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Drought Risk Assessment and Management

George Tsakiris [1]

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Abstract The paper presents an overview of issues related to the estimation of drought severity, the vulnerability of affected systems towards the drought hazards, the assessment of system drought risk and the required preparedness planning against droughts. To face these recurrent and temporary phenomena, a proactive approach is promoted based on technocratic support, systematic organisational and institutional structure and active public participation. Special emphasis is given to the simple and practical approaches, though scientifically sound, for the characterisation of drought episodes and the assessment of drought risk affected systems.

Keywords Drought severity · System vulnerability · Drought risk · Preparedness planning · Public participation

1 Introduction

Droughts are complex hazardous recurrent phenomena affecting most parts of the world. The impacts of droughts are economic, environmental and social. These impacts are more crucial on the climatic zones suffering from permanent water scarcity. They are also more severe for the affected systems which are not protected from these events.

Over the past few decades, droughts have dramatically increased in intensity and frequency. It is estimated that in Europe between 1976 and 2006 the total costs associated with drought episodes amounted to 100 billion euros, whereas the number of people affected by droughts was increased by almost 20%. Recent studies reveal that in areas such as the Mediterranean, more frequent and intense drought episodes are expected in the next decades (CEC 2007). This has put pressure on governments and institutions to provide measures in order to mitigate the impacts of future droughts.

In this review paper an attempt is made to look on the subject based on recently developed knowledge on this intensifying old complex problem for the modern societies. The paper

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✉ George Tsakiris
gtsakir@central.ntua.gr

[1] Centre for the Assessment of Natural Hazards and Proactive Planning, School of Rural and Surveying Engineering, National Technical University of Athens, Iroon Polytechniou 9, 157 80 Athens, Greece

builds on a number of specialised books on the subject (e.g. Wilhite 1993b; Vogt and Somma 2000; Rossi et al. 2003, 2007; Iglesias et al. 2009b; Pereira et al. 2009), the findings of some important European research projects (e.g. MEDROPLAN, SEDEMED, PRODIM), and a significant number of journal papers.

In short, the paper starts from the detailed description of the affected systems, assesses their ability to withstand certain level of drought pressure, and estimates the impacts for all possible levels of pressure. Then, it attempts to produce methodologies for linking drought severity with its probability of occurrence. Finally, by combining frequencies and system vulnerabilities, the drought risk is estimated.

On the response side, the paper elaborates on the proactive drought management based on the risk approach. As can be easily understood, the preparedness against droughts requires, apart from the technocratic support, systematic organisational and institutional structures, and active participation of stakeholders and the public. As known, droughts, unlike other natural hazards (e.g. floods, storms, earthquakes) do not occur abruptly. They affect large areas for extended period of time. Persisting droughts may last for years. It is, therefore, possible to make management plans for enhancing the capacity of the affected systems to withstand the pressure of drought episodes.

The paper is organised in three parts: (a) the recent approaches for identifying and characterising droughts events; (b) the system vulnerability and risk issues in relation to drought severity; and (c) the requirements (technocratic, organisational and institutional) for devising and implementing the preparedness and contingency plans.

2 Recent Approaches for Characterising Droughts

The general term describing the stress conditions due to lack or deficiency of water in an area is called water scarcity. Water scarcity can be either permanent or temporary. In the latter case, we have the phenomenon of drought, which is associated with natural but temporary imbalance of water availability caused mainly by low precipitation (Tsakiris et al. 2013). It should be noted that besides the above definition, several official documents, mainly by the European Union and international organisations, define water scarcity as the permanent phenomenon characterising an area. Therefore, to avoid confusion, droughts are distinguished from (permanent) water scarcity due to their temporary nature.

The temporary character of droughts calls for temporary measures to mitigate the extra pressure on the water systems, due to the occurrence of these events. Infrastructures or permanent new projects are not generally among the actions to be taken to combat drought episodes. They may be among the options, if the affected system is totally unprotected or its infrastructure is very basic.

Identifying and characterising droughts is generally a difficult task. It is difficult to specify the onset and the termination of a drought event, as well as the exact area which is affected. Due to the uncertainties associated with the phenomenon of drought, it has been characterised as a “creeping phenomenon” (Wilhite 1993a).

To start with the drought characterisation, we are faced with several dimensions which should be analysed in relation to each other: intensity, cumulative deficit, duration, areal extent and timing of occurrence. As expected, monitoring and simultaneous analysis of all these dimensions is rather impossible to perform, having in mind that final decisions should be taken by the decision makers with the assistance of stakeholders.

