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CLIMATE CHANGE IN THE LOW DNIESTER BASIN AS A FACTOR OF IMPACTS ON WATER ECOSYSTEMS

The article presents results of the analysis of a temperature-humidity regime in the Low Dniester basin in two periods: 1961-1990 and 1991-2018. Statistical comparison of the observed trends and averaged monthly, seasonal and annual temperatures and precipitation demonstrate an obvious warming of the studied region, with a tendency to increasing aridity.

Keywords: Dniester River; statistical analysis; temperature; precipitation; air humidity.

Effective dealing with a problem of identifying and predicting the environmental impacts on any aquatic systems is impossible without clear understanding of the basic nature of external factors causing these impacts. Only in this case one is ready to study consequences of the impacts, to anticipate their evolvement and develop measures for their preventing and mitigating. Although rivers, estuaries and seas differ in many respects, they share some common features. The adjacent aquatic environments are closely related chemically, physically and biologically, and this reality determines, in spite of inevitable differences, some identity of various effects upon their welfare [2, 4, 7].

Climate change introduces a new dimension in the environment and water ecosystems relationships [5, 6]. First of all, the global warming and corresponding alterations in the hydrological cycle, caused by this phenomenon, have resulted in the “death” of the conception of *stationarity*, which assumed that climate and hydrology are predictable, and as such their future can be based on past historical data, and the above mentioned relationships can be reliable in the future. Also, it is very likely that impacts of climate change on freshwater systems and habitats will be severe. The direction and magnitude of changes in air temperatures and precipitation will inevitably affect water temperature, quantity and quality with consequent effects on aquatic ecosystems. The effects for freshwater ecosystems, which should be taken in conducting the biological assessments and developing biodiversity visions for ecosystems conservation, are [1]:

– Climate change may alter the composition of water and riparian vegetation.

– Distributions of species will change as some of them can invade the higher latitude habitats or disappear from the lower latitude limits of their distribution due to warming of freshwater habitats. Projected increases in air temperature will be transferred, with local modifications, to ground waters, resulting in elevated temperatures and reduced oxygen concentrations.

– In a warmer and drier climate many streams fed by runoff might become intermittent because of their high flow variability; as streams dry, the mobile organisms are concentrated and biotic interactions intensify. Small, shallow habitats will first express effects of changed precipitation; of the greatest concern are habitats now occupied by threatened and endangered species.

– The cyclic swelling and drying of rivers directly affects aquatic organisms in terms of basic habitat availability, oxygen levels, turbidity, and food resources. Some habitats (swamps, lagoons, floodplain pools), which are considered marginal in dry seasons, become isolated from the main river channel and can dry up. The availability of marginal habitats during wet seasons and the severity of conditions in those habitats during dry seasons are equally dependent on the hydrologic regime, which in turn is dependent on precipitation [1].

The basic physical factor that affects many natural processes and human activities is air temperature. Warmer temperatures alter precipitation and runoff patterns, affecting the availability and abundance of aquatic ecosystems and their services as well as leading to a wide range of other impacts, including changes in geographic distribution of species, the timing of their life cycle events, etc. Trends in air temperature and precipitation can also increase the risk of severe weather and hydrological events, such as heat waves or intense floods. Understanding of these trends is important for refining future climate projections in terms of the climate sensitive environment and ecosystems.

The main purpose of the research, presented in this paper, is to demonstrate changes observed in recent decades in temperature-humidity conditions of the Low Dniester basin, which a priori affect the volume and quality of a river flow entering the Dniester Liman and the adjacent part of the Black Sea.

Material and methods

Climate, in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of key climatic variables over a certain period of time [3]. As such representative climatic period the World Meteorological Organization (WMO) considers 30 years. Based on this definition, in our research two climatic periods (1961-1990 and 1991-1918) were compared to define changes in climate of the Low Dniester basin. These periods reflect, respectively, the relatively “normal” regional climate of the second part of the 20th century and the climate of intensive global warming that is observed in the last decades. Some objective ‘shortening’ of the second periods (28 years) can be neglected.

As initial material the sets of historical observations at Moldova's weather stations located within this part of the Dniester River basins (four in total) were used.

