METHODICAL ASPECTS ON COMPLEX INDEXES USAGE IN IDENTIFICATION AND ESTIMATION OF CLIMATIC RISKS ON THE REPUBLIC OF MOLDOVA'S TERRITORY

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Keywords: Disaster Risk Index, drought phenomenon.

Abstract. Vulnerability is represented by the conditions determined by natural, social, economical and ecological factors or processes, which intensify a community's exposure to hazards' influence (Reducing Disaster Risk, global report, 2005). The Centre for Research on the Epidemiology of Disasters, Université Catholique de Louvain (UCL), Belgium (CRED), which is the most authoritative organization of calamities statistics of various origins, is based on the criteria which include the following requirements: *more than 10 human victims, not less than 100 affected, international help soliciting, and exceptional situation declaration*.

Introduction

Till now, there is no unanimously accepted terminology for the extreme natural phenomena definition neither on global level nor in the Republic of Moldova [1, 2, 3, 5, 6, 7, 8, 9, 10, 11]. The United Nations Disasters Relief Organization (UNDRO) has a mathematical definition, according to which the risk is the product of hazard (expressed in %), vulnerability (expressed by values within the 1 to 10 range) and the economical value of registered damages.

The UN Development Programme's (UNDP) Experts elaborated a unified definition of natural hazards risk (Disaster Risk Index, DRI), which is equal the *probability of negative consequences and foreseen losses* which result from the interaction of dangerous phenomena of natural and anthropic origin and of vulnerability conditions..

The need to organize a Drought Management Centre for the South-Eastern Europe became evident since the end of last century in order to diminish climatic risk effects caused by desertification process (especially by drought). The same idea was developed by the International Commission for Irrigation and Drainage (ICID) and by the United Nations Convention for Combating of Desertification

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(UNCCD). The focal national points at UNCCD and the permanent national representatives of World Meteorological Organization (WMO) agreed upon the principal responsibilities of the Drought Management Centre for South-Eastern Europe (DMCSEE) and the documents for project proposals. The DMCSEE mission, according to this document, is to coordinate and facilitate the development, evaluation and application of drought risk management's instruments and policies in South-Eastern Europe, the objective being its impact's prevention and mitigation. Therefore, DMCSEE concentrated its activity on monitoring and evaluating the drought, as well as on the risk and vulnerability caused by it.

At the national level, based on the data offered by the State Hydrometeorologic Service of the Republic of Moldova, an institution which manages the meteorological network and executes meteorological observations on climatic components, cartographical models were obtained, compatible with map-schemes obtained on the basis of the above-mentioned international and regional data.

Te necessity of natural risks evaluation including climatic ones at the regional level comes from the significant growth of their number and frequency.

1. Investigation materials and methods

The Romanian Explanatory Dictionary has the following definition for the term *aleatory:* depending on an unsure, casual event. The distinctive characteristic of such *events* (meaning physical manifestations carrying information) consists in the fact that they cannot be described by explicit mathematical relations, which allow exact estimation in the given time period. In fact, their evolution depends on *probabilistic laws*, which presume a certain degree of chance or probability for that particular manifestation to have a definite result. From this point of view, events or aleatory signals differ from the *deterministic* ones, the values of which can be determined with accuracy in each moment. Theoretic support which allows analyzing aleatory signals is offered by the *probability theory*, which mainly analyzes average values of physical manifestations on a large scale. A link between the multitude of certain physical manifestations and mathematical unified formalism is stated by the notion of *aleatory variable*, expressed by the function which associates a number to each possible result of a given experiment. An ensemble of aleatory variables defines an *aleatory process*.

An operator called mathematical *expectation,* which attaches to an aleatory variable the value resulting from the arithmetical average of an infinite number of individual realizations of reviewed physical manifestation plays a central role in the probability theory. The discrete or analogical function of the experiments is defined as:

$$E\{\mathbf{X}\} = \sum_{i=1}^{n} p_i x_i$$
$$E\{\mathbf{X}\} = \int_{-\infty}^{\infty} x f_X(x)\, dx \qquad (1)$$

where X - presumed aleatory variable which has *n* possible realizations with p_i probabilities in the discrete case, and respectively, the *probability density* xf_x in the analogical case. In the given work, as it was previously demonstrated, we refer only to discrete aleatory processes, the individual realizations of which are called *time series*. The term, which illustrates intuitively the notion of aleatory signal, as we have mentioned in the previous works, is *noise*. As a rule, this term is associated with discomfort which should be eliminated or at least mitigated. Frequently though, noise is layered over what we call „useful information", and the effort of separating them is extremely laborious. [12, 13].

