

## THE IMPACT OF CLIMATE CHANGE ON THE DYNAMICS OF AGRICULTURAL SYSTEMS IN SOUTH-WESTERN ROMANIA

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**Abstract.** The study means to quantify the impact of aridification on the dynamics of agricultural-production systems in South-Western Romania, where the consequences of climate change become ever more visible. Vast tracts of farmland and especially arable land are nowadays increasingly impacted by recurring droughts, which caused the aridification of large areas, and occasionally the complete elimination of vegetation. The question arises, in this context dominated by these phenomena, how do the other components of the impacted territorial systems react. This study establishes a correlation between the evolution of the aridification process and the dynamic of water resources at regional level, the latter being a vital component in the development of agricultural-production systems. Research methodology included a detailed analysis of aridification in correlation with the fluctuation of certain hydrological and hydrogeological parameters, as well as, indirectly, an analysis of the connection between water resources and regional crops. The results obtained emphasize the decline of agricultural-production systems as a result of the expansion of aridification and the decommissioning of irrigation systems which, over a long time, had compensated the absence of precipitations.

**Keywords:** aridification, territorial systems, territorial management, agriculture.

### 1. INTRODUCTION

Nowadays Romania faces the obvious effects of aridification, and the areas impacted worst are those located in the South and the East. A warning signal about this issue was rung by the fourth report of the Intergovernmental Committee for Climate Change. The report indicates that Romania is one out of the seven European countries most likely to be severely impacted by drought in the next few years.

The ever more visible global climate changes have a special impact on the natural and social environment. Numerous scientific works present the scale of the imbalances registered at the level of the impacted territorial systems (Jones & Moberg, 2003; Böhm et al., 2001; Klein Tank & Können, 2003; Vlăduț, 2011). The worst impacted component of the territorial system is agriculture, as, in the absence of specific improvement work, it suffers significant fluctuations (Parry et al., 2004, Bouma et al., 1998).

Aridification and the shrinking of areas worked generate a series of additional chain-reaction negative effects, including a change in the use of land across a particular territory, structural changes in the workforce, the migration of the active population and population aging.

In this global context, an important role is assigned to the creation of consistent strategies for territorial management, capable of alleviating aridification and therefore ensure the dynamic balance of the territorial systems. These strategies can ensure the optimal functioning at the level of the territorial systems dispose of at a given moment (Mocanu et al., 2011; Vanderpost et al., 2011; Heshmati et al., 2011; Sánchez-Picón et al., 2011; Nikolova & Boroneanț, 2011). Territorial management strategies must grant the due importance to the local communities, which have a very important part in both escalating certain imbalances at the level of territorial systems, and in alleviating them.

In scientific literature, aridification in Romania is first approached sometime after 1960 (Cernescu, 1961), with the concepts used being those of aridification and even desertification. The concept of aridification is used in order to define the process of deterioration of the land, because of climate changes and the deficient management of the land (Berbecel et al., 1970; Păltineanu et al., 2000; 2007).

Aridification, alongside other imbalances at the level of local systems, contributes to the accentuation of functional fractures and therefore to the rise of optimization costs. Scientific literature emphasizes the need for a system approach or simply the integrated approach to the dysfunctions so as to place territorial management strategies in a best-condition area (Janos et al., 2012a; Peptenatu et al., 2011; Braghină et al., 2011). One of the most important causes of this phenomenon in the area studied is the presence of sandy-textured soils on large areas, characterized by low water-retention capacity, very low fertility and high wind-erosion potential.

The first complex research into the use and capitalization of the sandy soils in Southern Oltenia was conducted in 1930 by the Romanian Institute for

Agronomic Research in the locality of Gârla Mare. Research continued starting 1956, conducted by an experimental center in Bechet (Dolj county), converted into the Bechet Sand-Improvement Research Station in 1970.

## 2. MATERIALS AND METHODS

The region studied is located in South-Western Romania, where aridification currently encompasses more than 150,000 hectares, but where the area risking aridification exceeds 700,000 hectares (Fig. 1).

Aridification as a process was analyzed from a historical perspective by means of the study of official documents concerning the effects of climate change on Romania, as well as numerous scientific works that tackled the trend towards aridification in individual instances. Special attention was paid to the feasibility studies that accompanied the implementation of certain projects concerning the irrigation systems in Romania, studies that created the big picture of the factors that contributed to the amplification of the effects of aridification on the local communities.

