

ESTIMATION OF ENVIRONMENTAL QUALITY BASED ON ECOMETRIC CLIMATIC INDICATORS (ON THE EXAMPLE OF THE REPUBLIC OF MOLDOVA)

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Key words: Ecometric climatic indicators, environmental quality, dry and droughty periods, potential evapotranspiration

Abstract. Aridity in new climatic conditions requires indexes which could adequately explain this process. All the more so, the quantities of atmospheric precipitations also continue to increase on the background of the temperatures increase in the conditions of the Republic of Moldova. Their variable character in the last period of time with the installation of dry and droughty periods alternating with rainy flood-provoking periods determines the selection of the most optimal ecometric indexes that could correctly explain the occurrence of pronounced desertification in the last period of time.

Introduction

Climatic ecometric indexes (Stanciu, 2005), serve as indicators in estimating environment's quality using climatic parameters such as temperature and amount of atmospheric precipitation in the annual, seasonal or monthly aspect, air humidity, actual and potential evapotranspiration - climatic indexes considered to have a direct projection in estimating the degree of desertification of a territory. Thus, climatic ecometric indexes can express the deficit and the excess of humidity, and thus, the degree of desertification on the basis of the temperatures increase. We should note that the initial data was collected from the meteorological stations of the State Hydrometeorological Service.

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1. Initial materials and research methods

Thus the Republic of Moldova has a meteorological network that currently includes 17 meteorological stations. The latter has been doing observations over several decades. The study period ranged from 1961 to 2016, being mentioned as a contemporary period in previous research (Nedelcov, 2012). The collected database was stored in the EXCEL format, which was then used in the STATGRAPHICS CENTURION XVI software to perform various statistical calculations (fig. 1).

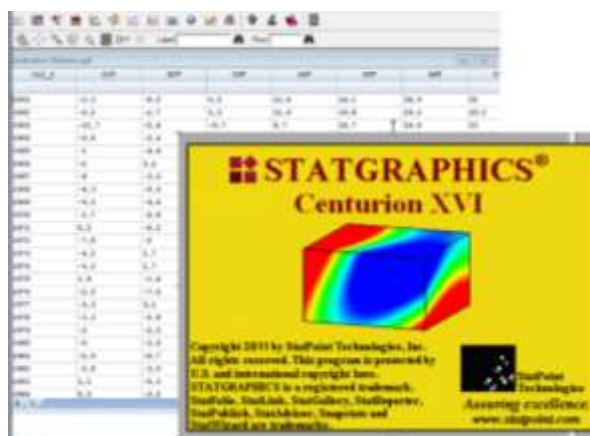


Fig.1. Statistical software Statgraphics Centurion XVI in statistical data processing

The data collected in the Surface Water Quality Guidelines elaborated by the State Hydrometeorological Service Anuar, 2015), according to the Water Pollution Index (IPA), had served as information support in the assessment of surface water quality. It should be noted that IPA is classified by 7 classes and is calculated by a fixed number of parameters (6) : ammonium nitrogen, nitrate nitrogen, petroleum products, phenols, dissolved oxygen and biochemical oxygen demand at 5 days.

To illustrate the sequence of rainy and arid months, the Lang Index (Ivanov, 2017) is used in the literature, which takes into account the precipitation-temperature ratio, serving as an indicator of the water inlet and outlet of the system, and the temperature serving as one of the main evapotranspiration factors:

$$R = \frac{P}{T} \quad (1)$$

The data in Table 1 reflects the numerical correlation between the Lang index and the characteristic climate of the area for which the assessment is made.

Table 1. The numerical correlation of the Lang index with the characteristic climate

R	Climate type
>160	Humid
160-100	Temperately humid
100-60	Temperately warm
60-40	Semiarid
40-20	Steppe
0-20	Desert

The definition of climatic types according to the Dantin-Revena coefficient (Stanciu, 2005), could complete the highlighting of the real degree of desertification on the territory of the Republic of Moldova in the context of climate changes (tab. 2). The Dantin-Revena thermo-pluviometric index (DR) was used more in the literature from abroad, and has the following aspect:

$$DR = \frac{100 \times T}{P} \quad (2)$$

where:

T - is the average annual temperature

P - The amount of annual rainfall

Table 2. Climate types definition according to Dantin-Revena Coefficient (DR)

DR	Climate
0-2	Humid
2-3	Semiarid
3-6	Arid
>6	Extremely arid (desert)

The edifying degree of continentality may also be the Diekman Index (Stoenescu, 1951). It is expressed by the difference between the sum of the precipitation quantities in the interval May-July and August-September interval (fig. 2).

In the temperate-oceanic climate with high autumn rainfall, the values of the difference are negative, in Central Europe the values approach 0, and in the continental climate, with abundant rainfalls at the end of spring and early summer, the values of the difference are positive, even exceeding the values of 100 mm (Stoenescu, 1951). For pluviometric stations with observation datasets longer than 40 years, in the Sub Carpathians of Moldova, the Diekman Indexes' (Id) difference values are all positive at values above 100 mm, highlighting a continental

precipitation regime. The highest values of the Diekman Index are recorded in sheltered areas with eastern exposure to the Carpathians, where convective processes are intense in the early summer (Stoenescu, 1951).

