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In memory of Georgii Lysychenko

The tendencies of climate change and water regime of the middle-lower part in the basin of Southern Bug River (in the region of location of the South-Ukrainian Nuclear Power Plant)

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Проаналізовано особливості зміни клімату та водності для середньо-нижньої частини басейну р. Південний Буг (у регіоні розташування Южно-Української атомної електростанції (ЮУ АЕС)) в другій половини XX ст. — на початку XXI ст. Унаслідок зміни клімату відбулося підвищення середньорічної температури повітря (на 0,16—0,28 °С на 10 років) та незначне підвищення річної кількості атмосферних опадів (на 1—2 %) у цьому регіоні за період 1945—2017 рр. Проте спостерігаються більш інтенсивне потепління та негативна тенденція до зниження річної кількості опадів (на 3—10 %, влітку на 20—30 %) за останні декілька десятиліть на метеостанціях Первомайськ та Вознесенськ. Такі регіональні зміни клімату можуть, певною мірою, призвести до зменшення водності у водоймах через аномальне підвищення температури та зменшення кількості атмосферних опадів влітку (липень—серпень) та збільшення випаровування в басейні р. Південний Буг. Незначне річне збільшення кількості опадів (і в холодний період року) у цій частині басейну не компенсує таку негативну тенденцію. Досить складна та небезпечна гідрологічна ситуація в басейні р. Південний Буг склалася на період 2015—2017 рр. унаслідок низького рівня води у водосховищах за весь період експлуатації, що пов'язано із складними погодними умовами (аридизацією кліматичних умов) та збільшенням споживання води (водність р. Південний Буг у серпні—вересні була на 12—15 % менша від місячної норми). У дельті р. Південний Буг також несприятлива ситуація, так, у Бузькому лимані відбуваються: підвищення солоності води, зменшення глибин, підвищення температури води, зменшення обсягів прісної води з річки та посилений приплив солоних вод з Чорного моря. Регіональні зміни клімату та водності можуть призвести до певних ускладнень у подальшій ефективній експлуатації ЮУ АЕС, а підняття рівня водосховищ може супроводжуватися негативним впливом на навколишнє середовище. Тому важливо знайти розумний компроміс між економічною доцільністю та збереженням навколишнього середовища.

Ключові слова: зміна клімату, приземна температура повітря, атмосферні опади, водність, водні ресурси, р. Південний Буг.

Introduction. The generation of energy at the South-Ukrainian Nuclear Power Plant (SUNPP) requires significant amounts of water for cooling systems taken from the South Bug. It is particularly noticeable in recent decades, that the operation of the SUNPP has a shortage of water resources, which somewhat limits its effective operation. Reducing water content in the basin of the Southern Bug River is due both to climate change in the region and through intensive water management activities [Aliyev et al., 2006; Khilchevsky, 2009; Afanasyev et al., 2012, 2014; Lysychenko, 2017].

The Southern Bug River is the most regulated among the largest rivers in Ukraine and the use of the river has exceeded the permissible standards. The total volume of artificial reservoirs in its basin is about 1.5 km^3, which is already 1.5 times more than the volume of the Bug River flow during its small flow. In accordance with the Water Code [Aliyev et al., 2006], in such circumstances the volume of the reservoir must be reduced to improve river flow.

The energy production at the South-Ukrainian NPP requires significant amounts of water for cooling systems from the Southern Bug River. Due to climatic changes in this region (the increase of the average annual air temperature and the decrease of the amount of precipitation, especially in the upper and middle part of the river) and intensive use of water resources and unsuccessful management, the exploitations of the SUNPP (that is connected with cooling) became more complicated.

In order to ensure the operations of Tashlytska Storage Plant (Tashlytska SP) and the SUNPP, it is planned to increase the level of the Oleksandrivske Reservoir from +16.9 to +20 m. With this aim, a catchment from the river is expected and an additional $51.65 \cdot 10^6$ m^3 of surface water in the reservoir will be accumulated, which will be accompanied by an increase in water losses from Oleksandrivske reservoir at $1.5 \cdot 10^6$ m^3 per year [Environmental ..., 2016].

Activity of the SUNPP in the modern limits already has a negative impact on the environment, but the concerns of ecologists are exacerbated by an increase in the level of reservoirs to mark +20 m, which will increase the load on natural ecosystems and the society, and will violate the number of international and national legal acts [Environmental ..., 2016].

The territory of the Bug Guard is the central element of the Bug-steppe biosphere center and the site of the largest concentration of biotic diversity, natural and historical landscapes, and archaeological sites [Afanasyev et al., 2012, 2014].

Therefore, it is important to find a reasonable compromise between economic feasibility and preservation of the environment.

Analysis of the last researches and publication. About impacts on the environment from the South-Ukrainian Nuclear Power Plant. The SUNPP is located in the southern part of the Dnipro Upland, on the left bank of the middle reaches of the Southern Bug River. The purpose of the SUNPP is the generation of electricity for the supply of consumers in the southern regions of Ukraine (with a population more than 5 million people) in Mykolaiv, Odesa, Kherson regions. The SUNPP provides more than 10 % of the total electricity production in Ukraine.

Due the Oleksandrivske and Tashlytske Reservoirs filling there was: seizure of lands of various purposes (natural and economic lands), the transformation of landscapes, the formation of specific microclimate, changes in surface runoff conditions; violation of the conditions for the existence of natural biodiversity and the forced migration of wild fauna.

As a result of the exploitations of the SUNPP for environment the following main influences are encountered:

Radiation influence. During operation of the SUNPP in the normal mode localization of radioactive products in the reactor plant is provided by special water and gas purification systems.

In the monitoring zone of the SUNPP air pollution by radioactive substances due mainly to the presence of artificial radionuclide ^{137}Cs and radionuclides ^{137}Cs, ^{60}Co, ^{58}Co, ^{54}Mn, ^{95}Zr, ^{134}Cs are registered in 75 ± 25 % of selected samples [Environmental ..., 2016; Lysychenko, 2017]. Episodically present in air radionuclides ^{51}Cr, ^{90}Sr, ^{131}I, ^{110m}Ag, ^{95}Nb, ^{103}Ru, mainly in period of planned production repairs.

In unusual situation it is probable contamination of environment by products from separation of radioisotopes, radioactive substances, in the form of products of neutron activation in the circumstances of corrosion of structural materials (tritium (^3H)), gaseous radioactive particles, including evaporation of tritium water and inert gases, aerosols, gaseous particles, etc.).

Also as potential sources of radioactive contamination of the Tashlyk Reservoir can be discharges through the drainage and sewage system from the control tanks of drainage water purification systems, and waters from specialized laundries.

In the zone of the SUNPP influence, state of radioactive contamination of the water catchment area is estimated as "satisfactorily" (radiation levels of cesium-137, strontium-90 and plutonium-239 within acceptable levels) [Environmental ..., 2016; Lysychenko, 2017].

Chemical influence. Sources of chemical impact on the environment are periodic non-radioactive emissions and discharges that occur in the facilities of the SUNPP and contain chemical elements and substaces, allowable content of which are regulated by sanitary norms and regulations.