Statistical analysis of instrumental observations included:

– Comparison of the key climatic variables – air temperature and precipitation – as principal indicators of climatic conditions that form the Dniester runoff from its watersheds. The estimated statistics included annual and monthly averages, standard deviations (*Sd*) and Coefficients of Variation (*CV*) for mean (*Tmean*), maximum (*Tmax*) and minimum (*Tmin*) temperatures, as well as analogous statistics for precipitation totals (*P*);

– Comparison of air temperature and precipitation trends in the two periods as indicators of the observed tendencies in climate dynamic.

The entire analysis was performed, using statistical tools provided by the *Microsoft Excel*.

Results and discussion

Air temperature and precipitation trends

Air temperature. The longest row of mean annual air temperatures has been recorded since 1890 in Moldova, at Chisinau weather station located in the Low Dniester basin (Fig. 1). On the whole, the observed series is consistent to those found globally [Available at: <https://earthobservatory.nasa.gov/world-of-change/Decadal-Temp>]; the regression coefficient (the first term of a temperature linear regression on a year) demonstrates a local temperature increase by about 0.12°C per decade. However, starting from the 1990s, the alternation of relatively warm and cold periods in Chisinau climate has been replaced by a steady temperature increase. This obvious fact necessitates a transition, in any applied meteorological and hydrological research and practices, from operating with the longest data series to periods that reflect a current climate more representatively.

The climatic situation in the Low Dniester basin confirms this conclusion. Fig. 2 demonstrates changes in air temperature trends caused by the global warming here, where regression coefficients show the values of temperature change per year. A slight decrease in mean and minimum temperatures (approximately by 0.08 and 0.01°C per decade, respectively) in 1961-1990 changed to their increase in the last thirty years (by ~0.6 and 0.4°C per decade). As for the maximum temperatures, their slight growth (about 0.2°C per decade), outlined in the second half of the last century, increased to 0.9°C per decade in subsequent years.

A more detailed comparison of the temperature regime in the basin (by months and seasons) is shown in Table 1 and Fig. 3.

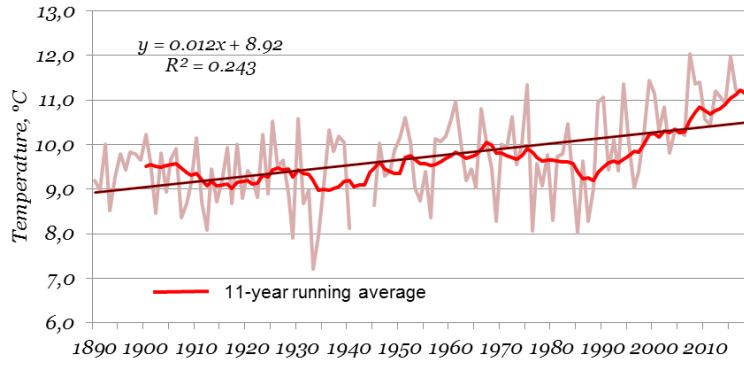


Fig. 1. Mean annual temperatures, approximated by 11-year running average, in Chisinau