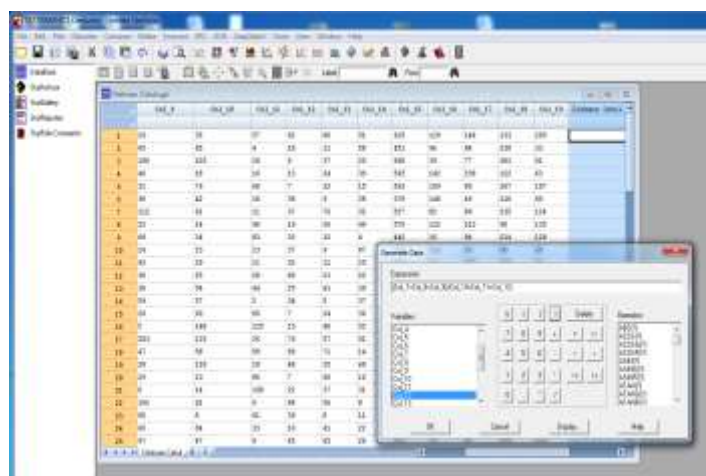


Fig. 2. Calculation of the Diekman Index (1981-2016)

The estimation of the uninterrupted duration with pluviometric deficiency during the year was performed based on the Gaussen ombrotermic diagram (Stanciu, 2005), which allows the graphical demonstration of the relationship between temperature and precipitation. The construction of the diagram is based on a double scalar rectangular system consisting of a horizontal axis and two vertical axes. The modality of construction included: drawing on the horizontal axis of the months of the year; on the left vertical axis - the average monthly temperature (5 °C); and on the left vertical axis - the monthly average values of rainfall, which is double when compared with the temperature (10 mm), were placed. It is important to mention that depending on the location of the two curves with respect to each other (the thermal curve is the red one and the ombric one - blue), the humidity deficiency interval is determined, i.e. if the thermal curve exceeds the ombric. In most cases, this coincides with the summer period.

One of the basic indexes reflecting the degree of aridity of a territory is the Aridity Index (Ia) proposed by UNEP (1992) and UNESCO (1979) being expressed as the ratio between the amount of atmospheric precipitation and evaporability (Păltineanu et al, 2007).

$$Ia = \frac{P}{E0} \quad (3)$$

Depending on the regional variation of its values, four categories of aridity for territories were established on global level (UNEP, 1992).

Table 3. UNESCO / UNEP classification of land according to degree of aridity

Category	Aridity index	Global area (%)
Hyperarid	< 0.05	7.5
Arid	0.05 -0.20	12.1
Semi-arid	0.20 -0.50	17.7
Dry subhumid	0.50 -0.65	9.9

Therefore, the UNESCO/UNEP aridity index shows the existence or absence of humidity deficiency in the analyzed area (tab.3). The limit between the semi-arid climate and the dry subhumid one is 0.50 units - a limitation in the characterization and conditions of aridity on the territory of the Republic of Moldova.

2. Analysis of the obtained results

Therefore, traditionally, the estimation of the degree of moisture assurance is performed on the basis of the Seleaninov hydrothermal coefficient (CHT) (Nedealcov, 2012).

Climate change in recent years, as shown by previous research, has a substantial influence on its values, as demonstrated by the digital map of its distribution in space with the inclusion of numerical values in recent years (fig. 3).

So, the estimation of the degree of aridity by means of the hydrothermal coefficient Seleaninov does not adequately reflect the state of the present climate on the territory of the Republic of Moldova.

To obtain comparative estimates to previous research (Nedealcov, 2012), the Aridity Index (Ia) was calculated for the vegetation period taking into account the entire updated period (1961-2016).

We were able to conclude that it reaches the limit of 0, 20 units that characterize the climate as arid in the temporal aspect in the south of the country in certain specific years (fig. 4), and especially in the last decades. These values are substantially different from the values that characterize the north of the country, where it varies within limits exceeding the climate characterized as dry-subhumid (0.65).

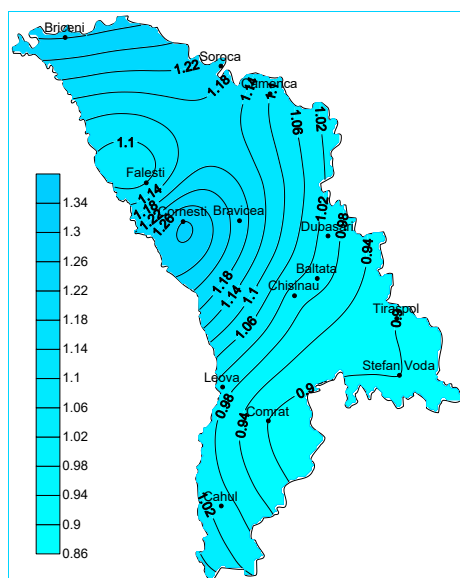


Fig. 3. Spatial distribution of Sleaninov hydrothermal coefficient (1960-2016)

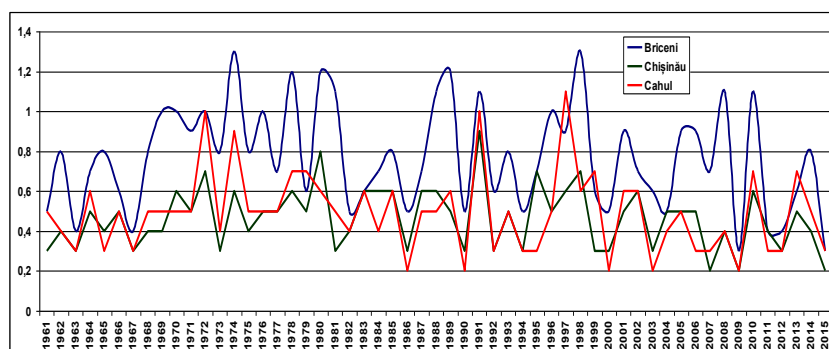


Fig. 4. Time analysis of the Aridity Index (Ia) for the Republic of Moldova territory

The cartographic modeling of I_a reveals the fact that the climatic conditions are characterized by the limit (0.5) between the semi-arid and dry climate during the vegetation period according to the values at Balti Steppe (to the north), in the south, southeast and the central-eastern part of the country (fig. 5). Values above 0.68 are characteristic for altitudinal territories in the northern and central parts of

the country. We also should mention that values are lower than those obtained in previous research, which serves as evidence that climatic conditions became more arid during the growing season.

