DROUGHT RISK ASSESSMENT BY MEANS OF DROUGHT HAZARD AND VULNERABILITY INDICES IN MUNTENIA REGION

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ABSTRACT. – Drought Risk Assessment by Means of Drought Hazard and Vulnerability Indices in Muntenia Region. This paper aims at portraying the climatic risk linked with the emergence of droughts in the historical province of Muntenia, Romania. The negative implications of droughts in the territory are a product of the interrelationship between the hazard characteristics and the conditions that convert the society vulnerable. In the following pages, we will attempt to determine the materialization in the territory of the concept of hazard, having as a starting point the precipitation data from 30 meteorological stations situated across Muntenia. On the other hand, the vulnerability was assessed with the help of three indicators that depict the degree to which the population and the territory are susceptible to dry phases in accordance with their characteristics, such as population density, on one hand, the land usage and the distance between a certain point and the nearest river, on the other. Finally, by multiplying the values resulted from the calculation of the hazard and vulnerability indices, the purpose is to create a map of the risk connected to droughts in Muntenia. In this way, the areas more prone and exposed to the adverse outcomes of droughts were highlighted, this representing the first step of future policies aiming at mitigating the negative effects the droughts have on the society and the environment.

Key words: drought, hazard, rainfall, vulnerability, socio-economic indicators, risk, Muntenia.

1. INTRODUCTION

Drought episodes develop over extensive areas, but its consequences are various due to the spatial differentiation which appears as a result of the geographical specific and varied processes impacting the manner in which a territory responds to droughts. Despite the fact the vulnerability and risk linked with this phenomenon must be evaluated as a point of departure for a prospect environmental policy, the failure of a comprehensive appraisal in our country has led to multiple negative impacts, on both the natural and socio-economic systems. Muntenia, because of its location in an area with low amount of rainfall and continental influences which lead to the prevalence of an anticyclonic regime, is prone to experience the most severe repercussions as a result of the general climate worsening. In addition to that, Muntenia is a province highly urbanized and densely populated, but also with vast

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areas transformed into agricultural lands, which are not in their entirety irrigated. In Romania, the analysis of the risk directly related to droughts and the implication it has on the socio-economic sphere are still in an initial stage of comprehension. However, understanding this process would have only positive aftermaths in drawing up the general directions of future actions which would consider the droughts' mitigation and the amelioration of the damage they have caused during time, evidenced by declining environmental and landscape values.

2. DATA AND METHODS

In assessing the risk of droughts, we are investigating the probability of the hazard occurrence and its impact on different natural or anthropic systems which are more or less vulnerable to external disturbances. Hence, the risk can be approximated by means of hazard and vulnerability indices juxtaposition. The subsequent methodology was based upon the one developed by some researchers from the Mekong River Commission for Sustainable Development, which was approached in order to determine the risk to which the Mekong river basin is exposed in respect with the intensity and frequency of droughts, as well as the specific of the population and its activities. Analogous to other natural hazards, the droughts impact depends on both their intensity, inherent characteristics and the specific of the population and the extent to which it can cope with changes appearing in its structure.

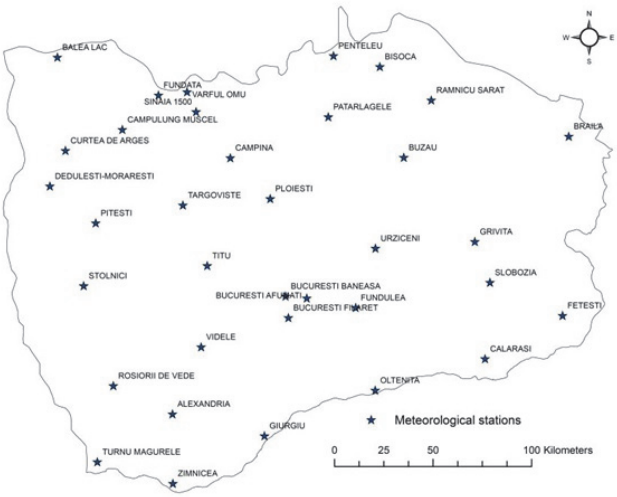

Fig. 1 Muntenia's meteorological stations

First of all, the quantification of the hazard indexes offers a proper image of the spatial distribution and frequency in time of periods with either a deficiency or abundance of rainfall. In this analysis, the average yearly quantities of precipitation were used in order to illustrate these aspects. The precipitation data

were provided for free by Marius Bîrsan from the National Meteorological Administration and belong to the Rocada project, covering the period from 1961 until 2010. The above indicators were collected from a network of 30 meteorological stations located across Muntenia (Fig. 1). For this study were used also data originating from some stations situated in the proximity of the envisaged province, more precisely some of the mountain stations, namely Bâlea Lac, Omu peak or Sinaia.

