CLIMATE CHANGE VULNERABILITY INDEX CASE STUDY FOR THE REPUBLIC OF MOLDOVA

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***Abstract**: The assessment of vulnerability to climate change focuses on identifying how threats from climate change can affect the ecological and socio-economic environment. This assessment takes into account the adaptation capacity and resilience of different institutions and key sectors to climate change and how climate change and other risks are reflected in the socio-economic and environmental dimensions at national, regional, and local level. Indicators of vulnerability to climate change can be aggregated by weighting to obtain Climate Vulnerability Index. The authors propose a new algorithm for calculating the Climate Vulnerability Index for the Republic of Moldova's administrative-territorial units as a composite index that includes three pillars: exposure, sensitivity and adaptive capacity. Each of the pillars includes a set of sub-indices, which in turn contain of several indicators.*

***Keywords**: Climate Vulnerability Index, exposure, environmental sensitivity, economic sensitivity, social sensitivity, adaptive capacity.*

Introduction

Climate change affects both nature and humanity. Its consequences are reflected not only in temperature and precipitation indices, but also in economic and social indicators. There are many negative consequences: people's well-being decreases, inequality increases. Simultaneously with the increase in human activity in the use of land resources, combustion of fossil fuels, the emission of heat-retaining gases into the atmosphere of the earth increases, and as a result, the warming of the atmosphere

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accelerates. All these changes accompanied by significant fluctuations in world average temperatures. Unfortunately, living organisms do not have time to adapt to a too rapidly changing climate, so the diversity of plants and animals decreases. Climate change reflected, not only in increasing temperatures, but also in extreme weather events, in sea level changes, the oceans are acidifying, in more frequent forest fires, in an increase in the frequency of hail, floods are more frequent in some areas, and rivers dry up in others.

Thus, the study of the influence of climate is very relevant; therefore is necessary to develop a Climate change vulnerability index. Climate change is affecting the agricultural sector, water resources, biodiversity, and population health. The impact of climate change is the result of the interaction of climate hazards, exposure and vulnerability of society and the economy. Among these three factors, namely vulnerability can determined by sensitivity and adaptation capacity, and can be applied to the development of state programs, strategies to overcome the negative impact of climate change.

Methodology

Vulnerability, in global practice, traditionally been determined by indices, for example, indices of vulnerability to climate change focused on tourism[1], agriculture[2], health and vulnerability indices to climate risks[3]. Most of these indices developed based on socioeconomic and biophysical indicators transposed into indices of exposure, sensitivity and adaptive capacity. Such estimates can be made both for the country and for the region, distinctly, etc. Vulnerability can be presented using the Climate Vulnerability Index (CVI), which in turn includes both sensitivity to climate hazards (S) and adaptive capacity (AC):

$$CVI = f(S, AC) \qquad (1)$$

The correlation between sensitivity, adaptive capacity and vulnerability is different. Vulnerability increases as sensitivity increases and vulnerability decreases as adaptive capacity increases. In the literature could be find the different opinions on the components of the Climate Vulnerability Index. In addition to the approach described in Equation 1,

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[1] A. Moreno & S. Becken, *A climate change vulnerability assessment methodology for coastal tourism,* Sustain Tour, 2009, Vol. 17, No. 4, 473–488.

[2] A. Monterroso, et al., *Two methods to assess vulnerability to climate change in the Mexican agricultural sector,* Mitig Adapt Strateg Glob Chang, 2014, Vol. 19, No. 4, 445–461.

[3] R. Pandey & S. Kumar, *Climate vulnerability index—measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India*, Mitig Adapt Strateg Glob Chang, 2012, Vol. 17, No. 5, 487–506.

there is another view when CVI includes not only sensitivity and adaptive capacity, but also exposure (E)[4]:

$$CVI = f(E, S, AC) \tag{2}$$

This method has been used in similar assessments in previous studies in the Republic of Moldova (TNC[5], R. Corobov[6], V. Raileanu[7]) as a way to report vulnerability which illustrates the spatial distribution of exposure, sensitivity and adaptive capacity.

Models of the combination of these three components applied in global practice for the assessment of the Climate Vulnerability Index are[8]:

$$CVI = E + S + AC, \tag{3}$$

$$CVI = (E - AC) \times S, \tag{4}$$

$$CVI = ((E + S + (1 - AC)) \div 3. \tag{5}$$

Each of the CVI components in turn is composed of a set of indicators, the units of measurement of which are different. All indicators must be standardized in order to eliminate the difference mentioned above and to make them comparable. One of the following two methods can be applied for this purpose.

The first method of standardization[9]:

$$I_{x,i} = (X_i - X) \div \Delta X, \tag{6}$$

where: $I_{x,i}$ – the standardized value of the indicator X for the district i;

X_i – the observed value of the indicator X for the district i;

X – the average value of the set of values of the indicator X for all districts;

ΔX – standard deviation of the set of values of the indicator X for all districts.

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[4] M. Hahn, A. Riederer & S. Foster, *The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change – A case study in Mozambique,* Global Environmental Change, 2009, Vol. 19, No. 1, 74–88.

[5] *Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change*, Chisinau, Imprint Plus, 2013, 397 p.