To study the phenomenon of drought, Tsakiris et al. (2013) proposed the use of the concept of "Water System", which is also used in water resources management plans. The water system is defined as the entity expanding over a geographical area which includes all watersheds and groundwater recharge areas together with all consumption centres and ecosystems associated with the processes occurring in the natural (abiotic or biotic) and human sub-systems. Such a water system may be a large river basin or, in some cases, a combination of adjacent river basins.

An element of the system is under drought condition, if it suffers from a sustained natural water input deficiency in relation to its normal conditions, for a significant period of time. Then, the water system is under drought if a critical number of its elements are under drought. It is evident that a spatial entity with fixed boundaries and all interacting elements can facilitate the development and implementation of operational management decisions to combat droughts and mitigate their impacts.

The natural water availability can be described by a number of alternative variables ranging from precipitation to the inflow in the reservoirs of the system. Needless to say, that the closer to the consumption centres the variables used, the more reliable the analysis of the phenomenon is expected to be. A shortcoming of this choice, however, is that the time available for the response is rather short.

Conventionally, droughts as natural phenomena, are characterised as meteorological, hydrological and vegetation/agricultural. Meteorological droughts can be assessed analysing precipitation (and possibly evapotranspiration) data, hydrological drought using streamflow or deep percolation data, and vegetation/agricultural drought using soil infiltration data.

To assess the severity of drought events a variety of indices have been proposed and used in the past. This serves the need for a single value classification through the combination of several indicators/variables. A large number of indices have been developed over the recent years (Mishra and Singh 2010; Zargar et al. 2011). A summary of some selected drought indices for the three types of drought with their strengths and weaknesses is presented in Table 1, modified from Tsakiris et al. (2007a, b). The two mostly used indices are the Palmer Drought Severity Index (PDSI), which uses a simplified form of soil water balance (Palmer 1965), and the Standardised Precipitation Index, which is based on the probability of precipitation at various time scales (McKee et al. 1993). An important step forward is the development of the Reconnaissance Drought Index (RDI), which, although similar to SPI, uses as its decision variable the ratio of precipitation over the potential evapotranspiration, thus acknowledging the fact that drought is not only a result of deficient precipitation (Tsakiris and Vangelis 2005; Tsakiris et al. 2007b). Thus, RDI avoids the complication of a comprehensive index, such as the PDSI, and approaches the easiness of calculation of the SPI. Quite recently, RDI expressions have been proposed which use the effective precipitation (Tigkas et al. 2017).

By comparing RDI and SPI, it has been shown that although in general the two indices produce similar results in the majority of the cases studied, there are cases in which the two indices give different results, mainly due to the influence of evapotranspiration. RDI, as a more comprehensive index, is considered more reliable and sensitive to climatic variability (e.g. Khalili et al. 2011; Safiolea et al. 2015).

Recently, several new drought indices have been proposed and are used, including: SPEI for the meteorological drought (Vicente-Serrano et al. 2010); SDI for the hydrological drought (Nalbantis and Tsakiris 2009); and RDIe for the agricultural drought (Tigkas et al. 2017). To facilitate the use of drought indices, a software package, named DrinC, has been developed and used extensively (Tigkas et al. 2015).

Since droughts are regional phenomena, drought indices are applied in all unit areas in which the area under study is divided. Fig. 1 presents the drought severity distribution

Table 1 Summary of popular drought indices (modified from Tsakiris et al. 2007a)