The spatial extent of the weather stations is, in our view, reasonable, as it covers the entire region, from the lowest (Buzău, 85 meters) to the highest altitudes (Vârful Omu, 2.505 meters). We decided to start collecting data beginning with 1961, because from that year, the meteorological stations on the Romanian territory were linked in a network, with standardized observation and measurements practices. So, starting from then, there are few inhomogeneities in measuring the weather parameters, the hours at which the observations are made and the location of the stations remained unchanged until the present day. Terink et al. (2011) used average yearly precipitation sums from October until May. However, in this paper, the data we used was for the whole year.

For calculating the mean amount of rainfall for a certain station during the envisaged period we made use of the following equation whose result would serve at estimating the drought hazard index:

$$DHI = 1 - \left(\frac{value - \min(values)}{\max(values) - \min(values)}\right) \quad (1)$$

where DHI – *the drought hazard index*
value - the average quantity of precipitation for a station
values - the average quantity of precipitation for all the stations.

The results range between 0,1 – insignificant probability of drought occurrences, and 1 – extremely elevated possibility of drought emergences. As it would have been predicted, the lower the quantity of precipitation, the more hazardous the given place to droughts. So, starting from this parameter, the areas with a higher drought index can be mapped and emphasized.

The vulnerability of a territory refers to the probable damage and losses caused by a natural hazardous event. At the same time, a domain is vulnerable only if it is populated and individuals undertake social and economic activities. In the case of general climate changes certain indicators portraying the exposure of human communities to the harmful effects of this phenomena especially on the water resources. When it comes to drought, however, the indicators should be chosen according to the scale of the hazard development, as well as its characteristics. In our study, three socio-economic metrics were identified as proper for the establishment of vulnerability, namely the population density, the land usage and

the distance between a certain point and the nearest river, in accordance with the equation:

$$DVI = \frac{VI_1 + VI_2 + VI_3}{3} \quad (2)$$

where VI_1 - *the vulnerability index for population density*

VI_2 - *the vulnerability index for the land usage*

VI_3 - *the vulnerability index determined by the distance from the closest river.*

The Gross Domestic Product per capita was not utilized as in the cited source for calculating the vulnerability index because of the fact the data offered by the National Institute of Statistics are not free to download.

Finally, the risk can be determined by multiplying the hazard and vulnerability calculated values for a specific territory. Therefore, it is enough just one indicator to have high values in order for the risk to be high as well. Also, if either the hazard or vulnerability is equal to 0, no matter how critically high is the other indicator, there will be no risk. An explanation of this situation would be that, even if droughts are frequent in a certain area, if it is not inhabited or introduced in the agricultural cycle, so with a low vulnerability, that area presents no risk to droughts. The same goes with the densely populated areas or the ones with an intense cultivation, but whose weather is not arid enough to generate droughts, so the hazard is null, as well as the risk.

$$DRI = DHI \times DVI \quad (3)$$

where *DRI - the drought risk index*

DHI - the drought hazard index

DVI - the drought vulnerability index

3. RESULTS AND DISCUSSION

3.1. Drought hazard index

As outlined in the Intergovernmental Panel on Climate Change glossary of terms, hazard refers to "the potential occurrence of a natural or human-induced physical event that may cause loss of life, injuries or other health impacts, as well as damage and loss of property, infrastructure, livelihoods and environmental resources". Because it constitutes a probability, the values for hazard can be placed on a scale ranging from 0 to 1. In our case, the drought hazard index is the average of the yearly precipitation sums, this methodology being inspired by the one used by Terink et al. (2011) in addressing the impact the droughts had in the Mekong river basin. So, as we are about to see, the lower the quantity of precipitation, the closer the hazard index to the maximum value of 1. For each station, consequently, the value is between 0 and 1 and by interpolating these values the drought hazard map was created (Fig. 2).

