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INFLUENCE OF THE SOUTH-UKRAINE ELECTRIC POWER PRODUCING COMPLEX ON THE ECOLOGICAL CONDITION OF THE SOUTHERN BUG RIVER

Ye. Bezsonov
Postgraduate Student*
O. Mitryasova
Doctor of Pedagogics, Professor, Head of Department
E-mail: lesya.solis.28@gmail.com
V. Smyrnov
PhD*
E-mail: vsmirnov@e-mail.ua
S. Smyrnova
PhD
Department of Biology
V. O. Sukhomlynskyi Mykolaiv National University
Nikolska str., 24, Mykolaiv, Ukraine, 54030
*Department of Ecology and Environmental Management
Petro Mohyla Black Sea National University
68 Desantnykiv str., 10, Mykolaiv, Ukraine, 54003

Виконано аналіз багаторічного розподілу стоку Південного Бугу у його нижній течії в зарегульованих та природних умовах. Доведено, що водність річки зменшується. Визначено ступінь зв'язку показників витрат води Південного Бугу з концентрацією у ній потенційно небезпечних речовин. Розраховано імовірність маловоддя за місяцями року. Визначено господарський ризик для Южно-Українського атомного енергетичного комплексу за умов дотримання встановленого об'єму санітарного попуску у нижню течію річки

Ключові слова: Південний Буг, прогнозування стоку, господарський ризик, екологічний стан, Южно-Український атомний енергокомплекс, статистичне середовище R

Проведен анализ многолетнего распределения стока Южного Буга в его нижнем течении в зарегулированных и природных условиях. Доказано, что водность реки уменьшается. Определена степень взаимосвязи показателей расхода воды Южного Буга с концентрацией в ней потенциально опасных веществ. Рассчитана вероятность маловодья по месяцам года. Определен хозяйственный риск для Южно-Украинского атомного энергетического комплекса при условии обеспечения утвержденного объема санитарного попуска в нижнее течение реки

Ключевые слова: Южный Буг, прогнозирование стока, хозяйственный риск, экологическое состояние, Южно-Украинский атомный энергокомплекс, статистическая среда R

1. Introduction

Today, with the increasing shortage of available high-quality surface water resources, it is quite difficult to overestimate the importance of fresh aquatic ecosystems in the human economy and ensuring the functional integrity of adjacent natural complexes. In p. 119 [1], for example, it is claimed that water resources are one of the cornerstones of sustainable development, as they are closely linked to a number of key global problems. And p. 150 emphasizes the critical role of oceans, seas and coastal zones in preserving the Earth's ecosystems.

The fact that the anthropogenic impact is the main factor, which causes the reduction of biodiversity and services provided by water ecosystems, is shown in [2]. This influence is especially perceptible in the arid territories, which greatly intensifies the phenomenon of desertification. It is emphasized that effective measures to combat desertification will lead to poverty reduction.

Given the growing scarcity of freshwater resources and the lack of a comprehensive understanding about the functioning regularities of water ecosystems, ensuring ecological safety of them and water as a resource is determined as the fundamental goal of humanity [3]. At the same time, the level of consumer culture is equivalent to technical development in significance.

In [4] p. 18.2, it is emphasized that water is necessary in all spheres of life. And p. 18.2 determined the priority in water use for human, economic and ecosystem needs. So, in the process of water resources development and exploitation, the priority should be given to the satisfaction of basic needs and preservation of ecosystems.

In this context, the issue of prioritizing water needs between human and natural systems, primarily in arid territories is especially acute. In particular, in Ukraine such areas are completely located in the Steppe zone. The described problem is typical of the Southern Bug River, the basin of which occupies a significant part of the arid Mykolaiv region and is completely located within Ukraine. The issue of fresh water allocation between the region's industry (the South-Ukraine electric power producing complex consumes this resource most of all) and water ecosystem needs is becoming the most acute in the low-flow period on the river, which is getting more low-flow and longer every year.

It is also known; that the ecological condition of the Southern Bug River is deteriorating. In particular, eutrophication processes are longer and more intensive. Given a number of objective reasons, the commercial value of water bioresources is almost diminished. Solid river runoff is being reduced, hydrochemical and microbiological indicators are becoming worse. General level of recreation attractiveness of the natural complex is decreasing.

Given this, the issue of forecasting the ecological state of the Southern Bug River becomes relevant, especially in its lower reach, which is suffering the most from economic activities upstream. This will ensure a high level of ecological safety in the basin area and scientifically grounded management of the ecosystem services (in particular, fresh water for household water supply) in the context of the transition to a sustainable (balanced) development.

2. Literature review and problem statement

In [5], sustainable (balanced) use of water resources is proposed to implement through the optimization of their consumption at all stages. Identification of the functioning regularities of river ecosystems and their value for the local population will contribute to their preservation in the context of the transition to sustainable development.

