Towards an adaptive preparedness framework for facing drought and water shortage

Tsakiris G.

in

López-Francos A. (comp.), López-Francos A. (collab.).
Economics of drought and drought preparedness in a climate change context

Zaragoza : CIHEAM / FAO / ICARDA / GDAR / CEIGRAM / MARM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 95

2010
pages 249-257

Towards an adaptive preparedness framework for facing drought and water shortage

G. Tsakiris

National Technical University of Athens,
Centre for the Assessment of Natural Hazards and Proactive Planning
9, Iroon Polytechniou str., 15773, Zografos Campus, Athens (Greece)
e-mail: gtsakir@central.ntua.gr

Abstract. The objective of the paper is to present a simplified practical procedure for devising an adaptive strategic water shortage preparedness framework to combat water scarcity in the Mediterranean region. Water shortage is the result of natural temporary phenomena such as droughts as well as climatic and human-induced changes. The paper addresses several technical and institutional aspects of the strategic preparedness plans. Simple methods to assess the drought severity, to estimate water shortage magnitude and its consequences are proposed. A risk assessment approach is assisted by multicriteria methods for selecting the optimal strategy to face water scarcity in future time horizons.

Keywords. Drought – Water shortage – Water scarcity – Drought risk – Risk management – Preparedness plan.

Vers un cadre adaptatif de préparation pour faire face à la sécheresse et la pénurie d'eau

Résumé. *L'objectif de cet article est de présenter une procédure pratique simplifiée qui permet de construire un cadre adaptatif de préparation contre la pénurie d'eau ayant pour but de combattre le manque d'eau en région méditerranéenne. La pénurie d'eau est le résultat de phénomènes naturels temporaires tels que les sécheresses et les changements climatiques naturels ou d'origine anthropique. Dans l'article on traite un certain nombre d'aspects techniques et institutionnels concernant les plans stratégiques de préparation. On propose des méthodes simples pour évaluer l'intensité d'une sécheresse et estimer la magnitude de pénurie d'eau et les conséquences liées à ces phénomènes. L'évaluation du risque qui intervient est assistée par de méthodes multicritères qui permettent de sélectionner la stratégie optimale pour faire face au manque d'eau dans des horizons temporels futurs.*

Mots-clés. *Sécheresse – Pénurie d'eau – Manque d'eau – Risque de sécheresse – Gestion de risque – Plan de préparation.*

I – Introduction

The global goal for ensuring water security worldwide faces a number of challenges for the years to come. Population growth, urbanisation, population mobility, frequent and intense droughts and other natural hazards, and lately the anticipated climate change, are expected to make matters worse for many parts of the globe.

Over the last decade international organisations and governments have focused their attention onto the escalating threat caused by more frequent and severe droughts and the higher vulnerability of the society and the environment to water stress in many regions of the world. Although the threat is directed mostly towards water deficient countries of the third world, there are signs that even the water sufficient developed countries of the North and particularly the Mediterranean region will face problems related to water availability in the future.

It has been noted that droughts have dramatically increased in number and intensity in the EU over the last three decades increasing the number of affected people by almost 20%. Recent droughts in Europe include the persistent drought 1989-1993 and the drought of 2003. This last drought only affected about 100 million people creating a cost of damage about 8.7 billion euros. The total cost of droughts in Europe for the last three decades amounts to 100 billion euros (Commission of the European Communities, 2007).

Drought, being the temporary decrease in water availability over a significant period of time affecting a large area initiated by deficient precipitation, was customarily considered as an interesting natural phenomenon within the climate variability of an area. Nowadays however it is realised that drought is a natural hazard affecting more people than any other hazard for long periods of time. Probably drought is one of the most complex natural hazards. Since its onset and termination are often difficult to determine drought has been characterised as a "creeping natural hazard" (Wilhite, 1993).

In most of the cases the occurrence of a drought episode is the reason for inadequacy for fulfilling the existing water demands, which in turn creates several impacts on the society and the environment.

The main objective of this paper is to present a simplified approach for linking science and policies and propose a series of basic steps for formulating an adaptive preparedness planning and mitigation process for combating droughts and water shortage in Mediterranean countries.

