THE INFLUENCE OF CLIMATE CHANGES ON THE WATER BALANCE IN THE WESTERN BUG RIVER BASIN – KAMIANKA BUZKA

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ABSTRACT. - The Influence of climate changes on the water balance in the Western Bug River basin – Kamianka Buzka. Quantitative indicators of water balance represent the ratio between the air and water components of the environment. Therefore, by analyzing the structure of water balance of the river basin, it is possible to estimate the local manifestations of the global climate change impact on the aquatic components. The main goal of this paper is to calculate and display water cycle process within the Western Bug River basin - city of Kamianka Buzka and to define its input-output elements. For this purpose the water balance equation of the catchment area was calculated monthly and yearly for climate normal and current periods and the general water balance equation was calculated for long-term (1961 - 2014) period. Meteorological components were determined as the weighted average for river basin, according to the observations at three meteorological stations. Compared to the climate normal period, the air temperature in the basin of the river Bug increased by 0.8°C, which led to an increase of both input and output parts of the water balance.

Keywords: climate change, water balance, period of climatic norm, long-term period, Western Bug River basin

1. INTRODUCTION

According to the data of the meteorological stations, where the notes about authentic temperature data have been made since the middle of the nineteenth century, the tendency of climate changes has been traced. The developments of this kind are fixed all over the planet. This question is also actual for the territory of Ukraine, that's why it requires special attention. Climate changes leave their own tracks on the hydrological regulations of the water objects and it can be followed in the process of water balance of this or that watercourse or well investigation. The water balance investigation is rather actual in hydrology, because it helps to learn about the mutual influence of the processes that take place in the catchment basin.

In the given work the influence of climate changes on the water balance and its components based on the example of the Western Bug River basin in the town of

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Kamianka Buzka is shown. The Western Bug is the tributary of the second order of the Wisla River and together with the San River it belongs to the basin of the Baltic sea. So this river flows on the territory of three states: the republic of Poland, the republic of Bilorus and Ukraine, where it originates in (Fig. 1). The Western Bug River belongs to trance border rivers and that is why the complex understanding of all modern processes, that take place in the bounds of its basin, through the evaluation of its quantitative indexes of its water balance, is an important component in the studying of its hydrological regime.

In Ukraine O. I. Lukianets and V. O. Balabukh research waterbalance. Hrebin V. V. Researches in details the parameter changes of the Ukraine's rivers hydrological regime, that take place as a result of climate changes. The scientists from Odesa ecological university carry out studies about the climate flow of the Ukrainian rivers. In this paper summarizes research the impact of climate change on water regime.

2. OUTPUT DATA FOR WATER BALANCE CALCULATION

The total basin area of Western Bug River is 39 580 km^2, a length of 772 km. The climate of the Bug basin is temperate. The basin experiences annual high-water levels during spring flooding due to thawing snow, after which a low flow period starts and lasts until October or mid-November. Occasional summer floods often occur in the headlands, where mountains influence favorable flash-flood conditions. In Autumn the water level increases are inconsiderable; in some years they do not happen at all. During the winter the river can have temporary ice-outs that sometimes provoke ice jams.

For the basin of the Western Buh river – Kamianka Buzka, the components of the balance were calculated and compared for two periods: modern (1990-2014) and the period of a climatological normal norm (in WMO this period includes 30 years , from 1961 to 1990. Now the preparation of the next normals for the period from 1971 to 2000 is being prepared.

For making of corresponding calculations the data of 54 hydrological years have been collected from 1961 to 2014. The data base from Yavoriv, Lviv and Brody meteorological stations (*Fig. 1*) has been collected and contains the following components: precipitation; absolute humidity; atmospheric temperature.

The computing method of standard observations at meteorological stations has been used for the calculation of evapotranspiration. It was suggested by A.R. Konstantinov and based on the theory of turbulent diffusion (Halushchenko, 1987).