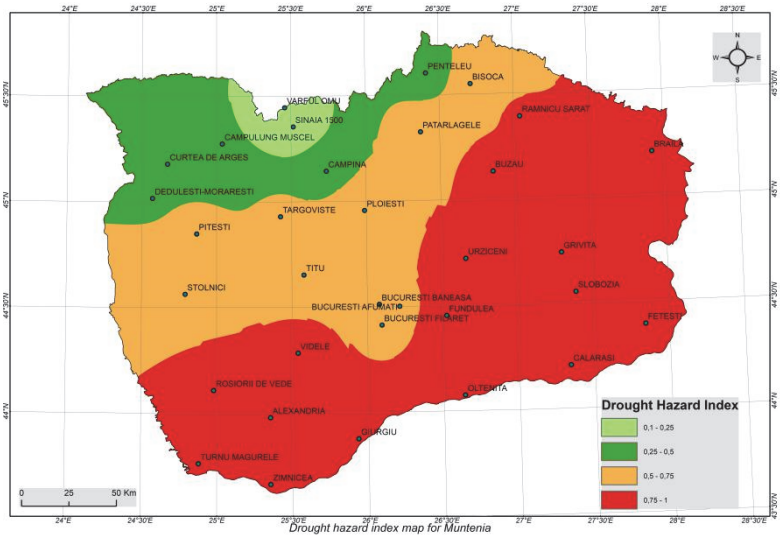

Fig. 2. Drought hazard map for Muntenia

From the above map, several observations can be made. Firstly, the areas which usually experience reduced amount of rainfall due to the geographical position within the country, low altitudes and characteristic continental air masses with a significant contribution in diminishing the quantity of precipitation, are more hazardous. In the case of Muntenia, these areas correspond to the Southern and South-Eastern parts of the province, the amount of rainfall only in a few situations exceeding 550 mm/year – Fundulea, 551.7 mm/year, Giurgiu, 573.2. Here, the index ranges from 0,75 to 1, making these places to be more prone to severe and prolonged droughts. Also, the shape formed by the line which circumscribe these areas is a result of the continental air masses intrusion that, regardless the season, they are lacking moisture, causing the weather to become harsher and dryer (Clima României, 2008). As we move Westwards and also Northwards, the index becomes smaller. In this way, it ranges from 0,5 to 0,75 right next to the areas where the index is the highest. Regarding the capital city, București, it is located in the sector where the index falls into the last-mentioned category, still the hazard is very likely to occur. Also, other settlements like Stolnici or Ploiești from the Romanian plain or Pătârlagele from the Subcarpathian and Bisoca at the contact between the Subcarpathian and Carpathians are included in the class in which the index is high. Then, the hilly and some parts of the mountains are classified as moderate hazardous because the index is smaller, ranging between 0,25 to 0,5. This reduction in the index value is a direct aftermath of the increased altitudes which determines an increase of the amount of rainfall, the case of Penteleu and of the sequence of hills and depressions which determine the appearance of the thermal inversions, as it happens in Câmpina or Câmpulung Muscel. Finally, the index is the smallest in

the highest mountains in the province, in areas above 1,500 meters. Thus, the surrounding area of Omu peak and Sinaia meteorological stations are characterized by a small probability of droughts emergence.

3.2. Drought vulnerability index

As we have seen, the distribution of droughts differs across Muntenia, some areas being more prone to droughts, thus more hazardous. The authorities, in their search to diminish the impacts the droughts have on the territory, should keep in mind the fact that only through the vulnerability mitigation of social and natural systems, this action is possible and sustainable. In fact, the evaluation of vulnerability represents the first measure so as to take action in a mid- and long-term run against negative impacts the droughts have, such as water shortages (Vogt et al., 2018).