In the atmosphere released gas-aerosol non-radioactive emissions from auxiliary structures and industrial premises: about 30 % consists of sulfur dioxide, 20 % — from solid particles (soot, dust), 20 % are non-methane volatile organic compounds, and rest are nitrogen dioxide, oxide and carbon dioxide, hydrocarbons, metal compounds, hydrogen sulfide, ammonia, chlorine, etc. [Environmental ..., 2016; Lysychenko, 2017].

Stationary and mobile sources in the territory of the SUNPP emits into atmosphere approximately 6 tons of pollutants per year [Environmental ..., 2016; Lysychenko, 2017].

Thermal influence. The most influential on the environment is thermal factor of the SUNPP. About 65—70 % of the heat generated in the reactors through cooling systems of the water reservoirs and discharged in the atmosphere are dumped. In comparison with the air temperature, the water temperature in the cooling water reservoir is increased and this leads to intense evaporation from the water surface, which increases the frequency of the evaporation fogs formation.

The evaporation of water during cooling is about $(40—45)\cdot10^6$ m^3 per year. According to the data presented in [Environmental ..., 2016; Lysychenko, 2017], the thermal flux into the atmosphere is equal to: during the operation of one power unit is $(1.7—2.6)\cdot10^9$ W, and from three power units are $(3.4—5.3)\cdot10^9$ W.

The problem statement. The purpose of this work is to analyze the peculiarities of regional climate change and of runoff from the middle-lower part of the basin of the Southern Bug River (the climatic landscape zone of the Northwest Greater Black Sea area) in the second half of the XX century and at the beginning of the XXI century in the region of the SUNPP location.

Materials and methods of research. The main results of work are obtained based on empirical data were processed according to known standard methods of statistical analysis of meteorological information by and by analytical review of published materials. In this study, empirical data were used from the meteorological stations Pervomaisk (1945—2017), Voznesensk (1945—2015) and Yuzhnoukrayinsk (2005—2017) (average annual and average monthly of surface temperature of air and atmospheric precipitation). Meteorological data of "The Ukrainian Cadaster of Climate" were also used for the period 1961—1990 (norms of the main parameters, including data about wind speed, relative humidity, evaporation and repeatability of fogs etc.) [The Climate ..., 2005].

The semi-empirical models, that by based on representation of time dependency of the mentioned climatic characteristics in form of three items (annual component and two harmonic components) and approximation of the dependency from geographical coordinates and the empirical constants (as a result of statistical analysis of data) were used here [Voloshchuk, Boychenko, 2003; Boychenko, 2008].

For the estimation of runoff of the middle-lower part of the basin of the Southern Bug River the data are used from the average annual and average monthly water consumption at the water posts of Pervomaisk and Oleksandrivka for the period of 1914—2016. During the research of runoff, characteristics within the Southern Bug River monitoring territory the observations data were used from the Hydrometeorological Service (data carried out by its departments from 1914). The length of the series consisting of the average monthly water consumption for each of the 12 months, the average annual, maximum and minimum daily and annual water use is more than 90 years old. During data processing the methods were used that are commonly used in hydrometry and hydrology [Rozhdestvensky, Chebotarev, 1974; Horoshkov, 1979; Galushchenko, 1987].

The cycles of fluctuations of annual water runoff of rivers are presented by indexes of integral curve, which have been calculated using the formula: $\sum(K_i-1)\ /$, where K_i — modular coefficient of runoff for each year: ratio of current year index (Q_i to its annual mean value Q_0, $K_i = Q_i / Q_0$, n — quantity of monitoring years. C_v — coefficient of variation of average annual water runoff for i-th year, n — quantity of monitoring years, calculated according to the formula: $C_v = \sqrt{\dfrac{\sum_i^n (K_i-1)^2}{n-1}}$ [Horoshkov, 1979]. Modular coefficient characterizes the dryness of the year. Thus years with modular coefficient more than 1.0 — water-rich, and less than 1.0 — water-poor.

In the research the materials "Environmental Impact Assessment (EIA): Increasing the level of the Oleksandrivske reservoir to the project mark of +20.7 m" were used [Environmental ..., 2016].

The results of the research. Climatic conditions of the landscape zone of the Northwest Greater Black Sea area (the middle-lower part of the basin of the Southern Bug River). The climatic conditions of the landscape zone of the Northwest Greater Black Sea area (the middle-lower part of the basin of the Southern Bug River). The climatic conditions in the region of the location of the SUNPP are moderately continental, with insufficient humidification regime, which is characteristic of the steppe zone (hot summer with the frequent occurrence of arid phenomena, warm and dry winters with precipitation in the form of snow, wet snow and rain) [Marynych, 1989; Lipinskyy et al., 2003].

The average annual air temperature in this part of the basin of the Southern Bug River ranges from 8 to 10 °C. The meteorological norms of temperature for the period 1961—1990 for the meteostations located in this region Pervomaysk and Voznesensk are 8.8 ± 0.9 and 9.6 ± 1.0 °C, and the annual amount of precipitation are 553 ± ± 113 and 517 ± 109 mm accordingly (in separate years the minimum amount of precipitation is ~285 mm, and the maximum is ~800 mm per year) [The Climate ..., 2005].

The seasonal course of surface temperature of air has a characteristic maximum in July 19—22 °C and a minimum in January at an average of –2 ÷ –7 °C, and in other seasonal periods, the average temperature is –1 ÷ 17 °C in spring and –3 ÷ 16 °C in autumn [The Climate ..., 2005].

The maximum atmospheric precipitation in the warm period of the year is 330—350 mm, and in the cold period of the year is 185—200 mm. However, there is a complete absence of precipitation (for example, in August 1961 at station Pervomaysk and in August 1958 at station Voznesensk) or excess of meteorological norm in 3—4 times (for example, in August 1947 at station Pervomaysk (236 mm/month) and in August 1948 at station Voznesensk (239 mm/month)) can be observed [The Climate ..., 2005].

Winter in this region is relatively warm (average temperature is –3.1 ÷ –2.1 °C) and with precipitation (most often during the last years) in the form of wet snow and rain in the past few decades but long-time average the height of the snow cover is ~5—11 cm with an average duration of 40—65 days, and the depth of freezing of the soil to 30 ± ± 15 cm [The Climate ..., 2005].

The total evaporation in the lower part of the basin of the Southern Bug River is seasonal: in winter, it is about 30—40 mm, in summer up to 200—300 mm, in spring up to 125—160 mm and in autumn up to 80—95 mm [Lipinskyy et al., 2003].

The fogs often appear in the cold period of the year in the lower reaches of the Southern Bug River, the average number of days with fog during the year is about 30—39 days [Lipinskyy et al., 2003; The Climate ..., 2005].

The vegetative period, in the lower part of the Southern Bug River basin lasts an average of 225 ± 4 days [Lipinskyy et al., 2003].