In order to count the average longstanding value of the precipitation, air temperature and humidity within the limits of the Western Buh River basin on the data basis of the observations on the meteorological stations in Yavoriv, Lviv and Brody the method of deliberation or the method of triangles has been chosen (Fig. 1). In the program of the ARC GIS was created a map of the pool and initially average weighted coefficients each weather stations. Then the general equation by triangles looks like this:

Fig. 1. ***Location of meteorological stations in the area of Western Bug River Basin- Kamianka Buzka with indication of the weighting coefficients***

In the program of Arc Gis the map of the pool was created and average weighted rates coefficients were calculated for each meteorological station. Then the general equation for the triangle method was applied as follows:

$$X=0.44*X1 + 0.34*X2 + 0.21*X3 \qquad (1)$$

Where: X.1- precipitation at Lviv; X2 - precipitation at Brody; X3 - precipitation at Yavoriv.

The first stage of work with information is to check it on uniform (Table 1). Homogeneity outgoing sequences hydrological and weather characteristics calculated compared with the period of climatic norm 1961-1990 and modern period 1991-2014 years. The Calculation Methodology for criteria of homogeneity of Willcoxon (U), St'yudent (T) and Fischer (F) is listed in works (Dohanovskyy A.M., Orlov V.G, 2011).

Table 1. ***Assessment of the basic composition of the water balance of the Western Bug River basin – Kamianka Buzka***

Where: U- Willcoxon, T- St'yudent, F- Fischer tests.

Description of water balance	The Criteria Homogeneity	The estimated statistics	Theoretical criterion	Adopted hypothesis
Precipitation, mm	F	1.623	2.174	Homogeneous
	T	1.233	2.007	Homogeneous
	U	430	247, 407/472, 593	Homogeneous
Total evaporation, mm	F	1.127	2.174	Homogeneous
	T	1.559	2.007	Homogeneous
	U	439	247, 407/472, 593	Homogeneous
Underground flow, mm	F	1.428	2.174	Homogeneous
	T	3.551	2.007	Uneven
	U	549	247, 407/472, 593	Uneven
Surface flow, mm	F	1.15	2.174	Homogeneous
	T	1.077	2.007	Homogeneous
	U	420	247, 407/472, 593	Homogeneous
Depth of runoff, mm	F	1.126	2.174	Homogeneous
	T	1.178	2.007	Homogeneous
	U	429	247, 407/472, 593	Homogeneous
Average annual air temperature, ° C	F	1.109	2.174	Homogeneous
	T	4.052	2.007	Uneven
	U	566	247, 407/472, 593	Uneven

Homogeneous, according to three assessment criteria, are rows in the annual amount of precipitations, depth of runoff and evaporation. And heterogeneity was recorded by Student and Willcoxon in the ranks of air temperature and permanent underground water flow. Such changes in the components of the water balance may have been caused by climate changes.

3. AIR COMPONENTS

Temperature changes during the reporting period can be displayed by differential integral curves (Fig.2). The method of constructing of differential integral curves is given in the work (G.S. Klein, 1981).Unlike the heat, in quantity of the atmospheric precipitation is not visible clear patterns for change, because their fluctuations have loop.

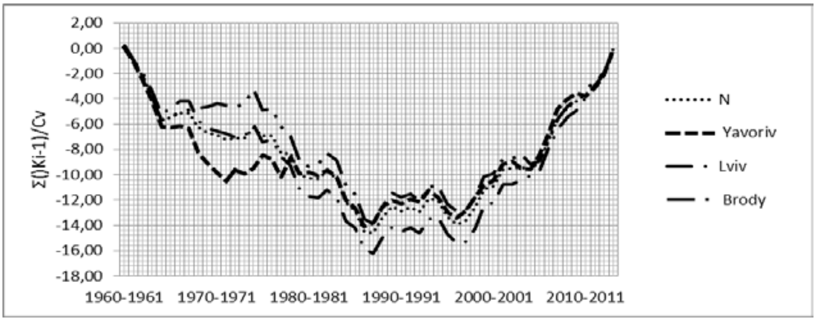


Fig. 2. ***Differential integral curves of average annual values of the air temperature according to the meteorological stations of Brody, Yavoriv and Lviv, where N - normal values***

That is, according to three meteorological stations: Yavoriv, Lviv and Brody - the upward trend in temperature can be observed since 1987/1988 . Comparing the climatic norm period and the current period, the temperature has increased from 7.5 ° C to 8.3 ° C, meaning 0.8 ° C.

