Feb. 2015. Vol. 2. No.9 ISSN 2311-2484
International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html

# IMPACT OF CLIMATE CHANGE ON WATER RESOURCES OF THE NORTH-WESTERN BLACK SEA REGION

**NATALIIA LOBODA, YULIIA BOZHOK**

Department of Hydroecology and Water Research, Odessa State Environmental University, Ukraine
E-mail: gideko@ogmi.farlep.odessa.ua , julia_bojok@mail.ru

## ABSTRACT

*Changes in climatic factors and runoff characteristics of river in North-Western Black Sea Region on the basis of hydrometeorological supervision are established. There is an increase of air temperatures and minor alteration of precipitation. This is the reason of reduction of an annual and maximum flow, increase of duration summer-autumnal low water, reduction of the winter low water, change of dates of the ice phenomena appearance.*

*Characteristics of aridity (index SPEI) and characteristics of flow during the summer-autumn low water period on the example Savranka River are determined. Using multiple linear regression model with stepwise selection of predictors links between established of low flow and drought are established.*

**Keywords:** ***climate change, water resources, index of aridity SPEI, low water period.***

## 1. INTRODUCTION

Changes in the global climate began to have a significant influence on the climatic factors of the flow and water resources of Ukraine in the late 80-ies of XX century. Analysis of the calculations of Ukrainian water resources using global warming scenarios (A1B, A2, B1) for the XXI century has shown that the negative consequences for Ukraine's economy may be in the south of Ukraine, and especially in the North-Western Black Sea Region [2].

North-Western Black Sea Region is located in the steppe zone of Ukraine [12]. The main element of relief is the Black Sea lowland. It consists of young marine sediments and has a flat surface with a small angle towards the Black Sea.

There are four deltas of large rivers on researched area: Danube, Dniester, Southern Bug, Dnieper. In interfluves of Danube-Dniester and Dnister-Southern Bug there are a lot of small and medium-sized rivers. They are originating in the uplands of forest-steppe zone and fall into the Black sea or estuaries. Such estuaries as Khadzhibey, Kuialnyk, Tyligul are located near the million citizen city Odessa. Socio-economic importances of their natural potential and ecological conditions are high. These closed type firths were formed as a result of the attack by sea to the river mouths. Names of estuaries have Turkish origin and often correspond to the names of the rivers that feed them. For example, Great Kuialnyk River falls into Kuialnyk estuary and Tyligul River inflow into Tyligul estuary.

As a result of the formation of sandy spits separation of estuaries from the sea was occurred gradually. Estuary's basins are located at 15-20 m below sea level. They are filled with many layers of silt deposits. Valley estuaries elongated in the meridional direction over long distances of 100-300 km. Their shape is winding because they were arisen in the former river channels. Natural resources of estuaries are used in recreation, ecological tourism, aquaculture and fishing. Activity of ecosystems of these estuaries is completely dependent on hydrological conditions. The main positive elements of the water balance of the estuary's watersheds are precipitation and water inflow from the rivers. Negative component is lost through evaporation from the land and water surface. Climate change can significantly affect on the water and salt balance of estuaries, and consequently their hydroecological state [1].

In the direction of river heads precipitation $X$ are decrease, the air temperature and the maximum possible evaporation $E_m$ are increase.

According to hydrological zoning, the upper and middle parts of the estuary's catchments are located in the insufficient water availability zone, southern part is in the extra insufficient water availability zone.

Feb. 2015. Vol. 2. No.9 ISSN 2311-2484
International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html

Indicator of aridity is the ratio of long-term average value of precipitation $\overline{X}$ and maximum possible evaporation $\overline{E}_m$ [10]

$$\beta_X = \frac{\overline{X}}{\overline{E}_m}. \qquad (1)$$

Providing $\beta_X \geq 1{,}0$ the proposed territory belongs to the zone of excessive moisture; when $0{,}8 \leq \beta_X < 1{,}0$ - to the zone of sufficient moisture; when $0{,}5 \leq \beta_X < 0{,}8$ - to the zone of low moisture. In the case when $\beta_X < 1{,}0$ there is a transition to semiarid zone. Periodically on this territory droughts are occurring. Climate of the zone is pertain to the moderate latitude deserts.