[6] R. Corobov, et. al., *Assessment of Climate Change Vulnerability at the Local Level: A Case Study on the Dniester River Basin (Moldova),* The Scientific World Journal, 2013, No. 1, 13 p.

[7] V. Raileanu, et al., *Vulnerability to climatic risks in national and local aspects,* Present Environment and Sustainable Development, 2019, Vol. 13, No. 2, 249-258.

[8] R. Ahumada-Cervantes, et al., *An indicator tool for assessing local vulnerability to climate change in the Mexican agricultural sector*, Mitig Adapt Strateg Glob Change, 2017, Vol. 22, No. 1, 137–152.

[9] Ibid, 143.

The second standardization method[10]:

$I_{x,i} = (X_i - X_{min}) \div (X_{max} - X_{min})$, (7)

$I_{x,i} = (X_{max} - X_i) \div (X_{max} - X_{min})$, (8)

where: X_{max} – the maximum value of the indicator X;

X_{min} – the minimum value of the indicator X.

If indicator X has a direct impact on the Climate Vulnerability Index, the Equation 7 is applied for standardization, and when the correlation between indicator X and CVI is negative – the Equation 8 is applied. Vulnerability studies could be developed both at the state level and at the administrative-territorial level, depending on the availability of statistical data necessary to perform the calculations. In our case study, the Climate Vulnerability Index was elaborated at the Administrative-Territorial Units (ATUs) level in the division of districts (32), Chisinau Municipality, Balti Municipality, A.T.U. Gagauzia. Vulnerability is conceptualized as an internal property of a system that can be expressed through a function, the endogenous variable of which is all the greater the less the adaptive capacity of the system to overcome its sensitivity to stressors. Therefore, the climate vulnerability of society and the ecosystem can be assessed in terms of their sensitivity to climate stress and its lack of adaptive capacity to overcome such sensitivity.

The ability to adapt to climate change is the ability of a system to adapt to changes caused by climate factors. In other words, after the climatic factors have acted and caused changes in the system, the latter will try to adapt to such changes in order to reduce the damage caused or to take advantage of such a change, or to respond to the consequences of the changes. Therefore, the adaptive capacity of a system facilitates it to reduce losses in the event of adverse climate change and helps the system to reap the beneficial changes.

Exposure assessment

The Exposure Component of the Climate Vulnerability Index is assessed on the basis of indicators that describe the probable climate changes of the Republic of Moldova, and which includes 16 extreme temperature and precipitation indices in the period 2008-2019. To facilitate the investigation of observed and projected changes, particularly in temperature and precipitation extremes, the Expert Team on Climate Change Detection and Indices (ETCCDI) defined a set of climate change indicators focusing on extreme events. These indicators describe

[10] M. Hahn, A. Riederer & S. Foster, *The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change – A case study in Mozambique,* Global Environmental Change, 2009, Vol. 19, No. 1, 76.

"moderate extreme events with a recurrence time of 1 year or less, forming a balance between data availability and robustness of changes"[11].

The climate change indices have been widely used to analyse global and regional changes of extremes in recorded observations (L. Alexander[12], L. Taranu[13], Yeon-Hee Kim[14]) as well as in future climate projections (F. Zwiers[15], L. Taranu[16], J. Sillmann & E. Roeckner[17], B. Orlowsky & S. Seneviratne[18]). The climate extreme temperature and precipitation indices which are used in this study for development of *E* index are summarized in Table 1.

Table 1: Climate extreme temperature and precipitation indices

Label	Name	Definition of the index	Units
TX_X	Max TX	Let TX_x be the daily maximum temperatures in month k, period j, then the maximum daily maximum temperature in each month is: $TX_{xkj} = max\ (TX_{xkj})$	C
TN_N	Min TN	Let TN_n be the daily minimum temperature in month k, period j, then the minimum daily minimum temperature in each month is: $TN_{nkj} = min\ (TN_{nkj})$	C
FD	Frost days	Let TN be the daily minimum temperature on day i in period j. Count the number of days where $TN_{ij} < 0C$	Days
SU	Summer days	Let TX be the daily maximum temperature	Days

[11] X. Zhang, et al., *Indices for monitoring changes in extremes based on daily temperature and precipitation data*, WIREs Climate Change, 2011, Vol. 2, No. 6, 851–870.

[12] L. Alexander, et al., *Global observed changes in daily climate extremes of temperature and precipitation,* Journal of Geophysical Research Atmospheres, 2006, Vol. 111, No. 5, 22 p.

[13] L. Taranu, *An Assessment of Climate Change Impact on the Republic of Moldova's Agriculture Sector,* A Research Study Complementing the Vulnerability and Adaptation Chapter of the Third National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change, Eds. V. Scorpan, et al., Chisinau, Tipografia Centrala, 2014, 260 p.

[14] Kim Yeon-Hee, et al., *Evaluation of the CMIP6 multi-model ensemble for climate extreme indices,* Weather and Climate Extremes, Vol. 29, 2020, 15 p.

[15] F. Zwiers, et al., *Climate Extremes: Challenges in Estimating and Understanding Recent Changes in the Frequency and Intensity of Extreme Climate and Weather Events,* Climate Science for Serving Society: Research, Modelling and Prediction Priorities, Eds. G. Asrar and J. Hurrell, New York, Springer, 2013, 339-389.