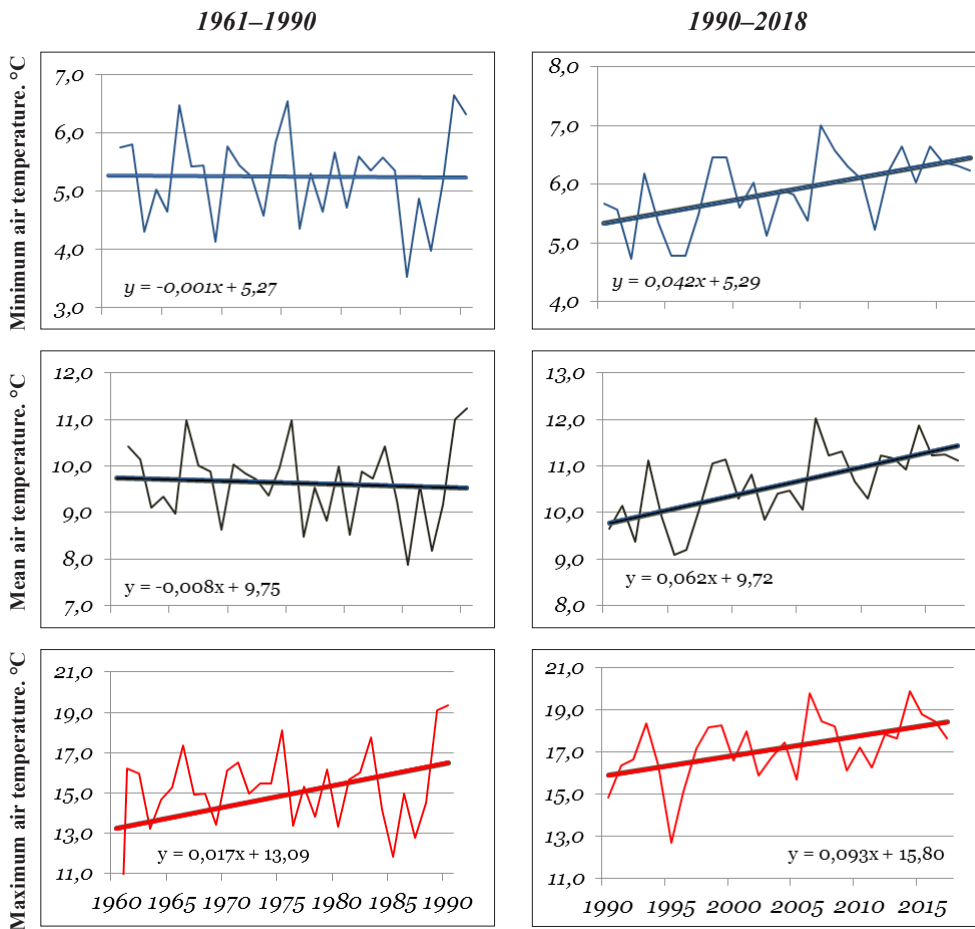


Fig. 2. Linear trends of air temperature in the Low Dniester basin in two climatic periods

Table 1

Seasonal temperature averages (*Av*) and standard deviations (*Sd*) in 1991-2018 vs. 1961-1990 (°C) in the Low Dniester basin

Air temperature	1961-1990		1991-2018		Difference	
	Av	Sd	Av	Sd	Av	Sd
<i>Winter</i>						
<i>Tmean</i>	-1.74	1.98	-0.85	1.47	0.89	-0.25
<i>Tmax</i>	4.74	5.80	7.79	4.97	3.05	-0.83
<i>Tmin</i>	-8.00	4.45	-6.28	3.89	1.72	-0.56
<i>Spring</i>						
<i>Tmean</i>	9.75	1.43	10.72	0.95	0.97	-0.48
<i>Tmax</i>	15.25	1.98	16.69	1.40	1.44	-0.58
<i>Tmin</i>	5.02	1.21	5.36	1.06	0.34	-0.15
<i>Summer</i>						
<i>Tmean</i>	20.33	0.83	21.97	1.11	1.64	0.28
<i>Tmax</i>	26.32	1.14	28.45	1.49	2.13	0.35
<i>Tmin</i>	14.76	0.82	15.92	1.24	1.16	0.42
<i>Autumn</i>						
<i>Tmean</i>	10.20	1.04	10.63	1.08	0.43	0.04
<i>Tmax</i>	15.21	1.68	15.80	1.26	0.59	-0.42
<i>Tmin</i>	5.80	1.07	6.21	1.30	0.41	0.23
<i>Year</i>						
<i>Tmean</i>	9.67	0.99	10.67	0.89	1.00	-0.10
<i>Tmax</i>	15.38	1.89	17.18	1.67	1.80	-0.22
<i>Tmin</i>	5.24	1.35	5.90	0.94	0.66	-0.41

