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Proactive Planning against Droughts

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Abstract

The paper presents a methodological framework based on the proactive planning approach for combating droughts and the associated water shortages. Three interrelated procedures tailored for each affected system are proposed: (a) the drought severity assessment; (b) the system vulnerability appraisal; and (c) the evaluation of drought risk. This scheme is assisted by the DPSIR methodology for the detailed estimation of drought risk of each affected system. The proposed methodological framework is put into practice through the preparedness and contingency plans against droughts. Further in this paper several technocratic and institutional aspects of these plans are discussed and brief guidelines for devising them are presented. Finally, the involvement of stakeholders and the public is examined in a decentralised decision system for the effective implementation of these plans in real world drought episodes.

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Keywords: drought assessment; proactive planning; drought risk; DPSIR; preparedness plan; contingency plan; public participation

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1. Introduction

Droughts are complex hazardous phenomena affecting most parts of the world. Recent studies revealed that more frequent and more intense droughts are anticipated in Europe and other parts of the world during the coming few decades [1].

It is known that droughts, unlike other natural hazards (such as floods or earthquakes) do not occur abruptly. They affect large areas for a considerable period of time. In some cases, persisting droughts last for several years. It is therefore possible to devise and implement in advance drought management plans at both preparedness and contingency modes [2].

The aim of this paper is to present and promote a methodological framework for combating droughts and the resulting water shortages in a proactive way.

The proposed methodology is based on the systemic risk approach which combines the drought severity assessment and the evaluation of drought risk in relation to the vulnerability to drought of the elements of each affected system.

The paper is structured in three parts: (a) clarification of concepts related to drought assessment; (b) presentation of the vulnerability - risk evaluation approach; and (c) presentation of the key elements for devising the preparedness and contingency plans to combat droughts and water shortages. The proposed methodology is assisted by the DPSIR method (Driver-Pressure-State-Impact-Response) mainly for the estimation of impacts of droughts (system risk) of each affected system.

Finally, some related social, institutional and legislative aspects, and the involvement of stakeholders and the public, are discussed for the effective implementation of these plans in a decentralised decision making system.

2. Basic notions

Some key concepts, used for the cases in which water is not sufficient, will be now defined and briefly discussed It must be accepted that the severity of deficient water availability lies on its impacts. Therefore, from numerous definitions of the terms used, the 'operational' rather than the 'conceptual' drought definitions are adopted in this study.

The general term describing the stress conditions due to lack or deficiency of water is defined as water scarcity. Water scarcity may be caused by either natural or human induced causes, or may result from the interaction of both. Table 1 presents the various types of water scarcity, their occurrence regime and their main causes.

Table 1. Types and causes of water scarcity.

Regime	Causes	
	Natural	Human Induced and Natural
Permanent	Aridity	Desertification
Temporary	Drought	Water Shortage

As known, Aridity is a natural 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, which in turn results in lower water resources availability.

Desertification and Water Shortage are mainly caused by human induced causes (or both human induced and natural) and they represent permanent and temporary imbalance in 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, whereas water shortage is the deficit of water supply to meet the demands, and is mainly caused by inappropriate or misuse of water resources, or man-made changes. However, it is very common that water shortages are 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 [3].

From the above it can be deduced that water scarcity, associated with aridity or desertification, calls for engineering and management measures that produce conservation and augmentation of water resources. On the contrary, water scarcity caused by droughts or water shortage related to drought require the development and implementation of preparedness and contingency plans to face the temporary conditions created.

Temporary water scarcity (that is drought and/or water shortage) is not directly 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 severe resulting in more adverse consequences. Therefore, if the assessment of these phenomena gives emphasis on the consequences, both the climatic regime (aridity) and the temporary deficiency (drought/water shortage) should be simultaneously studied.

Using an "operational" definition of temporary water scarcity (drought), the critical term of water availability, when it falls 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 total magnitude and the areal extent of the phenomenon. In fact, it is useful to know the temporal and spatial evolvement of each specific episode of drought.

Conventionally, drought may be treated as a meteorological, hydrological and 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 a reservoir in 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 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 derived. Table 2 presents the most commonly used variables representing water availability in the various expressions of drought [4].

Table 2. Variables representing water availability in the expressions of drought.

