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DMCSEE
Drought Management Centre for Southeastern Europe

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DROUGHT MANAGEMENT CENTRE FOR SOUTH-EAST EUROPE - DMCSEE

Summary of project results

www.dmcsee.eu

Drought Management Centre for South-East Europe - DMCSEE

Summary of the result of the project, co-financed by the South East Europe Transnational Cooperation Programme (contract no. SEE/A/091/2.2/X)

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FOREWORD

During the last century, mainly in the last 20 years, the South-Eastern Europe (like most of the other regions in the world) experienced impacts of increased climate variability, where in addition to rising temperatures the frequency of droughts significantly increased. According to available climate change scenarios, it is not likely that situation will improve in forthcoming decades. Projected climate would exacerbate water shortage and quality problems in many water scarce areas in the region. Heat waves in the summer as well as intense precipitation events are expected to become more frequent throughout Europe. Due to envisaged climate change scenarios risk of drought is likely to increase in southern part of Europe.

To reduce the negative effects of existing drought related risks as well as projected climate change impacts, the countries of South-Eastern Europe (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Former Yugoslav Republic of Macedonia, Greece, Hungary, Montenegro, Moldova, Romania, Serbia, Slovenia and Turkey) decided to establish a drought management center for South-Eastern Europe (DMCSEE). The idea was elaborated by International Commission on Irrigation and Drainage and UN Convention to Combat Desertification. The UNCCD national focal points and national permanent representatives with the World Meteorological Organization have agreed upon the core tasks of the DMCSEE. The mission of DMCSEE is to coordinate and facilitate the development, assessment and application of the drought management tools. DMCSEE should help to establish monitoring systems for early warning and than applying an approach to reduce the negative consequences by sustainable practices in agriculture and water management ensuring food security and efficient water use.

Slovenian environmental agency was entrusted with organization of DMCSEE work in 2006. As first step it was necessary to obtain necessary resources. To this end, the DMCSEE submitted application to the first call of South East Europe Transnational Cooperation Programme. The application was successful and 15 partners from 9 countries in the region, both EU members (Bulgaria, Greece, Hungary and Slovenia) and non-EU members (Albania, Croatia, Former Yugoslav Republic of Macedonia, Montenegro and Serbia) cooperated within the project. The DMCSEE project partnership was build on the initiative of national authorities, responsible for management of natural resources in the participating countries. The partnership consists of organizations capable of providing relevant data needed for regional drought monitoring and risk assessment: these were mainly national meteorological and hydrological institutions. Universities and institutes with research in the field of agricultural and soil science provided know-how on risk assessment and good practices. Since drought is not bounded by state borders, the region lacks data compatibility and coordination in drought management. This aim was reached by completing main project objectives. The information on the current status of drought among the DMCSEE countries is available on DMCSEE web site.

This final publication, devoted to the DMCSEE project, presents to you a variety of the project activities and outcomes. Some results will undoubtedly help decision makers in the countries in the planning of activities to reduce the effects of drought and to enable various industries as better prepare for drought. Some, based on relevant information about the status of drought, disseminated to users by DMCSEE web page, will help to organize effective measures to combat the drought. Without a doubt, the project results will be essential to achieve sustainable operation of the DMCSEE in the future.

Finally, we would like to thank all partners who participated in our work together during the last three years. Taking into account the great diversity in all areas among the countries in the SEE region, we hope that by working together we have built a good foundation for further work within DMCSEE. We also think that participation in this project has contributed to the future organization of work within DMCSEE, because the basis for cooperation within each participating country has been set. We look forward to our cooperation in the future!

Slovenian Environmental Agency

The well has run dry. Water is essential for life, health and sustainable development - yet more and more people lack access to fresh water.

DEFINITIONS OF DROUGHT

Sandor Szalai
Szent Istvan University

Drought is a complex phenomenon, which has no generally accepted definition. General approach is to use working definitions for limited use, i.e. for a given study. In this case, we use following definition for drought: temporal decrease in water availability which could lead to damages in different sectors of nature, economy and society. In this working definition some words needs for further explanation. Temporal means a shorter term negative anomaly from the long-term mean (it is usually the climatological mean or norm), If the negative anomaly length is comparable with the averaging period of the 'long-term' mean, we talk about aridity. The water availability is more or less than the average (normal) available water quantity. The natural and human-made systems are already adapted to the different spatial variability of water availability. Therefore, the anomaly has to reach a process-dependent threshold value to cause damages. The size and duration of harmful negative anomaly of water availability can depend on the given process, period of year and geographical location. This several parameter dependency makes the exact general definition of drought not possible.

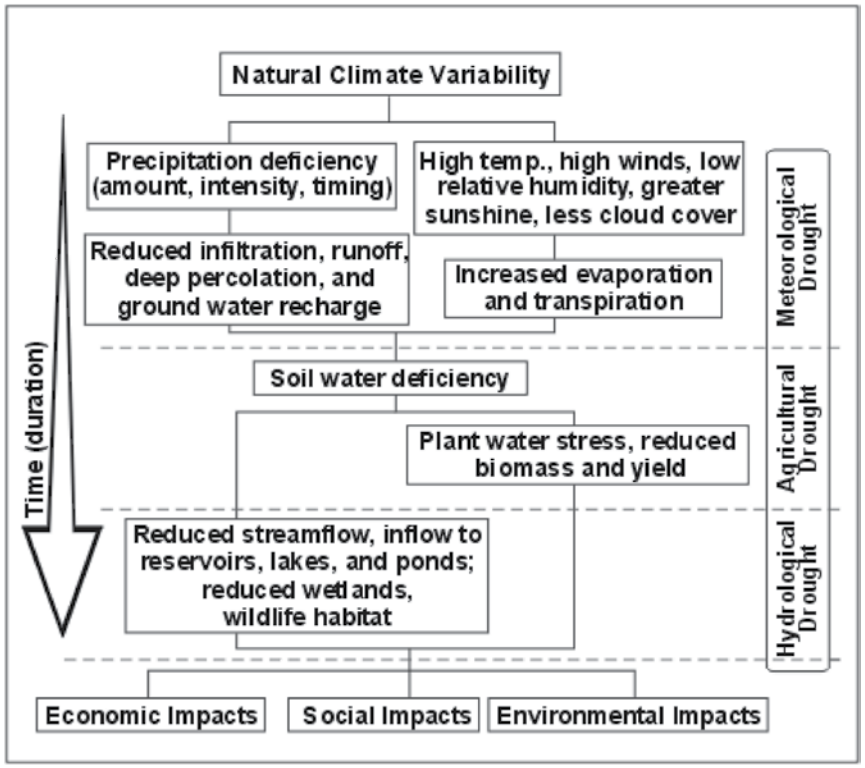
The origin of the reduced water availability is the reduced precipitation. It is not necessary that precipitation anomaly takes place exactly in the location of the drought; it can be in other regions as well. For example, reduced precipitation in the upstream area of a river can cause drought via reduced streamflow in the downstream region. It can be shifted even in time. For example the reduced winter solid precipitation can cause drought after the melting period.

There is a general agreement, that drought is solely a natural event. In fact, it cannot be isolated as sole consequence of natural variability, since according to the actual climate change theory, the human activity effects the temperature and the precipitation distribution on the Earth, which influences the drought frequency, strength and duration as well. However, drought is caused directly only by natural factors.

As it was mentioned above, drought depends on the feature of the effecting factors and the area (process) impacted. Therefore, we differ the droughts according to the area of effects, and we can talk about hydrological, agricultural, socio-economical, etc. droughts. According to the given local conditions, other types of droughts can be mentioned as well (for example, pasture drought in the regions having large cattles under extensive conditions). As it was already mentioned, the basic of any kind of drought is the longer negative anomaly of precipitation. This phenomenon is called meteorological drought. Depending of the duration of meteorological drought, the soil humidity will

be reduced (shorter term) and the groundwater table can be dropped (longer term). As far as it effects directly the agricultural production, it is called agricultural drought. The water is collected in lakes, reservoirs, rivers in a given territory (catchment area). If the territory is suffered by meteorological drought, then the water level of reservoirs, rivers, the streamflows, etc. will be reduced. This situation is called hydrological drought. This drought event can distribute to other territories easily.

If the drought event reaches such proportions, that the living conditions of the local inhabitants are in danger, then the population suffers impacts also in the social relations – in worst case, significant proportion of population can decide to migrate. This situation is known mainly from Africa and is called the social drought. It can be caused due to the drying out of meadows or strong reduction in the irrigation water supply.



Connection among different drought types (www-drought.unl.edu)

It is necessary to distinct drought and water scarcity. Drought is an originally natural event – temporal reduction of the water supply. But the sustainable use of natural resources, economy and society require (would require) the equilibrium between supply and demand. Water demand contains natural (plants, animals, human water requirements) and anthropogenic (industry, additional water need of agriculture, municipalities, etc.) factors. If the demand side is larger than the supply side for longer period of time, water scarcity is occurs. According to the above mentioned definitions, water scarcity is a natural and anthropogenic event. Therefore, water scarcity can and has to be reduced by supply and demand management methods as well.

Supply management is the planned use of different water reservoirs (groundwater, rivers, lakes, deeper layer waters, etc.). For this purpose we need to know the capacity of the given reservoirs, their recharge time. Usually, introduction of water sparing and efficient technologies are used as demand management methods, although the human habits (household water use, etc.) belong here as well.

Supply and demand management methods help to establish long term equilibrium between the water supply and demand, i.e. to improve and possibly remove the water scarcity. Long term water scarce situation could destroy the sustainability of available water resources. However, this problem is not direct subject of drought management practice.

Water: the
limited resource.
Save fresh water ... now!

IMPLEMENTATION OF DROUGHT MONITORING IN DMCSEE

Gregor Gregorič
Slovenian environmental agency

Since drought does not have unique definition, there is no universal quantity to measure its severity and duration. General practice is application of drought indices. Drought index is dimensionless numerical value, sometimes artificial blend of values of various variables and indicators, connected to anomaly of precipitation and/or state of water resources in aquifers. There used to be a tendency to develop specialized indices for different types of droughts and different climate regions. Therefore a lot of indices exist, but no one can be used universally.

Indices vary from quite simple quantities that use precipitation data only (such as the Standard Precipitation Index - SPI) to more complex indices that include assessment of available energy for evapotranspiration with the available (evapotranspirable) water amount. Complexity can increase with use of other than meteorological parameters, such as soil data. Soil is one of the largest water storage part of the climate system, therefore it is important to include it in the drought analysis. The main problem of the soil parameters is their large spatial variability, and lack of reliable methods for spatial interpolation.

However, drought monitoring is more than simple index calculation. Important issue is data quality control; since we are trying to assess anomalies from “normal” state, small differences and inhomogenities in historical data records can lead to large errors in final results. Monitoring system usually has to contain a real time information dissemination system, although in the case of drought early warning system does not need real time data because of the slow onset of the event; however, reasonably fast data availability system is requested. Drought early warning system can be very simple, based only on precipitation data, or it can be more comprehensive, containing interdisciplinary information. Interdisciplinarity requires common use of monitoring systems with harmonization of the development of the slowest system. Therefore, fitting of different monitoring systems is very important in the case of complex drought monitoring.

The Drought Management Centre for Southeastern Europe produces drought monitoring based on SPI.

Standardised precipitation index (SPI) has become one of most frequently used tools for drought monitoring throughout the world. Although developed quite recently (McKee has published his first article in 1993 with description of SPI calculation), it has nowadays most wide-spread use in practical drought monitoring. SPI is based on statistical techniques, which can quantify the degree of wetness or dryness on multiple time scales. Appropriate time scale should be selected according to typical temporal duration of dry anomaly which causes impacts to society and economy (in short – drought). This scale differs substantially among regions. Usually 1, 3, 6, 12 or even (sometimes) 24-monthly rainfall totals are taken into account and compared to the climatological rainfall records.

Since SPI depends only on precipitation amount, interpretation (mainly connected to its relation to drought impacts) has to be careful. On the first place, SPI requires different interpretations according to its time scale. For example, the 1-month SPI reflects mainly short-term conditions, and its application can be related closely to soil moisture. It can be potentially related to drought stress in certain development stages of crops. The 3-month SPI provides a seasonal estimation of precipitation, typically related to overall crop yield and streamflow conditions of small rivers. The 6- and 9-month SPI indicates medium term trends in precipitation patterns; and the 12-month SPI reflects the long-term precipitation patterns, usually tied to larger stream flows, reservoir levels, and even groundwater levels. Another advantage of the implementation of SPI comes from its standardization, which ensures that the frequency of extreme drought events at any location and any time scale are consistent. A drought event occurs at any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end and intensity for each month that the event continues. Table 1 represents SPI values and drought classification (according to cumulative probability).