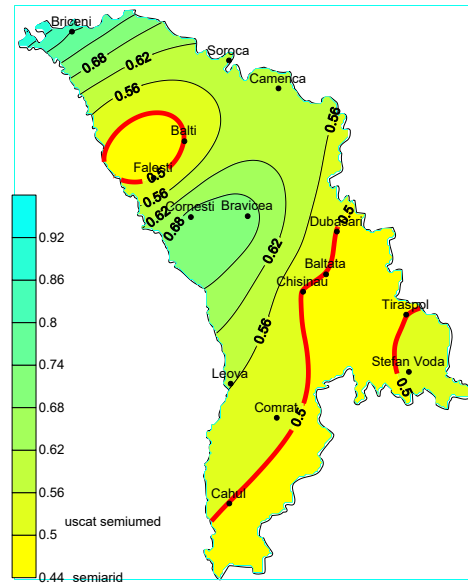


Fig. 5. The spatial distribution of aridity Index (Ia) (1960-2016)

Therefore, the increase in thermal maximums, the installation of dry periods in the last period of time, the tendency to intensify the evaporation process, the numerical increase of the values that characterize the climatic water deficit condition the estimation of the complex indexes by which the degree of continentality of a regional climate can be made evident. According to (Stoenescu, 1951; Anuar 2015), the Diekman Index (Id) can be considered as an edifier of continentality according to the atmospheric precipitation regime. It is expressed by the difference between the sum of the precipitation quantities in the May-July and August-September interval (fig. 6.a). In Fig. 6.b. modified Id data is presented taking into calculation October for the second interval as in recent years there is an essential change in the atmospheric precipitation regime. Regardless of the fact that in the second case the Id values are diminished for the last years, we consider it useful to introduce the October in calculation in order to highlight the actual manifestation of the pluviometric regime in the context of the regional climate warming.

a

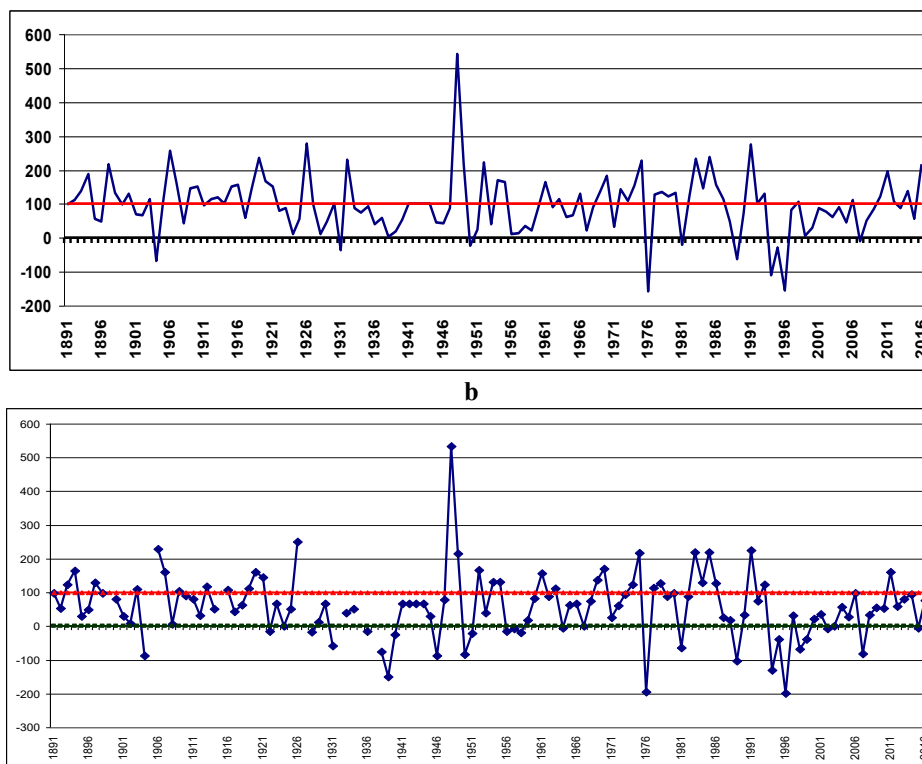


Fig. 6. Multiyear dynamics of Diekman Index, m. Chisinau (1891-2016)

Thus, the analysis of the multiannual dynamics of the Diekman Index over a period of more than a century demonstrates that in most years it has positive values and expresses the degree of continentality of regional climate. The period with the significant values of Id when these exceed the limit of 100 mm belongs to the end of the 40s and to the beginning of the 90s of the last century when the precipitation in May, June, July prevailed over the pluviometric quantities observed in August, September and October (fig. 6 a, b).

Absolute maximum values date back to 1948, when they were 533 mm (tab. 4), the multiannual average being 59.7 mm. The calculation of the intensity and frequency of the Diekman Index reveals (tab. 4) that the variability limits were between 45.7 and 140.9 mm during the series of instrumental observations in 54 cases and in 14 cases they were characterized by values of 140.9 ... 236.2 mm, fact confirmed by the analysis of the graph of the quintile proportion of the indexes (fig. 7).

