EVALUATION OF THE SOCIOECONOMIC EFFECTS OF DROUGHT IN THE TURNU MĂGURELE – GIURGIU SECTOR OF THE ROMANIAN DANUBE VALLEY

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Abstract. Drought is a climatic extreme event causing environmental damages that limit plant development and crop yields, with significant economic and societal impacts. Mitigation and adaptation measures to drought are the responsibility of both farmers and government entities requiring integrative management plans and strategies which account for the local particularities. The paper presents an assessment of socioeconomic effects of drought in the Turnu Măgurele – Giurgiu sector of the Romanian Danube Valley (RDV) based on a comprehensive analysis of specific climatic and socioeconomic indicators. Drought was quantified by the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI) at 1- to 24-month lags at three representative stations in the area, during the 1961–2017 period. The analysis shows that among the consequences of severe drought events that affected the study-area during the last decades were the yield losses and increasing prices in the crop market. The findings highlight, on the one hand, the losses to farmers as well as the role of compensation measures and, on the other hand, the anticipated increase of risk in agriculture. The response measures to drought mitigation in the sector and the RDV are discussed in a view of resource integrated policies and climate change adaptation strategies.

1. INTRODUCTION

An increased incidence of the drought phenomenon has been registered over the last decades in many parts of Europe, causing important damages to farmers, the economy and communities, and leading to governance initiatives with respect to adaptation and mitigation measures (White Paper for Climate Change, 2009; JRC Technical Report, 2015). However, drought per se is not a priority to be pursued in isolation, but in the context of integrative resource management which entails primarily an equitable use of water resources along with agricultural sustainability practices. This is particularly true as drought management has so far been dominated by decisions that envisage short-term solutions, mostly focusing on post-event measures (e.g. direct compensatory payments for farmers in case of crop calamities), rather than on long-term responses that center on agriculture sustainability (GWP CEE, 2015). Instead, as climate scenarios show increased frequency and intensity of droughts (ECLISE, 2015; Climate2C, 2015) coupled with increased water scarcity (JRC Technical Report, 2015), achieving an optimum balance between crop productivity and water use is necessary (Fereres, 2011).

Moreover, the economic and social impacts of droughts tightly relate to decreasing the vulnerability and increasing the resilience of the affected area. Counting for all the three elements of drought impacts, environmental, economic and social, implies multidimensional analyses which integrate specific climatic approaches, vulnerability and resilience-oriented studies, and finally risk management-related aspects. There is a vast domain of literature, especially in climatology, which focuses on drought as a natural hazard, calculating, developing and mapping drought specific indices

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(Merabti *et al.*, 2018; Blauhut *et al.*, 2016; Stagge *et al.*, 2015), while more recent researches also make approaches of vulnerability to drought and resilience aspects (Dumitraşcu *et al.*, 2017; Udmale *et al.*, 2015).

Worth-mentioning is that farmers' perception to the increased drought phenomena reflects the fact that their decision in terms of adaptation measures are guided by market dynamics and less by considerations on long-term or even medium-term climatic projections. Also, their concern and awareness about drought impacts are acknowledged (Sima *et al.*, 2015; Wilhite *et al.*, 2014; Paulo *et al.*, 2016). To improve the understanding of the economic consequences of drought, it is necessary to evaluate the socioeconomic effects that can be assessed from many perspectives, using different terms such as damage, cost, loss, that reflect the influence of disasters on the economy (Bachmair *et al.*, 2016, Musolino *et al.*, 2017). Usually, these studies are focused on losses in terms of crop production which burden on the population (Nath *et al.*, 2017; Udmale et al., 2015; Bodner *et al.*, 2015).

In the long run, the recent strategies connected to agriculture sustainability and climate change adaptation strongly advise on integrative drought management actions in which risk management is incorporated. These strategies also include vulnerability and resilience assessments (e.g. economic, social and environmental impacts of droughts), preparedness actions (e.g. monitoring and data collection, early warning and alert systems, capacity analysis) and contextual drought mitigation measures (WMO and GWP, 2017). As far as short-term decisions are concerned, drought risk management is relevant in the context of stabilizing the variation of yearly crop productions and, consequently, the crop market dynamics. It is acknowledged that climate along with crop management decisions are the factors that influence crop production which in turn influence farmers' profits and trigger price fluctuations in the markets (Hochrainer-Stigler *et al.*, 2017). In this respect, knowing what is the climate-induced crop yield variability is essential for adaptation strategies. Crop growth models show that observed weather variations account for more than 50% of the variability in wheat yields in Spain, Hungary and Romania, for instance, where water stress is a major driver of these variations (Frieler *et al.*, 2017).

Furthermore, complying with the Sustainable Development Goals (SDGs) on climate change and food security along with the complementary SDGs for water resources sustainability requires a shift in the decision-making process towards reduced risks from drought, contextual adaptation strategies and sustainable agriculture (Agenda 2030, 2015; SDG interaction road map).

The evolution of the main climatic conditions represent essential elements of agricultural production. Additionally, other drivers (*natural* – decreased of groundwater level, soil characteristics, temperature anomalies and *anthropogenic* – crop management practices, collapse of irrigation systems following the political transition period, farming techniques, fertilizes amounts) influence the dynamics of crop yields (Prăvălie *et al.*, 2016). In the Danube region, drought represents a major warning phenomenon, having a series of negative effects, including economic (crop shortage, decreasing food supplies stability and an increase in the price of agricultural products), social (poverty; negative influence on human activities and wellbeing), as well as ecological impacts (increasing decay of crops, reducing the biological potential of the soil). Drought is a representative phenomenon in the Romanian Danube Valley with increased frequency and stronger impacts on the environment and local communities, leading to unsustainable use of the natural resources. This is relevant for the agricultural productivity which has been strongly influenced by the transformations in the economy, social, technological, political and institutional settings since early '90s (Bălteanu *et al.*, 2013). For instance, in the Turnu Măgurele – Giurgiu sector, the irrigated agriculture has undergone a sharp decline due to massive deterioration of the irrigation systems and drop of the irrigation water demand due to farmland fragmentation.

The present study highlights the connections between drought episodes in the Romanian Danube Valley area, specifically in the Turnu Magurele – Giurgiu sector, over the last decades, and the socio-economic impacts associated to it. Particularly, it analyses the yearly yields fluctuations, crop prices evolution and reported areas affected by drought, along with two specific drought indices expressing the intensity of phenomena. In this context, it is obvious that the need for concerted measures which account for adaptation to climate change and increasing economic viability of farms and efficient use of natural resource are emphasized in the conclusion section of the paper.

2. STUDY-AREA AND DROUGHT CHARACTERISTICS

2.1. Study-area

The study-area is located in the south of Romania, along the Danube Valley, between Turnu Magurele and Giurgiu municipalities and contains the southern area of Boianu and Burnasului plains, as well as the Danube terraces and floodplain (Fig. 1). This area consists of 23 local administrative units, 41 villages and 3 urban settlements: the Giurgiu and Turnu Magurele municipalities and Zimnicea Town, all together, having about 160,000 inhabitants. The presence of the Danube River, as well as its floodplains and terraces, is reflected in the socioeconomic profile of the region (Bălteanu, Sima, eds., 2013). This sector has a strong rural character, little connected to large urban areas, while the main economic activity is agriculture, represented by the cultivation of grains, technical plants, and vegetables. The cultivated land area (143776 ha) accounted for 81.5% of the total land area and more than 70% of all cultivated land was grown with cereals.

In the Turnu Măgurele – Giurgiu Danube sector, the aridity and drought phenomena rank at the top of the hierarchy of dangerous meteorological phenomena in terms of surface-area coverage and duration through out the year. The study-area is characterised by an annual mean temperature of over 11°C. The intensification of drought processes, especially in the Danube floodplain, where the highest temperatures across the country are recorded (Bogdan *et al.*, 2016), have all together a great impact on crops, wellbeing, tourism, ecosystems and socioeconomic services. Frequent dryness and droughts coupled with human activity, have brought about desertification phenomena on the Danube terraces (*Geografia României*, vol. V, 2005).

