

REGIONAL CLIMATE CHANGE AND SURFACE WATERS

Gheorghe Duca¹, Maria Nedelcov², Serghei Travin³,
Viorica Gladchi⁴

Keywords: climate change, surface water, climate variability

Abstract: The actual period marred by the global warming requires expanding our knowledge on the regional particularities of climate changes manifestations as consequences of global climatic changes. It was stated that within the limits of Republic of Moldova's territory the pace of warming is much more accelerated than the global one. These consequences, in their turn, had led to the increase in degree of evaporation of surface waters, which had conditioned the doubling of still water's pollution in the region (Lake Beleu). We consider that the obtained results could contribute to the adequate management of water resources in the new climatic conditions.

Introduction

Great climate variability, over the past decades, requires detailed and permanent research, with the aim of taking into account the climate changes attested at global and regional levels. Taking into account the known results on the global climate issue, it is important to know its manifestation at regional and local level as well.

The research presented in this paper reflects the regional particularities of climate manifestation, in the context of the global climate warming and its consequences on the surface waters state from the Republic of Moldova territory.

$$x(t)=m(t)+C(t)+u(t), \quad (1)$$

where $m(t)$ - represents the trend of the series; $C(t)$ - the cyclic component; $u(t)$ - the residual series.

The cyclic components are presented as harmonic processes or components,

¹ Academy of Sciences of Moldova

² Institute Ecology and Geography

³ Russian Academy of Sciences

⁴ Moldova State University

$$C(t) = \sum_{i=1}^q (A_i \cos \frac{2\pi}{T_i} t + B_i \sin \frac{2\pi}{T_i} t) , \quad (2)$$

where unknown A_i , B_i , T_i are subject to determination.

In highlighting the cyclic component, the chronological series are represented as Fourier series (spectral analysis), representing a sum of harmonic components, sinusoidal

$$F_L(\omega) = \frac{1}{L} \int_{-L}^L x(t) e^{-i\omega t} dt \equiv U(\omega) - iV(\omega) , \quad (3)$$

where

$$A_j \approx U(\omega) = \frac{1}{L} \int_{-L}^L x(t) \cos \omega_j dt \quad B_j \approx V(\omega) = \frac{1}{L} \int_{-L}^L x(t) \sin \omega_j dt \quad (4)$$

Spectral density calculation is determined:

$$I_L(\omega) = \frac{L}{4\pi} |F_L(\omega)|^2 = \frac{L}{4\pi} [U^2(\omega) + V^2(\omega)] \quad (5)$$

Function construction $U(\omega), V(\omega)$ allows to find the periodic components in the time series $x(t)$, namely to determine the *parameters of the hidden periodicities*. Therefore, apart from calculating the trend, the division of time series into residual series and cyclical components allows a comprehensive assessment of regional climate trends.

Identification of the most significant periods of cyclic components was made on the basis of the correlogram and the periodogram.

Usually, the determination of correlogram is based on the serial correlation coefficients (fig.1a). The graphical representation of the autocorrelation coefficients, depending on the successive values of k (1 ... $n-1$), can be used to identify those periods (values of k), which separate significantly interleaved terms. Determination of the periodogram can be expressed as the Fourier series, representing a sum of harmonic, sinusoidal components. The higher value of the function $f(\omega)$ is directly dependent on the contribution of harmonic component brought to chronological series variation (fig.1b). Therefore, the choice of the harmonic components, which best adjusts to the variation of the chronological series, is based on the values of serial correlation coefficients, in the case of the

correlogram, or on quantities $f(\omega)$, in the case of the periodogram, selecting the harmonics corresponding to the highest values.