The average annual air humidity in the region is 70—75 %, in the cold period of the year its value reaches 83 ± 3, and in summer — 62 ± 3 % [The Climate ..., 2005]; in this region is 2—3 m/s (in winter up to 3—4 m/s and in summer up to 2 m/s. With strong winds at a speed of ≥15 m/s on average is 30—35 days, and in separate years up to 65 days per year is observed, and the repetition of hurricane winds at a speed of ≥30 m/s is fixed once every 25 years [Lipinskyy et al., 2003].

It should be noted, that the meteorological parameters might vary somewhat depending on the chosen period, due to the presence of quasiperiodic oscillations and under the influence of modern climate change [Lipinskyy et al., 2003].

Analysis of water regime of the middle-lower part of the basin of the Southern Bug River and of the influence from SUNPP. The Southern Bug River is the main waterway in the region (total length is 792 km, area of water catchment is $63.7 \cdot 10^3$ km^2, depth is 1.5—8.0 m, width of channel is 50—200 m, speed of water flow is 0.1—0.3 m/s, volume of average perennial runoff is 2.9 km^3) [Khilchevsky, 2009]. The Southern Bug River basin crosses the forest-steppe and steppe zone of Ukraine (the upper and middle parts are located on the Volyn-Podilskyii and Dnipro Highlands, and the lower one — in the Black Sea Lowland).

For water regime of Southern Bug River some uneven distribution of drainage by the territory of the basin, and during the year (prevailing snow and rain nutrition, and underground runoff) is typical.

The annual runoff of the Southern Bug River is formed in the upper reaches of the forest-steppe part of the basin (56 %), and the flow of steppe part of the basin (mainly in the lower part of the basin) is only 17.5 % from annual flow of the whole river. In spring, observed peak of flood on the river, and the rest of the year is a stable low flow with a slight increasing of water content in autumn and in separate winter thaws.

According to the analysis of hydrological data from 1914 to 2016, the longest series of runoff in the Southern Bug River is urban settlement Oleksandrivka, despite the significant overregulation (about 200 reservoirs and 6.9 thousand ponds with a total volume of 1.5 km^3), and widespread use of water resources for general needs, the average annual water discharge of the Southern Bug River in the mouth of the river during the period from 1914 to 1950 amounted to 87.0 m^3/s. After the creation of most reservoirs and ponds (1951—1980), it increased up to 93 m^3/s. And after the construction of the cooling water reservoir of the South-Ukrainian Nuclear Power Plant and the filling of the Oleksandrivske Reservoir to the project mark +14.7 m (1981—2006) it did not significantly change and is equal to approximately 91 ± 30 m^3/s (Fig. 1) [Romas et al., 2006; Khilchevsky, 2009; Lysychenko, 2017].

For Oleksandrivka received decrease of the annual runoff at –20 m^3/s per 100 years over the period in 1914—2016 years or for Pervomaisk change was negligible for period 1945—2016, but traced periods were with significant variations in water content (30—200 m^3/s). From the 70-s of the last century and until now, the period of reduction of water content is continuing [Environmental ..., 2016; Lysychenko, 2017].

Comparing the difference between the integral curves of the average annual air temperature (Fig. 2, *a*), annual precipitation (Fig. 2, *b*) and runoff (Fig. 2, *c*), it is possible to conclude that fluctuations of annu-

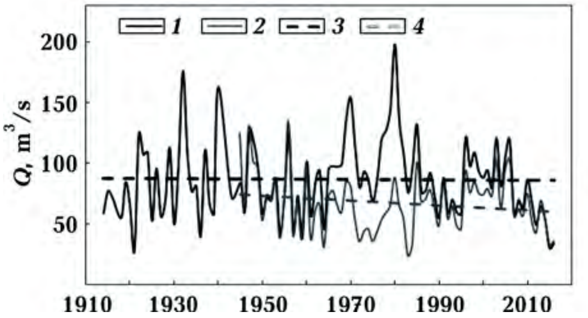

Fig. 1. Long-term changes in the runoff of the Southern Bug River and its trend lines on the water post of Pervomaisk (*1*) city and urban settlement Oleksandrivka (*2*) (*3*, *4* — linear trend, in accordance) for the period 1914—2017.

al runoff are determined, first of all, by the long-term dynamics of precipitation. The negative phase of fluctuations of annual precipitation is accompanied by shallowness of water, and moist (positive) by abundance of water.

The transition of annual precipitation into the positive phase (1968) caused an appropriate transition of runoff to the water-abundant phase in 1970.

It should be noted that during the last decade there has been a significant decrease in the average annual water consumption of the Southern Bug River within monitoring territory (by 20 % in Pervomaisk water post, and by 30 % in Oleksandrivka water post), the main factor of which is the negative phase of annual fluctuations of precipitation, which is accompanied by a shallowness cycle, which began in 2007 (see Fig. 2, *c*).

In Fig. 3 it is shown that at the beginning of the next hydrological cycle in 1981, it is expedient to divide the monitoring period into two periods: the first period from the beginning of the monitoring to 1980 and the second period from 1981 to 2016. For these periods, an intra-annual flow distribution was determined, which are presented graphically in Fig. 2, *c*.

As can be seen from Fig. 3 the intra-annual distribution of runoff in the zone of impact of the South-Ukrainian Energy Complex is characterized by certain uniformity during the year. Some increase of water discharge in the beginning of autumn (August—September) is explained by large discharges of water from the reservoir under the most unfavorable conditions for the formation of the runoff of the Southern Bug River in late summer—early autumn.

In general, on the water discharge formation from Southern Bug River — the urban settlement Oleksandrivka has a certain impact by Tashlyk Reservoir of the filling type, which is a water cooling reservoir for the South-Ukrainian Nuclear Power Plant, and by Oleksandrivske reservoir of the channel type operated by the South-Ukrainian Energy Complex.

Comparing the two mentioned above periods, it is noted a significant equalization

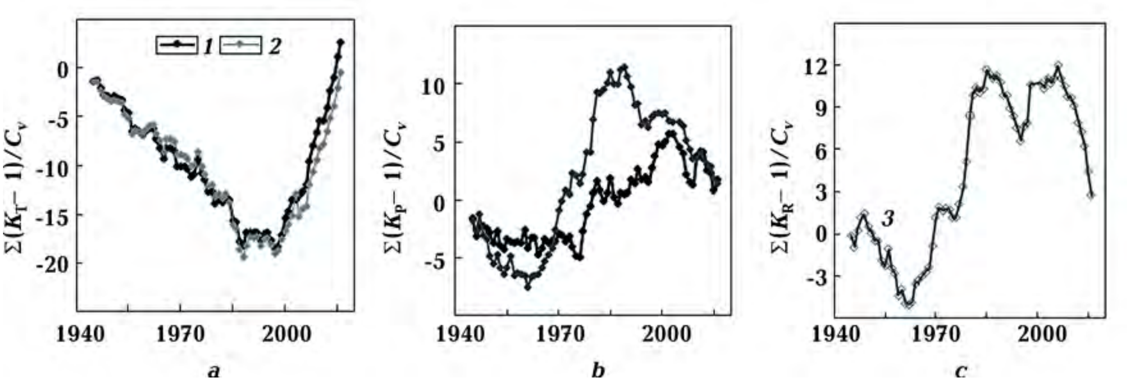

Fig. 2. Residual integral curve of the average annual air temperature (*a*), annual precipitation (*b*) from Pervomaisk (*1*) and Voznesensk (*2*) meteorological stations and runoff (*c*) from Oleksandrivka water post (*3*).