II – Basic notions

Some key concepts related to water stress condition will be now clarified. It must be accepted that the significance of deficient water availability lies in its impacts in the economy, the society and the environment. Therefore from the various definitions of the terms used, the "operational" rather than the "conceptual" definitions are adopted in this study.

The general term describing the stress conditions due to lack or deficiency of water is called *water scarcity*. Water scarcity may be created by either natural or human induced causes, or may result from the interaction of both (Pereira *et al.*, 2009).

As known *aridity* is a natural permanent imbalance in the water availability characterising the climatic conditions of a region. In contrast *Drought* is a natural but temporary imbalance of water availability caused mainly by low precipitation and thus resulting in lower availability of water resources.

Desertification and *water shortage* are mainly caused by human induced causes and they represent permanent and temporary imbalance in the water availability, respectively. Desertification is widely known as the process of land degradation and deterioration of its productivity, including the damage caused to the ecosystems. Water shortage is the deficit of water supply to meet the demands and is mainly caused by inappropriate misuse of water resources or due to man-made changes. However, in most of the cases water shortage is caused or initiated by intense drought episodes.

It is important to note that water scarcity is not only a quantitative concept but it affects and interacts with quality matters to a great extent. It has been observed that in most of the cases limited water availability means deterioration of water quality.

From the above it can be deduced that the water scarcity associated with aridity or desertification calls for engineering and management measures that produce conservation and augmentation of water resources. In the contrary, water scarcity initiated by droughts requires the development and the implementation of preparedness and contingency plans.

Temporary water scarcity (that is drought and/or water shortage) is not generally dependent on the aridity regime of the area. However the perception of these conditions in an arid area and the anticipated impacts are much more profound resulting in more adverse consequences. Therefore, if the assessment of these phenomena gives emphasis to the consequences both the climatic regime (aridity) and the temporary deficiency (drought/water shortage) should be simultaneously considered.

Using an "operational" definition of drought, the critical term of *water availability* (falling below a certain threshold for a substantial period of time) should be defined and the characteristics of the phenomenon should be described by specifying the commencement, the termination, the intensity, the magnitude and the aerial extent of the phenomenon. In fact it is useful to know the temporal and spatial evolvement of each episode of drought.

Conventionally drought may be treated as a meteorological, hydrological, agricultural phenomenon. In each of these expressions the variable representing water availability and the selected thresholds related to water availability are different. For instance drought may be determined by measuring the inflow of the reservoir of a water supply system, or by the precipitation recorded in a number of meteorological stations in the watershed under study. It is therefore difficult to find a common basis for assessing drought. However, in a particular water system (e.g. a watershed) located in a certain region, relationships between meteorological on one hand (initiating cause) and the subsequent hydrological and agricultural drought on the other, may be achieved.

After all, it should be stressed that apart from the different phases of drought the phenomenon/hazard is the same and it is basically meteorological.

III – Climate change and water scarcity

When calculating drought, time series of key meteorological/hydrological variables are analyzed and negative deviations from the normal conditions are identified. However in many cases due to some natural and man induced causes the time series are not stationary exhibiting some type of trend. This type of trend was observed in many meteorological stations in Greece which were analysed using drought indices incorporating precipitation and potential evapotranspiration. This long term trend was attributed to climate change.

Furthermore climate models predict severe changes in annual precipitation, mean air temperature and sea level in the areas of Eastern Mediterranean. Based on the recent report of IPCC (Intergovernmental Panel for Climate Change) during the course of 21st century severe trends of the major climatic variables are anticipated in the Mediterranean.

The customisation of the projections for the 2050 time horizon for selected Greek locations (Athens, Thessaly, Sparta, Cyclades and Crete) showed that a 5℃ average temperature rise and around 80-120 mm less annual precipitation are expected. These figures account for about 25% increase of potential evapotranspiration and 15% decrease in mean annual precipitation.

The level of these changes warn drought analysts that the frequency and severity of droughts will be substantially increased if the drought threshold remains constant. The above changes also indicate that drought indices should incorporate both precipitation and evapotranspiration in case they will be used for future time horizons.