Table. 4. Id's intensity and frequency, m. Chisinau (1891-2016)

Class	Lower limit	Upper limit	Frequency	Relative frequency
1	-240,0	-192,381	2	0,0168
2	-192,381	-144,762	1	0,0084
3	-144,762	-97,1429	2	0,0168
4	-97,1429	-49,5238	8	0,0672
5	-49,5238	-1,90476	13	0,1092
6	-1,90476	45,7143	23	0,1933
7	45,7143	93,3333	31	0,2605
8	93,3333	140,952	23	0,1933
9	140,952	188,571	8	0,0672
10	188,571	236,19	6	0,0504
11	236,19	283,81	1	0,0084
12	283,81	331,429	0	0,0000
13	331,429	379,048	0	0,0000
14	379,048	426,667	0	0,0000
15	426,667	474,286	0	0,0000
16	474,286	521,905	0	0,0000
17	521,905	569,524	1	0,0084

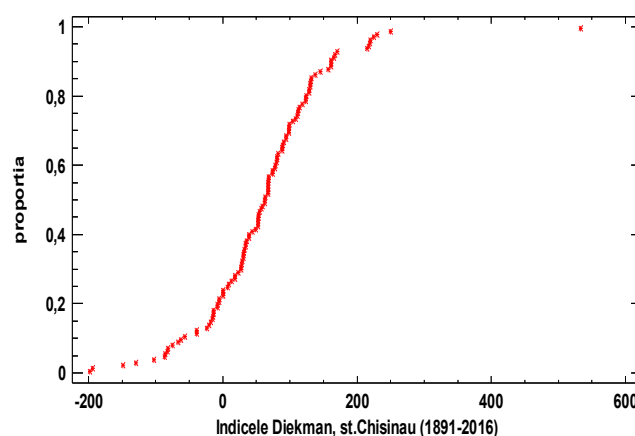


Fig. 7. Quantities of the Diekman Index calculated for the period of instrumental observations (1891-2016)

Aridity in new climatic conditions requires indexes which could adequately explain this process. All the more so, the quantities of atmospheric precipitations also continue to increase on the background of the temperatures increase in the

conditions of the Republic of Moldova. Their variable character in the last period of time with the installation of dry and droughty periods alternating with rainy flood-provoking periods determines the selection of the most optimal econometric indexes that could correctly explain the occurrence of pronounced desertification in the last period of time.

The spatial estimation of the maximum values of the Diekman Index recorded in 1948 (fig. 8) indicates that the most vulnerable territory for the increase of continentality was the territory located in the western central part, where the most essential pluviometric values prevailed for May, June July compared with August, September, October.

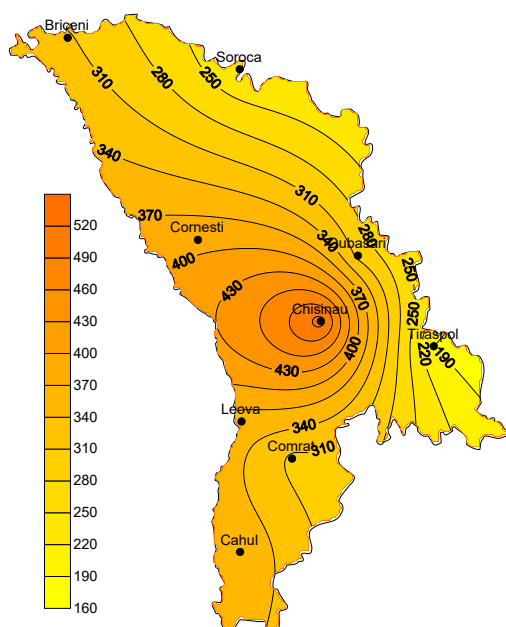


Fig. 8. The maximum values of the Diekman Index on the territory of the Republic of Moldova, 1948

In conclusion we find that the precariousness of the fall of the atmospheric precipitation in the second half of the warm season and the decrease of the rainfall in May, June and July fall within the limits of the corridor with values from 0 to 100 mm. At the same time, in the certain years that have been characterized as dry such as 2007, 2012 the degree of aridity has extremely dangerous influence on the quality of surface waters. These relate to the development of a registry with

several indexes that characterize the degree of climate continentality in order to highlight the desertification process in the context of climate change.

In our opinion, one of these indexes is the Lang (I_L) econometric index that can illustrate both the rainy and arid months sequence. It takes into account the precipitation - temperature ratio, as an expression of water inlet and outlet of the system, temperature being one of the main factors of evapotranspiration. The results obtained are extremely useful in the current estimation of regional surface water resources.

The calculation of the statistical indexes revealing the multiannual average for the last period of time (1961-2016) shows that according to I_L , the north of the country is characterized by warm temperate climate (76.2) and in the central and southern part according to the values of this index (55.4 ... 53.3), the climate is characterized as semiarid. The most insignificant values of the Lang Index (I_L) in the north of the country constituted 36.1, in the central part - 31.9 and in the south the lowest values were 29.8. At the same time, the highest values of I_L were registered in the northern republic, representing 121.5. The essential variability of this index is also expressed by the sigma values (tab. 5).

