Spatial and temporal relevance of some bioclimatic indexes for the study of the bioclimate of Moldova (west of the Prut river)

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ABSTRACT: This study originated in the necessity to identify usable bioclimatic indexes with good results in the overall bioclimatic characterization of Moldova west of the Prut River (hereinafter Moldova). For reasons related to the extent of the text, we have analyzed only a part of the bioclimatic indexes known in the literature (TEE - Equivalent Effective Temperature, THI - Thermo-hygrometric index, DI THOM - Thom Discomfort Index, RSI - Relative Strain Index, HI Heat index, HUMIDEX - HUMIDEX index, SSI - Summer SIMMER Index, ISE - Summer SCHARLAU Index, ISH - Winter SCHARLAU index and Pr - Wind-chill Index). Considering the large number of indexes (which vary in their structure and limitations of use) and a representative number of stations (14 stations), we have based our analytical approach on a standard time interval equal to one month. We have thus acquired a temporal resolution that enables us to identify the representativeness or non-representativeness of these indexes for Moldova and also their relevance / usefulness in depicting distinctive or detailed features of the Moldova bioclimate.

KEYWORDS: bioclimatic indexes, bioclimatic comfort or discomfort

1. Introduction

The issue of temporal and spatial relevance of some bioclimatic indexes for Moldova occurred when these indexes were computed based on monthly averages of temperature, humidity, effective surface tension of water vapours and wind speed. These data were used to determine monthly and seasonal values of 10 bioclimatic indexes.

The purpose of these calculations and analyses was to identify the mean bioclimatic coordinates for specific times of the year, with direct reference to the Moldova air space. Our analysis starts with these results.

Following the analysis of the temporal patterns and spatial distribution of the 10 indexes (TEE Equivalent Effective Temperature, THI - Thermo-hygrometric index, DI THOM - Thom Discomfort Index, RSI - Relative Strain Index, HI - Heat index, HUMIDEX - HUMIDEX index, SSI - Summer

SIMMER Index , ISE - Summer SCHARLAU Index, ISH - Winter SCHARLAU index and Pr - Wind-chill Index), we were able to identify both their limitations with respect to the studied territory and the temporal resolution at which these indexes are relevant.

Therefore, we provided answers to a series of questions such as: i) are monthly averages of temperature, humidity, surface tension of water vapours, wind speed, provided by the National Meteorological Administration (A.N.M) network, sufficient to facilitate bioclimatic studies for a specific territory (in our case Moldova)? ii) to what temporal level should we detail the bioclimatic analysis? iii) which bioclimatic indexes would best support our approach?

2. Study Area

The investigated area is located between the northern Romanian border with Ukraine, the eastern border with the Republic of Moldova, the western limits of the counties of Suceava, Neamţ, Bacău and Vrancea (roughly corresponding to the central axis of the Eastern Carpathians), and in the south the southern limits of the counties of Vrancea and Galaţi approximately placed on the contact line between the Moldova Plateau and the Romanian Plain Figure 1.

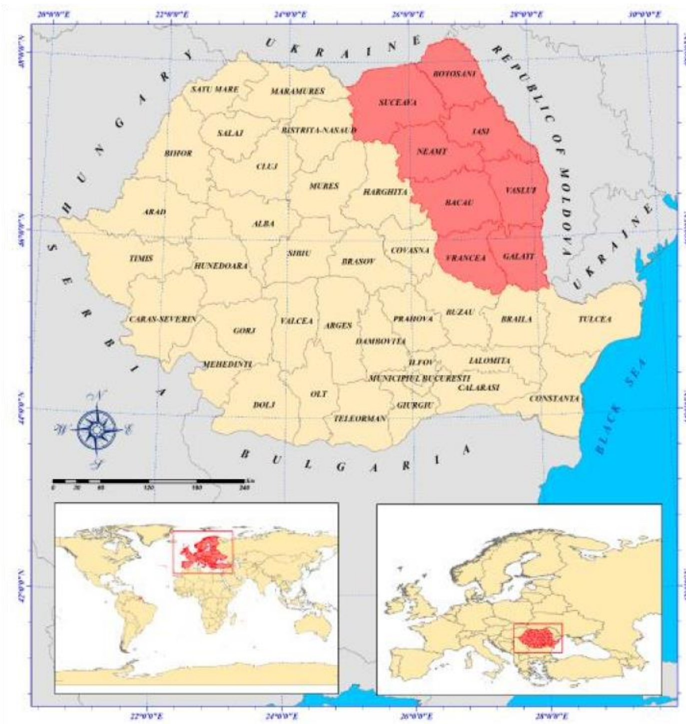


Figure 1. Location of the region of Moldova in Romania and its main the presence in the west administrative divisions, i.e., counties (Carpathians,

The temperate transition climate of our study area, resulting from the mathematical position on the Globe (48° 15' 43.329" - 45° 24' 1.5011"N and 24° 57' 47.0502"28° 15' 8.4509" E) and in Europe is nuanced by the following particularities: the nonlinear, often controversial development of the main pressure systems of Europe; the latitude differences between the northern and the southern extremities of the studied territory (2˚51'42.28"); the elevation differences of 2003 m a.s.l. (between the ridges or peaks of the Carpathians and the meadow plains in the south and southeast);

Subcarpathians and center (Central Moldavian Plateau) of forested landscapes; the extent and volume of lakes or humid areas (especially along river valleys); a series of local, but relevant events related to atmospheric dynamics (foehn winds, mountain-valley winds) etc.

3. Material and methods

To achieve the main objectives of this study we used monthly averages of air temperature, relative air humidity, water vapor pressure and wind speed recorded at 14 meteorological stations in the period 1961-2013 (Table 1). The database was provided by the National Meteorological Administration.