Unlike the temperature changes, there are not any clear patterns for changes in quantity of the atmospheric precipitation, because their fluctuations are cyclical in nature which can be traced on the differential integral curves (Fig. 3).

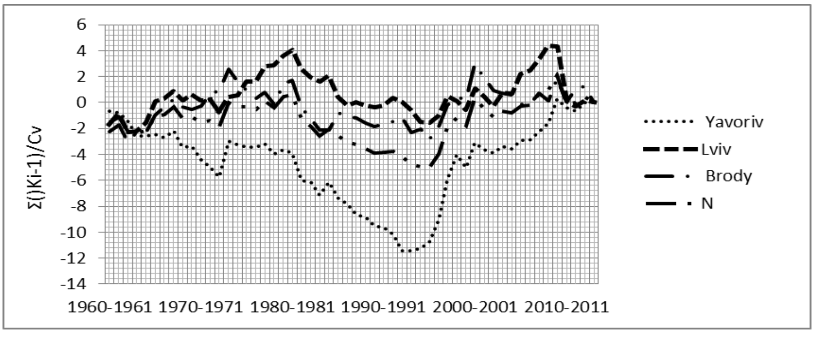
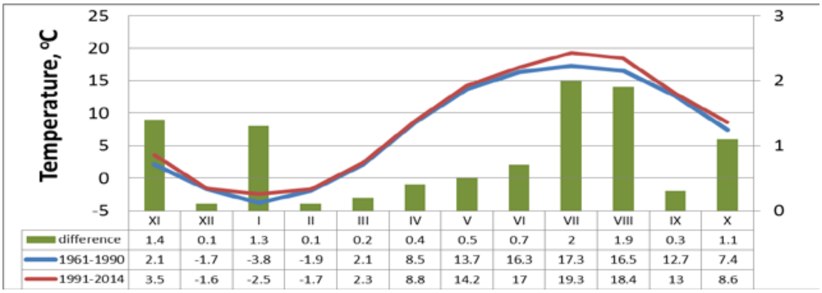


Fig. 3. ***Differential integral curves of precipitation according to the weather stations of Brody, Yavoriv and Lviv***

According to the observations at the meteorological station in Yavoriv, the very crucial period is the year of 1993 since which precipitation level has increased. The year of 1996 seems to be the similar period for Brody and Lviv.

More changes can be evaluated through graphs of internal distribution of annual precipitation quantity, average annual air temperature and evaporation.

According to the three meteorological stations for 1991-2014 period, air temperature has increased in comparison with the period of 1961-1990 (Fig.4).

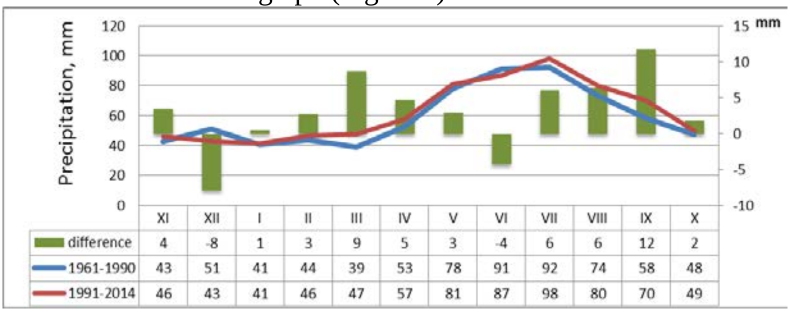


	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
difference	1.4	0.1	1.3	0.1	0.2	0.4	0.5	0.7	2	1.9	0.3	1.1
1961-1990	2.1	-1.7	-3.8	-1.9	2.1	8.5	13.7	16.3	17.3	16.5	12.7	7.4
1991-2014	3.5	-1.6	-2.5	-1.7	2.3	8.8	14.2	17	19.3	18.4	13	8.6

Fig. 4. ***Monthly distribution of air temperature in the basin of the rivers Western Bug River – Kamianka Buzka.***

The biggest difference between a period of climatic norms and a modern period is observed in July (2,0), August (18.1 °C), November(1.4 °C), January (1.3) and October(1.1 °C).