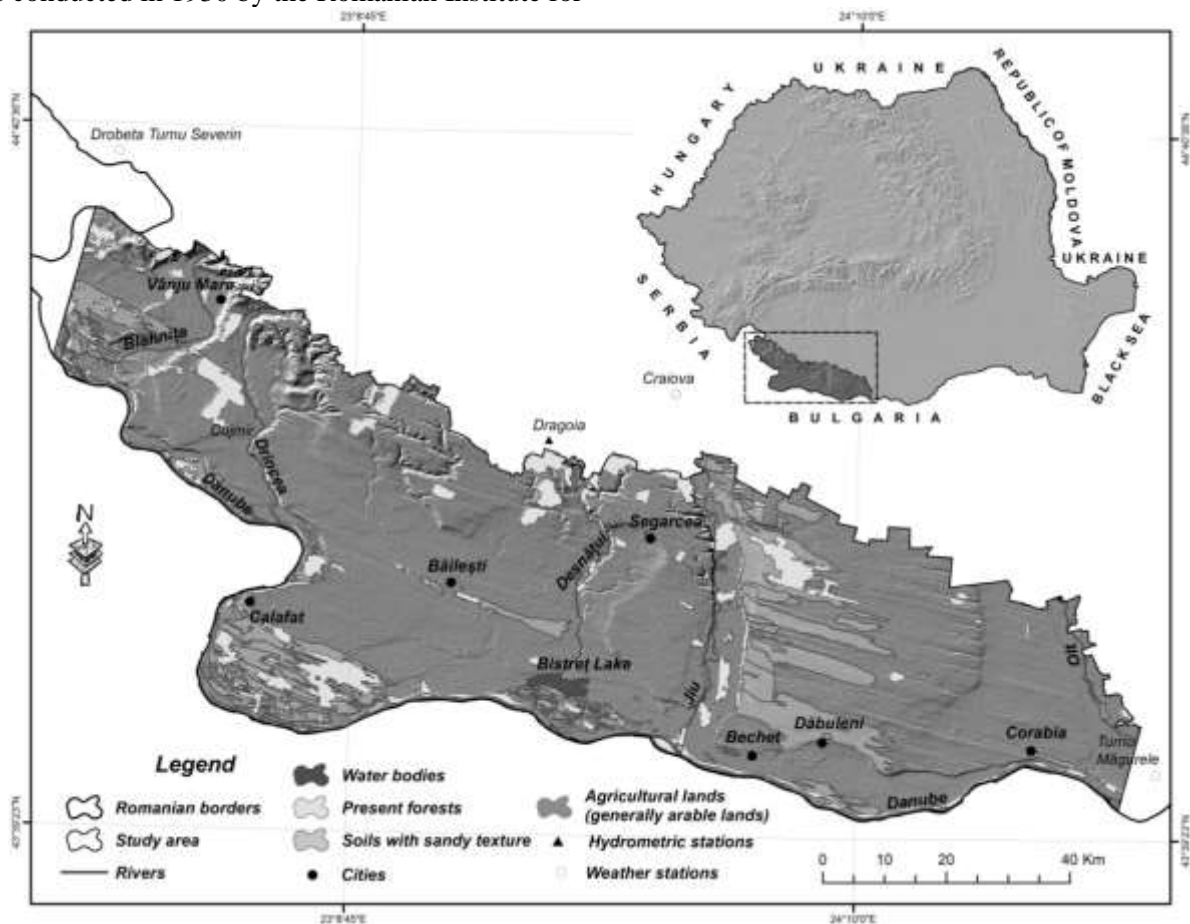


Figure 1. Location of the area studied in Romania.

Quantifying the trends towards aridification was accomplished by means of the De Martonne and UNEP aridity indexes, indexes relevant for the phenomenon analyzed (Prăvălie, 2013). The De Martonne aridity index is calculated starting from the relation between temperature and precipitations (De Martonne, 1926):  $I_{ar-DM} = P/(T+10)$ , where P stands for precipitations (mm), and T stands for mean annual temperatures (°C). The UNEP aridity index, suggested by the United Nations Environment Programme in 1992, is calculated according to the formula:  $I_{ar-P/PET} = P/PET$ , where P stands for the average annual precipitation (mm), and PET stands for potential evapotranspiration (mm), calculated by means of the Thornthwaite method (UNEP, 1992). There are several methodologies in scientific literature used to estimate potential evapotranspiration (Bandoc, 2012), but the Thornthwaite method is the most representative in Romania's case (Păltineanu et al., 2007).

Potential evapotranspiration was calculating by means of the Thornthwaite formula, defined as follows:

$$ETP = 16 \cdot \left( \frac{10t}{I} \right)^a F(\lambda)$$

where: t – average monthly temperature (°C)

I – annual thermal index calculated by means

of the formula  $I = \sum_{n=1}^{12} i_n$ ,  $i_n = \left( \frac{t}{5} \right)^{1.514}$

$$a = 6.67 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.49$$

F(λ) – adjustment factor depending on the latitude and the month of the year

The data on the temperature and precipitation climate parameters were extracted and processed from the European Climate Assessment & Dataset platform (European Climate Assessment & Dataset, 2013). The data used were the average annual values of the temperature and precipitation parameters from the weather stations closest to the area analyzed: Drobeta Turnu Severin, Craiova and Turnu Măgurele. The data were deemed as representative for the area analyzed, and they were analyzed for the maximal length of time available, 49 years (1961-2009).

In order to capture the impact of the climate changes on other components of the environment (the water resources in the region), the values obtained of the De Martonne and UNEP aridity indexes were statistically matched against the average annual volume flow rates of several rivers in Southern Oltenia: Drincea and Desnățui (at the Cujmir and Dragoia gauging stations) (Fig. 1). The data were obtained from the Jiu Drainage Basin

Administration and it spans 1961-2009; in the case of the Dragoia gauging station, the data available were limited to 1964-2009, so that the data for the three missing years was reconstituted so as to preserve the same time span for the analysis. The reconstruction was achieved by means of the linear regression equation, as a result of a high correlation quotient between the two sets of data during the time span shared (the correlation quotient r standing at 0.88).

In addition, with the same goal of capturing changes in water resources, there were also analyzed data on the fluctuation of groundwater levels during 1964-2008 at the Băilești hydrogeological station, data obtained from the National Hydrology and Water Management Institute (National Hydrology and Water Management Institute, 2013). In order to examine to what extent did climate change influence the fluctuation of groundwater levels in the past few decades, an attempt was made to correlate the evolution of evapotranspiration values and the drop of groundwater levels, as evapotranspiration is one of the components of the climate with the biggest influence on the dynamics of underground waters (groundwater) (Hübener et al, 2005).

The analysis of the impact on the agricultural system was accomplished by means of statistical correlations between the fluctuation of groundwater levels and the fluctuation of wheat, corn and sunflower crops during 1990-2003, data obtained from the County Department for Statistics Mehedinți, Dolj and Olt. The present study also used data on vegetable crops during the same time span, but, in the context where vegetable crops are irrigated, they were correlated with data on irrigated surfaces, data obtained from the Dolj branch of the National Land-Improvement Administration.

All of these correlations were checked for statistical validity, by means of the statistical-relevance test of the Bravais-Pearson r correlation coefficient (Minvielle & Souiah, 2003).