## 2. LITERATURE REVIEW

Series of hydrological observations are short and river flow is transformed by water management [7]. The effect of water management is intensify under global warming [3]. Statistical parameters of observed runoff series are calculated with large errors that exceed acceptable values. Isolines on maps of observed runoff characteristics carried by a dotted line. Scientists in Odessa State Environmental University have developed a method of calculating the characteristics of runoff using meteorological data (model "climate-flow") [6]. Spatio-temporal generalization of flow characteristics calculated by this model (named climatic flow), were included in the standard specifications of the country.. Changes in climatic factors of flow formation cause change of water resources. So its research and possible consequences are important for Ukraine, especially in seasons of low water content [8].

Model "climate-flow" allows calculating flow characteristics using scenarios of global warming. Assessment of possible changes in water resources is given as deviation (%) of the annual climatic flow, calculated according to the data from scenario A1B, between the forecast and actual period. The zero isoline on the map shows the boundary between the region of "increase" and "decrease" of water resources.

The figure 1 shows that in the middle of the XXI century the decrease of water resources practically in all territory territory is expected. In southern Ukraine, it can reach 60-70%, which means full destruction. In the north of the country and in the Carpathians increasing of the annual flow from 10% to 50% is possible [9].

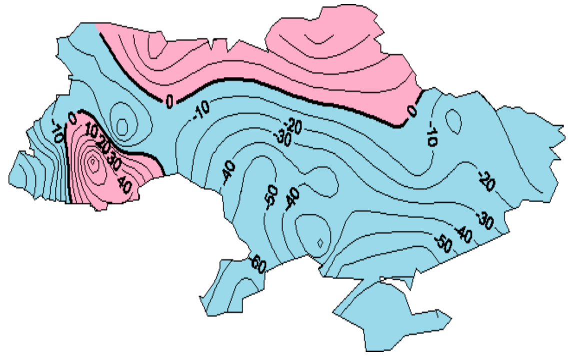

Figure 1 - Spatial distribution of relative deviation (%) of annual climatic flow for the period 2031-2050 comparing to 1989 (scenario A1B)

Meteorological drought causes changes in low water flow. As a quantitative indicator of drought standardized precipitation evapotranspiration index (SPEI) [11] can be used. The SPEI is based on precipitation and temperature data, and it has the advantage of combining multiscalar character with the capacity to include the effects of temperature variability on drought assessment. The procedure to calculate the index is detailed and involves a climatic water balance, the accumulation of deficit/surplus at different time scales, and adjustment to a log-logistic probability distribution. Mathematically, the SPEI is similar to the standardized precipitation index (SPI), but it includes the role of temperature. Under global warming conditions SPEI can identify an increase in drought severity associated with higher water demand as a result of evapotranspiration. SPEI has the advantage of being multiscalar, which is crucial for drought analysis and monitoring.

## 3. MAIN RESULTS

For the assessment of climatic characteristic changes observational data on meteorological stations Odessa (1900-2013), Lyubashevka (1961-2011), Rozdelnaya (1946-2010), Bashtanka (1936-2012) were used (figure 2).

The number of active meteorological stations greater than hydrological stations. Underground nutrition of rivers in the North-Western Black Sea Region is insignificant, as aquifers are located very deep. Many small and medium-sized rivers dries up during the summer-autumn low watet period. Withdrawal of water for household needs can reduce water resources. The main factor of water management is artificial reservoirs.