IV – Impacts of drought and water scarcity

Droughts as the other natural hazards should be assessed based on the consequences which they cause. Although the terms of hazard and risk have been used in many different ways in various disciplines, here the following definition of drought hazard is adopted:

Drought hazard is defined as the situation characterised by decreased water availability for a significant period of time and affecting a large area with the potential to create stress or to initiate failure or damages to the production and to the natural, modified or human systems.

As drought hazard is a potential threat, the real threat is the risk associated with the drought hazard taking into account the coping capacity and robustness of the affected system. This capability of the system to withstand the drought hazard is usually referred to as vulnerability of the system.

In order to reduce the drought risk we can reduce the vulnerability of the affected system by improving its conditions, by decreasing the magnitude of the water shortage (and therefore its consequences) and by improving the public awareness and public capacities (that is the so called social factor).

Considering the geographical area of the Mediterranean, the impacts of drought and water shortage can be of economic, environmental and social nature. These impacts can be either direct or indirect. They can be immediate or delayed, tangible or intangible. A comprehensive list of drought impacts may be found elsewhere (Rossi *et al.*, 2007).

Despite of the difficulties for estimating the consequences, there have been methods for a gross estimation of direct and indirect impacts (monetary or simply quantitative). These methods give rough estimates of consequences or the range of consequences using upper and lower bounds.

It should be noted that drought can be associated with the consequences following the flow chart illustrated in Fig. 1.

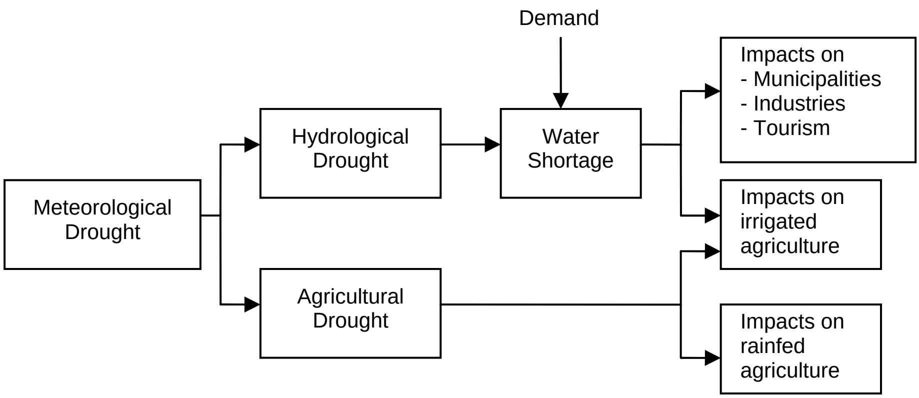

Fig. 1. Moving from drought hazards to drought consequences.

It is wise to move from meteorological drought to hydrological drought which is then used in order to estimate the water shortage that is the deficit created between demand and water availability. Finally, water shortage will be used for estimating the consequences in the various sectors. Only in the case of rainfed agriculture, the agricultural drought can be directly associated to the consequences as can be seen in Fig. 2.

Tsakiris (2007a,b) proposed a general evaluation procedure (for all hazards) for the calculation of the average (annualised) risk as a function of the probability distribution function of the phenomenon and the vulnerability function of the system affected by the natural hazard. In case of drought for each system (in which consequences can be estimated) the "consequences curves" can be constructed for the entire range of drought severity (Fig. 2).

Depending on the level of protection the level of consequences may be enclosed in the envelope between the non-protected and well protected system. The benefit achieved by moving from a non-protected to a well protected system in terms of consequences is represented by the difference of y-coordinates for each level of drought severity (Fig. 2b).

