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REGIONAL CLIMATIC CHANGES AND SMALL RIVER'S WATER QUALITY IN REPUBLIC OF MOLDOVA'S SOUTH (DANUBE RIVER BASIN)

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Key words: Climate variability, Danube basin, thermal regime

Abstract. Climate variability in decades requires detailed research aspect basin in order to take account of climate change attested, both in making various decisions applicative and at proper adaptation to these changes. Previous research results obtained in this section indicates that territory most vulnerable to climate change is largely located within the Danube basin within the territory of the Republic of Moldova. Therefore, the purpose of the proposed research in this paper was to record some changes in the current period and which are forecasts on thermal regime and precipitation in the scale time 2016-2035.

Introduction

Considerable climatic variability of the last decades conditions the necessity of thorough research on national, river basins' and local levels aiming to quantify the observed climatic changes for applied decision making process and for correct adaptation to these changes [2,3].

Preceding investigations' results obtained in this area indicate that the territory that is majorly limited by Danube basin within Republic of Moldova's boundaries is the most vulnerable to climatic changes.

That is why the aim of the investigations proposed in this work is to identify certain modifications that happened during the modern period and to forecast thermic and precipitation regime for the closest years (2016-2035). At the same time we should mention the tendency of decrease in water quality in republic's small rivers during the last years. The transboundary rivers (Dniester, Prut and Danube) although still have a higher water quality, are affected by the pollutants transferred by smaller rivers. Thus, according to

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State Hydrometeorology Service, small rivers' water quality is characterized by a high pollution degree and is quantified within the limits of III (moderately polluted) to VII (extremely polluted) classes, being mainly influenced by region's droughty conditions.

In this context, the knowledge of possible climatic changes for the region would allow preparing local public authorities to new expected climatic conditions, thus mitigating their impact on the quality of small rivers, especially those of Danube River basin limited by Republic of Moldova's boundaries.

Materials and methods

As initial investigation material we have used data from State Hydrometeorologic Service collected from 17 meteorological stations for 1986-2005 period in Republic of Moldova, the reference period used for calculations by Intergovernmental Panel for Climatic Changes (IPCC, 2014). RCP 4.5 included in the first atlas with timescale of 2016-2035 was used as climatic scenario.

The time series for 128 years for thermic regime (1887-2015) and for 124 years (1891-2015) for precipitation regime were used for identifying regional tendencies of climate's changes.

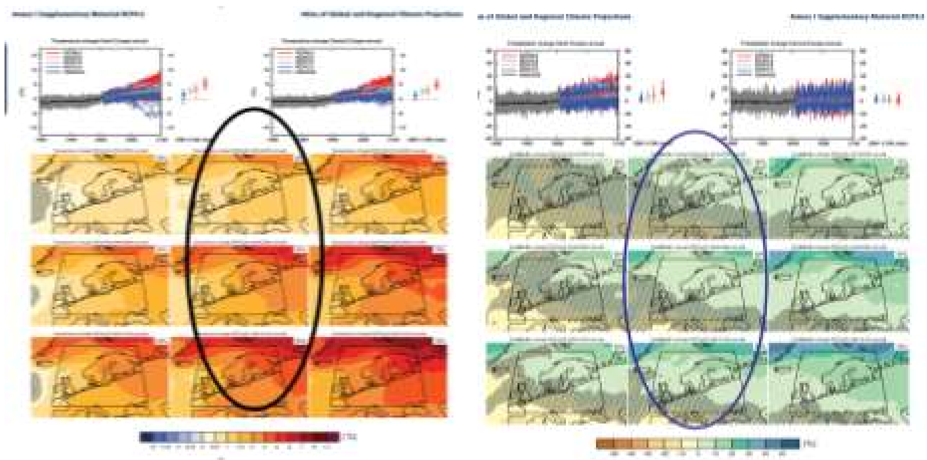

Fig.1 Regional climatic scenario RCP 4.5, for mean annual temperature and annual precipitations quantity [1]

It is a well-known concept of climate evolution acceptable within the limits of a certain „constraint" *(Tolerable Windows Approach, TWA)* at modern period. For mean global temperature it equals $T=2,0^0C$, which means the increase of its values by 2^0C till the end of the present century, which in its turn means that mean annual temperature's rate is acceptable within the limits of *0,015⁰C/year (T =0,015⁰C/year*). This method is of crucial importance for argumentation the effective measures for mitigation of harmful changes in climate.

