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Additional Information

A Review of Water Scarcity and Drought Indexes in Water Resources Planning and Management

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Abstract

Water represents an essential element for the life of all who inhabit our planet. But the random nature of this resource, which is manifested by the alternation of wet periods and dry periods, makes it even more precious. Whatever the approach (water planning, water management, drought, economy), in order to maximise the profit produced by the allocation of water it is necessary an understanding of the relationships between physical variables as precipitation, temperatures, streamflows, reservoir volumes, piezometric levels, water demands and infrastructures management. This paper attends to provide a review of fundamental water scarcity and drought indexes that enables to assess the status of a water exploitation system. With the aim of a better water management and governance under water scarcity conditions., this paper also presents a classification of indexes to help decision makers and stakeholders to select the most appropriate indexes, taking as the starting point the objectives of the analysis and the river basin features.

Keywords: Water planning, water management, water exploitation system, water scarcity indexes, drought indexes

1. Introduction

Water represents an essential element for the life of all who inhabit our planet. But the random nature of this resource, which is manifested by the alternation of wet periods and dry periods, makes it even more precious. Despite the social, economic and environmental significance that represents the lack of this resource, there is no unanimity concerning on the definition of concepts related to water scarcity, drought or water shortage in the literature (EU, 2012). As noted by Quiring (2009), this is a complex phenomenon that is difficult to accurately describe because its definition is both spatially variant and context dependent.

In general terms, water scarcity covers all aspects related to restricted water availability. According to EU (2007) water scarcity is defined as a situation where insufficient water resources are available to satisfy long-term average requirements and similarly, Van Loon and Van Lanen (2013) considered that water scarcity represents the overexploitation of water resources when demand for water is higher than water availability. Aridity, by contrast, is a climatic feature consisting of low ratio between precipitation and potential evapotranspiration (Tsakiris and Vangelis, 2005), representing a permanent phenomenon.

In the same way, the term drought has been defined in different ways. There are two main types of drought definitions: conceptual and operational. On the one hand, conceptual definitions are formulated in general terms to describe the concept of drought. According to this type of definition, as noted by Estrela and Vargas (2012), drought is a natural hazard that results from a deficiency of precipitation from expected or normal, which can in turn translate into insufficient amounts of water to meet the water needs of ecosystems and/or human activities. Whereas EU (2007) considers drought as a relevant temporary decrease of the average water availability. On the other hand, operational definitions are used to identify the beginning, end and severity of droughts. In this sense, there is no single operational definition of drought that can be used in all contexts. This is the reason why policy makers and resources planners use drought index thresholds to determine the accurate moment to implement preventive measures (Quiring, 2009).

According to the definition of drought as a natural hazard, there are different categories of droughts depending on the reference variable considered. In this study, we distinguish between three types of droughts:

i. Meteorological drought is defined as a continued shortage of precipitation. This is the drought that raises the other types of drought and usually tends to affect large areas. The origin of the lack of precipitation is associated with the global behaviour of the ocean-atmosphere system, where both natural and human factors, such as deforestation or the increase in greenhouse gases, have strongly influenced.
ii. Agricultural drought may be defined as a moisture deficit in the root zone to meet the needs of a crop, affecting the crop development and declining crop yields.
iii. Hydrological drought is defined as a period of low flows in watercourses, lakes and groundwater levels below normal. It is related to a period with a decrease in surface and groundwater water resources availability for established water uses of a given water resources system (Mishra and Singh, 2010).

As a consequence of the natural phenomenon, the terms operational drought (Sánchez-Quispe et al., 2001) and socio-economical drought (Mishra and Singh, 2010) are also used in the literature. Even though these terms do not represent a natural hazard, they can cause water shortage, understood as the deficit of water supply to meet social and environmental demands which are caused by intense drought episodes, an inappropriate use of water resources or man-made changes (Tsakiris et al., 2013). Operational drought refers to a period with anomalous supply failures (no satisfaction of water uses) in a developed water exploitation system. The causes include: the lack of water resources (hydrological drought), the excess of demand, or an inadequate design and management of the water exploitation system and its operating rules. Socio-economic drought is associated with the condition of water scarcity on people and the economic activity causing socio-economic, social and environmental impacts. In recent decades there has been an increase in the number of episodes of socio-economic drought that has led in many cases to significant economic losses, which are a consequence of the increasing pressure on water resources exerted by human activities. As noted by Tsakiris et al. (2013), it is estimated that the cost of drought in Europe during the last 30 years is 100 billion Euros. Figure 1 explains the relationship between these types of drought and the duration of the event.

Figure 1. Relation between different types and duration of drought events (modified from Villalobos (2007))

Whatever the approach (water planning, water management, drought management, economy), society expects that policymakers and stakeholders maximise the profit produced by the allocation of water. In this sense, the use of indexes is highly relevant for decision-making processes (Lama, 2011). Before continuing, it is required to distinguish between indexes and indicators, and their use in water policies. Indexes represent an aggrupation of variables or indicators which are weighted in order to take into consideration social preferences. They are used for the development of water policies and reflect social requirements. Whereas indicators are obtained as an aggrupation of variables and expect to communicate information about the water resources system. They are based on the knowledge and scientific judgment. So, when displaying environmental information, the level of its detail would be in inverse proportion of the number of users (Vardon et al., 2012). Researchers handle a mass of information, this information is aggregated so managers and analysts use indicators and finally, indexes are used by decision-makers and wider public (see Figure 2).