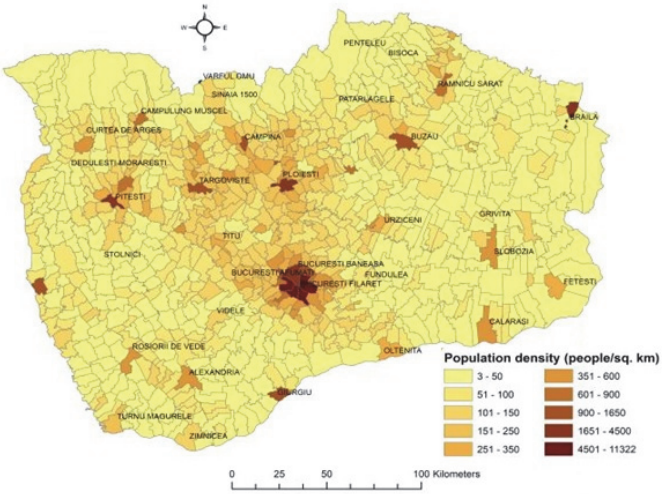

Fig. 3. Population density in Muntenia 2011

Therefore, for more susceptible communities and exposed sectors of the economy, like agriculture, suitable policies have to be deployed. Vulnerability refers to „the propensity or predisposition to be adversely affected", as mentioned again in the IPCC glossary of terms. In this framework, three factors had been used for measuring the territory's vulnerability. The population density (Fig. 3) represents a social factor, the land usage an economic one, whereas the distance between a certain point and the nearest river is both a social and a natural determinant. A conclusive situation is when, after a lenghtened drought, the available moisture in the soils is depleted because of the enhanced evapotranspiration, this circumstance „affecting directly the agricultural activity and food production" (Dabanli, 2011, p. 6). Also, during a drought event, the rivers flow and the groundwater reserves are lessened, affecting, beside the agriculture, the population. So, we can say that the more numerous is a city, the more it will be

impacted by a severe drought, during which the municipality would not be able to provide the citizens the demand of water.

In what follows, we shall turn our attention to the indicators used for mapping the vulnerability of the territory. To begin with, the data for the population density are from 2011, highlighting the dissemination of human communities within the territory and the most populous areas. The land usage was extracted from Corine Land Cover data base from 2018 and it depicts the proportion of natural areas in contrast with the ones converted into agricultural fields or urban settlements. In order to evaluate the vulnerability of each manner of land utilization, six classes were established, as follows: the urban areas were considered the most vulnerable to droughts, so they were given the highest indicator number, namely 5. Then, in descending order comes the agricultural fields completely dependent on precipitation, then the ones which are irrigated. With an index value of 2 are the natural areas, only partially modified by human intervention. Further, the grasslands are to a small extent vulnerable to droughts, due to their location at high altitudes or environmental stability. Finally, less susceptible to droughts are the bare rocks, cliffs and permanent water bodies, in this case the indicator having the value of 0. This classification is based on the one made by Tarik et al. (2011) in the article regarding the risk associated with droughts in Mekong river basin.

Table 1 . Classification of the types of land use, according to their vulnerability to droughts - (Source: Tarik et al., 2011)

Types of land use	Index value
Urban areas	5
Agricultural fields dependent on rain	4
Irrigated agricultural fields	3
Natural areas	2
Pastures	1
Others	0

The third indicator is the distance between a certain location and the nearest river which points out the degree of dependency on water resources. Consequently, the farther from a water body, the bigger the exposure to droughts of that particular point.

It was ascertained the distribution of the territories presenting a high vulnerability to droughts. They can be found across the driest areas of the province, in Bărăgan, where the hydrographic network is sparse, so the distances from rivers are great, fact that determined the third indicator to be the highest in this area. As well, the main land use is the agricultural one, but it is pretty much subordinated to weather evolution, although there are some irrigation systems. However, the required cost for their putting into operation is too heavy for the local farmers to afford, according to the National Administration for Land Improvement. Hence, they are conditioned by the weather patterns, more specifically by the ones of

precipitation. Following, a high vulnerability index characterizes also the capital city, because of its elevated population density and a totally urbanized area, circumstances which determine the first two indicators to be at their maximum. Nonetheless, it may be important to touch upon the point that this vulnerability, in the case of București, is only hypothetical, causing possible damages only if the sources of water from the reservoirs supplying the city would fail. Other cities are also prone to more negative consequences caused by droughts, they being located both in the Romanian Plain, but also in the Sucarpathian depressions, the cause being again the population agglutination in these areas and the high degree of urbanization. Less, but still significantly vulnerable to droughts, are the territories overlaying the majority of the Romanian Plain, as well as the Subcarpathian, fact that can be explained by the existence of important human communities and the transformation of the biggest part of the land into agricultural fields. Less vulnerable are the Subcarpathian hills, the mountains and the river valleys. Here, all the indicators have low values – the population density is low, the environment is less impacted by human intervention, thus the land is in its natural state in several areas, the agriculture is not practised and the rivers are numerous. So, as a conclusion, the vulnerability of the territory is directly linked with the elevation of the relief.