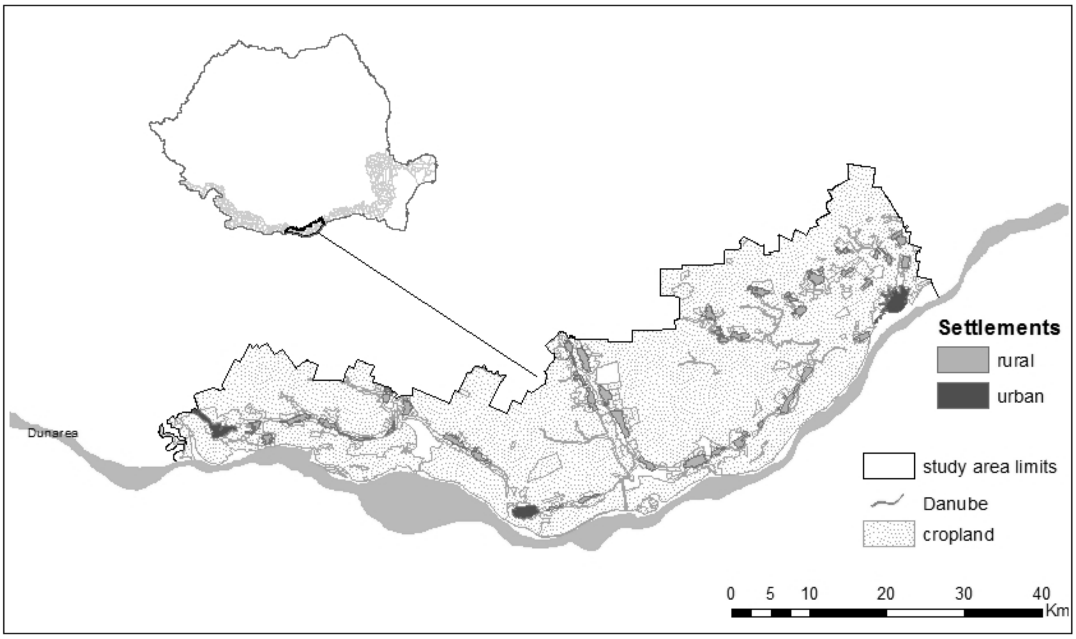


Fig. 1 – Study-area – Romanian Danube Valley –Turnu Măgurele – Giurgiu sector.

2.2. Drought in the past and its associated effects

The analysis of historical extreme climatic events, which have caused lots of damage, having a profound impact upon agriculture, the economy, population and ecosystems, highlights a past age marked by years with extreme drought in the Romanian Danube Valley.

For the Romanian Country, Corfus (1975) analyzed some chronicles from the 16th–18th centuries, inventoried some extreme climatic events, which caused material damages and socioeconomic imbalances. In addition, information on drought in the Turnu Măgurele – Giurgiu sector was documented from sources such as: RPR Geographical Monograph, 1960; Prefecture of Teleorman County, Prefecture of Giurgiu County, Teleorman County Museum, "Teohari Antonescu" Museum (Giurgiu County); Iordan, 2012, Mateescu, 2013, annual reports from the National Meteorological Administration (Romania), National Institute of Hydrology and Water Management, Ministry of Agriculture and Rural Development, the League of Associations of Agricultural Producers in Romania. Information on drought and its impacts was recorded in a disaster loss database (Table 1).

The extreme drought, that characterizes the localities in Turnu Măgurele – Giurgiu sector, has a major impact not only on agriculture, but also on the population, and the socioeconomic structure. The periods considered to be dry generate poverty, partial or complete loss of agricultural production followed by an increase in prices for agricultural crops, the impossibility of seeding for autumn crops, a decrease in water resources (dry fountains), socioeconomic consequences such as decrease in the Danube's flow rate by more than 50 %, as well as in other main rivers, insufficient vegetation and the impossibility of a feeding the animals as required.

Table 1

Drought events and their associated losses in the Romanian Danube Valley, Turnu Măgurele – Giurgiu sector

Year	Losses
1718	Dried wells; compromised yields, increased prices for agricultural products
1794	Dried wells (in July)
1795, 1798	Increased prices for agricultural products, hunger
1810–1811	Increased prices for agricultural products, reduced crop yield, hunger (the winter and spring seasons were characterised by lack of precipitation)
1882	Low levels of surface water sources
1834–1836	Hunger, decrease of water resources, reduced crop yields, increased prices for agricultural products
1866	Consecutive extremely hot days compromised almost totally the agricultural production
1903	Decrease of water resources, reduced yields after a dry summer
1907, 1916, 1924, 1928, 1934	Reduced yields, increased prices for agricultural products, increased food prices, higher incidence of disease in wild animals due to lack of food and water supplies
1945–1949	The extreme drought compromised almost totally the agricultural production in Teleorman and Vlaşca (today Giurgiu County) counties; increased food prices; depleted national economic growth; hunger; low levels of water sources
1951–1953	Reduced yields, low levels of water for agriculture, increased prices for agricultural products
1964	Low levels of water resources after a no-rain spring; compromised yields
1973	Damage to crop quality, increased prices for fruit and vegetables
1982, 1986	Decrease of grain crops, higher prices for agricultural products and for water
1990	Lower yields, damages to water quality
1992	The lack of precipitation in winter and spring led to lower yields and damages to crop quality.
2000	Extreme drought; compromised agricultural production (especially winter wheat production in Teleorman County); soil erosion; reduced income for farmers; large areas affected by drought, unemployment, poor soil quality, low water levels, poor conditions for autumn crops sowing

2001	Low levels of water sources for agriculture
2002	Higher prices for agricultural products
2003	Low water levels, dried wells, compromised yields (especially winter wheat), income loss for farmers due to reduced crop yields; drought caused a series of negative effects, mostly on the rural population dependent on agricultural activity requiring direct responses on the social, economic and political level
2007	Extremely dry year; reduced crop yields, 3,000 drinking-water wells were in danger of drying up, increased fire hazard (in Teleorman and Giurgiu counties); higher levels of nitrite were registered in July in some localities of the analyzed sector, as well as in neighbouring localities in Olt Country (e.g. Tia Mare, Grojdibodu) due to shallow groundwater levels.
2008	Lower crop yields, 50% of winter wheat and rapeseed crops were compromised (in Teleorman County)
2009	Reduced yields (especially sunflower, winter wheat, rapeseed), impact on the national economic growth, compromised yields (Teleorman and Giurgiu counties), agriculture highly affected by drought degree after a no-rain spring; more food imports, consequences were felt at the level of international economic relations
2011	Lower yields, poor sowing conditions for wheat, barley and rapeseed (i.e in Teleorman County only 40% of the intended area was cultivated)
2012	Extremely dry year; decreases in soil moisture (pedological drought); rapeseed was sown on less than 60% of the intended area due to lack of rainfall and, therefore, poor soil conditions); poor conditions for autumn crop sowing; decrease in water resources; socioeconomic consequences of low Danube levels (e.g. the discharge of the Danube and of its main tributaries as below 60% than their regular discharge (e.g. the Danube water level: Turnu Măgurele – 115 cm, Giurgiu – 125 cm); river navigation was affected and increased transportation costs as products had to be carried by alternative means.
2014	Reduced yields (especially maize), decreases in soil moisture
2015	Lower yields; maize and sunflower crops were compromised; 60% of the rapeseed and winter wheat crops were affected; increased prices for fruit and vegetables; discharge levels of the Danube and of its main tributaries decreased by more than 50%; low water levels; increase of irrigation costs; reduced income for farmers, the national economic growth was affected; increase in food imports; degradation of forest ecosystems
2016	Damage to crop quality, low water levels
2017	Reduced yields (e.g. rapeseed, barley, winter wheat); decreases in soil moisture

The first drought event mentioned by Corfus (1975) for the Romanian Danube Valley dates back to the years 1718–1719, when drought caused significant damage (e.g. low crop yields, higher prices for agricultural products, hunger, little water availability). In the 1945–1949 period, several significant dry events with associated phenomena (heat waves, extremely consecutive hot days) compromised almost entierly the agricultural production, leading to hunger and a difficult economic situation, in Teleorman and Vlaşca (today Giurgiu) counties.

In the Romanian Danube region, considering the intensity of the meteorological drought phenomenon, there were periods with hydrological drought, characterized by the decrease of the water resources debits, which hardened the water supply of the localities, industry as well as agriculture. The exhaustion of water resources, as a result of the dry periods, strongly affected the population from the Danubian localities in 1718, 1794, 1882, 1834, 1903, 1964. After 1990, as well, the dry periods had a direct impact upon the water resources: in 2007 (extremely dry year), in Teleorman and Giurgiu, 3000 fountains with drinking water were in danger of drying up (SGA Report – Water Management System, 2007). In July, the same year, in a few localities from the sector, but also in the neighbourhood localities from Olt country (Tia Mare, Grojdibodu), while the water level decreased in the shallow ground water, the level of nitrite increased (Report ASP – Public Health Authority, 2007). The drying up of water resources was noticed in other Danubian settlements, as well the request for water for domestic chores, gardens and green spaces exceeding the quantity of water delivered by the supplying system.

As well, the information about the past drought events and their effects in the study-area could be synthethised and grouped into three categories of impacts: social, environmental and economic (Table 2).