Thus, the stochastic model evaluates extremes variability as an aleatory torrent of homogenous events, the principal character of which is torrent's density (*λ 1/year)* in time and is characterized by certain particularities. Therefore, the climatic risk notion includes *probability of manifestation of a certain climatic extreme within the limits of the prevention interval.* In this case, extreme from the statistical point of view means *the least probability of manifestation of a phenomenon in time* [14, 15, 16, 17, 18, 19].

On the basis of the given affirmations, extremes are identified with aleatory series in three codified stages, according to the trihotomic method -1, 0 and +1,0, in the case when :

$$\left\{ \begin{array}{l} -1\, c\hat{\imath}nd\, W_{(\tau)} \le a' \\ 0\, c\hat{\imath}nd\, a' \le W_{(\tau)} \le a'' \\ +1\, c\hat{\imath}nd\, W_{(\tau)} \ge a'' \end{array} \right\} \qquad (2)$$

where a' and a'' - criteria (values) corresponding to the level for extreme's determining.

The differentiation of extreme's density conditions depends on the width of the differential „corridor" determined by the level values *(*a' and a''*)* of the indexes used for the identification of a certain phenomenon (fig.1a).

Thus, the indexes climatic series are represented by $W_0(\tau)$ function, which changes sign in $\tau_0, \tau_1 \ldots, \tau_n$ points and which have constant values according to the above-mentioned conditions in the given time when an aleatory process *W(τ)* is investigated.

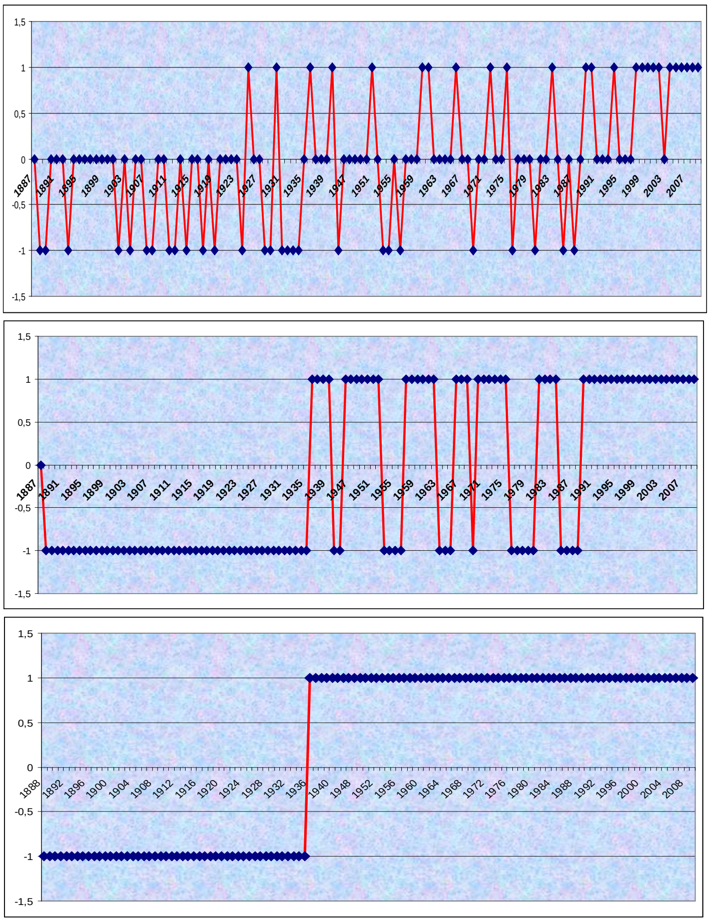

Fig.1 - Trihotomic method of mean annual temperatures time series transformation in order to identify and study the regularities of extreme thermal conditions dynamics

The intersection points are viewed as a flux, a torrent of aleatory events with a λ density. In the case of a high statistical conformity, such succession of extreme conditions has to be modeled according to the law of „rare events” on the basis of which lies the generalized Poisson distribution with parameter λ [18, 19].