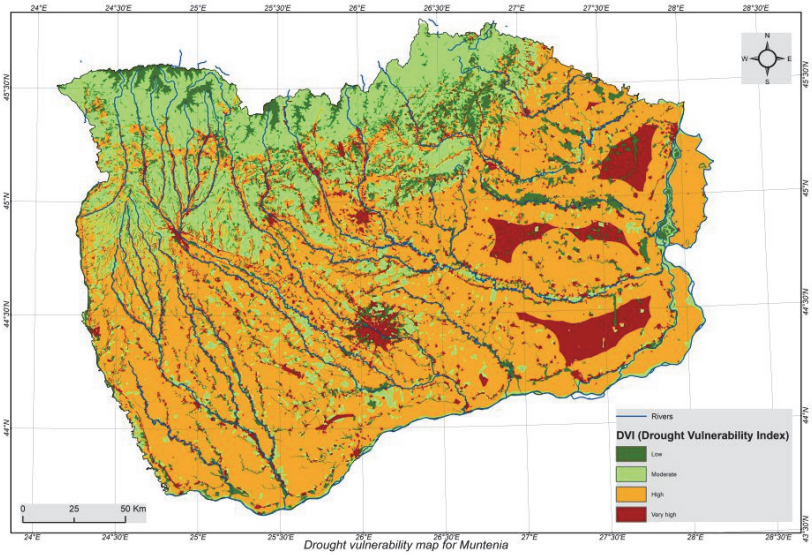

Fig. 4. Drought vulnerability map for Muntenia

3.3. Drought risk index

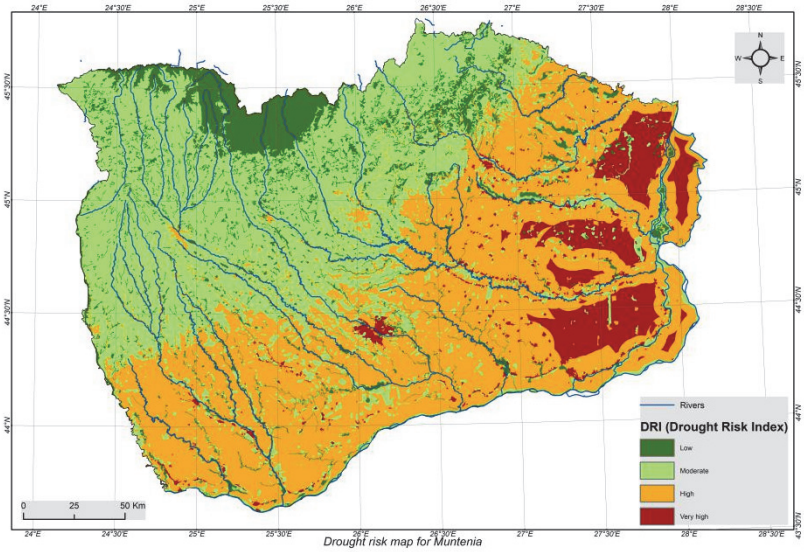

Fig. 5. Drought risk map for Muntenia

In conformity with the World Bank definition, the climate risk represents a conjunction between the exposure to the hazard, the degree to which the society is affected, as well as its capacity to adapt to changes. The drought risk index was calculated, in this case, by multiplying the hazard and the vulnerability related to droughts. This procedure is aimed at identifying the places worst impacted by droughts, so as to ascertain the main actions pointed at mitigating these effects, but also some adaptation plans for the communities. Muntenia is in a different way at risk in face of the droughts occurrences, due to the various intensities the hazard has according to the terrain elevation and air masses origin, on one hand. Moreover, the vulnerability plays a major role in determining the value of the risk index, because the higher the susceptibility of the environment or the society to droughts, the higher the risk they are exposed to. It is known how difficult it is to forecast future droughts, still their negative outcomes can be mostly reduced by proper interventions and policies. This is why the procedure through which the risk is mapped symbolizes the starting point for its better management. In respect of the risk, Muntenia is divided quite equally between the areas with a low and moderate drought risk and those characterized by a high and very high risk.