Table 2

Types of drought impacts

Impacts	Consequences/damages
✓ Reduced crop yields	✓ Increased prices for agricultural crops/products
✓ Damage to crop quality	✓ Increased prices for food and water, increased irrigation costs
✓ Decrease in water availability	✓ Unemployment, reduced quality of life, poverty, migration, socioeconomic inequalities etc.
✓ Reduced water levels	✓ Reduce income for farmers
✓ Damages to air and water quality	✓ Loss of national economic growth, affect international economic relations
✓ Soil erosion/poor soil quality	✓ Affect river navigation, increased transportation costs
✓ Affect population heath	✓ Food security
✓ Degradation of forest ecosystems	✓ Increased agri-food imports

Social impacts Environmental impacts Economic impacts

3. DATA AND METHODS

There are many methodological approaches with various degrees of complexity to assess drought. In recent years, the assessment of drought and its socioeconomic effects is defined as a combination of drought characteristics and potential adverse consequences for economic activities, crop production, human health and environment (Udmale *et al.*, 2014).

To monitor and quantify drought, various indices have been developed, but a unique and universally accepted drought indicator does not so far exist (Heim, 2002; Dai, 2011a). A large number of studies related to drought analysis and monitoring have been made using either the standardized precipitation index (SPI), based on a precipitation probabilistic approach (McKee *et al.*, 1993), or the newly-developed standardized precipitation evapotranspiration index (SPEI) based on precipitation totals and temperature means (Vicente-Serrano *et al.*, 2010).

The latter index follows a simple approach to calculate potential evapotranspiration (PET) based on a normalization of the simple water balance (Thornthwaite, 1948). In developing the SPEI, Vicente-Serrano *et al.* (2010) followed the same conceptual approach like that used by McKee *et al.* (1993) to develop the SPI. Mathematically, SPEI is similar to SPI, but it includes the role of temperature.

In this study we have calculated and analyzed SPI and SPEI at three representative stations in the study-area: Turnu Măgurele, Zimnicea and Giurgiu. The geographical coordinates of the stations presented in Table 3 have been used to extract precipitation and temperature data from the ROCADA dataset (Dumitrescu and Birsan, 2015) at the closest gridpoint to each station. ROCADA contains daily records of nine meteorological variables throughout Romania at a spatial resolution of 0.1°, covering the 1961–2013 period.

Table 3

Geographical coordinates of stations used in this study

Station	longitude	latitude
Turnu Măgurele	**24.8800**	**43.7605**
Zimnicea	**25.3551**	**43.6618**
Giurgiu	**25.9342**	**43.8755**

In order to extend the period to the present time, we used the ERA-Interim (Dee *et al.*, 2011) daily temperature means and precipitation totals for the 2014–2017 period. Daily data of both ROCADA and ERA-Interim datasets were aggregated to monthly means, both for temperature means and precipitation totals. To ensure that this extension is reliable, a comparison between ROCADA and ERA-Interim monthly means have been done for the common period 1979-2013 of these data sets, prior to the completion of input data for SPI and SPEI calculation.

According to Dai (2011a), drought can be classified into: (1) *meteorological drought,* when dring a period of months to years precipitation is below normal. It is often accompanied by above-normal temperatures and precedes and causes other types of droughts; (2) *agricultural drought* is a period with dry soils that results from below-normal precipitation, intense but less frequent rain events, or above-normal evaporation, all of which lead to reduced crop production and plant growth; (3) *hydrological drought* occurs when the river streamflow and water storage in aquifers, lakes, or reservoirs fall below long-term mean levels. Hydrological drought develops more slowly, because it involves stored water that is depleted but not replenished. A lack of precipitation often triggers agricultural and hydrological droughts, but other factors too, including more intense, but less frequent precipitation, poor water management, and erosion, can also cause or enhance these types of droughts.

The SPI is based only on precipitation and is designed to identify precipitation deficit at different time lags (1, 3, 6, 12 and 24 months), using monthly precipitation totals. The drought on these time scales is relevant for agriculture (1, 3, and 6 months), hydrology (12 months), and socioeconomic impact (24 months), respectively. The SPEI is similar to the SPI, but it includes the role of temperature. It is based on a water balance in which potential evapotranspiration (PET) is involved.

According to SPI and SPEI values, moisture categories are presented in Table 4 a). A number of descriptive studies examine the losses in agricultural production associated with drought, based on the correlation between some socioeconomic and drought indicators (Labudová *et al.*, 2017; Potopová *et al.*, 2015).

The annual series of crop yield of winter wheat, maize, barley, rapeseed, vegetables and sunflower at local administrative units as reported by the National Institute of Statistics and the county Directions for Agriculture during 1990–2017 were used to assess crop sensitivity to drought as quantified by SPI and SPEI. To compare yield variability among the crops with different means and standard deviations, the series of crops were standardized using the Z-score transformation (Wu *et al.*, 2004). The indicator of agricultural drought risk can be represented by the residuals of the de-trended yield $y_i^{(T)}$. The the standardized yield residuals series (SYRS) were computed as:

SYRS$=\frac{y_i^{(T)}-\mu}{\sigma}$ where $y_i^{(T)}$ is the yield residual, μ is the mean of the yield residuals, and σ is the standard deviation of yield residuals. The yield categories according to SYRS values are presented in Table 4 b).

Table 4

Classes of moisture categories according to e SPI & SPEI (a) and yield categories according to SYRS (b)

(a)

SPI & SPEI	Moisture category	Frequency (%)
>2.00	**Extreme wet**	2
1.50 to 1.99	Severe wet	6
1.00 to 1.49	Moderate wet	10
0.99 to - 0.99	Normal	65
-1.00 to -1.49	Moderate drought	10
-1.50 to -1.99	Severe drought	5
< - 2.00	**Extreme drought**	2

(b)

SYRS	Yield category	Frequency (%)
>1.50	**High Yield increment**	2.3
1.00 to 1.49	Moderate yield increment	4.4
0.51 to 0.99	Low yield increment	9.2
0.50 to - 0.50	Normal	68.2
-0.51 to -0.99	Low yield losses	9.2
-1.00 to -1.49	Moderate yield losses	4.4
< - 1.50	**High yield losses**	2.3

The SYRS is a standardized variable which allows the comparison between crop growing in various agricultural technology levels and/or in different climatic conditions.

Crop damages caused by extreme weather and decrease of agricultural productivity due to drought threaten economic stability, food security and health. Because of it, the indicators of damage and of economic losses are at the core of disaster loss analysis. The degree of damage details depends on the availability of quantitative information in the affected areas. Systematic collection of information on damage and losses is crucial to effectively support drought risk reduction policies and to enable designing of specific measures for agriculture, the economy and quality of life.

There are several considerations in analyzing the socioeconomic profile of the study-area and the socioeconomic impact of drought.

Socioeconomic indicators (Table 5) are compiled by using available sources for the study-area: the databases of the National Institute of Statistics and the League of Associations of Agricultural Producers in Romania, the Annual reports of the Ministry of Agriculture and Rural Development and the National Land Improvement Agency, as well as the statistical data provided by the Directions for Agriculture of the Teleorman and Giurgiu counties.

Table 5

Overview of selected indicators/indices

	Indicators /Indices	**Data requirements**	**Data sources**	**Temporal aggregation and resolution used**
Drought	**SPI**	Monthly precipitation totals (mm)	ROCADA and ERA-Interim	1, 3, 6,12, 24 month lag; 1961–2017
	SPEI	Monthly precipitation totals (mm) and temperature means (°C)	ROCADA and ERA-Interim	Timescales of 1–6, 9, 12, 24 months; 1961–2016
	Extremly hot units (Tmax32)	Number of 5 consecutive days with Tmax≥32°C	ROCADA	Daily, 1961–2013
Agriculture losses	Crop production	Annual crop yields (t/ha)	INS, DADR-TR, DADR-GR	Annual, 1990–2017
	Percentage of crop yield losses (Y%)	% reduction in either quantity of crop yield	INS, DADR-TR, DADR-GR	Annual, 1990–2017
	SYRS	Standardized yield residuals series	DADR-TR DADR-GR	Annual, 1990–2017
Economic losses	Prices of agricultural products	Yearly average price of the main crop products sold in the agro-food markets of Turnu Măgurele – Giurgiu sector	INS, MADR, LAPAR	Annual, 2000–2017
	Monetary losses	Monetary losses caused by depleated production	DADR-TR, DADR-GR	Annual, 1990–2017
Socio-economic profile	HHI	Hirschman-Herfindahl Index – Statistical measure of sectoral concentration	INS	2011
	Employed population rate (%)	Employed population rate by activity of the national economy (agriculture, industry, service) – local administrative units	INS	2011
	Poverty rate	% of poor persons out of total population – local administrative units	Local councils of Teleorman and Giurgiu counties	2017

Acronyms and abbreviations: INS – National Institute of Statistic; DADR-TR – Teleorman Direction for Agriculture; DADR-GR – Giurgiu Direction for Agriculture; SNIF – National Land Improvement Agency; LAPAR – League of Associations of Agricultural Producers in Romania; MADR – Ministry of Agriculture and Rural Development