According to fig.1, even in the transformed series, the $W_0(\tau)$ function presents a difficult succession of anomalies with different signs. In their turn, negative anomalies are „complicated” by the positive ones.

That's why the transformation or generalization of the climatic process can be continued until the stage when generalization and identification of certain positive or negative trends in its manifestation is possible.

This is why it is necessary to find the smallest interval. Let us assume that it is $T_к$, $T_{к+1}$ with L_0 length, then, applying the method of elimination of the smallest interval. For this, from the multitude of passages (zeroes of the $W_0(\tau)$ function) we exclude this interval's limits. As a result, instead of three neighboring intervals ($T_{к-1}$, $T_к$), ($T_к$, $T_{к+1}$), ($T_{к+1}$, $T_{к+2}$), we obtain a single one with a constant sign $L_{1,;}$ then, we repeat the elimination operation of the smallest interval, and so on. The procedure continues until we eliminate all the passage intervals of the $W_0(\tau)$ function for certain time periods (fig.1.b, c).

Thus, on the example of mean annual temperature, as a result of the transformations made, we can identify the warm and cold periods. We state that for positive anomalies in this period according to the trihotomic method coincides with the period within the limits of the mid 30's of the XX century and until now, and the negative ones - within the limits of the end of the XIX century– the middle of 30's, XX century.

We state that time series transformation and priorities generalization of such a study can be found in the works of Sazonov, Drozdov and others.[4] and in whose investigations no diminishing of the initial series' stochastic structure is done. In our case, we had excluded empirical values close to climatic norm because such problem definition makes its resolution difficult. Such an affirmation is confirmed by the actual data, such as test evaluations, which demonstrate the aleatory nature in the dynamics of the thermal regime (fig. 2), with the exception of frequency amplitudes of 0.1-0.3, when the confidence interval is surpassed, which shows us that in such a time period the values have a periodicity in their manifestation.

In the proposed interpretation of the climatic extreme's stochastic nature and namely from the position of the informational theory, the climatic processes' distinction into three characteristic stages includes the smallest deviation because in this case the condition of maximum entropy is respected. At P probability of each possible stage, equal to 0.33, entropy – the uncertainty unit, according to Sazonov, reaches its maximum values.

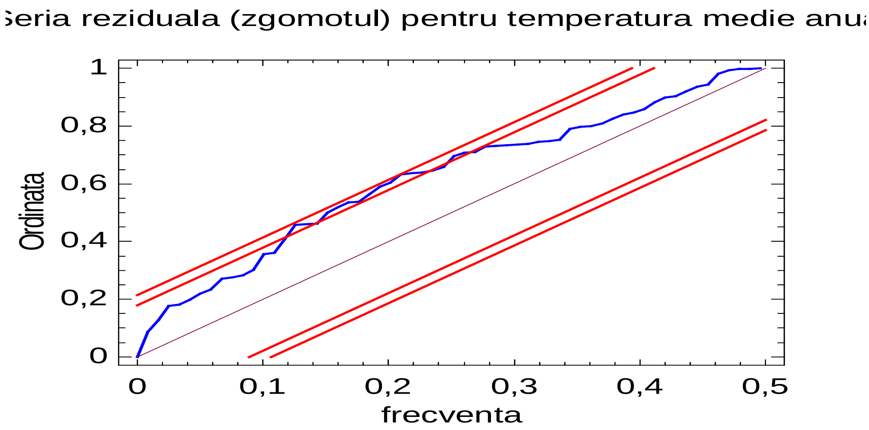

Fig. 2 - Integral spectral function of mean annual temperature and 75% and 95% confidence levels of “stochastic noise”

The transformation of the initial series of climatic parameters identifies characteristics expressed by extremes dynamics and reflects long-term fluctuations characteristic to the climatic processes that are determined by inert long-term factors (fig.1c).