Feb. 2015. Vol. 2. No.9 ISSN 2311-2484
International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html


Figure 2 - Geographical location of North-Western Black Sea Region

Growth tendency of average annual air temperature was established (Figure 3). 1989 is a turning point for meteorological characteristics of the researched territory. Since 1989 number of cases where the temperature exceeded the standard deviation $\sigma_T$ are increasing. The nature of the changes in air temperature of cold (from November to March) and warm (April to October) periods are the same.

In fluctuations of annual precipitation and precipitation of warm period statistically significant trends were not found (Figure 4). According to the weather station Odessa upward trend in precipitation of cold period was noticed.

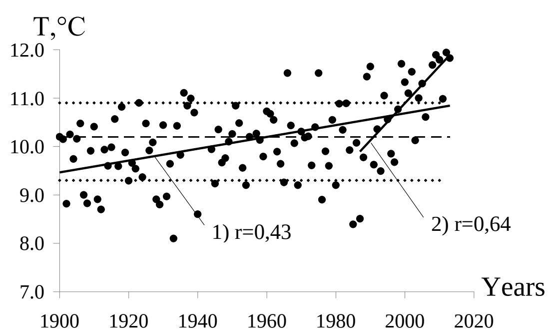


Figure 3 - Time series of the annual air temperature, Odessa (-- -- average long-term value, —— trend line, ⋯⋯ standard deviation, r - correlation coefficient), (1 - 1900-2013, 2 - 1989-2013)

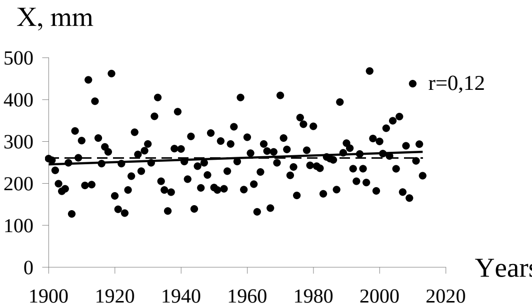


Figure 4 - Time series precipitation of warm period, Odessa, 1900-2013
(- - - average long-term value, —— trend line)

Rising air temperature on the background of constant precipitation cause enhance in aridity. In the last decades indicator of aridity $\beta_X$ became less than 0,5. This means transition of examining area to semiarid zone.

Increasing of air temperature of warm period accompanied by rising water temperature (Figure 5). Terms of rivers freezing shifted to later dates and opening of rivers - to earlier. For example, since 1989 in the synoptic season "autumn-winter" appearance of floating ice on the rivers is observed on 11 days later, and release of ice is occurred on 5 days earlier than before 1989.

There was snow cover on the watersheds of estuaries less than in 50% of cases in the last century. In recent decades, spring floods are formed not every year. Rising temperature in the cold season cause positive air temperature during the winter months, shallow freezing of underlying surface and increase of the number and duration of thaws. These circumstances contribute to the formation of surface melting runoff losses for infiltration into the soil. Maximum discharges of spring flood are decreased (Figure 6).

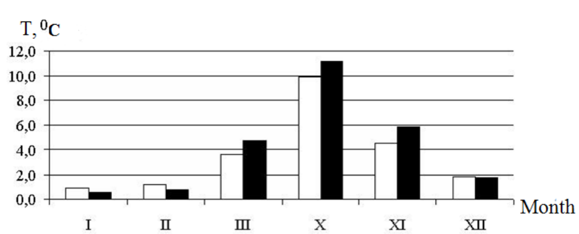


Figure 5 - Distribution of ten-day water temperature within the year, Tyligul River (Left columns - 1960-1988, right columns - 1989-2008)

Feb. 2015. Vol. 2. No.9 ISSN 2311-2484
International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html

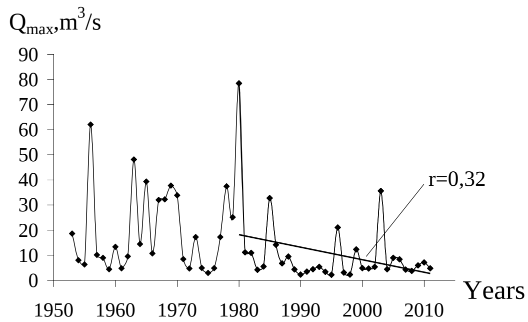


Figure 6 - Maximum discharges of spring flood, Savranka River

Rising of air temperature in the season "summer-autumn" caused a prolongation of periods without precipitation (Table 1) and the total number and duration of droughts (Table 2). Categories or drought index defined by the SPEI [4,11].