4. RESULTS

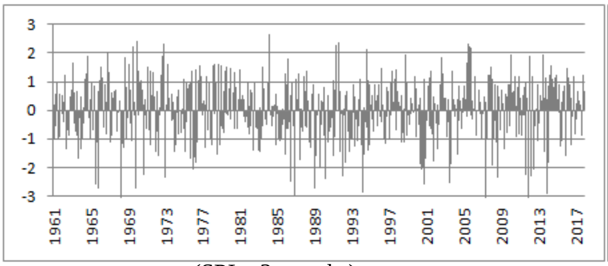
4.1. Drought characteristics

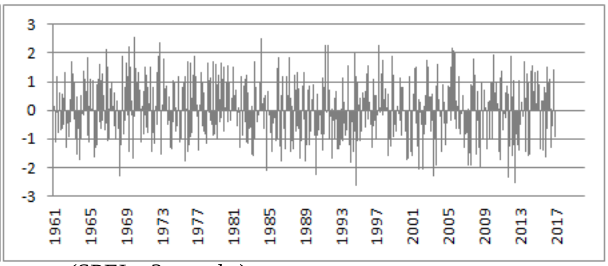
The SPI and SPEI was calculated for 1-to-24 time scales at each station in the study-area: Turnu Măgurele, Zimnicea and Giurgiu. Because the evolution of both indices at these stations looked very much alike and, in order to better link drought indicators with available socioeconomic data for the study-area, representative SPI and SPEI have been calculated from the averaged data from the three stations. The temporal evolution of representative SPI and SPEI for the study-area is presented in Fig. 2a) and b), respectively. Both SPI and SPEI at 1-and 3-month lags show high interannual variability.

Out of the 684 months (January 1961 – December 2017), the SPI-1mo shows 57 months with moderate drought, 21 months with severe drought, and 25 months with extreme drought. According to SPI-1mo, the highest droughty months were April 1968 (-3.52), November 2011 (-3.63) and April 2007 (-3.73). Out of 673 months (January 1961 – December 2016), the SPEI-1mo shows 83 months with moderate drought, 33 months with severe drought, and 9 months with extreme drought. The most droughty months according to SPEI-1mo were September 2011 (-2.36), July 2012 (-2.56) and September 1994 (-2.66).

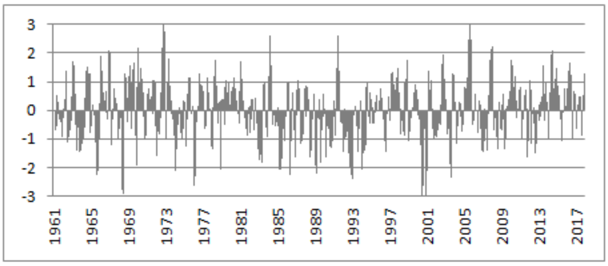
Out of the 102 months for which the SPI-3mo were lower than -1.0, 62 months showned moderate drought, 18 months severe drought, and 22 months extreme drought. According to SPI-3mo, the highest droughty months were June 1968 (-2.93), December 2000 (-2.95) and July 2000 (-2.96). Out of the 122 months, SPEI-3mo shows 72 months with moderate drought, 38 months with severe drought, and 12 months with extreme drought. According to SPEI-3mo, the highest droughty months were December 2000 (-2.32), October 1992 (-2.75) and September 2012 (-2.91).

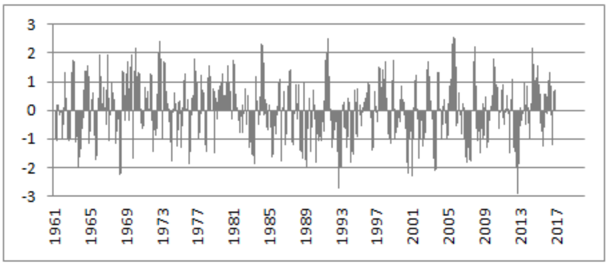
(a) (SPI – 1 month) (b) (SPEI – 1 month)



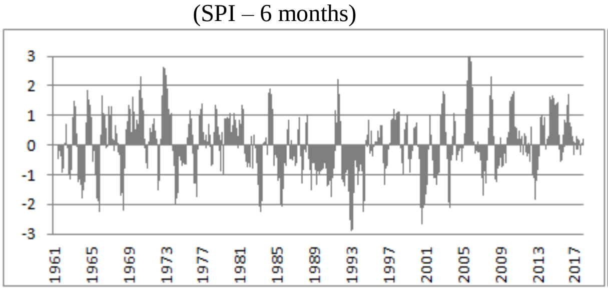


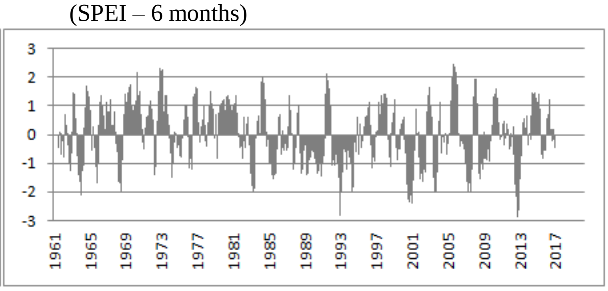
(SPI – 3 months) (SPEI – 3 months)



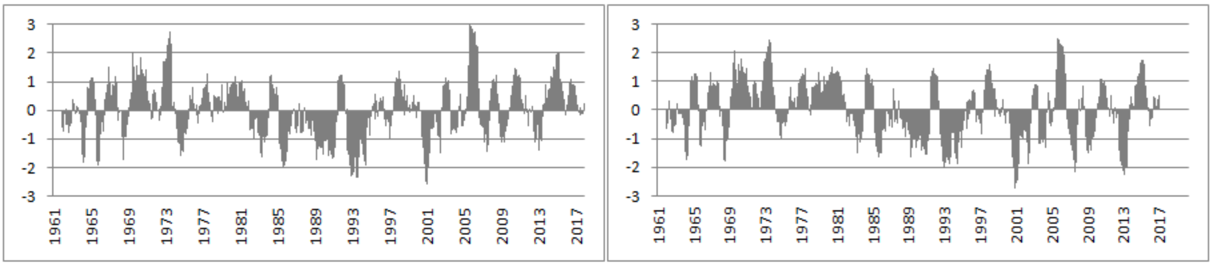


(SPI – 6 months) (SPEI – 6 months)





(SPI – 12 months) (SPEI – 12 months)



(SPI – 24 months) (SPEI – 24 months)

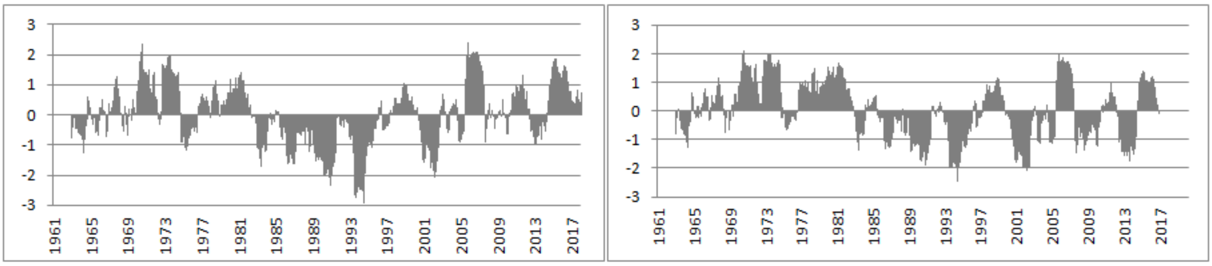


Fig. 2 – Temporal evolution of drought based on SPI (a) and SPEI (b) calculated at 1-to-24 month lags.

Drought appears, first, on short time-scales and if dry conditions persist, it develops on longer time-scales. The use of several SPI time-scales takes into account the role of previous conditions in quantifying drought severity, allowing for a better understanding of the time-scales of water supplies.

This is mostly evident starting with SPI and SPEI at 6-month lag. Out of the 101 months for which the SPI-6mo was lower than -1.0, 65 months had moderate drought, 29 months had severe drought, and 17 months extreme drought. According to SPI-6mo, the highest droughty months were August 2000 (-2.68), February 1993 (-2.84) and January 1993 (-2.91). The years ranking at the top of extreme drought months are 1965, 1968, 1983, 1985, 1992, 1993, 1994, 2000 and 2003. Out of the 111 months, SPEI-6mo shows 63 months with moderate drought, 31 months with severe drought, and 17 months with extreme drought. According to SPEI-6mo, the highest droughty months were December 2012 (-2.67), January 1993 (-2.82) and November 2012 (-2.87). The years ranking at the top of extreme droughts months are 1964, 1983, 1992, 1993, 2000, 2003, 2007 and 2012. Out of the years with extreme drought, 1982, 1992, 1993, 2000 and 2003 were identified both with SPI and SPEI standing for precipitation deficit and high temperatures. As the time-scales for calculating SPI and SPEI increase, wet and dry conditions, as well as their persistence, can be clearly identified. The previous conditions in SPI and SPEI calculation point out on the persistence of dry and wet conditions for time-lenghts of a few months up to some years.