Drought type	Water availability variable
Meteorological	Precipitation, precipitation and evapotranspiration
Hydrological	Streamflow, reservoir storage or recharge of aquifers
Agricultural	Soil moisture supply

It is easily understood that regardless of the different expressions of drought, the phenomenon is basically of meteorological nature. However, since the impacts influence the life and activities of people, the flora and fauna, and the environment, it is wise to monitor the variable associated directly with these activities. This may also limit the uncertainty in projections to the future time horizons and may also convince all the involved agencies and stakeholders to agree upon the necessary actions to mitigate combat these adverse impacts. Based on this one can say that the inflow or reserve of the main reservoir of a water supply system is the most reliable variable to analyse.

The monitoring of drought conditions based only on precipitation may not be totally reliable. However, it can produce information in advance which is useful for the early warning of an approaching drought episode.

In all cases, however, and irrespective of the monitored variable, the threshold chosen for recognising a drought should be significantly lower than the median (or mean) of the selected variable. Also for characterising a drought episode, the period in which the variables remain below this threshold should be significant, dependent on the system studied and the type of impacts under study (e.g., several months).

3. Impacts of droughts

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, given the coping capacity, the resilience and the exposure of each affected system. This capability of the system to withstand the exerted pressure is usually measured by a metric known as vulnerability of the system.

In order to reduce the drought risk, one can decrease the vulnerability of the affected system by improving its coping capacity, mitigating the magnitude of the water shortage (and therefore its consequences) and improving the public awareness and public capacities (the so called social factor).

Having in mind the geographical area of the Mediterranean, the impacts of drought and associated 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 are presented in Table 3 as compiled from [5] and [6].

Table 3. List of drought impacts (compiled from [5, 6]).

Economic Impacts
1. Economic damage to agricultural production (crop reduction, damage in cultivations, epidemic, plants diseases)
2. Economic damage to forest production (decrease of forest growth, woods fires, trees diseases)
3. Economic damage to foremilk products and beef (reduction of pasture productivity, forced reduction of stock-farm, closing or reduction of public farm for pasture, increase of thefts, pasture fires)
4. Economic damage to fishing (damage to river habitat and fishes caused by reduced flows)
5. Economic loss to industries connected with agricultural production (food industries, industries producing fertilizing, etc.)
6. Economic damage to industries struck by hydroelectric energy reduction
7. Unemployment caused by production decrease
8. Economic damage to reduced navigability of streams, rivers and canals
9. Damage to tourism sector due to the reduced water availability in water supply and/or water bodies
10. Economic loss to entertaining
11. Economic damage to producers and tradesmen of amusing equipments
12. Pressure on financial institutions (more risks in lending, capitals decrease etc.)
13. Loss in public and local management revenue (because of reduction of taxes and taxes for hunting or fishing license, etc.)
14. Income reduction for water firms due to reduced water delivery
15. Additional costs deriving from integrative water resources use
16. Costs in emergency measures to improve resources and decrease demands (additional costs for water transport and removal, costs of advertising to reduce water use, etc.)
Environmental impacts
1. Lack of feed and drinking water
2. Increase of salt concentration (in streams, underground layers, irrigated areas)
3. Loss in natural and artificial (fish, landscapes, etc.)
4. Damages to river life (flora, fauna)
5. Damage to air quality (for example polluting dust)
6. Damage to landscape quality (soil erosion, dust, reduced vegetation coverage etc.)
Social impacts
1. Inconveniences due to water system rationing
2. Risks for health connected with increase of pollution concentration and discontinuous water system
3. Impacts on way of living (unemployment, reduced saving capability, difficulty in personal care, reuse of water at home, street and cars washing prohibition, doubt on future, decrease of fest and amusing, loss of property)
4. Inequity in drought impacts and mitigation measures distribution
5. Risks on public security due to more frequent fires (forests, pasture)
6. Abandon of activities and emigration (in extreme cases)

Despite the difficulties for estimating the drought impacts, there have been methods for a gross estimation usually in monetary or simply quantitative terms. These methods (e.g., the economic loss functions) produce rough estimates of impacts or a range of them. These simplistic methods, however, can be misleading due to the complicated nature of impacts. It is to note that the impacts of droughts on the water bodies can be apart from hydrological, physico-chemical and biological.