Mean annual temperature has a tendency of increase with the rate of 0*,0117⁰C/year* on Republic of Moldova's territory for 128 years (1887-2015), which seems to conform to the „constraints" installed by the concept of acceptable climatic evolution *(Tolerable Windows Approach, TWA).* However, the rate of warming has increased in the past few decades.

That is why it is extremely necessary to know the tendencies of regional climate's manifestations for closer future years, based on climatic investigations included in the last Report (Ar5) and in the first Atlas of Intergovernmental Panel for Climatic Changes (IPCC) (fig.1). All climatic investigations elaborated in Atlas of Global and Regional Climatic Scenarios have the most „actualized" reference period (1986-2005), served as a base for different timescales' calculations: for the future 20 years (2016-2035), mid-century (2046-2065) and century's end (2081-2100).

The given work had taken into account physical-geographical factors that contributed in redistribution of climatic elements in elaborating cartographical models on the regional, river basins', and local levels.

When identifying the ratio of independent variables' influence (geographical factors: geographical latitude and longitude, absolute and relative altitude, exposition and inclination of slopes, old erosional fragmentation degree) on the dependent values' variability (temperature, atmospheric precipitations) we had executed an optimal selection (fig.2) of significant predictors, using multiple regression analysis with several alternative procedures:

- the step procedure with point-by-point including of variables;
- the step procedure with point-by-point excluding of variables;
- selection according to Melous criteria, which has the following expression:

$$C= (SSEp -S^2) - (N-2p) \quad (1)$$

where S^2 – mean square error of the model and comprises a multitude of variables, *SSEp* – the sum of square errors of the model with p parameters *p*, and *N* the volume of selection.

- selection by the version of coefficient of determination R^2, corrected at the level of a multitude of parameters in the model that is calculated by the formula:

$$R^2=1-[(n-1)*(1-R^2)]/ (N-P) \quad (2)$$

As the influence of different physical-geographical factors in distribution of climatic fields is not equivalent, we select a set of factors “responsible” for their “prediction”. In the obtained regressional model it is imperative that we follow the R^2 value (determination coefficient) the significance level of the each factor apart that has been introduced in the model. These are the basic indicators of model’s quality obtained in statistical software Statgraphics Centurion XVI.

Subsequently the obtained regression equations together with informational layers that characterize physical-geographical factors allow elaborating of digital maps with redistribution in space of climatic elements in study in ArcGIS 10.2 software. Thus Regional Geographical Informational Systems as an investigation tool ensure stocking and operative testing of necessary data for complex climatic interpretations.