In the context of the problem of surface water quality deterioration, in [6] water ecosystem and resources value for a human is proposed to determine through the ecosystem services consumed. As a result, this should rationalize financial resources and water consumption processes. However, it should be noted that this approach shows the main problem of the whole system of environmental protection – the objective determination of the value of one or another component of the ecosystem or their complex.

The fact that the value and integrity of aquatic ecosystems are appropriate to determine through analysis of the quantity and quality of ecosystem services is also mentioned in [7]. A similar statement, in the context of the transition to sustainable development, is found in [8].

According to the findings of the World Health Organization, about 80 % of all people's diseases depend on the quality of drinking water [9, 10], which is especially relevant for developing countries [11], including Ukraine. Based on this, the logical conclusion is that the ecological safety level of water ecosystems largely determines the development level of a region or settlement.

Previous investigations [13–19] of the Southern Bug ecosystem definitely took place, but they were unsystematic and point-in-time. This is largely due to the idea that the conditions in the upper, middle and lower reaches of any river are very different [12].

Thus, in [13] the results of the study regarding the qualitative and quantitative composition of phytoplankton in the upper reach of the Southern Bug River, and in [14] – economic development are presented. The hydrological regime of the middle reach is described in [15], and in general along the riverbed – in [16]. In [17], current negative trends in the functioning of the Southern Bug River aquatic ecosystem are generalized.

In [15, 18], the problem of the river runoff damming (regulating) as one of the most negative factors of impact on the water ecosystem functional integrity was emphasized. Actual data for analysis, which confirm this, are found in [19]: 9.9 thousand artificial reservoirs were created in the S. Bug basin with a total volume of more than 1.5 km^3 (of which 187 reservoirs with a total volume of almost 0.9 km^3).

From the point of view of the sustainable development principles and patterns of the river functioning, the creation of hydraulic structures in its basin (especially for energy needs) cannot be considered an environmentally safe alternative to the modern concept of energy production. In support of this opinion, here are some negative examples from the world practice. This is the hydroelectric power plant "Three Gorges Dam" on the Yangtze River in China: processes of eutrophication have become more intense, landslides have become more frequent, migration routes of sturgeon species have been destroyed, about 1300 archeological sites are flooded. The Tsimlyansk reservoir on the Don River in Russia: increased salinity of the Azov Sea waters and decreased productivity). Dozens of water reservoirs on the rivers Syr Darya and Amu Darya destroyed the Aral Sea. Actually, the situation is typical of the states, in which the hydropower industry is one of the most developed. These are China, Brazil, the USA, Russia, and India.

In the context of the implementation of the provisions of the EU Water Framework Directive in the Ukrainian environmental legislation, in [16] an environmental assessment of the Southern Bug River sections was carried out. It is based on the use of bioindication methods, water hydrochemical analysis (based on the concentration data of nitrogen and phosphorus compounds) in order to ensure the complexity of the obtained value.

Not least, selectivity of research of the Southern Bug River parameters is due to the lack of free access to monitoring data of stream flow measuring stations and a very small amount of the latter.

It should also be noted that the issue of river flow forecasting today is considered very carefully and often is not included in the study. This statement is valid for the rivers within Ukraine, and for the world practice. This suggests insufficient knowledge of this aspect of economic activity. In addition, it is necessary to determine the environmental and economic risk as the main forecasting tool.

The city of Mykolaiv is the last and largest settlement, which is located on the Southern Bug River, namely at the mouth: partly – along the area with the estuarine type of water regime. This is the second settlement in the south of Ukraine, according to the State Statistics Committee of Ukraine, by the capacity of industrial production, which currently has a significant resource and human potential for further development. And a very important place in the functioning of the city, given geographic location, peculiarities of development and modern structure of the industrial complex, is occupied by the presence of surface fresh natural watercourses. Thus, the aquatic ecosystem is crucial to ensure the functional integrity of the surrounding natural and socioecological systems [20].

Therefore, a mandatory prerequisite for ensuring the ecological safety of the region and the city, inparticular, is the forecasting of the consequences of unbalanced nature management in the river basin (especially in the lower reach). The latter is the result of ignoring the patterns of development and the dynamics of the aquatic ecosystem hydrological processes.

Regulation of riverbeds for nuclear or hydropower needs is fairly typical and common to most countries in the world practice. In the context of this, it is relevant to determine the causal relationships in the "human-nature" system at the regional level. In particular, calculations of economic risk for man-made water users will reveal the degree of danger of the ecological situation in the river basin.

The results of the study will allow us to create a scientifically grounded basis for making appropriate decisions with the purpose of solving existing and preventing ecological problems.