Index	Description and Use	Strengths	Weaknesses
Meteorological Drought Indices			
Percent of Normal Precipitation and Accumulated Precipitation Departure	• Simple calculation • Used by general audiences	• Effective for comparing a single region or season	• Precipitation does not have a normal distribution • Values depend on location and season
Deciles (Gibbs and Maher 1967)	• Simple calculation grouping precipitation into deciles • Used by the Australian Drought Watch System	• Accurate statistical measurement • Simple calculation • Provides uniformity in drought classifications	• Accurate calculations require a long climatic data record
Standardized Precipitation Index (SPI) (McKee et al. 1993)	• Based on the probability of precipitation for any time scale. • Used by many drought planners	• Computed for different time scales, provides early warning of drought and help assess drought severity	• Values based in preliminary data may change • Precipitation is the only parameter used
Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis 2005; Tsakiris et al. 2007b)	• Similar to SPI • Basic variable P/PET • Recently used by researchers and institutions of droughts	• Drought is based on both precipitation and potential evapotranspiration • Appropriate for climate change scenarios	• Data needed for calculation of PET
Meteorological and Vegetation/Agricultural Drought Indices			
Palmer Drought Severity Index (PDSI) (Palmer 1965; Alley 1984)	• Soil moisture algorithm calibrated for relatively homogeneous regions • Used in the USA to trigger drought relief programs and contingency plans	• The first comprehensive drought index, widely used • Very effective for agricultural drought since it includes soil moisture	• PDSI may lag emerging droughts. Less well suited for mountainous areas of frequent climatic extremes Complex • Categories not necessarily consistent, in terms of probability of occurrence, spatially or temporally
Crop Moisture Index (CMI) (Palmer 1968)	• Derivative of the PSDI Reflects moisture supply in the short term	• Identifies potential agricultural droughts	• It is not a good long-term drought monitoring tool
Hydrological Drought Indices			
Palmer Hydrological Drought (PHDI) (Palmer 1965)	• Same as PDSI but more exigent to consider a drought end. The drought event terminates only when the ratio of Pe (moisture received to moisture required) is 1	• Same as PDSI	• Same as PDSI
Surface Water Supply Index (SWSI) (Shafer and Dezman 1982)	• Developed from the Palmer Index to take into account the mountain snowpack	• Represents surface water supply conditions and includes water management • Simple calculation • Combines hydrological and climatic features. Considers reservoir storage	• Management dependent and unique to each basin, which limits inter-basin comparisons • Does not represent well extreme events

represented by the drought index RDI, for one particular year (1965–1966) in the eastern part of the island of Crete, Greece.

Over the last few decades, other indices have been developed, based on remote sensing data. Remote sensing is an important tool for the detection of the spatial and temporal drought distribution at various scales. A number of satellite drought-monitoring indices are developed based on AVHRR, MODIS and other satellite data. These indices [e.g. NDVI (Peters et al. 1991), VCI (Kogan 1997), SDCI (Rhee et al. 2010) TCI (Kogan 1995), ESSMI (Carrao et al. 2016), etc.] are normally radiometric measures of vegetation condition, using the unique spectral signatures of canopy elements (Huete et al. 2002; Wan et al. 2004). Remote sensing drought indices are more appropriate for monitoring agricultural droughts.

It should be mentioned that the European Union, in an attempt to improve the knowledge on droughts in its member states, has adopted initially three drought indices: the standardised precipitation index (SPI) for meteorological drought; the fraction of absorbed photosynthetically active solar radiation (fAPAR) for drought impacts on vegetation; and the water exploitation index plus (WEI+) for the pressures caused by water abstractions.

Based on the drought indices, the severity of drought can be assessed once the variable used, its critical threshold for the identification of drought, the affected system and the time period of analysis have been decided. Regarding the latter, several periods, known as reference periods, have been proposed and used. These are periods of 3, 6, 9 and 12 months starting from the beginning of the hydrological year, which for the Mediterranean region is the beginning of October (Tsakiris 2008). Monthly data are required, and therefore, the monitoring system should be tuned accordingly.

Drought dimensions are usually studied separately using univariate frequency analysis (e.g. Tallaksen et al. 1997; Cancelliere and Salas 2004). Recently, the dimensions of droughts are studied in relation to each other (Dalezios et al. 2000; Loukas and Vasilliades 2004). A boost in this multidimensional frequency analysis has been realised by the extensive use of copulas (Chen et al. 2013). Several two-dimensional copulas have been used by various researchers. For instance, Shiau (2006) and Shiau and Modarres (2009) modelled the joint distribution of duration and severity, and Tsakiris

