SPATIO-TEMPORAL ANALYSIS OF TEMPERATURE'S VARIABILITY ON THE EXAMPLE OF MEAN TEMPERATURE OF THE WETTEST AND DRIEST QUARTER FOR REPUBLIC OF MOLDOVA'S TERRITORY

ANALIZĂ SPAŢIO-TEMPORALĂ A VARIABILITĂŢII TEMPERATURII PE EXEMPLU DE TEMPERATURĂ MEDIE A CELUI MAI UMED ŞI CELUI MAI USCAT TRIMESTRU PENTRU TERITORIUL REPUBLICII MOLDOVA

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Mean temperature of the wettest quarter (BIO8) and mean temperature of the driest quarter (BIO9) are one of the statistical bioclimatic indexes that characterize temperature's variability and are used in study of living organisms' responses to climatic changes. The article presents regional cartographic models for BIO8 and BIO9 and their temporal analysis for the 1960-1990 and 1991 - 2020. We had used Mann-Kendal trends and Sen's Slope in order to discern the temporal trends that are statistically significant, and the changes of bioclimatic indexes per decade. The spatial distribution of the indexes BIO8 and BIO9 was executed using regression models with a considerably low mean absolute error and relatively high R^2. The maps of the spatial distribution were executed in ArcGIS 9.2, Spatial Analyst package, Map Algebra, based on the above-mentioned models.

Keywords**:** *BIO8, BIO9, bioclimatic indexes, mean temperature of the driest quarter, mean temperature of the wettest quarter, multiple regression*

INTRODUCTION

Biological species are affected by both biotic and abiotic factors. Climate change, in turn, affects these constraints, in turn affecting the spatial distribution of species to varying degrees. At the same time, its relationship with climate varies, among other things, depending on the ability of the species to adapt to local conditions, as well as on the restrictions imposed by the environment associated with the availability of habitat.

Basic list of bioclimatic predictors, proposed by Michael S. O'Donnel and Drew A. Ingnizio [1], includes 19 climate indices, reflecting information on both annual conditions (annual mean temperature, annual precipitations sum, annual ranges of temperatures) and seasonal mean climate conditions and intra-year seasonality. Mean temperatures of the wettest and driest quarter, for example, are used for examining how these environmental factors affect species seasonal distributions.

The present article focuses on the two above-mentioned bioclimatic indices, while aiming to develop the remaining 17 indices for Republic of Moldova in the future works.

MATERIALS AND METHODS

As the initial data we had used data on monthly precipitation sums (1961-2020) and monthly mean temperatures (1961-2020) for 13 meteorological stations from State Hydrometeorological Service (table 1). We had derived 12 sets of consecutive three months of precipitations and temperatures, for the last set we had used two months of the next year (12th quarter of 2019 - December 2019 + January 2020 + February 2020) [1]. In order to calculate the necessary bioclimatic predictors, we identify three consecutive months with the highest/lowest total precipitation sum. If same sum of precipitation was recorded for two different quarters, we used the temperature data from the quarter that comes first in chronological order. We then calculate the average temperature for the three months with the highest/lowest cumulative rainfall, thus obtaining indices BIO8 and BIO9.

Table 1

Geographical coordinates of the meteorological stations used in this study

No	Meteorological station	Latitude (N)	Longitude (E)	Altitude (m)
1	Briceni	48°21’07.56’’	27°6’7.69’’	257
2	Soroca	48°11’54.76’’	28°18’42.66’’	171
3	Balti	47°46’28.69’’	27°57’2.33’’	102
4	Chişinău	46°58’24.31’’	28°51’07.36’’	172
5	Făleşti	47°34’59.77’’	27°42’18.77’’	160
6	Leova	46°29’18.38’’	28°17’01.12’’	159
7	Cahul	45°53’57.12’’	28°12’49.05’’	113
8	Comrat	46°18’10.09’’	28°37’45.63’’	136
9	Bravicea	47°22’20.09’’	28°26’18.08’’	79
10	Camenca	48°02’58.74’’	28°41’10.60’’	150
11	Balţata	47°03’19.24’’	29°02’09.94’’	78
12	Corneşti	47°22’01.66’’	27°59’38.31’’	234
13	Tiraspol	46°52’10.86’’	29°35’10.34’’	35