It should be noted that drought can be associated to the impacts following the steps described in Table 4, according to the methodology DPSIR (Driver-Pressure-State-Impacts-Response). As can be seen from Table 4, the meteorological drought [Driver] creates the hydrological and agricultural droughts (that is less inflows to the corresponding systems) [Pressure]. Therefore, low storage is recorded in the facilities of the water supply and distribution systems (municipal, irrigation, hydrodynamic) [State], resulting in adverse consequences such as hardship and hygiene problems in the municipalities and reduced production (and thus less revenue) for the industrial, touristic and irrigated agriculture sectors [Impacts]. Finally, for the rainfed agriculture a lower level of soil moisture is recorded due to drought [State], which in turn leads to less crop production and less revenue [Impacts]. Finally, the final stage of the DPSIR methodology, the response, is dealt within the next sections of the paper.

Table 4. Moving from meteorological drought to drought impacts according to the DPSIR method.

Driver	Pressure	State	Impacts	
Meteorological Drought	Hydrological drought	Low storage in water supply systems	Hardship (municipalities) Less revenue (Industry-Tourism Irrigated agriculture)	← blue water →
	Agricultural drought	Low soil moisture in the root zone of the crops	Less production Less revenue (Rainfed agriculture)	← green water →

It is interesting to see that the direct influence on rainfed agriculture is studied separately from the influence on the organised storage and distribution systems [7]. The first, in modern terms, is referred to as "green water" and the latter as "blue water". The impact of droughts on the green water is direct and cannot be easily avoided. On the other hand, the blue water is directly associated with the available infrastructure, and therefore, with the investments on engineering projects for storing and managing the water resources devoted to fulfil the requirements of the affected system.

Following a common procedure for evaluating the risk from a natural hazard, Tsakiris [8] proposed the calculation of the annualised risk, R(D), as a function of the pdf of the phenomenon, fD(x), the function of vulnerability of the system, V(x), and the potential consequence x (impact on the totally unprotected system), integrated over a long period of time (T years), according to the equation:

$$R(D) = \int_{0}^{T} x \cdot V(x) \cdot f_D(x) dx \tag{1}$$

in which V(x) is a 1-1 function taking values between 1 and 0. One means totally unprotected system and zero means totally protected system.

The estimation of annualised drought risk in agricultural systems is explained in detail in [8] and [9]. The annualised risk 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 also be used for identifying the Less Favoured Areas (LFA) in Europe based on the criteria included in the 'Climate Variability and Impact on Agriculture' [10].

Needless to say that the estimation of impacts and the risk in various sectors of the economy is a difficult task and in many cases can not be approached by 1-1 functions. There are also cases in which impacts can not be estimated at all. In these cases, the risk can be defined in a different way (e.g. as the exceedance probability of demand over availability).

4. Assessing drought severity

To facilitate the assessment of drought in an easy to understand way, special indices have been employed which represent the severity of each episode or period under drought. A large variety of indices (mainly of meteorological nature) have been proposed and used with varying success in various parts of the world. A software named DrinC (Drought Indices Calculator) was developed for the calculation of the most popular indices [11]. DrinC operates on a Windows platform and has been programmed in Visual Basic.

It is interesting to note that attention of the researchers has been mainly paid, so far, to the assessment of drought severity through the use of indices. The PDSI (Palmer Index), the Deciles and the SPI (Standardised Precipitation Index) are, among many others, the most popular indices used for assessing the severity of meteorological drought. Further, a new index the Reconnaissance Drought Index (although similar to SPI is based on both precipitation and potential evapotranspiration and is called RDI) [12]. The RDI has been extensively tested in a large number of watersheds in several parts of the world and has proved to be a comprehensive and sensitive drought index. The differences between SPI and RDI may be clearly illustrated when drought severity maps are generated. Since drought is a regional phenomenon, the spatial representation of each drought index is also of importance. For this purpose, illustrative pseudo-3D maps, the method of runs and the ‘or more’ cumulative severity-area curves have been successfully applied so far.

Apart from the indices selected to represent drought severity, the other dimensions of drought, that is the areal extent and the duration, could also be modelled.