Table 5. Statistical indexes that characterize the Lang Index (I_L)

Statistical indexes	Briceni			Chişinău			Cahul		
	I_L annual	I_L summer	I_L July	I_L annual	I_L summer	I_L July	I_L annual	I_L summer	I_L July
X	76,2	12,9	4,9	55,4	8,9	3,1	53,3	9,0	2,9
σ	20,7	4,2	3,3	12,7	3,2	1,8	13,5	4,0	2,1
Minimum	36,1	2,9	0,2	31,9	2,7	0,2	29,8	2,6	0,0
Maximum	121,5	23,3	16,3	85,8	17,6	7,6	53,3	9,0	2,9

Therefore, the great climatic variability of the Lang Index determines the specificity of its manifestation in the new climatic conditions. The analysis of its annual manifestation shows that in 41 cases in 55 years, in the north, the climate has been characterized as a warm temperate climate. As we move towards the central regions, only in 20 cases the climate was characterized as warm, in 28 cases it was established as a semiarid.

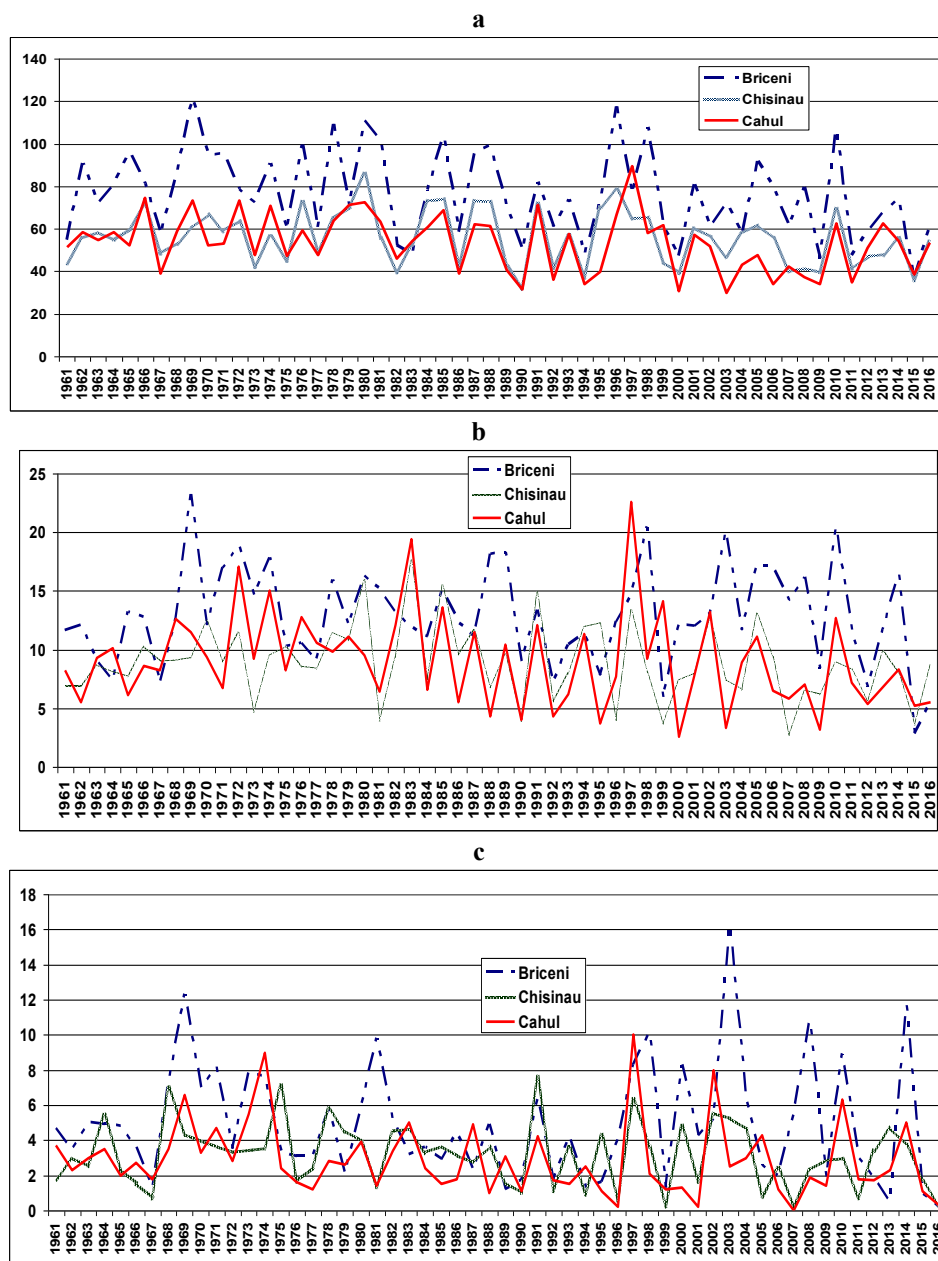


Fig. 9. Dynamics of the Lang (I_L) ecometric index, in annual (a), seasonal (b), monthly (c) aspects

The number of cases with a steppe climate increases from 1 to 7. The years with warm temperate climate continue to decrease and the years with steppe climatic up to 25 continue to increase in the south of the country. It increases significantly, i.e. up to 13 cases, when the climate was characterized as steppe (fig. 9).