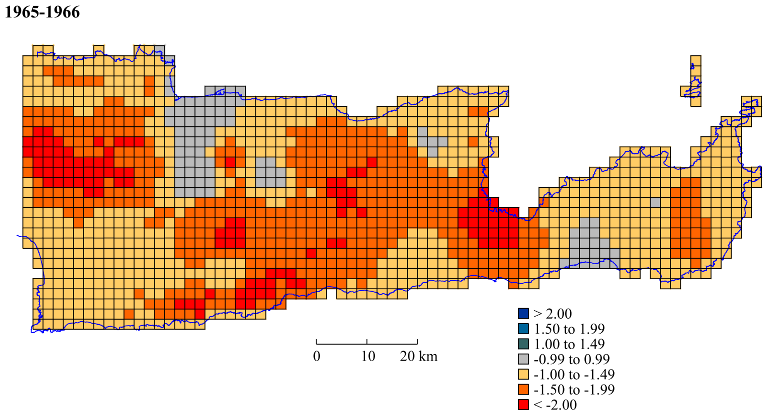


Fig. 1 The distribution of drought severity represented by RDI for the year 1965–1966 in Eastern Crete, Greece

et al. (2016) modelled the severity and the areal extent with the use of Gumbel-Hougaard two dimensional copulas. Song and Singh (2010) modelled the joint distribution of drought duration, severity and inter-arrival time using a trivariate Plackett copula. In most of the above multivariate methods the results are rather difficult to be understood by managers and stakeholders, and therefore, they cannot be proposed to be used in the drought risk management plans. Further, most of them use very simplistic approaches to characterise a drought event. For example, they usually define drought for the periods in which the index SPI is below 0 (Shiau 2006), whereas drought is identified if SPI is less than −1.

3 System Vulnerability and Risk in Relation to Droughts

It should be admitted that considerable efforts have been made to analyse the complex phenomenon of drought and assess its severity. On the contrary however, very limited research has been conducted to assess the impacts of droughts on the affected systems and revise strategies to protect these systems. To study this topic therefore, we should start by defining the affected system, its sub-systems, and finally, its elements. We then can study in detail the impacts on the system for any level of drought pressure, with the final goal to find the relation between the possible remediation actions/measures (response) and the causes (drivers).

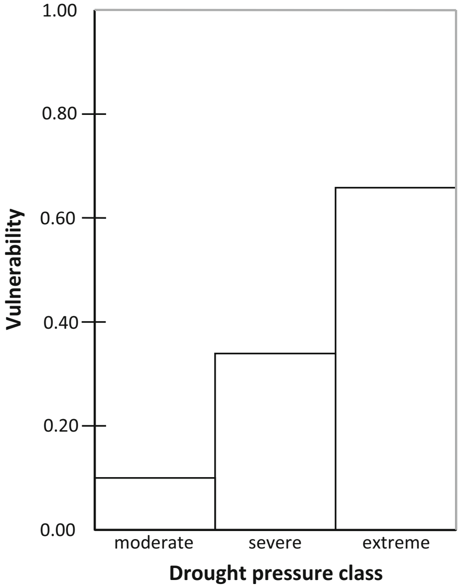
Starting from the developments in EU and the implementation of the Water Framework Directive by the European member states, the system can be considered as the river basin (RB), as defined in the documents for the Common Implementation Strategy (CIS) of EU. The advantages of this choice are multiple. The river basin includes all related watersheds together with all water consumption centres and environmental sites and ecosystems. The responsible authority is the River Basin Organisation (RBO) which is in charge for implementing the River Basin Management Plans (RBMPs) in which any drought risk management plan should be incorporated.

In this system, we may distinguish a number of sub-systems, (e.g. the municipal, the agricultural, the industrial), and a number of elements in each sub-system (e.g. each municipality in the municipal sub-system or each irrigation project in the agricultural sub-system). To simplify the methodology of risk calculation, let us considered annual reference periods. From the frequency analysis of annual droughts in the river basin we can estimate the frequencies f_1, f_2 and f_3 of the three classes of drought severity S_1, S_2 and S_3, corresponding to moderate, severe and extreme conditions.

Let also V_{ijk} be the vulnerability of the i-th element of the j-th sub-system for the k-th level of drought severity. The vulnerability can be expressed as a function between 1 and 0, with 1 meaning a totally unprotected system, and 0 meaning a fully protected system. In Fig. 2, a typical step function of the vulnerability of an element is presented. The vulnerability of an element of a system towards a drought episode is mainly dependent on the following factors: Exposure, Capacity, Social conditions, Severity of the event, and Connection with other elements or systems. The vulnerability is greatly influenced by the conditions prior to the event of drought.

If, instead of independent annual droughts, we analyse prolonged droughts with two consecutive or more drought years, the vulnerability functions should be modified for the years after the first, accordingly. This is imperative due to the fact that for persistent droughts, the capacity of the suffering systems has weakened (Al-Faraj and Tigkas 2016). For this modification, multiplicative or other more complex models have been proposed (Tsakiris et al. 2010).