In turn, rising air temperature of warm period cause a growth of evaporation from the land surface and the water surface of artificial reservoirs (Figure 7).

Table 1 - The largest duration (days) of periods without precipitation of varying availability

| Meteorological station | Period | Availability (%) | | | | | | The largest duration | Data of the beginning and the end of the period without precipitation of the largest duration |
|---|---|---|---|---|---|---|---|---|---|
| | | 5 | 10 | 25 | 50 | 75 | 90 | | |
| Lyubashevka | Before 1989 | 50 | 47 | 42 | 36 | 26 | 18 | 59 | 15VIII-12X 1983 |
| | After 1989 | 75 | 56 | 47 | 39 | 29 | 25 | 78 | 6IV-22VI 2007 |
| Bashtanka | Before 1989 | 83 | 70 | 57 | 43 | 31 | 27 | 92 | 06.07-05.10 1954 |
| | After 1989 | 91 | 68 | 51 | 45 | 32 | 25 | 96 | 12.10-15.01 1989 |

Table 2 - Duration (in months) of various categories of droughts using index SPEI

| Meteo-rological station | Period | Total number of months in the period | Total number of months with droughts | Categories of droughts | | | |
|---|---|---|---|---|---|---|---|
| | | | | Low | Temperate (moderately dry) | Intensive (severely dry) | Extremal (extremely dry) |
| Lyubashevka | 1962-2011 | 600 | 300 | 195 | 67 | 24 | 14 |
| | Before 1989 | 324 | 130 | 86 | 21 | 20 | 3 |
| | After 1989 | 276 | 170 | 109 | 46 | 4 | 11 |
| Bashtanka | 1936-2012 | 912 | 468 | 302 | 111 | 44 | 11 |
| | Before 1989 | 624 | 324 | 220 | 66 | 33 | 5 |
| | After 1989 | 288 | 144 | 82 | 45 | 11 | 6 |

Artificial reservoirs regulate the flow within the year. They act as evaporators, when its total area of water surface more then 0.3% of the catchment area of the river. Because of the decline or lack of river flow during spring flood 80 percent of the ponds are dry up. Necessity to fill it almost every year with losses for additional evaporation from water surfaces significantly reduces the surface flow from the rivers to the estuaries. Lessening of the positive components of the water balance of estuaries contributes to its gradual shallowing and increasing salinity, which began to grow intensively (Figure 8).

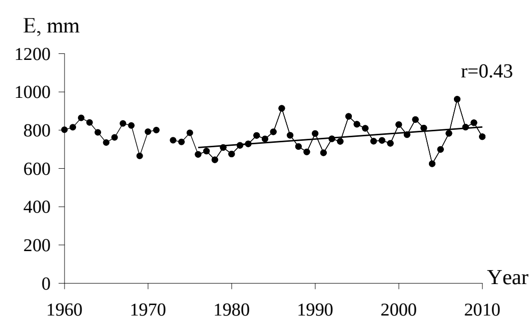


**Figure 7 - Time series of evaporation from the water surface (Bolgrad), 1960-2010**

Feb. 2015. Vol. 2. No.9 ISSN 2311-2484
International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html