[16] L. Taranu, et al., *Vulnerability Assessment and Climate Change Impacts in the Republic of Moldova: Researches, Studies, Solutions*, Chisinau, Bons Offices, 2018, 352 p.

[17] J. Sillmann & E. Roeckner, *Indices for extreme climate events in projections of anthropogenic climate change,* Climatic Change, 2008, Vol. 86, 83–104.

[18] B. Orlowsky, & S. Seneviratne, *Global changes in extreme events: Regional and seasonal dimension,* Climatic Change, 2012, Vol. 110, 669–696.

		on day *i* in period *j*. Count the number of days where $TX_{ij} > 25C$	
TR	Tropical nights	Let *TN* be the daily minimum temperature on day *i* in period *j*. Count the number of days where $TN_{ij} > 20C$	Days
TN90p	Warm nights	Let TN_{ij} be the daily minimum temperature on day *i* in period *j* and let $TN_{in}90$ be the calendar day 90th percentile centred on a 5-day window. The percentage of days is determined where $TN_{ij} > TN_{in}90$	%
TX90p	Warm days	Let TX_{ij} be the daily maximum temperature on day *i* in period *j* and let $TX_{in}90$ be the calendar day 90th percentile centred on a 5-day window. The percentage of days is determined where $TX_{ij} > TX_{in}90$	%
WSDI	Warm spell duration	Let TX_{ij} be the daily maximum temperature on day *i* in period *j* and let $TX_{in}90$ be the calendar day 90th percentile centred on a 5-day window for the base period 1961–1990. Then the number of days per period is summed where, in intervals of at least 6 consecutive days: $TX_{ij} > TX_{in}90$	Days
GSL	Growing season length	Let *T* be the mean temperature *((TN+TX)/2)* on day *i* in period *j*. Count the number of days between the first occurrence of at least 6 consecutive days with $T > 5C$ and the first occurrence after 1st July *(NH)* or 1st January *(SH)* of at least 6 consecutive days with $T_{ij} < 5C$	Days
PRCPTOT	Total wet-day precipitation	Let PR_{ij} be the daily precipitation amount on day *i* in period *j*, then: $PRCPTOT_j = \Sigma PR_{ij}$	mm
R10mm	Heavy precipitation days	Let PR_{ij} be the daily precipitation amount on day *i* in period *j*. Count the number of days where $PR_{ij} > 10mm$	Days
R20mm	Very heavy precipitation days	Let PR_{ij} be the daily precipitation amount on day *i* in period *j*. Count the number of days where $PR_{ij} > 20mm$	Days
R95ptot	Contribution from very wet days	$100 \times r95p \div PRCPTOT$ where: *r95p* – the 95th percentile of wet-day precipitation amounts	%
RX1day	Max 1-day precipitation	Let PR_{ij} be the daily precipitation amount on day *i* in period *j*. The maximum 1-day value for period *j* is: $RX1day_j = max(PR_{ij})$	mm
RX5day	Max 5-day precipitation	Let PR_{kj} be the precipitation amount for the 5-day interval ending *k*, period *j*. Then	mm

		maximum 5-day values for period j are: $RX5day_j = max\,(PR_{kj})$	
SDII	Simple daily intensity	Let PR_{wj} be the daily precipitation amount on wet days, $PR \geq 1mm$ in period j. If W represents number of wet days in j, then: $SDII_j = \Sigma PR_{wj} \div W$	mm

To assess the observed exposure to climate change, 16 indices from Table 1 have been recalculated from 0 to 1 using Equation 7. The normalized indicators were summed and divided by the number of exposure components to obtain the climate exposure integral index for 2008-2019 (Equation 9):

$$E = \Sigma\, XE_i \div k, \quad (9)$$

where: E – the exposure integral index;
XE_i – the i^{th} normalized exposure variable (XE),
k – the number of indicators in the exposure integral index.

Data analysis and statistical tests were done using Python[19], ClimPACT2 tool, R scripting (R Core Team) and Excel.

According to the data presented in Figure 1 (a), the districts with the lowest standardized values of exposure to climate risks are: Cahul and Taraclia (0.4083), Straseni (0.4287), Criuleni (0.4223), Dubasari and Orhei (0.4307). The highest values of exposure to extreme temperature and precipitation "*very high degree of exposure*" are attributed to the districts: Hancesti, Leova, Cantemir and Cimislia (0.4608); Balti Municipality, Ocnita, Riscani (0.4568); Chisinau Municipality, Anenii Noi and Ialoveni (0.4559); Nisporeni, Ungheni, Telenesti (0.4535); Drochia, Soroca (0.4525); and Falesti, Glodeni, Singerei (0.4517).

In Northern Region the highest values of exposure to climate change based on extreme temperature and precipitation indices are attributed to the districts: Balti Municipality, Ocnita and Riscani (0.4568), following by Drochia, Soroca (0.4525), and Falesti, Glodeni, Singerei (0.4517).

The high exposure to climate change caused by extreme temperature and precipitation of Northern Region's districts during the 2008-2019 time period is mainly determined by high value in FD (0.56), TN90p (0.50), GSL (0.57) and R95ptot (0.55) in Balti Municipality, Ocnita and Riscani; and by TN90p (0.59), GSL (0.56), PRCPTOT (0.51) and R95ptot (0.51) in Drochia, Soroca.

