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Procedia Engineering 89 (2014) 1470 – 1477
Procedia Engineering
www.elsevier.com/locate/procedia

16th Conference on Water Distribution System Analysis, WDSA 2014

Water Accounts and Water Stress Indexes in the European Context of Water Planning: the Jucar River Basin

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Abstract

Currently, water accounts are one of the next steps to be implemented in European River Basin Management Plans. One of the major handicaps lies on computing water resources availability as it depends on several factors, some of which are difficult to quantify. Building water accounts is a complex task, mainly due to the lack of common European definitions and procedures for calculating water availability. For their development, when data is not systematically measured, simulation models and estimations are necessary. The main idea of this paper is to obtain a general scheme to quantify water availability in a river basin and apply it in the European context of water planning. The Jucar River Basin, located in the eastern part of the Iberian Peninsula in Spain, has been taken as a study case. Overall, as the European Union consists of countries with different hydrology, emulating the hydrological cycle may not always be enough. Consequently, a possible procedure would be to incorporate all the elements necessary for determining water accounts within the hydrological models, or within water resources management models, or an intermediate solution.

Peer-review under responsibility of the Organizing Committee of WDSA 2014

Keywords: Jucar River Basin; water availability; drought indexes; exploitable water resources

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Peer-review under responsibility of the Organizing Committee of WDSA 2014
doi:10.1016/j.proeng.2014.11.431

1. Introduction

Currently, water accounts are one of the next steps to be implemented in the River Basin Management Plans in Spain [1]. In order to assess water resources, water accounts, defined by United Nations, have become a very powerful tool for improving water management, as they provide a method of organizing and presenting information relating to the physical volumes of water in the environment, water supply and economy [2]. The main interest of the System of Environmental-Economic Accounting for Water (SEEAW) [3] is to provide a standard approach and therefore the possibility to compare results between different areas [4]. In this sense, several indicators derived from the water accounts cover many critical aspects of water management under an Integrated Water Resource Management (IWRM) [3]. One of these water indicators is water resource availability.

Water availability has been often used in a broad context, when actually one of the major difficulties in water planning is determining the water availability in a basin with the aim of distributing it sustainably [5]. Many studies have used this concept in different senses: the European Environmental Agency (EEA) [6] considers precipitation, river flows and water storage in snow and glaciers as a measure of the availability of freshwater resources. While other authors have estimated the water availability by employing drought indexes [7] or the indicator of exploitable water resources [8]. Furthermore, Lange et al. [9] and Sun et al. [10] consider that regional water resource availability can be well described by water yield, defined as the difference between received precipitation and evapotranspiration, and Alcamo et al. [11] have developed the WaterGAP model to compute both water availability and water use on the river basin scale.

This concept is extremely important in Mediterranean countries. Historically, Spain, has suffered important drought periods that have caused severe impacts. Water scarcity and the frequent drought periods explain, in part, the ancient building tradition of hydraulic works in Spain [12].

The aim of this paper is to obtain a general scheme to assess water availability in a river basin, taking as study case the Jucar River Basin (Spain) whereas other Mediterranean basins it is currently water-stressed. In this sense, water accounts have been applied in the Jucar River Basin District in recent years. Andreu et al. [13] reported an application of General Purpose Water Accounting [14] to the Jucar Water Resources System and also the Halt-Jucar-Des project [4] has provide an opportunity to test and check the feasibility of applying the SEEAW [3] to produce water accounts. From the above it follows that there is no unanimity in the methodology to determine water availability. It is necessary that policymakers and stakeholders make a decision about the methodology to determine water availability in order to include it in the policy review on water scarcity and droughts that is currently being carried out to be integrated into the "Blueprint to safeguard Europe's water resources" [5].

The remainder of this paper is structured as follows. Section 2 lists the materials and methods used to describe water availability. This is followed by the case study in Section 3 where the methodology described is used. And finally, sections 4 discuss results and conclusions for future directions.