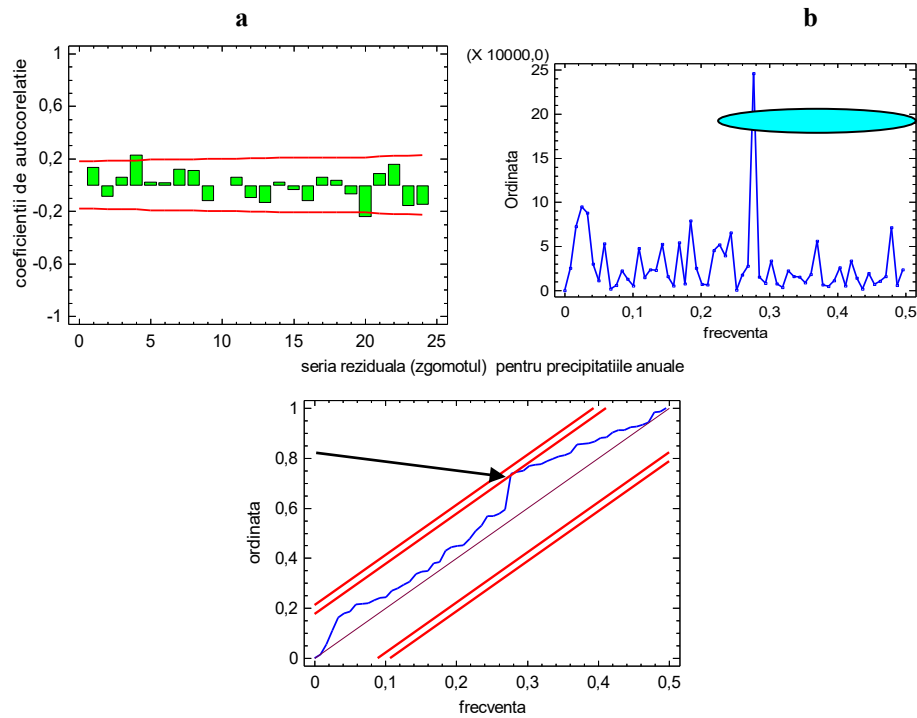


Fig.1. Correlogram, periodogram and random or residual series (on the example of the annual amount of atmospheric precipitation, Republic of Moldova)

The periodogram and the correlogram shown in fig.1 demonstrate that the statistical series, which characterize the annual quantities of atmospheric precipitations, include the cyclic component, in the amplitude range of 0.3.

In case the evaluation of the residual series does not exceed the boundaries of the credibility regarding the "white noise" (fig.1c), the random character in manifestation of certain meteorological elements (in our case of the annual atmospheric precipitation) is confirmed. Note that the residual series (noise) is obtained by extracting from the real series the values of the adjusted series.

The magnitude of the residue can be estimated based on the standard error of the estimate:

$$ES = \pm \sigma^z \sqrt{1-r^2} \quad (6)$$

where, σ^2 the standard deviation of real time series, r^2 - the determination index, which expresses the ratio between the explained variance and the total variance.

In case (fig.1) a certain level of amplitude (0.3) exceeds the line of credibility of the white noise, it is observed that the fluctuations, with the nominated frequency, include the cyclic component.

Testing the level of concordance of empirical data and adjusting it to a certain theoretical distribution is of particular interest, as they allow to draw a conclusion on the nature and variability of the climate at regional level.

Depending on the specificity of the thermal and pluviometric regime manifestation, for certain time scales, the experimental sample can be concordant with various theoretical distributions.

In order to approximate the empirical data with the various theoretical distributions (45 alternative theories) there is the Statgraphics Centurion XVI program.

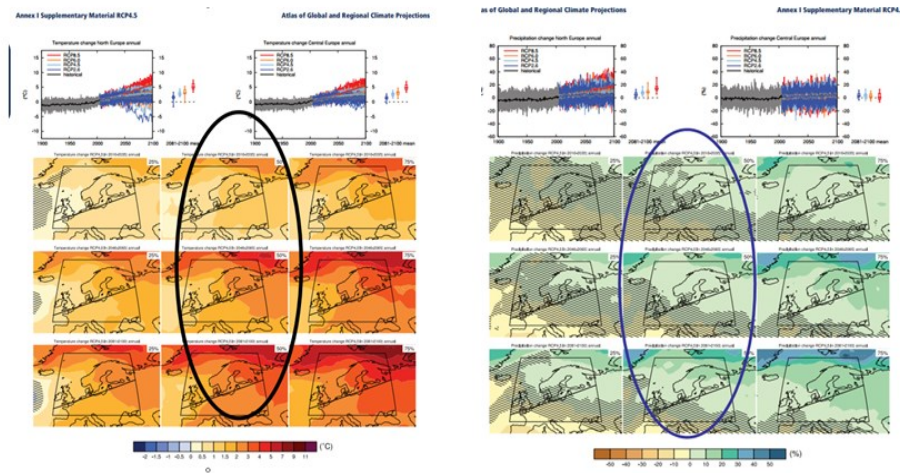


Fig.2. Regional climate scenario RCP 4.5, on average annual temperature and annual rainfall [3]

We consider that only such approach can highlight the special peculiarities of the meteorological parameters which characterize the real climate. At the same time, the "regionalization" of various climate prospects, especially those contained in the first *Atlas of the Intergovernmental Panel on Climate Change* [3], allow the alignment of regional research to international ones. We mention the fact that the prospects are based on the most "updated" reference period,

1986-2005 (fig.2). In this paper, on the example of the RCP 4.5 climate scenario, digital maps were developed reflecting the average temperature and the expected annual rainfall amounts in the future years (2016-2035) on the territory of the Republic of Moldova. Thus, the numerical model of the relief was elaborated and it highlighted the weight of each physical-geographic factor in the redistribution of climatic elements.