In particular, Table 1 shows that in the second climatic period the annual *Tmean*, *Tmax* and *Tmin* increased in absolute values by 1.0, 1.8 and 0.7°C, respectively. With regard to seasonal temperatures, the highest *Tmean* increase was observed in summer (1.6°C), the smallest – in autumn (0.4°C). *Tmax* increased mostly in winter (by 3.1°C) and to a lesser extent – in autumn (by 0.6°C). The greatest increase in *Tmin* was observed in winter (1.7°C), the smallest – in spring (0.2°C). In addition to the analysis of average values, the standard deviations (*Sd*) were evaluated to quantify the amount of temperature interannual variability. A low *Sd* indicates closeness of data points to the average value, while a high *Sd* indicates that they are spread out over a wider range. According to this indicator, the most stable interannual temperature regime is observed in the spring-summer period, the most unstable – in winter. A comparison of temperature variability in two climatic periods indicates a slight decrease in its annual value for all parameters, despite a general temperatures increase. As for individual seasons, the temperatures variability decreased in winter and spring, and increased in summer and autumn for *Tmean* and *Tmin*.

Although the annual course of air temperature was preserved in 1991-2018 (Fig. 3), with its minimum in January-February and maximum in July-August, its increase is visually observed practically in all months and by all temperature variables except for *Tmin* in December.

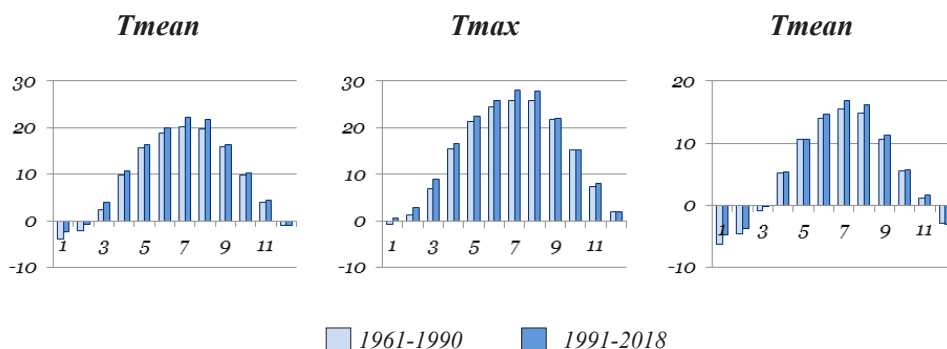


Fig. 3. Average monthly air temperatures ($^{\circ}\text{C}$) in the Low Dniester basin in two climatic periods

Precipitation. Precipitation, in the form of rain and snow, is the primary source of the Dniester runoff. On average, maximum precipitation occurs in summer, minimum – in winter (Table 2). If we compare annual precipitation totals for the two periods, they have not changed much over the past thirty years, decreasing by only 6 mm.

Table 2

Precipitation seasonal averages (*Av*), standard deviations (*Sd*) and Coefficient of variation (*CV*) in 1991-2018 vs. 1961-1990 in the Low Dniester basin

Season	1961-1990			1991-2018			Difference		
	Av, mm	Sd, mm	CV, %	Av, mm	Sd, mm	CV, %	Av, mm	Sd, mm	CV, %
Winter	110	53	48	98	46	47	-12	-7	-1
Spring	122	49	40	118	40	34	-4	-9	-6
Summer	192	60	31	178	65	36	-14	5	5
Autumn	108	58	54	133	58	43	25	0	-11
Year	532	109	20	526	97	18	-6	-12	-2

Despite this result, some changes in precipitation trends direction are observed (Fig. 4): their slight decrease (about 0.2 mm/year) was replaced by an increase in subsequent years (about 0.5 mm/year). However, these differences give no grounds to speak about significant changes in the total amount of precipitation falling in the Low Dniester basin.

Fig. 4 also demonstrates that basinwide precipitation is extremely variable, with consecutive dry and wet years occurring many times since 1961. The level of inter-annual fluctuations was additionally estimated by the Coefficient of variation (Table 2). This statistic, which is also known as *relative standard deviation (RSD)*, is defined as a ratio of the standard deviation of an observation set to its average value. Expressed usually as a percentage, *CV* shows the extent of population dispersion in

relation to its average; in our case, CVs are variability of seasonal and annual precipitation comparatively to their corresponding averages.