The generated risk map is conclusive and very similar to the one depicting the vulnerability. In this manner, the highest risk is encountered in vast territories from Bărăgan and between the Danube branches, but also București and other settlements such as Buzău, Urziceni, Alexandria and those located along the Danube present an extremely high risk. For these locations, both vulnerability and hazard have high values with repercussions on the risk level. They are either

densely populated, with the land converted into urban areas or agricultural fields dependent on precipitation or irrigated, with higher vulnerabilities, or situated away from a river. This situation is even worse, because at high drought risk are, firstly, the most populous cities, the most relevant being București which in the case of a severe dry phase would have numerous citizens directly impacted by the negative consequences of droughts, especially by water shortages. In addition, one of the most important agrarian regions of the country, Bărăgan, depends almost entirely on the weather fluctuations, placing it in the series of territories with an increased level of risk. So, if a drought hits this area, the consequences at national level would be very damaging, as the agricultural output would be reduced and the national market would be invaded by more expensive and sometimes low quality products from the external markets. Also, the configuration of the areas with a moderate risk differs between East and West, they being more extended from the valley of Ialomița to Olt river valley. The risk value decreases as the altitude becomes higher and as we move westwards, to reach its minimum on the highest mountains. Likewise, at low risk are, like a break-in in the territories at high risk, the floodplains of the rivers, namely Argeș, Buzău or Călmățui rivers.

The risk can be, nevertheless, enhanced by the periodic heat waves which hit our country. When they are simultaneous with droughts and last for several days, they affect profoundly the urban sites, the agriculture and energy production. So, the heat waves influence both the intensity of droughts, thus increasing the hazard index, and also the social vulnerability which manifests through heat stress, health problems and low crop production, that in turn impacts the quality of life.

Intriguing is, however, the perception the communities generally have as regards the unleashing of droughts. Because this process is slow, and its consequences are visible only in time, the droughts are not considered, in the first instance, as destructive as the floods, for example, which have a sudden outbreak and immediate negative implications. Nevertheless, the droughts are more hazardous, firstly because of their greater spatial extent and secondly for their disruptive nature. The impact they have on the human activities has to be mitigated through policies aiming at the identification and management of water resources. The most affected is the agriculture, especially in the countries where the irrigation systems are not perfected and the farmers rely upon the weather evolution. This happens also in most of the situations in Romania and Muntenia is not an exception from this unfortunate state of affairs. This is why, when a drought event begins, the agriculture is even more at risk than in normal situations which are caused by the general air masses circulation and the continental nature of the region. In order to diminish the risk, the droughts emergence can be forecast through statistical methods that estimate the evolution of the synoptic situation across Europe and elsewhere.

To point out what has been stated up until this point, the hazard and vulnerability which combined result in the degree to which a territory is at risk to droughts, behave differently and exemplifies various aspects of the natural

environments, as well as of the society and the manner in which it evolved so far. From our findings, several generalizations can be pointed out regarding the risk to droughts Muntenia is exposed to. Firstly, the more remote is a place, the less vulnerable is to droughts, but this is applicable only in those mountainous regions which are protected by the high altitude from those extreme weather events that would eventually cause droughts. Still, the situation changes for Bărăgan, which is another remote place from Muntenia because of the scarcity of transport infrastructure and settlements, but here, the hazard is at its maximum value, so the risk, through the combination of the two indicators, is high. The risk is high also in the populated areas, of whom stands out București, but the lands considerably exploited for crop production too, characteristic being again the Bărăgan, with the majority of the terrains converted into agricultural fields. In the future, the derived map from the risk spatialization should be subject to improvement by including in this analysis more detailed data at a regional scale, data which would portray other aspects of the society, such as the gross domestic product per capita, the irrigated land from the total agricultural land or the quantity of municipal water used. By doing so, a better comprehension of the regional context which determines the risk to droughts to be higher could be gained, with many positive implications in the management of possible difficult situations arising from droughts.

4. CONCLUSIONS

The procedure of mapping the drought's inherent risk is rather complex and difficult because a series of factors should be considered in the evaluation of the hazard spatial extent and the vulnerability differentiation across Muntenia. This integrated approach is, in our opinion, very valuable as it can represent the starting point for the decision makers to mitigate the negative and harmful outcomes of the droughts. From this paper, several conclusions can be drawn. In the first place, the intensity of the hazard is directly connected to the different climatic influences which determine the characteristics of the weather and by extension of the droughts in distinct parts of the province. Another decisive factor is the altitude which plays a significant role in either in the limitation or favouring of dry episodes. When it comes to vulnerability, each of the three indicators employed shows another aspects of the exposure to droughts of both the environment and population. In this sense, the most vulnerable are the territories with high densities of population, the urbanized areas and the ones situated at a distance of more than 10 km from the nearest permanent water body. By means of multiplying the two stated indicators, the risk index was calculated, offering an overall picture of the potential impact of the droughts. The areas presenting a high risk overlap the territories where the hazard is more probable to occur and where the territory and the society are more exposed to the damaging consequences this climatic hazard involves.

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