In the case of the geographical latitude and absolute altitude, the highest percentage was indicated, fact also confirmed by the significance of each physical-geographic factor, as well as of the whole model.

Thus, in regional aspect, for a period of 130 years (1887-2017). on the territory of the Republic of Moldova, the average annual temperature - indicator of the heating process (fig.3) is $0.0129^{\circ}\text{C} / \text{year}$.

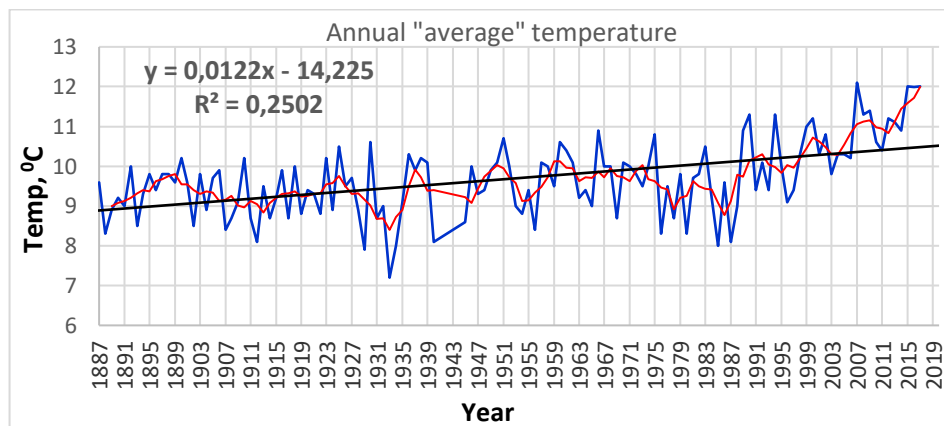


Fig.3. The tendency of change in the annual average temperature (1887-2017)

Although it would seem that we fit into the "expected climate corridor" [3], the obtained scientific results show a more pronounced "warming" rate [2] over the last decades.

The annual thermal anomalies reveal the fact that they are characterized by the predominance of the positive sign (fig.4), the intensity of which increases significantly over the last 18 years (2000-2017). Thermal deviations, practically annually, were the most essential in the series of instrumental observations (1887-2017).

This conclusion is also confirmed by the comparative estimation of the values that characterize the coldest and the warmest years, manifested on the territory of the Republic of Moldova, for two investigated intervals (1887-2010 and 1887-2016), which show a "retention" in time of the values that

characterize the coldest years and an essential change of the warmest years, recorded in the series of instrumental observations.

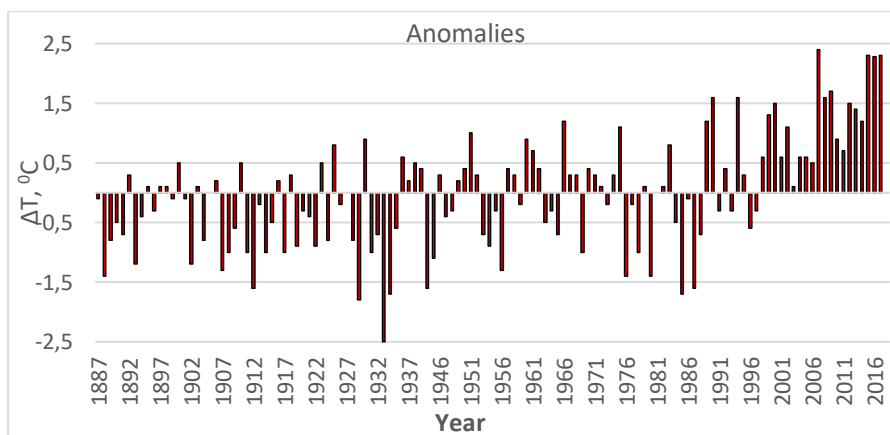


Fig.4. Evolution of annual thermal anomalies reported over the reference period 1961-1990

Thus, the lowest thermal values of the year remain unchanged (tab.1), as in the case of research results included in the *Atlas of Climate Resources of the Republic of Moldova* [2].