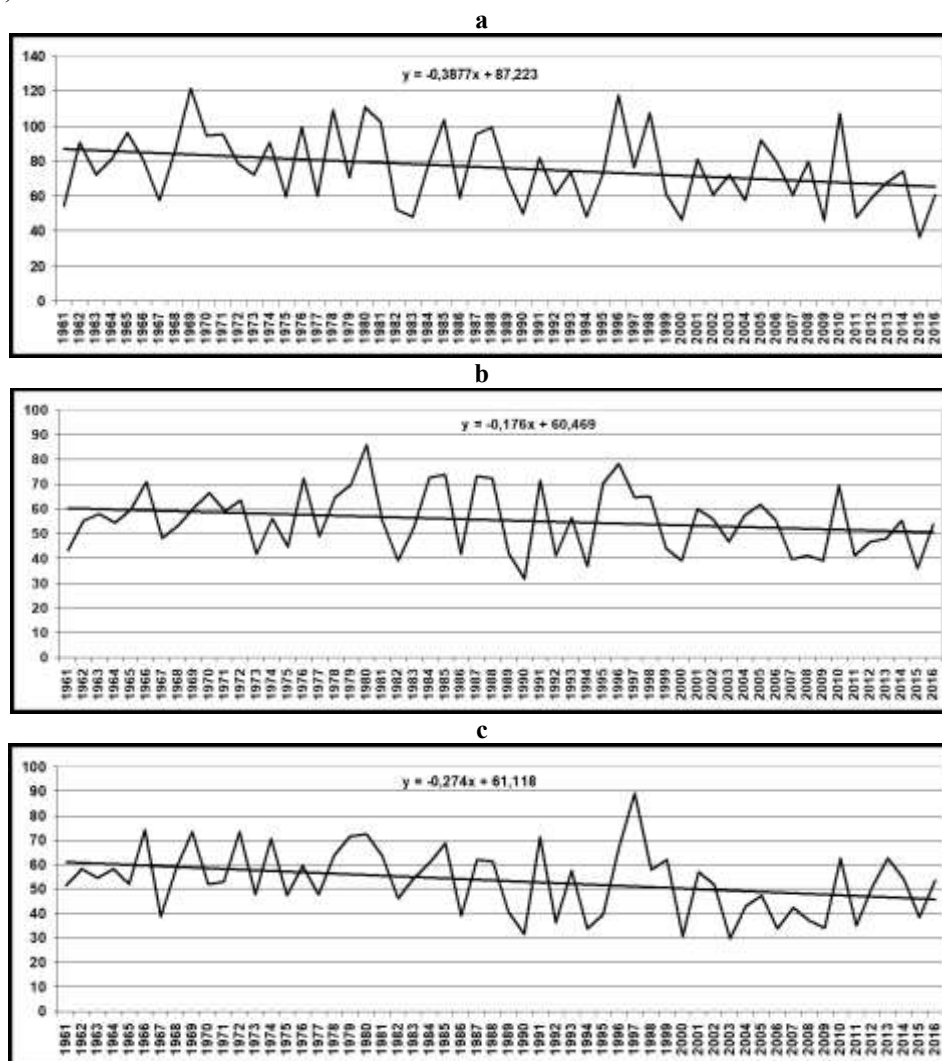


Fig. 10. The regional trends of the Ecometric Lang Index (I_L), a-Briceni, b-Chisinau, c-Cahul

According to its analysis at smaller scales, namely in the seasonal and monthly aspect (Fig. 9 b, c), we note that the climate is characterized as desert throughout the country.

The trend with which this phenomenon manifests (fig. 9 a, b, c) demonstrates that the desertification process will continue throughout the country in the future. At the same time, we find that in the north of the country (fig.10 a) this trend is much more pronounced, which is necessary to be taken into account in the monitoring of surface waters limited in the conditions of the current climate.

Thus, under the conditions of climate change, we observe a decreasing tendency for values and therefore the process of desertification intensifies on the territory of the Republic of Moldova (fig.10 a, b, c), especially in the summer season.

The analysis of the low values of the Lang Index (Table 6) shows that of the top 10 years with the most significant values 5 years in the northern part of the country, 6 years in the center and 7 years in the south of the country belong to the last two decades (2000-2015), which allows us to conclude that the process of desertification is intensifying recent time.

Table 6. Years with the lowest values of the Lang Index (1961-2016)

Briceni		Chişinău		Cahul	
Anii	I _L	Anii	I _L	Anii	I _L
2015	36,1	1990	31,9	2003	29,8
2009	45,9	2015	35,8	2000	30,5
2000	46,5	1994	36,7	1990	31,6
2011	47,8	2000	39	1994	33,9
1994	48	1982	39,2	2006	33,9
1983	48,2	2009	39,2	2009	34
1990	49,7	2007	39,8	2011	35
1982	52,3	2008	41,2	1992	36,2
1961	54,5	2011	41,2	2008	37,3
2004	57,2	1992	41,3	2015	38,5

The estimation of the uninterrupted rainfall duration during the year based on the Gaussen ombrothermic diagram shows that it varied significantly from north to south in some years.

Thus, for example, in 2015 the pluviometric deficiency in the north of the country was installed between May and September, in the center - in April and in the south of the country the longest duration with a pluviometric deficit was