3. The aim and objectives of the study

The aim of the study is to determine the forecast indicators of the ecological state, especially water flow parameters, of the Southern Bug River, which largely determine the level of socio-economic development of the Mykolaiv region of Ukraine and the safety of the South-Ukraine electric power producing complex functioning.

To achieve the aim, the following objectives were set:

– to determine the presence and significance of the influence of the riverbed regulation factor for the Southern Bug River on the water supply of natural and artificial consumers in the lower reach of the river using statistical methods;

– to formalize the degree of connection of water flow in the river with the concentration of pollutants in it;

– to substantiate the ways of further development of the ecological situation in the Mykolaiv region, taking into account water availability of the Southern Bug River;

– to calculate the economic risk for the largest and most dangerous, from the ecological point of view, man-made water consumer in the Mykolaiv region – South-Ukraine electric power producing complex (SUEPPC).

4. Materials and methods of research of distribution patterns of the Southern Bug River runoff in the lower reach

Based on the analysis of qualitative and quantitative indicators of the Southern Bug River, it was proved [20, 21] that the state of the environment in the Mykolaiv region is deteriorating. To confirm the above conclusions, let us use statistical tools in the programming environment R. The latter is gradually becoming the universally accepted world standard for carrying out scientific and technical calculations and statistical analysis of data [22, 23]. Thus, with the aid of R, an analysis of the influence of "deaf" regulation of the riverbed and construction of the South-Ukraine energy complex in the 80–90-ies of the twentieth century on the level of provision of the average monthly and average annual flow in the lower reach of the Southern Bug (from the city of Voznesensk to the city of Mykolaiv) was made.

Having an array of data for 80 years, more than 28 thousand values (1936–2016), two samples are selected. The first (vector x1) covers the period of 1936–1983 and characterizes the river before the construction of the specified man-made object. The second is limited by 1984–2016 years, when the construction began (vector x2).

By using Student's criterion, namely the *t.test* function in the environment R, the influence of the regulation factor on the annual hydrological regime of the Southern Bug River has been checked by comparing two dependent (pair) samples:

```
> x1<-c(70.58,112.25,250.27,216.11,72.64,
57.75,62.98,51.86,49.58,61.36,64.65,67.91)
> x2<-c(83.12,97.00,131.51,129.48,64.67,
58.46,53.46,42.06,52.62,78.19,72.29,71.91)
```

```
>t.test(x1,x2,paired=TRUE)
Paired t-test
data: x1 and x2
t = 1.4047, df = 11, p-value = 0.1877
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-9.597608 43.459274
sample estimates:
mean of the differences
16.93083
```

Note that the dependent (paired) samples are those that contain the results of measurements of any sign and taken on the same objects before and after the experiment. In this experiment scheme, the investigator more accurately assesses the effect of the action because of tracking it on the same object (objects).

According to the calculations of the software R, an alternative hypothesis is confirmed *(alternative hypothesis: true difference in means is not equal to 0*), namely the difference between the sample means of the two samples is not equal to zero. However, negative values of water consumption, which are the lower limit of the 95 % confidence interval are not possible:

95 percent confidence interval:
–9.597608 43.459274.

Therefore, it was decided to use the single-entry t-criterion: the significance of the change in average water consumption in the S. Bug River was estimated after the SUEPPC construction (the average monthly values for 1984–2016 years). The average water consumption for 1936–1983 was determined at the level of 94.83 m^3/s (mu=94.83):

```
>t.test(x2,mu=94.83)
One Sample t-test
data: x2
t = -2.0429, df = 11, p-value = 0.06577
alternative hypothesis: true mean is not equal to 94.83
95 percent confidence interval:
 59.65507 96.13993
sample estimates:
mean of x
77.8975
```

In this case, one-parameter analysis according to Student's criterion shows that the probability of getting such (or greater) value of *t*, provided that the investigated null hypothesis is correct, turned out to be quite small: p-value=0.06577 (at a level close to 5 %). Accordingly, we can reject the null hypothesis (river runoff regulation and exploitation by the SUEPPC do not affect the level of water flow in the lower reach of the river) and take an alternative (alternative hypothesis: true mean is not equal to 94.83). In this case, the risk of error is about 6.5 %.

In addition to the t-criterion, the number of degrees of freedom (*df=11*), p-value and sample mean (*sample estimates: mean of x*), the program calculated the 95 % confidence interval (*95 percent confidence interval*). It allows determining the true difference between the sample mean of water flow in the river and that determined before the SUEPPC construction. Accordingly, by repeatedly conducting a similar test for the conditions, when the SUEPPC is operated together with the Tashlyk cooling pond and Oleksandrivskiy reservoir (after 2006), it was found that the average annual value of water flow will range from 59.65 to 96.14 m^3/s in 95 % of cases. As stated in [24], the pressure on the water ecosystem occurs, when the volume of water intake from the river exceeds one third of the river runoff. Since the average annual runoff of the Southern Bug is at a level of 2.8 km^3, it is easy to calculate the minimum annual average value of water flow in it, which provides 2/3 of the river runoff:

2.8·2:3=1.87 km^3
1.87 km^3:31536000 c=59.3 m^3/s.