Figure 2. Aggregation of information in water resources planning and management

To date, scientists and researchers have defined a huge quantity of water indicators related to different approaches, such as water productivity, ecosystem services, weather forecasting, or drought management, as an example, Lloyd-Hughes (2014) noted that more than one hundred indexes have been proposed for use only in drought monitoring.

The target of this paper is to present a review of water indicators related to water planning and management. In order to do this, in section 2, we present a review on drought and water scarcity indexes along with indicators derived from water accounting (section 3) and performance indexes (section 4). In section 5, we propose a recompilation and classification of water related indexes in order to organise them according to the context of use, the key issue represented and the river basin features, which may be useful during the decision making process. Finally, conclusions and recommendations are presented.

2. Drought and scarcity indexes

The severity of droughts is represented by drought indexes, which have been developed to detect, monitor and assess drought events (Estrela and Vargas, 2012). Several drought indexes have been defined in last decades. The most commonly variable employed in their definition is precipitation in combination with other variables such as temperature, soil moisture, etc. The most frequently drought indexes are the Palmer Drought Severity Index (PDSI) (Palmer, 1965), rainfall deciles (Gibbs and Maher, 1967), Crop Moisture Index (CMI) (Palmer, 1968), Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982); Standardized Precipitation Index (SPI) (McKee et al., 1993) or the Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis, 2005). An extended state-of-the-art review on drought concepts has been provided by Mishra and Singh (2010).

To assess water scarcity, the most commonly approaches are the water resource vulnerability index (Raskin et al., 1997), water stress index (Falkenmark et al., 1989), International Water

Management Institute (IWMI) indicator (Seckler et al., 1998), critical ratio (Alcamo et al., 2000) and the water poverty index (Sullivan, 2002). An extended state-of-the-art review on water scarcity has been provided by Rijsberman (2006).

The use of water scarcity and drought indexes is not addressed only to describe or characterize the situation of a river basin, but they may also be applied in order to mitigate long-term drought risk. An example of the application of measures to reduce drought impacts is the case of the National Drought Indicator System in Spain which is described below.

2.1. Status Index from the National Drought Indicator System in Spain

Spain, as a Mediterranean country, has always presented water scarcity problems related with prolonged drought episodes. This country represents an example of an ancient tradition in water planning, where water resources are heavily regulated, being the fifth country in the world with the highest number of large dams (Instituto Nacional de Estadística, 2008). During decades, drought management in Spain was carried out as an emergency situation, being necessary the application of several Royal Decrees to mitigate the negative impacts. Due to the need of anticipation in the application of mitigation measures, it was essential to develop a system of indicators to warn when the measures have to be taken and what kind of measures were the most appropriate given the current level of risk, in other words, depending on the severity of the situation existing at any given moment.

This system of indicators consists of spatially distributed control points in the area of the river basin and collects information about reservoir storages, groundwater piezometric levels, streamflows, reservoir inflows and precipitation (MMA, 2007). Each River Basin Authority has adopted a calculation method for the definition of the drought indicator. According to these criteria, these indexes take values between 0 and 1, low values corresponds to drought conditions and values between 0.5 and 1 indicate the absence of problems related with drought. By weighting the index value in each zone we obtain an overall index value. These indexes allow us to classify the water exploitation systems into four hydrological states: normal, pre-alert, alert and emergency (see table 1). Haro et al (2014) discussed the validity of the application of this approach in any kind of system. They showed how this methodology fails at determining the drought status of within-year regulated systems, being thus necessary to adopt a different approach depending on the system's operation. Figure 3 shows the basin drought status for the water exploitation systems in late June 2014.

Figure 3. Basin Status Index in June 2014 (www.magrama.es)

As mentioned above, one of the main functions of the National Drought Indicator System (MMA, 2007) is the application of measures to reduce the impact of droughts based on the state of the indicators. Three types of measures are considered:

i. Strategic measures. They represent the medium and long term answer. They often require substantial investments such as construction of new reservoirs, desalination, reuse systems, etc.
ii. Tactic measures. They represent the short term response. They would be measures to promote voluntary savings for both supply and irrigation, or, accelerate the development of planned infrastructure.
iii. Emergency measures. They respond to unexpected circumstances. They are measures such as the construction of new emergency wells, the establishment of supply restrictions or prohibition of uses, among others.

The following table shows the relationship between the hydrological state of the system and the type of measure to be applied:

Table 1. Relationship between the hydrological state of the system and type of measures to be applied

3. Indicators derived from water accounting

Water accounting is an approach focused on the presentation of information relating to the water resources in the environment and the economic aspects of water supply and use (Vardon et al., 2007). Among its goals is to achieve a sustainable water balance and an equitable and transparent water governance for all water users (www.wateraccounting.org). As noted by Molden and Sakthivadivel (1999), their methodology is based on a water balance approach where, based on conservation of mass, the sum of inflows must equal the sum of outflows plus any change in storage. Water accounting covers a range of methods of reporting water information (Godfrey and Chalmers, 2012). Some examples of water accounting systems are the System of Environmental-Economic Accounting for Water (SEEAW) (UN, 2012) and the Water Footprint Accounting (Hoekstra, 2003).