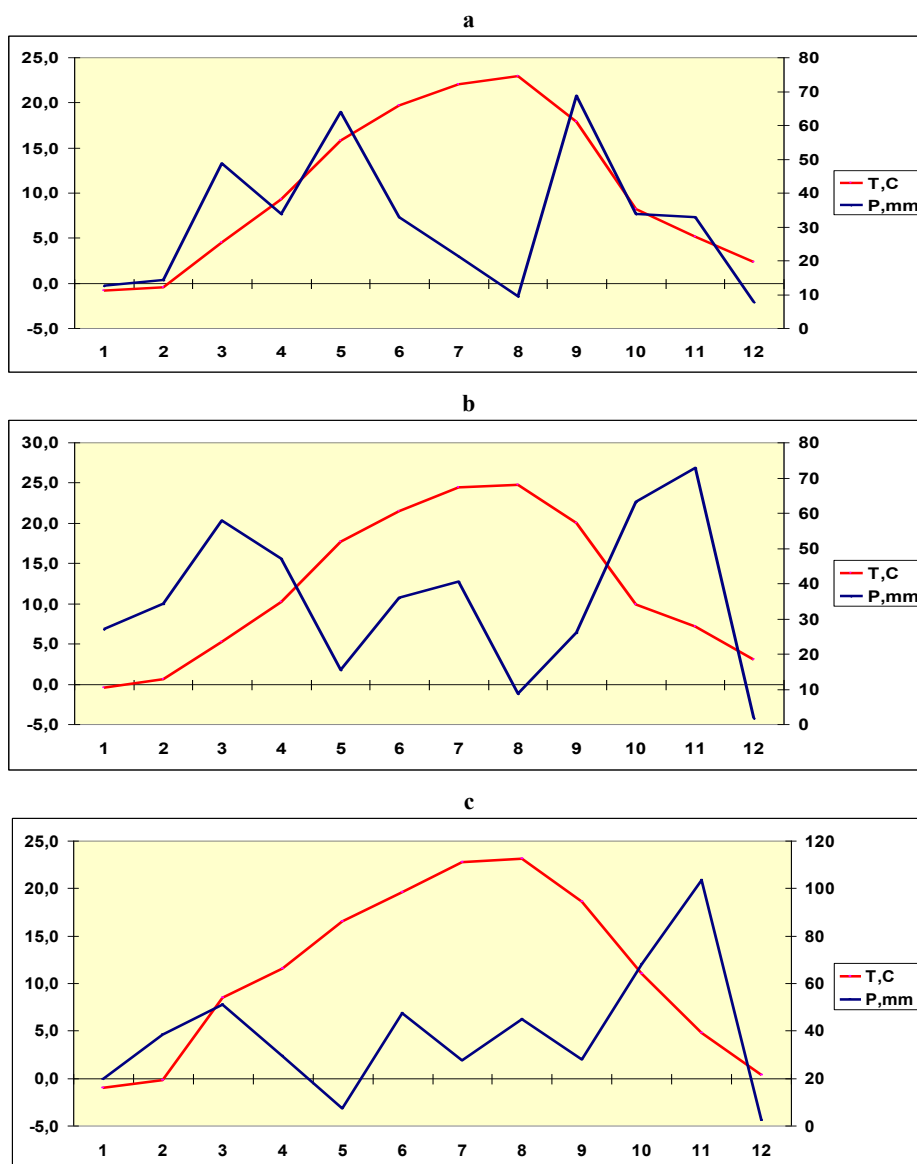


Fig. 11. Gausson's ombrothermic diagram (a- Briceni, b-Chisinau, c-Cahul)

registered from March to October (fig.11a, b, and c). Undoubtedly, these evaluations are extremely useful in the realistic estimation of aridity conditions in

the context of climate change, especially in countries with unstable humidity regimes of which the Republic of Moldova is a part.

The obtained results lead to the conclusion that in some extreme years the uninterrupted dry periods can essentially vary in the territory and hence influence the quality of the surface waters differently. We consider it useful to apply a series of climatic ecometric indexes that could scientifically argue the manifestation of this process in order to concretize the specificity of aridity in the new climatic conditions.

Together with some ecometric indexes described above, the Dantin-Revena coefficient was also taken into account. It emphasizes on climate continentality and reveals that in present, 20 -22 cases of semi-arid climate were established, especially in the central and southern part of the country (fig. 12), in the south of the country the climate was characterized as arid during five years.

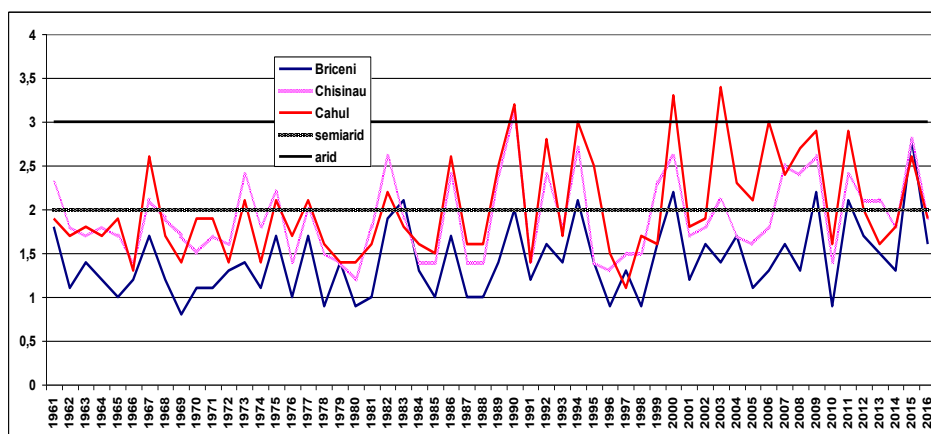


Fig. 12. Evolution the Dantin-Revena coefficient (1961-2016)

Thus, the climate was established as semiarid in 6 cases (1983, 1994, 2000, 2009, 2011, and 2015) in the north of the country, in Briceni. Arid conditions, according to the Dantin-Revena Coefficient, were not recorded for the study period (1961-2016) in this area of the country. 20 years (1961, 1967, 1973, 1975, 1982, 1986, 1989, 1990, 1992, 1994, 1999, 2000, 2003, 2007, 2008, 2009, 2011, 2013, and 2015) with semiarid climatic conditions, and 1990 was classified as arid in the central part of the country, in Chisinau. Semiarid climatic conditions were established during most of the years (1967, 1973, 1977, 1982, 1986, 1989, 1990, 1992, 1994, 1995, 2000, 2003, 2004, 2005, 2006, 2007, and the southern climate was recorded as arid during 5 years (1990, 1994, 2000, 2003, 2006) (fig.12).