Composition of the present work also involved the use of information on the condition of the vegetation, by means of remote-sensing methods, as they enable the assessment of the aridification process. The condition of the vegetation, in analyses conducted at regional scale, is quantified by means of the digital vegetation indexes, which are then in turn used to estimate other indicators (Helldén & Tottrup, 2008). The digital indexes are suitable to both the analysis of processes such as land deterioration (Barrio et al., 2010), the decline of water resources (Sawaya et al., 2003; Sîrodoev & Knight, 2007; Peptenatu et al., 2013) and desertification (Vogt et al., 2011; Zucca et

al., 2012), as well as to the study of certain socio-economic effects of those processes such as the ecological quality of a territory (Sîrodoev & Lisetsky, 2009) and the disuse of farmland (Alcantara et al., 2012). Although the use of remote-sensing materials in such studies is subject to certain limitations (Wessels et al., 2012; Prischepov et al., 2012), when applied at a regional scale it generates credible and valid results (Prischepov et al., 2013).

NDVI was the first digital index used to assess the productivity and quality of the biomass (Helldén & Tottrup, 2008). This index may be calculated because of the fact that the difference between vegetation reflectance in the near-infrared and red spectral bands is the highest. Areas with the maximal NDVI values correspond to high green-leaf density (as the thicker foliage of trees covers a bigger surface). The index values may fluctuate from -1 to +1. In real life, the “useful” range is located between 0.1 and 0.9: higher values are extremely rare, while lower values correspond to areas without any vegetation (barren rock, sand or water). In our analysis the NDVI values were derived from Landsat5 satellite images acquired in 1990 and 2011 (NASA Landsat Program, 1990 and 2011).

### 3. RESULTS AND DISCUSSIONS

#### 3.1. Evolution of the aridification process

The temporal analysis of the De Martonne aridity index reveals the onset of the conditions for aridity particularly after 1980 when there can be observed a frequent fluctuation of the values approximately in the 10 – 15 range, a range typical of a semiarid climate (De Martonne, 1926). The most representative years are 1985, 1992 and 2000, when the De Martonne index values dropped below

the landmark value 15, especially as far as the Craiova and Turnu Măgurele stations were concerned (the all-time low recorded being 11.7 mm/°C in 1992, at the Craiova weather station, with a second-lowest value of 11.9 mm/°C recorded in 1992, at the same station) (Fig. 2). In general the aridity values recorded at the Drobeta Turnu Severin station are lower as a result of local particularities such as the proximity to the mountain area, with the role of an orographic barrier, with mountainsides facing South in the path of tropical air, among others, factors that bring about a higher likelihood for the occurrence of precipitation (Vlăduț, 2004).

The UNEP aridity index indicates a visible trend towards aridification as a result of the frequent fluctuations of the values in the 0.2 - 0.5 range, a range that indicates the existence of the features of a semiarid climate (UNEP, 1992). The representative years are those with long-term droughts, that is: 1982 (with a 0.5 mm/mm value recorded at the Craiova station), 1985 (0.4 mm/mm recorded at the Craiova and Turnu Măgurele stations), 1990 (0.5 mm/mm recorded at the Craiova and Turnu Măgurele stations), 1992 (0.4 mm/mm in Craiova and 0.5 mm/mm in Turnu Măgurele) and 2002 (0.4 mm/mm recorded at all three stations) (Fig. 3). Therefore, by means of the trends of the two aridity indexes, the conclusion may be drawn that in the past three decades Southern Oltenia suffered a deterioration of the weather conditions, a situation mostly due to the drop in precipitation and the rise of average annual temperatures.

The analysis of the fluctuation of the average annual volume flow rates at the Cujmir and Dragoia gauging stations on the Drincea and Desnățui rivers (Fig. 1) may indicate a direct correlation between climate changes and the decline of the water resources at local and regional scale.

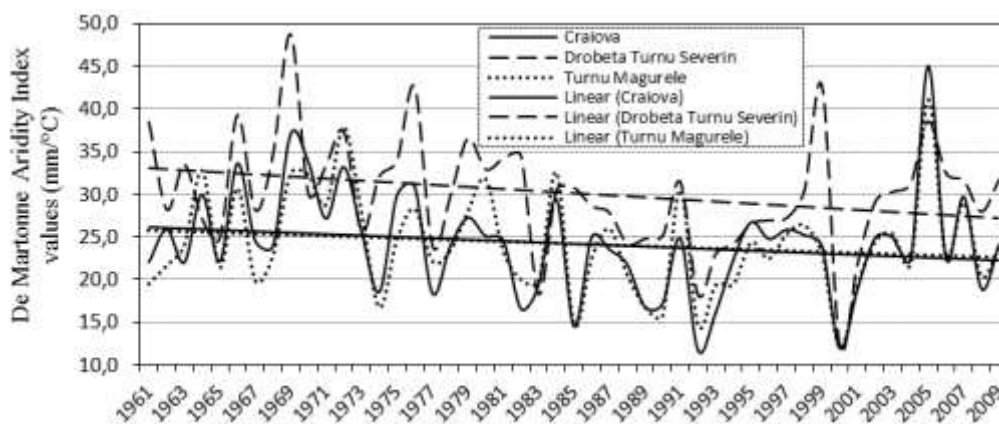


Figure 2. Annual evolution of the De Martonne aridity index and the linear trend at the Craiova, Drobeta Turnu Severin and Turnu Măgurele weather stations (1961-2009).