3.1 The System of Environmental-Economic Accounting for Water

The SEEAW has been developed by the United Nations Statistics Division (UNSD) in conjunction with the London Group on Environmental Accounting (UN, 2012). Its main objective has been standardizing concepts related to water accounting, providing a conceptual framework for organising economic and hydrological information. In this sense, water accounting generally, and particularly the SEEAW, expects to become a useful tool for helping the decision-making process on issues of allocating water resources and improving water efficiency among others. In this sense, the SEEAW constitutes a structured database from which researchers may obtain many water-related indicators (UN, 2012). Each of these tables allows us to obtain the indicators of internal renewable water resources, external renewable water resources, total natural renewable water resources and total actual renewable water resources.

As noted by UN (2012), it is also possible to link the list of indicators proposed in the second World Water Development Report (UN, 2006) and the SEEAW. The cited indicators are the index of non-sustainable water use, the relative water stress index, the water reuse index, the total actual renewable water resources (TARWR) volume, the surface water as a percentage of

TARWR and the groundwater development (groundwater as a percentage of TARWR). Margat (1996) proposed several indicators that could be obtained from the water accounts and expected to cover essential aspects of water availability and use. These indicators are: validity of hydrological basis, density of internal resource, concentration index of the resource, regularity index of the resource, independence of the reference territory, freedom of action index, resource per capita, exploitation index, consumption index, water resource wearing and water sanitation and purification index.

3.2 Water Exploitation Index

Water Exploitation Index (WEI) (EEA, 2005) is obtained as the percentage of mean annual total demand for freshwater with respect to the long-term mean annual freshwater resources and shows to which extent the total water demand puts pressure on water resources. The way to build the WEI indicator is by using data from SEEAW Tables 3.1, 6.1 and 6.2 (EEA, 2013). Values of WEI in a river basin between 0 and 20% show a situation of no stress; values between 21 and 40 % indicate water stress; and values upper than 40% represent extreme water stressed river basins (see Figure 4).

Figure 4. Water exploitation index in European Union (Source of data: http://www.eea.europa.eu/data-and-maps/figures/water-exploitation-index-2014-towards)

Despite being the index employed by the EU, there are different key issues that jeopardise the use of this index. One of them is seasonality. As it is based on annual averages it is not able to display a scarcity event at monthly scale. There may be situations in which having the same annual average of resources and demand, the pressure on the resources may be completely different due to the irregularity of resources (EEA, 2013). It is useful to analyse monthly ratios and suggest an aggregation method to describe the water stress situation in the river basin. On the other hand, the uncertainty in the assessment of demands and water resources values may result in incorrect values of the indicator.

In order to solve the limitations presented by the WEI, a modified water exploitation index called WEI+ has been defined (CIRCABC, 2012). The index focuses on the assessment of net consumption and it is defined at monthly level as follows:

$$WEI+ = \frac{(abstractions - returns)}{renewable\ water\ resources} \qquad \text{(Eq. (1))}$$

Where abstractions mean the volume of water intaken for a determined use (agrarian, urban, industrial) and returns refer to the volume of water which comes back to the environment after being used. There are two ways of addressing the renewable water resources (RWR): (1) by employing the hydrological balance equation, using precipitation (P), external inflows (ExIn), actual evapotranspiration (Eta) and change in natural storages (ΔS); or (2) by naturalisation of streamflows, using the outflows and the change in storage of artificial reservoirs (ΔSart).

$$RWR = ExIn + P - Eta - \Delta S \qquad \text{(Eq. (2))}$$

$$RWR = Outflow + (abstractions - returns) - \Delta Sart \qquad \text{(Eq. (3))}$$

Considering all these difficulties, several indicators have been considered for the presentation of water accounts (EEA, 2013). Firstly, the WEI has been normalised to reflect the entirety of resources before abstraction takes place. The nWEI is computed monthly and at sub-basin scale as follow:

$$nWEI = \frac{abstractions}{outflow + abstractions - returns} \qquad \text{(Eq. (4))}$$

Whilst environmental requirements are not explicitly considered in SEEAW tables, the ecological needs represent an important issue, in this sense, a potential indicator of ecological stress for rivers (ESIr) has been defined similarly to the nWEI:

$$ESIr = \frac{outflow}{outflow + abstractions - returns} \qquad \text{(Eq. (5))}$$

This indicator presents two problems: the first is that the denominator tends to zero if outflows are scarce; and the second problem is considering the final balance when actually there may be water bodies impacted with local withdrawals (EEA, 2013).

The third indicator represents a consumption index (WEI_{+c}) and it is computed as follows:

$$WEI_{+c} = \frac{(abstractions - returns)}{outflow + abstractions - returns} \qquad \text{(Eq. (6))}$$

Since nWEI, ESIr and WEI_{+c} are defined at monthly level, it is required some aggregation before their presentation. The EEA (2013) has proposed a percentile distribution to aggregate the indexes during the considered period. According to this report, mapping the indexes at 50% suggests structural water availability issues; by contrast, the 90 % indexes show there may be a recurrent water supply problem.

3.3 Water Footprint and Virtual Water

The Water Footprint approach was introduced by Hoekstra (2003) because of the need for an indicator based in freshwater use. It is defined as the total volume of freshwater that is used to produce the goods and services consumed by an individual or community (Hoekstra and Chapagain, 2008). The water footprint allows for the differentiation of the consumed water according to its origin, distinguishing between blue water footprint, green water footprint and grey water footprint. The blue water footprint represents the consumption of liquid water available en rivers, lakes, wetlands and aquifers; the green water footprint refers to the use of rainwater stored in the soil as soil moisture which is available to plants; and the grey water footprint is defined as the volume of freshwater needed to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra, 2009).