Tabel 1 The meteorological stations in Moldova ordered north to south, according to latitude

No	Meteorological Station	Altitude (m a.s.l.)	Latitude	Longitude
1	Rădăuţi	383	47˚ 50' 16.222" N	25˚ 53' 25.562" E
2	Botoşani	121	47˚ 44' 08.274" N	26˚ 38' 43.907" E
3	Suceava	356	47˚ 37' 58.368" N	26˚ 14' 25.924" E
4	Cotnari	275	47˚ 21' 29.882" N	26˚ 55' 32.206" E
5	Poiana Stampei	917	47˚ 19' 28.730" N	25˚ 08' 03.977" E
6	Iaşi	99	47˚ 10' 15.416" N	27˚ 37' 41.819" E
7	Roman	221	46˚ 58' 08.707" N	26˚ 54' 42.515" E
8	Ceahlău Toaca	1805	46˚ 58' 38.978" N	25˚ 56' 59.718" E
9	Vaslui	101	46˚ 38' 45.966" N	27˚ 42' 51.898" E
10	Bacău	182	46˚ 31' 54.803" N	26˚ 54' 44.984" E
11	Târgu Ocna	239	46˚ 16' 21.702" N	26˚ 38' 27.673" E
12	Bârlad	173	46˚ 13' 58.931" N	27˚ 38' 39.909" E
13	Focşani	49	45˚ 41' 15.047" N	27˚ 11' 59.134" E
14	Galaţi	67	45˚ 28' 22.469" N	28˚ 01' 56.159" E

Statistical and mathematical methods were employed for meterological data processing, using the functions implemented in the Microsoft Excel program. Mapping was performed using ArcGIS 9.3.1 software, which enabled us to construct the cartographic material. Linear regression and ordinary kriging were basic working methods employed in the construction of maps. The resulting cartographic material was further subjected to critical analysis. Comparison of the temporal trends and spatial distribution of the obtained results enabled us to identify the applicability ranges of the selected indexes.

4. Results and Discussion

The first index referred to in our analysis was the equivalent effective temperature - TEE (°C). We used the equation proposed by Missenard, 1937 (Krawczyk, 1975; Teodoreanu, 2003; 2007), and the calculation formula [1] which did not require the wet-bulb temperature values:

$$TEE = 37 - \frac{37 - t}{0{,}68 + 0{,}00014f + \frac{1}{1{,}76 + 1{,}4v^{0{,}75}}} - 0{,}29\left(1 - \frac{f}{100}\right) \qquad [1]$$

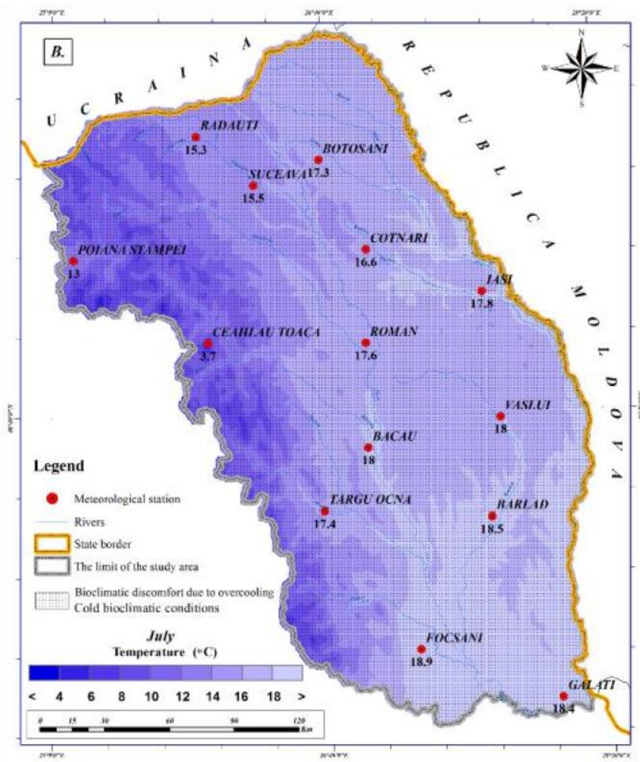
where: t - the dry-bulb air temperature (°C), v - the wind speed (m/s) and f - the relative humidity (%).

The index is applicable to air temperatures between + 20°C and + 45°C and atmospheric pressure values between 800 and 1100 hPa. At temperatures higher than 45°C with variable humidity and atmospheric pressure, the TEE index indicates only extreme values depicting conditions of intense heat.

Table 2 shows the conditions and types of bioclimatic comfort or discomfort corresponding to different values of TEE (°C).

a) TEE index (°C)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
TEE ≤ 27	Cold	Bioclimatic discomfort due to overcooling
27 < TEE ≤ 34	Cool	
34 < TEE ≤ 47	Comfort	Bioclimatic comfort
47 < TEE ≤ 51	Warm	Bioclimatic discomfort due to overheating
TEE > 51	Hot	

Because of the limitations of use, the TEE bioclimatic index was computed only for June, July and August.



Using monthly averages of meteorological elements in the calculation of TEE generated unreliable results, even for the three summer months for which the index is applicable. This can be clearly observed in the resulting cartographic outputs (of which we selected the map for July – Figure 2) where, even for the hottest month of the year, the 'bioclimatic discomfort due to overcooling' characterizes the entire territory of Moldova and does not reflect the real climatic and bioclimatic conditions.

Therefore, based on the obtained results and the climatic and bioclimatic features of our study area as highlighted by numerous studies (ref), we recommend using the TEE index only for shorter time intervals (hours to days) and solely

Figure 2 The spatial distribution of TEE index values to characterize the thermal and in Moldova for July (1961-2013) hygric conditions of air baths.

The thermo-hygrometric index - THI (°C) or the thermal stress indicator is a computational variation of the Thom discomfort index. It is obtained based on relative air temperature and humidity, thus being avoided the use of wet-bulb temperature which is largely unavailable at Romanian meteorological stations.

The calculation formula used in this paper for THI [2] was proposed by Kyle in 1994:

$$THI\,°C = T_{usc} - (0.55 - 0.0055 \cdot UR) \cdot (T_{usc} - 14.5) \quad [2]$$

where: Tusc is the dry-bulb air temperature (°C) and UR is the relative air humidity (%).

THI can be calculated for the entire year and is applicable to each month of the year. The drawback of this index is that for values higher than THI 30°C, it indicates only hot intervals, no matter how high air temperature and how variable air humidity are. THI thresholds correspond to different conditions, from excessively cold to very warm and torrid (Tabel 2).

Tabel 2 The THI threshold values (°C) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) THI index (°C)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
-20 < THI ≤ -10	Excessive cold	Bioclimatic discomfort due to overcooling
-10 < THI ≤ -1.8	Very cold	
-1.8 < THI ≤ +13	Cold	
+13 < THI ≤ +15	Cool	
+15 < THI ≤ +20	Comfortable	Bioclimatic comfort
+20 < THI ≤ +26.5	Warm	Bioclimatic discomfort due to overheating
+26.5 < THI ≤ +30	Very hot	
THI > 30	Torrid	

In the absence of any temporal and meteorological limits of applicability, the thermohygrometric index THI can be calculated for every month of the year and provides meaningful results for Moldova.