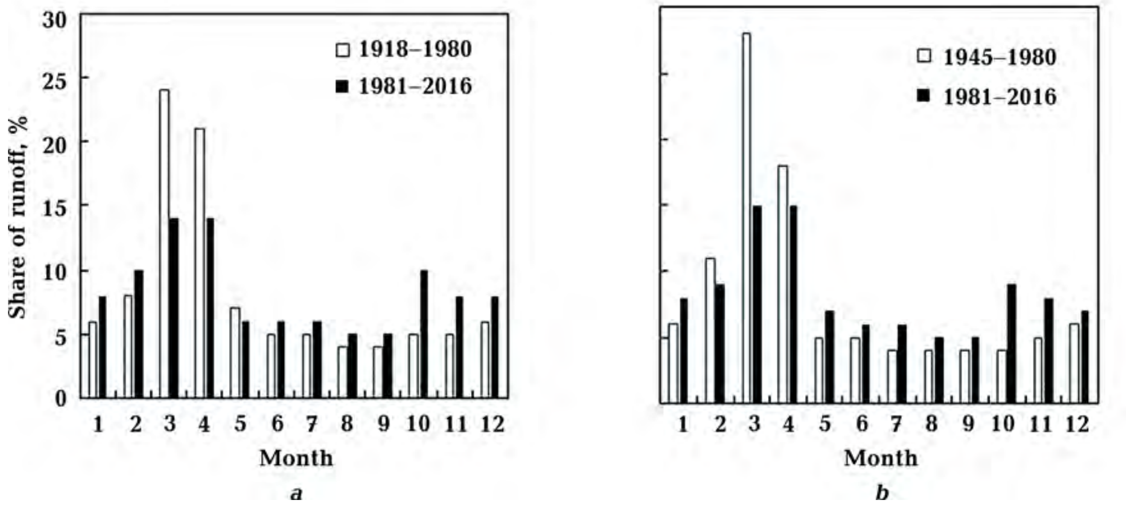

Fig. 3. The average annual distribution of runoff (share in the year expressed in percentage) of Southern Bug River from Pervomaisk (*a*) and Voznesensk (*b*) meteorological stations.

of the flow of the river on the monitoring territory. The runoff significantly decreased in the spring period, on the Pervomaisk water post by average 13.7 %, and on the Oleksandrivka water post by 17.4 %, and increased in summer, autumn and winter periods.

The water intake for reversible water supply of the SUNPP is carried out from the Southern Bug River through the Tashlyk SP cooling pond (in 2010—2014 volume of reversible water supply was $3.38—350 \cdot 10^9$ m^3, and the expenses for household needs are fluctuating significantly, from $0.60 \cdot 10^6$ to $1.43 \cdot 10^6$ m^3) [Lysychenko, 2017]. After elevating of Oleksandrivske reservoir up to 14.7 m, the area of the water basin increased from 770 hectares to 1025 hectares, compared to the area at level 8.0 m, which was 255 hectares [Khilchevsky, 2009; Magas, Trokhymenko, 2013].

In the last decade a tendency was observed to some increased oxygen content in water. In the warm period of year, situation was sometimes observed with an oxygen concentration of ~4 mg/dm^3 (limit of concentration). However, it should be taken into account the ratio between increasing of oxygen content and increasing of average water temperature (this was probably due to the intensification of phytoplankton development) [Khilchevsky, 2009].

According to the data [Lysychenko, 2017], mineralization of water in the urban settlement Oleksandrivka (in the region of the SUNPP location) is: in the spring flood — 600 mg/dm^3; summer—autumn low water periods — 674 mg/dm^3; in winter low water periods — 701 mg/dm^3.

During last decade, pH level of surface water of the Southern Bug River basin fluctuated within the range of 7.71—7.94. Fixed increase of pH for the city of Pervomaisk, which correlates with the decrease of CO_2 content in water and pH increase in the lower part of the river (urban village Oleksandrivka) is explained by the influence of the sedition phenomena [Khilchevsky, 2009].

In the delta of the Southern Bug River, there are the unfavorable situation also. So, in the Bug Liman take place: increase of water salinity, decrease of depths, increase of water temperature, reduce of volume of fresh water flow from river and intensification of water inflow from the Black Sea (through raising sea level at 18—20 cm during the last 100 years), periodic traces of the hydrogen sulfide from the Black Sea in water, high content of nutrients (ammonia and nitrate nitrogen, mineral phosphorus, etc.) [Kostyushin, 2007; Afanasyev et al., 2012; Magas, Trokhymenko, 2013]. All this has led to the degradation of inherent biodiversity in the estuary and cause the increasing the number of marine species.

Features of climate change in the middle-lower part of Southern Bug River. Global warming observed since the end of 19th century is caused not only by natural climate changes on the centuries scale but also by anthropogenic load on the Earth's climate system, expressed, first of all, in the intensification of greenhouse effect. In accordance with [IPCC, 2014], the global temperature for the last ~150 years was on average increased by 0.8 ± 1 °C.

The analysis of data of instrumental observations of a network of meteorological stations of Ukraine for the last 100—130 years showed that its climatic conditions have reacted to global warming as follows: the annual temperature increased by 0.8 ± ± 0.2 °C/100 years and linear trend of temperature for the last 50 years was even almost twice as much (1.3 ± 0.3 °C/100 years, insignificant increase of the annual sums of precipitations (5—7 % for 100 years) [Boychenko et al., 2016b].

In the conditions of the current regional peculiarities of climate change and taking into account long-term prospects, the ecologically unfavorable situation in the basin of the Southern Bug River is even more complicated, in the context of increased anthropogenic load on the environment [Boychenko et al., 2016a].

Analysis of meteorological observations data for the climatic landscape zone of the Northwest Greater Black Sea area (in the location of the SUNPP) in the XX century showed that the following climate changes occurred, namely [Boychenko, 2008; Boychenko et al., 2016b]: an increase in the average annual surface temperature only at 0.4 ± 0.1 °C per 100 years; an increase in the annual amount of precipitation by 5—10 %; aridization of climatic conditions, during the warm period of the year (reduction of atmospheric precipitation, especially in May and August—September); decrease in the amplitude of the seasonal temperature variation: significant warming in winter and spring months up to ~0.4 ± 0.1 °C per 100 years, and in summer months the warming is insignificant.

However, more significant global warming is characteristic in the second half of the XX century and in the beginning of the XXI century [IPCC, 2014]. These manifestations are also characteristic on a regional scale [Voloshchuk, Boychenko, 2003; Boychenko et al., 2016b].

The climate change for the middle-lower part of the basin of the Southern Bug River (in the location of the SUNPP) for the period 1945—2017 will be considered and used data for the meteostations Pervomaysk, Voznesensk and Yuzhnoukraiinsk.