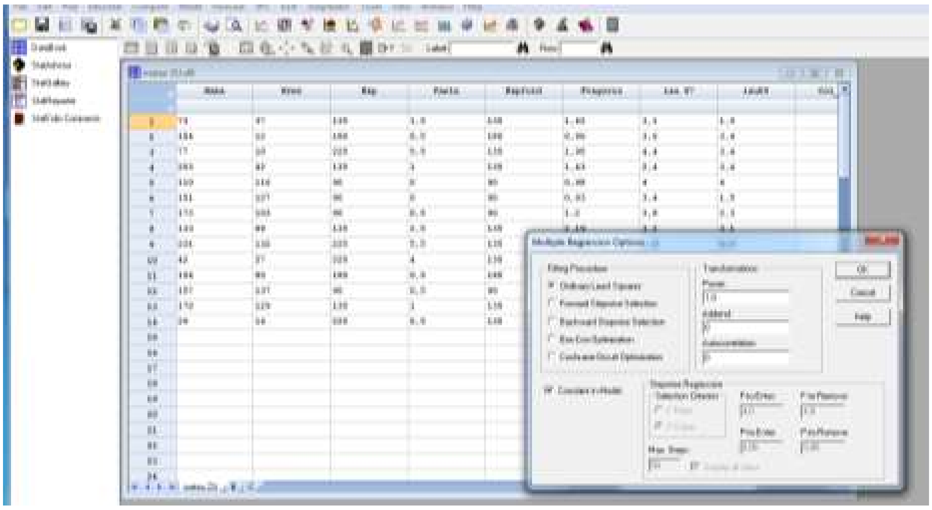

Fig.2. Physical-geographical factors’ ratio estimation in climatic parameters redistribution using multiple regression analysis

Water quality estimation in small rivers on the country’s South was executed according to Surface water quality Guide elaborated by State Hydrometeorologic Service [4], and especially using Water Pollution Index (*IPA*), which is calculated by the formula:

$$IPA = \sum \frac{Ci}{CMAi/6} \quad (3)$$

where:
Ci – mean concentration of parameters;
CMAi – maximal allowable concentration of parameters;
6 – the number of parameters used for calculation

Results and discussions

Thus, air's mean annual temperature (fig. 3) on Republic of Moldova's territory shows a rate of increase by 0.0117^{0}C/year during 1887-2015.

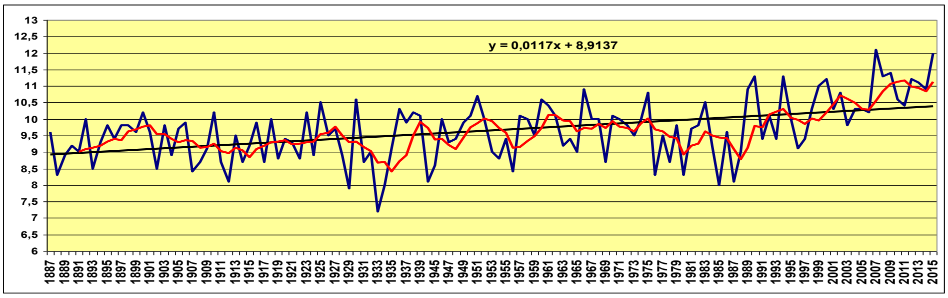

Fig. 3. Modification tendency of mean annual temperature (1887-2015)

The analysis of annual thermic deviations demonstrates that they are characterized by the preponderance of positive anomalies, prevalently in the end of 90s of XX century and the beginning of XXI century (fig. 4), and their intensity has significantly increased during last 16 years (2000-2015). Thermic more or less annual deviations were also the most essential in the set of instrumental observations.

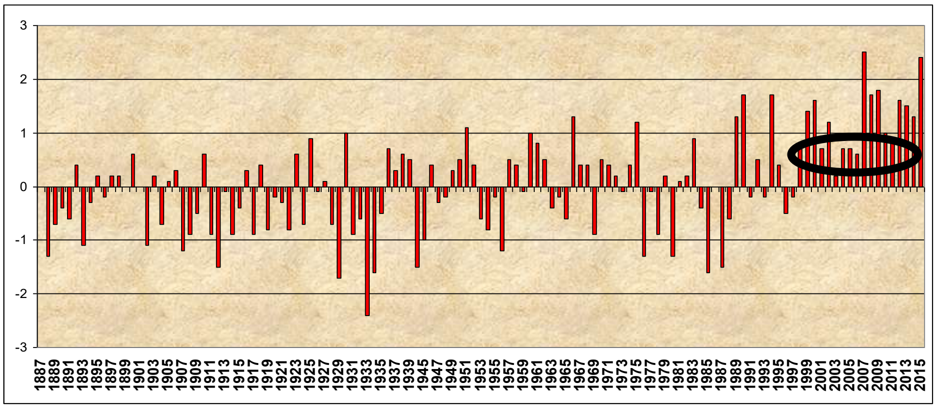

Fig.4. Annual thermic anomalies' evolution reported in the reference period of 1961- 1990