Closely linked to the concept of water footprint is the virtual water (Allan, 1998), understood as the volume of water used in the production of a commodity, good or service. It refers to the idea that when a country imports one kilogram of a product (no matter the good or service) implicitly, this country also imports the amount of water used to produce it. Both concepts (virtual water and water footprint) are interesting in water scarcity countries because their assessment could inform the decision makers about the possibility of producing those goods most suited to local environmental conditions (Aldaya et al., 2010).

When producing the water accounting in a country, there are several terms which are not considered (Hoekstra, 2012); they do not differentiate between water uses for domestic consumption, for producing export products or water uses outside the country to support national consumptions. A scheme to obtain the national water footprint accounting is described below. The water footprint in a nation has two terms: the internal water footprint (the amount of water resources used to produce the goods and services that are consumed by national population) and the external water footprint. The first one is obtained as the difference between the uses of water within the nation minus the virtual water imported from other countries. In the same way, the external water footprint (the amount of water resources used in other nations to produce goods and services that are consumed by national population) is obtained as the virtual water imported into the nation minus the amount of virtual water exported to the other nations. This separation of components allows for evaluating the dependency ratio of water resources in a country (WD) defined as the external water footprint (WF_E) divided between the national water footprint (WF) (Rodríguez et al., 2008).

$$WD\ (\%) = \frac{WF_E}{WF} \cdot 100 \qquad \text{(Eq. (7))}$$

As water footprint is composed by the set of goods and services consumed by an individual or community, it can be calculated at different levels of consumer activity (Fulton et al., 2014). So, if researchers want to use water footprint accounting as an indicator of water resources management, the best territorial unit is the river basin (Pellicer et al., 2013), even though, as noted by Zeng et al. (2012), water footprint assessment studies at river basin level are rare in the literature largely due to the lack of statistical data at this level.

The approach of water footprint has been used in the definition of the water scarcity index (Zeng et al., 2014). This index has been used to describe the severity of water scarcity in the form of a water scarcity meter to allow an easy interpretation. It has two components: the blue water scarcity index (I_{blue}) and the Grey water scarcity index (I_{grey}). I_{blue} is defined as the ratio of the water withdrawal to freshwater resources and, I_{grey} is defined as the ratio of grey water footprint to freshwater resources. A review on the indicator of water footprint for European countries has been done be Vanham and Bidoglio (2013).

4. Performance Indexes

As noted by Hashimoto et al. (1982) the operational status of a water resources system can be described as either satisfactory or unsatisfactory. The level of a system performance was described, in Hashimoto et al (1982) research, from three different points of view: (1) how often the system fails (reliability), (2) how quickly the system returns to a satisfactory state once a failure has occurred (resiliency), and (3) how significant the likely consequences of failure may be (vulnerability).

Derived from the adoption of the aforementioned concepts, in this sub-section, several indicators are presented which describe the possible performance of a water resources system.

4.1 Sustainability Index

To quantify the sustainability of water resources systems, Loucks (1997) proposed the sustainability index (SI), with the aim of facilitating the evaluation and comparison of water management policies. This index is based on reliability (Rel), resilence (Res) and vulnerability (Vul) concepts. For the *i*th water user the index proposed by Loucks (1997) was:

$$SI^i = Rel^i * Res^i * \left(1 - Vul^i\right) \qquad \text{(Eq. (8))}$$

Sandoval-Solis et al. (2011) proposes a variation of Loucks' SI considering a geometric average of *M* performance criteria (C_m^i) for the *i*th water user:

$$SI^i = \left[\prod_{m=1}^{M} C_m^i\right]^{1/M} \qquad \text{(Eq. (9))}$$

For instance, if the performance criteria are C_1^i= Rel^i, C_2^i= Res^i and C_3^i= Vul^i, the SI for the *i*th water use is:

$$SI^i = \left[Rel^i * Res^i * \left(1 - Vul^i\right)\right]^{1/3} \qquad \text{(Eq. (10))}$$

The main advantage of this index is that it allows the inclusion of other criteria according to the necessities of each territory and the use of geometric average to scale the values of SI.

4.2 Efficiency Indicators

Martin-Carrasco et al. (2013) suggests four water indexes to evaluate water scarcity at a river basin scale. The use of the efficiency indicators requires grouping the demands across several classes depending on their respective use of water. For each demand category, model results are analysed through the Demand-Reliability curve. Based on this curve, it is possible the determination of the four water indexes:

- Demand Satisfaction Index (I_S), which evaluates the system's capacity to supply its demands
- Demand Reliability Index (I_R), that quantifies the reliability of the system to satisfy demands
- Sustainability Index (I_U), which evaluates the natural resources available for development in the system
- Management Potential Index (I_M), which quantifies the proportion of the demand with unacceptable reliability that is close to the acceptable level.

In systems affected by water scarcity problems, the indicators can also diagnose its causes, and anticipate possible solutions.

4.3 Water Allocation Index

Milano et al. (2013) use a water allocation index (WAI) in order to assess the capacity of water resources to meet current and future water demands. This index is obtained by means of the quotient between water supply and water demand (%) for each year of a given period. By employing this index different water demand satisfaction classes have been defined for environmental flow requirements and the domestic sector and for the agricultural sector. Table 2 shows a classification of water demand satisfaction classes based on the WAI for environmental flow requirements and the domestic sector and for the agricultural sector.