We had analysed temporal data for the obtained bioclimatic predictors BIO8 and BIO9 for the reference (1961-1990) and contemporary (1991-2020) periods in [2] Microsoft Excel 2010, trends statistics were analysed using Makesens 1.0 template, created by the researchers at the Finnish Meteorological Institute [3] and applying Mann-Kendall Test [4,5] and Sen’s slope [6]. The template makes it possible to estimate the sig-

nificance level α (0.001***,0.01** and 0.1+) by non-parametric methods and has been widely used world-wide in climatic and hydrological applications as in many cases meteorological and hydrological time series are not normally distributed, so the parametric methods are not applicable [7, 8, 9, 10, 11].

When performing the spatial distribution analysis of the indices, we had used the multiple linear regression equations in order to calculate the redistribution of climatic data in conditions of heterogeneous relief of the Republic of Moldova. We had chosen the equations that had the lowest mean absolute error, highest R^2 and are best fitted according to the observed-predicted plot. The physico-geographical layers used for the spatial models are absolute altitude and its derivatives (relative altitude, slopes, exposition) and latitude and longitude. The resolution of all the above-mentioned rasters was 200 meters.

The resulting equations were used to obtain cartographic models of spatial distribution of bioclimatic indices, using ArcGIS 10.2.2., Spatial Analyst /Map Algebra function. We had used the cartographic method known as choropleth maps with the unified color scheme for the legends, in order to demonstrate the climatic changes that may have occurred in the contemporary period in comparison to the reference one.

RESULTS AND DISCUSSIONS

When analyzing time trends, it is necessary to understand whether they are statistically reliable. The results of a similar Mann-Kendall test are shown in Table 2. The average temperatures of the wettest trimester underwent some changes over two thirty-year periods. Thus, if in the base period (1961-1990) only one station showed a statistically reliable growing trend, namely, Chisinau, then during the period of active climate change we observe a complete absence of any statistically reliable trends. Although, if we analyze the entire observation period (1961-2020), then several weather stations will immediately show statistically reliable growing trends, namely Bravicea, Briceni, the above-mentioned Chisinau, as well as Cornesti and Falesti. The other meteorological stations also demonstrate increasing trends, although they are statistically insignificant. The mean increase of the BIO8 index per decade in the whole 60 years period is equal to 0.43 °C per decade.

As for the average temperatures of the driest trimester, the situation here is even more interesting. The period taken as the basis for observations, 1961-1990, demonstrates a statistically reliable decreasing trend for seven out of thirteen weather stations, and the decrease over the decades is quite rapid, on average by -3.09 °C, if we take into account only those stations that demonstrated a statistically significant drop in values. However, over the next thirty years the situation changes dramatically. Now we are observing seven weather stations, with a slightly changed composition, demonstrating a statistically significant growing trend, with an increase of 2.78 °C per decade. If we take the entire observation period, the changes will remain statistically significant only for two stations: Chisinau and Falesti.

Table 2

BIO8 and BIO9 linear trends, °C\decade

Stations	1961-1990		1991-2020		1961-2020	
	BIO8	BIO9	BIO8	BIO9	BIO8	BIO9
Balţata	0.47	**-4.09***	0.21	**2.38+**	0.27	-0.43
Bălţi	0.28	-1.17	0.26	**2.73****	0.23	0.22
Bravicea	0.37	**-2.37***	0.56	0.96	**0.39+**	-0.41
Briceni	0.24	-2.11	0.29	1.29	**0.47****	-0.38
Cahul	-0.24	-1.3	0.12	**2.54***	0.22	0.52
Camenca	0	**-4.04***	0.11	0.86	0.07	-0.55
Chişinău	**1.25+**	**-2.85+**	0.34	**2.45+**	**0.43+**	**0.22+**
Comrat	0.34	**-2.77***	0.16	0.82	0.27	-1.01
Corneşti	0.84	-2.04	0.39	1.41	**0.51***	-0.38
Făleşti	-0.07	0.39	0	**1.73+**	**0.37+**	**0.58+**
Leova	0.37	**-3.24***	-0.08	**3.13***	0.4	0.26
Soroca	0.27	-2	0.2	**4.55****	0.14	0.24
Tiraspol	-0.16	**-2.34+**	-0.15	1.28	0.15	-0.06