Changes in the internal distribution of such an element of water balance as precipitation are shown in the graph (Figure 5).



	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
difference	4	-8	1	3	9	5	3	-4	6	6	12	2
1961-1990	43	51	41	44	39	53	78	91	92	74	58	48
1991-2014	46	43	41	46	47	57	81	87	98	80	70	49

Fig. 5. ***Mothly distribution of the atmospheric precipitations in the basin of the Western Bug River – Kamianka Buzka***

Comparing the current period and the period of climatic norms, having analyzed the distribution of atmospheric precipitations, we can say that the reduction of its quantity occurred in December (-8 mm) and in June (-4 mm). The tendency towards increasing can be traced in all other months of hydrological year. The largest amount of precipitations increased in September (12 mm) and March

(9 mm). Air temperature changes greatly influence the process of total evaporation. Its long-terms dynamics is shown in Figure 6.

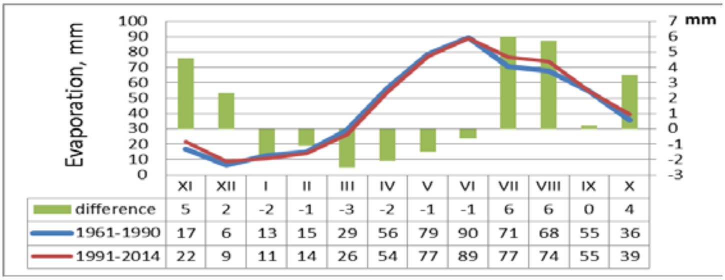


Fig. 6. ***Annual distribution of total evaporation per months in the basin of the Western Bug River – Kamianka Buzka***

Total evaporation is a link between meteorological and hydrological processes. The annual distribution of total evaporation per months in the basin of the Western Bug -Kamianka - Buzka is shown in (Fig. 6). Evaporation rates mostly rose in July and August (6 mm), whereas this element of water balance decreased in March (-3mm).

4. WATER COMPONENTS

River water flow is the process of water moving in the course of its circulation in nature by draining the earth's surface, layer of soil and subsoil.

The primary element of the flow is the slope runoff, which is an important element of the water balance. In general, flow is divided into surface and underground, as shown in Figure 4. Also the curves differences (Figure 7) show the average meanings of runoff.

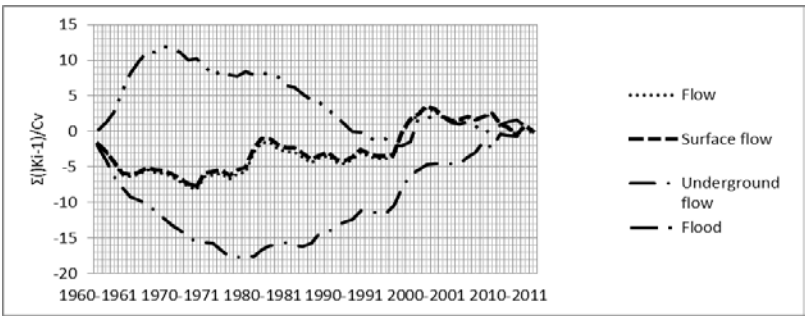


Fig. 7. ***Differential integral curves of Bug River runoff according to the hydrological station of Kamyanka-Buzka***

Analyzing the curves, it may be argued that there is a similar trend to changes in surface and underground water flow for a long-term period (1961-2014). Since 1979 the trend evident of redistribution and increase of underground runoff has been admitted. The highs of spring floods for the current period have been decreased compared to the period of climatic norm. Monthly distribution of runoff layer for the period of climatic norm for the current period is shown in Figure 8.