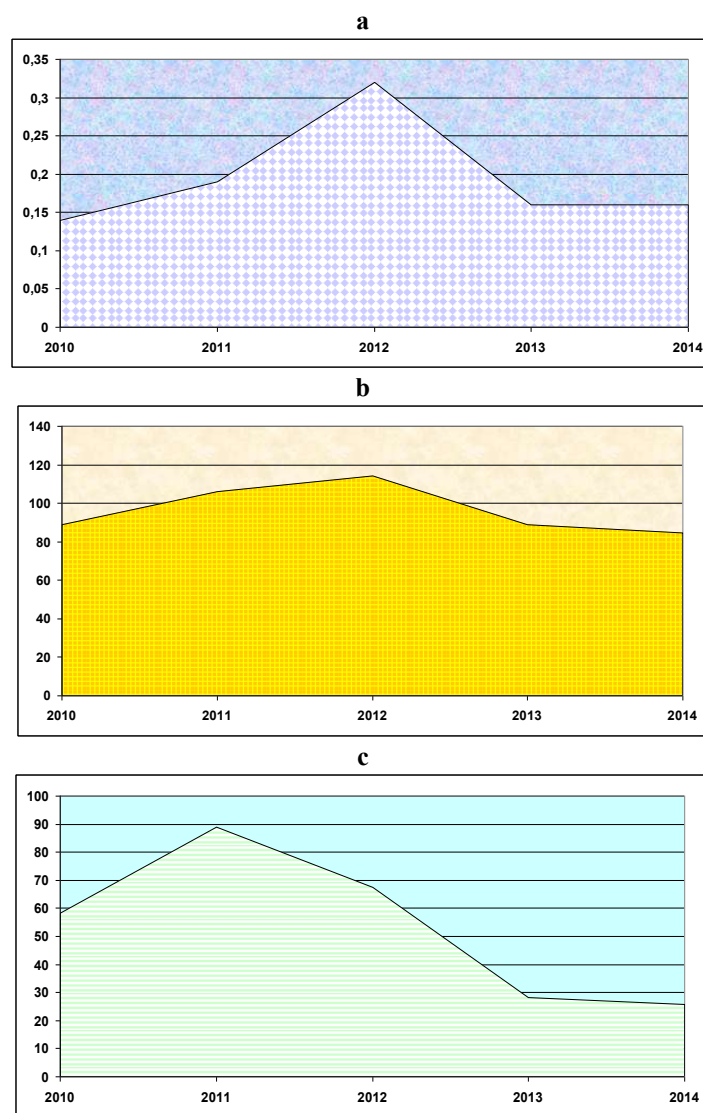


Fig. 13. The values of dissolved oxygen (a), ammonium ion pollution (b), and oxygen's biochemical consumption (c) in 5 days (CBO₅)

According to the data of the physico-chemical investigations carried out by the State Hydrometeorological Service during the year 2015, the quality of the Dniester River corresponds to the third class (moderately polluted) in all the

monitored sections, except for the south-east of the country (Palanca village), where the water quality is attributed to the fourth (polluted) class, due to the low dissolved oxygen concentrations, largely determined by the establishment of the uninterrupted droughts that year. The monitoring of the water quality in Prut on the territory of the Republic of Moldova, performed monthly in 8 sections reveals the fact that for most of the sections monitored on the Prut River was certified as the second quality class except for the village of Lipcani, which was assigned quality class I. So, in the northern part of the Prut basin, the highest quality class is attributed to oxygen. During the last 5 years, the quality of Prut water, according to the IPA, is characterized by a level of pollution with non-essential deviations. The IPA ranged from 0.62 (Class II - Clean) in Ungheni t. section, 2010, up to 1.34 (class III - moderately polluted) in Valea Mare v. section in 2013. Regarding the quality of water in Danube River during the last 5 years, in the monitoring section of the DMCM – Giurgiulesti v., a slight increasing trend is observed in the level of pollution in the dry years in the region (2011, 2012, 2014) (according to IPA) due to the increased evaporability within this area.

So, in certain years, the quality of the Dniester, Prut, Danube Rivers (fig.13 a, b, c) can undergo essential changes, characterized by moderate pollution due to biogenic elements, copper compounds, phenols, petroleum products.

The quality of water in small rivers can be characterized by a high degree of pollution with ammonium ions, nitrite, copper compounds, with a high level of biochemical oxygen demand (CBO_5) and a low level of oxygen dissolved in water - determined to a great extent also by the increase of the desertification, especially in the south of the country, where this influence is felt more significantly (fig. 13).

Therefore, highlighting the regional particularities of desertification in the new climate conditions requires the indexes which could adequately explain this process. The results obtained are extremely useful in the proper management of surface water resources. It has been found that, the level of eutrophication increases in extremely dry years, and the degree of water pollution may double due to the concentration of pollutants as a result of increased evaporability.

Conclusions

In conclusion we would like to state that the uneven distribution of water resources and climatic changes, which has become more and more obvious in recent years, can lead, according to the estimates, to the occurrence of arid areas in the south and south-east of the country.

The results of the research on the impact of climate change on water resources imply the long-term development of new criteria and techniques for estimating the degree of desertification, including the involvement in research of a huge amount

of data and corresponding econometric climatic indexes. This is also conditioned by the fact that the countries of South-Eastern Europe where the Republic of Moldova is also situated, as opposed to the countries of Western and Northern Europe, are characterized by the lack of sufficient water resources, are at risk of becoming countries with an additional factor limiting economic development unless a strict policy of rational water use is promoted.

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