Table 1: Drought classification by SPI value and corresponding event probabilities

SPI value	Classification	Cumulative probability (%)
2.00 or more	Extremely wet	2.3
1.50 do 1.99	Very wet	0.4
1.00 do 1.49	Moderately wet	9.2
0 do 0.99	Mildly wet	34.1
0 do -0.99	Mild drought	34.1
-1 do -1.49	Moderate drought	9.2
-1.50 do -1.99	Severe drought	4.4
-2.00 or less	Extreme drought	2.3

One of the problems might be inconsistent conclusions obtained due to different time lengths of precipitation record are involved in the SPI calculation. The longer the length of record used in the SPI calculation, the more reliable the SPI values will be, especially for long-time-scale SPI values. The use of robust data is desirable in the analysis of the climatic responses of hydrologic processes because of disparities in station records including inhomogeneity and inconsistency of observations in space and time. In order to minimize possible problems with inconsistency, calibration period as well as basic data treatment has to be standardized.

World-wide use, moderate data requirements and calculation robustness are main reasons why to implement SPI index in the region. It is also important that neighbouring countries exchange experiences with software applications, calibration data records and data quality control and treatment.

Meteorological networks, types of observations and data availability are very important factors of drought monitoring. There are large differences in type and availability of data in the DMCSEE partnership – both due to nature of partner institutions (some partners are operating national meteorological networks, other have limited access to national data) and due to situation within national meteorological offices in the countries (in some cases there were serious reductions of network and /or automatization of measurements, there are also cases where data is not available in digital form). In any case, close cooperation of national meteorological services is crucial for successful implementation of drought management. Meteorological services are operating different types of station network; networks are also internally heterogeneous. The backbone of most systems are still manual meteorological stations, based on voluntary and professional observers. Most services are trying to establish network of automatic meteorological stations which will eventually replace manual observations. However, due to dependence of SPI (as well as other drought indices) on homogeneous historical data set on site of measurement requires this transition to be prepared and executed carefully.

Operative SPI calculations are performed on the basis of daily precipitation data. Most stations have data records available for 40 years or less (see figure 2). For this reason – and to avoid extreme years in the beginning of 21st century – the most appropriate calibration period was agreed to be 1971-2000. Although it is true that international standard climatological reference period is still set to period 1961-1990, due to practical reasons (approx. one third of total number of stations more) it was decided to use data after 1971. With this choice of calibration period, there are approximately 860 stations available for SPI calculation on monthly basis in the partner countries.

Figure 1: map of stations with available calibration and calculation data sets for SPI index (as reported by partners)

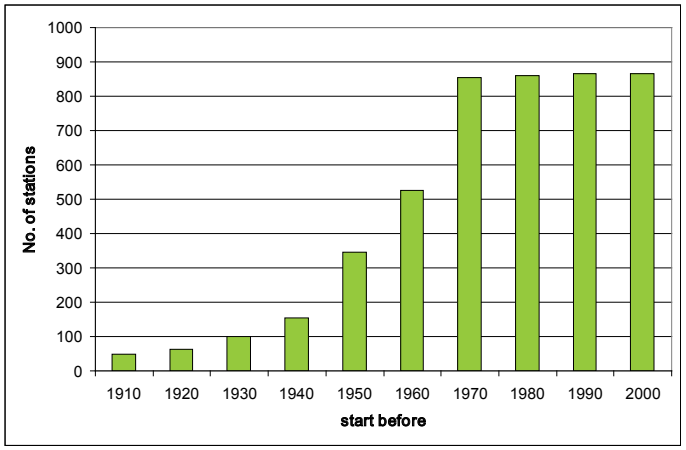


Figure 2: Number of stations according start of available data records

Point calculations of SPI index can be illustrative for drought conditions in present and past time periods over certain geographical location. However, mapping of the SPI index yields maps, that can be used for overview of situation over larger regions and that can show dynamic development of drought. Usually, geostatistical methods such as kriging or optimal interpolation are used for mapping. Figure 3 shows example of such map.

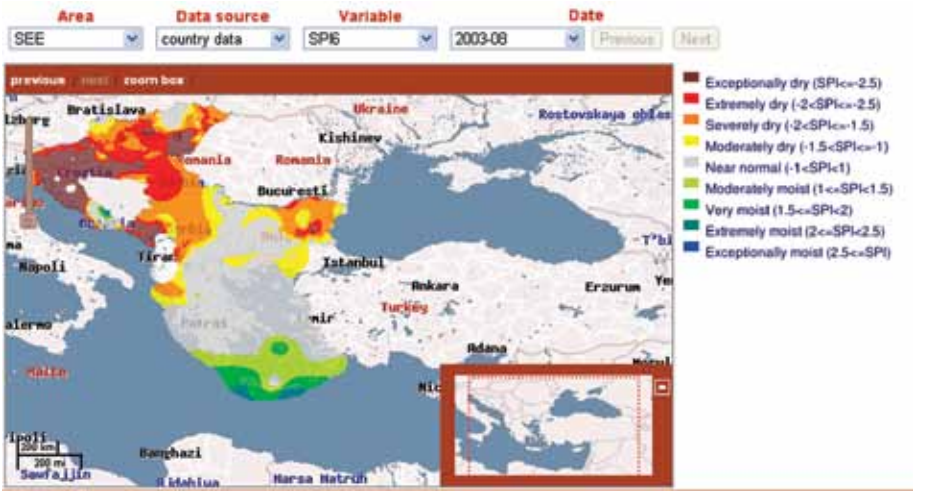


Figure 3: Example of regional SPI map

Implementation (calculation and mapping) of SPI is definitely not the only and final step in development of drought monitoring system. However, due to its simplicity and robustness the World Meteorological Organization has declared SPI as the reference drought index. Therefore it is essential first step and basic ingredient for regional products. With more sophisticated tools (such as irrigation optimization procedure), it is possible to assess severity of specific (agricultural) drought more accurately for specific practices (assessment of crop yield). However, complexity and focus on specific impacts of drought essentially causes loss of generality. Successful drought monitoring system should cover both – general overview of situation as well as assessment of specific impacts.

Vulnerability analysis provides a framework for identifying the social, economic, and environmental causes of drought impacts.

THE PALFAI DROUGHT INDEX

Arpad Herceg
ATI-VIZIG

The Palfai drought index (PAI) developed in Hungary for users in agriculture and in water management has been used for numerical characterization of droughts since the beginning of the 1980s.

This index characterizes the strength of the drought for an agricultural year with one numerical value, which has a strong correspondence with crop failure.

During the course of the DMCSEE project we analyzed the possibility of using the PAI in the South-East European area, and we also examined what kind of changes demands its wider practice considering especially the basic data availability.

The calculation of the base-value of PAI is essentially simple because data requirements can be easilly met, only monthly mean air temperature and sum of precipitation are needed for calculations.

However, in the formula of PAI the determination of three correction factors, based on daily temperature and precipitation values, as well as groundwater levels is difficult. For easier practical use we have developed a new, simpler method for the calculation of these factors, which is based on monthly mean air temperature and monthly sum of precipitation.

The equation for the new method, base-value of the modified index, named Palfai's Drought Index (PaDI) is:

$$PaDI_o = \frac{\left[\sum_{i=apr}^{aug} T_i\right] \; / \; 5*100}{c + \sum_{i=oct}^{sept} \left(P_i * w_i\right)}$$

where

PaDI0 – base-value of drought index, °C/100 mm
Ti – monthly mean temperature from April to August, °C,
Pi – monthly sum of precipitation from October to September, mm,
wi – weighting factor,
c – constant value (10 mm).

The weighting factors (wi) of precipitation in Table 1 show the difference between the soil moisture accumulation and the water demand of plants.

Table 1. Weighting factors

Month	wi weight factors
October	0,1
November, December	0,4
January-April	0,5
May	0,8
June	1,2
July	1,6
August	0,9
September	0,1

Calculation of PaDI $$PaDI = PaDI_o * k_1 * k_2 * k_3$$

PaDI – Palfai Drought Index, °C/100 mm
k1 – temperature correction factor,
k2 – precipitation correction factor
k3 – correction factor, which characterizes the precipitation circumstances of the previous 36 month

From the correction factors the temperature factor k1 represent the relation between examined and annual summer mean temperature, the precipitation factor k2 represent the relation between examined and annual summer precipitation sum and k3 represent the effect of precipitation circumstances of previous 36 month.

For eight Hungarian stations we have determined the PAI and PaDI values for the period 1961-2009, and there is no significant difference between the results. Because the geographical and climate relations of Hungary and the South East European countries somewhat differ, the classification of drought strength is wider for PaDI (Table 2.): seven classes have been introduced instead of the five used before.

Table 2. Drought categories

PaDI, °C/100 mm	Description
< 4	year without drought
4 – 6	mild drought
6 – 8	moderate drought
8 – 10	heavy drought
10 – 15	serious drought
15 – 30	very serious drought
> 30	extreme drought

The PaDI results for some stations from the SEE region for the time period 1961-2009 are represented in column graph format on Fig.1.

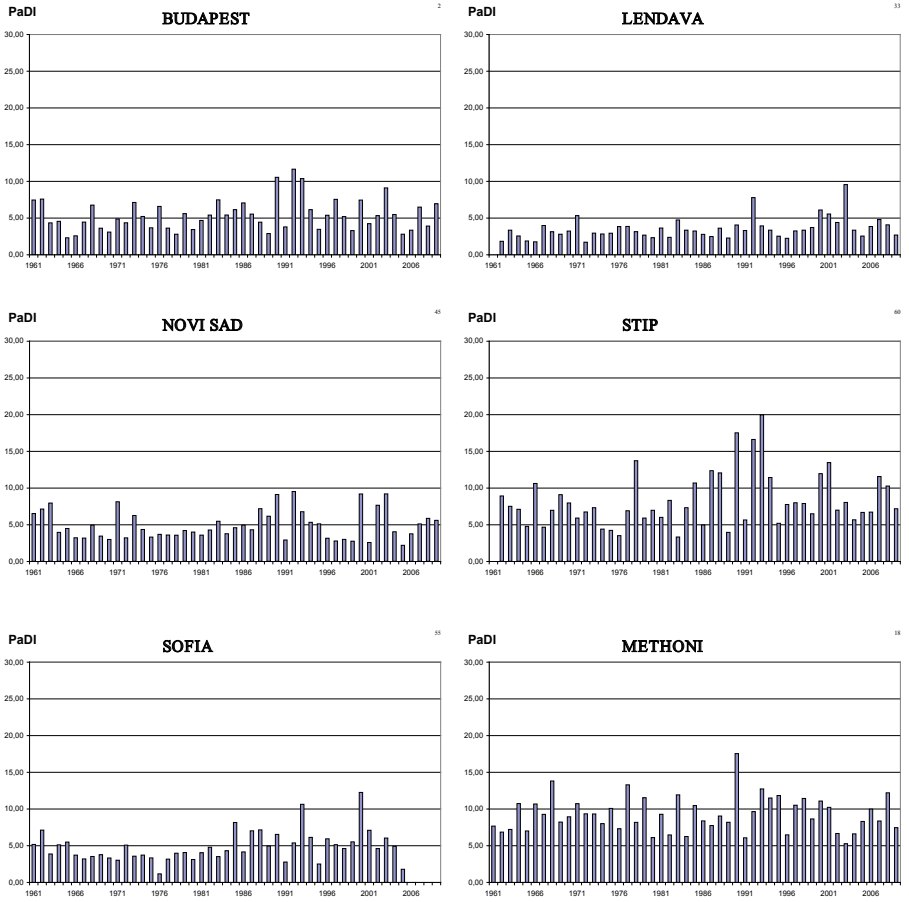


Fig 1. PaDI time series for 10 stations: Budapest (H), Lendava (SLO), Novi Sad (SRB), Stip (MK), Sofia (BG) and Methoni (GR)

According to the figures in the second part of the examined period the more droughty years are more common. The highest values of PaDI in the whole region are in the following years: 1990, 1992, 1993, 2000, 2003 and 2007.

For these droughty years the spatial distributions of PaDI for SEE region was defined using all 63 stations. The distributions are presented on Fig.2. It can be established,

that the strength of drought shows different spatial distribution year by year, but affects mainly the southern part of the examined area. In the Carpathian Basin the drought intensity is smaller (except in 2003), but frequency is similar.