According to SPI and SPEI values calculated for 12-month lag, droughts were moderate and they persisted more than five consecutive months in the study-area, during the 1961–1985 period. From March 1983 to January 1986, the precipitation deficit was associated with positive temperature anomalies which roughened the drought from moderate to severe.

At the beginning of 1989, the longest period of moderate and severe drought during 1961–2017 started and lasted 27 months according to SPI and 17 months according to SPEI, respectively.

Severe-to-extreme drought persisted from July 1992 to October 1993, according to SPI and SPEI. At the end of 2000 and the beginning of 2001, precipitation deficit and positive temperature anomalies produced extreme drought with top values of SPI (-2.6 in January, 2001; -2.52 in February, 2001; -2.49 in December, 2000) and SPEI (-2.76 in December, 2000; -2.52 in January, 2001 and -2.48 in February, 2001).

The SPI and SPEI values calculated for a 24-month accumulation period clearly emphasize the persistence of moisture deficit. These periods usually precede, overlap and succeed the corresponding periods of SPI and SPEI at a 12-month lag: March 1986 to February 1987, February 1989 to June 1991, May 1993 to July 1995, September 2000 to July 2002, June 2003 to January 2005, August 2007 to December 2008, November 2009 to January 2010 and, September 2012 to April 2014. According to SPI-24 mo, the highest droughty months were June 1994 (-2.93), August 1993 (-2.76) and July 1993 (-2.69) and, according to SPEI, June 1994 (-2.48), February 2002 (-2.09) and May 1994 (-2.09), respectively. The periods with the longest persistence of severe and extreme drought were 1992–1995, 2000–2002, 2012–2014.

4.2. Socioeconomic effects of droughts

4.2.1. Socioeconomic profile

The knowledge of the socioeconomic profile of the Romanian Danube communities is important for understanding their vulnerability to climate change and their adaptation capacity. Therefore, it is important not only to study the impact of drought, but also to highlight the socioeconomic aspects in the study-area.

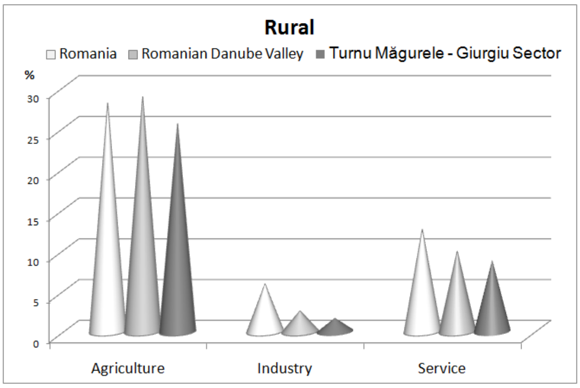
The socioeconomic indicators that have been used in this study are relevant to demonstrating the link between changes in the environment, economy, and society. In the Romanian Danube River area, which is recognized to have a high agricultural potential, the transition and post-transition periods favoured a series of fundamental socioeconomic changes which increased the risk of poverty, decreased the level of the labour force employment and, reduced industrial activities.

In order to provide an overall picture of demographic and socioeconomic changes, some indicators like population change, ageing population, migration rate, poverty, employed population rate, unemployment rate were selected for this analysis. According to the demographic and socioeconomic characteristics (e.g. birth-rate decrease, demographic aging, the migratory movement of population in search for work and unemployment rate), the rural settlements display a low living standard. In 2017, local councils of Teleorman and Giurgiu counties information that poverty rates across the 26 LAU2 from the study-area ranged from 36% in Giurgiu and 52.3% in Frumoasa (Teleorman County). The poverty rate varies between urban and rural areas: in 2017 – 41 percent urban areas, compared to 46 percent in rural areas. Figure 3 presents a comparative image of the employed population rate at three territorial levels: Turnu Magurele–Giurgiu sector, the Romanian Danube Valley and country-level in both rural and urban areas. For the rural area, the picture shows a low degree of working-age people employment in industry and services as compared to the agricultural sector. The urban labour-force is predominantly involved in services. The prevailing degree of employment in agriculture confirms the lack of development initiatives of the local authorities/policy makers that might have facilitated the region's economic growth. The lack of economic development is associated with an uneven increase of socioeconomic vulnerability of localities in the analyzed sector and with the reduction of resilience under various stress drivers.

The analysis of the employed population by different sectors of the national economy, not only highlights the lack of diversity of income sources, but it also points out that the main income source of the population in the Romanian Danube region is agriculture, which is greatly exposed to drought.

Another issue resealed by our analysis is limited access to those financial resources which could have enhanced adaptability to drought conditions.

According to the data provided by the National Institute of Statistics, the 2011 census indicates that the rural settlements in the study-area are dominnatly agricultural. The prevailing percentage of the employed population in agricultural sector is concentrated in the localities where the population is unable to adapt to the new rules of the market economy: e.g. Găujani (82%), Bragadiru (81%), Viişoara and Lisa (80%), Traian (79%), Ciuperceni (78%). In the urban environment, the services sector is better developed. However, the agricultural sector, although with a low percentage of employed population, significantly contributes to the earning revenue of the urban inhabitants in the Turnu Măgurele – Giurgiu sector.



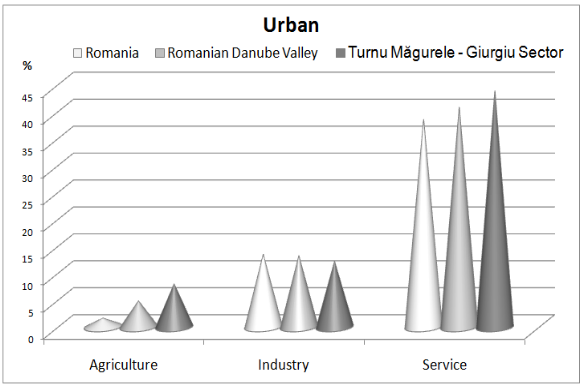


Fig. 3 – Employed population rate by activity in the national economy.

The region's economy must adapt to all sectors of activity, in order to promote flexibility and social inclusion in the labour market, as a strategy of continuous adaptation. The region's lack of alternatives and of economic efficiency do affect the population involved in sectors that do not offer financial opportunities and the necessary resources for adopting a response model.

The Hirschman-Herfindahl Index (HHI – developed by Hirschman, 1945 and Herfidahl, 1950) represents a statistical measure of economic activities concentration. For the purpose of this analysis, it indicates the degree of sectoral concentration. Regional employment shares are divided in six branch-aggregates (agriculture, production branches, construction, services – including trade and tourism –, knowledge-intensive branches, public services, education). The HHI is calculated by summing up the squares of regional employment shares of the mentioned sectors. The normalized HHI ranges from 0 to 1.

The sectoral concentration analysis of the Turnu Măgurele – Giurgiu region highlights that the majority of settlements are "highly concentrated", demonstrating its deeply agricultural character. Therefore, the rural settlements display a high concentration, except for the larger communes and urban settlements where the index values are slightly lower (Turnu Măgurele – 0.06; Zimnicea – 0.08; Giurgiu – 0.12) (Fig. 4). Regarding the structure of the economy, the adaptation potential of the Danube settlements, which depend on agriculture, is a limited one compared with knowledge-intensive services (e.g. IT, research, development, innovation), which have the potential to swich from less to more profitable industries.