The years 1933, 1929, 1934, 1985, 1912, 1940, 1987, 1888, 1976, 1980 were the coldest years in the series of instrumental observations when the average annual temperature constituted $7.2 \dots 8.3^{\circ}\text{C}$.

In the case of the warmest years, 2007 remains the warmest year of the series of instrumental observations (1887-2017), after which the years 2015, 2017 and 2016 with significant thermal values. So, the last three years have recorded some of the highest values, which again indicates that we are on the verge of substantial climate change. Year 2009 is ranked fifth, compared to the previous survey.

The three-year period (2015, 2016, 2017) of high thermal values induces that 2012 year as the temporal limit of the extreme warmth, when the annual average temperature was 11.2°C as compared to the multiannual average of 9.6°C . We note that the year 2013, which is placed above the limit of the extreme warmth years, also recorded high values (11.1°C).

If, according to, in the last two decades, the manifestation of very hot years had a repeatability once in 2 years (tab.1), with the inclusion of the last 6 years, we find that 8 years of the top 10 very warm years (from the time series 1887-2017) belong to the period 2000-2017 (2007, 2015, 2016, 2017, 2009, 2008,

2000, 2012). The 11th year is 2013, which in the previous study period (1887-2016) ranked 10th in the top of the hottest years.

Tab. 1. Top of the coldest and warmest years recorded between 1887-2017

1887-2010 [2]				1887-2017			
coldest years		warmest years		coldest years		warmest years	
1933	7,2	2007	12,1	1933	7,2	2007	12,1
1929	7,9	2009	11,4	1929	7,9	2015	12,0
1934	8,0	1990	11,3	1934	8,0	2017	12,0
1985	8,0	1994	11,3	1985	8,0	2016	12,0
1912	8,1	2008	11,3	1912	8,1	2009	11,4
1940	8,1	2000	11,2	1940	8,1	1990	11,3
1987	8,1	1999	11,0	1987	8,1	1994	11,3
1888	8,3	1966	10,9	1888	8,3	2008	11,3
1976	8,3	1989	10,9	1976	8,3	2000	11,2
1980	8,3	2002	10,8	1980	8,3	2012	11,2

We also notice the significant share of the last three years in estimating the climate warming trend at regional level. Thus, only with the inclusion of the last year 2017, the trend values increase by 0.0006°C , ie from $0.0123^{\circ}\text{C} / \text{year}$ (1887-2016) to $0.0129^{\circ}\text{C} / \text{year}$ (1887-2017) for the whole series of instrumental observations.

Those remarked, once again, demonstrate that climate change persists with a pronounced warming trend, which should be taken into account in the case of the volume of surface water leakage and its quality.

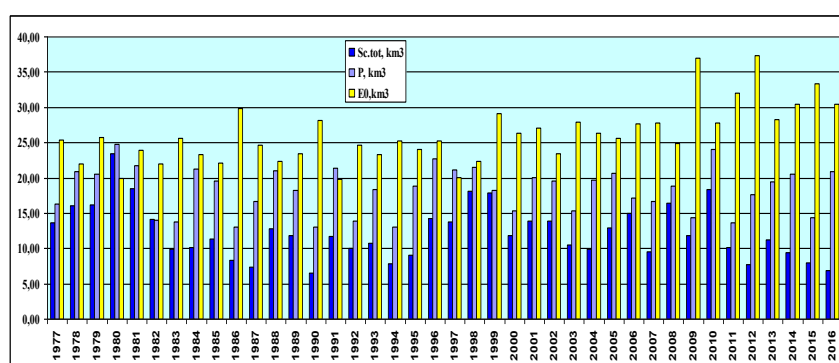


Fig.5. The dynamics (1977-2016) of total surface water leakage, atmospheric precipitation and average evaporation of seasonal evaporation, km3

The concomitant analysis of the total leakage dynamics, atmospheric precipitation and average evaporation of the sum of seasonal evaporation, in km^3 , reveals that their values, starting with 2010 are decreasing in case of precipitations and are increasing in case of evaporation, demonstrating that the specificity of the water balance in the Republic of Moldova (fig.5) is quite different, as compared to other time periods.

For this period of time, the values that characterize the evaporation are substantially increasing and the values that reveal the total surface water leakage decrease significantly.