Table 2. Water demand satisfaction classes based on the water allocation index for (1) environmental flow requirements and the domestic sector and for (2) the agricultural sector (Milano et al., 2013)

4.4 The reliability criterion established in the Spanish Guidelines of Water Planning

The criterion established in the Spanish Guidelines of Water Planning (BOE, 2008) is a simple binary criteria (complies/does not comply). It indicates that for the purposes of resource allocation and reservation, urban demand is considered satisfied when the deficit in one month does not exceed 10% of the corresponding monthly demand and when in 10 consecutive years, the sum of deficits is less than 8% of the annual demand. Similarly, agrarian demand is considered satisfied when the deficit in one year does not exceed 50% of the corresponding demand; for two consecutive years, the sum of deficit does not exceed 75% of annual demand; and in ten consecutive years, the sum of deficit does not exceed 100% of the annual demand.

4.5 Performance Weighted Index (IPOC)

The Performance Weighted Index (IPOC, in Spanish) was used in the National Hydrological Plan (MMA, 2001). This index evaluates the global performance of a water resources system by the average of the ratio between the deficit in one, two and ten consecutives years, and the acceptable deficit during the same periods for each considered demand. If there is no fault in the system IPOC is 1 and, if there is a failure in one or several demands IPOC will be greater than 1.

This index attempts to be more flexible than the reliability criterion established in the Spanish Guidelines of Water Planning (BOE, 2008), which considers that the systems fail if there is one demand that contravenes the criterion. Moreover, in order to consider the relevance of each demand or group of demands, these deficits are weighted to avoid that a failure in a non-relevant demand for the exploitation system involves the failure of the global system.

4.6 Exploitable Water Resources

In order to quantify water availability, AQUASTAT (FAO's global water information system) suggests the use of the indicator of exploitable water resources. This indicator is defined as the part of the water resources considered to be available for development under specific technical, economic and environmental conditions but, despite its significance, there is disagreement in regard to the best process for calculating exploitable water resources (UNSD, 2012).

Pedro-Monzonís et al. (2015) have determined the key issues for determining this indicator in a Mediterranean river basin. In that work, the exploitable water resources have been obtained as the maximum demand that can be served in a water exploitation system while complying with the reliability criteria established by law. Once the hypothesis about the obtaining of natural streamflows and the reliability criteria for considering the supply to be satisfied is selected, the steps used to obtain this indicator are as follows: (a) select the possible places in the system where new water allocations could be required and their type of use (urban or agrarian); (b) analyse the possibility of increasing each single demand while considering the other demands as zero, and execute the simulation model. The final result is achieved when the maximum demand is obtained while fulfilling the required reliability criteria.

5. Classification of Water Related Indexes in Water Resources Planning and Management

As seen, in the literature there is a huge amount of indicators and indexes related to water. Each of them has been defined under different assumptions or conditions, so, its applicability may be adequate or not in all areas of study. The classification of water scarcity and drought indexes proposed below attempts to organise them according to the context of use, the key issue represented (aridity, water scarcity or drought), the type of drought analysed and the utility. In this sense, the context of use distinguishes between natural use, water resources planning and water allocation, and management. This distinction is done to discern on whether the considered variables to define these indexes are influenced by the management of the river basin or they are independent of human activities.

Firstly, Table 3 groups water scarcity and drought indexes in the context of natural water use due to the fact that, a priori, human activities do not have influence in variables as precipitation, temperature or potential evapotranspiration. Frequently, these indexes are used to determine drought periods, aiming to identify drought properties, such as intensity, duration and magnitude. Moreover, as a universal definition of drought suitable in all circumstances does not exist, most of these indexes are also used as an operational definition of drought, providing information about levels of severity. In this sense, Quiring (2009) indicates that the most commonly indexes used for monitoring drought and determine the operational drought definition (thresholds) are PDSI, precipitation and streamflows.

Table 3. Classification of water scarcity and drought indexes in the context of natural water use. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological

drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Secondly, Table 4 groups water indexes related to variables which may be affected by the use of water infrastructures or traditionally used in water planning for water allocation. In the case of indicators derived from water accounting, they show a current description of the river basin and allow the decision makers and stakeholders to make comparisons between the use and pressures of water resources in different regions. But, in the case of performance indexes, as water resources planning consists of the analytical study of the water resources to identify and solve the river basin problems in the long term, it is difficult to untie these indexes and the human activities. In other words, new measures are proposed aiming to improve the status of the water resources system, reflected by these kind of indexes.

Table 4. Classification of water stress indexes in the context of water resources planning and water allocation. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Finally, Table 5 shows the indexes related to the management stage. As expected, to solve water scarcity problems policymakers resort to water resource management, using the implementation of preventive measures in order to reduce the effects of droughts (Estrela and Vargas, 2012; Van Loon and Van Lanen, 2013). In this case too, these indexes are also used as an operational definition of drought, helping drought planners to decide when to start implementing drought measures. The importance of these indexes is crucial due to the fact that the application of specific measures are conditioned by the immediacy or the legal and administrative procedures (Ferrer and Pedro-Monzonís, 2014), and they need a clear identification of their application timing. As seen, the amount of this kind of indexes in the literature is lower than previous groups, possibly due to the fact that this index represent a practical activity more than a research activity.