Comparative estimation [2,3] of the values that characterize the coldest and warmest years on Republic of Moldova's territory for two time periods (1887-2010 and 1887-2015) shows us a „conservation" in time of the values that characterize the coldest years and an essential modification of the warmest years registered in the set of instrumental observations.

Thus, the lowest thermic values of year remain unchanged; being registered in 1933 and 1929, when mean annual temperature had constituted 7.2 – 7.9^{0}C. Also low values, and namely within the limits of 8 - 8.3^{0}C characterize the following cold years: 1934, 1985, 1912, 1940, 1987, 1888, 1976, and 1980.

In the case of the warmest years, the 2007 remains to be the warmest in the whole set of instrumental observations (1887-2015), followed by the year 2015m which also has significantly high value. The third place is for 2009, and years 2012, 2013, while being placed after 2000 according to its values still exceed very warm years - 1966, 1989, and 2002. Year 1999 represents the temporal limit of extremely warm years, as then mean annual temperature equaled to 11,0^{0}C, while mean multiyear is equal to 9,6^{0}C.

If, according to [2, 3], in the last two decades the return period for the extremely warm years had manifested as once per two years (Tab. 1), then while including the last five years we are able to state that 7 years from the top ten of the very warm years (from the time series of 1887-2015), belongs to the years in 2000-2015 period (2007, 2015, 2009, 2008, 2000, 2012, 2013).

According to RCP 4.5 climatic scenario, within republic's boundaries, it is projected an increase of mean annual temperature by approximately 1.5...2.0^{0}C. Cartographic model (fig.5b) that reveals mean annual temperature's spatial distribution during 2016-2035 shows us that in the Southern and South-Eastern extremity the values exceed 2.5^{0}C. In the country's northern parts mean annual temperature can reach the values of 10.5-11.0^{0}C. We should note that according to the cartographic model elaborated for the period of 1986-2005 (fig.5a), in the Southern and South-Eastern parts the mean annual temperature had values of 10.5-11.0^{0}C and only in the Northern parts and on the altitudes it varied within the limits of 9.5-10.^{0}C, being close to the climatic norm (9,6^{0}C) of this value.

Table 1. Top ten of coldest and warmest years during 1887-2015 period

1887-2010 [3]				1887-2015			
The coldest year		The warmest year		The coldest year		The warmest year	
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	**2009**	**11,4**
1985	8,0	1994	11,3	1985	8,0	1990	11,3
1912	8,1	**2008**	11,3	1912	8,1	1994	11,3
1940	8,1	**2000**	11,2	1940	8,1	**2008**	**11,3**
1987	8,1	1999	11,0	1987	8,1	**2000**	**11,2**
1888	8,3	1966	10,9	1888	8,3	**2012**	**11,2**
1976	8,3	1989	10,9	1976	8,3	**2013**	**11,1**
1980	8,3	**2002**	10,8	1980	8,3	1999	11

These results demonstrate that such accelerated rhythm of warming and also so much varied in space predominately in the country's South, could have negative consequences on the natural pollution of small rivers.