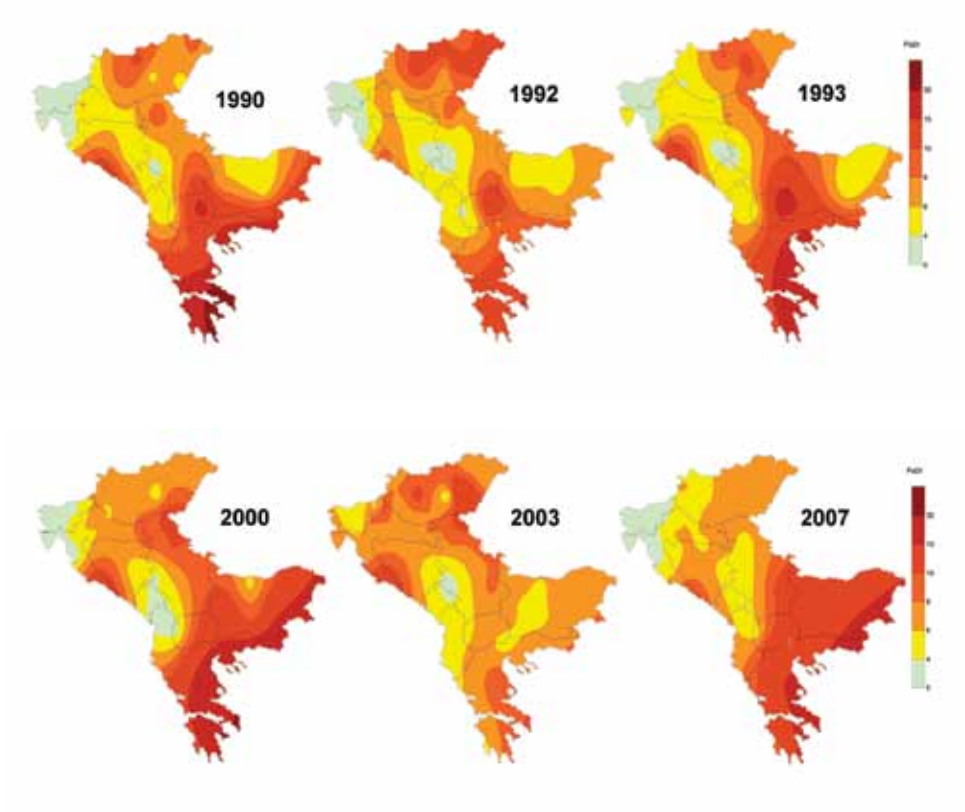


Fig. 2. Spatial distributions of PaDI in SEE region for years 1990, 1992, 1993, 2000, 2003 and 2007.

The map on Fig. 3 constructed from the 10% probability of occurrence of PaDI shows the spatial difference of drought intensity inside the region.

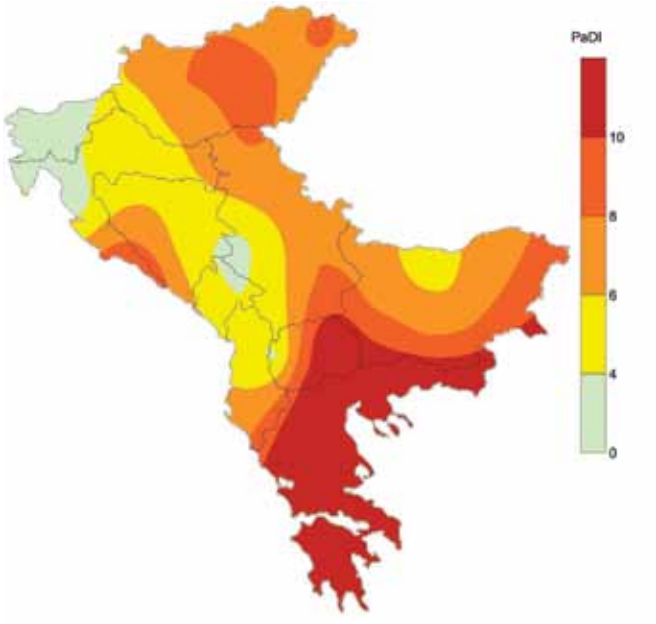


Fig.3. The 10% probability of occurrence of PaDI in SEE region

As PaDI shows the strength of drought for a whole agricultural year, the application of SPI3 or SPI6 is also practical for the characterization of seasonal drought. Beside drought characterization of past years PaDI is also useful for drought forecast in a way that the known raw data in the past is expanded month by month into future with the presumed data in more variations.

Vulnerability map is synthesis of variety of data and serves as an indicator of areas deserving a detailed drought risk evaluation.

EXTENDING DROUGHT MONITORING PRODUCTS: ESTIMATION OF SNOW COVER WATER CONTENT

Gabor Balint, Zsolt Mattanyi

VITUKI

Precipitation falling to the land surface is one of the most important elements of the hydrological cycle, and it is the only input term of the water balance on the earth surface. In those areas of the Earth where a part of the annual precipitation falls in form of snow the rhythm of the hydrological cycle, that is that of the water balance within the year, follows a pattern that deviates from that of the precipitation record. Precipitation falling in solid state enters the hydrological cycle with a time lag that might be as much as several months after the precipitation event. Therefore, instead of considering the observed values of precipitation when describing various elements of the hydrological cycle, it is more expedient to take the surface water income into account. This is the fraction of precipitation which is present in the land surface in liquid state. Consequently the most important task of the various snow models is to transform the observed precipitation values into surface water income values.

The HOLV snowmelt model is developed by Hungarian Hydrological Forecasting Service (VITUKI OVSZ). The model originates from the early 80's and it is under continuous development. A few years ago the model became distributed, since then the calculations are executed over a grid with 0.1 degree resolution (Figure 1).

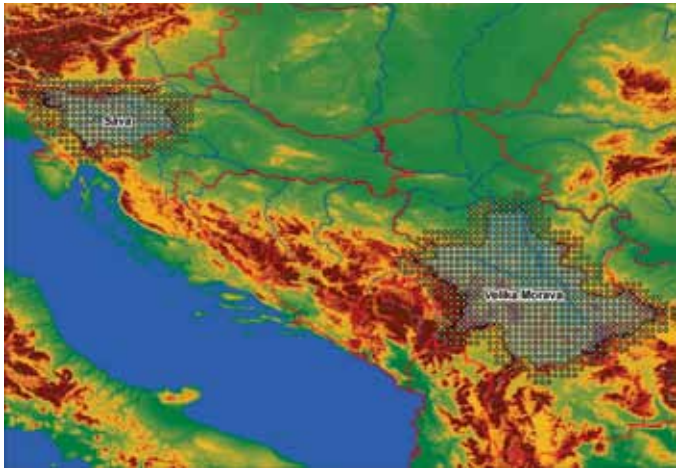


Figure 1: Grid resolution over the catchments used in the HOLV snowmelt model

The HOLV snowmelt model has a flexible structure; it's able to change its own structure in function of data availability. In case when only precipitation and air temperature data are available temperature index method is used. When also other data are accessible (cloudiness, dew point, wind speed) using of energy balance model is to be preferred.

If there are suitable data available for calculation of the energy terms, the energy balance method can be applied. In the most practical cases these terms can not be computed with acceptable accuracy. In these cases temperature index method can be used.

The temperature index is considered time-variable, as a consequence of seasonal changes of the solar radiation values corresponding to the same air temperature, and even of changes of the albedo of the snow surface.

HOLV snowmelt model is for daily use, it is run every day after receiving the morning datasets. It calculates all the values for the last 24 hours. If calculations are skipped on a certain day, they have to be done subsequently. The calculations need to be carried out with a daily time step. Since the application presumes conditions free of snow when started, it is proper to begin the calculations at the time of the year when the catchments are covered with minimum quantity of snow.

Among the objectives of DMCSEE project, the possible usage of satellite information for snow water content calculation was included. Temporal evaluation of snow cover over large areas can be successfully observed using different satellite images (Figure 2).

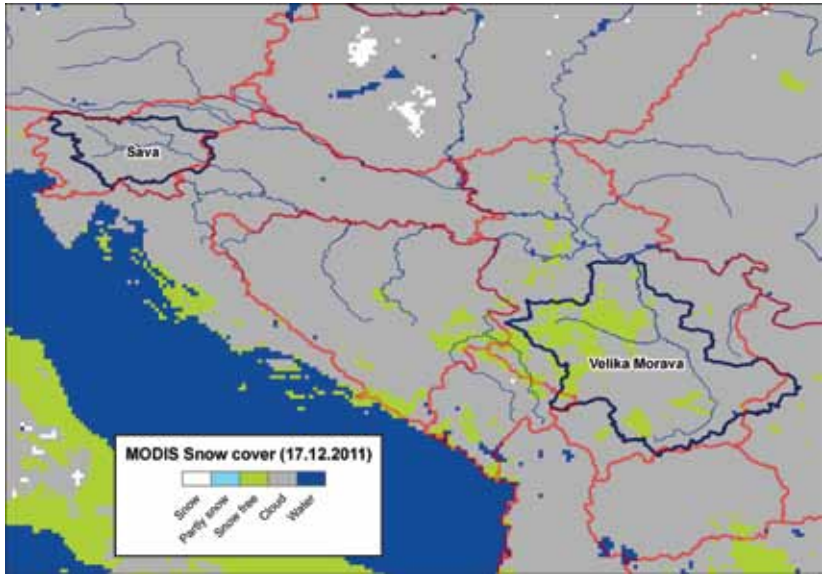


Figure 2: Satellite image with snow information from MODIS

The quality of the snow related processes calculation (like snow accumulation, snow melting) might be improved by application of satellite images. However, after a detailed investigation, it becomes obvious that the development of a universally applied correction method based on satellite information meets serious difficulties. The main sources of uncertainties are:

- *satellite information is available only for cloud free areas;*
- *satellite information provide data on snow coverage only without any information on the quantity of snow water content.*

Overall, the inaccuracy of the method for snow water content calculation using the satellite information can be unacceptably high.

In accordance with the data availability the HOLV model (originally used for upper and middle Danube catchments) was applied to upper Sava and Velika Morava catchments within the framework of the DMCSEE project. Catchment's characteristics and new meteorological stations were considered and the model was tested on these two catchments.

Figure 3 shows an example of snow water content map based on calculations with HOLV model with locations of meteorological stations inside the upper Sava catchment. Figure 4 presents the same for Velika Morava catchment.

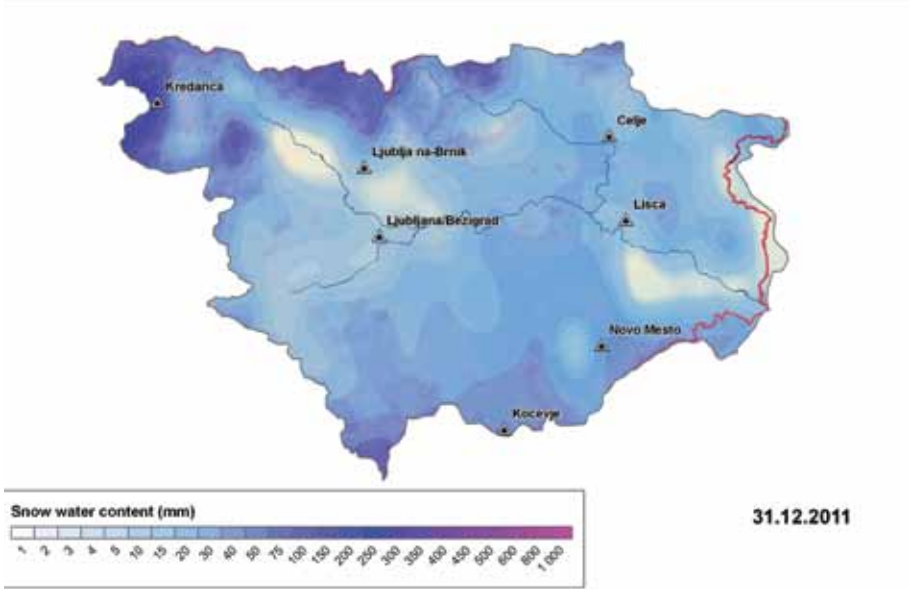


Figure 3: Snow water content distribution over the upper Sava basin (31.12.2011)