In the temporal evaluation of risk, the probability represents an important characteristic of aleatory phenomena and is defined by its quantitative dimension. Mathematically, the total probability (P) is calculated as:

$$P=[(m_i-0.3/n+0.4)]\ 100\%\ , \qquad (3)$$

where P – insurance in percent, m_i – number of rows in arranged statistic series; n - observation period.

While probability is an objective characteristic of individual events, it becomes evident and gains a value for investigation only when a large number of aleatory events of the same kind which are manifested independently are subject to observation. Reciprocal independency and disorder of individual events of an ensemble make it possible for a proportion of events in this ensemble to be in the same situation or situations, which lead to the same result (which realizes in the same way). Such phenomenon is called frequency and is expressed by the relation between the number of cases that are realized and the number of possible cases. Frequency is realized on the ensemble level, as statistical average of individual components and it has necessary values for the ensemble: its stability increases as the number of ensemble’s components increases.

Probability is often determined by frequency. Probability and frequency are equal as numerical values (quantitative), but differ in qualitative aspect and on the level of existence to which they refer and which they describe: probability characterizes the individual level and evaluates chance, and frequency characterizes the ensemble level and values necessity.

The practical aspect of probabilistic evaluation is prognosis – quite useful information for land management in conditions of actual climate changes.

2. Obtained results analysis

For the Republic of Moldova's territory, it is important to know the risk manifestation of temperatures under -17 ^{0}C, -23 ^{0}C and -25 ^{0}C that are in fact criteria of frost degree identification, and also critical temperatures, at which viticultural and pomicultural plants are damaged.

Grape cultivars that are sensible to frost are *Prima*, *Ora*, *Isa*, *Danlas*, *Lival*, and are proposed for temporal registration in order to investigate their productivity, and they have critical temperatures of damage < -17 ^{0}C. Their manifestation probability analysis in space show that the above-mentioned frost-sensitive cultures on the Republic's territory can be compromised once every two years in the South of the Republic and nearly each year in the Northern and partially Central parts. (fig. 3 a).

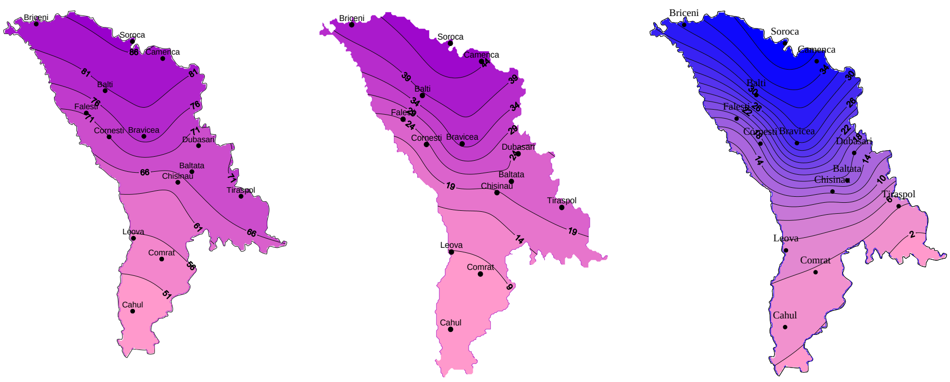

Fig.3 - Grape's cultivar damaging risk (a) sensible to frost (probability %, T< -17 ^{0}C), relatively resistant (b) to frost (probability %, T< -22 ^{0}C) and frost resistant (c) (probability %, T< -25 ^{0}C) on the Republic of Moldova's territory

For the grape cultivar relatively resistant to frost (*Ester*, *Favorit*), the critical temperatures of damage to frost are < -22 ^{0}C. The spatial modeling of the manifestation probability of this thermal fund allows us to state that the damaging risk for this cultivar appears in the Republic's south once in ten years. Northwards, the risk becomes more frequent and in the Central part it is manifested once per 5 years, and in Northern part – once per 2-3 years (fig.3 b).

Some grape frost-resistant cultivars, such as the Talisman cultivar proposed for temporal registration for production testing, have critical damaging temperature of -25^{0}C.