2. Materials and methods

The main challenge in water accounting is related to the collection of the required data [1]. The hydrological cycle describes the movement of water in the Earth. The United Nations Statistics Division (UNDS) [3] describes it as a succession of stages: owing to solar radiation and gravity, water keeps moving from land to oceans into the atmosphere in the form of vapor and, in turn, falls back onto the land and oceans and other bodies of water in the form of precipitation. In this way, the importance of hydrological cycle lies on knowing how much water is available but, due to the difficulty of gauging the components of the hydrological cycle, the use of simulation models has become an essential tool extensively employed in last decades.

Generally, we can distinguish between two types of simulation models. The first ones are hydrological models which their main process constitutes on describing the hydrological cycle. As noted by Estrela et al. [15] these models estimate variables such as precipitation, snow, actual evapotranspiration, soil moisture, surface and groundwater runoff, aquifer recharge, volume storage in soils, etc. An example of this kind of model is Patrical Decision Support System (DSS) [16], which allows constructing hydrological cycle spatially distributed models, with monthly time step simulation; and it has been applied in different studies for the River Basin Management Plan in the Jucar River Basin District.

In the second group, we find the water resource management models, which may require the results obtained with a hydrological model as an input. This kind of model is used to assess the system behaviour for given scenarios. Their topology must include the main system features, such as rivers, reservoirs, aquifers, existing uses represented by the demand centers, hydraulic connections, the possibility of using returns and other unconventional resources, environmental constraints or operating rules [17]. An extended state-of-the-art review on simulation modelling approaches is given by Rani and Moreira [18].

We can notice that hydrological cycle simulation models enable us to assess the renewable water resources in a river basin. And water resources management models help us to know its water availability in each month of the simulation period, as they consider the existing technologies in place for abstraction, treatment and distribution of water [3] and their operating rules. In this sense, Patrical DSS will help us to analyse the influence of precipitation in the Jucar River Basin by applying several indexes such as the percent of normal precipitation and the standard precipitation index (SPI) [19]. Moreover, the monitoring of water resources in dam reservoirs will allow us to analyse the impacts of operational droughts in the water resources system.

3. Case study: The Jucar River Basin

3.1. Description of the basin

The Jucar River Basin is located in the eastern part of the Iberian Peninsula in Spain (see figure 1). This basin is the main, of the 9 principal water exploitation systems in the Jucar River Basin District, thus giving it its name. The Jucar River has a length of 497.5 km, traversing the provinces of Teruel, Cuenca, Albacete and Valencia, having its mouth at the Mediterranean Sea. It is the most extensive system (22,261 km^2) and with more water resources of the Jucar River Basin Agency.

Fig. 1. Location of the Jucar River Basin in Iberian Peninsula.

Physically, the Jucar River Basin is described as an interior mountainous zone, with spots at high altitude and a coastal zone composed by plains. The average precipitation is 510 mm/year, and the average temperature is 13.6ºC. Average natural resources reach 1,279 hm^3/year that represent the top limit of the renewable resources of the basin. The total population depending on the Jucar River Basin represents a water demand of 127 hm^3/year and the water demand for irrigated agriculture reaches 990 hm^3/year. The supply to urban areas comes mainly from wells and springs, however Albacete, Sagunto and Valencia metropolitan areas use surface water. It is noteworthy that water demands are concentrated in harvest months; however, natural resources are slightly higher during the winter and go down in summer. Using the values of total natural resources and total water demands for the 1980/81-2008/09 period, a first indicator of the water stress in the system is deduced by the ratio between both values, resulting in a value of 87%. This ratio represents a first approximation to the water exploitation index (WEI) at the river basin level and it considers that a region is characterized as being under water stress, if the WEI exceeds 20%, and under severe water stress if it exceeds 40%. This first indicator is not sufficient, since it does not take into account agrarian returns, neither reuse of sewage treatment stations, nor any transfers that may occur in the system. Still, it reflects the high degree of exploitation suffered by this system.