[19] Guido van Rossum, *Python Tutorial*, Amsterdam, Centrum voor Wiskunde en Informatica, 1995, 65 p.

A comparative analysis of exposure to climate change based on extreme temperature and precipitation indices of the districts of the Central Region have showed that Hancesti (0.4608), Chisinau, Anenii Noi, Ialoveni (0.4559), and Nisporeni, Ungheni, Telenesti (0.4535) have reached the highest degree of exposure caused by climate change during the 2008-2019 time period, while Criuleni (0.4223), Straseni (0.4287), Dubasari, and Orhei (0.4307) districts the lowest. This fact can be explained by high value in TNn (0.51), TN90p (0.53), PRCPTOT (0.58), R20mm (0.51), R95ptot (0.60), RX5day (0.50) in Hancesti, and TNn (0.53), SU (0.51), PRCPTOT (0.58), R20mm (0.50), R95ptot (0.57) in Chisinau Municipality, Anenii Noi, Ialoveni.

In Southern Region, the highest values of exposure to climate change caused by extreme temperature and precipitation are attributed to the districts: Cantemir, Cimislia, Leova (0.4608), and for Cahul, and Taraclia the lowest (0.4083). The high exposure to climate change caused by extreme temperature and precipitation in the districts of Southern Moldova during the 2008-2019 time period is mainly determined by high value in TNn (0.51), TN90p (0.53), PRCPTOT (0.58), R20mm (0.51), R95ptot (0.60), and RX5day (0.50) (Figure 1 (a)).

Sensitivity assessment

Sensitivity defines the degree, to which the system is susceptible to direct or indirect climatic impacts[20]. Based on the availability of regional statistical data, the period of 12 consecutive years 2008-2019 was used. The sensitivity pillar includes the Environmental Sensitivity Index (*ESI*) and Socio-Economic Sensitivity Index (*SESI*), which in turn are divided into 2 and 7 sub-indices, accordingly (Table 2).

In the process of selecting the indicators, it has emerged from the availability of statistical data in territorial profile and degree of correlation between the indicators studied and climate change.

Table 2: List of indicators grouped by sensitivity sub-indices

Sensitivity sub-indices	Indicators	Type of correlation
Environmental Sensitivity (ES)	Emissions of pollutants into the air from stationary sources of economic operators, tonnes	↑
	Formation of production and consumption waste, thousands of tons	↑

[20] *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, 2007, 976 p.

Sensitivity of Water and Sewerage Supply (SWSS)	Water capture, millions of cubic meters	↑
	Water use (without water used repeatedly and in closed circulation), millions of cubic meters	↑
	Water supply systems - Rural, units	↓
	Sewerage systems - Rural, units	↓
Demographic Sensitivity (DS)	Stable population at the beginning of the year - rural, people	↑
	Stable population at the beginning of the year - women, people	↑
	Population density, inhabitants per 1 km2	↑
	The coefficient of population aging, at the beginning of the year - urban, the number of people aged 60 and over per 100 inhabitants	↑
	Coefficient of population aging, at the beginning of the year - rural, Number of people aged 60 and over per 100 inhabitants	↑
	Coefficient of population aging, at the beginning of the year - men, number of people aged 60 and over per 100 inhabitants	↑
	Coefficient of population aging at the beginning of the year - women, number of people aged 60 and over per 100 inhabitants	↑
Labour Market Sensitivity (LMS)	Number of officially registered unemployed (at the end of the year), persons	↑
Social Security Sensitivity (SSS)	Number of pensioners registered with the social insurance bodies, persons	↑
Sensitivity of Public Health (SPH)	Average number of doctor visits per year per inhabitant, visits per 1 inhabitant	↑
	Requests for emergency medical assistance per 1000 inhabitants, persons per 1000 inhabitants	↑
	Population morbidity per 100,000 inhabitants - General incidence, cases per 100,000 inhabitants	↑
	Population morbidity per 100,000 inhabitants - General prevalence, cases per 100,000 inhabitants	↑
	Mortality rates at the beginning of the year - Diseases of the circulatory system, the number of deaths per 100,000 inhabitants	↑
	Mortality rates at the beginning of the year - Malignant tumours, the number of deaths per 100,000 inhabitants	↑

	Mortality rates at the beginning of the year - Diseases of the digestive tract, the number of deaths per 100,000 inhabitants	↑
	Mortality rates at the beginning of the year - Accidents, intoxications and traumas, number of deaths per 100,000 inhabitants	↑
Land Use Sensitivity (LUS)	Area sown on cereals and legumes on agricultural holdings and farms (hectares), hectares	↑
	Area sown on technical crops in agricultural enterprises and farms (farmers), hectares	↑
	Area sown on potatoes, vegetables and pumpkin crops on agricultural enterprises and farms (farmers), hectares	↑
	Area sown on fodder crops on agricultural holdings and farms (farmers), hectares	↑
	Fruit area of multi-annual seed plantations on agricultural enterprises and farms (farmers), hectares	↑
	Fruit area of multi-annual stone fruit plantations on agricultural enterprises and farms (farmers), hectares	↑
	Fruit area of vineyards in agricultural enterprises and farms (farmers), hectares	↑
Phytotechnical Sensitivity (PS)	Average harvest per 1 hectare of wheat (autumn and spring) in agricultural enterprises and peasant households (farmers) with an area of agricultural land of 10 hectares and over, quintals	↓
	Average harvest per 1 hectare of maize for grain in agricultural enterprises and farms (farmers) with an area of agricultural land of 10 hectares and over, quintals	↓
	Average harvest per 1 hectare of sunflower in agricultural enterprises and farms (farmers) with an area of agricultural land of 10 hectares and over, quintals	↓
	Average harvest per 1 hectare of sugar beet in agricultural enterprises and farms (farmers) with an area of agricultural land of 10 hectares and over, quintals	↓
	Average harvest per 1 hectare of grapes in agricultural enterprises and farms (farmers) with an area of agricultural land of 10 hectares and over, quintals	↓
Sensitivity of	Livestock, on January 1 cattle in all categories	↑