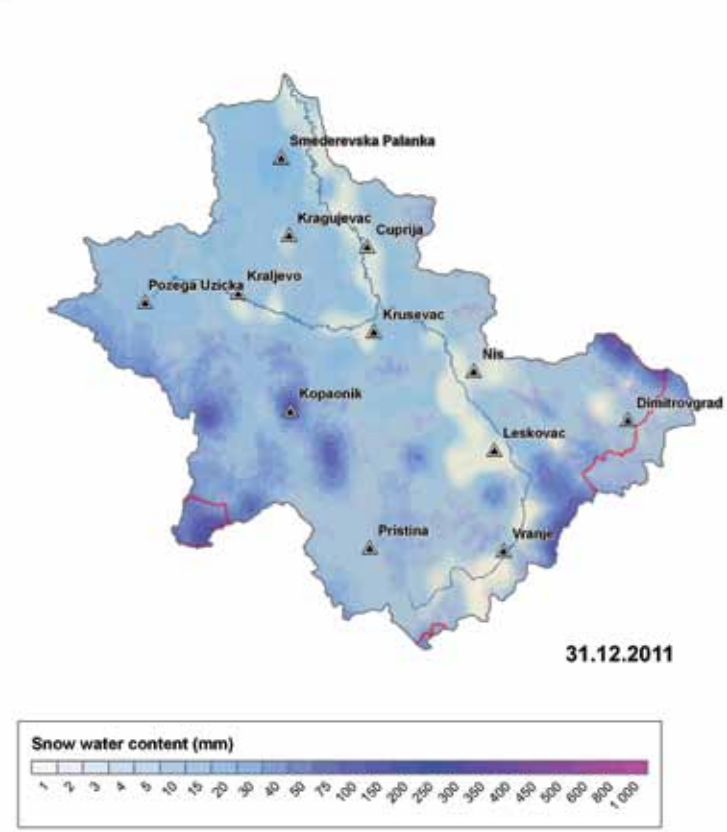


Figure 4: Snow water content distribution over the Velika Morava basin (31.12.2011)

The final result is a complex snow accumulation and ablation model ready to be used by the project partners for any hydrological catchment or the entire DMCSEE region.

DROUGHT VULNERABILITY ASSESSMENT - INTRODUCTION AND THEORETICAL BACKGROUND

Christos Karavitis

Agricultural University of Athens

Vulnerability as well as its relative terms – resilience and adaptive capacity – have been proved difficult to be conceived and applied (Walker et.al, 2004; Füssel, 2007). Those difficulties usually derive from the fact that vulnerability has been used by a plethora of researchers in a variety of disciplines (Adger, 2006) including social, economic and environmental sciences. As a result, a rich literature has been developed and a great number of definitions has been provided. Throughout the majority of vulnerability literature, regardless of background, two issues are either implied or clearly stated:

1. *Vulnerability generally has a human or society-oriented perspective.*
2. *A link to coping and the capacity to handle stress or perturbation is usually present.*

That last aspect is included in the following definitions that represent only a small sample of the available ones:

- *The characteristics of persons or groups in terms of their capacity to anticipate, cope with, resist, and recover from the impacts of environmental change (Bohle, 2001).*
- *The exposure to hazard by external activity (e.g. the climatic change) and coping capacity of the people to reduce the risk at a particular point of time (Laneweg and Guiterrez-Espeleta, 2001).*
- *The degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/ stressor (Turner et al, 2003)*
- *The degree to which human and environmental systems are likely to experience harm due to a perturbation or stress (Luers et al, 2003).*
- *Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.*
  Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001).

Vulnerability is a dynamic systemic attribute that fluctuates in time following the various changes that occur in the system of interest (Adger and Kelly, 1999; Dalziell and McManus, 2004; Leichenco and O'Brien, 2002; Luers, 2005; Miller et.al, 2010). In a similar manner, the vulnerability definitions provided in relative literature are not static at all. They too do change following the changes of human perspectives regarding the systemic functionality and the relations that occur between systems and components in a variety of scales.

Most recent changes and efforts in the field of vulnerability include the integrated forms of Social-Ecological Systems – SES (Berkes and Folke, 1998) and the principles of Panarchy described by Holling (2001), Gunderson and Holling (2002) and other authors.

Vulnerability is composed of two basic elements and described by the following equation 1 (UNESCO, 2004):

VULNERABILITY = HAZARD X IMPACTS (EQ. 1)

That equation can include exposure as well but the role of exposure is not clear. Exposure can be considered both as vulnerability component as well as the relation that connects the examined hazard to the system of interest (Gallopin, 2003). In both cases, no hazard exposure means no vulnerability. Vulnerability is also connected to risk according to the following equation 2 and therefore vulnerability assessments are crucial parts of risk assessment.

RISK = HAZARD X VULNERABILITY (EQ. 2)

Vulnerability assessments can become challenging tasks since not all the systemic components present the same vulnerability on a specific hazard and therefore assumptions (weights) should be made so as for the average systemic vulnerability to be measured.

In an example borrowed from water resources management, the basic elements of vulnerability assessment are presented as follows (Office of Water/EPA 816-F-02-025, 2002). These are conceptual in nature and not intended to serve as a detailed methodology:

1. *Characterization of the water system, including its mission and objectives;*
2. *Identification and prioritization of adverse consequences to avoid;*
3. *Determination of critical assets that might be subject to malevolent acts that could result in undesired consequences;*
4. *Assessment of the likelihood (qualitative probability) of such malevolent acts from adversaries;*
5. *Evaluation of existing countermeasures; and*
6. *Analysis of current risk and development of a prioritized plan for risk reduction.*

As it has been previously stated, the vulnerability term encloses difficulties. Measuring the vulnerability of an area or a system is even more challenging since the ability of a particular system to cope with potential stresses or the pressure required for an ecological threshold to be crossed cannot be exactly determined in space and time (CCSP, 2009). For that purpose a variety of vulnerability indices has been developed by a plethora of institutions. The following indices serve as examples (Kaly et.al, 2004):

- *The Composite Human Vulnerability Index – developed by the Indian Institute of Technology in Bombay,*
- *The Key Indicators for Global Vulnerability Mapping – developed by the United Nations Environment Programme (UNEP),*
- *The Coral Reef "Vulnerability Index" of Exposure to Climate Change – developed by Greenpeace,*
- *The Environmental Vulnerability Index – developed by South Pacific Geoscience Commission (SOPAC)*
- *The Climate Vulnerability Index – Developed by Sullivan and Huntingford(2009).*

Those indices are trying to define different aspect of a generalized – in the context of hazards – vulnerability. Other indices have been developed for the vulnerability of a specified hazard to be measured. The Indices composure is based on the hazard perception as well as on the nature of the hazard itself.

Drought is one of those hazards and according to Hagman (1984) it is a complex natured event that affects human activities more than any other natural hazard. Drought is a frequent event that occurs in a number of regions worldwide regardless their natural humidity/aridity status (Bordi et al., 2006; Eriyagama et al., 2009). As a phenomenon, it attracts both public and interdisciplinary scientific attention due to fact that it causes a plethora of social, economic, and environmental impacts (Yevievich et.al., 1983;Rossi et.al., 1992; Karavitis, 1999b;: Wilhite et.al., 2000;Cancelliere et.al., 2005). According to

Bruce (1994) droughts have caused losses that are counted into billions of US dollars. In general (Eriyagama et.al., 2009), the impacts' magnitude on an area is affected by the density of human activities, needs, demands, level of socioeconomic structure and the environmental connectedness.

Drought literature is rich and provides a series of case studies all over the world. All in all, drought is a dynamic phenomenon seemingly difficult to confront. Nascent sources of difficulties in applying appropriate management responses may be derived from the following causes of confusion: elusive drought definitions; diversified and devastating drought impacts; and absence of systematic response mechanisms. Such causes are further exemplified in the following (Karavitis 1992; 1999a). A precise, unambiguous definition of drought remains elusive. One source of confusion in devising an objective definition may be that drought implies a variety of things to various professionals according to the specialized field of study (meteorology, hydrology, water resources, economy, agriculture etc.). A second problem is eliciting because the definition of drought is strongly related to the geographical, hydrological, geological, historical and cultural traits of a given locale. A third factor is the difficulty to modify existing drought terminology according to updated techniques and practices (Karavitis 1999a). Nevertheless, there is a tendency that drought may be defined as a precipitation deficit over an extended period of time (NDPC, 2000; Cancelliere et. al., 2005;Wilhite et.al, 2006;Eriyagamaet.al., 2009). Thus, a broader and possibly more operational definition of drought may be: the state of adverse and wide spread hydrological, environmental, social and economic impacts due to less than generally anticipated water quantities (Karavitis 1992; 1999b). Such water deficiencies may primarily originate from precipitation decreases, usually accompanied by physical and/or management inefficiencies in water supply and distribution systems most of the times over a large area.

There are many efforts for planning and management actions for droughts, nevertheless, deficiencies still pertain in such attempts. Such efforts are becoming even more difficult given the latest climatic anomalies and instabilities (Milly, at al, 2008). Nevertheless, the major challenge for any drought related research may be the development of comprehensive and effective drought management schemes.

A comprehensive drought responses plan may be focused around existing schemes for drought control measures. Short-term responses should be initiated and terminated according to the drought duration, while long-term ones should be already designed and implemented. All the options and responses of a comprehensive management scheme are presented in Figure 1. Given such considerations, a drought responses plan should be classified in the following parts (Yevyevich and Vlachos, 1983; Grigg, et al, 1990; 1993; Karavitis, 1992,1999b):

Supply augmentation measures. Such measures should examine all the potential water supply resources for the area. They should be already in place before a drought (base and emergency supply). Perhaps with the exception of water purchases, systems supply augmentation should be avoided during the drought as a crisis management action. The existing system designed after long-range planning should be capable of operating under drought conditions according to contingency plans; it should also be

well maintained and improved in order to minimize the losses;

Demand reduction measures. These responses should aim towards the reduction of water consumption according to conservation principles. They may be short- and long-term ones. The long-term measures should be in place according to proactive planning (i.e., legal measures, zoning/land use, landscape changes, agricultural changes such a changing to less water consumptive crops, irrigation scheduling, etc.). The short-term measures should be initiated during and terminated after the drought (i.e., water restrictions, reduction of uses, pricing, etc.). The implementation and enforcement framework for demand reduction measures should also be in place (economic, legal and institutional). Finally, such measures should be implemented orderly and timely according to contingency plans; and

Impact minimization. Such responses should concentrate on anticipatory strategies, relief, and recovery measures. The framework for such responses should already be in place (economic, legal, and administrative). Spread of drought risk, damage recovery and compensation should be some of the measures considered, according to a drought master plan.

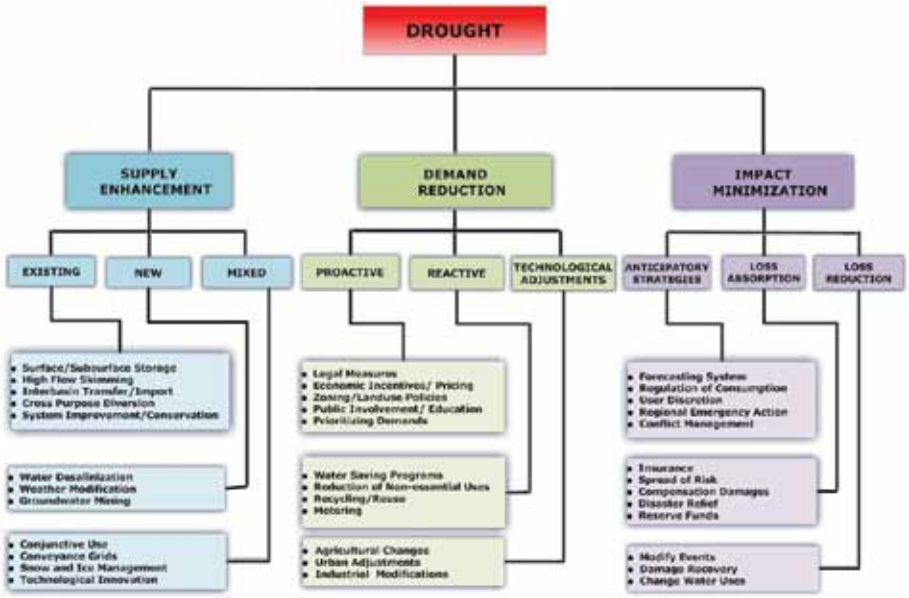


Figure 1. Comprehensive Management Scheme (Adapted from Yevyevich and Vlachos, 1983; ,Karavitis 1992, 1999b)

However, in order for such schemes to be applied decisions and decision-making unquestionably must take place about the onset, areal extent, and severity of a drought. In this effort quest drought index methods may be used. These methods characterize a drought according to a specific index. The drought indices are usually derived from a time period of relevant data ion record and from a usually combined with an arbitrary scale, based on which a drought is classified. Thus, a drought indicator should primarily be an objective measure of the system status that may help in identifying the onset, increasing or decreasing severity, and termination of a drought. Nevertheless, no single indicator or index alone may precisely describe the onset and severity of the event. Numerous climate and water supply indices are in use to present the severity of drought conditions. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses (Karavitis et al, 2011). In the literature, different indices have been discussed and applied. Among those are: Palmer Drought Severity Index (PDSI) (Palmer 1965), Deciles (Gibbs and Maher, 1967), Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982), Palfai Aridity Index (PAI) (Palfai, 1990), the Standardized Precipitation Index (SPI) (McKee et al., 1993), and Percent of Normal (Willeke et al., 1994). The nature of the indicator, local conditions, data availability, and validity usually determine the indicator to be applied (Skondras et al. 2011).