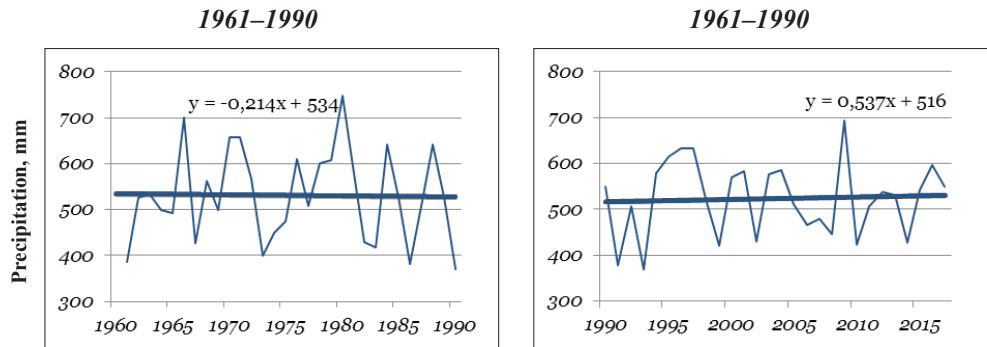


Fig. 4. Annual precipitation trends in the Low Dniester basin in two climatic periods

Analysis of Table 2 leads to the following conclusions:

- the variability of precipitation decreases with an increase in the period of averaging: CVs of annual precipitation is about two times less than seasonal CVs;
- the variability of precipitation is higher in the cold period (autumn-winter) than in the warm one (spring-autumn);
- in all seasons of 1991–2018, with the exception of summer, the variability of precipitation decreased to a maximum in the autumn (by 11%); the variability of summer precipitation during these years increased by 5%;
- a slight decrease in the variability of annual precipitation (-2%) is in good agreement with the general preservation of their annual totals.

Although the total annual precipitation remains almost unchanged, there is an observed certain redistribution of them by months (Fig. 5).

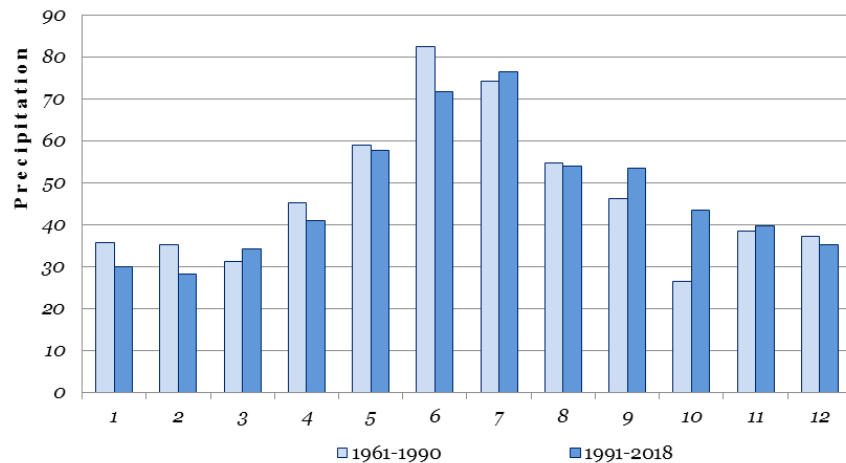


Fig. 5. Average monthly precipitation (mm) in the Lower Dniester in two climatic periods

Firstly, the annual course of monthly precipitation has somewhat leveled off. In particular, the precipitation maximum observed earlier in June (76 mm) has now decreased to 65 mm and become almost equal to the July precipitation. The November precipitation minimum completely disappeared, and the March minimum shifted to February. Furthermore, not so significant changes in precipitation patterns are also observed in the remaining months.

Regime of humidity

An increase in air temperature that is not compensated by a corresponding increase in precipitation inevitably leads to a decrease in climate humidity. Coefficient of humidity (*CH*), calculated as a ratio of precipitation to potential evaporation, was selected as an indicator of the air moisture content.

Table 3

Coefficient of humidity in the Low Dniester basin in two climatic periods

Climatic period	Month						
	4	5	6	7	8	9	10
1961-1990	0.57	0.53	0.63	0.60	0.38	0.56	0.58
1991-2018	0.45	0.47	0.42	0.43	0.34	0.63	0.93

This indicator is based on its strong ($R > 0.95$) and statistically significant ($p < 0.001$) relationships with monthly mean air temperatures and precipitation: positive – for precipitation and negative – for air temperature [8]. In other words, with an increase in precipitation the *CH* increases, with an increase in temperature, and consequently, with increased potential evaporation – it decreases. Thus, any *CH* decrease indicates an increase in climate aridity, and vice versa.