Table 5. Classification of water stress indexes related to the management stage. [In Key issue column, A means aridity, S means scarcity, D means drought; In Type of drought column, M means meteorological drought, A means agricultural drought, H means hydrological drought, O means operational drought and S means socio-economical drought]

Some impressions derived from the previous tables are described below:

- Not always the classification between key issue and type of drought is easy or possible, and in some cases it could have more than one solution. The NDVI can be an example: it seems to represent clearly an agricultural drought (A) and, in fact, this is accurate when we refer to rainfed agriculture. But in irrigated agriculture, which depends on rivers or streamflows, it can represent a hydrological drought (H) or an operational drought (O) when surface water comes from artificial reservoirs.
- We can find in the literature many indexes related to the context of natural water use, which, in many cases, are used to identify the magnitude of drought periods. Sometimes, their usability during water resources management processes is limited. This may be due to the fact that these indexes require the definition of a threshold to identify the kind of measures to be applied according to the level of risk.
- There are few indexes related to the management stage. The reason may be that this is a relatively new approach which has been carried out since the last decade, and the availability of data from reservoir and piezometric levels is not vast enough to carry out a deep investigation. However, there are many indexes related to the water planning in the long term, which, in most cases, use simulation models to address the lack of data.
- We have also seen that, in some cases it is difficult to distinguish the key issue between aridity and scarcity. Especially in the case of water management systems, where demand is established by human beings and it could change according to decisions which sometimes are included in the analysis.

- In connection with the different types of drought, the distinction between operational and socio-economic drought may be difficult. Especially, when operational decision such as water allocation during drought periods may originate socio-economic effects.

6. Conclusions

In this paper, several water indexes have been summarized. Some of them have served to identify the types of drought (meteorological, agricultural, hydrological, operational or socio-economic), while others allow us to characterize the pressures on the water resources, to justify the allocation of new demands, or the volumes used to produce goods and services among others. This vast amount of indexes and indicators demands collecting information related to a huge variety of disciplines, representing a complex issue, and moreover, when there is no unanimity about basic terms as water scarcity and drought.

A priori, there is not a unique indicator suitable for all areas of study. In this sense, there is a clear need for using different indexes according to the proposed objectives. To do this, knowing the limitations of these indexes is crucial. That is why this paper presents a review of water scarcity and drought indexes related to water planning and management, with the aim of analysing whether they are appropriate for the climate of the region or for the objectives of the study. For this purpose, the different approaches to analyse the status of a river basin have also been reviewed. For example, in recent years, drought episodes have required the implementation of anticipation measures which have influenced the new policies for water resources management (short term) and planning (long term). According to this target, it is noteworthy that a key feature of drought management plans is the use of water drought indexes to establish a link between the current river basin status and the measures to be taken. On the other hand, indicators derived from water accounting allow a general description of the river basin, with an emphasis on water economics and the benefit of natural water and managed water. If our goal is the purposes of resource allocation it may be desirable the use of simulation models to obtain performance indexes which evaluates the status of the water resources system.

This recompilation and classification of indexes aims to be useful to select the most appropriate index, taking as the starting point the objectives of the analysis and the river basin features (a natural system or an altered system due to their water management). In any case, the combined use of all of these indicators may help in the decision-making process.

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References

Alcamo, J., Henrichs, T., Rösch, T., 2000. World water in 2025 - Global modeling and scenario analysis for the world commission on water for the 21st century. In: Report A0002, Center for Environmental Systems Research, University of Kassel, Kurt Wolters Strasse 3, 34109 Kassel, Germany.

Aldaya, M.M., Martínez-Santos, P., Llamas M.R., 2010. Incorporating the Water Footprint and Virtual Water into Policy: Reflections from the Mancha Occidental Region, Spain. Water Resour Manage (2010) 24:941–958, DOI 10.1007/s11269-009-9480-8

Allan, J.A., 1998. Virtual water: a strategic resource, global solutions to regional deficits. Groundwater, 36 (4), 545–546

Boletín Oficial del Estado, BOE, 2008. Instrucción de Planificación Hidrológica. Ministerio de Medio Ambiente, y Medio Rural y Marino.- 15340 - ORDEN ARM/2656/2008, de 10 de septiembre. Boletín Oficial del Estado 229, 38472-38582.

CIRCABC, 2012. 'Informal meeting of Water and Marine Directors of the European Union, Candidate and EFTA Countries. Copenhagen, 4-5 June 2012. Synthesis', Communication and Information Resource Centre for Administrations, Businesses and Citizens (https://circabc.europa.eu/sd/d/b5d535f4-0df2-4b7b-aa39-a71483ab8fd4/Synthesis_Water_and_Marine_Directors_Copenhagen.docx) (accessed 07.10.2014)

Estrela, T. and Vargas, E., 2012. Drought Management Plans in the European Union. The case of Spain. Water Resour Manage, 26, pp. 1537-1553.

EU, 2007. Addressing the Challenge of Water Scarcity and Droughts in the European Union, Communication from the Commission to the European Parliament and the Council, Eur. Comm., DG Environ., Brussels, 2007.

EU, 2012. Report on the Review of the European Water Scarcity and Droughts Policy, Communication from the Commission to the European Parliament and the Council, The Eur. Econ. and Soc. Comm. and the Comm. of the Reg., DG Environ., Brussels, 2012.

European Environment Agency, EEA, 2005. The European environment – state and outlook 2005. European Environmental Agency, 2005, Copenhagen.

European Environment Agency, EEA, 2013. Results and lessons from implementing the Water Assets Accounts in the EEA area. From concept to production. EEA Technical report No 7/2013, European Environment Agency.