Tabel 3 Monthly and annual average values of THI in Moldova (1961-2013)

Meteorological station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
Rădăuţi	-2.8	-1.4	2.7	8.8	13.9	16.7	17.9	17.2	13.2	8.5	3.5	-1.1	8.1
Botoşani	-1.5	0.1	4.5	10.7	15.5	18.3	19.6	18.9	15.0	10.1	5.1	0.4	9.7
Suceava	-2.4	-1.0	3.0	9.2	14.1	16.8	18.2	17.6	13.8	9.1	4.0	-0.7	8.5
Cotnari	-1.1	0.0	4.3	10.3	15.4	18.3	19.6	19.2	15.4	10.6	5.2	0.5	9.8
Poiana Stampei	-5.4	-3.6	0.3	5.5	10.5	13.4	14.8	14.3	10.4	5.8	0.9	-3.9	5.3
Iaşi	-1.7	0.1	4.8	11.2	16.0	18.8	20.2	19.5	15.6	10.7	5.3	0.3	10.1
Roman	-2.6	-0.8	3.9	10.3	15.2	18.0	19.4	18.8	14.9	9.9	4.5	-0.7	9.2
Ceahlău Toaca	-6.4	-6.9	-4.5	0.2	5.6	8.4	10.1	10.0	6.4	3.1	-1.2	-4.9	1.6
Vaslui	-2.0	-0.2	4.4	10.8	15.7	18.6	20.0	19.4	15.3	10.3	5.1	0.0	9.8
Bacău	-2.0	-0.2	4.3	10.5	15.5	18.4	19.9	19.2	15.1	10.1	4.9	-0.1	9.6
Târgu Ocna	-0.9	0.5	4.5	10.3	15.0	17.9	19.3	18.7	14.8	10.0	5.2	0.7	9.7
Bârlad	-1.5	0.4	5.0	11.2	16.1	19.2	20.6	20.1	16.0	10.9	5.6	0.4	10.3
Focşani	-1.0	1.0	5.8	11.8	16.7	19.8	21.2	20.6	16.7	11.4	5.9	0.7	10.9
Galaţi	-0.6	1.2	5.7	11.6	16.5	19.6	21.2	20.7	16.8	11.8	6.3	1.2	11.0

Very cold	Cold	Cool	Comfortable	Hot

THI monthly values accurately encompass the annual succession of bioclimatic conditions in the targeted locations – Tabel 3. We therefore suggest that THI monthly values are representative for the bioclimatic characterization of Moldova, as they accurately depict the bioclimatic features of this territory. Provided that we add diurnal or hourly data to our analysis of this index, the results will likely be more applicable, clearer and more varied.

The Thom Discomfort Index (DI THOM) (°C). This index was proposed by Thom and Bosen in 1959. In the literature it is regarded as one of the best/most representative indexes for assessing effective temperature. DI THOM discomfort index values express the combined effect of temperature, humidity and air dynamics on the sensations of heat or cold felt by the human body.

The DI THOM index can be computed based on several formulas, of which we selected the formula [3]. This formula does not include wet-bulb air temperature, unavailable for our study area.

$$DI\,Thom\,(°C) = (0.8 \cdot T_{usc}) + [0.08 \cdot (U_r - 3.2)] \quad [3]$$

where: Tusc is the dry-bulb air temperature (°C) and Ur is the relative humidity.

The relationship between the values of DI THOM, bioclimatic conditions and human body thermal reactions are shown in Table 4.

Table 4 The DI THOM threshold values (°C) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) DI THOM (°C)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
DI < 21	Comfort	Bioclimatic comfort
21 ≤ DI < 24	Slight discomfort	Bioclimatic discomfort due to overheating
24 ≤ DI < 27	Moderate discomfort	
27 ≤ DI < 29	Enhanced discomfort	
DI > 29	Risk of heat shock	

It is applicable for the temperature interval of 21 - 47 °C (dry-bulb air temperature). Given the temperature range of applicability and the obtained results, in our study area the timeframe for calculating the DI THOM index is restricted to the months of July and August.

For Moldova, DI THOM was calculated based on monthly temperature and relative humidity. We show that the obtained results are not representative even for the two months of applicability, i.e., July and August. More specifically, the spatial distribution of the discomfort index DI THOM for each of the above mentioned months (of which we selected July - Figure 3) suggests that Moldova is entirely characterized by conditions of bioclimatic comfort. Such a result does not agree with the real climatic conditions, primarily in low elevation plain areas, where heat discomfort types generally prevail during summer. However, DI THOM index may be applicable to Moldova for time intervals of one to several days with warm to hot conditions.

The Relative Strain Index (RSI). According to Chang (1992), this index was calculated based on a reference system represented by a 25 years old medium-sized man, in good health, dressed in work clothes and seated. RSI enables an assessment of the heat stress conditions and is applicable to the investigated area only for the summer season, but with restricted use.

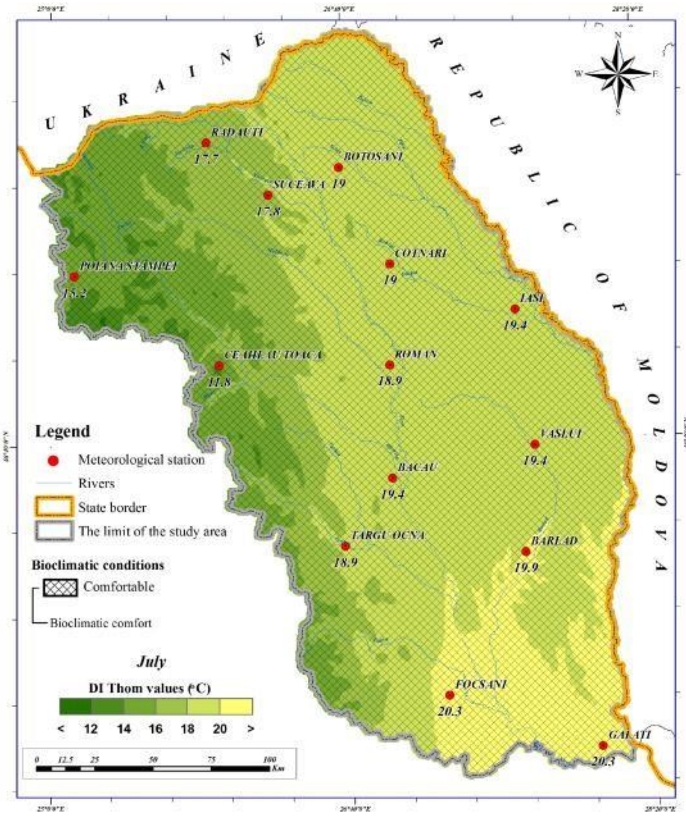


Figure 3 The spatial distribution of DI THOM index values in Moldova for July (1961-2013)

More specifically, at temperatures below + 26 °C and relative humidity variations, RSI always shows values characteristic of the bioclimatic comfort category; moreover, the

RSI interval +26° - +35°C indicates generalized discomfort for the entire population, whereas above + 35 °C it shows enhanced discomfort.