An important stage in the process of forecasting the impact of man-made objects, in particular, energy, on the integrity of the studied aquatic ecosystem is the determination of risks of disturbances in the sustainable flow of ecosystem services. In this case – the water flows in the river at the level of 20 m^3/s. As it is known that the operation of three nuclear units of the SUEPPC every second requires 3 m^3 of water, which goes on cooling the power units and immediately evaporates. This is the lowest limit of "safe" water flow, because under such conditions in the lower reach of the Southern Bug River it is still possible to provide a sanitary flow at 17 m^3/s.

Based on an array of actual data (more than 28 thousand values) of daily water flow for the 80-year period (1936–2016 years), their probability distribution is constructed. It is characterized by a normal distribution curve with a left shift – to the region of low values (Fig. 1). Herewith, in 1936–1983 the left-shifted distribution of values of water consumption was expressed more clearly. This is due to the fact that the reservoir, in this case, performs the function of equalizing the runoff (regulation of dangerous effects of water) throughout the year.

It is worth noting that in 2007, the average decade water flow in the Southern Bug River, according to the stream flow measuring station in the village of Oleksandrivka (Voznesensk district of Mykolaiv region), was 15.2 m^3/s for 20 days and 12 m^3/s for 10 days. In 2012 – 10.3 m^3/s for 60 days, and in 2015 – less than 17 m^3/s for 126 days.

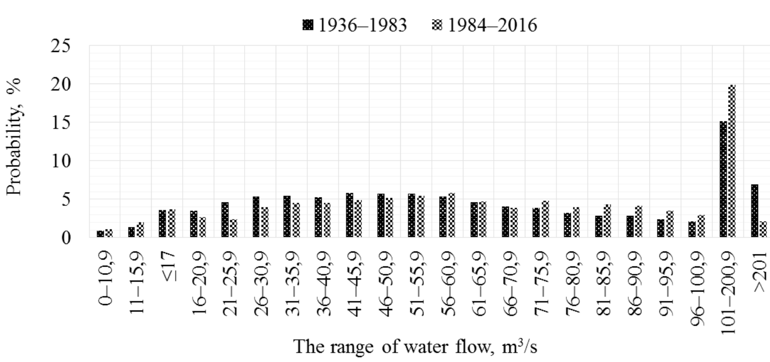

Fig. 1. Annual probability distribution of water flow in the Southern Bug River

In Fig. 1, it can be seen that there are three positions in the ranges, which require an explanation. In the first case (W≤17), the emphasis is placed on the group of values that are less than or equal to the value of the established sanitary flow below the dam of the Oleksandrivska hydropower station. The ranges (101<W<200.9) and (W>201) are introduced to ensure the legibility and representativeness of Fig. 1. A more detailed analysis of the probability of water flow in the low-flow period (May-October) is given in Fig. 2.

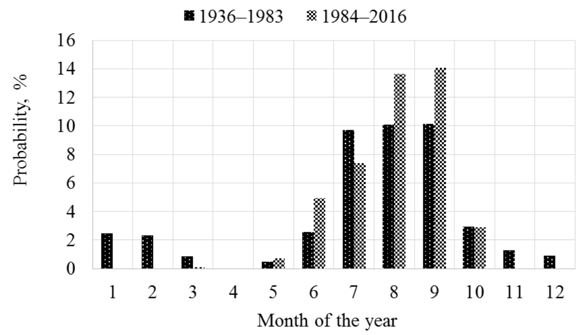

Fig. 2. Probability (%) of water flow below sanitary discharges (17 m^3/s) during the year

Note that after the commissioning of the SUEPPC, the water flow of the river began to decrease. And in this case, two main reasons can be distinguished. The first is the significant water needs for cooling nuclear reactors, especially during the warm season (from 3 m^3/s, plus evaporation from the water mirror of the reservoirs). The second is global climate changes, which are characterized by an increase in extreme temperatures in the summer and autumn periods. For the latter, similar ideas are found in [18].