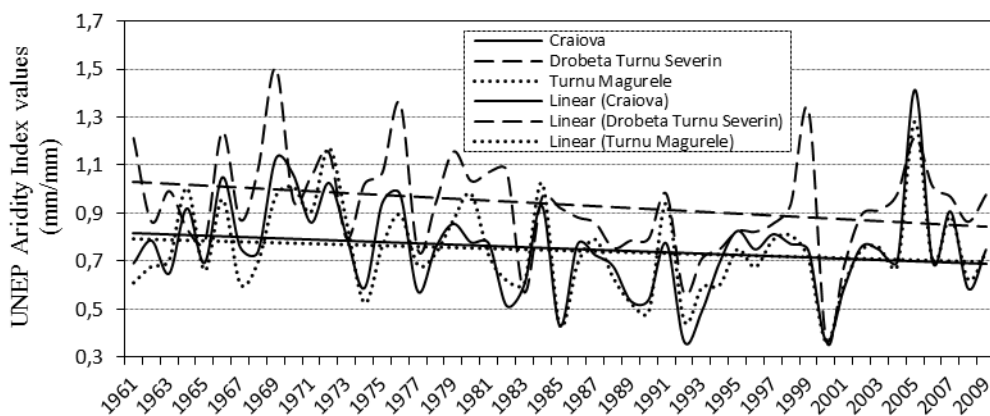


Figure 3. Annual evolution of the UNEP aridity index and the linear trend at the Craiova, Drobeta Turnu Severin and Turnu Măgurele weather stations (1961-2009).

During the time span analyzed (1961-2009) there can be observed a clear decline of the average annual volume flow rates at the two gauging stations (Fig. 4), the main cause being linked to the changes in the weather conditions.

In order to highlight the connection between the conditions for aridification and the changes in the status of surface water flows, a statistical correlation was drawn between the temporal fluctuations of the De Martonne and UNEP aridity index and the temporal fluctuation of the average annual volume flow rates (Fig. 5). Data from the Cujmir gauging station were correlated with aridity data from the Craiova and Drobeta Turnu Severin weather stations, as they are located in relatively similar geographical conditions to those of the respective gauging station. In the case of the Dragoia gauging station, the aridity data correlated were obtained from the Craiova and Turnu Măgurele weather stations, stations selected along similar criteria.

In the wake of the analysis of the statistical correlations, one notices that, as far as the Cujmir gauging station is concerned, the correlation indexes fluctuate around 0.5, while as far as the Dragoia

gauging station is concerned, the correlation coefficients have higher values, fluctuating around 0.6. Although the correlations are not very high, they are statistically significant, a fact confirmed by the results of the Bravais-Pearson statistic-relevance test (Minvielle & Souiah, 2003). The conduct of that test confirmed the statistical relevance, even for a very low error margin ( $\alpha=0.02$ ), thus establishing a direct connection between the aridification of the weather conditions and the changes in surface water flow.

This analysis of the connection between aridification conditions and the impact on water resources, as well as the natural component of the area analyzed, matched in the anthropic sector with the political changes with obvious effects starting 1989 on economic matters across the entire national system, reveals a clear process of expansion of the effects of aridification. These matters have had – and they still have – major negative effects on the local communities involved. Thus, large areas of farmland have been abandoned, especially land where vine and cereals used to grow. This situation gradually led to an accentuation of the deterioration of those tracts of land.

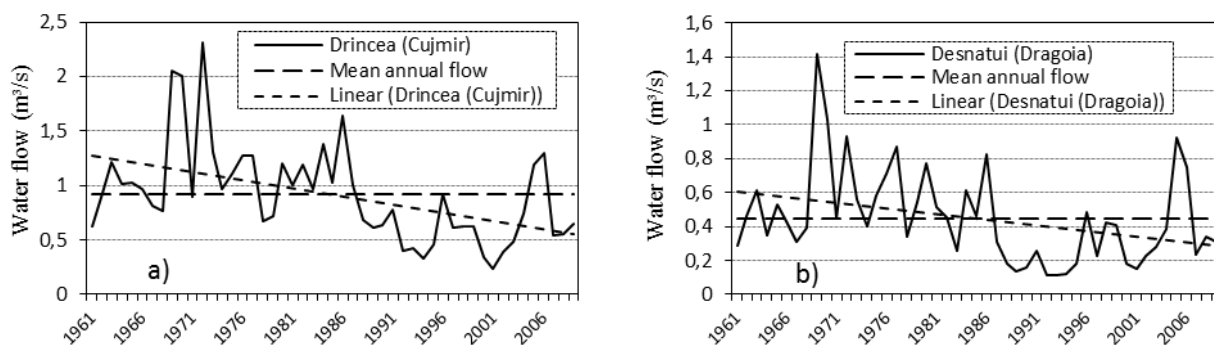


Figure 4. Fluctuations in the average annual flow rates of the Drincea (a) and Desnățui (b) rivers at the Cujmir and Desnățui gauging stations (during 1961-2009) (processed data from the Jiu Drainage Basin Administration).