Apart from those indices, more complex ones have been developed recently so as for drought to be examined. Most of them are referring to drought vulnerability concept. The drought vulnerability approach has gained ground in the context of climate change. According to that context, droughts are expected to be increased in frequency, intensity and duration in various regions (IPCC, 2007). Therefore the drought vulnerability is expected to be increase as well. That is the reason due to which, more extensive research on drought vulnerability has to be conveyed.

DROUGHT IMPACTS ARCHIVE AND DROUGHT VULNERABILITY INDEX

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Description of drought impact archive

It is generally stated that vulnerability assessment is a challenging task. Archive reports help water systems evaluate the susceptibility to potential threats and identify corrective actions that can reduce or mitigate the risk of serious consequences from adversarial actions.

Evidently, such an assessment for a water system takes into account the vulnerability of the water supply (both ground and surface water), transmission, treatment, and distribution systems. An effective vulnerability assessment serves as a guide to the water utility by providing a prioritized plan for security upgrades, modifications of operational procedures, and/or policy changes to mitigate the risks and vulnerabilities to the utility's critical assets.

The nature and extent of the vulnerability assessment will differ among systems based on a number of factors, including system size, potential population affected, source water, treatment complexity, system infrastructure and other factors.

The description of drought impacts play a crucial role in the vulnerability assessment document since it highlights part of the observed systemic weaknesses that need to be eliminated for the system to withstand potential loss in future drought events.

In this regard, partners from each participating country in DMCSEE Project – namely Slovenia, Hungary, Bulgaria, Greece, Croatia, Serbia, Montenegro, F.Y.R.O.M and Albania - reviewed information sources (scientific publications, research projects, newspapers, field experiments, etc.)in order to create an Archive database on recorded drought periods for South East Europe. In most of the countries available information is strongly related to agricultural drought. Records of yearly crop yields are among the most important sources. Information coming from the newspapers and other media services at that time during the drought period includes data on social, economic, hydrologic and meteorological impacts of the drought phenomenon.

The following tables (Table 1 and 2) can serve as examples of the impact archive that has been developed. Table 1 presents drought descriptions of Greece for 2007 and Table 2 illustrates part of drought impact assessment

Table 1. Drought description in Greece for 2007

Greece	AllGreece	www.in.gr	13/3/2007	Measures against drought, fires, blackouts and the government announced
Greece	Thessaly-Cyclades	Kathimerini	18/3/2007	Drought hits Cyclades - Thessaly
Greece	Chios	I Alithia	12/4/2007	Subsidies for Drought
Greece	Chios	I Alithia	24/4/2007	Drought and the planned model of development for our county
Greece	Ikaria	www.nikaria.gr	14/5/2007	Drought in Ikaria
Greece	Cyclades	www. kykladesnews.gr	25/5/2007	ACTIONS BY THE DROUGHT IN THE CYCLADES: Full abstraction works on all islands
Greece	Thessaly	Ethnos	17/7/2007	Thessaly on brink of civil war for Drought
Greece	Thessaly	Eleftherotypia	23/7/2007	Drought "burn" the plain of Thessaly
Greece	Cyclades	Kathimerini	1/8/2007	Here and now works against Drought. Inanemergency, Cyclades
Greece	Cyclades	Kathimerini	1/8/2007	Was intensified the Drought in Cyclades
Greece	AllGreece	Eleftherotypia	9/8/2007	What we make for the Drought* Limit adequacy in the whole country
Greece	Samos	www.samos.gr	29/8/2007	Measures for Drought

Table 2.Drought impact assessment

	Drought Impacts			Policy Action
SEE countries	**Supply Enhancement**	**Demand Reduction**	**Impact Minimization**	**Infrastructure**
Slovenia	Drainage systems Reservoirs, dams etc.	Irrigation Tillage	Retention of snow Establishment of the windbreaks	Infrastructure maintenance needs
Greece	Reservoirs, dams etc. Improvement of the existing maintenance procedures, conservation, groundwater use, emergency water hauling by ships	No irrigation possible in drought periods WD – WS = DEFICIT COST		Crisis management Announcement of master plan (2008) New dams construction

According to the information provided by Table 2,Greece and Slovenia followed different drought mitigation approaches – in the form of actions and policies – in order to confront drought impacts. Among the various options to mitigate drought impacts, supply enhancement and demand reduction, are the most important for both countries.

The above presented information on drought vulnerability can also be incorporated as part of an integrated vulnerability index.

DVI Description with example

Within the framework of DMCSEE Project, the AUA partner, Greece, has developed an SPI based – among other parameters– Drought Vulnerability Index (SDVI) and applied it in Greece on a country scale. The first version of SDVI was presented during the 5th DMCSEE Meeting and Training at Lasko, Slovenia, 28th/6 – 1st/7/2011.

The SDVI presented is composed of six components in four categories:

1. *SPI-6 and SPI-12 that represent the water availability for domestic (households and tourism) and agricultural (irrigation) use respectively.*
2. *Supply and Demand that describe the deficits in supplying capacity and in demand coverage. Their magnitude depends on the available amount of water.*
3. *Impacts that describe the impacts that might have been caused due to the supply - demand deficiencies.*
4. *Infrastructure that describes the current infrastructure level of development regarding the level of deficiency.*

Those six factors were classified into the following vulnerability categories according to their performance (Table 1) and weights were assigned. In the present effort, equal weighting for all factors has been selected.

Table 1.Vulnerability level, scales and categories.

Vulneraility Level	SCALES											
	SPI			Supply		Demand		Impact		Infrastructure		
Less Vulnerable	0	Wet	≥ 1,50	0	No Deficits	0	No Deficits	0	None	0	Complete	
Vulnerable	1	Quite Wet	0 to 1,49	1	15% Deficits	1	15% Deficits	1	15% Losses	1	15% Deficiency	
Highly Vulnerable	2	Quite Dry	0 to -1,49	2	16-50% Deficits	2	16-50% Deficits	2	16-50% Losses	2	16-50% Deficiency	
Extremely Vulnerable	3	Dry	≤ -1,50	3	>50% Serious Deficits	3	>50% Serious Deficits	3	>50% Losses	3	>50% Deficiency	

The final SDVI Scores are calculated according to the following equation (Equation 3).

$$SDVI = \sum_{i=1}^{6} FixWi \qquad \text{Eq.3}$$

Where:

Fi = Indicator Performance

Wi = Indicator Weight

Application Procedure

1. *The SPI 6 and 12 have been calculated on a country scale. For that application, data from 46 stations were collected in collaboration with the National Meteorological Service of Greece (HNMS), the Ministry of Public Works and the Public Power Corporation S.A., covering different time periods from 1947 to 2009. Continuing, the SPI has been spatially visualized using Kriging (Hole effect) in an ArcGIS 10 environment for the Index's value to be known for every single part of the country.*
   Based on the produced map, the SDVI can be calculated for any desired area even when climatic data (for the SPI calculation) do not exist as long as data on the remaining indicators are available.
2. *Data on water demand, supply, relative infrastructure and impacts have been gathered for those areas from the appropriate local and national authorities and agencies and turned into their scaled values.*
3. *The SDVI value per selected area and month has been calculated according to Equation 3. Continuing, those values were classified into the following arbitrary vulnerability classes (Table 2). Finally, the SDVI has been visualized using the Inverse Distance Weighting method in GIS and the results for both the Index performance and drought vulnerability in Greece were deduced.*

An example for August 2003 is presented (figure 2).

Table 2.SDVI scales

SDVI	Vulnerability scale	Signal
0.00 - 0.49	No or least vulnerability	
0.50 - 0.99	Low vulnerability	
1.00 - 1.49	Medium Vulnerability	
1.50 - 1.99	High Vulnerability	
2.00 - 2.49	Very high Vulnerability	
2.50 - 3.00	Extreme Vulnerability	

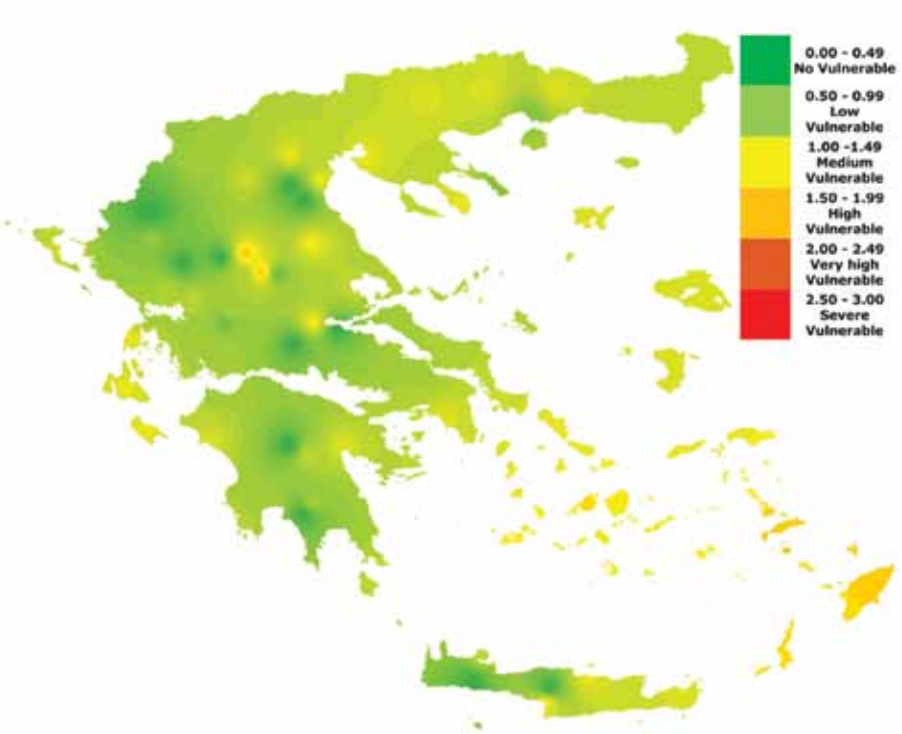
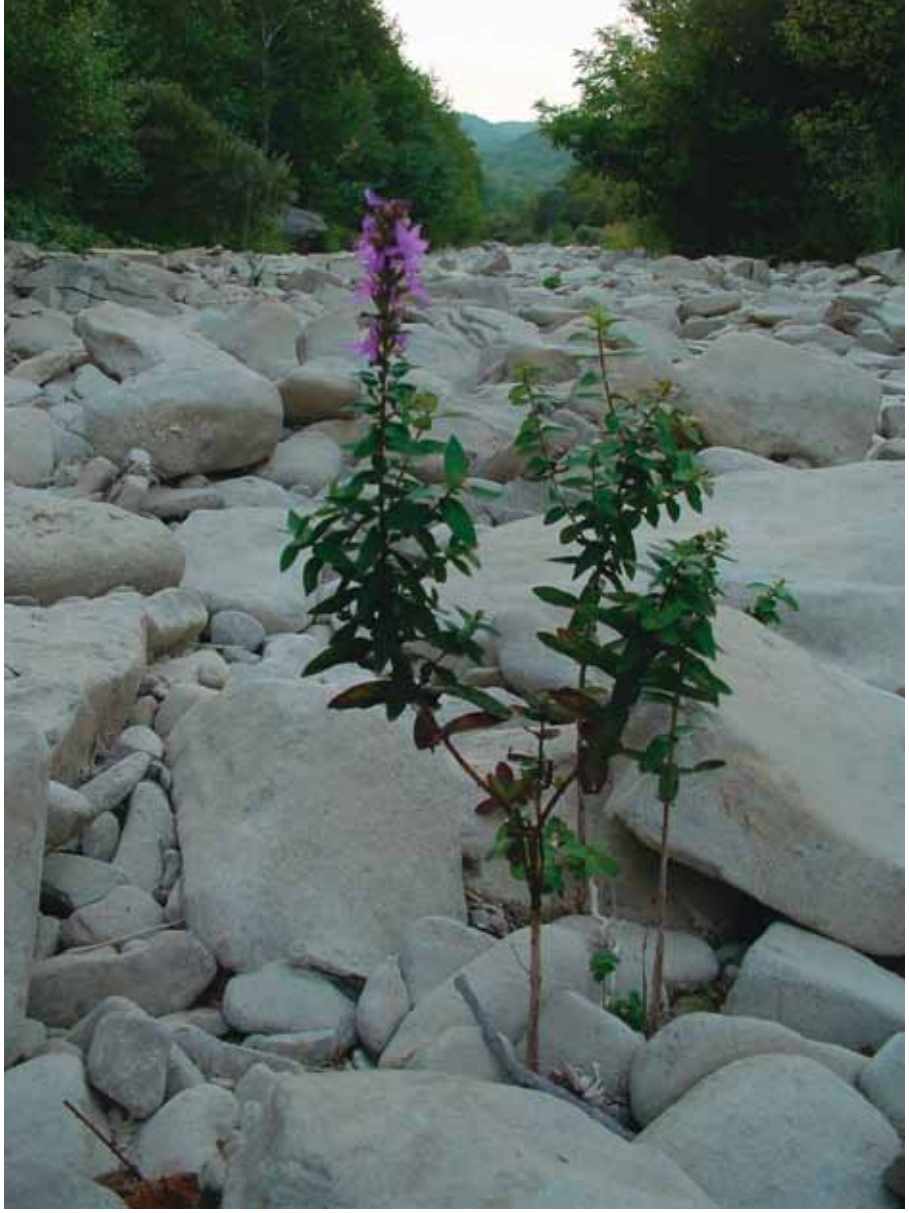