Using these statistical dependencies, calculated in [8] for 1961-1990, and assuming they did not change fundamentally for the subsequent years, the air humidity in the Low Dniester basin was compared for the assessed periods (Table 3). The analysis of this table shows that in the study area, since the former climatic thirty years, the warm period has been becoming more and more arid, reaching an aridity maximum in August. Only last two months have become more humid, approaching the optimal value of air humidity ($CH = 1.0$), or equality of precipitation with potential evaporation, in November.

Conclusion

The comparison of temperature-humidity conditions of the Lower Dniester basin in the periods before and after the onset of global warming demonstrates clearly its obviousness in a regional manifestation. The climate transition to a new state requires its further deep research, first of all, taking into account its applied aspects. This is

especially important for all systems related to freshwater, which is most sensitive to the impacts of climate change and variability and directly or indirectly transmits the consequences of these impacts to other natural and social systems.

It is highly likely that the climate change in the Low Dniester basin, either directly through changes in the air temperature-humidity conditions or indirectly through changes in parameters of the river flow, will inevitably affect the state of aquatic and riparian ecosystems both in the basin itself and in the Black Sea coastal waters.

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ЗМІНА КЛІМАТУ В БАСЕЙНІ НИЖНЬОГО ДНІСТРА ЯК ФАКТОР ВПЛИВУ НА ВОДНІ ЕКОСИСТЕМИ

Резюме

Проблема. Очевидно, що біотичний склад, структура та функції прісноводних екосистем багато в чому залежать від кліматичних умов басейну річки. Ця залежність ускладнюється в контексті глобального потепління, коли багатомісячна відносна стабільність клімату або його стаціонарність зникає і спостерігається все більша зміна клімату.

Мета. Метою даного дослідження було порівняння температурно-вологісних умов у басейні Нижнього Дністра у два періоди (1961-1990 та 1991-2018 роки), які відповідно характеризують різні кліматичні тридцятиріччя за класифікацією ВМО.

Методика. Для кожного періоду розглядалися середньорічні та сезонні значення ключових змінних клімату (температури повітря та опадів), а також їх лінійних трендів. В якості початкової інформації були використані спостереження на метеостанціях Молдови, розташованих в цій частині басейну Дністра.

Результати. Аналіз показав, що у другому періоді щорічна середня (T_{mean}), максимальна (T_{max}) і мінімальна (T_{min}) температури збільшилися в абсолютному виразі на 1.0-1.8 та 0.7°C відповідно. Що стосується сезонних температур, то найбільше зростання T_{mean} спостерігалось влітку (1.6°C), найменше – восени (0.4°C). T_{max} збільшувалась переважно взимку (на 3.1°C), а в меншій мірі – восени (на 0.6°C). Найбільше збільшення T_{min} також спостерігалось взимку (1.7°C), найменше – навесні (0.2°C). У той же час загальна зміна кількості опадів була надзвичайно мала: за рік вони зменшувались лише на 6 мм. Невелике збільшення кількості опадів (на 25 мм) відзначено лише в осінні місяці. Аналіз лінійних трендів підтвердив результати порівняльного аналізу. Негативні тренди температури повітря в 1961–1990 роках, за винятком невеликого позитивного значення для T_{max} , за останні три десятиліття змінилися на їх позитивні значення для всіх параметрів. Зокрема, протягом цього періоду збільшення середньої температури повітря становило 0,6°C за десятиліття. Незначна негативна тенденція опадів (~ 2 мм/рік) у 1961–1990 роках змінилася на їх незначне збільшення (~ 0,5 мм/рік).

Висновки. Підвищення температури повітря, яке не компенсується збільшенням кількості опадів, неминуче супроводжується підвищенням кліматичної посушливості, що вже характерна для північного узбережжя Чорного моря, що негативно позначається на існуванні та розвитку водних і наземних екосистем цього регіону.

Ключові слова: Дністер, статистичний аналіз, температура, опади, вологість повітря.

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