a b

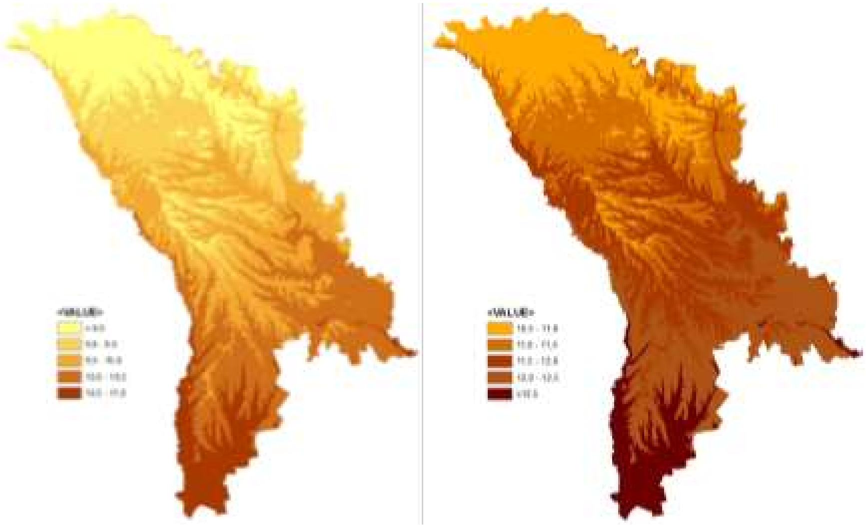

Fig.5. Cartographic modeling of annual mean temperature (a- 1986-2005; b- forecasted in 2016-2035 according to RCP 4.5) on Republic of Moldova's territory

In the case of atmospheric precipitations, an increase in the quantity of annual precipitations by 0.5994 mm/year is observed for the period of 1891-2015 (fig.6). We also state that in previous investigations [2, 3] the quantity of annual precipitations on Republic of Moldova's territory has a rate of increase of 0,719 mm/year during 1891-2010.

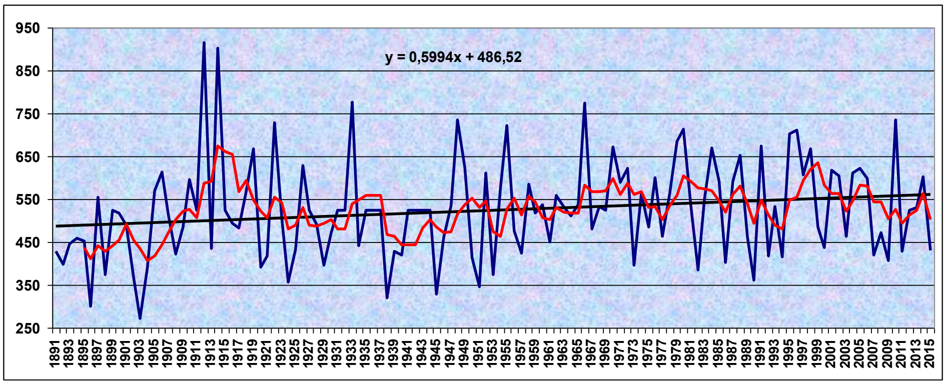

Fig. 6. The tendency annual precipitations' modification (1891-2015)

So, despite the fact that this increase in the annual precipitations' quantity is preserved, still the last five years had influenced significantly the numerical values of this increase. Actually, it is by 0.12 mm/year lower then the previously studied period (1891-2.010).

During the last decades we can observe a frequent alternation of positive and negative pluviometric anomalies, which shows an extremely variable manifestation character for both years with pluviometric exceeds and deficits (fig. 7).