Statistically significant trends are marked with bold; statistical significance α=0.1+; 0.05*;0.01**

The change in trend from decreasing to increasing is easy to explain if we take into account, firstly, the essence of the bioclimatic index BIO9, and secondly, the frequency of appearance of certain trimesters in the time series (table 3 and 4). In fact, both indices indicate not only the temperature regime characteristic of a particular period with excess or insufficient moisture, but also the specific three months that demonstrate this excess or insufficient moisture regime. An analysis of the frequency of certain trimesters in time series showed that, for example, in the case of temperatures in the dry trimester, there was a shift in the dry trimester from the ninth and first trimesters, that is, the cold period, to the winter period, which also included late autumn and early spring (11th and 2nd trimesters being third most frequent during 1991-2020).

Average temperatures, both during the winter period and during the transit periods, which are spring and autumn, show an increase in values, in full accordance with observations both in Moldova and at the international level [12, 13]. And this increase in temperatures causes a change in the trend of average temperatures in the dry trimester from decreasing to increasing over the past 30 years compared to the reference period.

Table 3

The most frequently occurring quarters for mean temperature of wettest quarter (BIO8)

Stations	BIO8, 1961-1990			BIO8, 1991-2020		
	m.f.*	second m.f.	third m.f.	m.f.	second m.f.	third m.f.
Chişinău	5	6	7	5	4	6
Briceni	5	4	6	5	6	7
soroca	5	6	7	5	7	4
Făleşti	5	6	7	5	6	4
Leova	5	6	7	5	6	7
Cahul	6	5	7	6	5	9
Comrat	5	6	11	5	6	9
Bravicea	6	5	7	6	5	4
Bălţi	5	6	7	5	4	7
Camenca	6	5	7	5	4	6
Balţata	5	6	7	5	4	6
Corneşti	6	4	5	5	4	6
Tiraspol	6	5	4	5	6	9

*m.f. –most frequent

Table 3

The most frequently occurring quarters for mean temperature of driest quarter (BIO9)

Stations	BIO9, 1961-1990			BIO9, 1991-2020		
	m.f.*	second m.f.	third m.f.	m.f.	second m.f.	third m.f.
Chişinău	8	9	1	1	12	2
Briceni	9	1	12	12	1	10
soroca	9	10	1	12	1	2
Făleşti	9	1	8	1	12	11
Leova	1	9	12	1	11	12
Cahul	9	1	8	1	12	11
Comrat	1	9	10	1	2	10
Bravicea	9	1	10	12	1	11
Bălţi	9	1	8	12	1	2

Camenca	1	9	10	1	12	11
Balţata	9	1	8	1	12	2
Corneşti	9	1	10	1	12	10
Tiraspol	9	1	12	1	12	2

*m.f. –most frequent

Of all the observed trends, the fact that the driest trimester is often not only occurs during the winter period, but also in the spring, is the most threatening for Moldovan agriculture [14, 15]. However, it should be noted that the duration of the dry period is one of the limiting factors for the spread of some invasive species, for example, the Asian ladybug or horsechestnut leafminer [16, 17].

Spatial modeling of average temperatures in the driest and wettest trimesters showed, first of all, a complex relationship between the physical and geographical features of the territory of the republic and the index BIO8 (table 4). The regression equation nevertheless models 97% of the available observation data (table 5).

Table 4

The parameters of bioclimatic index BIO8' multiple regression equation T = Ah*H + Ay*Y + Ahrelsq*Hrel*Hrel + Ahsq* Ah*Ah + Aslope*Slope + Aexp*Exp +C and BIO9' multiple regression equation T= Ay*Y +C

Bioclimatic index	P values for independent values' regression equations'						
	C	Ah	Ahrelsq	Ahsq	Aslope	Aexp	Ay
BIO8	0.0051	0.0008	0.0022	0.0037	0.0055	0.0034	0.0002
BIO9	0.0007	-	-	-	-	-	0.0013

Where C- constant, Ah– absolute altitude, Ahrelsq – relative altitude squared, Ahsq – absolute altitude squared, Aslope- slope's inclination angle, Aexp- exposition of the slope, Ay – latitude.