RSI index values are calculated based on the dry-bulb air temperature (°C) and the pressure of water vapor (hPa) with the formula [4]

$$RSI = \frac{T_{usc} - 21}{(58 + e)} \qquad [4]$$

where:

Tusc is the dry-bulb air temperature (°C) and e - the water vapor pressure (hPa).

The relationship between RSI values and induced bioclimatic conditions is shown in Table 5.

Table 5 The RSI threshold values (units) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) RSI index (units)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
RSI ≤ 0.15	Comfort	Bioclimatic comfort
0.15 ≤ RSI ≤ 0.25	Discomfort for sensitive people	Bioclimatic discomfort due to overheating
0.25 ≤ RSI ≤ 0.35	Discomfort for all people	
RSI > 0.35	Enhanced discomfort for many people	

The index allows an assessment of the heat stress conditions and is partially applicable to Moldova, however, only during the summer but not when based on the monthly averages of meteorological elements. This is because in Moldova the monthly average temperatures from June to August do not exceed 23 °C even in the south and southeastern parts. We therefore suggest that RSI should be computed for Moldova only using daily averages or hourly values.

Our recommendation is to use RSI in analyzing the relationships between climate and population during tropical heat waves (during summer or the warm season) or in situations of massive warming due to prolonged anticyclone conditions.

The Heat index - HI (°C) or apparent temperature (TA) allows an assessment of bioclimatic discomfort from exposure to weather conditions characterized by high values of air temperature and relative humidity. The equation for calculating this index [5] was obtained by Steadman based on a multiple regression analysis, following a study conducted and published in 1979.

HI is computed with the formula:

$$\begin{aligned} \boldsymbol{HI} = &-42.379 + 2.04901523 \cdot (T_{usc}) + 10.14333127 \cdot (UR) \\ &- (0.22475541 \cdot (T_{usc}) \cdot (UR)) - \left(6.83783 \cdot (10^{-3}) \cdot (T_{usc}{}^{2})\right) \\ &- (5.481717 \cdot (10^{2}) \cdot (UR^{2})) + \left(1.22874 \cdot (10^{-3}) \cdot (T_{usc}{}^{2}) \cdot (UR)\right) \\ &+ ((8.5282 \cdot 10^{-4}) \cdot (T_{usc}) \cdot (UR^{2})) \\ &- \left(1.99 \cdot (10^{-6}) \cdot (T_{usc}{}^{2}) \cdot (UR^{2})\right) \quad [5] \end{aligned}$$

where: Tusc is the dry-bulb air temperature (°C) and UR is the relative air humidity (%).

The study performed by Steadman (1979) describes the bioclimatic conditions of 'humid heat' felt by various human subjects who were exposed to various environmental conditions. The equation for determining HI is only applicable for air temperatures higher than 27°C and relative air humidity exceeding 40%.

The complex relationships between different values of HI, the bioclimatic conditions and the sensations felt by the human body are shown in Table 6.

Table 6. The HI threshold values (˚C) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) HI index (°C)	b) Bioclimatic conditins	c) Type of bioclimatic comfort/discomfort
HI < 27	Comfort	Bioclimatic comfort
27≤ HI < 32	Caution	Bioclimatic discomfort due to overheating
32≤ HI < 40	Alert	
HI > 40	Danger	

In Moldova the average monthly temperature was below 23 °C, whereas the relative humidity exceeded 75% on average for each month and with equal spatial distribution. Moldova does not fall within the limits of applicability of this index when multi-annual monthly averages of temperature and humidity are used for its calculation. For specific instances occurred within a month, identifiable in the database of the stations particularly located in the south, east and southeast, this index can be applied. In other words, at a daily or hourly temporal resolution, there can be identified numerous instances when temperature rises beyond certain thresholds (during tropical and torrid days, heatwaves or sultriness) and the HI index is higher than the alert threshold (over 32°C HI), inducing bioclimatic discomfort due to overheating. Therefore, for Moldova we recommend using this index only to quantify the relationship between bioclimate and population during summer days, tropical or torrid days, heatwaves and sultriness, with due attention to the lower thresholds of applicability.

The HUMIDEX index (expressed in °C) was calculated based on physiological studies conducted in Canada in 1965, which took into account the combined effect of temperature and air humidity (the latter being expressed by the actual water vapor pressure). The calculation formula for this index is [6]:

$$HUMIDEX = T_{usc} + \left(0.555 \cdot (e - 10)\right) \quad [6]$$

where: Tusc is the dry-bulb temperature (°C) and e - the actual vapor pressure (hPa).

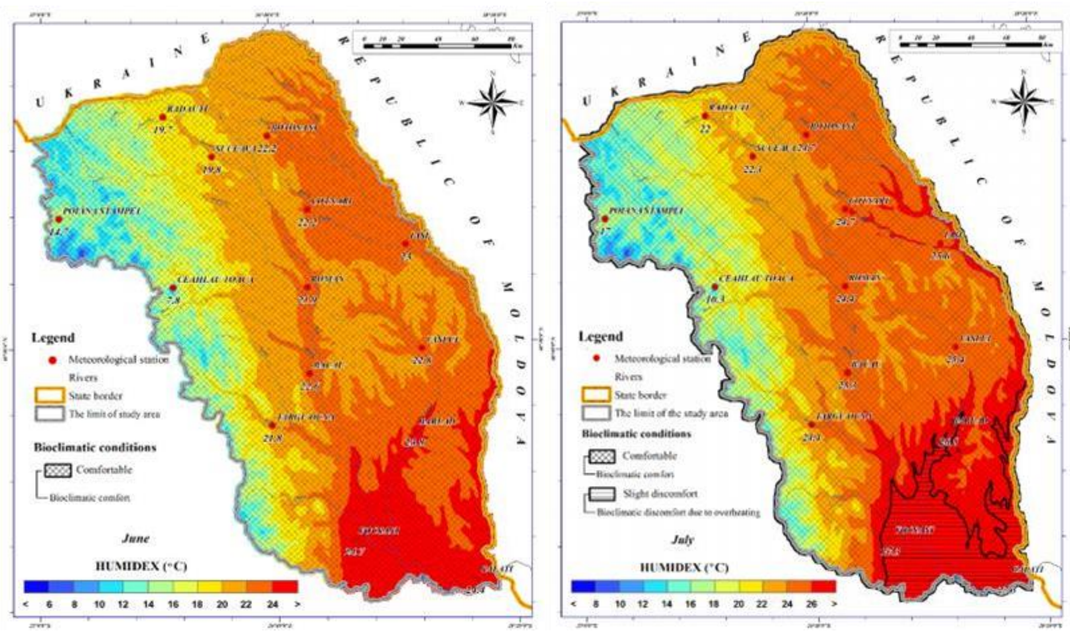
The equation proposed by Masterton and Richardson (1979) can be applied with valid results only for air temperature values between +20°C and + 55°C. The complex relationships established between the different HUMIDEX values and the sensations felt by the human body are mathematically presented in Table 7.