Fig. 2 A typical step function of vulnerability of an element



The average (annualised) risk of each element at risk (R_{jk}) can be calculated using the following equation (Tsakiris 2009):

$$R_{ij} = \sum_{1}^{3} x_{ijk} \cdot V_{ijk} \cdot f_k \tag{1}$$

in which: x_{ijk} is the potential consequences/losses of the element ij in quantitative terms (e.g. monetary units); V_{ijk} is the vulnerability of the element ij under the drought pressure of class k; and f_k is the relative frequency of drought pressure of class k.

It should be noted that R_{ij} is expressed in quantitative terms such as monetary units as the consequences. The expected total annualised drought risk of the entire system, R_{total}, can be calculated as the sum of annualised risks of all the elements:

$$R_{\text{total}} = \sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} \tag{2}$$

The total annualised risk represents the average (annual) level of losses of the entire system (in monetary units) due to drought hazard (that is the sequence of drought events). As understood, this quantity may be the major decision variable for any actions which can be implemented to mitigate the consequences of droughts affecting the system under study.

As expected, the critical procedures related to the application of the above methodology is the estimation of losses of each element for each level of drought pressure. Although high uncertainties are associated with such estimations, the large number of elements of each sub-system and the detailed calculation procedure which can be followed, may end up in figures of losses with reasonable accuracy. A simplified example of the calculation of R_{total} is presented in Table 2. In this example, three sub-systems with one element each, are used to demonstrate the proposed methodology.

It should be emphasised that the estimation of damages/losses for any level of pressure class (severity level), and therefore, the vulnerability of each element, is a rather complex task. In most cases, droughts create water shortages and the water shortages losses. In other cases, such as the rainfed agriculture, droughts affect directly the soil moisture and the crop yield production. In the former case, we deal with blue water problems, whereas for the latter with green water problems. In both cases, however, the consequences can be direct or indirect, tangible or intangible.

Using the tool of total annualised risk, all possible actions may be assessed based on a single figure and set in a descending order of preference. For a more comprehensive approach, a set of solutions may be selected using a rigorous multicriteria approach (Tsakiris et al. 2015). The use of the multicriteria approach, although scientifically sound, has a strict prerequisite: to be accepted by all involved players who have to adopt also all the associated assumptions. In this detailed analysis, several criteria can be used.

4 Drought Management Plans

As mentioned earlier, drought is a long-lasting phenomenon, which allows for preparedness and defence. The so called "Drought Management Plan" (DMP) involves three stages: the strategic, the tactical and the emergency. According to the stage, different organisations may be responsible for devising and implementing the plan. However, since coordination is of great importance in this type of activities, the River Basin Organisations (RBOs) are the most appropriate bodies to coordinate all consecutive stages of DMPs in European countries.

In fact, by proposing a drought management plan, we move from the disaster management, conventionally applied by governments in drought events during the previous decades, to drought risk management which is a proactive approach (Tsakiris 2016). This proactive approach has been proposed by various organisations and institutions since the early nineties, mainly as recommendations to governments for devising their national drought management policy. In this context, we should refer to the 10-step process for policy and preparedness planning (Wilhite 1993b; IDMP 2014). In Table 3, the outline of the latest version of this proposed process is presented. Needless to say, that when applying this methodology, each country would require adapting it to its institutional and technical capacity, and its legal system.

During the first stage, the vulnerable systems are identified, the concepts, the methods, the criteria and the prioritisation of measures are adopted by all participating bodies (authorities,

Table 2 The calculation of R_{total} in a simplified example with three sub-systems with one element each

Severity level	Relative frequency	Vulnerability		
		Element (1.1)	Element (2.1)	Element (3.1)
1 (moderate)	0.30	0.10	0.50	0.33
2 (severe)	0.10	0.33	0.75	0.66
3 (extreme)	0.05	0.66	1.00	0.90
Potential losses (monetary units)		200	350	500

$$\begin{aligned} R_{\text{total}} &= 0.30(0.10{\cdot}200 + 0.50{\cdot}350 + 0.33{\cdot}500) \\ &\quad +0.10\,(0.33{\cdot}200 + 0.75{\cdot}350 + 0.66{\cdot}500) \\ &\quad +0.05\,(0.66{\cdot}200 + 1.00{\cdot}350 + 0.90{\cdot}500) = 220.45_{\text{monetary units}} \end{aligned}$$