Prognosis manifestation of T< -25 ^{0}C shows that the optimal area for cultivation is the South and South-East of the Republic, where this low thermal fund is manifested once per 50 years. Thus, this cultivar's damaging risk is low for this region, and the proposed favorable area for cultivation is up to a latitude lower than that of the city of Chisinau (fig.3 c), until the border with the probability manifestation of 10% of this thermal fund.

It should be noticed that the multitude of climatic risks conditions the possibility of using both local and international databases, especially CRED and DMCSEE informational databases. For the Republic of Moldova, according to CRED, in the 1900-2011 period, the biggest material damages were registered in the last two decades, after the drought manifestation in 2007 (52%) and floods (43%), that make for 95% of the total material losses (fig.4).

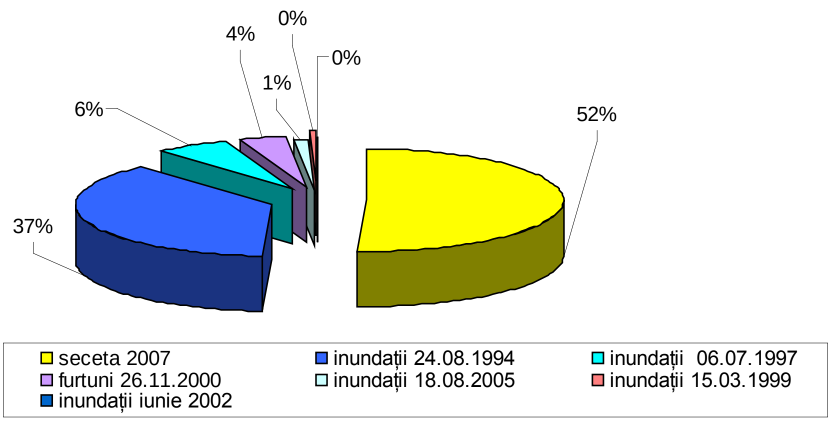

Fig.4 - Share of climatic factors in material losses (1900-2011 period) on the Republic of Moldova territory (source: CRED CRUNCH)

Alternation of droughts with pluviometric maximums can be observed both through the years and during the same year.

Thus, in June 2007, on the background of intensive drought in the South-Eastern part of Republic, the maximum daily precipitations in Comrat was of 78mm, exceeding significantly the climatic norm for this region. Map-schemes elaborated on the basis of this index by the Drought Management Centre of South-Eastern Europe show that the drought in 2007 had a damaging character in May, June, July (fig.5a) and can be qualified as severe and extreme for both duration and intensity. The comparative analysis of fig.5a with fig.5b shows the inverse character of the zonality principle when the June drought is considered, which is conditioned by specifics of atmospheric circulations generated over the Black Sea basin, which caused abundant rainfall on June, 4 (fig.5 c). Thus, cartographical models of regional data are extremely necessary, as they can explain drought manifestation in dependency with territorial relief and local specifics of atmospheric circulations. Even more, the Black Sea basin's influence on the background of long-lasting drought can sometimes provoke rainfalls that exceed monthly climatic norm in the South-Eastern part of the Republic.

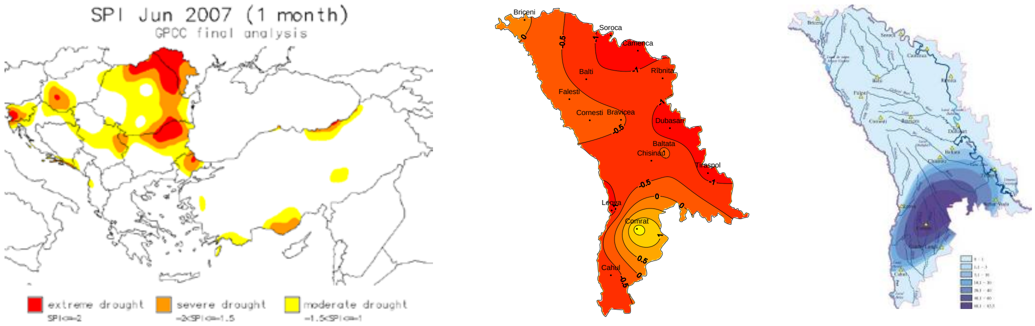

Fig. 5 - Spatial distribution of drought phenomenon (a – according to the indicated source, b – regional models) and of pluviometric maximums (c- regional models) in 2007

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In the context of climate changes, the specific feature of the humidification regime of the last years consists in frequent alternation of antipode drought-humid periods. This fact determines the elaboration of new complex climatic indexes, which allow adequate characteristic of the humidification regime and of antipode extremes manifestation.