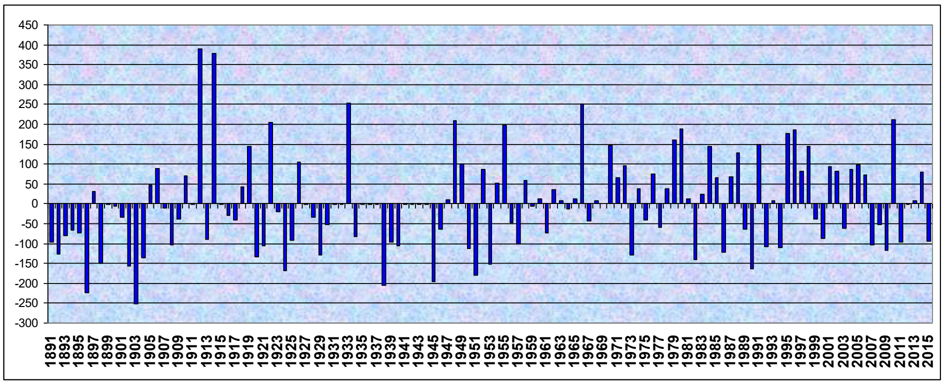

Fig.7. Annual pluviometric anomalies evolution referred to the reference period 1961-1990

Table 2. The top ten of the most dry and rainy years registered in the period of 1891-2015

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

In 1903, the annual quantity of atmospheric precipitations constitutes just 271.8 mm, and in 1912 the most significant values of 915 mm were registered (tab. 2). If we include the last 5 years, the position of the rainy and dry years remains unchanged, compared to the previous investigations obtained in this area. Thus the above related confirms that though the pluviometric anomalies are manifested with an increased frequency (by their antipodal alternation); their absolute intensity was not yet surpassed (tab.2).

Climatic investigations of pluviometric regime according to the same RCP 4.5 climatic scenario demonstrate a decrease of precipitations' sums by 10% in southern and central parts (excepting the altitudes) and on the contrary, their increase by 10% in country's northern parts. The role of physical-geographical factors greatly affects precipitation's spatial distribution.

Cartographic model elaboration (fig.8b) that reveals spatial distribution of annual quantities of precipitations in 2016-2035 demonstrates, that they can reach 450-500 mm in Southern and South-Eastern extremity, while the observed value during 1986-2005 was 450 mm -550 mm and 750-800 mm in Northern and Central parts (on the altitudes), while in the reference period it was 700 mm or less (fig.8a).

a **b**

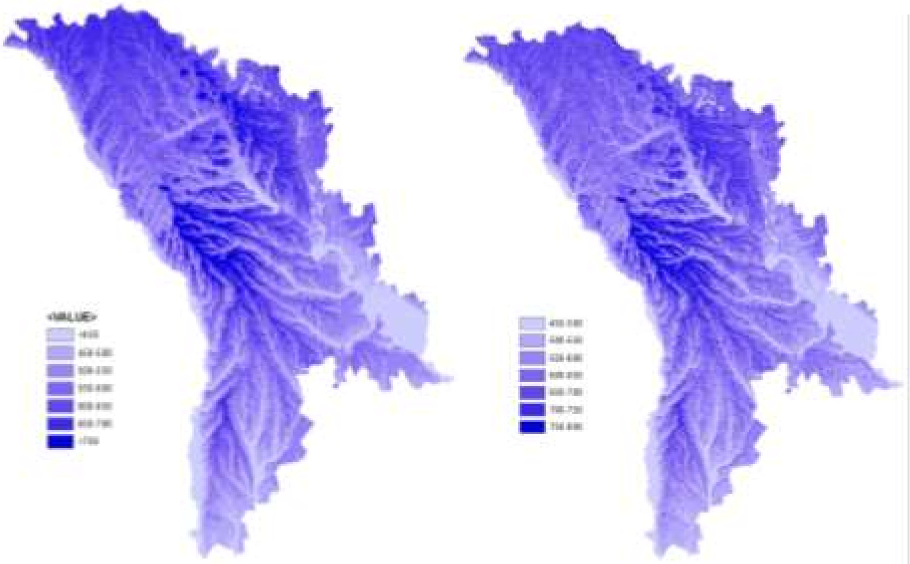

Fig.8. Cartographic modeling of annual quantities of atmospheric precipitations *(a- 1986-2005; b- forecasted 2016-2035 according to RCP 4.5) on Republic of Moldova's territory*

When we talk about the variability of geographical factors that influence spatial distribution of thermic and pluviometric regime in the Danube River's basin (Republic of Moldova), one can observe it on the map of absolute altitudes (fig.9), the values ranging within the limits of 5-384 m.

