Science of the Total Environment 610–611 (2018) 276–290

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Improvement of the drought indicators system in the Júcar River Basin, Spain

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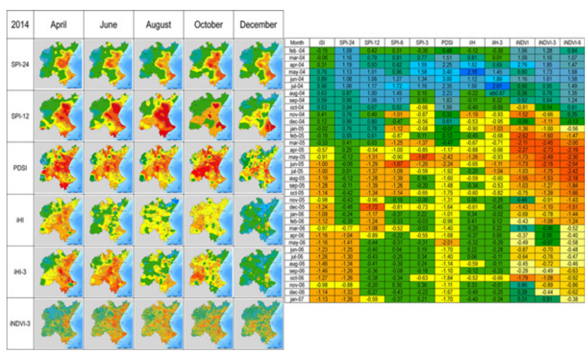
HIGHLIGHTS

- SPI-12 or SPI-24 can be used to define the "prolonged drought" required by EU.
- There is a high correlation between operational drought indices and long-term SPI.
- Moisture content index is correlated with the short-term precipitation index.
- Various indices are necessary to detect different types of drought.
- A unique aggregated indicator could hide a significant drought in a specific area.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 June 2017
Received in revised form 27 July 2017
Accepted 28 July 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
distributed drought monitoring
drought indices
remote sensing
prolonged drought

ABSTRACT

Droughts are one of the gravest natural threats currently existing in the world and their occurrence and intensity might be exacerbated in the coming years due to climate change. The severe impacts that droughts cause to inland water resources and to the associated socio-economic activities justify the continuous monitoring of the drought. The case study presented shows a practical application of a distributed drought monitoring system implemented in a real river basin district, the Júcar River Basin District (43,000 km^2), where drought periods of marked intensity have occurred historically and the climate ranges from humid in the north to semiarid in the south. Five drought indices have been applied: Standardised Precipitation Index (SPI) for meteorological drought; Palmer Drought Severity Index (PDSI) and a new soil moisture index (HI), for edaphic drought; Normalised Difference Vegetation Index (NDVI) for the vegetation activity; and Spanish Status Index (SI), for the operational drought. All indices are standardised to compare them.

The relationship between the standardised operational drought index SI and the long-term meteorological indices, SPI-12 or SPI-24, show that in a medium size basin the concept of "prolonged drought" required by the European Commission under the Water Framework Directive could be defined by the use of accumulated precipitation indices. The number of months to be accumulated depends on the size of the basin and the water management system properties. In large basins, such as the Júcar river basin (22,000 km^2), there are significant deviations due to the spatial distribution of the drought. The use of a unique aggregated indicator could hide a significant drought in a specific area, or on the other hand show a non-real drought. Evolution of drought indices for each water management system must be accompanied by spatially distributed drought maps to better understand the drought status and its evolution.

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http://dx.doi.org/10.1016/j.scitotenv.2017.07.250
0048-9697/

1. Introduction

Droughts are a natural hazard for the environment, the economy and the social development. Although by itself is not a disaster, whether it becomes one depends on its impacts on society and environment (Wilhite and Buchanan-Smith, 2005). Droughts are present all over the world and affect the arid and semi-arid regions and also humid and sub-humid regions (Mishra and Singh, 2010). The spatial extension, from local to regional scale, and the duration in time, from weeks to years, also can be very variable (Andreu et al., 2015). Droughts are a slow-onset natural hazard (Sivakumar et al., 2011), which appears when precipitation is under the normal values during a period of time. The unusual low values of precipitation can be transferred in a fast way (weeks or a few months) to other components of the hydrological cycle (soil moisture, river flows), or on the contrary, in a much slower one (many months or even years) to other components of hydrological cycle such as piezometric levels or groundwater discharges. Due to these characteristics, the Drought Management Plans have demonstrated to be valuable management tools to fight this type of anomalies (Estrela and Vargas, 2012).

The Drought Indicator System has a significant role in the declaration of a drought and in the application of the measures defined in the Drought Management Plans (Estrela and Sancho, 2016). The Drought Indicator System is a powerful tool to support the water managers and final users to understand how and where the drought has been occurring. There is a wide range of drought indicators to determine each type of drought: meteorological, defined as a lack of precipitation over a region for a period of time; hydrological, related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system; agricultural, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources; and socio-economic drought, associated with failure of water resources systems to meet water demands (Mishra and Singh, 2010). An extensive revision of drought indices is included in Mishra and Singh (2010) and Pedro-Monzonís et al. (2015). Besides, remote sensing provides a synoptic view of the Earth, and is an advantageous source of information in evaluating the drought impacts (Quiring and Ganesh, 2010).