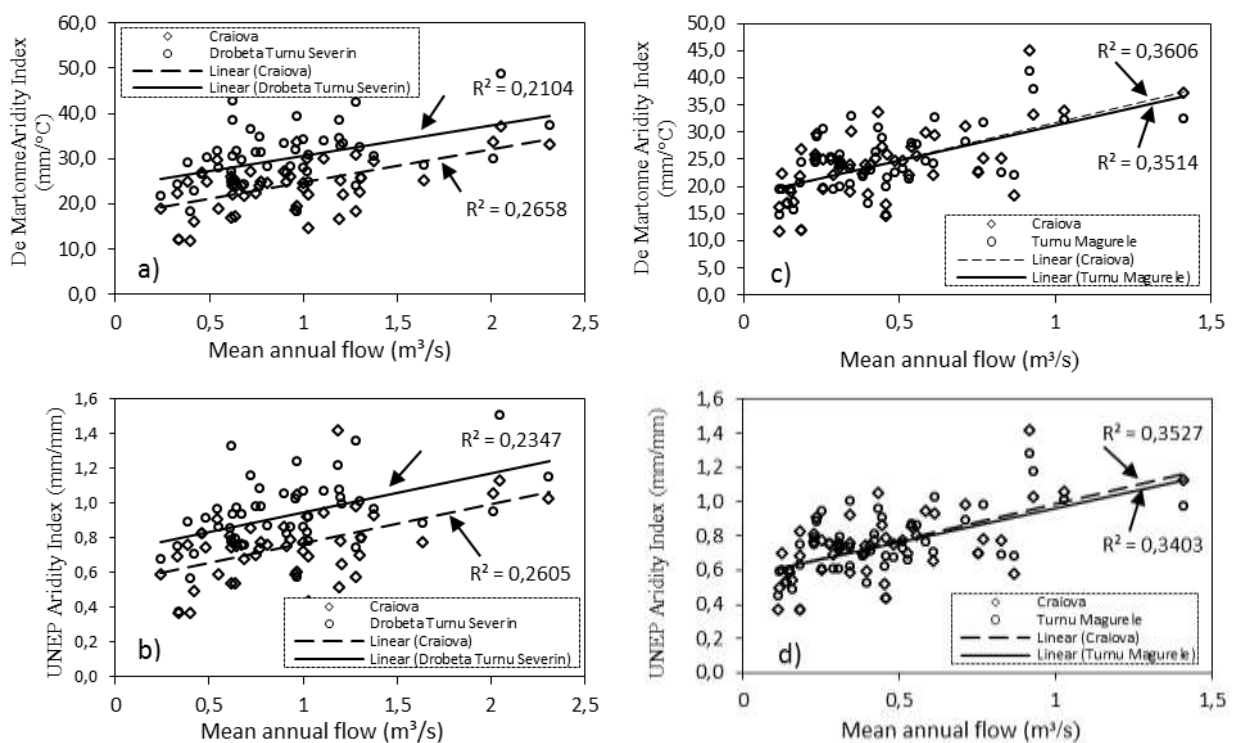


Figure 5. Linear correlations between the annual values of the De Martonne and UNEP aridity indexes and the annual average flow rates of the Drincea river at the Cujmir station, during 1961-2009 (a, b). 5 Linear correlations between the annual values of the De Martonne and UNEP aridity indexes and the annual average flow rates of the Desnățui at the Dragoia station, during 1961-2009 (c, d).

The analysis of the NDVI index by 1990 indicates a predominance of the areas with dense vegetation (more than 60% of the surface of the area), distributed fragmentarily, but with a slight concentration in the central area of the area studied and in the major rivers' meadows (Fig. 6). The areas with an average density, too, are distributed more or less evenly across the territory. The areas with low vegetation density are grouped into several areas in the interior, East of the Jiu river and West of the Drincea river. In addition to them, there can be observed a higher concentration of these areas in the sand-dune areas: in the Danube bend South of Calafat and in the Dăbuleni region.

The 2011 view shows a different situation (Fig. 6). The areas with dense vegetation, although they have retained first place in the area studied, have declined significantly in terms of importance (up to 40% of the total). Areas with average vegetation have remained all but unchanged, while areas with sparse vegetation or without vegetation have expanded considerably, particularly in the Jiu-Desnățui-Drincea interfluves. One should also notice the expansion of these areas on small surfaces in the sand-dune region along the Danube. The analysis of the changes that occurred at the level of barren areas, corresponding to values lower than 0.1, offers information on the deterioration of the vegetation

layer and implicitly of the agricultural crops. The 88% expansion of the barren areas by 2011 (95,382 hectares) compared to 1990 (11,052 hectares) is mostly due to climate factors, that is to the climate changes consisting in the rise of temperature and the drop of average annual precipitation, particularly in the past three decades.

Thus, there emerges the shape of a decline in the quality of the vegetation layer (as much as to its disappearance), in the Western half of the area studied. The expansion of barren areas and areas with low-density vegetation suggests the presence of trends towards the deterioration of the quality of landscapes, which turn into drier landscapes. The causes of this process are complex, both of a physico-geographical nature (the evolution of the climatic, hydrological and hydrogeological variables), as well as socio-economic nature (the decay of irrigation systems, deforestation, farmland disuse, etc.). Aridification of the area impacts on biomass production, it contributes to the decline of soil fertility, it cuts down on crop yields and it raises the costs of farming in the area. In the longer run, aridification will have undesirable effects on the overall economy of the region and on the population, possibly leading to the population's further impoverishment, migration to other regions in the country and amplification of population aging.