Animal Production (SAP)	of households, heads	
	Livestock, on 1 January of pigs in all categories of households, heads	↑
	Livestock, on 1 January of sheep and goats in all categories of households, heads	↑

In the process of selecting the indicators, it has emerged from the availability of statistical data in territorial profile and degree of correlation between the indicators studied and climate change.

In the Table 2 is shown the list of finally selected indicators, which are grouped by sensitivity sub-indices. The correlation sign also is specified in the given table. In the case of the positive correlation (↑), Equation 7 will be applied for standardization (normalization), and in the case of the negative correlation (↓) – Equation 8.

To assess sensitivity to climate change, have been used 38 indicators grouped into nine sub-indices (Table 2), which are calculated using the following formula:

$$SSI_i = \Sigma V_i \div n, \quad (10)$$

where: SSI_i – sensitivity sub-indices i (e.g. environmental sensitivity, water and sewerage sensitivity, demographic sensitivity, etc.);

V_i – sensitivity variable (indicator) i;

n – the number of component indicators of the sensitivity sub-indices.

The Integral Sensitivity Index (S) was calculated according to the following formula:

$$S = 0.5 \times ESI + 0.5 \times SESI, \quad (11)$$

$$ESI = 0.5 \times ES + 0.5 \times SWSS, \quad (12)$$

$$SESI = 0.5 \times SS + 0.5 \times EcS, \quad (13)$$

$$SS = 0.25 \times DS + 0.25 \times LMS + 0.25 \times SSS + 0.25 \times SPH, \quad (14)$$

$$EcS = (LUS + PS + SAP) \div 3, \quad (15)$$

where: *SS* – Social Sensitivity;

EcS – Economic Sensitivity.

Sensitivity is the degree of damage to society and the ecosystem caused by climate change. The effect can be direct (changes in crop yields in response to changes in environment or temperature variability) or indirect (damage caused by an increase in flood frequency). The highest cumulative territorial sensitivity was registered by the Chisinau Municipality, A.T.U. Gagauzia, Falesti, Hancesti and Balti Municipality (Figure 1 (b)).