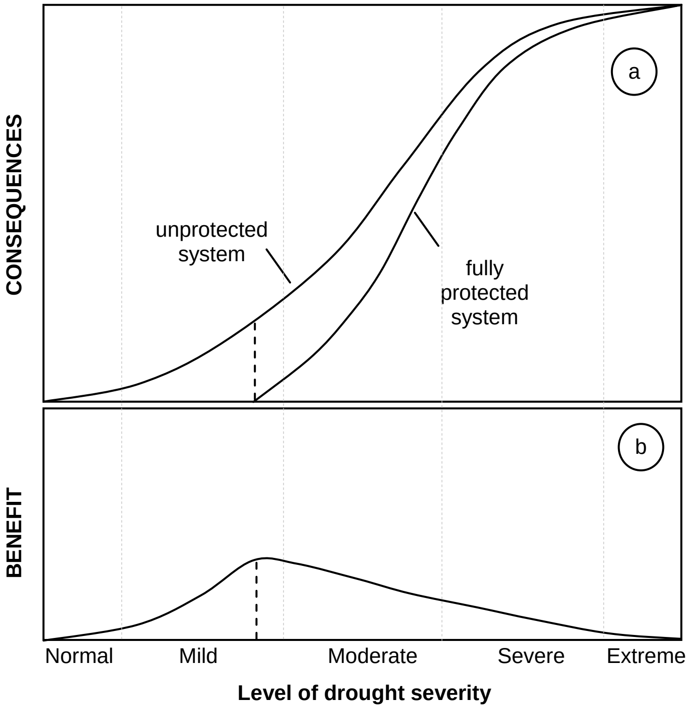

Fig. 2. The consequences curves and the benefit achieved by protecting the system against drought.

Assuming that drought severity follows a certain probability density function the average (annualised) anticipated loss $\overline{L}$ for a large number of years can be calculated simply by the equation:

$$\overline{L} = \sum_{i=1}^{n} (F_{i+1} - F_i) \cdot x_{i,i+1} \qquad (1)$$

in which F_i and F_{i+1} are the cumulative probabilities of the boundaries of each severity class, and $x_{i,i+1}$ is the anticipated loss of the system at the severity level represented by the class.

The average loss can be the decisive factor for the prioritisation of actions which should be taken for reducing the vulnerability of each system.

The proposed procedure may be also used for identifying the Less Favoured Areas (LFA) based on the criterion of "Climate Variability and Impact on Agriculture" (JRC-European Commission, 2007).

V – Constructing a strategic preparedness plan

This section addresses important technical and institutional aspects which may be essential for preparing a strategic preparedness plan to face water shortage caused mainly by drought. It is of great importance that the preparedness process is characterised by simplicity and transparency.

1. Monitoring of water-related variables

Several variables of the hydrologic cycle are usually recorded by various agencies having different interests. For drought-water scarcity monitoring it would be wise to use existing meteorological-hydrological networks. Only if there are areas not covered sufficiently or key variables not measured, enhancement of the existing networks should be realised. Since drought is a long lasting phenomenon, the time step of records is rather long (e.g. one month) and therefore, under normal conditions, these types of data are easily available at the lowest cost if any.

The database which should be constructed to store all historical data should include reliable long time series of selected stations of a rather dense monitoring network. As an example at least 50 years of monthly data are required from a meteorological monitoring system in which the distance between stations is not greater than 15 km for the most demanding variable (e.g. precipitation).

From all water-related variables which can be recorded, a subset including precipitation, temperature, evaporation, streamflow, groundwater, reservoir storage and water demand may be the least required. It should be noted however that some variables may be calculated from other variables which are directly measured (e.g. evapotranspiration from temperature, wind speed and air humidity).

The issue of vital importance for an effective drought preparedness plan is the easy access to this data-base by all stakeholders, the NGOs and the public. Therefore, the most convenient way should be found for the free availability of timely and reliable data and information (e.g. through the internet, leaflets, etc.).

2. Drought indices – Uni-dimensional drought analysis

To facilitate the assessment of drought in an easy to understand way, special indices have been employed representing the severity of drought for each period. A large variety of indices have been proposed and used with varying success in various parts of the world. A software package named DrinC (Drought Indices Calculator) was recently developed in the framework of SEDEMED II project for calculating a number of popular indices. DrinC operates on Windows platform and is programmed in Visual Basic.