3.2. Results

The most commonly employed variable for characterizing drought and consequently water availability is precipitation. The figure 2 shows the annual precipitation in Jucar water resources system for the period 1940-2009 obtained with Patrical DSS. As we can see, there has been a slight reduction in precipitation in the last 30 years. We can also see the indicator of percent of normal precipitation (PNP), considered as normal precipitation the annual average precipitation (over 510 mm/year). The main advantage of this index is that it is easily understood by the general public, and it recognizes droughts in preparatory phase before than other indexes. Among its disadvantages it is also noteworthy that this index considers a Gaussian distribution of rainfall, and another limitation arises when analyzing large regions in cohabiting both arid and wet lands.

From time series of monthly precipitation we have obtained the SPI [19]. It is considered that the system is in drought situation when the SPI value is less than or equal to -1, and the drought period is finished when SPI is positive again. According to Fernández [20], droughts can be classified according to this index: during a soft drought, SPI is in the range [0; -0,99], during a moderate drought, SPI is in the range [-1; -1,49], during a severe drought, SPI is in the range [-1,5; -1,99] and an extreme drought occurs if SPI is less or equal -2. The SPI has been calculated by adjusting the precipitation time series to a normal probability distribution.

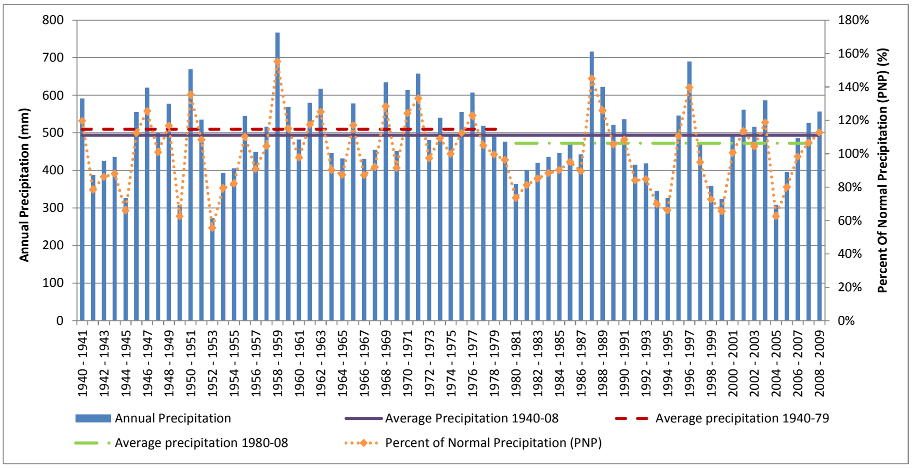

Fig. 2. Annual precipitation in Jucar water resources system for the period 1940-2008.

Figure 3 shows the evolution of the SPI over 3, 12, and 48 month intervals from 1940 to 2008. Specifying an aggregation period in defining drought is related to several basic characteristics of drought, as frequency and duration [21]. As the aggregation period is longer, the number of drought events is smaller, but these events are of longer duration. The figure shows that the longer period where the SPI is continuously negative over 48-month intervals is 1980/81-1986/87, whereas the SPI values for the same period indicates the existence of a moderate drought, while SPI over 3 month intervals indicates that the drought was extreme. The reason is that 3-month SPI is adequate for drought seasonal or short-term, 12-month SPI allows us to evaluate an intermediate drought, and 24, 36 or 48-month

SPI is employed for long-term drought [21]. Moreover, the period 2004/05-2007/08 has been, so far, the most important period of drought that occurred in the Jucar River Basin. This circumstance is not directly visible in the figure, although a sequence of negative SPI is observed in this period. One aspect to be considered is the index spatial aggregation, as significant differences between recorded rainfall in headwaters and lower basins are common. A more detailed analysis would consider a regionalization that would help to characterize the spatial variability of rainfall in the river basin [21].