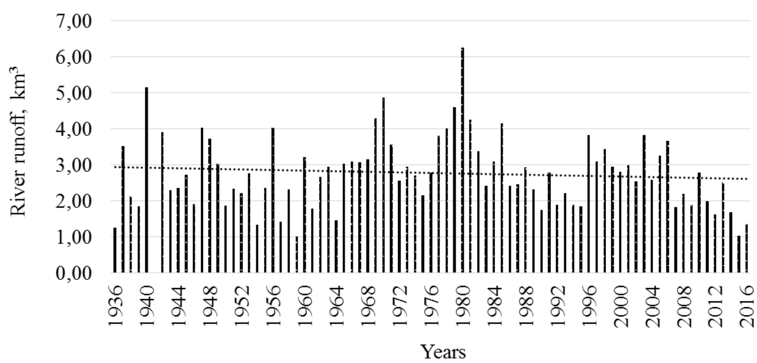

Fig. 3. Dynamics of the Southern Bug River flow for 1936–2016 years

Analysis of the river flow trend for the period of 80 years (y=–0.0042·x+2.9536) using MS Excel software (Fig. 3) confirms the above-mentioned arguments. However, to give more weight to the opinion, we propose to use an additional method.

Thus, to reveal the cyclicity of climatic phenomena and hydrological indicators of water objects, the method of difference integral curve is often used. Its essence is that first, for a given series of observations, the modular coefficients are calculated (K) (1):

$$K = \frac{M_i}{M_{cp}}, \tag{1}$$

where M_i is a certain value of the studied series, M_{cp} is the average value of the studied series.

Then their deviation from the mean (K–1) is determined and at last, an integral curve is constructed by sequential summation of these deviations using the expression (2):

$$f(t)=\sum_{i=1}^{n}(K-1). \quad (2)$$

Thus, the difference integral curve is the incremental sum of deviations of modular coefficients from the average multi-annual value of the series at the end of each year, M_i (Fig. 4). Positive deviation values of the modular coefficients, when summed up for the time interval, give the inclination of the difference integral curve up relative to the horizontal line, and their negative values – the inclination of the curve down.

In Fig. 4, as for the values of modular coefficients, and for the difference integral curve, there is a clear tendency towards a gradual decrease in the river flow. In the first case, the number of the modular coefficients values hits above 0 becomes smaller, and in the second – the presence of a stepped downward broken curve, the segments of which are very similar to the straight-line dependence is indicative.

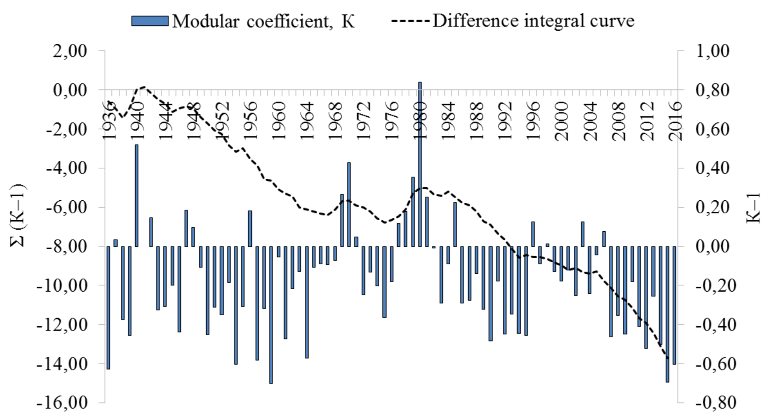

Fig. 4. The difference integral curve and the graph of the modular coefficients of the annual runoff of the Southern Bug River for 1936–2016 years

However, even 80 years of observations are not enough to clearly distinguish the runoff cycles, but only to hypothetically assume that current low-flow periods on the river are similar to 50–60 years of the twentieth century (because it is difficult to determine the influence of the Dnipro River regulation over the specified time interval) and in 10–15 years, a full-flow cycle will begin again on the Southern Bug, or this is the result of the SUEPPC operation.

One of the most likely effects of low-flow in the lower reach of the river is the increased concentration of pollutants, entering the river along with household wastewater. We confirm this conclusion by comparing the two samples through Student's test in the statistical environment R. Note that, when performing a two-sample t-test, R assumes by default that the variances of the compared samples are not equal, and, as the result, performs a t-test in the Welch modification (Welch Two Sample t-test). The following is the code for running the t-test for the importance of water consumption in the formation of phosphate concentration in the lower reaches of the river.

```
> d< – read.table (“clipboard”, header=F, sep=”,”, col.names = c (“month”, “fosfaty”, “water”))
>head(d)
month fosfaty waterflow
110.170086.56
220.1480 102.04
330.0700 141.73
440.0578 137.99
550.065868.35
660.116059.50
>t.test(d$water,d$fosfaty)
Welch Two Sample t–test
data: d$water and d$fosfaty
t = 9.432, df = 11, p–value = 1.322e–06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
63.5356 102.2136
sample estimates:
mean of x mean of y
83.01583330.1412167
```

After analyzing the results, with a 99 % confidence (p–value=1.322e–06) it can be asserted that the concentration of phosphates in the Southern Bug River depends on the water flow.