It is shown in Fig. 4 shown, the long-time course of air temperature at the meteorological stations Pervomaisk (for the period from 1945 to 2017) and Voznesensk (for the period from 1945 to 2015): the values of the coefficients of linear trends are, respectively, 0.28 and 0.16 °C per 10 years (at average temperature of 9.2 ± 1.0 and 9.9 ± 0.9 °C, respectively).

It should be noted, that for the last several decades, the rates of warming, both in the whole territory of Ukraine and this region became significantly higher [Boychenko

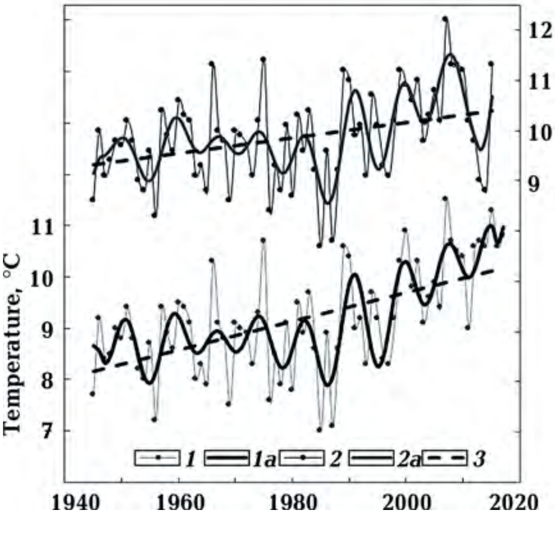

Fig. 4. Long-time changes of average surface temperature of air for the meteostations of Pervomaisk for the period 1945—2017 (*1*, scale on the left) and Voznesensk for the period 1945—2015 (*2*, scale on the right) (*1a*, *2a* — semi-empirical model, *3* — linear trend).

et al., 2016a, 2017a]. So, the values of the coefficients of linear trends at the meteostations Pervomaysk (for period 1971—2017) and Voznesensk (for period 1971—2015) are, respectively, 0.50 and 0.28 °C per 10 years.

The warming of the climate on the planet caused the spatial-temporal redistribution of atmospheric precipitation in Ukraine. Thus, in the XX century in the southwestern, southern and southeastern regions of Ukraine was an increase in the annual amount of precipitation within 10 ± 5 % [Voloshchuk, Boychenko, 2003; Boychenko et al., 2016b].

According to meteorological observations at weather stations Pervomaisk and Voznesensk for the period 1945—2017, the annual amount of atmospheric precipitation are 538 ± 107 and 566 ± 131 mm per year, respectively and the values of the linear trend coefficients are 2.2 and –1.5 mm per 10 years, respectively (Fig. 5). Thus, over the past 70 years in this region as a whole, the annual amount of precipitation has increased on 1—2 %, that is within the limits of statistical error. However, for the last several decades for this region negative the values of the coefficients of linear trends are characteristic at the meteostations Pervomaisk (for the period 1971—2017) and Voznesensk (for the period 1971—2015) they are, respectively, –17.9 and –54.5 mm per 10 years.

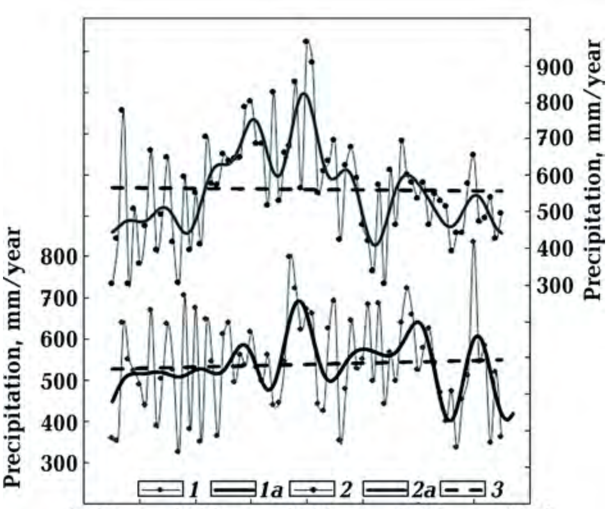

Fig. 5. Long-time changes of the annual sums of atmospheric precipitation for the meteostations of Pervomaisk for the period 1945—2017 (*1*, scale on the left) and Voznesensk for the period 1945—2015 (*2*, scale on the right) (*1a*, *2a* — semi-empirical model, *3* — linear trend).

Such regional climate change can lead, to a certain extent, to the decrease of water content of the reservoirs, due anomaly increasing temperatures and decreasing precipitations in summer (July — August) and increased evaporation in basin of the Southern Bug River. Slight increase annual the amount of precipitations (and in the cold season) in this part of the basin do not compensate such negative tendency (the drain in this part of the basin is only 16—18 % of the annual flow of the entire river). So, rather complicated and dangerous hydrological situation in the basin of the Southern Bug River and reservoirs for period 2015—2017 due to the lowest water level by period of operation of reservoirs was due to the difficult weather conditions (aridization of climatic conditions) and increased water consumption (the runoff of the Southern Bug River in August—September was about 12—15 % less than the monthly norm) [Boychenko et al., 2017a].

The seasonal course of surface temperature and amount of atmospheric precipitation and peculiarities of their changes. As noted above, the seasonal course of surface temperature of air has a characteristic maximum in July 19—22 °C and a minimum in January at an average of –2 ÷ –7 °C), and in other seasonal periods, the average temperature is –1 ÷ 17 °C in spring and –3 ÷ ÷ 16 °C in autumn [The Climate ..., 2005]. The precipitation has maximum in the warm period of the year 330—350 mm, and in the cold period of the year 185—200 mm [Lipinskyy et al., 2003, The Climate ..., 2005].

The analysis of the seasonal distribution of the mean square deviation of the surface temperature and the amount of precipitation (characteristic variability of the weather), showed the presence of a clearly expressed nature [Lipinskyy et al., 2003; The Climate ..., 2005]. Therefore, for meteorological stations Pervomaisk and Voznesensk the maximum of volume of the mean-square deviation of the temperature falls on November—March (about 2.0—3.5 °C), and in the warm period of April—September 1.6—1.9 °C. We note that it is for the cold period characterized by a significant temperature variation of temperature with its significant fluctuations, especially through 0 °C. The situation is on the contrary, for the seasonal distribution of the value of the mean-square deviation of the amount of precipitation, the maximum of the mean-square deviation falls on May—September and varies within 35—47 mm/month (due to intensification of synoptic processes and the inherent maximum rainfall in summer), and in the cold period of October—April 22—28 mm/month.

In the conditions of modern climate change, certain tendencies appeared during the seasonal course of temperature. So, on the meteostations Pervomaisk (for the period 1945—2017) and Voznesensk (for the period 1945—2015) the maximum warming was typical for January—March (0.35—0.54 °C per 10 years), and April—December a warming was less intense with 0.1—0.27 °C per 10 years. However, for the period 1971—2017, with a certain warming in the cold period of the year (0.37—0.54 °C per 10 years), there was a tendency for significant warming in July—August (0.76—1.1 °C per 10 years) (Fig. 6, *a*).