Falkenmark, M., Lundqvist, J., Widstrand, C., 1989. Macro-scale water scarcity requires micro-scale approaches. Nat. Res. Forum 13, 258–267.

Ferrer, J. and Pedro-Monzonís, M., 2014. De la planificación a la gestión y explotación: Sustitución de recursos en el ámbito de la Demarcación Hidrográfica del Júcar. Aplicaciones de Sistemas Soporte a la Decisión en Planificación y Gestión Integradas de Cuencas Hidrográficas (ed. Solera A. et al.), pp. 295-304, Ed. Marcombo, Barcelona.

Fulton, J., Cooley, H., Gleick, P.H., 2014. Water Footprint Outcomes and Policy Relevance Change with Scale Considered: Evidence from California. Water Resour Manage 28(11): 3637-3649. DOI 10.1007/s11269-014-0692-1.

Gibbs W.J. and Maher J.V., 1967. Rainfall Deciles as Drought Indicators. Bureau of Meteorology Bull. 48. Commonwealth of Australia, Melbourne, Australia.

Godfrey, J.M. and Chalmers, K., 2012. Water Accounting, International Approaches to Policy and Decision-making. Edward Elgar Publishing Limited. 2012, Cheltenham, UK – Northampton, MA, USA.

Haro, D., Solera, A., Paredes-Arquiola, J., Andreu, A., 2014. Methodology for Drought Risk Assessment in With-year Regulated Reservoir Systems. Application to the Orbigo River System (Spain). Water Resour Manage 28:3801-3814. DOI 10.1007/s11269-014-0710-3

Hashimoto, T., Stedinger, J.R., Loucks, D.P., 1982. Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. Water Resour. Res., 18 (1), 14–20.

Hoekstra, A.Y. (Ed.), 2013. Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual Water Trade. Value of Water Research Report Series No. 12, UNESCOIHE, Delft, The Netherlands. February 2003. (www.waterfootprint.org/Reports/Report12.pdf) (accessed 24.09.2014).

Hoekstra, A.Y. and Chapagain, A.K., 2008. Globalization of Water: Sharing the Planet's Freshwater Resources. Blackwell Publishing, 2008 Oxford, UK.

Hoekstra, A.Y., 2009. Human appropriation of natural capital: a comparison of ecological footprint and water footprint analysis. Ecological Economics 68, 1963–1974.

Hoekstra, A.Y., 2012. Water Footprint Accounting. In: Godfrey, J.M., Chalmers, K., editors. Water Accounting. International Approaches to Policy and Decision-making. Edward Elgar Publishing Limited. Cheltenham, UK – Northampton, MA, USA; pp. 58-75.

Instituto Nacional de Estadística, 2008. Cifras INE, Estadísticas e Indicadores del Agua. Boletín Informativo del Instituto Nacional de Estadística, 2008.

Lama, B., 2011. Metodología de evaluación e identificación de políticas de adaptación al cambio climático en la gestión de recursos hídricos. Doctoral thesis. Department of Civil Engineering, Higher Technical School of Civil Engineering (ETSICCP), Technical University of Madrid (UPM).

Loucks, D.P., 1997. Quantifying trends in system sustainability. Hydrol. Sci. J., 42(4), 513-530

Lloyd-Hughes, B., 2014. The impracticality of a universal drought definition. Theor Appl Climatol (2014) 117:607–611, DOI 10.1007/s00704-013-1025-7

Margat, J., 1996. Les ressources en eau. Conception, évaluation, cartographie, comptabilité, Editions BRGM, Orléans 1996, FAO, Vol. 28.

Martín-Carrasco, F., Garrote, L., Iglesias, A., Mediero, L., 2013. Diagnosing Causes of Water Scarcity in Complex Water Resources Systems and Identifying Risk Management Actions. Water Resour Manage 27:1693-1705 DOI 10.1007/s11269-012-0081-6

McKee, T.B., Doesken, N.J., Kleist, J., 1993. The Relationship of Drought Frequency and Duration to Time Scales, Paper Presented at 8th Conference on Applied Climatology. American Meteorological Society, 1993 Anaheim, CA.

Milano, M., Ruelland, D., Dezetter, A., Fabre, J., Ardoin-Bardin, S., Servat, E., 2013. Modeling the current and future capacity of water resources to meet water demands in the Ebro basin. J. Hydrol. 500; 114-126 http://dx.doi.org/10.1016/j.jhydrol.2013.07.010

Ministerio de Medio Ambiente, MMA, 2001. Ley 10/2001, de 5 de julio, del Plan Hidrológico Nacional. Madrid. Ministerio de Medio Ambiente.

Ministerio de Medio Ambiente, MMA, 2007. Orden MAM/698/2007, de 21 de marzo, por la que se aprueban los planes especiales de actuación en situaciones de alerta y eventual sequía en los ámbitos de los planes hidrológicos de cuencas intercomunitarias.

Mishra AK and Singh VP. A review of drought concepts. J. Hydrol. 391, 2010, pp. 202-216.

Molden, D. and Sakthivadivel, R., 1999. Water Accounting to Assess Use and Productivity of Water, International Journal of Water Resources Development, 15:1-2, 55-71, DOI: 10.1080/07900629948934

Palmer, W.C., 1965. Meteorologic Drought. US Department of Commerce, Weather Bureau, Research Paper No. 45, p. 58.

Palmer, W.C., 1968. Keeping track of crop moisture conditions, nationwide: the new crop moisture index. Weatherwise, 21, 156–161.