Approximation of the connection of the nitrates average monthly concentration and the average monthly water flow in the river in the MS Excel environment revealed a rather significant (R^2=0.7357) mathematical model (Fig. 5) (3).

$$y=252.49\cdot\ln(x)-936.96. \quad (3)$$

The presence of dependence is also confirmed by the analysis in the R environment, where the probability that under current conditions, with increasing water flow in the river, the concentration of nitrates will remain unchanged or decrease is only 2 % (p-value=0.01817).

```
>t.test(d$nitraty,d$waterflow)
Welch Two Sample t-test
data: d$nitraty and d$waterflow
t = 2.7006, df = 13.007, p-value = 0.01817
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
16.35484 147.13016
sample estimates:
mean of x mean of y
164.7583383.01583
```

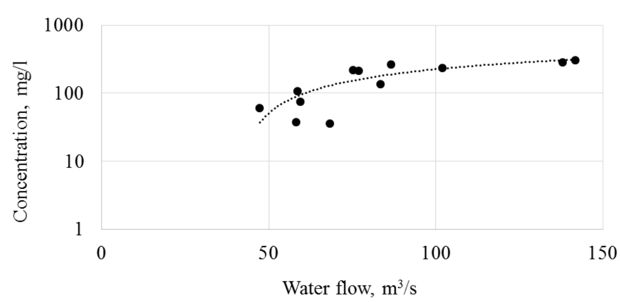

Fig. 5. Dependence of nitrate concentration on water flow at the mouth of the Southern Bug River

In the statistical environment R, using the *cor* function, we find the correlation coefficient for the following pair of indicators (Table 1).

Table 1
The degree of relationship between some indicators of the Southern Bug River

No.	Investigated factor systems	Value of the correlation coefficient, r
1	The average monthly water flow – the average monthly total phosphorus concentration	–0.74
2	The average monthly water flow – average phosphate concentration	–0.77
3	Annual runoff – the volume of fish caught	0.79
4	The average monthly water flow – average nitrate concentration	0.83

Note that the correlation coefficients greater than 0.7 indicate a high degree of dependence, and those within 0.5–0.7 show the average level of dependence. A value less than 0.5 corresponds to a low degree of dependence [25].

The main result of the research is the establishment of the fact that the river runoff is gradually decreasing and this phenomenon with different intensity will be observed over the next 10–15 years. This is affected by, as was determined, both anthropogenic and natural (climatic) factors. Since the identified low water risk today is estimated at the level of 43.60 % (about 80 days) for six months (May-October), and compared with the period of 1936–1983 years it has increased by 7.67 %, now a strategic approach to the allocation of water resources of the Southern Bug River is needed. This is especially important in the context of current trends in industrial production growth in the country and the potential increase of the population in the basin of the water object.

The main task, as already emphasized, is the inventory and decommissioning of "unprofitable" reservoirs and ponds, which no longer properly implement the design functional purpose.

5. Determination of economic risk

Risk is defined as the probability of unwanted events (the number between 0 and 1, sometimes multiplied by 100 for conversion to percents). To assess the actual risk, probability is interpreted as relative frequency, that is the ratio of the number of actual undesirable events to the total number of possible events [23].

Ecologic risk of industrial objects in the design process during an ecological examination is usually is limited to the consideration of emergencies such as earthquakes, floods, etc. Forecasting of ecological risks from weather conditions within the dynamic balance of natural ecosystems is performed today only for agrarian production. In this study, an analysis of the influence of the Southern Bug River hydrological parameters on the risk to water supply was carried out. In other words, the forecasting of the so-called economic risk to water users in the river basin is made.

The above analysis of statistical data (Fig. 1) revealed that the normal distribution curve of water flow is asymmetric with a significant shift to the left. This means a considerable predominance of the probability of low water over a flood.

The low-flow period covers six months – from May to October. The duration of water flow below the established sanitary discharge (<17 m^3/s) can be observed from 1 to 126 days (in 2015).

Economic risk, as one of the types of ecological risk, characterizes the danger to the man-made object from threats of natural origin. For example, from the lack of river water, which is consumed to meet technological needs. In accordance with the Water Code of Ukraine, such water users are the primary candidates for limitation of water supply during critical periods.

For the Southern Bug River, as was noticed, the reduction of water consumption to the values of ≤20 m^3/s will be considered as critical, when there is a real threat to the existence of a water ecological system.

Economic risk, like any other, except for individual, is determined by the dependence (4) [26]:

$$R=P\cdot D, \tag{4}$$

where P is the probability of an unfavorable event for an object; D is the damage that threatens the object due to the event.