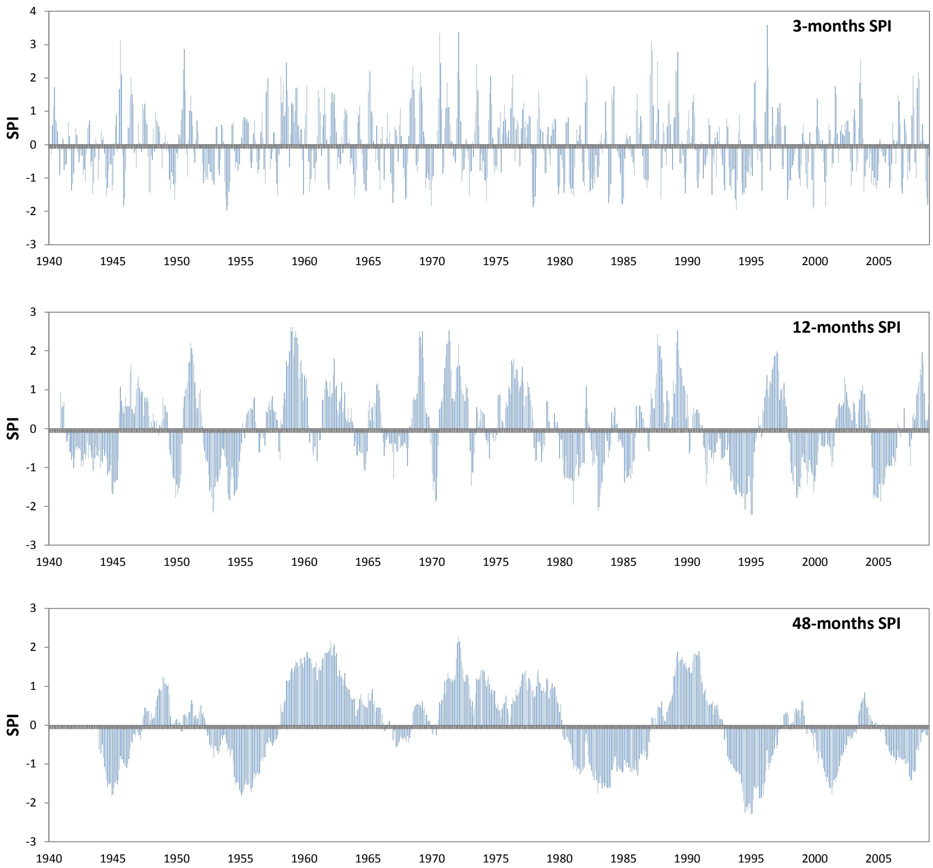

Fig. 3. Evolution of the 3-, 12- and 48-month SPI in the Jucar River Basin from 1940 to 2008.

SPI methodology can be applied to other sources of water in a water resources system as soil moisture, stream flows and storages in reservoirs [19]. The above indicators (PNP, SPI) do not consider the amount of current demands in the system. However, an indicator of operational drought itself takes into account the system needs, since it is based on data that are themselves influenced by the use made of water. A reduction of inputs results in a decrease in stored volumes, reaching more frequently the state of severe or extreme drought. A first indicator of operational drought index is the standard reserves index (SRI) [21]. This index shows the state of reserves in the system and helps explaining why in highly regulated systems, such as Jucar water resources system, in which occurs extreme drought conditions, they manifest less frequently but with a longer duration. The following chart shows the SRI in the Jucar water resources system in the main reservoirs (Alarcón, Contreras and Tous) for the period 1994/95-2008/09 once Tous reservoir became operational. It is possible to check the beginning and end of the drought periods as well as the severity levels reached according to SPI classification. As an example, the drought in the system during the period 2004/05-2007/08 was the more intense drought registered in the basin in the recorded history. But, comparing SPI and

SRI results for the period 1999/00-2002/03, the charts show the existence of a severe meteorological drought but instead, the operational drought had no incidence in the system at all.