Table 3 The 10-step process of policy and preparedness planning (IDMP 2014)

Steps	Actions
Step 1:	*Appoint* a national drought management policy commission
Step 2:	*State* or *define* the goals and objectives of a risk-based national drought management policy
Step 3:	*Seek* stakeholder participation; *define* and *resolve* conflicts between key water use sectors, considering also transboundary implications
Step 4:	*Inventory* data and financial resources available and *identify* groups at risk
Step 5:	*Prepare/write* the key tenets of a national drought management policy and preparedness plans, which would include the following elements: • Monitoring, early warning and prediction • Risk and impact assessment • Mitigation and response
Step 6:	*Identify* research needs and *fill* institutional gaps
Step 7:	*Integrate* science and policy aspects of drought management
Step 8:	*Publicise* the national drought management policy and preparedness plans and *build* public awareness
Step 9:	*Develop* educational programs for all age and stakeholder groups
Step 10:	*Evaluate* and *revise* national drought management policy and supporting preparedness plans

institutions, stakeholders). Communication and monitoring systems are established and drafts of the second and third stage are elaborated.

During the second stage, decisions are taken based on the established monitoring system and the agreed criteria. Assignments are also made to organizations responsible for the monitoring, the water supply and distribution, as well as environmental services.

The plan of the second stage is responsible for providing information on the evolvement of drought and warning for the level of surveillance (alert or alarm), according to the prevailing conditions. Detailed cost analysis is performed for any drought pressure during this stage of all damages/losses of the major systems. Also, a cost effectiveness analysis (CEA) of all feasible actions to be taken is performed. Very useful at this stage is a multicriteria analysis of measures in relation to economic, environmental and social aspects of the measures. Based on this analysis, the prioritisation of measures to be implemented is achieved.

Finally, the third stage, usually named as contingency plan, incorporates all the decisions regarding the short and long-term mitigation measures taken by the responsible body with the participation of all stakeholders.

A major part of the drought management plan is the identification, the selection and the prioritisation of the most appropriate measures or combination of measures. Theoretically, there is a large number of measures, most of which aim at the minimisation of impacts on the affected systems. These measures are devoted to upgrade public awareness, build capacity of the systems mainly by education, develop early warning systems, promote insurance programmes, etc. The rest of possible measures may be divided into two categories: those aiming at demand reduction and those providing increase of water supply. Both these categories are associated with the demand for water, and therefore, they are alternatives considered for the management of water shortage management created by drought and not directly with the drought itself as a natural hazardous event.

The demand reduction measures include economic incentives for water saving, deficit irrigation in agriculture, replacement of crops to less water-demanding, recycling of water in industry to save fresh water, treated wastewater reuse in irrigation, water loss management in water distribution systems, etc. A comprehensive list of measures for all the sectors affected by droughts can be found elsewhere (Iglesias et al. 2009a). From the above possible alternatives, the drought management plan should propose the most appropriate ones based on criteria as the technical viability, the economic effectiveness, the environmental suitability and the social acceptance. Additional criteria are linked with the compatibility with the measures taken and implemented in the river basin management plan (RBMP) (as proposed by the WFD for the European countries), and the time needed for the measure to be operational. An interesting approach based on a multicriteria methodology for the selection of measures is presented by Tsakiris et al. (2015) using two types of criteria: the beneficial and the constraining. The beneficial criteria include the viability, the implementation time, the cost-effectiveness, and an indicator of significance, of each measure, whereas the constraining criteria include the environmental suitability, the social acceptability and the compatibility with the long-term planning.

Several theoretically interesting problems need proper solutions by applying operational research methods, facilitated by a number of simplifying assumptions. Due to the uncertainties encountered in the analysis of the effectiveness of measures, fuzzy logic, interval and probabilistic programming, and several other methods can be used. For using these types of methods, the agreement of the stakeholders should be obtained from the beginning of the process.

The scenarios which are studied should be based on a certain level of drought pressure. For practical purposes, an annual drought event with return period of 10 years can be assumed, so that the average damages/losses can be estimated and the appropriate measures selected. Since the 10-year drought can be obtained with different values of the variables characterising the drought event, a historical drought in the area with this probability of occurrence can be selected as the "design event". Obviously, if the number of drought years is relatively small, the available sample of hydro-meteorological data must be extended to some hundreds of years by using the appropriate time series models. By this way, the selection of the "design event" is less biased and more reliable.