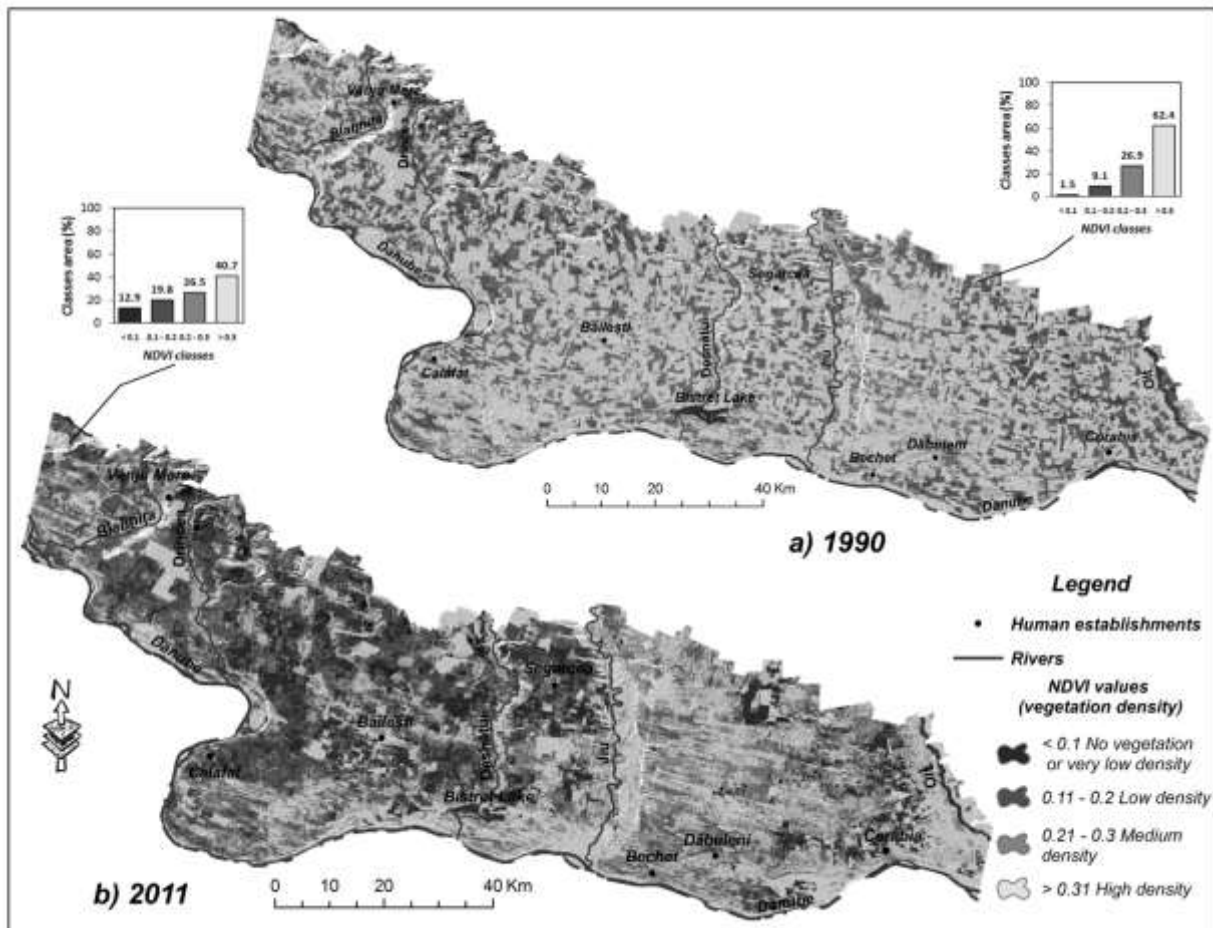


Figure 6. Spatio-temporal evolution of the NDVI index values by 1990 and 2011

### 3.2. Crop yield evolution

In addition, in the past two decades, territorial systems at regional level have been severely impacted by changes in the underground water resources, with the agricultural system typically suffering worst. As far as the piezometric level is concerned, the data obtained from the Băilești hydrological station are relevant in order to extrapolate the analysis to the scale of the entire area analyzed.

By analyzing the graph in figure 7 (a), one notices an upward trend for the depth of groundwater level during the time span analyzed (1964-2009). The time span characterized by a relative rise of the level of groundwater, 1971-1990, is explained by large-scale water-management and irrigation projects, meant to make up for the precipitation deficit. The political and social reform launched after the 1990 transition year led to a massive collapse of the irrigation systems both at the level of the area studied and across the country (Grumeza & Kleps, 2005; Dumitrașcu, 2006). A large part of the irrigation systems have been decommissioned or abandoned, and the surface of farmland that could still benefit

from irrigation nowadays has shrunk in the context of the excessive costs entailed by maintaining the irrigation systems.

One other major cause of the changes in groundwater level is the rise of the evapotranspiration level, as a result of the changes in the climate parameters (the rise of average annual temperature) in the context of global climate changes (Fig. 7b). In order to determine the connection between the two components, a statistical correlation was established between the average annual potential-evapotranspiration values at the Craiova weather station (the weather station closest of all three to the Băilești hydrogeological station) and average annual groundwater depth levels at the Băilești station (Fig. 8). The correlation is statistically significant, even for a very low 0.02 margin of error, according to the Bravais-Pearson statistic-relevance test.

The increasingly frequent droughts have brought about the rise of the expenses incurred by using irrigation to make up for the water deficit, and abandoning the irrigation system, which has led to oscillating evolutions of crop yields.

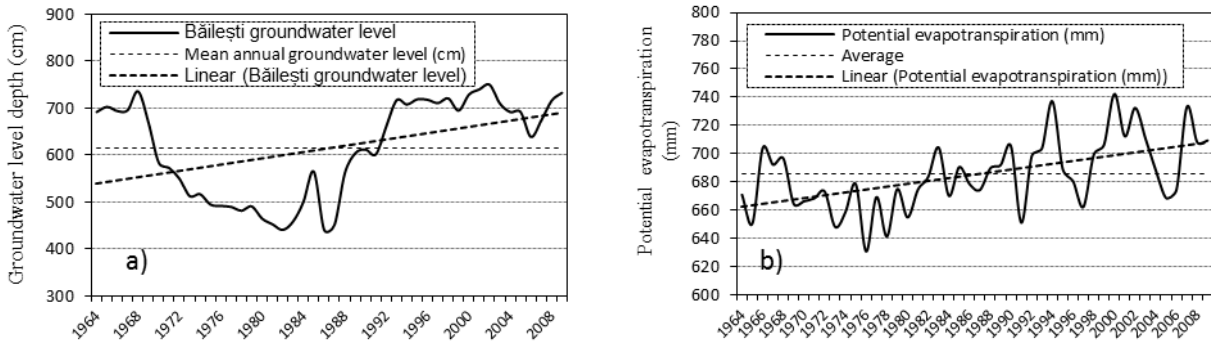


Figure 7. Groundwater level depth fluctuation (expressed in cm from local height) at the Băilești hydrological station (1964-2009) (a) and fluctuation of average annual potential evapotranspiration (mm) at the Craiova weather station (1964-2009) (b)

