentioned (Table 4).

Table 4. Distribution of the Runoff Modulus by the Dnister Basin (l/s*km^2)

No.	Forecasting Period	Runoff Modulus (l/s*km^2)	
1	2011 – 2040	Without the coefficient	**23.45– 0.85**
		With the coefficient	**26.23 – 1.01**
2	2041 – 2070	Without the coefficient	**22.36 – 0.76**
		With the coefficient	**22.22 – 0.91**
3	2071 – 2100	Without the coefficient	**20.88 – 0.80**
		With the coefficient	**23.33 – 0.96**

Conclusions.

1. For development of the forecast of the changes in the runoff in the Dnister basin, REMO regional climatic model was used. The conducted verification has shown that the model forecasts the changes in the runoff modulus in the basin in a sufficiently veracious way, including the regularities and local particularities of formation of the runoff in different parts of the studied basin.

2. In the process of the research, the use of the adjustment coefficient C_a was proposed, which would allow mitigating the deviation of the modeled values of the runoff modulus and would allow to forecast the runoff of the Dnister basin rivers in the future in a more accurate way.

3. The forecast of the runoff made in 30-years periods has shown that in the first period the runoff value will increase (as compared with the control period 1971-2000) in average for the Dnister basin by +0.47 l/s*km^2; in the second period there will be a decrease in the runoff value by -0.62 l/s*km^2; in the third period the runoff value will decrease by -0.21 l/s*km^2.

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