Figure 2.DVI Greece, August 2003.

According to the initial results, Greece can be classified as a country with medium vulnerability. The islands of the southeastern Aegean present the higher vulnerability due mainly to tourism and high seasonal water demand. The mainland and especially the northwestern part of the country ilustrates low or no vulnerability due to low demand and thus minimal drought impacts. By comparing such results with actual observations, it may be derived that DVI performed satisfactorily. Nevertheless, further research has to be conducted, in order to produce a more accurate, more descriptive index, able to be used in a wider spectrum of locales around the world.



The mission of the proposed DMCSEE is to coordinate and facilitate the development, assessment, and application of drought risk management tools and policies in Southeastern Europe with the goal of improving drought preparedness and reducing drought impacts. Therefore DMCSEE will focus its work on monitoring and assessing drought and assessing risks and vulnerability connected to drought.

DROUGHT VULNERABILITY ESTIMATES BASED ON CROP-YIELD MODELS

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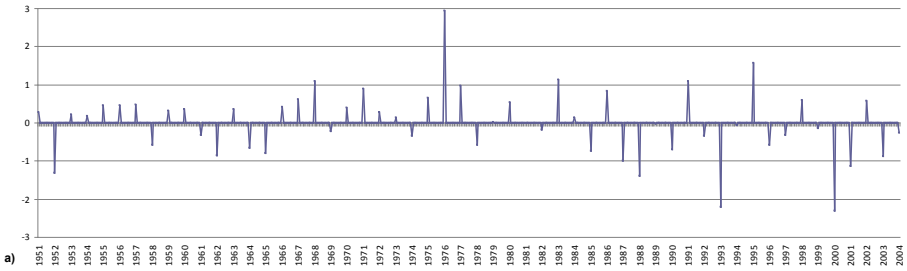
There are a lot of facts proving that Global Climate Change affects the frequency and severity of extreme events as meteorological and consequent agricultural drought. The necessity to develop methodologies and simulation tools for better understanding, forecasting and managing the risk of such events is evident for the society. This study assesses the vulnerability of agriculture to drought using the WINISAREG model (Teixeira et al. 1992; Pereira et al. 2003) and seasonal standard precipitation index SPI2 for the period 1951-2004. The model was previously validated for maize hybrids of different sensitivity to water stress on soils of small, medium and large total available water (TAW) in various locations of Bulgaria (Popova et al., 2006; Popova, 2008; Popova and Pereira, 2010; Ivanova and Popova, 2011). Simulations are performed for the regions of Plovdiv, Stara Zagora, Sandanski and Sofia (South Bulgaria) and Pleven, Lom, Silistra and Varna (North Bulgaria).

Climate: The studied regions are representative for a Moderate Continental (Sofia, Pleven, Lom, Silistra), a Transitional Continental (Stara Zagora and Plovdiv), a Transitional Mediterranean (Sandanski) and a Northern Black Sea (Varna) climate. A version of seasonal standard precipitation index SPI (Pereira et al., 2010), that is an average of the index during periods of crop sensitivity to water stress, is used as a specific drought indicator. Average SPI2 for several periods referring to maize sensitivity to drought, such as the vegetation season "May-Aug", the Peak Season "June-August", and the High Peak Season "July-August" were used to define categories of agricultural drought. The SPI2 relative to "July-Aug", that is in fact the usual irrigation period in this country, indicate that the High Peak Season in 1993 and 2000 was the driest in Sofia (Fig. 1a) and Sandanski over the last 54 years.



a)

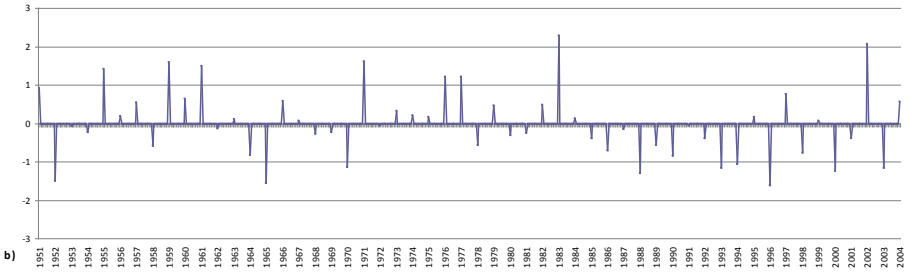


Figure 1. Evolution of High Peak Season (July-Aug) SPI2 at: a) Sofia and b) Plovdiv, 1951-2004.

Seasonal SPI2 “July-Aug” in Fig.1b also shows that in the region of Plovdiv, Thracian Lowland, summer is become dryer over the last 20 years when compared with the previous 34 years. However that is not the case with the studied regions in North Bulgaria.

Monthly precipitation relative to the average, wet and very dry season, having probability of exceedence 50, 10, 90 %, are compared. Results indicate that precipitation totals for June, July and August in the average season are the largest in Sofia, that is double than in Plovdiv, Sandanski, Lom and Varna.

Soil: The usual soils in South Bulgaria are the chromic luvisols/cambisols of predominantly medium total available water TAW (136 mm m -1) and the vertisols of large TAW (170≤TAW≤180 mm m -1). The typical soils in the plains of North Bulgaria are the chernozems of medium to large water holding capacity (157≤TAW≤180 mm m -1) and the vertisols (TAW≥170 mm m -1). Alluvial/deluvial meadow and light-textured luvisol soils of small TAW≤116 mm m -1 are well identified over the terraces along the rivers.

Crop data: Maize was selected as a typical summer crop. Crop coefficients Kc, depletion fraction p for no stress and the yield response factor Ky (Allen et al., 1998) were calibrated and validated using detailed independent datasets relative to long term experiments with late maize varieties carried out under different irrigation schedules in Tsalapitsa, Plovdiv, Pustren and Zora, Stara Zagora, and Bojurishte, Sofia field (see Varlev et al., 1994; Eneva, 1997; Varlev and Popova 1999; Popova and Pereira, 2010; 2011; Popova, 2008; Popova et al.,2006; Ivanova and Popova, 2011). Additional data on rainfed and maximum yields were used to adjust the yield response factor Ky to semi early maize hybrids for Sofia field (Rafailov 1995; 1998; Jivkov, 1994; Mladenova and Varlev, 1997 in Varlev, 2008; Stoianov, 2008).

Simulation model: The WinISAREG model (Pereira et al., 2003) is an irrigation scheduling simulation tool for computing the soil water balance and evaluating the respective impacts on crop yields. The model adopts the water balance approach of Doorenbos & Pruitt (1977) and the updated methodology to compute crop evapotranspiration and irrigation requirements proposed by Allen et al. (1998). Yield impacts of water stress are assessed with the Stewart one-phase model when the yield response factor Ky is known (Doorenbos & Kassam, 1979). Procedures for ETo-PM computation when some climate data are missing (Allen et al., 1998) were validated using data relative to seven meteorological stations in the Thrace plain (Popova et al., 2006) and Sofia field (Ivanova and Popova, 2011). These procedures proved to be accurate providing small standard errors of estimates (SEE), including when only maximum and minimum temperature data are used, which yields lower standard error 0.44<SEE<0.52 mm day-1 than when using Hargreaves equation, which tends to overestimate ETo for the observed conditions.

Drought vulnerability estimates

Irrigation Requirements, NIRs: Probability curves of maize net irrigation requirement (NIRs, mm) were built using ISAREG model simulations over the period 1951-2004 (Popova (Ed.), 2012). Results relative to Plovdiv show that in soils of large TAW (180 mm) net irrigation requirements (NIRs) range from 0-40 mm in wet years having probability of exceedance PNIRs>95% to 140-220 mm in average demand seasons (40%<PNIRs<75%) and reach 350-380 mm in very dry years (PNIRs <5%) (Fig.2). In soils of small TAW (116 mm), NIRs reach 440 mm in the very dry year.

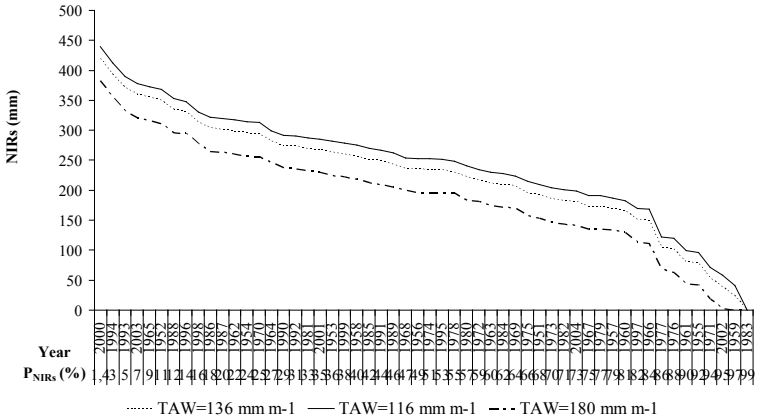


Figure 2. Net irrigation requirements (NIRs) probability of exceedance curves relative to soil groups of small, medium and large total available water (TAW) at Plovdiv, South Bulgaria, 1951-2004.

NIRs in Sofia and Silistra are about 100 mm smaller than in Plovdiv. Contrarily, NIRs in Sandanski are up to 110 mm larger when compared with Plovdiv (Fig.3).

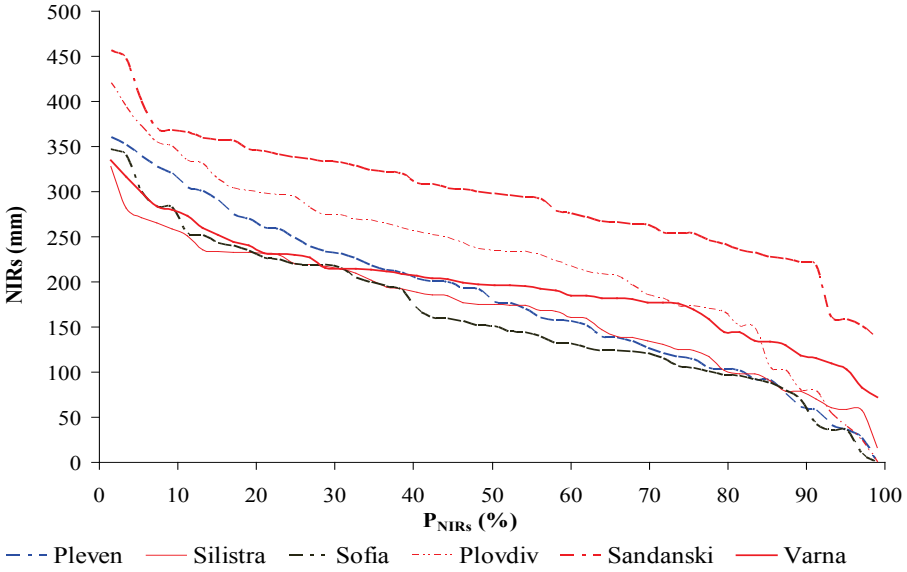


Figure 3. Comparison of Net irrigation requirements (NIRs) probability of exceedance curves relative to six climate regions and soils of medium water holding capacity (TAW= 136-157 mm m-1), 1951-2004.