Table 7 The HUMIDEX threshold values (°C) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) HUMIDEX (°C)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
H < 27	Comfort	Bioclimatic comfort
27 ≤ H < 30	Little discomfort	
30 ≤ H < 40	Discomfort	Bioclimatic discomfort due to overheating
H > 40	Great discomfort	

For Moldova, the HUMIDEX index could be calculated only for June, July and August.

In June (Figure 4), the spatial distribution of HUMIDEX values indicates bioclimatic comfort for the entire study area. However, the bioclimatic reality of this month is more nuanced, but these aspects are not evident when using monthly averages of temperature and humidity for the calculation of HUMIDEX.



Figures 4 and 5 The spatial distribution of the HUMIDEX index in Moldova for June and July (19612013)

July is characterized by the persistence of bioclimatic comfort over 85-90% of the territory of Moldova. Bioclimatic discomfort due to overheating appears in the south eastern part, where the index rises beyond the threshold of 27°C (Figure 5). There are, without doubt, other areas of Moldova apart from the south-eastern extremity (such as the low elevation areas located in Moldova Plain) which, for timeframes shorter than one month (several days), exhibit discomfort due to overheating, blurred mainly by the temporal resolution of our analysis.

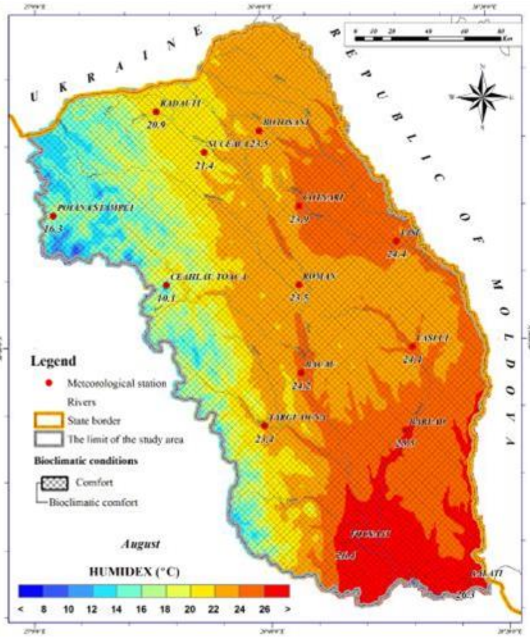


Figure 6. The spatial distribution of the HUMIDEX index in Moldova for August (1961-2013)

For August, HUMIDEX monthly values show that bioclimatic discomfort moves towards the Romanian Plain, and bioclimatic comfort is present throughout the entire study area (Figure 6). The known bioclimatic reality only partly agrees with the obtained results.

Therefore, based on the previous findings, we suggest this index should be used only in bioclimatic analyses of shorter time intervals, i.e., several days or during certain days. Extending the analysis to longer timeframes could lead to partially correct results (as in the case of analyses performed on monthly averages), or non-representative and even erroneous results (the case of analyses performed on seasonal averages).

The Summer SIMMER Index - SSI (°C). This bioclimatic discomfort index was presented at the 80th conference of the American Meteorological Association, which was held in Long Beach, California on June 11, 2000. The index is a new version of the summer SIMMER index, first calculated by *John Pepi* and published in *Weatherwise* Journal, issue 40, in 1987.

This index describes the heat stress conditions during the warm season. It was calculated based on physiological models and human trials conducted over the course of 75 years by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Kansas State University.

The summer SIMMER index was tested physiologically and confirmed by objective scientific laws. It is a complex indicator of the state of bioclimatic comfort / discomfort.

The calculation formula proposed by *Pepi* in 2000 is:

$$SSI = 1.98 \cdot \left(T_{usc} - (0.55 - 0.0055 \cdot (UR)) \cdot (T_{usc} - 58)\right) - 56.83 \quad [7]$$

where: Tusc is the dry-bulb temperature (°C) and UR the relative air humidity (%).

SSI can be calculated only for air temperatures between +22°C and +53°C. Above +53°C, the index displays only values indicating a very warm bioclimate which induces bioclimatic discomfort enhanced due to overheating. The relationships established between SSI, resulting bioclimatic conditions and the sensations felt by the human body are rendered in Tabel 8.

For Moldova, the conditions of applicability of the SSI index are met in July and August. The applicability values were determined for July and August only at the meteorological stations Vaslui, Bârlad, Focşani and Galaţi.

Tabel 8 The summer SIMMER index threshold values (˚C) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) SSI index (°C)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
SSI < 20.9	Cold	Bioclimatic discomfort due to overcooling
20.9 ≤ SSI < 24.7	Cool	
24.7 ≤ SSI < 28.0	Comfort	Bioclimatic comfort
28.0 ≤ SSI < 32.4	Warm	Bioclimatic discomfort due to overheating
32.4 ≤ SSI < 37.4	Hot	
37.4 ≤ SSI < 44.0	Very hot	

Considering these two months (of which we exemplify with July - Figure 7), the SSI values up to 14°C show that bioclimatic discomfort due to overcooling prevails in our study area, together with a cold bioclimate which would cause the largest part of the population to experience a slight discomfort by cooling. This result is contrary to the reality even in high mountain areas . We therefore believe that this index cannot be used with satisfactory results in the bioclimatic characterization of Moldova, neither for the two summer months and nor for the 4 meteorological stations for which we have identified applicability temperature values.