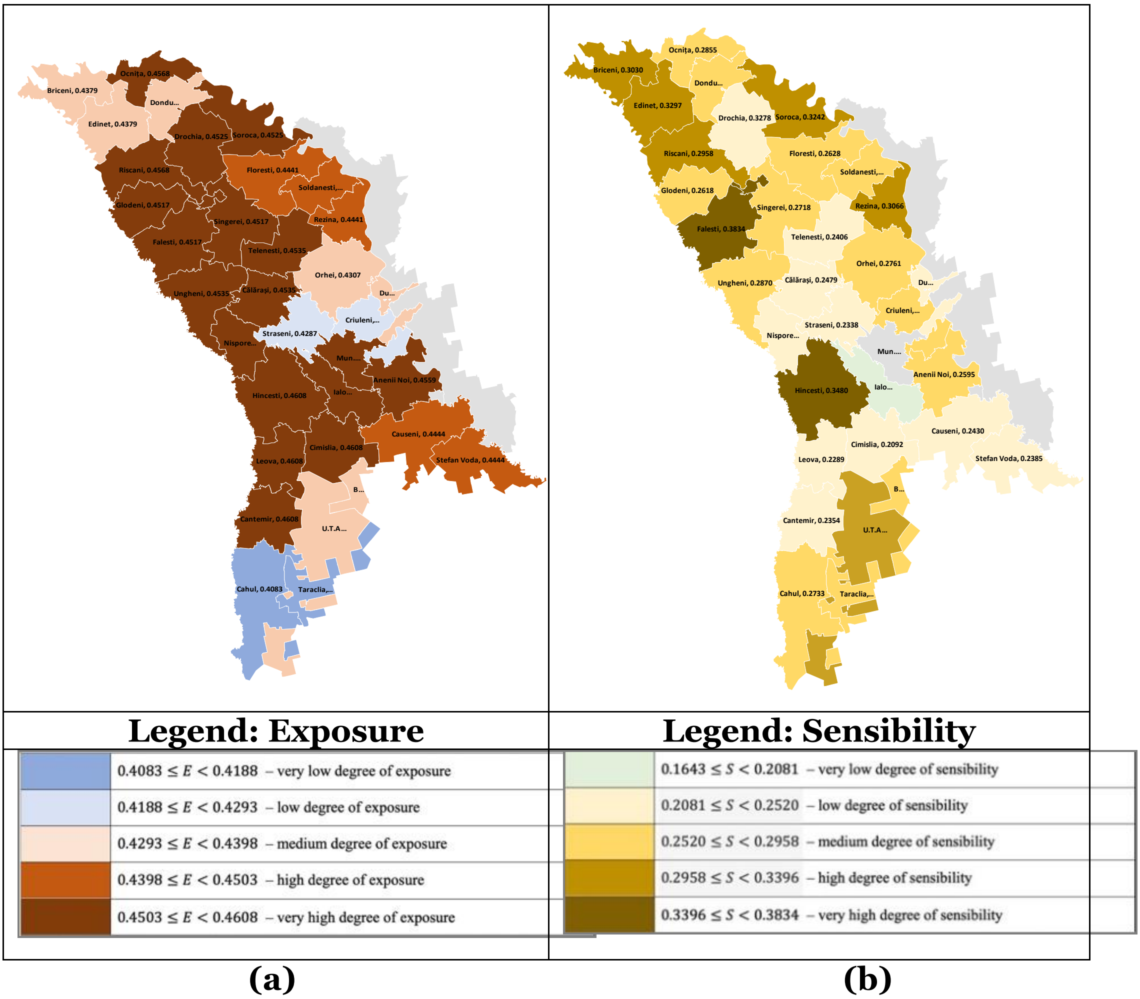

Figure 1. The Spatial Development of the Exposure Index (a) and the Sensibility Index (b), 2008-2019

Chisinau is in the top by sensitivity to climate change, because it recorded the highest volume (number) of: emissions of pollutants into the air from stationary sources of economic agents, production and consumption waste, water demand, officially registered unemployed, pensioners, visits to the doctor during the year to a resident, population morbidity per 100,000 inhabitants (both incidence and prevalence), and so on.

In Northern Region, the most sensitive to climate change is Falesti district, followed by Balti and Edinet municipalities, and the lowest level of sensitivity have reached Glodeni and Floresti districts. The high sensitivity of Falesti district is mainly determined by a large volume of production and consumption waste, the high level of emissions of pollutants into the air from stationary sources of economic agents, a large number of officially registered unemployed and relatively high numbers of goats and sheep.

The analysis of the value of the integral sensitivity index in the Central Region is highlighted that except of Chisinau, the most sensitive to climate change risks is Hancesti district, which recorded the high values at the same indicators as Falesti district. In addition, the increased sensitivity of the mentioned above district was also caused by other indicators: the number of pensioners, requests for emergency medical assistance per 1000 inhabitants, mortality rate due to accidents, intoxications and traumas, the area sown for fodder crops on agricultural enterprises and farmer's households, the orchard and vineyards area, cattle herd (Figure 1 (b)).

A comparative analysis of the sensitivity in Southern Region have shown that the A.T.U. Gagauzia has reached the highest degree of damage to ecosystem and society caused by climate change, and Cimislia district – the lowest. This fact can be explained by the ascending trends of: the emissions of pollutants in the atmospheric air from the stationary sources of the economic agents (during the years 2008-2016), water demand (2011-2019), population density (2008-2019), coefficient of aging of the urban population (2008-2019), number of pensioners (2008-2017), mortality rate due to malignant tumours (2008-2017), population morbidity per 100,000 inhabitants (2008-2017), average number of visits to the doctor during the year (2010-2016), the area sown with technical crops in agricultural enterprises and households (2008-2019), sheep and pig herd (2008-2019) (Figure 1 (b)).

Assessment of adaptive capacity

The adaptive capacity describes the ability of the population, the economy and the ecosystem to adapt to changes caused by climate change. In our study this pillar includes 7 sub-indexes. The list of 23 indicators, grouped into these seven sub-indices, that have used for the Republic of Moldova's adaptive capacity assessment is presented in Table 3.

Sub-indices of adaptive capacity to climate change were assessed using the following formula:

$$ACS_j = \Sigma V_j \div m, \quad (16)$$

where: ACS_j – adaptive capacity sub-indices j (e.g. adaptive capacity: industry, adaptive capacity: agricultural production, adaptive capacity: transport, etc.);

V_j – the variable (indicator) of adaptive capacity j;

m – the number of component indicators of the adaptive capacity sub-indices.

The highest level of cumulative adaptive capacity in the division of Administrative-Territorial Units (ATUs) was registered by the Chisinau Municipality, A.T.U. Gagauzia, Anenii Noi, Balti Municipality and Edinet (Figure 2 (a)), and the smallest one in Dubasari, Leova, Nisporeni districts. Chisinau is on the top, because it recorded the highest values on most indicators: value of manufactured industrial production, production of main industrial products, road transport of goods, performed by enterprises and organizations, passenger transport by bus and minibus, number of students at general primary and secondary education institutions, number of computers in primary and general secondary education institutions, existing capacity of the tourist reception structures with accommodation functions, etc.