Pedro-Monzonís, M., Ferrer, J., Solera, A., Estrela, T., Paredes-Arquiola, J., 2015. Key issues for determining the exploitable water resources in a Mediterranean river basin. Sci Total Environ 503-504: 319-328. http://dx.doi.org/10.1016/j.scitotenv.2014.07.042

Pellicer-Martinez, F., Perni, A., Martínez-Paz, J.M., 2013. La Huella Hídrica Total de una Cuenca: el caso de la Demarcación Hidrográfica del Segura. VIII Congreso Ibérico sobre Gestión Planificación del Agua.

Quiring, S.M., 2009. Developing Objective Operational Definitions for Monitoring Drought. J. Amer. Meteor. Soc., 48: 1217-1229. DOI: 10.1175/2009JAMC2088.1

Raskin, P., Gleick, P., Kirshen, P., Pontius, G., Strzepek, K., 1997. Water Futures: Assessment of Long-range Patterns and Prospects. Stockholm Environment Institute, Stockholm, Sweden.

Rijsberman, F.R., 2006. Water scarcity: Fact or fiction? Agricultural Water Management 80; 5-22

Rodríguez, R., Garrido, A., Llamas, M.R., Varela, C., 2008. La huella hidrológica de la agricultura española. Papeles de Agua Virtual No 2. Fundación Marcelino Botín. Santander.

Rouse, J.W., 1974. Monitoring the vernal advancement of retrogradation of natural vegetation. NASA/GSFC, Type III, Final Report, 1974 Greenbelt, MD, pp. 371.

Sánchez-Quispe, S.T., Andreu, J., Solera, A., 2001. Gestión de recursos hídricos con decisiones basadas en estimación del riesgo. Departamento de Ingeniería Hidráulica y Medio Ambiente. Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Editorial Universidad Politècnica de València.

Sandoval-Solis, S., McKinney, D., Loucks, D., 2011. Sustainability Index for Water Resources Planning and Management. J. Water Resour. Plann. Manage., 137(5), 381–390.

Seckler, D., Amarasinghe, U., Molden, D., DeSilva, R., Randolph, B., 1998. World Water Demand and Supply, 1990–2025: Scenarios and issues. Research Report 19. International Water Management Institute, Colombo, Sri Lanka 1998.

Shafer, B.A. and Dezman, L.E., 1982. Development of a Surface Water Supply Index (SWSI) to Assess the Severity of Drought Conditions in Snowpack Runoff Areas. In: Preprints, Western Snow Conf., Reno, NV, Colorado State University, pp. 164–175.

Sullivan, C.A., 2002. Calculating a water poverty index. World Dev. 30, 1195–1210.

Tigkas, D., Vangelis, H., Tsakiris, G., 2013. The RDI as a composite climatic index.European Water 41: 17-22.

Tsakiris, G. and Vangelis, H., 2005. Establishing a Drought Index incorporating evapotranspiration. European Water 9/10:3–11

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G., Poelmans, L., De Becker, P., Batelaan, O., 2013. A System-based Paradigm of Dorught Analysis for Operational Management. Water Resour Mange 27: 5281-5297 DOI 10.1007/s11269-013-0471-4

United Nations, UN, 2006. World Water Development Report 2: Water a Shared Responsibility (United Nations publications, Sales No. E.06.II.A.4)

United Nations, UN, 2012. System of Environmental-Economic Accounting for Water. United Nations, Department of Economic and Social Affairs, Statistics Division, (United Nations publication, Sales No. E.11.XVII.12) New York.

Vanham, D. and Bidoglio, G., 2013. A review on the indicator water footprint for the EU28. Ecol. Indic. 26; 61-75, http://dx.doi.org/10.1016/j.ecolind.2012.10.021

Van Loon, A.F. and Van Lanen, H.A.J., 2013. Making the distinction between water scarcity and drought using an observation-modeling framework, Water Resour. Res., (49), doi:10.1002/wrcr.20147.

Vardon, M., Lenzen, M., Peevor, S., Creaser, M., 2007. Water accounting in Australia. Ecological Economics 61: 650-659. DOI: 10.1016/j.ecolecon.2006.07.033

Vardon, M., Martinez-Lagunes, R., Gan, H., Nagy, M., 2012. The System of Environmental-Economic Accounting for Water: development, implementation and use. In: Godfrey JM, Chalmers K, editors. Water Accounting. International Approaches to Policy and Decision-making. Edward Elgar Publishing Limited. Cheltenham, UK – Northampton, MA, USA; pp.32-57.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2010. A Multi-scalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index – SPEI. J. Climate, 23, 1696-1718. doi: 10.1175/2009JCLI2909.

Villalobos, A.A., 2007. Análisis y seguimiento de distintos tipos de sequía en la cuenca del río Júcar. Tesis Doctoral. ETS Ingenieros de Caminos, Canales y Puertos. Universidad Politècnica de València.

Zeng, Z., Liu, J., Koeneman, P.H., Zarate, E., Hoekstra, A.Y., 2012. Assessing water footprint at river basin level: a case study for the Heihe River Basin in northwest China. Hydrol. Earth Syst. Sci., 16: 2771-2781. doi:10.5194/hess-16-2771-2012

Zeng, Z., Liu, J., Savanije, H., 2013. A simple approach to assess water scarcity integrating water quantity and quality. Ecol. Indic. 34; 441-449