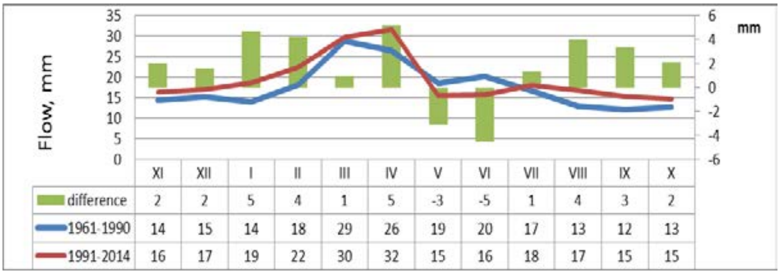


Fig. 8. ***Monthly distribution of runoff layer in the basin of the Western Bug River at – Kamianka Buzka***

Having analysed the figures, river flow increased compared to the climatic norm period (1961-1990) most of all - in April, January, February and August (4.0 mm).

5. WATER BALANCE

In the basin of the Western Bug River (Kamianka Buzka) in the modern period, rising of average annual temperature from 7.5^{o}C to 8.3^{o}C is fixed, that is 0.8^{o}C more in comparison with the period of climatic norm. It is a local manifestation of the global climate changes. The violation of homogeneity in the rows of the average annual air temperature according to Student's and Willcoxon's tests (Table 1), the configuration of the difference integral curve (Fig. 2) and the growth of the total value of violation (μ) of water balance (Table 2) by almost 40% in the modern period are additional confirmations of the global climate changes.

Table 2. ***The distribution of components of the water balance for a long-term period, the period of climatic norm and the modern period***

Elements of water balance	Long-term period 1961-2014	Period of climatic norm 1961-1990	Modern period 1991-2014	Difference
X, mm	725	714	740	26
$Y_{surf.}$, mm	136	134	133	-1
$Y_{uf.}$, mm	83	79	102	23
$Y_{dr.}$, mm	220	213	235	22
Z, mm	529	520	532	12
μ	-23	-18	-26	-8

Where: X - precipitation, Y_{uf} - underground flow, Y_{surf} - surface flow, Y_{dr} - depth of runoff, Z - total evaporation

Practically all components of the water balance reacted on the temperature growth (Table 2).

Since the Western Bug River basin is located in the zone of excessive moisture, there was an increase in both profitable and expenditure parts. But unlike the profitable part of water balance (precipitation), which grew up on the 26 mm, the expenditure part (runoff and evaporation) grew up on the 34 mm. A value of constant underground runoff had the greatest respondence among the components of the expenditure part of the water balance. It has grown by 23 mm, which is about 30% of the value of underground drainage during the climatic norm. The reason for this increase in underground drainage on the one hand may be an increase in air temperature during the winter baseflow (Fig. 4). On the other hand, the growth of the underground flow during the summer-autumn baseflow may be due to the increase of rainfall average of 6 mm in July and August (Fig. 5).

Consequently, the increase of temperature and flow in winter led to lowering of total layer water flow during the spring flood on 5 mm or 8%. The annual rainfall distribution (Fig. 5) also has a clear tendency to growth, with the exception of June and December. Instead, the annual distribution of the value of total evaporation is characterized by two mutually compensating fields (Fig. 6). Its sharp increase (on 23 mm) from July to December is partially offset by decrease (on 11 mm) in the remaining months. Peaks of magnitude evapotranspiration (Fig. 6) are caused by peaks of average monthly temperature growing (Fig. 4).

6. CONCLUSIONS

Water balance is the result of the complex study of water regime in a particular water body or territory using water-balance method, which contains quantitative characteristics of the individual components of this regime in their relationships. The growth of air temperatures in the basin of Western Bug River (the town of Kamianka Buzka) on $0{,}8^0$C in comparison with the period of climatic norm has led to an increase in both profitable and expenditure parts. However, the expenditure part is more sharply increased. This led to an increase of the water balance value violation, which indicates the existence of homogeneity violations in the river flow formation.

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