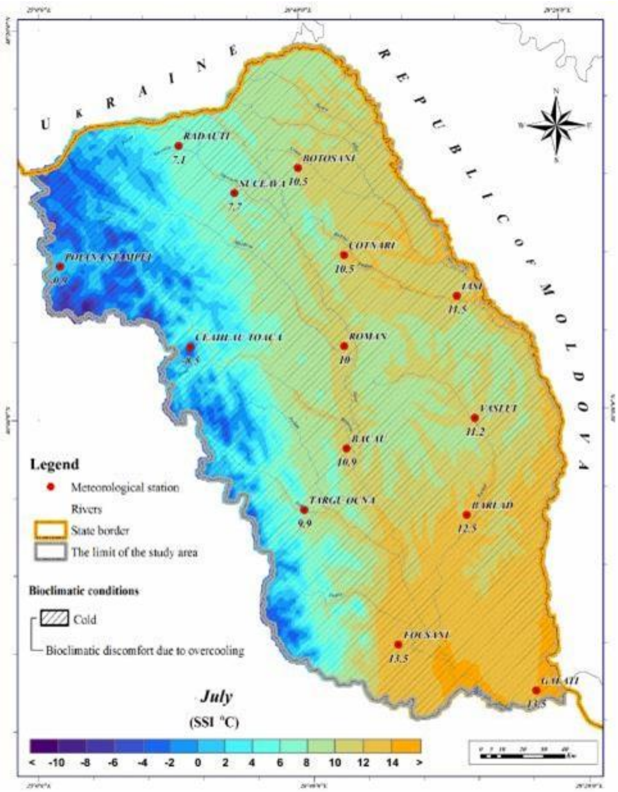


Figure 7 The spatial distribution of the SSI index in Moldova for July (1961-2013)

The summer SCHARLAU index can be calculated according to the thresholds of applicability only for relative humidity values higher than 30%, air 39°C and atmospheric calm. Under variable humidity and at temperatures lower than +17°C, conditions are created that describe a relative state of bioclimatic comfort; in situations when temperature is higher than +39°C, conditions are met that induce a state of increased discomfort mainly caused by overheating.

The relationships between ISE, resulting bioclimatic conditions and the sensations felt by the human body are quantified and shown in Tabel 9.

Table 9 The ISE index threshold values (units) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) ISE (units)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
IS ≥ 0	Comfort	Bioclimatic comfort
-1 < IS < 0	Little discomfort	Bioclimatic discomfort due to overheating
-3 < IS ≤ -1	Moderate discomfort	
IS ≤ -3	High discomfort	

The actual value of the SCHARLAU index is given by the difference between the critical temperature (Tc) and the local dry-bulb temperature (Tusc), according to the formula [8]:

$$ISE = Tc - T_{usc} \quad [8]$$

and

$$Tc = (-17.089 \cdot \ln(UR)) + 94.979 \quad [9]$$

where: UR is the relative humidity (%).

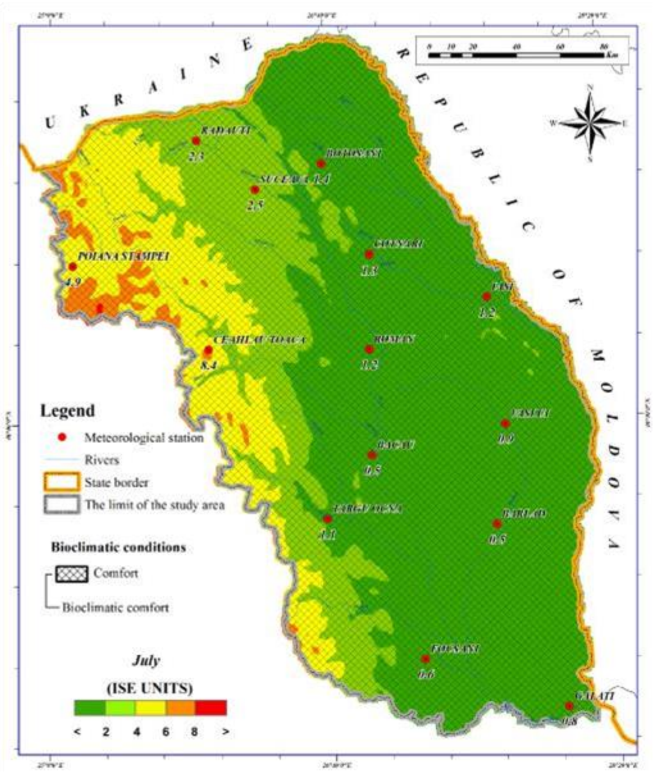


Figure 8 The spatial distribution of the ISE index in Moldova for July (1961-2013)

This difference (ΔT) can be positive, when local temperature (Tusc) does not exceed critical temperature (thus not generating discomfort), and negative when local temperature exceeds critical temperature (which causes discomfort by overheating, whose low/ moderate / high intensity will depend on ΔT values).

The Winter SCHARLAU index (ISH) (expressed in units). According to the methodology for calculating ISH, for the temperature interval 5°C to +6°C, any relative humidity value higher than 40% is associated to a critical air temperature value, for which in the absence of wind, the human body begins to feel discomfort by overcooling as a result of unfavorable bioclimatic conditions of humid cold. Provided that humidity is variable (from 40 to 100%) and temperatures are higher than +6°C, conditions are met for a relative state of bioclimatic comfort, whereas at temperatures below -5°C, conditions for high bioclimatic discomfort occur.

The quantifiable relationships between the values of ISH, the ISE can be calculated for our study area from May to September. However, for this interval, its values indicate only climatic comfort. We exemplify with the hottest month of the year (Figure 8), to show the drawbacks of using the index for the bioclimatic characterization of Moldova. Thus, calculated based on monthly averages of temperature and relative humidity, this index shows no real relevance. For shorter time intervals (days, hours) the relevance increases.

Table 10 The ISH index threshold values (units) a), bioclimatic conditions b) and the relationship with the thermal sensations felt by the human body c)

a) ISH (units)	b) Bioclimatic conditions	c) Type of bioclimatic comfort/discomfort
IS ≥ 0	Comfort	Bioclmatic comfort
-1 < IS < 0	Little discomfort	Bioclimatic discomfort due to overcooling
-3 < IS ≤ -1	Moderate discomfort	
IS ≤ -3	High discomfort	

ISH is calculated based on the formulas [10] and [11]:

$$ISH = T_{usc} - Tc \quad [10]$$

where: T_{usc} is the local dry-bulb temperature and Tc is the critical temperature.

This last parameter of the formula [10] is calculated using the formula [11]:

$$Tc = (-0.0003 \cdot UR^2) + (0.1497 \cdot UR) - 7.7133 \quad [11]$$

where: UR is the relative air humidity (%).