Economic entities, dependent on water supply from the Southern Bug River, are public utilities of the Pervomaisk, Pivdennoukrainsk, Voznesensk, Nova Odesa and Mykolaiv cities, industrial enterprises of these cities, inhabitants of coastal settlements, irrigation systems for agricultural purposes. A characteristic feature of the consumers is the increased demand for water in the summer period, which further exacerbates the problem of economic risk to water supply during the low-flow period.

In the S. Bug River ecosystem, as was noticed, the South-Ukraine electric power producing complex is the most powerful consumer of water. It consists of the South-Ukraine nuclear power plant (SUNPP), Tashlyk cooling pond and Oleksandrivske reservoir. During the SUNPP operation, only one third of energy is converted into electricity, and two thirds are released into the atmosphere by evaporation of water from the reservoir surface.

To ensure the operation of each of the three nuclear-million- units, it is necessary to evaporate about one cubic meter of water per second. Compensation of water losses from the Tashlyk reservoir is carried out by pumping from the river (Oleksandrivske reservoir). We take the SUNPP as an example for further economic risk determination.

In the formula (4), the damage D takes into account all the negative consequences of a probable event. For a power plant, this is primarily a reduction in electricity production due to the temporary decommissioning of the unit (or units) for the period of critical low water flow according to the dependence (5).

$$D=z\cdot\tau\cdot10^6 \text{ (kWh)}, \tag{5}$$

where z is the number of nuclear units, which are withdrawn from operation due to the critical reduction of water flow in the river; τ is the duration of the switching off period of the power source (hours).

Table 2 gives an example of calculation of economic risk in the low water flow period.

Fig. 6 graphically shows the value of damage to the SUNPP because of limiting water consumption.

Knowing the daily capacity of each of the power units (which is about 1000 MW), it is easy to determine economic risks and losses (in monetary terms) for any period.

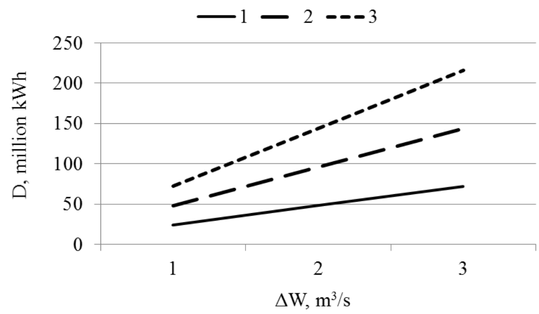

Fig. 6. The dependence of the electrical production reduction (*D*) on the decreasing of water intake from the river Δ*W*: 1 — the duration of the restriction is 1 day, one unit does not work; 2 — the duration of the restriction is 2 days, two units do not work; 3 — the duration of the restriction is 3 days, three units do not work, stop of the nuclear power plant

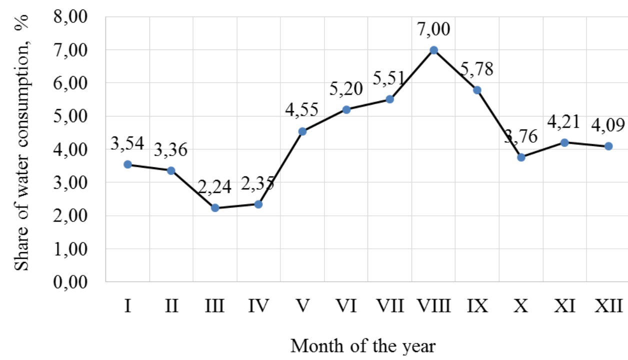

Fig. 7. Volume fraction of the SUNPP water intake from the Southern Bug River throughout the year

Table 2

Determination of economic risk for the SUNPP

No.	*Wm*	Δ*W*	*P*, %	Stopped units	Number of days	D, million kWh	*R*
1	19	1	55.93	1	1	24	13.42
2					2	48	26.85
3					3	72	40.27
4	18	2	48.4	2	1	48	23.232
5					2	96	46.464
6					3	144	69.696
7	17	3	43.6	3	1	72	31.392
8					2	144	62.784
9					3	216	94.176

6. Discussion of the results of the research of water management situation in the lower reach of the Southern Bug River

In accordance with the results, the longer the restrictions will last due to the shortage of water resources, the greater losses will be incurred both by the enterprise and by the related industries. However, since today the economic development of the state is a priority, the damage to the water ecological system can only be estimated roughly, based on some material and energy flows. But even the value of the evaluation of some ecosystem services in the lower reach of the Southern Bug River is almost identical to the annual productivity of the SUNPP [27].

It is not difficult to determine the monthly share of consumption of the SUNPP from the river: if the technogenic object consumes 3 m^3/s, then for a year – 94608000 m^3. It follows that about 7884000 m^3 accounts for each month. Knowing the average monthly water flow in the Southern Bug after damming (data for 1984–2016), we get the following distribution (Fig. 7).