Attention has been paid so far to the assessment of drought severity through the use of indices. The PDSI (Palmer Index), the Deciles and the SPI (Standard Precipitation Index) are among many others the most popular indices used for assessing the severity of meteorological drought. Recently a new index based on both precipitation and potential evapotranspiration, called RDI (Reconnaissance Drought Index), was proposed in the framework of MEDROPLAN project and was improved during the implementation of PRODIM project (Tsakiris and Vangelis, 2005;Iglesias *et al.*, 2009). The new index was tested in a large number of watersheds in the Mediterranean region. Although in some cases RDI behaves in a similar manner as SPI, in other cases deviates substantially from SPI, giving a more sound representation of drought conditions. The differences between SPI and RDI may be clearly illustrated when drought severity maps are produced.

As mentioned earlier RDI is a more suitable index than SPI for studying drought severity under climatic change since it incorporates both precipitation and potential evapotranspiration which are directly affected by this change.

Apart from the severity indices selected to represent drought severity, the other dimensions of drought that is the areal extent and duration should be also modelled. A major step for dealing with these complications was proposed recently (Tsakiris, 2008b).

Drought is conceived as a multidimensional phenomenon (severity, duration, areal extent) which is difficult to model for resulting in meaningful management decisions. The simplifications proposed are to replace the three dimensions of drought by a unique dimension in an attempt to reach a practical way to assess the severity of drought and perform a meaningful frequency analysis. The river basin or sub-basin is used as the territorial unit for the analysis replacing the areal extent (Water Directive 2000/60), whereas the reference period is introduced for replacing the duration on the temporal scale. For standardisation purposes reference periods of 3, 6, 9 and 12 months starting from the onset of the hydrological year (October for the Mediterranean) are proposed.

Based on the above considerations, drought severity could be represented by the Reconnaissance Drought Index and complementarily by the Standardised Precipitation Index if only precipitation data are available. The proposal for the uni-dimensional analysis of drought is presented in detail in the past (Tsakiris, 2008b).

3. Options and option selection

In most situations related to water shortage conditions it seems that a limited number of solutions exist. However, a thorough study of all the related variables and conditions reveals a great number of options which could be tested for inclusion in the drought preparedness and mitigation planning. The variety of options actually applicable to a particular set up is highly dependent on the characteristics of the basin/water system, on its geographical coordinates and on the economic and social conditions of the area. Options may differ greatly dependent on whether they are to be used for the strategic planning (unconditional drought – water shortage risk management) or for the real time operational management (conditional risk management).

An indicative list of options and tasks generally available in situations of water shortage is presented elsewhere (Tsakiris, 2008a). The options, apart for the organisation to face drought (task force, etc.), maybe grouped into the following three categories under the titles:

(i) Demand reduction measures.

(ii) System improvements.

(iii) Emergency water supplies.

To compare all these options which exhibit different nature, a multicriteria approach can be used. Recently outranking multicriteria methods incorporating a fuzzy set approach and the 0/1 programming were used for selecting the most appropriate actions for facing water scarcity problems in a water system (Tsakiris and Spiliotis, 2010).

In case a more practical approach for the selection of options is to be followed, the prioritisation principle in fulfilling the various demands is applied. More clearly the lack of each unit of water during a certain period may cause a certain stress or damage in the corresponding sector. Through an expert evaluation all units of demand may be characterised by a certain priority. This prioritisation is the cornerstone of equitable and rational management of water demand in case of limited water supply.

It is obvious that prioritisation is a key element which should be agreed upon by all interested parties within the strategic plan for facing droughts and water shortage.

VI – Institutional and governance issues

Water scarcity and its consequences can be faced more effectively at a regional scale. Therefore the first step towards the construction of a strategic or tactical preparedness plan is to establish a task force of competent scientists and policy makers for devising a transparent, easy to understand, comprehensive plan which will be then presented to all stakeholders. Through this public discussion the plan will be finalised and approved by the regional society.

It should be reminded that a water shortage preparedness plan has three distinct components which should be addressed: the technical component, the institutional component and the implementation process.