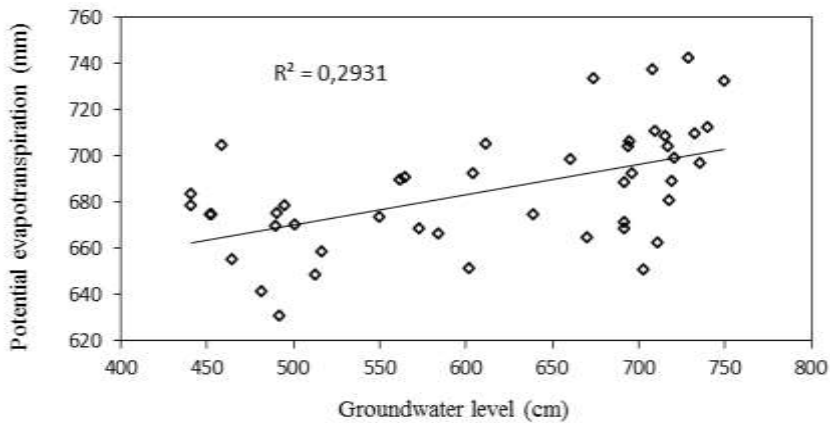


Figure 8. Linear correlation between the average annual potential-evapotranspiration values (mm) at the Craiova weather station (a) and average annual groundwater depth at the Băilești station (b) (1964-2009)

In the area studied, wheat, corn, sunflower and vegetable crop yields registered a downward trend (Fig. 9). The ever lower yield of the main crops has led to the abandon of large tracts of arable land and to a drop in the profit for farmers and the companies providing services for the agricultural sector.

The analysis of the connection between climate as a factor and crop yields indicated that there is no direct statistical correlation between the aridity index values and crop yields during the time span covered by both sets of data, 1990-2003. In exchange, indirectly, there is a strong connection between climate changes and crop yields, with groundwater level playing an essential part in this situation. Crops in Southern Oltenia were heavily impacted after 1990, upon the disappearance of the irrigation system with its role of balancing the soil's water intake-water outflow ratio, by fluctuations in the potential evapotranspiration values – which registered an upward trend starting that time, alongside the rise of annual average temperature.

This upward trend in potential evapotranspiration is responsible to the biggest extent for the decline of groundwater level in the past two decades, a situation confirmed by the 0.54 r correlation coefficient, statistically valid (Fig. 8). Later on, the correlations between the fluctuation of groundwater level and the fluctuations of wheat, corn and sunflower crop yields have confirmed the presence of r correlation coefficients of 0.55, 0.56 and 0.51, respectively (Fig. 10 a, b, c), statistically relevant at least in the case of an accepted margin of error  $\alpha=0.1$  (Minvielle & Souiah, 2003).

Therefore, the influence of climate changes on the decline of the groundwater level, a decline that brought about important drops in crop yields, establishes an indirect connection between the climate factor and agriculture. Vegetables are a case apart, as vegetable crops were not influenced by weather conditions, at least during the 14-year time span analyzed. As previously mentioned, vegetable crops depend mostly on localized irrigation, a situation confirmed by the correlation of irrigated surfaces and crop yields obtained (Fig. 10 d), statistically relevant for a very low margin of error ( $\alpha=0.02$ ).

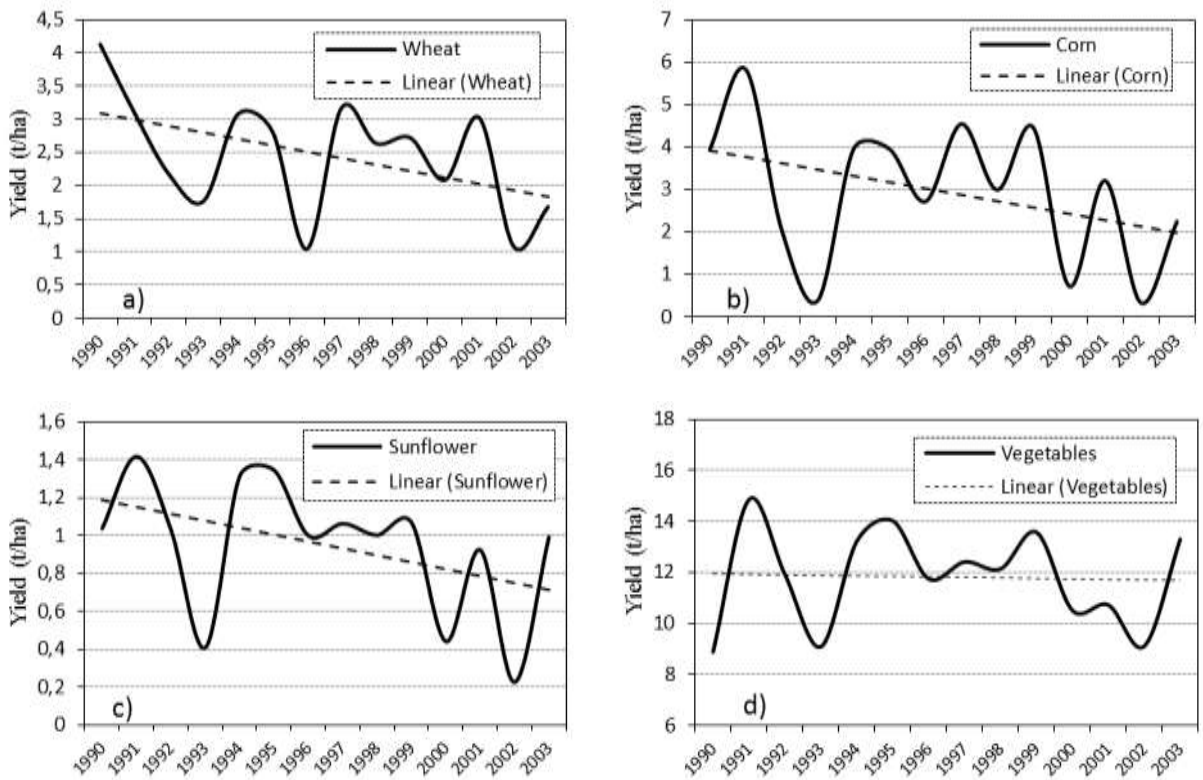


Figure 9. Evolution of the wheat production (a), corn (b), sunflower (c) and vegetable crop yields (d) during 1990-2003. Source: County Department for Statistics Mehedinti, Dolj and Olt.