Considering the trend of NIRs for the period under study, an average increase by 80mm over the whole period is found for Plovdiv.

Rainfed maize yield and risky years

Validation of Ky factor for rainfed maize: Relative yield decrease (RYD, %) is simulated with option 'maize without irrigation' and yield response factor Ky = 1.6 for a soil of small TAW (116 mm m-1), Sofia and Plovdiv (Fig.4). Additional RYD data from long-term field experiments carried out with semi-early maize hybrids in Chelopechene, Sofia field, are plotted in Fig.4a. Similar analyses are performed for Tsalapitsa, Plovdiv (Fig.4b), and Pustren, Stara Zagora, but using crop data relative to the late maize hybrid H708 (Popova et all. 2011b; Popova (Ed.) 2012). Results show that the adopted Ky=1.6 could reflect well the impact of water stress on rainfed maize yield in these sites. Regression between observed and simulated RYD (%) yielded coefficient of determination R2 between 61% and 82%, indicating that adopted Ky factor is statistically reliable to be used in the study.

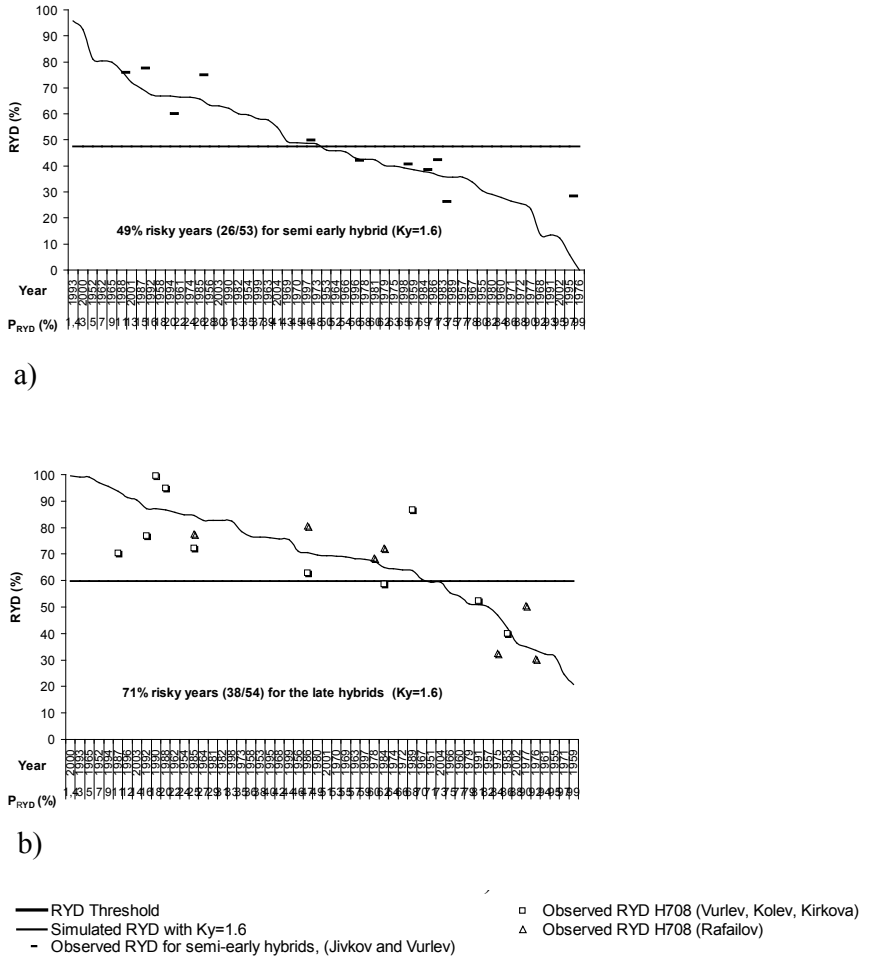


Figure 4. Probability of exceedance curve of relative yield decrease RYD for rainfed maize, Ky=1.6, soil of small TAW (116 mm m-1) at: a) Chelopechene, Sofia field, and b) Tsalapitsa, Plovdiv, 1951-2004.

When soil water holding capacity ranges (116<TAW<180 mm m -1) the RYD differs by about 20% (Fig.5). Differences are smaller over the very dry/very wet years in Plovdiv, Stara Zagora and Sandansky region.

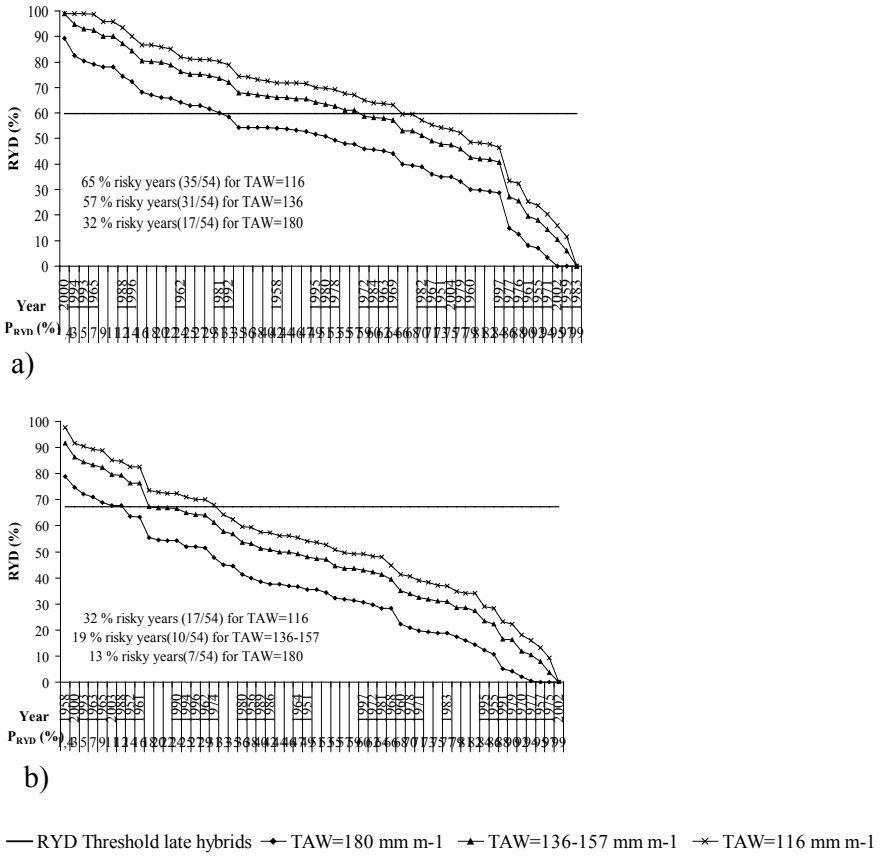


Figure 5. Probability exceedance curves of relative yield decrease under rainfed maize RYD for soil groups of small, medium and large total available water (TAW), Ky=1.6, at: a) Plovdiv, South Bulgaria and b) Pleven, North Bulgaria, late maize hybrids (H708, 2L602, BC622), 1951-2004.

Results indicate that severe drought affects rainfed maize productivity during the high sensitive periods of 1993 and 2000 in Sofia field (Fig.4a). Grain yield was almost totally lost in 2000, 1993, 1965, 1952 and 1994 for the soils of small TAW in Plovdiv region (Figs.4b and 5a). Severe droughts occurred in 1958, 2000, 1993, 1963 and 2003 for Pleven community (Fig.5b).

The RYD probability of exceedance curves, built for each climate region and soils of medium TAW (136-157 mm m -1) are compared in Fig.6a. Relative yield decrease RYD is the largest in the region of Sandanski ranging from 65 to 85% over the average demand

years (40<PRYD<75%). It is also very high in the region of Plovdiv (60<RYD<70%) but lower in Sofia and Pleven (30<RYD<50%) over the same years. In the very dry years (PRYD<5%) yield losses are over 90% in Plovdiv and Sandanski and more than 80% in Sofia field, Silistra, Pleven and Varna (Fig.6a). During the very wet years (PRYD≥85%) yield losses drop below 20% in all agricultural regions, except for Varna and Sandanski. Considering an economical RYD threshold of 60 and 48% of potential maize productivity in Plovdiv and Sofia, about 30% of the years are risky when TAW=180 mm m -1 in Plovdiv that is double than in Sofia and half than in Sandanski (Fig.6b). In North Bulgaria the economical RYD threshold is 67, 55 and 60% for Pleven, Lom and Silistra. When TAW=180 mm m -1 only about 10% of the years are risky in Pleven and Silistra that is half than in Lom. When TAW is medium (157 mm m -1) the risky years rise to 18, 35 and 45% in the three sites respectively and reach 50% in Varna (Fig.6a).

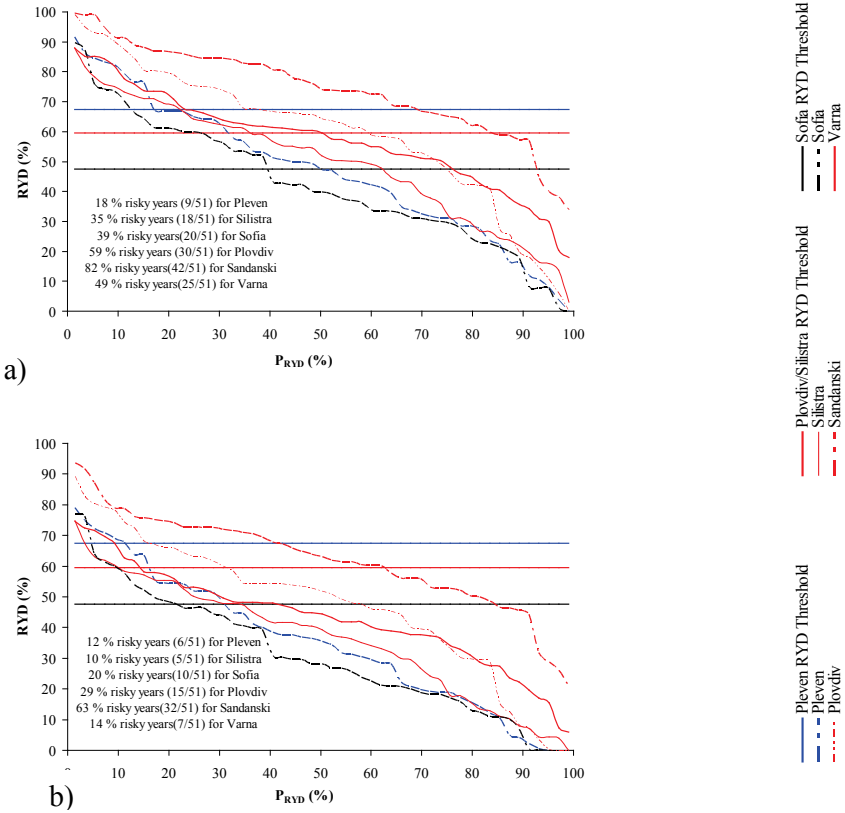


Figure 6. Comparison of relative yield decrease (RYD, %) probability of exceedance curves, Ky = 1.6, relative to six climate regions and two soil groups of: a) medium (136-157 mm m-1) and b) large (180 mm m-1) TAW, rainfed maize, 1951-2004.

Rainfed maize is associated with great yield variability in this country (29<Cv<72%) (Table 1).