The difference between TUSC and Tc can be either positive, when local temperature is higher than critical temperature (which does not cause discomfort), or negative when local temperature is lower than critical temperature. The latter causes discomfort by overcooling, and the intensity of the discomfort rises with the increase in the ΔT negative values, i.e., below 0.

For Moldova, this index can be applied with relevant results for 9 months of the year, from September to May.

We argue here the relevance of the ISH index with selected cartographic material for 5 out of the 9 relevant months for which we conducted the analyses.

The mapping of the ISH values (Figures 8 Figure 12. The spatial distribution of the ISH index 12) shows a logical progression of the for May in Moldova (1961-2013) succession of the bioclimatic types from

September to May. Consequently, we suggest that ISH can be used with conclusive results in bioclimatic studies of Moldova for the time interval September - May. For this timeframe, ISH can be calculated from monthly, daily or hourly averages of temperature and relative humidity.

The Wind-chill Index (Pr) (kcal/m2/h). Pr was formulated based on an experiment conducted by Paul Siple and Charles Passel, during an expedition in Antarctica in the winter of 1941.

The cooling process of the human body is very complex and depends on the heat sensitivity of the human subject exposed to cold, health condition, age, gender, clothing, diet and caloric intake etc.

Pr expresses the intensity of caloric losses (W) suffered by the unit of body surface (m2) per unit time, by combining multiple physical processes such as radiation, conduction, convection and evaporation (Ionac and Ciulache, 2008).

The wind intensifies convection and evaporation processes on the surface of exposed skin, often with negative consequences in winter and positive in summer.

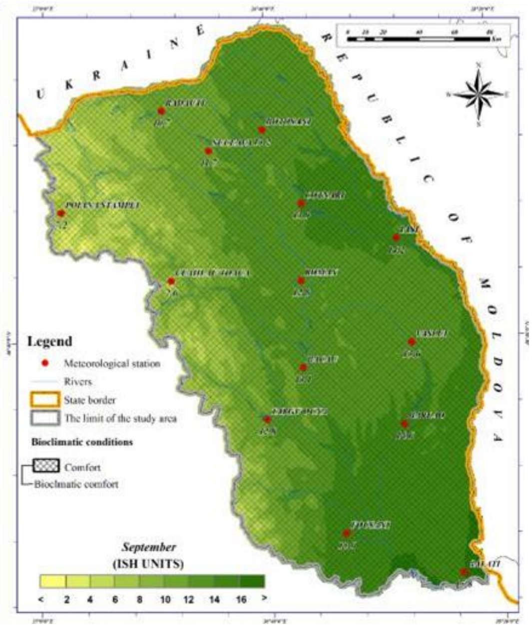
Globally, there have been several attempts to establish such an index. In the literature there are several formulas for calculating the Pr (the latest version proposed by Kursch et al. 2004 and now recognized by the W.M.O.).

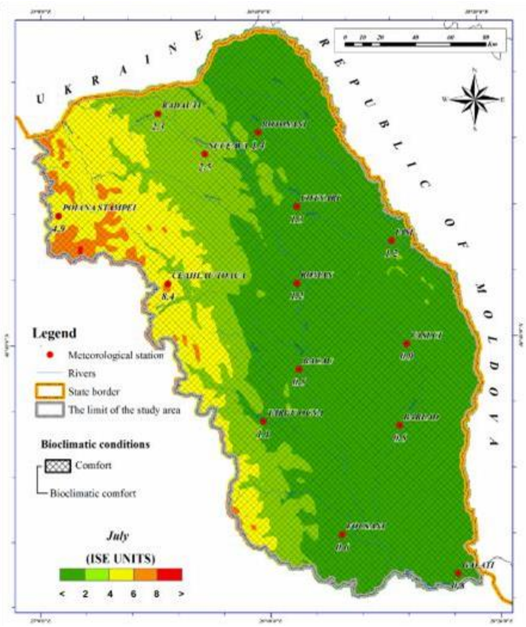
The equation for calculating the Pr used in this study was proposed by Siple and Passel in 1945, modified in 1974 by Beçancenot [cited by Escourrou (1989) and Teodoreanu (2002)]. One of the reasons considered in the choice of this equation [12] is its applicability for all the temperature and wind speed ranges recorded at the meteorological stations in our study area and used in the calculation of monthly averages of air temperature and wind speed.

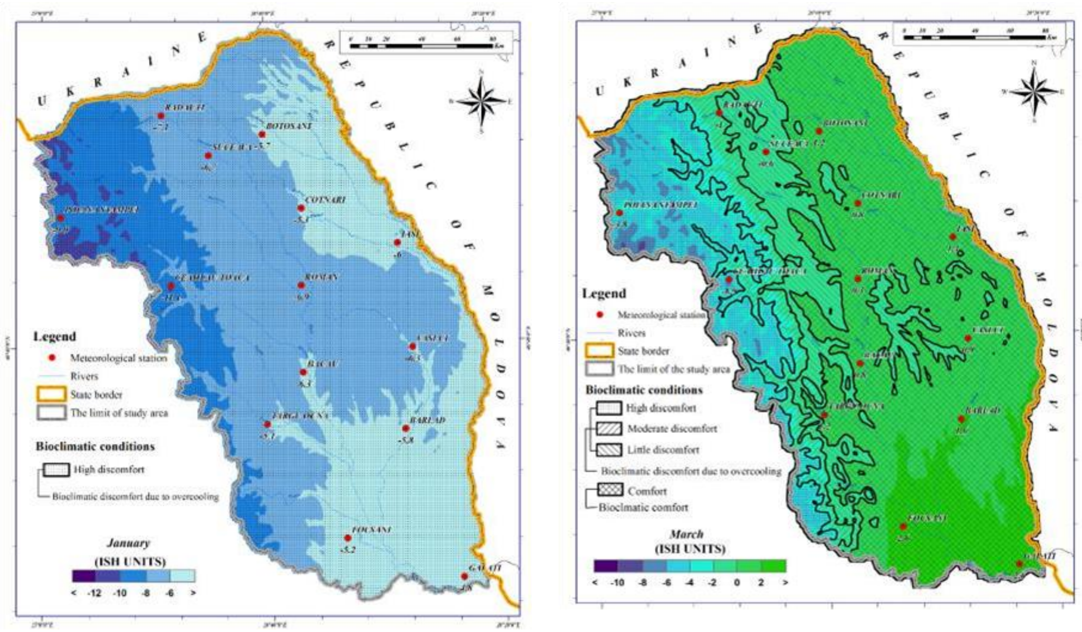
$$Pr = \left(10\sqrt{V} + 10{,}45\right) \cdot (33 - t) \; [\mathbf{12}]$$

where: Pr is the cooling power of the wind (kcal / m2 / h), V is the wind speed (m / s) and t is the air temperature (°C).