For the seasonal distribution of the amount of precipitation in the conditions of modern climate change some tendencies are also revealed. Thus, for the meteorological stations Pervomaisk (1945—2017) and Voznesensk (1945—2015) insignificant increase of precipitation in the cold period of the year and decrease in summer were characteristic (Fig. 6, *b*) [Boychenko et al., 2017b, 2018].

However, for the period from 1971 to 2017 (with insignificant increase for precipitation in the cold period of the year: 2—4 mm/ /month per 10 year), a tendency for a significant decrease for precipitation in July—August (10—15 mm/month per 10 year) appeared. Moreover, this decrease for precipitation in July—August is accompanied by a significant increase in the temperature: 0.7—1.0 °C per 10 years.

Such a significant increase in the temperature in summer intensifies the evaporation and leads, to reduce of the water content of reservoirs inclusive.

It was established that, against the background of a general decrease in values of the continentality indexes on the territory

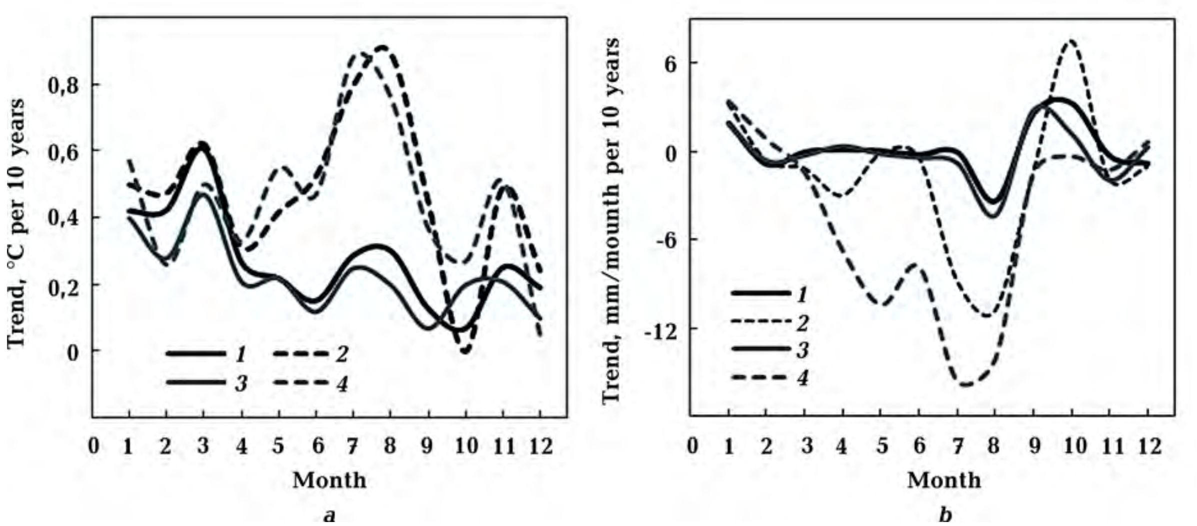

Fig. 6. The seasonal course of average temperature (*a*) and the sums of precipitation for the meteostations Pervomaisk (*1* — for the period from 1946 to 2017; *3* — for the period from 1971 to 2017) and Voznesensk (*b*) (*2* — for the period from 1971 to 2015; *4* — for the period from 1971 to 2015).

of Ukraine for the XX century and in the beginning of the XXI century (due to the significant warming during the cold period of the year, which is a manifestation of the effect of climate decontinentality [Voloshchuk, Boychenko, 2003; Boychenko et al., 2016b], there are the increasing trends for the period of 1971—2017 (due to the temperature rise in the warm season, especially in May—August). So, the amplitude of temperature for the period of 1900—2017 decreased by –0.5 ± 0.2 °C per 100 years and in the period of 1971—2017 intensively increased by 1.1 ± 0.6 °C per 100 years.

For the long-time course of continentality indices and the amplitude of the seasonal course of surface temperature (A) there is a certain cycle: a decrease in 1905—1920, 1940—1960, 1975—1995, and an increase in 1920—1940, 1960—1975 and 1995—2017 within ~5—10 % [Boychenko et al., 2017b, 2018]. Index of continentality Gorczynsky K_G for meteorological stations Pervomaisk and Voznesensk is about 38 ± 5 for the period 1945—2015, and the value of the amplitude of the seasonal temperature is A = 12.9 ± 1.3 °C. For the middle-lower part of the basin of the Southern Bug River in the ÕÕ century and at the beginning of the XXI century there was a general tendency to reduce the values of continentality indices and the amplitude of the seasonal temperature variation (due to warming in the cold season), so, the amplitude decreased by –0.7 ÷ –1.1 °C per 100 years. For the period of 1971—2017, the tendency of their increase (due to the temperatu-re increase during the warm period of the year, especially, in May—August) and the period of 1971—2017 is intensively increasing on ~1.2—1.71 °C per 100 years.

It should be noted that at the meteostation Pervomaisk seasonal changes are more intense than at the meteostation Voznesensk (due to microclimatic features).

Microclimatic features in the region of the location of the South-Ukraine NPP. Microclimatic features in the region of the location of the South-Ukraine NPP. The influence on the microclimatic conditions of the area can be caused by peculiarities of orography and intensive evaporation of water in the cooling systems of the SUNPP, which is about (40—45) · 10^6 m^3 per year [Environmental ..., 2016; Lysychenko, 2017].

An analysis of the changes in the microclimatic conditions in the 30 km zone of the impact of the SUNPP was conducted by comparing the thermal regime and the humidification regime at the meteostations of Pervomaisk, Voznesensk and Yuzhnoukrainsk for the period 2006—2017. The correlation coefficients for these stations for the temperature are 0.91—0.96 %, and for atmospheric precipitation are less 0.60— 0.75 %.

The difference in temperature between reservoirs and the South Bug River leads to significant evaporation from the surface of water and the formation of evaporation fogs.

During the year, the water temperature is several degrees higher on the surface of the Tashlyk Reservoir (an area of 1.2 km^2); in winter, in the cooling-reservoir the temperature water is constantly within the range of 5—9 °C [Environmental ..., 2016; Boychenko et al., 2017a].

The number of days with fog during the year, are observed on average at stations Pervomaisk — 38,8 ± 10,7 days, Voznesensk — 30,4 ± 8,6 days, and days with fog are more often observed in October—March 25—34 days and in April only 4—5 days [Lipinskyy et al., 2003; The Climate ..., 2005].

The analysis of the possible influence of SUNPP on microclimatic conditions (increasing temperature, intensity of evaporation and repeatability of fogs) showed, that in the conditions of modern climate changes it is necessary to take them into account during the operation of the South-Ukraine NPP in the future.