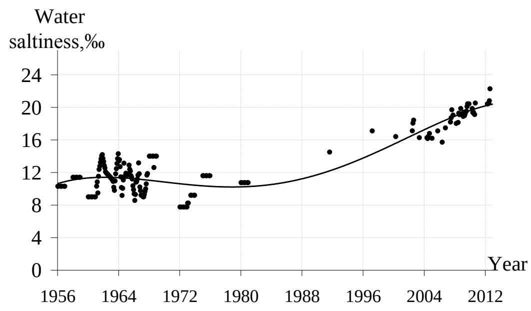


**Figure 8 – Changes of water saltiness in Tyligul Estuary, 1956-2012**

Changes in the hydrological regime of rivers and estuaries as a result of increase in aridity necessitate new approaches to the calculation and prediction of runoff. Growth of duration of periods without precipitation and formation of meteorological droughts cause hydrological droughts. They accompanied by a decrease in surface and underground flow and the inability to fill a large number of artificial reservoirs. Drought affects on characteristics of minimum summer low flow, because under the long-term lack of precipitation the river flow is formed only owing to water from groundwater aquifers. In turn, groundwater supplies in the period of meteorological drought are also depleted. This leads to its drying.

As quantitative index of meteorological drought SPEI was chosen. As a quantitative indicator of water content monthly discharges of the low flow period ware elected. The beginning of the summer-autumn low water on the Savranka River is May, the end is October-November. Summer-autumn low water period goes into winter. The beginning of the winter season refers to December, the end is relate to February. For studying the impact of drought on the hydrological regime of rivers of North-Western Black Sea Region runoff observations on Savranka River (observation period 1953-2011) were used. Savranka River have a very little impact of water management and have sustainable underground supply. For folding calculation and forecasting techniques this river was chosen.

The main research method is the method of multiple linear regressions with a stepwise selection of the optimal predictors [5]. As predictors the average monthly discharges of summer-autumn low water period, the minimum daily discharges for each month of low water, duration of period when actual discharges were lower than the discharges of 75 percent availability, precipitation, air temperature, aridity index SPEI, index of the North Atlantic oscillation (NAO), the number of days in the month with a temperature higher 15ºS were assigned. Predictors in regression model were taken with different time shift (from 1 to 2 months).

The main factor that affects on the average monthly flow during low water is characteristic of water content (discharge) of previous month. In reviewing the data before 1989 drought (index SPEI) as statistically significant predictor was not found. According to the post-1989 index SPEI was detected as the second important predictor in determining the average monthly flow during low water and minimum daily flow for each month.

A general view of the developed regression equations are:

$$Q_{m,i} = a_0 + a_1 Q_{m,i-1} + a_2 SPEI_{i-1} \qquad (2)$$

$$Q_{\min d,i} = b_0 + b_1 Q_{\min d,i-1} + b_2 SPEI_{i-1}; \qquad (3)$$

where $Q_m$ - the average monthly water discharge, m$^3$/s; $Q_{\min,d}$ - the minimum daily water discharge, m$^3$/s; SPEI - index of aridity; $i$ - the number of a calendar month.

Multiple regression coefficients are varied in the range from 0.46 to 0.89.

Index SPEI characterizes the aridity of the climate. During the summer-autumn low water period it can take negative values. Therefore, the increase of SPEI in absolute value causes reduction of low-flow characteristics.

In presented equations data of previous months were used. This can give an opportunity to forecast hydrological characteristics of the minimum flow using data on water content and SPEI of last months.

Such structure of the regression model can be used for prediction of the minimum flow characteristics. For example, in order to determine the minimum daily flow of June such regression equation was derived

$$Q_{\min,d_{VI}} = 0{,}274 + 0{,}759 Q_{\min,d_V} + 0{,}162 SPEI_V,$$
$$R=0{,}80 \qquad (4)$$

where $Q_{\min,d_{VI}}$ - the minimum daily water discharge in June, m$^3$/s; $Q_{\min,d_V}$ - the minimum daily water discharge in May, m$^3$/s; $SPEI_V$ - index of aridity in May.

Testing predictions of this equation for the period 1982-2011 was made. It was detected that standard deviation of the predicted value σ is 1,66. Acceptable error δ is 1,12.