The current Drought Indicator System in Spain is formed basically by an operational drought index, the Status Index (SI). This index reflects the amount of available water for the end users in each month, in relation with the amount of available water for that month historically. This index is useful to characterise the socio-economic drought. The index consists of selected control points distributed throughout the Spanish River Basin Districts which include the following information: volume stored in surface reservoirs; groundwater in aquifers; river flow discharges; reservoir inflows and precipitations in those areas where they are significant in relation to the water resources availability to supply the main water demands (Estrela and Vargas, 2012). This index is an aggregated index for socio-economic drought in each water resources system, which should be complemented with a set of other indicators that show the rest of drought types and their spatial variability.

Recently, in 2016, the Royal Decree by which Spanish river basin management plans were approved established that indicator systems of River Basin Authorities should be able to separately diagnose situations of drought and water scarcity. The European Water Framework Directive determines that temporary deterioration in the status of water bodies shall not be in breach of the requirements of this Directive if this is the result of circumstances of natural cause or force majeure which are exceptional or could not reasonably have been foreseen, in particular extreme floods and prolonged droughts, or the result of circumstances due to accidents which could not reasonably have been foreseen. The European Commission (EC, 2007) indicates that the identification of situations of prolonged drought should be performed using natural indicators based on precipitation as the main underlying parameter to indicate that it is a 'natural cause or force majeure', and that the circumstances are exceptional or could have not reasonably been foreseen.

This manuscript includes the application of a set of spatially distributed drought indicators in a real case, the Júcar River Basin District (RBD), which is a large district (43,000 km^2) formed by the aggregation of several river basins and is located in the Spanish Mediterranean area. The Júcar RBD includes nine water resources systems with different climates, from humid to semiarid, so the drought indices would be tested in different climate conditions. Climate change could be a significant impact in the natural resources of this river basin (Estrela et al., 2012) and drought could be increased in number and intensity in the future (Pérez-Martín et al., 2015). The standardised form of five types of indices are applied: for meteorological drought, the Standardised Precipitation Index (SPI; McKee et al., 1993); for edaphic drought (agricultural) a modified Palmer Drought Severity Index (PDSI, Palmer, 1965) and an expressly created Humidity Index in soil (iHI); for the vegetation response, the standardised Normalised Difference Vegetation Index (iNDVI; Jordan, 1969), and for the operational drought, the standardised Status Index (iSI).

The iSI and iNDV indices are directly derived from observed data and reflect the real situation observed in the river basin. The first one mainly indicates the amount of available water to supply water demands. The second one indicates the vegetation activity in a month iNDVI, in a season (three months) iNDVI-3 or during six consecutive months iNDVI-6, derived from the EOS-Aqua satellite equipped with the MODIS sensor. The meteorological (SPI) and edaphic (PDSI and iHI) indices are derived from precipitation and temperature data. Different monthly accumulations for SPI are considered for the short-term (SPI, SPI-3, SPI-6) and the long-term (SPI-12 and SPI-24). The modified PDSI and the iHI are obtained by the water balance in soil calculated with the Patrical model (Pérez-Martín et al., 2014).

The remainder manuscript includes in section two the Data Set and the indices used. The third section describes the study case results. Discussion is included in the fourth section and finally, the fifth section contains the conclusions.

2. Data set and indices used

The Júcar River Basin District (JRBD) is located in the eastern part of the Iberian Peninsula in Spain and is formed by the aggregation of river basins that flow into the Mediterranean Sea. The whole territory includes nine water resources systems (WRS or system), 1) Cenia-Maestrazgo, 2) Mijares-Plana de Castellón, 3) Palancia y los Valles, 4) Turia, 5) Júcar, 6) Serpis, 7) Marina Alta, 8) Marina Baja and 9) Vinalopó-Alacantí, and its total area is around 42.735 km^2 (Fig. 1). The Júcar RBD presents a Mediterranean climate. The total annual precipitation is around 500 mm, oscillating between maximum annual values of 780 mm for the wet years and just over 300 mm for the dry years. Precipitation in the autumn is almost half of the annual precipitation in the coastal area. The second highest value occurs during the spring and, during the summer, rain is almost non-existent. The same variability can be observed in regards to spatial distribution. There are areas such as Marina Alta with average annual values around 730 mm, and maximum values of 1.325 mm, whereas other areas like Vinalopó-Alacantí receive much less rainfall, with average annual values of 345 mm and minimum values of 190 mm. Approximately 80% of the total water received in the form of precipitation is returned to the atmosphere through evaporation, while the remaining 20% is groundwater and surface runoff (Pérez-Martín et al., 2014). The annual value of potential evapotranspiration for the period 1940/41–2010/11 is 890 mm/year, actual evapotranspiration is around 409 mm/year, infiltration is 64 mm/year, surface runoff is 31 mm/year and total runoff is about 95 mm/year (Pérez-Martín et al., 2014).

The Júcar RBD has a population of around 5 million people (11% of the Spanish population) and has an irrigated surface of about 389.000 ha mainly concentrated in the lower Mijares, Palancia, Turia and Júcar basins, the region of Mancha Oriental, and the irrigated valleys