For the last two components, regional organisations are the most appropriate for the job. Since the water shortage preparedness plans interact with the main water resources management plans for each river basin (or water district in case of small river basins) according to WFD (Directive 2000/60) the burden for implementing these plans can be undertaken by the regional organisations (e.g. RBOs-river basin organisations) responsible for the implementation of water management plans.

VII – Conclusions

In this paper proactive management of water systems to face droughts and the consequent water shortages is approached as a process starting with the modelling of droughts, assessing the vulnerability of each water system and estimating the annual (average) loss from drought events.

Methodologically the phenomenon of drought is analysed as a uni-dimensional phenomenon by replacing the areal extent of drought by the river basin or sub-basin as the territorial unit, and its duration by the reference period.

The drought severity is proposed to be represented by the RDI and complementarily by SPI drought indices so that simple monitoring facilities are required and unique results are produced.

Further drought is the cause for creating water shortages in the water systems. In turn the impact of water shortages in each sector reflects the vulnerability of each system. The estimated average loss is then considered as the key determinant for prioritisation in fulfilling the water demand and for improving the system under drought risk.

Regarding the implementation of the preparedness planning process the regional organisations (e.g. River Basin Organisation-RBO), proposed in the framework of Directive 2000/60 for water resources management, could also be the responsible agencies for devising, supervising and implementing such processes.

Acknowledgements

The assistance of PRODIM (INTERREG IIIB/ARCHIMED) partners provided through extensive discussions during the PRODIM meetings is acknowledged.

References

Commission of the European Communities, 2007. Addressing the challenge of water scarcity and droughts in the European Union. Communication from the Commission to the Council and the European Parliament, Brussels.

Iglesias A., Cancelliere A., Wilhite D.A., Garrote L. and Cubillo F., 2009. *Coping with Drought Risk in Agriculture and Water Supply Systems – Drought Management and Policy Development in the Mediterranean.* Series: Advances in Natural and Technological Hazards Research, Volume 26. Springer, 320 p.

JRC-European Commission, 2007. *Common Biophysical Criteria for defining Areas which are Less Favourable for Agriculture in Europe.* Proc. from Expert Meeting, Ispra (Italy, 19-20 April 2007. JRC, Eliasson A., Terres J.M. and Bamps C. (eds). Luxembourg: EC-JRC / IES, 80 p.

Pereira L.S., Cordery I. and Iacovides I., 2009. *Coping with Water Scarcity. Addressing the Challenges*. Dordrecht: Springer, 382 p.

Rossi G., Castignione L. and Bonaccorso B., 2007. Guidelines for planning and implementing drought mitigation measures. In: Rossi G., Vega T. and Bonaccorso B. (eds). *Methods and Tools from Drought Analysis and Management*, Ch. 16. Dordrecht: Springer, p. 325-347.

Tsakiris G., 2007a. Practical application of risk and hazard concepts in proactive planning. In: *European Water*, 19/20, p. 47-56.
Tsakiris G., 2007b. A paradigm for applying risk and hazard concepts on proactive planning: Application of rainfed agriculture in Greece. In: Drought Management Guidelines Technical Annex*. Options Méditerranéennes, Series B, no. 58*, p. 297-304.
Tsakiris G., 2008a. Drought induced water shortage management: An overview. In: *Proceedings of the International Symposium "Water Shortage Management"*, Athens (Greece), 20 June 2008, p. 7-20.
Tsakiris G., 2008b. Uni-dimensional analysis of drought for management decisions. In: *Proceedings of the International Symposium "Water Shortage Management"*, Athens (Greece), 20 June 2008, p. 45-52.
Tsakiris G. and Spiliotis M., 2010. Planning against long term water scarcity: A fuzzy multicrireria approach. In: *Water Resources Management* (under review).
Tsakiris G. and Vangelis H., 2005. Establishing a drought index incorporating evapotraspiration. In: *European Water*, 9/10, p. 3-11.
Wilhite D., 1993. The enigma of drought. In: Wilhite D. (ed.). *Drought Assessment, Management and Planning: Theory and Case Studies*. Boston: Kluwer Academic Publishers, p. 3-30.