A measure of the accuracy of prediction methodology is mean square error of test prognosis

International Journal of Research In Earth & Environmental Sciences

http://www.ijsk.org/ijrees.html

$$S = \sqrt{\frac{\sum_{1}^{n}(y - y')^2}{n}}, \qquad (5)$$

where $y$ - the actual value of the quantity; $y'$ - the predictive value of the quantity; $n$ - number of members of the series.

The quality criterion of the methodology is ratio S/σ, which in this case is equal to 0,65. So quality of the forecast is seen as "satisfactory".

## 4. CONCLUSION

Climatic factors of flow formation in the North-Western Black Sea Region change as follows: air temperature is increase with insignificant changes in precipitation. Rising air temperatures causes increase of evaporation both the land surface and the water surface. This fact leads to the increasing of runoff losses for evaporation and corresponding decreasing of water resources. Climate change causes a prolongation of periods without precipitation and meteorological droughts, which significantly affected on the low flow characteristics in the period of summer-autumn low water. It is shown that quantitative indices of aridity can be used in calculations and predictions of minimum flow on the rivers of Northwestern Black Sea.

## REFRENCES:

1. Actual problems of estuaries on North-Western Black Sea Region / Ed. by *Tuchkovenko Y.S., Gopchenko E.D.*. - Odessa, 2011. - 224p. (rus)

2. Assessing of the impact of climate change on sectors of the Ukrainian economy / Ed. by *Stepanenko S.M., Polevoy A.N.* - Odessa: Ecology, 2011. - 605 p. (ukr)

3. *Gopchenko E.D., Loboda N.S.* Evaluation of possible changes in water resources of Ukraine under global warming // Hydrobiological journal. Kiev -– Vol.36, №3. - 2000. - P. 67 - 78.

4. *Hisdal H., Tallaksen L.M.* Drought event definition / Techn. Rep. To the ARIDE Project. - Oslo, 2002. - N 6.

5. *Loboda N.S.* Methods of statistical analysis in hydrological calculations and predictions. - Odessa: Ecology, 2010. - 184 p. (ukr)

6. *Loboda N.S.* The assessment of present and future Ukrainian water resources on meteorological evidence// Climat and Water.-1998.-Vol.1.-P.1486-1494.

7. *Loboda N.S. & Phan Van Chinnh*. Statistical modelling and estimating the irrigation and man-made effect on annual runoff and water resources // GIS and Remote Sensing in Hydrology, Water Resources and Environment. (proceedings of ICGRHWE held Tree Gerges Dam, Chine.) – 2004. – IAHS Publication 289 in the IAHS Series of Proceedings and Reports. – P.215-218.

8. *Loboda N., Glushkov A., Khohlov V.* Using meteorological data for reconsturction of annual runoff series over an ungauged area: Empirical orthogonal function approach to Moldova-Southwest Ukraine region // Atmospheric Research. – 2005. - Vol 77/1-4. – P. 100-113.

9. *Loboda N.S., Serbova Z.F., Bozhok Y.V.* Impact of climate change on water resources of Ukraine in modern and future conditions (under scenario of global warming A1B) / Ukrainian hydrometeorological journal, Odessa, 2014, Vol.15., P.149-159. (ukr)

10. *Rodda J. K.* Facets of hydrology - Leningrad: Gidrometeoizdat, 1987. - Vol.2. – 534 p. (rus)

11. *Sergio M. Vicente-Serrano, Santiago Begueri'A, Juan I. Lo'Pez-Moreno*. A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index // Journal of climate. - 2010. - P. 1698-1718

12. *Sukhodolov A. N., Loboda N.S., Katolikov V.M., Arnaut N.A. and others*. Chapter 13. Western Steppic Rivers // Rivers of Europe. Edited by Klement Tockner, Christopher T. Robinson, Urs Uehlinger, Academic Press is an imprint of Elsevier, 2009. – P.497-524.