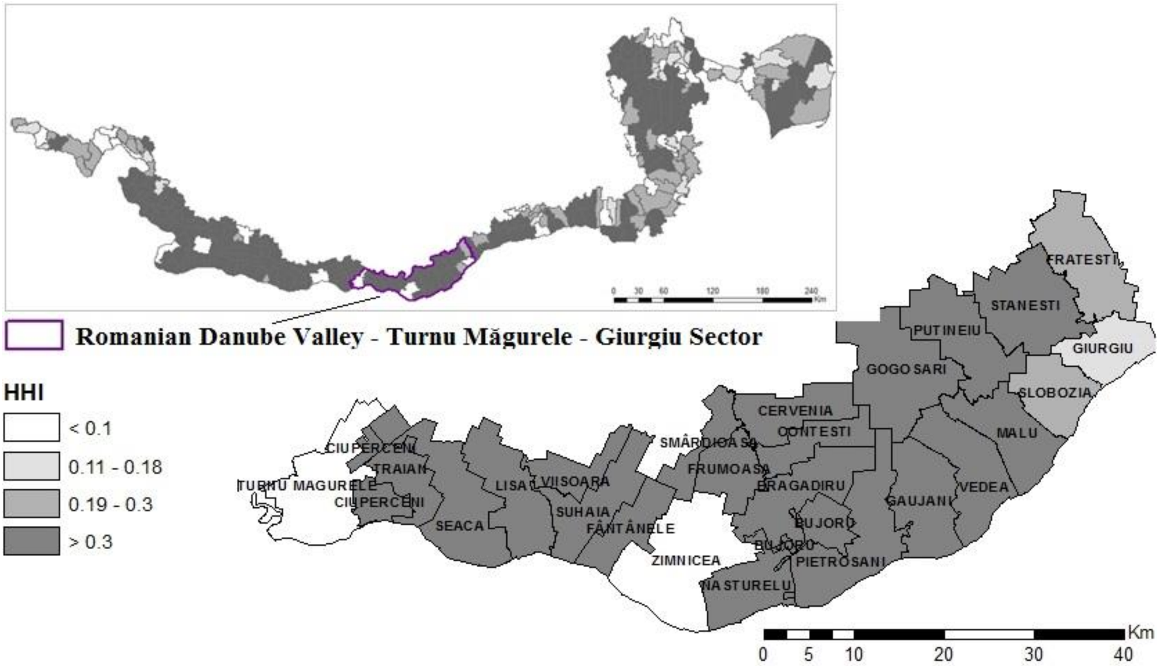


Fig. 4 – The Hirschman-Herfindahl Index.

4.2.2. Crop yield losses

Assessing the socioeconomic effects of drought usually means evaluating the intensity and persistence of this phenomenon and, of identifying its direct and indirect consequences on the socioeconomic sector (Wilhite *et al*., 2014). Also, studies on the drought impact focusse on losses of crop production which affect the rural communities (Howitt *et al*., 2015).

The main effect of drought in agriculture is the decrease of the main crop yields (Potopová *et al*., 2015), which has a direct and significant effect on the livestock sector and reduces the income of agricultural producers. Drought impacts on agriculture are assumed to be well-represented by the values calculated for losses in the agricultural sector caused by drought-induced limited crop-water availability.

The annual crop yields of winter wheat, maize, sunflower, barley and rapeseed over 1990–2017 at the local administrativ units were collected in the Turnu Măgurele – Giurgiu sector County Direction for Agriculture. Winter wheat is the largest grain crop in the study-area, accounting for about 39% of the total crop production in the sector, followed by maize (27%), barley (13%), sunflower (11%) and rapeseed (10%) (Fig. 5a). Winter wheat covers 28% of the total planting areas, followed by maize (26%), barley and sunflower (16%) (Fig. 5b).

The temporal evolution of cultivated areas and total crop yield in the Turnu Măgurele – Giurgiu sector is shown in Fig. 6. According to the data provided by the county Directions for Agriculture, the evolution of cultivated areas during the 1990 – 2017 period (Fig. 8) highlights some fluctuations generated either by the meteorological conditions, or by the property-related country legislation, or both. After 2007, a slight increase both in cultivated areas and in total crop yields is observed, mainly due to adaption to climate change policies which came to support the Romanian farmers.

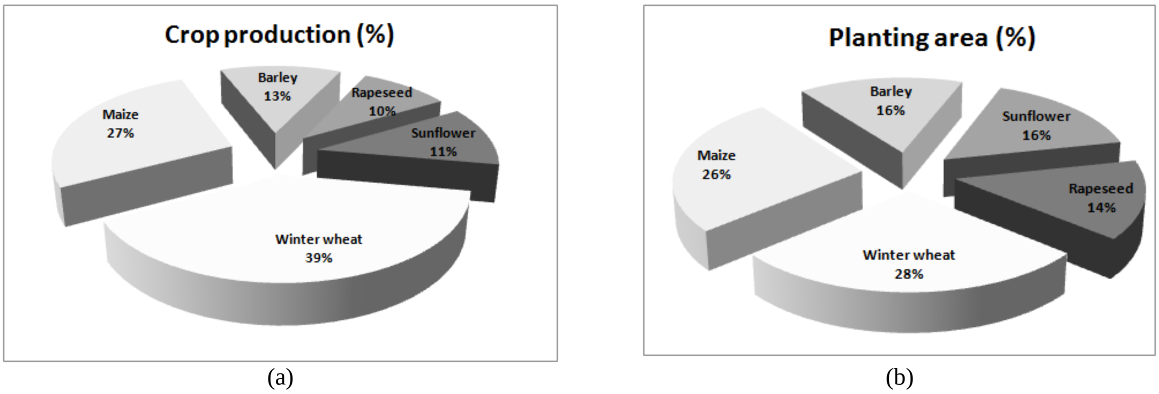


Fig. 5 – Crop production (a) and cultivated area (b) for the main crops in Turnu Măgurele – Giurgiu sector.

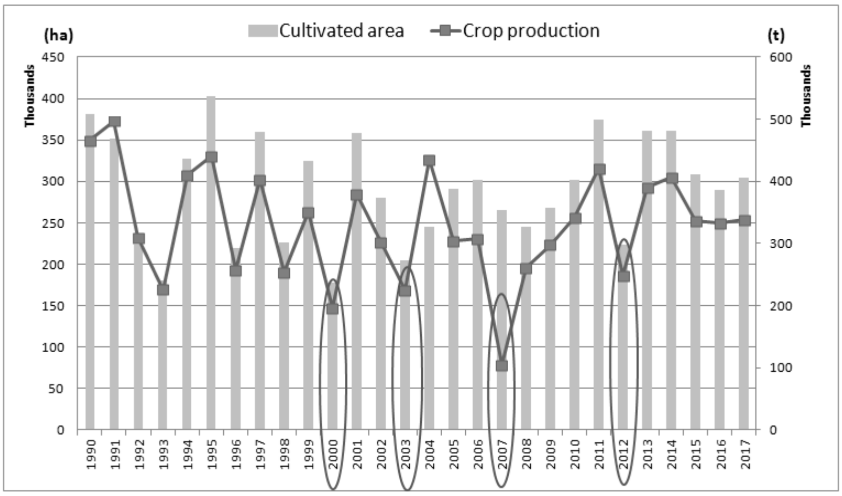


Fig. 6 – Cultivated area and total crop yield in the Turnu Măgurele – Giurgiu sector of the Romanian Danube Valley (1990–2017).

In the years 2000, 2003 and 2012 the cultivated areas shrank significantly. This can be attributed largely to both weather conditions (precipitation and soil moisture deficit associated with high temperature anomalies) and lack of adequate agricultural policies. Weather characteristics in those years prevented farmers from sowing certain types of crops in optimal conditions. For example, during 2000 and 2003, the farmers of Teleorman and Giurgiu counties had difficulties in sowing wheat and barley and managed only to plant 40% of the cultivated area; in 2012, the rapeseed was cultivated less than 60% than it was planned to due to lack of precipitation that prevented proper land tillage.

Drought can be a major determinant factor of food security. During the analyzed period, the total crop yield in the study-area registered some falls especially in 1993, 2000, 2007 and 2012. The minimum value of the total production was less than 110,000 tonnes in 2007, when many crop yields were significantly affected: maize (less than 1 t/ha), sunflower (less than 0.5 t/ha) and wheat (little above 1.5 t/ha).

The temporal evolution of the standardized yield residuals series (SYRS) for six agricultural crops (winter wheat, maize, barley, vegetables, rapeseed, and sunflower) during the 1990–2017 period is shown in Fig. 7.

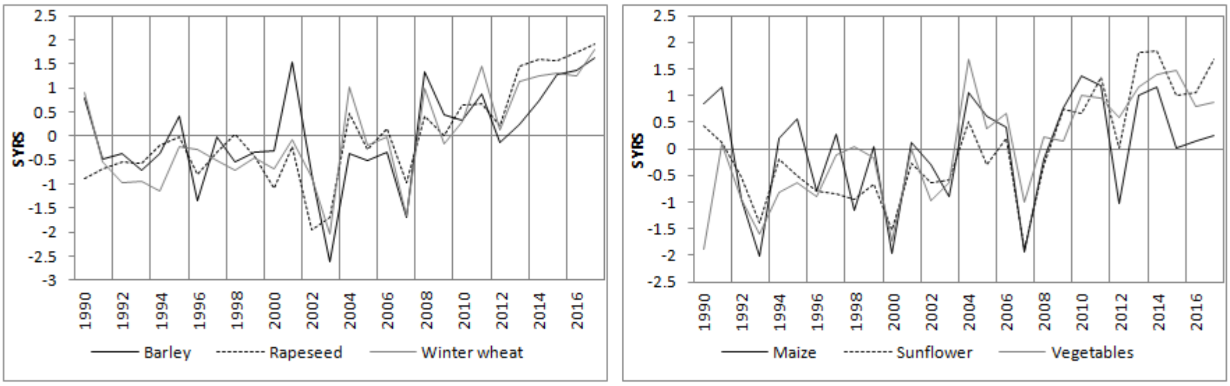


Fig. 7 – Temporal evolution of the SYRS for barley, rapeseed, winter wheat, maize, sunflower and vegetables in the local administrative units during the 1990–2017 farming years.