By comparing Fig. 2, 7, it should be noted that four months are the most unfavorable and dangerous for the round-the-clock work of the SUNPP: June, July, August and September.

Current low level of ecological safety (which continues to deteriorate) in the Mykolaiv region [21] is caused by the following factors:

– an increase in water intake for the needs of industry in the upper reach of the Southern Bug;

– neglect of the river ecological system needs in water;

– lack of proper control and monitoring systems for pollution sources of the water object;

– high level of damming in the river basin;

– disregard for the regularities of the functioning of the water and adjacent natural complexes and systems;

– unbalanced and unsystematic approach to environmental management;

– lack of development strategy and care about water resources.

This allows confirming that the Southern Bug River in the near future can completely lose its recreational, cultural, fishing and, partly, industrial significance.

The situation in the river basin is to some extent unique. Despite the relatively low water flow of the river, dry summer, features of the landscape and surrounding ecosystems, the SUEPPC with three power units and two reservoirs at the end of the twentieth century was put into operation. At the same time, one of the reservoirs has a dam, which completely blocks the riverbed of the Southern Bug. This man-made object should be considered as the main cause of reduction of the river flora and fauna biodiversity, recreational and tourist attractiveness of the Mykolaiv region of Ukraine and hydrological regime of groundwater.

In the world practice, there are similar examples, when a nuclear power plant (NPP) is built on the banks of a river or reservoir (call them internal NPP). However, the approach to this process is quite different.

Usually, nuclear power plants are projected alongside the sea or ocean, so there are few internal NPP in the world. Most of them are in the USA, Europe and post-Soviet countries. When analyzing the on-line map of the NPP location in the world, it is difficult not to notice the difference in the approach of the western countries to the placement of NPP on the riverbank from the Ukrainian and Russian experience.

Similar to the SUNPP, the Cooper Nuclear Station (Nebraska, Missouri River) is also located in the steppe zone. However, this did not lead to the creation of a reservoir. Similar man-made objects are located in India (Narora Atomic Power Station, Gang River) and Brazil (Central Nuclear Atucha I, Parana River). The difference lies only in the greater water flow of the river.

Regarding the placement of NPP in a complex with reservoirs, the world practice is also different. Usually, the reservoir was created first, and then the NPP (Rostov NPP, Don River, Russia; Balakovo NPP, Volga River, Russia; Zaporizhzhya NPP, Dnipro River, Ukraine). Only in India (Rajasthan Atomic Power Station, Chambal River), the reservoir was created for the NPP.

In Europe, there is no example of a reservoir to meet the water needs of an NPP.

Therefore, in the present, when demand for atomic and hydropower is restored, the relevance of similar studies at the regional level is increasing.

And since it was discovered that in the world and Ukrainian practice, there is a dualistic approach to the NPPs functioning on the rivers, the question remains as to the objectivity of assessing and fixing ecological changes that occur in natural and socioecological systems.

In general, the results of the research allow improving the existing approaches to the definition of the risks to water supply of nuclear technogenic objects in the Steppe zone.

7. Conclusions

1. Based on the use of statistical methods and the method of the difference integral curve for the analysis of the spatial-temporal distribution of the Southern Bug runoff, with a 95 % confidence it can be said about the decrease of the water flow of the river in the lower reach. Over the past 20 years, for the period of low water, the decline is set at 7.67 %. The phenomenon of low water (especially in the summer-autumn period), which will be observed and strengthened in the next 10–15 years, was significantly intensified by the commissioning of the South-Ukraine electric power producing complex.

2. Using the statistical environment functions of *R*, a sufficiently strong correlation between water consumption in the river and pollutants is established. For phosphates r is –0.77, total phosphorus – (–0.74), nitrates – 0.83. Approximation of the dependence of the latter on the water flow of the river in the lower reach is made. As the concentration of phosphates in the low water warm period of the year increases with decreasing runoff, the intensity of eutrophication is increasing, which affects the integrity and balance of matter and energy flows in the ecological system of the Southern Bug basin.

3. The economic risk for the technogenic object (South-Ukraine nuclear power plant) is calculated for the low water flow period. The minimum risk value is calculated at the level of 13.42 million kWh. Besides, for a minimum of 80 days in the low water flow period, water intake from the river for industrial needs may be prohibited. The risk value in these conditions is 2511.36 million kWh. The most acute problem of prioritizing water needs between the river ecosystem and the industrial plant is from June to September, and is quite significant in May and October.

4. Because the Southern Bug basin is characterized by a high level of riverbed damming, it is expedient to consider the inventory of all reservoirs and ponds in the river basin, for decommissioning those hydraulic structures, which do not properly perform their functional purpose. In practice, this will minimize the losses calculated in the work and prevent a number of negative processes.

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