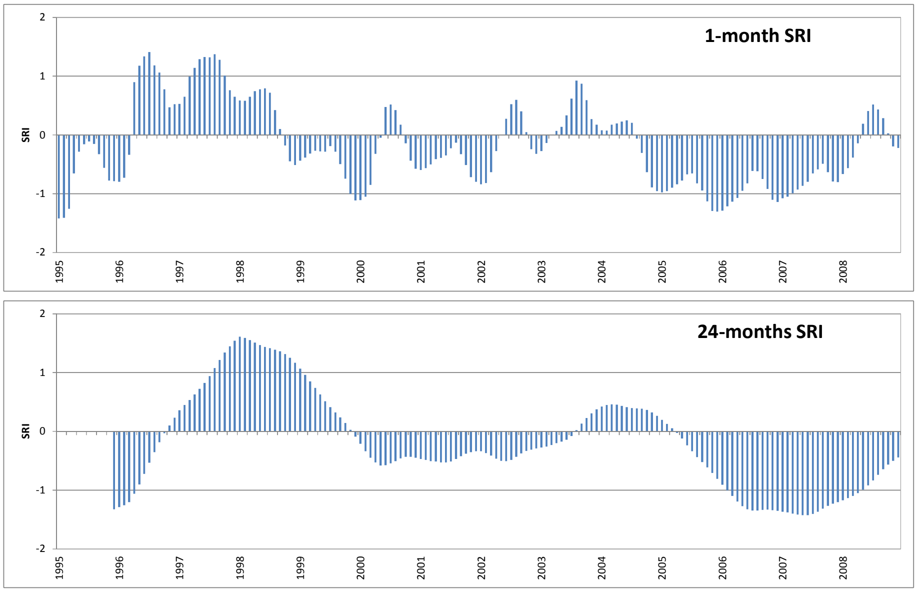

Fig. 4. Evolution of the 1-24 month SRI in the Jucar River Basin from 1995 to 2008

4. Discussion and Conclusions

Worldwide studies have shown that the Mediterranean region is one of the most vulnerable areas to water crisis [22]. In this paper, several indexes have been applied in the Jucar River Basin to characterize meteorological (PNP, SPI) and operational droughts (SRI) and test their influence in water availability. Figures 3 and 4 have demonstrated that precipitation, despite being the most commonly employed variable for characterizing droughts, may not be enough. While in countries lacking water storages infrastructures, directly dependent on rainfall to supply water demands, a decrease in rainfall during some months or weeks can become a drought, in others, droughts can extend for years producing major impacts [12]. It is noteworthy that the European Union (EU) consists of countries with different physical characteristics, different hydrology, based on different productive sectors and differences both in infrastructure and demands. Not surprisingly, in the most vulnerable areas to water scarcity, it is common the use of non-conventional water resources. A clear example is the use of wastewater resources by the Member States shown in figure 5a. It is found that in countries like Spain or Italy wastewater resources are no longer seen as non-conventional resources due to its high level of implementation.

In view of these differences we have designed a general scheme for analyzing water availability and consequently water accounts that should include the casuistry to justify the point of view of the EU. In figure 5b the process to obtain water availability begins with climate data, where rainfall and evapotranspiration are the main processes. This calculation continues trying to emulate the entire hydrological cycle, in which both, the estimation of the natural resources of the basin and its uses to characterize it are involved. Once the uses are known, it is possible to distinguish between natural uses and economic uses, and depending on the relationship of the latter and natural resources the WEI is obtained. Until now, that would be proposed from the EU, however, in countries like Spain, this approach is not enough.

Once renewable resources have been estimated, they are broken down between the surface runoff and groundwater. Moreover, demands can be quantified from economic uses. Depending on the characteristics of each river basin, these demands are only supplied with natural resources, or in most cases, it is necessary the operation of certain regulatory infrastructures and pumping wells that allow to use these resources when demands require it. Thus, it is no longer sufficient to consider only natural resources but it would be more appropriate to refer to these as conventional resources. Furthermore, these conventional resources could be not sufficient to serve the demands of the system; in this case we should refer to the use of non-conventional resources (wastewater reuse, desalination, transfers) which will guarantee the supplies. These two terms have been grouped by the term "generated resources" that can vary depending on the horizon scenario analyzed.