Air's mean temperature's cartographic modeling for 1986-2005, which is the reference period proposed by Intergovernmental Panel for climatic investigations of nearest future years, indicates that thermic values (fig.10a) of the extreme South of region in study were the highest from the whole Republic of Moldova's territory and are within the limits of 10.5-11.0^{0}C.

Thermic regime simulation for the period of 2016-2035 demonstrates that mean annual temperature (fig.10b) will be 12.5...12.9^{0}C in the southern parts Danube River's basin within Republic of Moldova's boundaries.

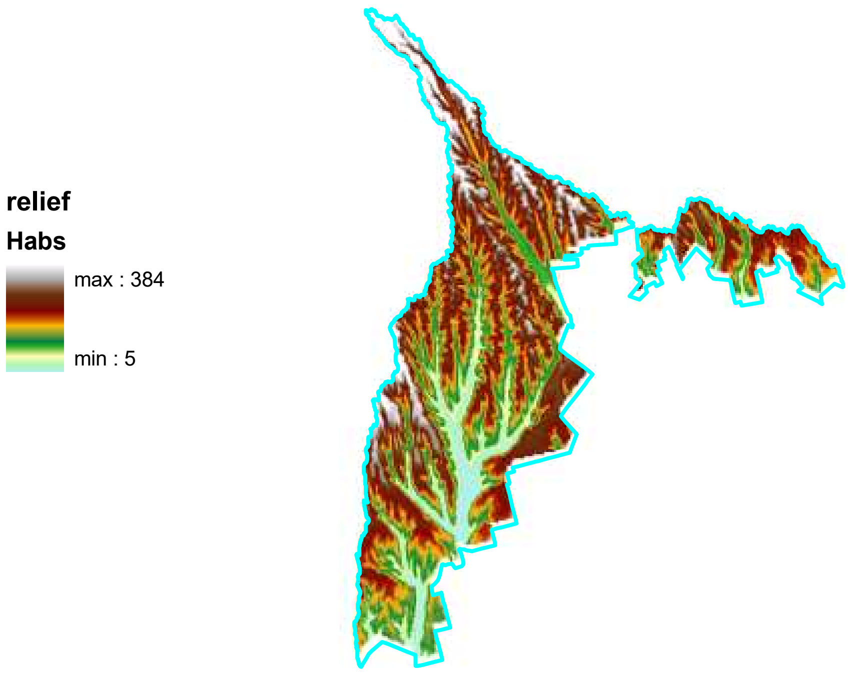

Fig.9. Absolute altitude map within the limits of Danube River's basin (Republic of Moldova)

We consider these conclusions to be of great importance for decision-making of authorities aiming for strategies of adaptation to new expected climatic conditions and for mitigation of the effect of small rivers' pollution.

Thus, mean annual temperature will reach the highest values of 12.5...12.9^{0}C (fig.10) and annual quantity of atmospheric precipitations will be 450-500 mm or less in the nearest future years (2016-2035), in the valleys of small rivers in Danube River's basin, and such would be the climatic conditions to which all everyday activities would have to adapt and take into account.

a b

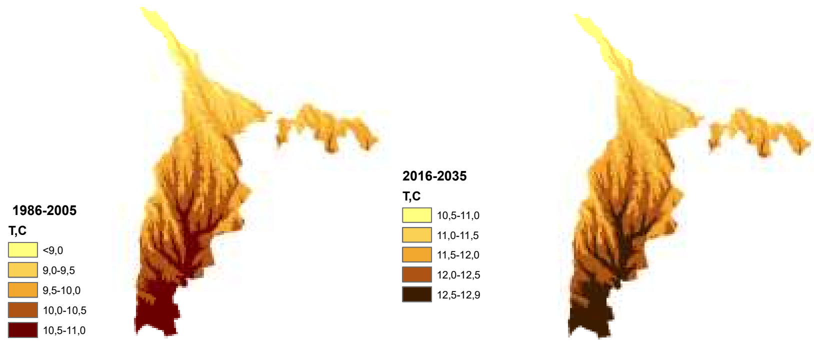

Fig.10. Air's mean annual temperature's spatial distribution for *1986-2005 period (a) and simulated according to RCP4.5 scenario for 2016-2035 (b) in Danube River's basin*