Scenarios of possible of climate change for the middle-lower part of the basin of the Southern Bug River (the climatic landscape zone of the Northwest Greater Black Sea area) by 2050. The regional scenarios of the possible climate changes by 2050 for Ukraine were developed, that take into account the established tendencies of the transformation of the climatic fields of annual surface temperature and annual sums of precipitation in the territory of Ukraine for the XX century [Voloshchuk, Boychenko, 2003] and the possible scenarios of future global climate changes (RCP4.5 — $\Delta T \sim 2.0$ °C and RCP8.5 — $\Delta T \sim 4.0$ °C for the end XXI century) [IPCC, 2014], namely [Boychenko et al., 2016b].

Scenario 1: it is likely not to exceed ($\Delta T \sim$ $\sim 1.4 \pm 0.2$ °C) and increase of the annual precipitation sums by 10 ± 5 % and the climate aridity in the warm period of the year (May—August).

Scenario 2: it is likely to exceed ($\Delta T \sim 2.4 \pm$ ± 0.3 °C) and differential spatial distribution of annual precipitation sums, namely the increase in northern, northwest and northeast regions by 15 ± 5 % and decrease in southern, southeast and southwest regions by 15 ± 5 %. At such a level of warming in the northern regions, a display of the effect of excessive moisture is possible, and in the south, on the contrary, aridization of the climate with the display of the effect of desertification is possible.

Further, the contrast of sums precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

For the climatic landscape zone of the Northwest Greater Black Sea area (the middle-lower part of the basin of the Southern Bug River), we have developed scenarios of possible changes of the temperature by the 2050, which take into account the global and regional peculiarities of climate change.

Note, that the warming in the territory of Ukraine in the XX century has a heterogeneous character, so in the southern regions the warming has been 10—20 % slower, but for the last decades, the warming has been significantly intensified, due to a significant increase in the temperature in summer [Voloshchuk, Boychenko, 2003; Boychenko et al., 2016b].

When constructing scenarios for possible changes in temperature for the climatic landscape of the Northwest Greater Black Sea area were taken into account by global scenarios of temperature changes RCP4.5 and RCP8.5 to the end XXI century [IPCC, 2014], semi-empirical scenarios for Ukraine (Scenario 1 and Scenario 2) [Boychenko, 2008], and tendencies of climate change in the region for in the second half of the XX century and in the second half of the XX century and at the beginning of the XXI century) [Boychenko et al., 2016b]. Consequently, climate change scenarios for the climatic landscape zone of the Northwest Greater Black Sea region are as follows (scenarios are countdown from 1900):

- *optimistic scenario* (scenario of global warming RCP4.5 + Scenario 1 for Ukraine + + temperature trends for in the second half of the XX century) it is $\Delta T_{2050(O)} \approx 1.4 \pm$ ± 0.3 °C;
- *pessimistic scenario* (global warming scenario RCP8.5 + Scenario 2 for Ukraine + + temperature trends for the period 1950—2015) it is $\Delta T_{2050(P)} \approx 2.2 \pm 0.3$ °C.

Fig. 7 shows optimistic and pessimistic scenario of climate changes landscape zone of the Northwest Greater Black Sea area (in the middle lower part of the basin of the Southern Bug River) by 2050. Note, that the temperature Anomalies of meteostation Pervomaiysk, and meteostation Vosnovensk are countdown from the period 1945—2015.

Summary and Conclusions. Feature of climate change and water regime for the

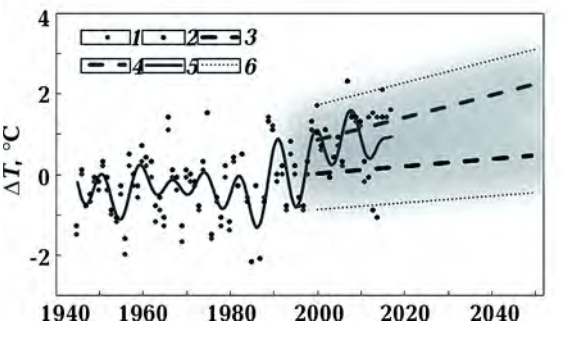

Fig. 7. Scenarios of temperature changes for the climatic landscape zone of the Northwest Greater Black Sea area (in the middle lower part of the basin of the South Bug River) by 2050: *1* — temperature anomalies of meteostation Pervomaisk, *2* — temperature anomalies of meteostations Vos-novensk, *3* — semi-empirical oscillation model, *4* — optimistic scenario, *5* — pessimistic scenario, *6* — confidence interval.

middle-lower part of the basin of the Southern Bug River (in location of the South-Ukrainian Nuclear Power Plant) of the second half of the XX century and at the beginning of the XXI century are analyzed. Due to climate change, the increase of the average annual air temperature (on 0,16—0,28 °C per 10 year) and insignificant increase of annual the amount of precipitation in this region (on 1—2 %) for period 1945—2017 occurred. However, more intense warming and negative tendency decrease of annual the amount of precipitation (on 3—10 % and in summer on 20—30 %) for the last several decades at the meteostations Pervomaisk and Voznesensk and was observed.

Such regional climate change can lead, to a certain extent, to the decrease of water content of the reservoirs, due anomaly increasing temperatures and decreasing precipitations in summer (July—August) and increased evaporation in basin of the Southern Bug River. Slight increase annual the amount of precipitations (and in the cold season) in this part of the basin do not compensate such negative tendency (the drain in this part of the basin is only 16—18 % of the annual flow of river). Rather complicated and dangerous hydrological situation in the basin of the Southern Bug River and reservoirs for period 2015—2017 due to the lowest water level by period of operation of reservoirs was due to the difficult weather conditions (aridization of climatic conditions) and increased water consumption (the runoff of the Southern Bug River in August—September was about 12—15 % less than the monthly norm).

In the delta of the Southern Bug River, there are the unfavorable situation also. So, in the Bug Liman take place: increase of water salinity, decrease of depths, increase of water temperature, reduce of volume of fresh water flow from river and intensification of water inflow from the Black Sea.

The regional climate change and water content can lead to some complications in the further effective exploitation of SUNPP and raising the level of the reservoir, probably, will be accompanied by negative environmental impact that should be avoided. Therefore, it is important to find a reasonable compromise between economic feasibility and preservation of the environment.