During the analyzed period, SYRS had some fluctuations generated by the meteorological conditions. According to SPEI results, the years ranking at the top of extreme droughty months during 1990–2017 are 1992, 1993, 2000, 2003, 2007 and 2012. Maize and sunflower yields had similar negative responses to drought during the 1993, 2000, 2007 and 2012 extreme drought. The most dramatic yields losses were reported in 1993 (SYRS < -2 – maize), 2003 (SYRS < -2,5 – barley and < -2 – winter wheat and rapeseed) and 2007 (SYRS < -2 – maize and sunflower). The vegetables yield was continuously increasing since 1993 without being significantly impacted by drought.

According to the data provided by the County Direction for Agriculture, the rapeseed and sunflower acreage rapidly expanded during the last years of the analysed period in the Turnu Măgurele – Giurgiu sector. For example, in 2017 the sunflower and rapeseed acreages increased by 2.1 and 2.9 times, respectively, as compared to 1990.

The percentage of yield losses for the main crops that could largely be attributed to drought (Table 6). Crop yield losses (Y,%) were calculated by dividing the annual crop yield (winter wheat, maize, barley, sunflower, rapeseed, vegetables) by the mean yield value of the quadratic trend and multiplying the results by 100% (Potopová *et al.*, 2015). During the study years, severe to extreme droughts limited crop water availability and substantially reduced crop yields. The results show that the degree of yield losses due to the drought impact varies with the crops (e.g. the year 2007 was outstanding in terms of yield losses for winter wheat, maize, barley and sunflower). As a consequence of drought in 2007, the production of maize and sunflower at the country level dropped by 57 and 64%, respectively. The most dramatically maize yield losses (81–83%) were reported when severe drought occurred during the crop risk period (in July–August <flowering, fertilization, grain filling and maturity>, the daily water consumption increased significantly).

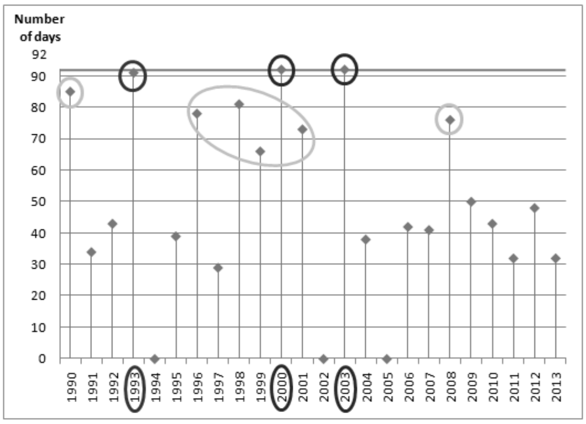
The analysis of drought indicators in connection with crop-yield indicators demonstrates that apparent similar severity drought has a different impact on crop production in that crop-yield losses depend on drought onset relative to the growth cycle (e.g. maize is relatively tolerant to water deficits during the vegetative and ripening stages, but less during the flowering stages) (Pauw *et al.*, 2010; Ştefan, 1997).

Table 6

Percentage of attributed yield crop losses (Y, %) due to severe drought in Turnu Măgurele – Giurgiu sector

Year	Y (%)					
	Winter wheat	Maize	Barley	Sunflower	Rapeseed	Vegetables
1993	31%	68%	20%	54%	25%	31%
2000	22%	81%	8%	56%	47%	33%
2007	53%	83%	48%	74%	42%	19%
2012	4%	42%	4%	20%	3%	0%

There are several studies estimating the potential impact of climatic anomalies on Romanian agriculture (Sandu *et al.*, 2010; Grumeza, 1989; Topor, 1963). These studies, focussed mostly on climatic influences on agricultural crop yields, state that 29 days without, or with insignificant precipitation (<10 l/m^2) from June to August proved detrimental to agricultural crops (Sandu *et al.*, 2010, Grumeza, 1989). In Turnu Măgurele – Giurgiu area, the number of consecutive days with less than 10 mm/day from June to August over 1990–2013 is given in Fig. 8 (a). According to this climatic aspect, the years with top extreme drought are 1990, 1993, 2000 and 2003, with maximum values in 2000 and 2003 (92 consecutive days). Because most of the intervals with precipitation deficit are associated with positive temperature anomalies during the agricultural years, other climatic parameters – the number of hot days with Tmax≥32°C and the number of consecutive days with Tmax ≥ 32°C from June to August – were calculated at three meteorological stations in the study-area: Turnu Măgurele, Zimnicea and Giurgiu.



Year	Meteorological station	Total number of hot days	Maximum number of consecutives hot days
2012	Turnu Măgurele	51	17/ 30 June – 16 July
	Zimnicea	60	17/ 30 June – 16 July
	Giurgiu	60	17/ 30 June – 16 July
2007	Turnu Măgurele	50	17/ 15–31 July
	Zimnicea	58	17/ 15–31 July
	Giurgiu	60	17/ 15–31 July
2000	Turnu Măgurele	44	13/ 11–23 August
	Zimnicea	50	15/ 10–24 August
	Giurgiu	49	14/ 11–24 August

Fig. 8 – Total number of consecutive days with precipitation less than 10 mm/day (a); total number of hot days (with Tmax ≥ 32°C) and consecutive hot days (b) from June to August.

In the 1990–2017 period, the Turnu Măgurele – Giurgiu sector witnessed several significant dry events with associated phenomena (heat waves, extremely hot consecutive days) compromised almost totally the agricultural production, leading to a difficult economic situation, in Teleorman and Giurgiu counties. The dry intervals had a direct effect upon agricultural crops, leading to the depreciation of vegetation and reduction of the annual agricultural production, by gradual deterioration until complete loss of crop. The agricultural year 1999–2000 was characterized by a significant decrease of maize, rapeseed and sunflower crop yields. That was because of lack of precipitation (excessively dry < 100 l/m^2) from May to August, which is the period of maximum plant water consumption, and May to June for the autumn/winter crops, respectively.

The lack of precipitation coupled with the extremely high temperatures, which significantly affected the grain crops (wheat, maize and sunflower), led to a drastic decrease in yield (Fig. 8b). From May to June, wheat experienced a risk period (which corresponds with heading, flowering and ripening), when drought and high temperatures cause substantial yield losses (Ştefan, 1997). The wheat yield losses can thus be attributed to both drought (1993, 2000, 2003) and high temperature anomalies associated with precipitation defficits (2000, 2007, 2012). The analysis of maize crop yield series during the 1990–2017 points out a high sensitivity of this crop which is strongly influenced by climatic anomalies in terms of precipitation and temperature. Plant development is highly related to temperature variations, the maize production registering significant decrease in 1993, 2007, 2012 which were years of servere drought and strong positive temperature anomalies. Although the maize demand for humidity is different throughout the vegetation period, yet the plant is very resistant to drought.

Food security and poverty are mainly affected by drought, through the loss of capital, incomes and higher food prices. The major economic impact of drought is reflected in the reduction of crop yields and in the evolution of the annual mean prices for the products sold in agro-food markets. There is a direct impact of drought on the crop production sub-sector, and an indirect, or induced effect on other sectors of the economy (for example: industry, trade) which directly or indirectly depend on the agricultural sector. In many settlements of the Turnu Măgurele – Giurgiu sector, cereal crop yields were compromised by drought up to 50%. The local authorities decided to stop harvesting operations in some areas because the profits were below than expenditures. The steep decrease of agricultural harvests as a result of drought is usually followed by an increase of the price of agricultural products and food imports. Another consequence of the price increase in agricultural products is connected with the reduction of livestock and the higher price of meat products.

Analysing the evolution of the annual mean prices for the products sold in the agro – food markets of Turnu Magurele – Giurgiu sector during 2000–2017, highlights a general growth tendency, especially after the extremely dry years: 2000, 2007 and 2012. The years following the severe drought periods, affected extended areas of agricultural land, with significant price increases for all the five crops selected for this in the analysis (Fig. 9).