Table 5

Statistical parameters that explain BIO8 and BIO9 regression model

Indexes	Model's P value	R^2, %	Standard estimation error, ^oC	Mean absolute error, ^oC
BIO8	0.0009	97.3449	0.17328	0.0835628
BIO9	0.0013	70.1574	0.623484	0.465926

Zones highlighted in brown on the map are an ecological niche for those biological organisms whose development requires relatively high temperatures during periods

of maximum moisture, while zones highlighted in green are, on the contrary, for those species that do not require high temperatures during these periods (fig1.). There is also a quite obvious logical tendency for temperatures to decrease from south to north.

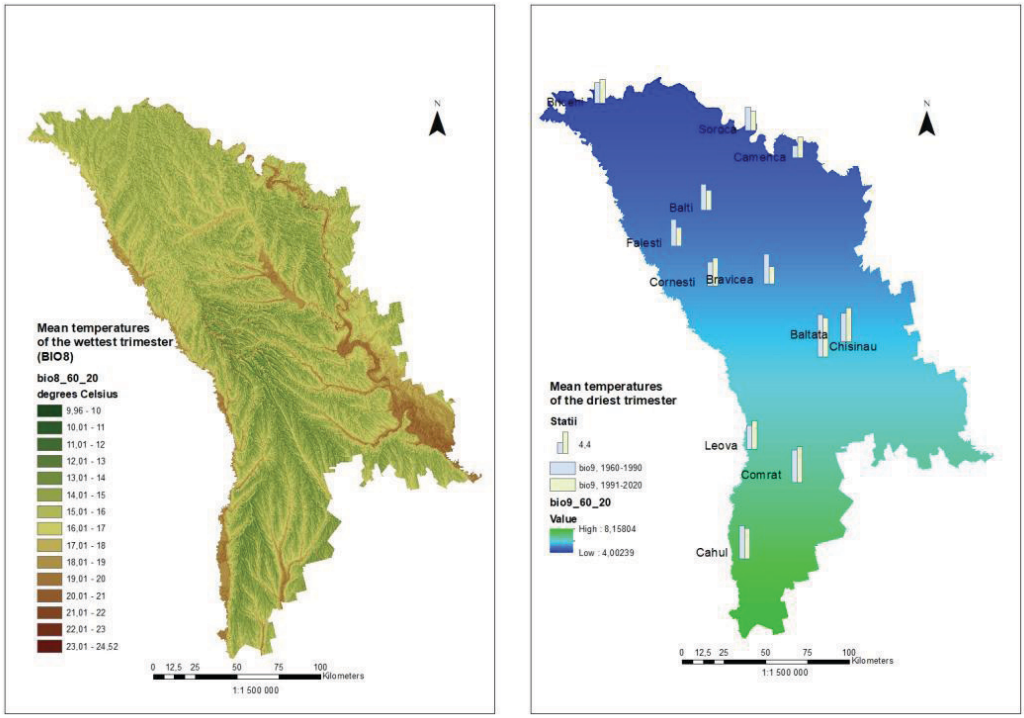


Fig. 1. Spatial distribution of mean temperatures of the wettest (left) and driest quarters, 1961-2020

The average temperatures of the driest trimester, on the contrary, have a very simple pattern. The model explains 70% of the observation data, and there is, again, a decrease in temperatures from 8°C in the south to 4°C in the north of the republic. We also showed the average value over 30 years for each weather station, for six stations it increased compared to the reference period.

CONCLUSIONS

Bioclimatic indices characterize climatic conditions that define the boundaries of ecosystems and biomes. Detailed, high-resolution GIS systems enable better prediction and analysis of these boundaries, which is especially important in the face of climate change. Average temperatures of the dry and wet trimesters were simulated for the first time for the territory of the Republic of Moldova with high resolution of 200 meters. Adding to this the remaining 17 bioclimatic indices will make it possible in the future to characterize any ecological biomes for the territory of the Republic of Moldova.

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