Since drought is conceived as a multidimensional phenomenon (severity, duration, areal extent), it is difficult to model all the dimensions and reach results which can lead to meaningful management decisions, several simplifying representations have been proposed, such as to replace the three dimensions of drought by a unique dimension, in an attempt to reach a practical and easy way to assess the severity of drought and perform a meaningful frequency analysis. The river basin or sub-basin can be 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 beginning of the hydrological year (October for the Mediterranean) have been proposed [13].

Needless to say that for advanced detailed studies, all the three dimensions of droughts can be carefully modelled. Recently, the use of copulas has facilitated the studies dealing with all the dimensions of drought [14, 15].

It should be stressed here that the impacts of drought multiply if the drought event lasts for several consecutive years. Therefore, apart from the single year drought (which maybe an event with high probability), the multiyear droughts (with lower probability of occurrence) should be also studied in detail, due to their catastrophic consequences [16].

5. Drought preparedness and contingency plans

5.1. From crisis management to risk management approach

When working with water scarcity, one can easily understand that due to many different definitions, many different sectors of interest, different variables examined and even different severity indices used, it is rather a utopia to expect to devise a unique detailed procedure for developing and implementing preparedness plans and contingency plans for all types of regions using the same tools. However, what is most important in the development of such plans, is to work on the same framework, to reach a common language and common presentation of results, in order to devise procedures for risk assessment and management meaningful to agencies and stakeholders.

As easily understood, the cornerstone of this initiative is that drought is considered as a natural hazard, and therefore, the approach to be followed will be a risk management approach. This calls for assessing the water shortages created by drought in all the affected systems and for estimating the impacts on each of these systems. Therefore, attention is focused on the vulnerability of each system and specifically on all its elements.

Finally, it is clear that the preparedness planning approach, as a risk management approach, is a proactive planning approach which is proposed to replace the crisis management approach. As known, the latter has been the commonly applied practice of the past to face these phenomena in most countries and regions of the world.

5.2. Tasks

Although in most situations related to water stress conditions it seems that a stalemate is reached, a thorough study of all the related variables and conditions reveals a great number of options and tasks that are available for drought preparedness and mitigation planning. The variety of options actually applicable to a particular setup is highly dependent on the characteristics of the affected system, on its geographical coordinates and its economic, environmental and social conditions. Options may differ, dependent on whether they are to be used for strategic planning (unconditional drought risk management) or for real time management (conditional risk management). In the latter case the initial conditions may play a decisive role on the selection of measures.

It should be stressed that the selection of the appropriate option/measure or combination of options/measures should be based on a multicriteria evaluation (see for example [17, 18]).

An indicative list of options and tasks, generally available in situations of water shortage, is presented in Table 5 below, compiled from various sources. The options are grouped into four different categories under the titles:

a. Severity Assessment – Transparency
b. Demand Reduction Measures
c. System Improvements
d. Emergency Water Supplies

Table 5. Major water shortage management options / tasks.

A.	**Severity Assessment – Transparency**
a.	Frequent information of water shortage severity
b.	Meetings and public discussions
c.	Task force establishment
d.	Analysis of demand and efficiency
e.	Preparation of options and responsibilities
f.	Targets in various uses
g.	Official request to central government and/or EU
h.	Planning of employees' vacations
B.	**Demand reduction measures**
a.	Public learning campaign appeals for voluntary conservation from
	i.Farmers
	Industrialists Touristic agents Public
	ii.Bonuses and incentives
b.	Free distribution and/or installation of particular water saving devices
	i.Extensive installation of water meters (in all types of systems)
	ii.Low-flow showerheads
	iii.Shower flow restrictions
	iv.Toilet dams

v. Displacement devices
vi. Pressure-reducing valves
c. Restrictions on non-essential uses
i. Street flushing
ii. Pavement hosing
iii. Car washing
iv. Lawn sprinkling
v. Filling of swimming pools
vi. Water cooled air conditioning without re-circulation
vii. Public fountains
viii. Park irrigation
ix. Irrigation of golf courses
x. Irrigation of perennial and drought resistant crops
d. Prohibition of selected commercial and institutional uses:
i. Car washes
ii. School showers
iii. Irrigation of non-important plants
e. Drought emergency pricing:
i. Irrigation water charge per volume
ii. Drought rate (special extra charge for irrigation)
iii. Drought surcharge on total water bills
iv. Summer use charge
f. Rationing programmes
i. Per area and crop allocation of irrigation water
ii. Per capita allocation of residential use
iii. Per household allocation of residential use
iv. Prior use allocation of residential use
v. Percent reduction of commercial and institutional use
vi. Percent reduction of industrial use
vii. Complete closedown of industries and commercial establishments with heavy use of water