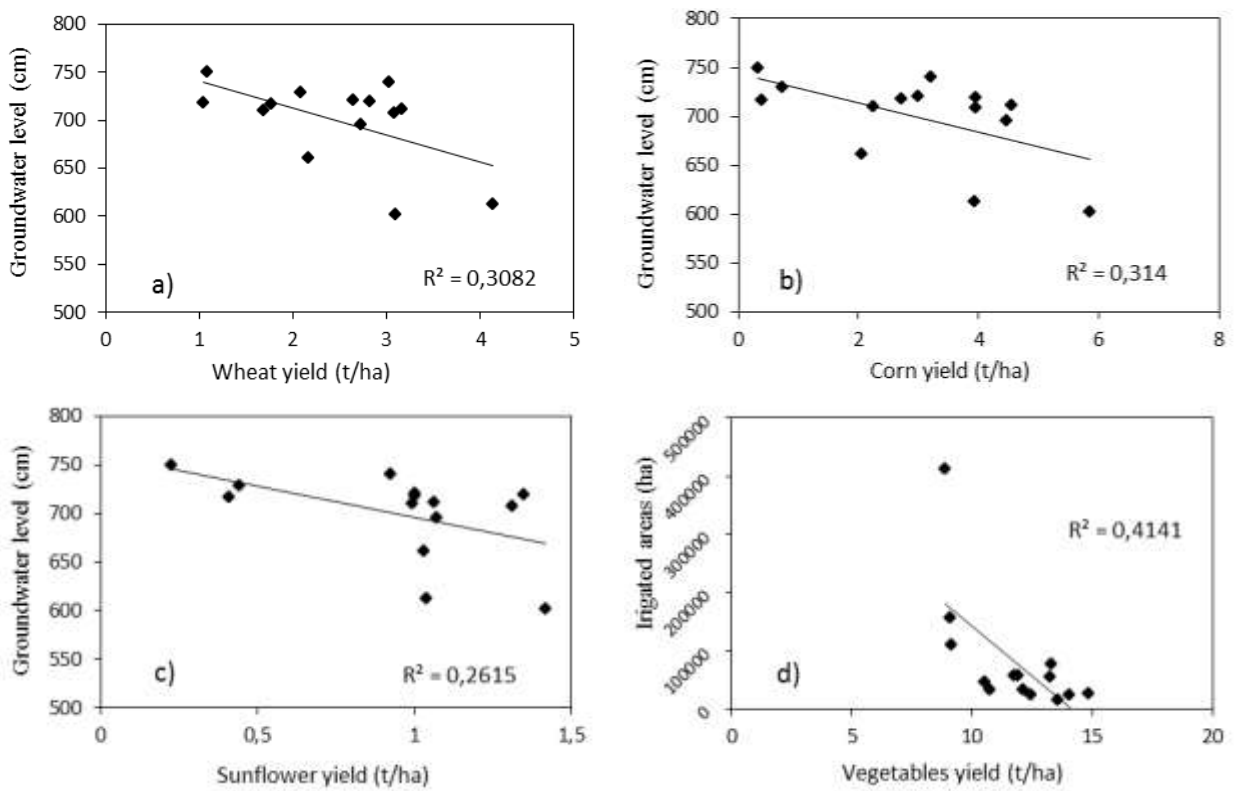


Figure 10. Linear correlations between the fluctuation of groundwater level (cm) and wheat (a), corn (b), sunflower (c) crops, as well as between the irrigated areas (ha) and vegetable crops (d), during 1990-2003.

#### 4. CONCLUSIONS

Post-1990 socio-economic changes in Romania, as well as the effects of climate change, have brought about a series of changes at the level of the system components, particularly on the economy and the population.

Aridification is a phenomenon that contributes to increasing the vulnerability of the systems impacted, by multiplying the negative effects of an ecological, economic and social nature. Research into the causes that contribute to amplifying the effects is one of the priorities of contemporary society, and the interdisciplinary approaches of the complex relations between the components of territorial systems are a major concern for the scientific world (Braghină et al., 2010; Peptenatu et al., 2010; Ianoş et al., 2012a; Petrişor et al., 2010; Bostenaru, 2006).

Aridification has brought about significant structural changes, growing ever more visible in the absence of efficient territorial-management strategies. Aridification is an effect of global warming, and the post-1990 escalation of these effects is brought about by socio-economic factors. The destruction of the irrigation systems and of the forest shelter belts, as a result of the uncertain state of land ownership, were the main factors that contributed to amplifying the effects of aridification on the yield of agricultural systems.

Drafting territorial-management strategies that would contribute to alleviating these effects is one of the priorities of decision-makers (Ianos et al., 2012b; Komac et al., 2011; Peptenatu et al., 2012a; 2012b; Stringer et al., 2009; Cheval et al., 2011), as postponing their creation and implementation means higher costs for fighting aridification.

#### AKNOWLEDGEMENTS

This work was supported by the project Territorial Management Based on Growth Poles Theory (UEFICSU-PNII-Idei, 1950) and the contract POSDRU/86/1.2/S/57462, strategic project “Optimization of the insertion process on the labour market concerning the geography graduates”, co-financed by the European Social Fund, through the Sectoral Operational Programme for the Human Resources Development 2007-2013.

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Received at: 08. 04. 2013

Revised at: 08. 07. 2013

Accepted for publication at: 18. 07. 2013

Published online at: 20. 07. 2013