	South Bulgaria								North Bulgaria			
	Sofia field		Thracian Lowland				Sandanski		Danube Plain			
	Sofia		Plovdiv		Stara Zagora		Sandanski		Pleven	Lom	Silistra	Varna
Climate region	Continental		Transitional continental				Transitional Mediterranean		Continental			Black sea
Maize hybrid	semi early		Late (H708, 2L602, BC622)									
TAW mm m^{-1}	Average Yield, kg ha^{-1}	Cv, %	Average Yield, kg ha^{-1}	Cv, %	Average Yield, kg ha^{-1}	Cv, %	Average Yield, kg ha^{-1}	Cv, %	Cv, %	Cv, %	Cv, %	Cv, %
116	4421	42	3894	69	3723	59	2292	72	50	55	46	50
136-157	4920	37	4550	59	4299	52	2906	59	44	47	40	42
180	5896	29	5915	43			4250	41	34	35	30	30
173					5483	41						

Table 1. Variability of rainfed maize grain yield characterized by the average value, kg ha-1, and the coefficient of variation Cv, %, climate regions and soil groups in Bulgaria, 1951-2004.

In Sofia field Cv is within the range 29-42% for semi early maize hybrids. The smaller Cv=29% refers to the soils of largest TAW while Cv=42% is typical for the soil group of small TAW. Late hybrids (H708, 2L602 and BC622) grown without irrigation on soils of small TAW (116 mm m-1) produced the most variable yields in Sandanski (Cv=72%) and Plovdiv (Cv=69%). A value of Cv=59% is found for Stara Zagora. The variability of rainfed maize in the Danube Plain (Pleven, Varna and Silistra) is much lower than in the Thracian Lowland. Results indicate that, regardless of the fact that drought impacts are mitigated in North Bulgaria, in some areas (Lom) it is a key factor of yield variability under rainfed conditions (35<Cv<55%). Considering the trend of RYD for the period under study, an average decrease of 19% for grain production is found for non irrigated maize (late hybrid H708) in Plovdiv region.

Deriving of drought vulnerability categories

Seasonal SPI2, computed for crop specific periods important for yield formation, was related to relative yield decrease RYD of rainfed maize and irrigation requirements NIR simulated for each climate region and soil group (Popova et al., 2011a; 2011b; 2011c; 2011d; Popova (Ed), 2012; Popova et al., 2012a; 2012b). In Plovdiv region reliable relationships (R2>91%) were found for seasonal agricultural drought relating the SPI2 for "July-Aug" with the simulated RYD of rainfed maize (Fig.7a). The study proved that

relationships for Stara Zagora, Lom and Silistra were statistically significant as well (83<R2<86%) while the correlations were less accurate (73<R2<83%) for Sandanski, Sofia, Pleven and Varna (Fig.7b)

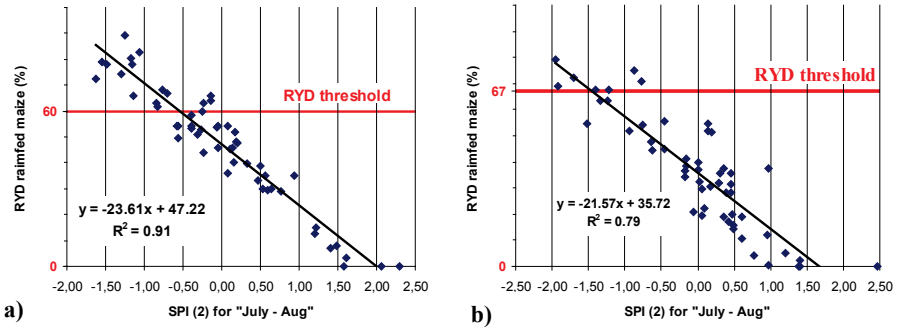


Figure 7. Relationships between seasonal SPI2 "July-Aug" (X-axis) and relative yield decrease of rainfed maize RYD with Ky=1.6 (Y-axis) for: a) Plovdiv and b) Pleven; soils of large TAW (180 mm m-1), late maize hybrids.

Results indicate that when rainfed maize is grown on soils of large TAW maize development is less affected by the water stress. In such soils (as show experiences for south Bulgaria) economical losses are produced if High Peak Season SPI2 is less than +0.20 in Sandanski, -0.50 in Plovdiv (Fig.7a) and Stara Zagora, and -0.90 in Sofia. In North Bulgaria the respective SPI2 "July-Aug" threshold ranges between -0.75 (Lom) and -1.50 (Pleven, Fig.7b). The corresponding thresholds were identified for NIR, namely 240 and 190 mm for Sandanski/Plovdiv and Sofia and 250 and 220 mm for Pleven and Lom/ Silistra/Varna respectively.

The results prove that rainfed maize is significantly less vulnerable to drought in North than in South Bulgaria. If TAW≥180 mm m-1, North Bulgaria, maize without irrigation is associated with important economical losses only during the very dry and moderately dry years heaving seasonal SPI2 "July-Aug" less than -1.50 (Pleven, Fig.7b), -1.25 (Silistra) and -1.00 (Varna). However, if TAW<116 mm m-1, rainfed agriculture is related to high economical losses along the Black Sea coast (Varna) and in Lom region during normal years of SPI2 "July-Aug" less than +0.20.

In final analyses positive economical threshold of SPI2 "July-Aug" signifies a territory highly vulnerable to drought even during wet seasons, while negative threshold is associated with resilient to drought areas.

Drought vulnerability mapping

The derived reliable relationships and specific economical thresholds are currently used for drought vulnerability mapping at national and regional (SEE) scale (Popova (Ed), 2012; Popova et al., 2012a; 2012b).

Since water holding capacity has largest impact on vulnerability assessment, soil map taken from the USGS database was used as basis for mapping. Maps of High Peak Season SPI2 "July-Aug" spatial distribution relative to the very dry (2000), the average (1970) and the moderately dry (1981) year are elaborated, as presented in Figs. 8a, 8b and 8c.

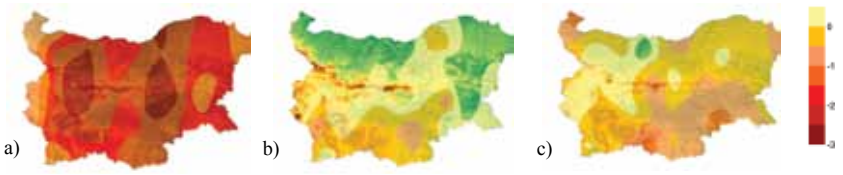


Figure 8. Spatial distribution of seasonal SPI2 "July-Aug" relative to the year of: a) extreme (2000), b) average (1970) and c) moderate (1981) irrigation demand, Bulgaria

The latter maps and the derived relationships between simulated RYD (%) and High Peak Season SPI2 are used then to predict the distribution of yield losses of rainfed maize in Bulgaria in the same particular years (Figs. 9a, 9b and 9c).

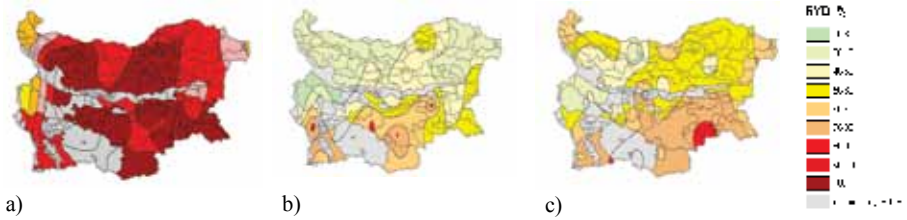


Figure 9. Spatial distribution of relative yield decrease (RYD, %) for rainfed maize relative to the year of: a) extreme (2000), b) average (1970) and c) moderate (1981) irrigation demand, Bulgaria

The elaborated maps correspond to soils of medium TAW (136-157 mm m-1) that are widespread in a different degree over the main geographical regions of Bulgaria. Thus they express drought vulnerability of rainfed agriculture in this country. Considering the adopted methodology of drought categorization, RYD losses should be enlarged by about 6% for the soils of small TAW (116 mm m-1) and reduced by 13% for these of large TAW (180 mm m-1). Similarly, spatial distribution of net irrigation requirements NIR (mm) is mapped for maize for the year of extreme, medium and moderate irrigation demand (Figs.10a, 10b and 10c). These maps characterize the vulnerability of irrigated agriculture to drought in Bulgaria.

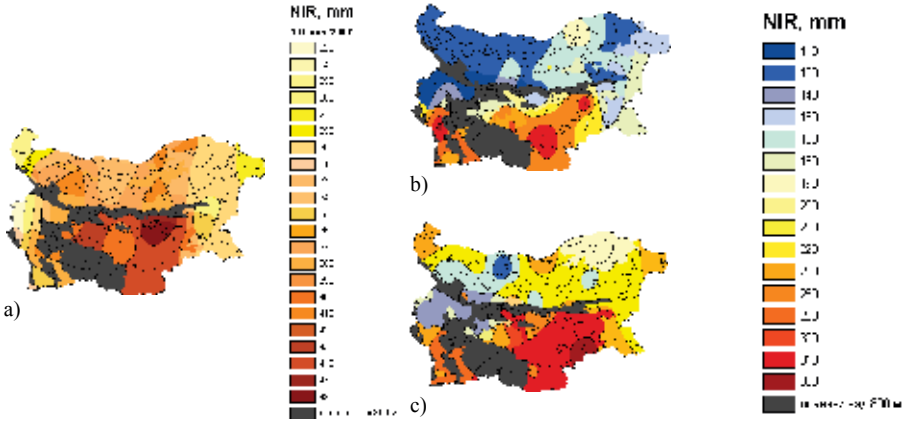


Figure 10. Spatial distribution of net irrigation requirements (NIR, mm) for maize relative to the year of: a) extreme (2000), b) medium (1970) and c) moderate (1981) irrigation demand, Bulgaria

Conclusions

The study relative to eight climate regions, three soil groups and the period 1951-2004 in Bulgaria shows that:

In soils of large water holding capacity (TAW 180 mm m-1), Plovdiv (Transitional Continental climate), net irrigation requirements (NIRs) range 0-40 mm in wet years and 350-380 mm in dry years. In soils of small TAW (116 mm m-1), NIRs reaches 440 mm in the very dry year. NIRs in Sofia and Silistra (Continental climate) are about 100 mm smaller than in Plovdiv while in Sandanski and Northern Greece (Transitional Mediterranean climate) they are 30-110 mm larger.

Rainfed maize is associated with great yield variability in Bulgaria (29%<Cv<72%). The smallest Cv refers to Sofia field for soils of large TAW (29%) while Cv=42% is typical for soils of small TAW there. The most variable yields are found in Sandanski (Cv=72%) and Plovdiv (Cv=69%) if TAW=116 mm m-1. The variability of rainfed maize yield in the Danube Plain (30<Cv<55%) for Pleven, Varna and Silistra is much lower than in the Thracian Lowland.

Considering an economical relative yield decrease (RYD) threshold of 60 and 48% of the potential maize productivity in Plovdiv and Sofia, 30% of years are risky when TAW=180 mm m-1 in Plovdiv, that is double than in Sofia and half than in Sandanski. In North Bulgaria the economical RYD threshold is 67, 55 and 60% for Pleven, Lom and Silistra. When TAW=180 mm m-1 only about 10% of the years are risky in Pleven and Silistra that is half than in Lom. When TAW is medium (157 mm m-1) the risky years rise to 19, 35 and 45 % in the three sites respectively and reach 50% in Varna.

In Plovdiv region reliable relationships (R2>91%) were found for seasonal agricultural drought relating the SPI2 for “July-Aug” with the simulated RYD of rainfed maize while in Stara Zagora, Sandanski and Sofia the relationships were less accurate (73<R2<83%). The study found statistically significant correlations between SPI2 “July-Aug” and simulated RYD of rainfed maize for North Bulgaria (R2>0.81) as well.

When maize is grown without irrigation on soils of large TAW maize development is less affected by the water stress and economical losses are produced if high peak season SPI2 is less than +0.20 in Sandanski, -0.50 in Plovdiv and Stara Zagora and -0.90 in Sofia field. This threshold ranges between -0.75 (Lom) and -1.50 (Pleven) for North Bulgaria. Corresponding NIR thresholds were identified.

The derived reliable relationships and specific thresholds of seasonal SPI2 “July-Aug”, under which soil moisture deficit leads to severe impact of drought on rainfed maize yield for the main climate regions and soil groups in Bulgaria, are representative of a wider area of Continental, Transitional Continental / Mediterranean and Black Sea climate in SEE. They are used for elaboration of drought vulnerability maps and identification of drought prone territories at regional and national level.

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