Within the boundaries of the Republic of Moldova (fig.6a), an increase of the average annual temperature is projected by approximately $1.5 \dots 2.0^\circ\text{C}$ for the coming decades (2016-2035).

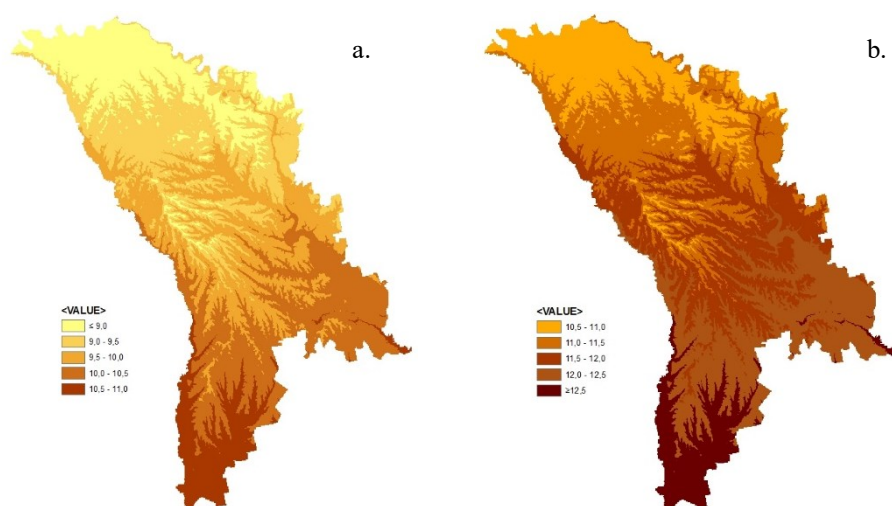


Fig.6. Cartographic modeling of the annual average temperature (a- 1986-2005, b- projected 2016-2035 with RCP 4.5) on the territory of the Republic of Moldova

The digital map (fig.6b), which reflects the spatial distribution of the annual average temperature in the near future years (2016-2035). shows that in the south and south-east extremity, it could be above 12.5°C . In the northern part of the country, the average annual temperature could reach $10.5-11.0^\circ\text{C}$. We notice that according to the cartographic model elaborated for the period 1986-2005 (reference period included in international research) in the south and south-east part, the average annual temperature was $10.5-11.0^\circ\text{C}$ and only in the

north part and on altitudes - ranged within $9.5-10.0^{\circ}\text{C}$, being near the climatic norm (9.6°C).

Based on the above, we believe that surface waters, especially in the south and south-east part, will continue to bear the impact of climate change in the coming years. Knowing the accelerated heating rhythm and space-differentiated appearance help us to carefully select climate change mitigation measures and the correct management of water resources.

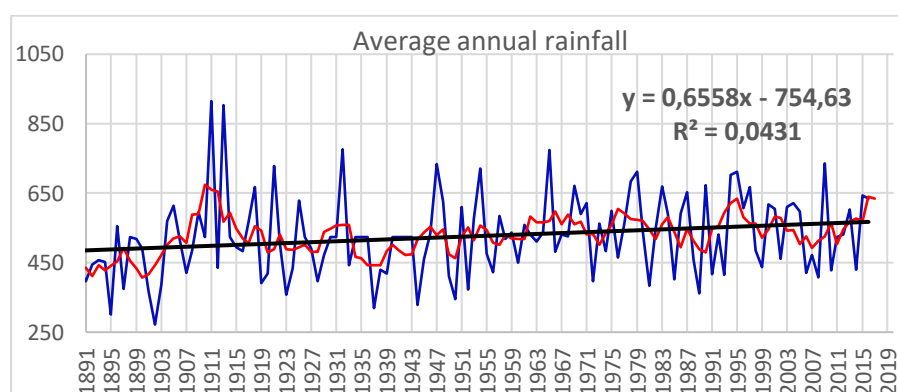


Fig.7. The trend of change of the amount of annual rainfall (1891-2017)

In the case of the atmospheric precipitation, for the period 1891-2017 there is an increase of the annual precipitation amount by 0.6558 mm / year (fig.7), compared to the previous researches, when the annual precipitation amount on the territory of the Republic of Moldova record an increase of 0.719 mm / year during the years 1891-2010.

So, notwithstanding the same increase in annual rainfall, the last five years have significantly influenced the numerical value of this increase. This actually represents 0.0632 mm / year less than the previous study (1891-2010).