The knowledge of pluviometric regime in Danube River's basin is of no less importance. In the case of atmospheric precipitations, the cartographical models elaborated according to the requirements included in the same *Atlas of Global and Regional Climate Projections (AR5)*, reveal that the nearest future years will demonstrate a *decrease* by 10% of annual atmospheric precipitations in the valleys of small rivers in this region according to the most dramatic climatic scenario (RCP4.5).

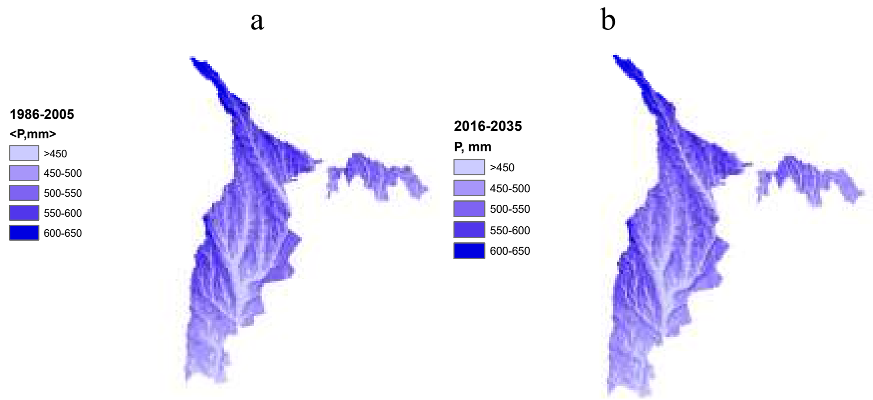

Fig. 11. Spatial distribution of annual quantity of atmospheric precipitations for 1986-2005 period (a) and simulated according to RCP4.5 scenario for 2016-2035 (b) in Danube River's basin

Thus, we can observe the increase of the area where annual sums (fig.11b) of atmospheric precipitations are within the limits of 400-450 mm, compared to a more limited area with the same values (fig.11 a) registered during 1986-2005.

According to State Hydrometeorologic Service's data during the past five years the water quality in Lunga River [4], according to IPA is characterized by a high pollution level that has changed essentially: water quality is improving in Ceadir-Lunga town's section, in the upstream, also improving in 2014 compared to the preceding years in the downstream from Ceadir-Lunga town, in hydrometric point. Nevertheless, the situation remains to be quite serious. IPA value during the above-mentioned period had varied from 2.54 (IV quality class– degraded) in Ceadir-Lunga town's section, in the upstream, till 11.24 (quality class V-polluted), Ceadir-Lunga town's section, in hydrometric point, both being registered in 2012, when climatic conditions were extremely droughty. The data analysis indicates an extremely high level of pollution for Lunga River, being among the most polluted aquatic bodies that had been monitored on republic's territory.

In conclusion we would like to state that the intensity and frequency of climatic extremes' manifestation affects the particularities of regional specifics of climate's manifestation on the actual stage. That is why a continuous study on the estimation of regional climatic changes aiming to apply adequately the adaptation measures, based both on these phenomena's accelerated rate of manifestation and the specifics of small rivers' pollution as the consequence of aridization.

Thus, there is no doubt, that the territory included in the limits of Danube River's basin (within Republic of Moldova) represents an area with the newest climatic conditions, and considering that state of small rivers' water quality, is a deplorable one.

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