The tendencies of climate change and water regime of the middle-lower part in the basin of Southern Bug River (in the region of location of the South-Ukrainian Nuclear Power Plant)

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Feature of climate change and water regime for the middle-lower part of the basin of the Southern Bug River (in location of the South-Ukrainian Nuclear Power Plant) of the second half of the XX century and at the beginning of the XXI century are analyzed. Due to climate change, the increase of the average annual air temperature (on 0.16—0.28 °C per 10 year) and insignificant increase of annual amount of precipitation in this region (on 1—2 %) for period 1945—2017 occurred. However, more intense warming and negative tendency decrease of annual amount of precipitation (on 3—10 % and in summer on 20—30 %) for the last several decades at the meteostations Pervomaisk and Voznesensk were observed. Such regional climate change can lead, to a certain extent, to the decrease of water content of the reservoirs, due to anomaly increasing temperatures and decreasing precipitations in summer (July—August) and increased evaporation in basin of the Southern Bug River. Slight increase of the annual amount of precipitations (and in the cold season) in this part of the basin do not compensate such negative tendency. Rather complicated and dangerous hydrological situation in the basin of the Southern Bug River and reservoirs for period 2015—2017 due to the lowest water level by period of operation of reservoirs was due to the difficult weather conditions (aridization of climatic conditions) and increased water consumption (the runoff of the Southern Bug River in August—September was about 15 % less than the monthly norm). In the delta of the Southern Bug River, there is the unfavorable situation also. So, in the Bug Liman take place: increase of water salinity, decrease of depths, increase of water temperature, reduce of volume of fresh water flow from river intensification of the influx of salt water from the Black Sea. The regional climate change and runoff can lead to some complications in the further effective exploitation of SUNPP and probably there will be accompanied by negative environmental impact that should be avoided. Therefore, it is important to find a reasonable compromise between economic feasibility and preservation of the environment.

Key words: climate change, surface temperature of air, atmospheric precipitation, water content, water resources, the Southern Bug River.

References

Afanasyev, S., Peters, A., Stashuk, V., & Iarochevitch, O. (Eds). (2014). *Pivdenny Bug River Basin Management Plan: River Basin Analysis and Actions*. Kyiv: Interservice Publ. http://www.buvr.vn.ua /vodni-resursi/49-plan-upravlinnya-richkovim-basejnom-pivdennogo-bugu (in Ukrainian).

Afanasyev, S., Vasylchuk, T., Lietytska, O., & Bilous, O. (2012). *Assessment of the ecological status of the Southern Bug River in accordance with the requirements of the EU Water Framework Directive*. Kyiv: Interservis Publ. https://www.researchgate.net/publication /275332910_Ocinka_ekologicnogo_stanu_ricki_Pivdennij_Bug_u_vidpovidnosti_do_vimog_Vodnoi_amkovoi_D (in Ukrainian).

Aliyev, K. et al. (Eds). (2006). *EU Water Framework Directive 2000/60/EC Definitions of Main Terms.* Kyiv (in Ukrainian). http://www.dbuwr.com.ua/docs/Waterdirect.pdf.

Boychenko, S.G. (2008). *Semi-empirical models and scenarios of global and regional changes of climate*. Kyiv: Naukova Dumka (in Ukrainian).

Boychenko, S., Havryliuk, R, Movchan, Ya., Tarasova, O., Sharavara, V., & Savchenko, S. (2016a). Water supply and water discharge: challenges and concept of responses-context of climate change and exhaustions of water resources. In *Water Supply and Wastewater Removal* (pp. 3—14). Lublin University of Technology.

Boychenko, S., Voloshchuk, V., Movchan, Ya., Serdyuchenko, N., Tkachenko, V., Tyshchenko, O., & Savchenko, S. (2016b). Features of climate change on Ukraine: scenarios, consequences for nature and agroecosystems. *Proceedings of the National Aviation University,* (4), 96—113. doi: https://doi.org/10.18372/2306 — 1472.69.11061.

Boychenko, S., Movchan, Ya., & Tyshchenko, O. (2017a). Modern tendencies of climate, water resources and ecosystems changes in the middle-lower part of Southern Bug River, Ukraine. *Proceedings of the National Aviation University,* (3), 78—89. doi: https://10.18372/2306-1472.72.11988.

Boychenko, S.G., Voloshchuk, V.M., & Serdyuchenko, N.N. (2017b). Modern space-time variations of the index of continentality and the amplitude of a seasonal course of the surface air temperature on the territory of Ukraine. *Dopovidi NAN Ukrainy,* (9), 64—75. doi: https://doi.org/doi.org/10.18372/2306-1472.69.11061 (in Russian).

Boychenko, S., Voloshchuk, V., Kuchma, T., & Serdyuchenko, N. (2018). Long-time changes of the thermal continentality index, the amplitudes and the phase of the seasonal temperature variation in Ukraine. *Geofizicheskiy zhurnal, 40* (3), 81—96. https://10.24028/gzh.0203-3100.v40i3.2018.137175.

Environmental Impact Assessment (EIA): Increasing the level of the Oleksandrivske reservoir to the project mark of 20,7 м. (2016). Retrieved from: http://www.sunpp.mk.ua/ru/node/4563 (in Ukrainian).

Galushchenko, N. G. (Ed.). (1987). *Hydrological and water balance calculations*. Kiev: Vysshaya Shkola (in Russian).

Horoshkov, I. F. (1979). *Hydrological calculations*. Leningrad: Hydrometeoizdat (in Russian).

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R. K. Pachauri and L. A. Meyer (Eds). IPCC, Geneva, Switzerland. Retrieved from: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

Khilchevsky, V. (Ed.). (2009). *Water resources and quality of river waters of the Southern Bug basin*. Kyiv: Nika-center (in Ukrainin).

Kostyushin, V. (Ed.). (2007). The Southern Bug meridional river corridor: biodiversity and valuable areas. Wetlands International. Black Sea Programme. Kyiv Publ., http://www.duecomk.gov.ua/data/press/12.pdf (in Ukrainian).

Lipinskyy, V., Dyachuk, V., & Babichenko, V. (Eds). (2003). *The Climate of Ukraine*. Kyiv: Rayevskyy Publ. (in Ukrainian).

Lysychenko, G. V. (Ed.). (2017). *Integrated geoecological monitoring of the Tashlyk Hydroelectric Pumped Storage Power Plant and the Oleksandrivske Water Reservoir (1998—2016).* Kyiv: Naukova Dumka (in Ukrainian).

Magas, N., & Trokhymenko, A. (2013). Evaluation of modern anthropogenic pressure of the South Bug river basin. *Ekologichna bezpeka,* (2), 48—53. http://www.kdu.edu.ua/EKBjurnal/2013_2(16)/index.htm (in Ukrainian).

Marynych, O. M. (Ed.). (1989). *Geographical Encyclopedia of Ukraine* (Vol. 1). Kyiv: UE Publ. (in Ukrainian).

Romas, M. I., Chunarev, O. V., & Shevchuk, I. O. (2006). On Water Supply of Nuclear Power Plants in Ukraine when Introducing New Capacities. *Naukovi pratsi UkrNDGMI, 255*, 257—265 (in Ukrainian).

Rozhdestvensky, A. V., & Chebotarev, A. I. (1974). *Statistical Methods in Hydrology*. Leningrad: Hydrometeoizdat (in Russian).

The Climate Cadastre of Ukraine (standard norms for the period 1961—1990). (2005). Retrieved from: http://cgo-sreznevskyi.kiev.ua/index.php?dv=pos-klim-kadastr (in Ukrainian).

Voloshchuk, V. M., & Boychenko, S. G. (2003). Scenarios of possible changes of climate of Ukraine in XXI century (under influence of global anthropogenic warming). In V. Lipinskyy, V. Dyachuk, V., & Babichenko (Eds), *The Climate of Ukraine* (pp. 308—331). Kiev: Raevsky Publ. (in Ukrainian).