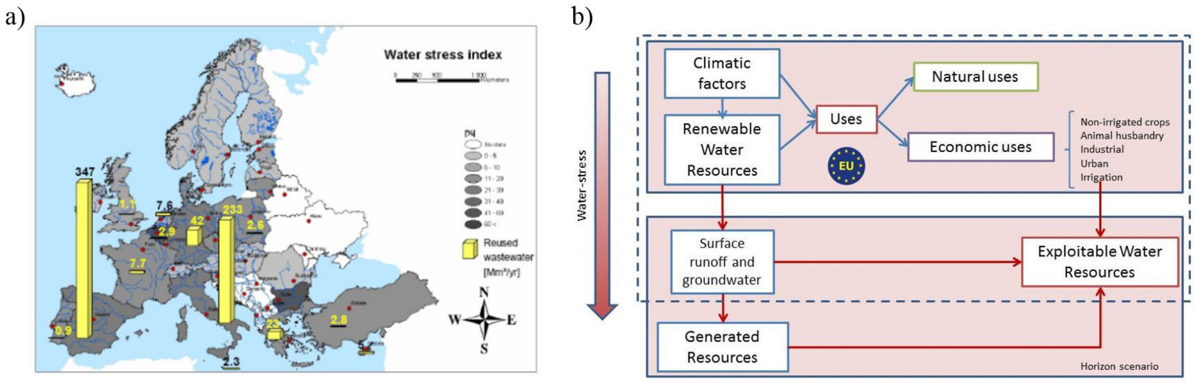

Fig. 5. a) Wastewater reuse in European Union [23]; b) Proposal for a general scheme for the study of water availability.

Finally, water availability can be described by the use of the indicator of exploitable water resources, defined as the part of the water resources considered to be available for development under specific technical, economic and environmental conditions [3] and obtained as the maximum demand that can be served by the system satisfying the officially established guarantees and the environmental requirements [8]. To do this, emulating the hydrological cycle is not enough, and it is essential to use water resource management models. In this sense, it is necessary that EU water policies define the methodology to determine this indicator since different aspects relating to the scenario definition must be taken into consideration such as the topology, the quantification of the natural resources and the reliability criteria to know whether the demands are satisfied ([8], [17]).

These two approaches represent the two extremes in the casuistry of analyzing problems within the context of water resources. We can find cases involving both problems and even cases where the situation analyzed is in an intermediate state between both. A good procedure would be to incorporate all the elements and variables necessary for the exercise of building water accounts within hydrological models or within management models; or a mixed intermediate solution [4]. This approach needs an objective criterion for the selection or classification of water resources systems in either band of the problem that is outlined in the figure 8. In this situation, the first step may be to conduct a preliminary classification of the regions that comprise the EU in order to apply different methodologies that are appropriate to the physical and socioeconomic characteristics of each Member State. It is crucial that policymakers and stakeholders make a decision about the methodology to determine water availability in order to include it in the policy review on water scarcity and droughts that is currently being carried out to be integrated into the "Blueprint to safeguard Europe's water resources" [5]. It is noteworthy that, in Spain, a large part of these methodological decisions are included in the Spanish Statement of Water Planning [24] with normative status guaranteeing consistency and comparability of the results.

Acknowledgements

The authors wish to thank the Confederación Hidrográfica del Júcar (Spanish Ministry of the Environment) for the data provided in developing this study and the Spanish Ministry of Economy and Competitiveness for its financial support through the projects SCARCE (Consolider-Ingenio 2010 CSD2009-00065) and NUTEGES (CGL2012-34978). We also value the support provided by the European Community's Seventh Framework Program in financing the projects DROUGHT-R&SPI (FP7-ENV-2011, 282769), ENHANCE (FP7-ENV-2012, 308438), WAMCD (EC-DG Environment No. 07.0329/2013/671291/SUB/ENV.C.1) and LIFE ALBUFERA (LIFE12 ENV/ES/000685).

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