Table 3: List of indicators grouped by adaptive capacity sub-indices

Adaptive capacity sub-indices	Indicators	Type of correlation
Adaptive Capacity of Industry (ACI)	The value of manufactured industrial production (current prices), million lei	↑
	The value of the delivered industrial production, millions of leis	↑
	Volume of meat production, tons	↑
	Production volume of canned vegetables and fruits, tons	↑
	Flour production volume, tons	↑
	The volume of feed production ready for animal feed, tons	↑
	Production volume of bread and bakery products, tons	↑
	The production volume of natural grape wines, thousand dals	↑
Adaptive Capacity of Agricultural Production (ACAP)	Raising of live cattle and poultry on agricultural enterprises and farms,	↑
	Sale for slaughter of live cattle and poultry to agricultural enterprises and farms (quintals), quintals	↑
	Average annual quantity of milk, calculated per cow, on agricultural holdings and farms (kilograms), kilograms	↑
	Average annual egg production per laying hen on farms and (farmer's) farms, pieces	↑
Adaptive Capacity of	Length of local roads (end of year), kilometres	↑
	Length of national roads (end of year),	↑

Transport (ACT)	kilometres	
	Goods transported, thousands of tons	↑
	Transported passengers, thousands of passengers	↑
Adaptive Capacity of Health Care (ACHC)	Number of doctors per 10,000 inhabitants, persons per 10,000 inhabitants	↑
	Average medical staff per 10,000 inhabitants, persons per 10,000 inhabitants	↑
Adaptive Capacity of Education (ACE)	Students in general primary and secondary education institutions, number	↑
	Students at a computer in primary and secondary schools, people	↑
Adaptive Capacity of Providing the Population with Living Space (ACPPLS)	Providing the population with living space - Urban localities, m2 of total area per 1 inhabitant	↑
	Providing the population with living space - Rural localities, m2 of total area per 1 inhabitant	↑
Adaptive Capacity of Tourism Sector (ACTS)	Existing capacity of collective tourist reception structures with accommodation functions, as of December 31, number of beds	↑

In Northern Region, the highest adaptive capacity was observed in Balti Municipality, Edinet and Riscani, and the lowest one in Glodeni and Singerei districts. Compared to other ATUs in the region, Mun. Balti recorded the highest value of manufactured and delivered industrial production, as well as high values for the following indicators: meat production including poultry, production of bread and bakery products, road transportation of goods, performed by enterprises and organizations, passenger transportation performed by buses and minibuses, number of doctors per 10,000 inhabitants, number of average medical staff per 10,000 inhabitants, number of students in primary and general secondary education institutions, and existing capacity of tourist reception structures with accommodation functions (Figure 2 (a)).

Anenii Noi is presented the highest adaptive capacity in Central Region (except Chisinau Municipality), which is determined by high values of indicators: volume of meat production, raising cattle and poultry in live mass, sale for slaughter of cattle and birds, length of national roads, and providing population with living space (urban localities), etc.

The analysis of the value of adaptive capacity integral index in Southern Region's ATUs have shown that the A.T.U. Gagauzia has reached the highest degree of adaptive capacity to climate change, and Leova district - the lowest one. The high adaptive capacity of the A.T.U. Gagauzia was ensured by the high values recorded by the indicators: industrial production, industrial production delivered as for example - volume of flour production and volume of natural grape wines, raising of cattle and poultry, sale for slaughter of cattle and poultry, average annual quantity of milk, per cow, length of local roads, and national roads, volume of goods transported, number of doctors, per 10,000 inhabitants, number of average medical staff, per 10,000 inhabitants, etc.

Therefore, a weighting and aggregation methodology is needed that would incorporate the different distribution of ATUs in the assessment of adaptive capacity to climate change.

Climate vulnerability assessment

In the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) is defined "the climate vulnerability as a function of its components: exposure, sensitivity and adaptive capacity"[21]. In its Special Report on Extreme Events[22] and the latest released fifth assessment report, the IPCC revised its understanding of vulnerability and converges with the approach of the newly introduced concept of 'climate risks' by defining it as "the propensity or predisposition to be adversely affected"[23].

In addition to the differences in definition, vulnerability assessment is considered an increasingly important tool for monitoring and estimating adaptation activity, contributing to the National Adaptation Planning (NAP) process (Reporting, Monitoring and Review)[24]. Furthermore, as funding for adaptation measures increases, such as through the Green Climate Fund[25], the need for indicators to monitor and assess the success of adaptation in reducing risks and vulnerabilities is becoming increasingly evident[26].

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[21] *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, 2007, 976 p.

[22] *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, Special Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, 2012, 582 p.

[23] *Climate Change 2014: Impacts, Adaptation and Vulnerability, Part A: Global and Sectoral Aspects*, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge, Cambridge University Press, 2014, 32 p.

[24] K. Fritzsche, et. al., *The Vulnerability sourcebook. Concept and guidelines for standardized vulnerability assessments*, GIZ, 2014, 178 p.