In recent decades, a frequent alternation of positive and negative pluviometric abnormalities is observed, which demonstrates the extremely variable nature of both pluviometric and pluviometric excesses (fig.8). In 1903, the annual amount of atmospheric precipitation amounted to only 271.8 mm, and in 1912 the most significant values of 915 mm were recorded (tab. 2).

We mention that lately, only 2010 year added significant rainfall (735mm). At the same time, frequent alternations of pluviometric deficiency and surplus as well as various climate scenarios, developed globally and regionally, reveal that the trend of decreasing the annual amount of atmospheric precipitation in the coming years will persist in Southeast Europe.

The "regionalization" of the climatic prospects on the pluviometric regime, with the same RCP 4.5 climate scenario, shows that for the territory of the

Tab. 2. Top of the coolest and warmest years recorded between 1891-2016

dry years		rainy years	
1903	271,8	1912	915
1896	301	1914	903
1938	320	1933	777
1945	329	1966	774
1951	345	2010	735
1924	357	1948	734
1990	361	1922	729
1902	368	1955	721
1953	373	1980	712
1898	374	1996	711

Republic of Moldova there is a decrease of 10% in the southern and center parts (except for altitudes) and, on the contrary, increases (10%) in the northern part of the country. The role of physical-geographic factors leaves their mark on their spatial distribution.

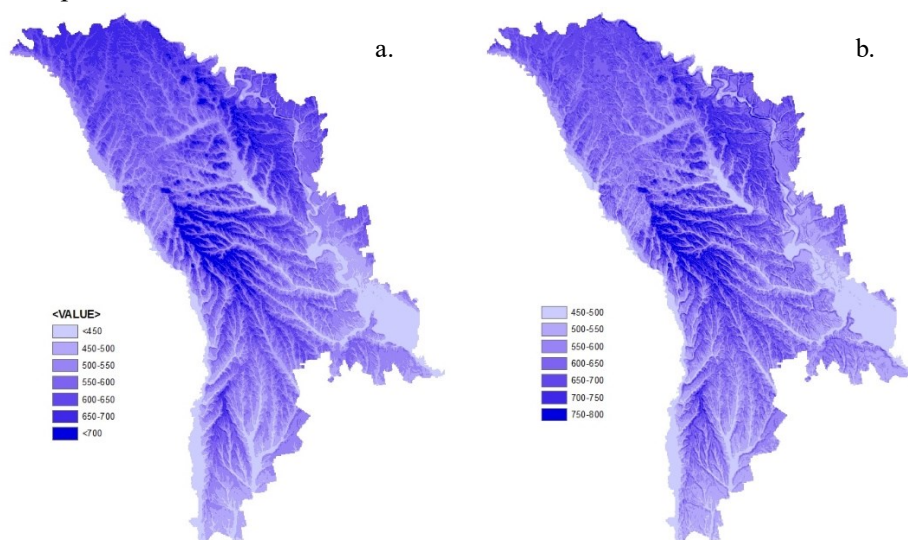


Fig.9. Cartographic modeling of the annual amount of atmospheric precipitation (a- 1986-2005, b- projected 2016-2035 with RCP 4.5) on the territory of the Republic of Moldova

The development of digital maps (fig.9b), which reveals the spatial distribution of annual rainfall between 2016 and 2035, shows that in the south and southeast part, rainfall amounts could reach 450-500 mm, as compared to 450 mm - 550 mm observed in 1986-2005 period and 750-800 mm in the north and central parts (at altitudes), as compared to 700 mm and less in the reference period (fig.9a).

As a conclusion, we can see that a 10% decrease in the annual amount of atmospheric precipitation, due to the increase of the thermal regime in the south and south-east part of the country, will further aggravate the current state of surface waters, and if no necessary steps will be taken to redress the already created environmental situations.

Bibliography

NEDEALCOV, M. *Resursele agroclimatice în contextul schimbărilor de climă.* Tipografia "Alina Scorohodova" 2012, Chişinău, 306 p. ISBN 978-9975-4284-8-4.

NEDEALCOV, M., RAILEAN, V.; CHIRICĂ L., COJOCARI, R.; SIRBU, R.; COICEANU, A. RUSU, V. *Atlasul „Resursele climatice ale Republicii Moldova”* Editura „Ştiinţa”, Chişinău, 2013. 76 p. ISBN 978-9975-67-894-0.

*** <http://www.ipcc.ch/report/ar5/wg1>