The selection of measures should always start with the scenario of "business as usual", followed by the easiest and low-cost actions, and then gradually moving to more expensive and difficult to implement actions. Priority should be given to reallocation of water resources and water saving activities. Priority also should be given to the temporary measures which will not remain when the situation comes back to normal. We should have in mind that drought is a temporary phenomenon and can be dealt with temporary measures. Costly permanent structural measures are not generally in the centre of the scope of drought management plans. However, they can be selected only if it is deliberately proved that the suffering systems have quite inadequate capacity to face even usual drought years.

As understood from the above, the drought management plan is not only a technocratic activity. For the successful implementation of any measures, the participation of all key stakeholders is of great importance. The selection of stakeholders can vary from area to area depending on the main activities in each area and the existence of vulnerable to drought systems. An indicative list of stakeholders, who can assist the authorities (e.g. the RBO) during all stages of the management process, is presented in Table 4.

A very common problem in drought conditions is how we can cope with less quantities of available water resources. Here, the prioritisation for fulfilling existing demands is the key for mitigating the losses caused by drought. As an illustrative simplistic example, Fig. 3 is presented. The bar-chart of the figure represents the crop water demand of a monoculture, which should be irrigated with less quantity of water. Each block of demand is a unit volume of water demanded at the corresponding fortnight. As illustrated in the graph, the fulfilment of each crop water demand can be given different priority (in the example there are 3 priorities). These priorities can be derived by the dated production function or yield model of the crop for

Table 4 Indicative list of stakeholders

Urban water consumers
Water utility companies
Farmer unions
Touristic enterprises
Industrial facilities
Local authorities
Meteorological and hydrological services
Geological institutes
Research, training and development institutions
Ministries (e.g. Rural Development, Environment, Tourism etc.)
Non-governmental organisations
Insurance companies
Banks and rural lending institutions
University professors and other experts

deficient irrigation. If this information is available, then, depending on the situation, the third priority units or even the second priority units, can be omitted from application.

If the sensitivities of the crops to water deficits are known for each stage of growth, optimal allocation of the limited water volumes can be obtained for each crop and the group of crops covering an irrigation area, using conventional optimisation methods. Since irrigated agriculture is the sector which is most vulnerable to drought and the sector which uses large quantities of water, the optimised deficit irrigation is a very promising measure in the drought management plan which can save significant water quantities.

5 Conclusions

Drought is a natural complex recurrent phenomenon with multiple dimensions. The present study attempted to review the most remarkable developments related to drought severity characterisation, evaluation of the risk of the affected systems and the formulation and implementation of Drought Management Plans (DMPs). The study adopted the simplifying approaches, which have been devised during the last few decades for the practical and effective characterisation of drought severity by using drought indices and predetermined reference periods. It is concluded that, over the years, the need for a paradigm shift from disaster

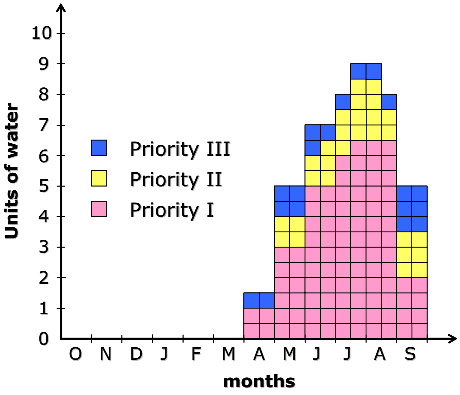


Fig. 3 A prioritisation scheme example for an irrigated area with monoculture

management to drought risk management is widely accepted by organisations and governments. However, it is true that very little has been done by governments on the real operational level so far. The proactive approach for facing droughts, adopted in his study, is based on the evaluation of drought risk of all affected systems. Thus, before formulating the drought management plan, each system is analysed and its vulnerability is assessed. Then, the main objective of DMP is to explore ways to minimise the risk of the affected systems. It is also concluded that the formulation - and to a greater extent- the implementation of DMPs are not only of technocratic nature, but they call for a competent institutional infrastructure and an effective implementation process. Critical for the successful implementation of DMPs is the selection of organisations and stakeholders who will carry out the entire process. In EU countries, the River Basin Organisations can be a right choice for the organisation in charge for devising, supervising and implementing the DMPs, together with their responsibility to devise and implement the river basin management plans.

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