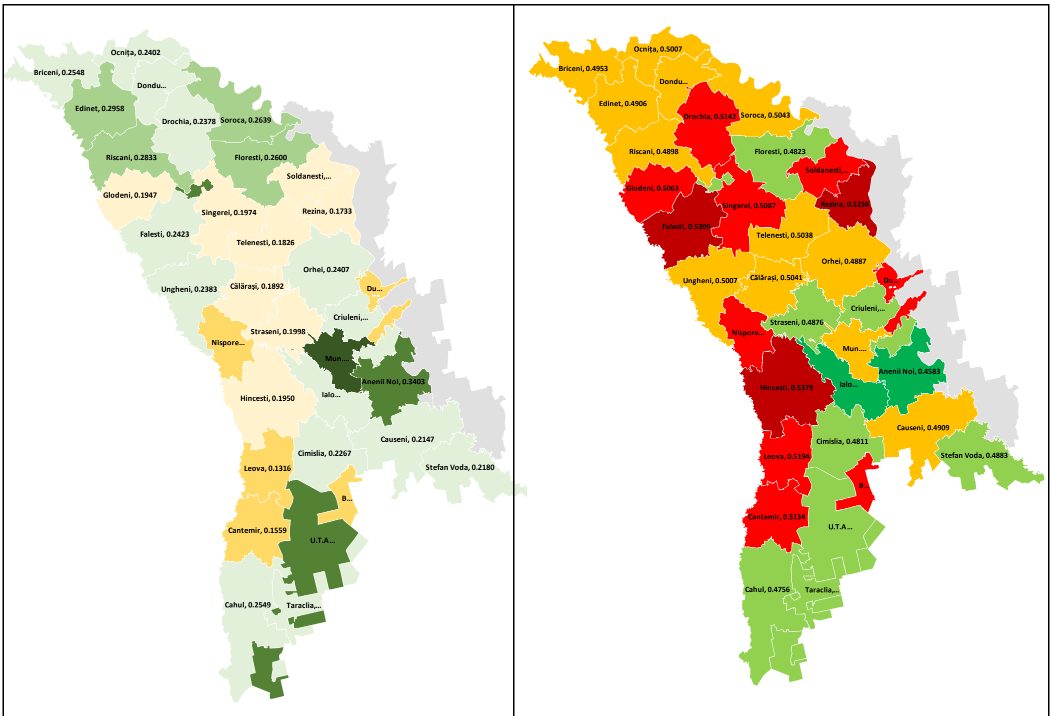
[25] P. Stoll, W. Pauw, F. Tohme & C. Grüning, *Mobilizing private adaptation finance: lessons learned from the Green Climate Fund,* Climatic Change, 2021, Vol. 167, Art. number: 45, 19 p.

[26] N. Lamhauge, E. Lanzi & S. Agrawala, *Monitoring and Evaluation for Adaptation: Lessons from Development Co-operation Agencies,* OECD Environment Working Papers, 2012, No. 38, 49 p.

We have used the Equation 5 to assess observed vulnerability to climate change during the 2008-2019 in this study.

In Northern Region, the „high degree of vulnerability” are attributed to the ATUs - Drochia (0.5142), Glodeni (0.5063), and Singerei (0.5087), while „low degree of vulnerability” to climate risks is detected in Floresti (0.4823), and Balti Municipality (0.4861).

The districts with „high degree of vulnerability” to climate risks in Central Region during the 2008-2019 time period were Dubasari (0.5166), Nisporeni (0.5141), and Soldanesti (0.5094), but „low degree of vulnerability” were Criuleni (0.4759), and Straseni (0.4876) (Figure 2 (b)).



Legend: Adaptive Capacity

	$0.1078 \le AC < 0.1578$ – very low degree of adaptive capacity
	$0.1578 \le AC < 0.2077$ – low degree of adaptive capacity
	$0.2077 \le AC < 0.2576$ – medium degree of adaptive capacity
	$0.2576 \le AC < 0.3076$ – high degree of adaptive capacity
	$0.3076 \le AC < 0.3575$ – very high degree of adaptive capacity

Legend: Vulnerability

	$0.4557 \le CVI_i < 0.4721$ – very low degree of vulnerability
	$0.4721 \le CVI_i < 0.4886$ – low degree of vulnerability
	$0.4886 \le CVI_i < 0.5050$ – medium degree of vulnerability
	$0.5050 \le CVI_i < 0.5215$ – high degree of vulnerability
	$0.5215 \le CVI_i < 0.5379$ – very high degree of vulnerability

(a) **(b)**

Figure 2. The Spatial Development of the Adaptive Capacity (a) and the Vulnerability (b) to climatic risks, 2008-2019

In Southern Region, the „high degree of vulnerability" of ATUs are detected in - Basarabeasca (0.5151), Cantemir (0.5134), and Leova (0.5194) districts, while „low degree of vulnerability" in Cahul (0.4753), Cimislia (0.4811), and A.T.U. Gagauzia (0.4742).

Conclusion

The mapping technique was applied to visualise the information described above about Exposure, Sensitivity, Adaptive capacity and Vulnerability territorial development across of the Republic of Moldova's administrative-territorial units, and identify the districts with high Exposure, Sensitivity, and Vulnerability and better Adaptive capacity potential.

A comparative analysis of vulnerability to climate change based on exposure, sensitivity, and adaptive capacity assessment of the Republic of Moldova's 35 ATUs show that the most vulnerable to climate change with „very high degree of vulnerability" during the 2008-2019 observed time period were the following districts: Hincesti (0.5379), and Rezina (0.5258) in Central Region, Falesti (0.5309) in Northern Region, while „very low degree of vulnerability" to climate risks was detected in Ialoveni (0.4557), and Anenii Noi (0.4583).

Therefore, the government must promote policies aimed at increasing the capacity to adapt to climate change in districts of the Republic of Moldova, especially in Dubasari (0.1078), Leova (0.1316), Nisporeni (0.1325), Basarabeasca (0.1502), Cantemir (0.1559), etc.

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