C. System improvements
a. Raw water sources
b. Water treatment plant
c. Distribution system:
i. Reduction of system pressure to minimum possible levels
ii. Implementation of a leak detection and repair programme
iii. Discontinuing hydrant and main flushing
d. Selection of individual household inspection for repairs

D. Emergency water supplies
a. Inter-use transfers
i. Purchase of water rights of farmers
ii. Planned reallocation of irrigation to municipal use
iii. Water trade - water banks

b. Inter-district transfers
 i. Emergency interconnections
 ii. Importation of water by trucks
 iii. Importation of water by railroad cars
c. Cross-purpose diversions
 i. Reduction of reservoir releases for hydropower production
 ii. Reduction of reservoir releases for flood control
 iii. Diversion of water from recreation water bodies
 iv. Relaxation of minimum streamflow requirements
d. Auxiliary emergency sources
 i. Utilization of untapped creeks, ponds and quarries
 ii. Utilization of dead reservoir storage

Most of the above options are difficult to be decided and more difficult to be implemented. It is, therefore, of outmost importance that criteria and thresholds are elaborated and agreed by all stakeholders for all the levels of risk in the drought monitoring process such as alert, alarm and emergency.

Among the options/measures, of particular interest is the establishment of a reliable and widely accepted prioritisation scheme for water demand fulfilment in the rationing programmes during a severe or extreme drought episode.

5.3. Institutional and governance issues

Similarity to the water resources management plans, drought and water shortage preparedness and mitigation plans have three dimensions:

- technocratic dimension
- institutional context
- implementation process

For the latter two, the establishment of river basin organizations (RBO) seems to be essential for an effective implementation of such preparedness plans. If needed a Special Task Force can be established within each RBO (with coordination responsibilities) for avoiding fragmentation of the decision making process. The key critical issues and implications in the organisational process lie on:

- the acceptance for the decentralisation in decision making (local players take decisions)
- the consistent commitment of governments to the creation and implementation of management at the basin or water system scale
- the acceptance of shared responsibilities between the central government and local communities by agreeing on the specific rights and responsibilities assigned to each actor
- the participation of stakeholders in the framework of river basin organisations.

In this context, decentralisation in decision making is of outmost importance. The RBOs should be based fully on institutionalised initiatives rather than relying too much upon charismatic individuals. It should be noted that the decentralisation process is a process of trust building between central and local agencies and the users. Therefore, it is a long lasting process, in some cases taking decades to stabilise [19]. It should be recognised, however, that significant steps towards decentralisation have taken place through the water resources management plans of the Water Framework Directive in most European countries, according to the first assessment reports on the implementation of WFD in Europe [20].

6. Concluding remarks

In this overview paper, an attempt was made to devise a methodological framework for the preparedness plans against droughts and water shortages in advance of any drought episode. The proposed framework is based on two parts: (a) the risk evaluation and (b) the rational selection of measures. The first part comprises the following steps: 1) determination of each affected system and its elements; 2) appraisal of vulnerability of systems and their elements; and 3) evaluation of drought/water shortage risk. This part is assisted by the analysis provided by the DPSIR method. The second part comprises the following steps: 1) identification of viable measures; 2) multicriteria assessment of their effectiveness; and 3) prioritisation in the implementation of measures.

We should bear in mind that apart from the technocratic approach, the institutional, legislative and social dimensions are cornerstones for the implementation of each plan. In both parts, but mainly in the second part of the proposed framework, the involvement of all principal stakeholders is essential for the success of the preparedness plans to combat drought and water shortage.

It is concluded that the preparedness plans against droughts should be devised well in advance of any drought episode. Each plan should involve a detailed organisational structure, responsibilities, priorities, groups of interest, timetable of activities, media of communication and operational monitoring systems.

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