The direct links between Pr values and the sensations felt by the human body are shown in Tabel 11.







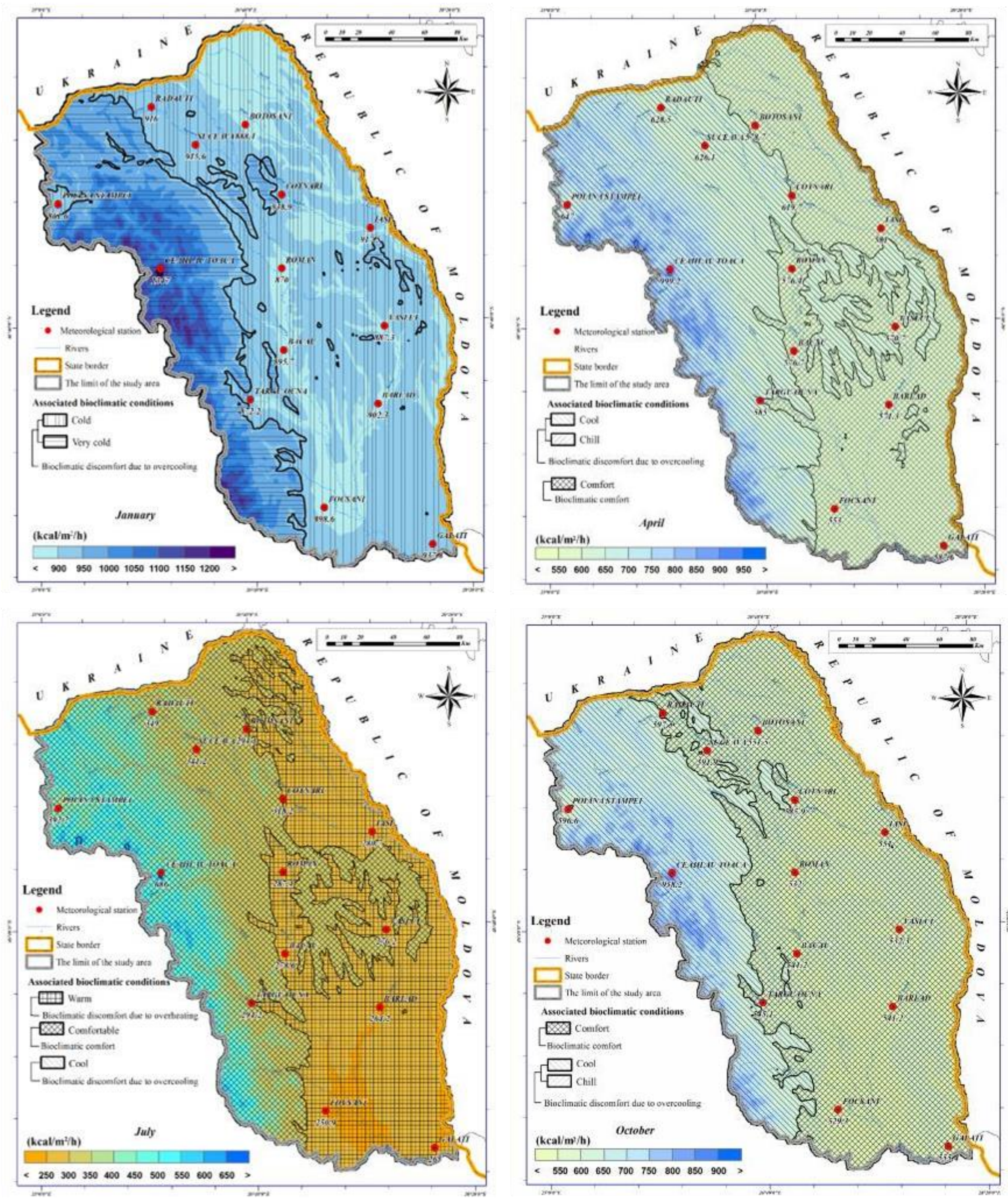
Figures 8 - 11. The spatial distribution of the ISH index in Moldova for September - **Fig. 8**, November **Fig. 9**, January - **Fig. 10** and March - **Fig. 11** for the time interval 1961-2013

Table 11 The Pr index threshold values a), associated bioclimatic conditions b) type of stress felt by the human body c), thermoregulatory mechanisms d) and type of bioclimatic discomfort / comfort felt by the human body e)

a) Wind-chill - Pr (kcal/m^2/h)	b) Associated bioclimatic conditions	c) Type of stress	d) Thermoregulatory mechanisms	e) type of bioclimatic discomfort / comfort
0 - 149	Very hot	Hypotonic	Stress by triggering thermolysis in summer	Bioclimatic discomfort due to overheating
150 - 299	Warm			
300 - 599	Comfortable	Relaxing	No need for thermoregulation	Bioclimatic comfort
600 - 899	Cool	Hypertonic	Stress by triggering thermogenesis, in winter	Bioclimatic discomfort due to overcooling
900 - 1199	Chill			
1200 - 1499	Cold			
> 1500	Very cold			

For Moldova, the Pr index (ultimately indicating heat loss at the skin level) can be calculated with good results from the monthly averages of air temperature and wind speed for every month of the year (including summer - Figures 13-16).

Mapping the temporal trends and spatial distribution of Pr over an average year highlights the relevance of this index in characterizing the bioclimate of Moldova. More relevant results can be obtained from the analysis of case studies, using daily and hourly Pr values.



Figures 13 to 16. The spatial distribution of the Pr index in Moldova for January - Fig. 13, April - Fig. 14, July - Fig. 15 and October - Fig. 16 for the time interval 1961-2013.

4. Conclusions

Of all the 10 bioclimatic indexes analyzed in the present study, only two (THI and Pr) showed conclusive results at an average monthly temporal resolution, for all the months of the year and for all the meteorological stations in Moldova. ISH can be used with good results for the September to May time interval. The other indexes analyzed (TEE, DI THOM, RSI, HI, HUMIDEX, SSI, ISE) did not generate conclusive results for Moldova at a monthly temporal resolution. We therefore suggest that these indexes should not be used for extensive, general bioclimatic assessments of Moldova, but only in analyses focusing on limited timeframes (days or hours) and areas (groups of stations in certain areas or climatic zones in Moldova).

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