Taking into account that in the period of growth and development of agricultural plants on the Republic's territory, the humidification deficit is a limiting factor in cultivation, therefore we propose to evaluate this deficit by the Dry periods Index (I_{zu}), which represents the relation between the number of dry days registered in given years with their multiyear average expressed as:

$$Izu = \frac{\sum zu_{(V-VIII)}}{\overline{X} zu_{(V-VIII)}} \qquad (4)$$

where $\Sigma zu_{(V-VIII)}$– dry days sum registered in May-August, when growth and development of agricultural plants take place, $\overline{X}\ zu_{(V-VIII)}$ – dry periods' multiyear average (May-August)

At the same time, the maximum daily precipitations can generate big amounts of water that fall in very short periods of time. Having a pronounced intensity, these can determine high floods that can have severe consequences for constructions and human settlements, conditioning accelerated erosion on the slopes without forest vegetation. The fundamental processes that lead to synoptic situations development capable to produce big quantities of atmospheric precipitations are convection and turbulent exchange inside the air masses. In the last period, they manifest with increased intensity and frequency.

While estimating the periods with precipitations in excess, the author, for the first time, proposes the Index of Pluviometric excesses (Ip) with the following formula:

$$Ip = \frac{\sum P\max - Pmed}{\sum P\max} * 100\% \qquad (5)$$

Thus, the Index of pluviometric excesses *Ip* is an indicator of the danger level during abundant precipitations manifestation. Cartographic modeling of *Ip* in June 2011 shows that it varied within the limits of 65-85%, which indicates severe pluviometric excesses (fig.6) on the Republic of Moldova's territory.

The North-Eastern part of the Republic and the Tigheci Hills were near the limit of damaging pluviometric excesses, as the values were equal to 80%. At the same time, we should mention that multiyear data analysis demonstrates that when 89% is surpassed, the risk of floods appears. In the given case, as the dangerous limit of daily pluviometric extremes was not surpassed, the floods risk hadn't been registered on the Republic's territory.

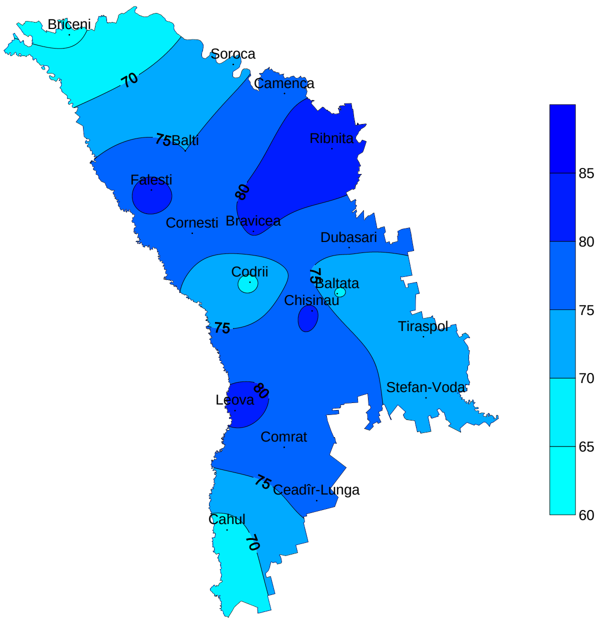

Fig.6 - Cartographic modeling of Ip on the Republic of Moldova's territory, June 2011

In conclusion, we should state that the instable character occurring in the regional climatic system conditions us to elaborate complex indexes which could contribute to adequate evaluation of climatic risk factors in actual climate conditions.

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