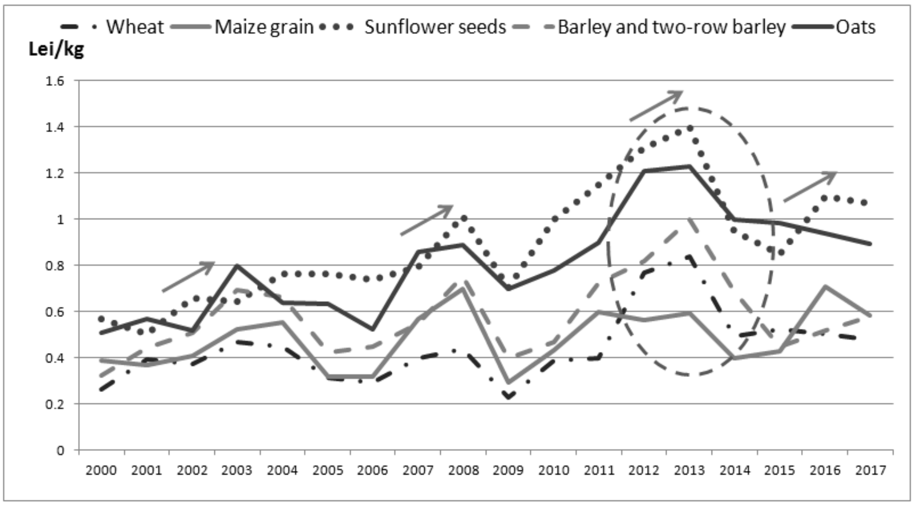


Fig. 9 – Annual mean prices of products sold in the agro-food markets of Turnu Măgurele – Giurgiu sector during 2000–2017.

Although the rural population of the Romanian Danube settlements is strongly affected by the damage produced by drought in the agricultural sector, the impact of the phenomenon indirectly affects the urban population as well, taking into account the price of agricultural products, as a barometer of the intensity of extreme weather phenomena. Drought-induced higher prices would attract goods from other regions to flow into the local market, which helps amend supply shortages and limits price increases. In this case, producers outside the drought-affected area benefit from favorable prices.

Drought-induced losses are not completely supported by farmers, because a part of such losses are covered by consumers through increased prices. The higher the prices, the stronger effects on consumers' purchasing power. It is even possible that farmers could benefit from the consequences of drought, given the increase in pricees. The ultimate losses supported by farmers could be very different from the actual impacts caused by drought. Therefore, it is not appropriate to match the farmers' income losses with drought-induced economic damage. It is also important to identify the losses supported by different stakeholders. Farmers purchasing crop insurance will recover part of their losses as compensations from the insurance companies, while some eligible farmers may receive direct disaster assistance from the government.

The assessment of monetary losses associated to drought is very important in analysing the impact of this phenomenon on the population. The monetary losses attributed to drought are calculated according to the price of product categories multiplied with the quantity of products attributed to drought damage. In the international literature (Chau *et al*., 2015; Gill *et al.,* 2013; Diersen *et al.*, 2003) the assessment of monetary loss as a result of dry phenomena is based on the historical data concerning the agricultural product prices, in the agricultural years characterized by optimal conditions (without extreme fluctuations). The monetary losses were calculated by the annual quantity of products attributed to drought damage multiplied with the annual mean prices of agricultural products (mean prices of each year without, or with insignificant drought-induced yield losses: 2004, 2011, 2014).

The results show that the monetary losses vary due to drought impact. The major monetary losses were recorded in 2000, 2007 and 2012 (Fig. 10), during severe wet growth season, specifically during the flowering to ripening stages (winter wheat: May – June; sunflower and maize: July – August). The year 2007 was ranked the highest in terms of monetary losses. As a consequence of drought during 2007, the lost production was almost 160 mill. RON.

In 2000, the lack of precipitation in the sowing and ripening stages of maize (Fig. 2), coupled with extremely high temperatures during the flowering stage (Fig. 8b) led to a sharp decrease in yields and the production lost was almost 112 mill. RON.

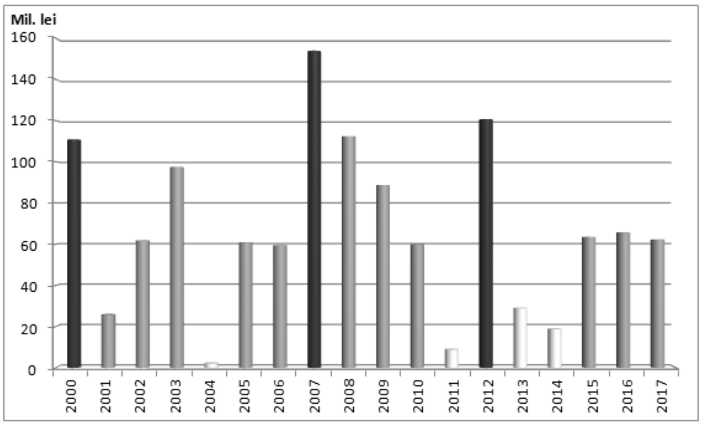


Fig. 10 – Annual monetary losses associated to drought in the Turnu Măgurele – Giurgiu sector during the 2000–2017 period.

Considerable economic losses of 120 mill. RON were recorded in Turnu Măgurele – Giurgiu sector as a result of the 2012 drought. In that same year, the agriculture, forestry and fishing sectors combined generated only 4.9% of the total real GDP among all industries in the Romanian economy.

5. DISCUSION AND CONCLUSIONS

The assessment of the socioeconomic impact of drought in the Turnu Magurele – Giurgiu sector of the Romanian Danube Valley shows a strong dependence of the rural communities on the agricultural sector, specifically on the production of raw crop products.

The analysis of drought with SPI and SPEI indices shows that both precipitation deficits and high temperature anomalies had an adverse impact on crop yields. The top extreme drought years were 1990, 1993, 2000, 2003, 2007 and 2012 which were the years of higher wheat and maize yield lossess.

The price of crop products in the market are directly responsive to the yearly yield fluctuations through increased prices during the droughty years. This is also a speculative possibility for the farmers who act in their own economic interests the periods of drought events, in that the yields of the agricultural year previous to drought are stored in order to be sold at higher prices during the drought year.

In the study-area, the agricultural sector is the main source of employment in the rural communities. This explains the severity of drought impacts on farmers' income and the financial hardships faced by the population due to the drought. In the Turnu Măgurele – Giurgiu sector, the major economic effect of drought is reflected in the reduction of crop yields and in the evolution of the annual mean prices for the products sold in agro-food markets. During the analyzed period, the total crop yield in the study-area had some falls specifically in 1993, 2000, 2007 and 2012. The results of the study show that, drought events in the last 27 years have caused large economic losses for farmers and consumers.

Drought-response measures in the Romanian Danube Valley relate to drought risk reduction actions and drought mitigation measures, whereby their efficiency strongly depends on the economic and societal context and on the operation of the governance structures. The National Plan for Agriculture and Rural Development 2014–2020, under the National Programme of Rehabilitation of the Primary Irrigation Infrastructure (MADR, 2015) and the connected legislation and institutional arrangements set out the necessary regulatory framework for investments and fund access and allocation for modernization of the large irrigation systems and increase of the irrigated areas, as a major structural measure and response to drought conditions. Nevertheless, it is not only the technology that is necessary in managing drought.

There is a crucial need to integrate contracting measures, such as irrigation into broader territorial development and efficient national policies and strategies of using resource (Garrido *et al*., 2011). Therefore, the use of water for irrigation, the land-use policy and the agricultural policy integrate across connected domains of water policy, energy security, food production and climate change adaptation strategy, responding to the principles of managing water-food-energy nexus (EC, 2013.; Bizicova *et al.*, 2013). Along with the sustainable and equitable use of resources which is one of the direct effects of public policy integration, the policies have to integrate the impacts on ecosystems, local communities and local cultures into the way they are designed and operate (Garrido *et al*., 2011). In this way, public policy integration is more likely to ensure the necessary implementation framework for actions that envisage the increase of the multifuntionality of farms and therefore diversification of their economic activity, sustainable intensification of agricultural activities where possible, increase of food production quality along with preservation of ecosystem services, development of agricultural products processing units and deconcentration of agricultural production, etc. (CAP, 2013). They contribute to drought resilience increase and mitigation and ultimately lead to the premises for rural communities' development. Moreover, strengthening cooperation among profile research institutes and stakeholders with interests in the sustainable use of resources aims at ensuring integrative management and providing long-term solutions for extreme event (drought) control, as well as sustainable development. It is, therefore, important to benefit from the comprehensive and accurate monitoring data of the drought phenomenon in the Danube Valley along with its associated economic and societal impacts. In this respect, interdisciplinary approaches based on a suite of integrative and innovative methodologies and technologies, such as the use of remote sensing for satellite derived-data and process-based models, are able to provide insightful results for the support of extreme weather events management. For instance, process-based crop model simulations not only account for weather influences on crop yields, but also provide options for agricultural practices. Complex models, process-based models coupled with economic prediction models are important tools for differentiating between the drivers that influence crop productions, as well as for exploring various scenarios for drought-risk reduction and appropriate adaptation strategies.

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