Characterization of drought in Italy applying the Reconnaissance Drought Index

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Abstract: The mitigation of drought impacts is one of the most important challenges in the management of water resources and can only be properly realized through integrated management of this phenomenon. Regional drought analysis is conventionally based on drought indices for the identification of drought intensity, duration and areal extent. The aim of this study is to characterize the impact of the drought phenomena in Italy through the application of the Reconnaissance Drought Index (RDI). The basic form of the index is the ratio of the cumulative precipitation to potential evapotranspiration, for a specified reference period; it represents the intensity of water consumption in a given system, which varies in time and space but is entirely independent of the crops and soil characteristics and is also easily determinable. The Reconnaissance Drought Index (RDI) was considered more appropriate to the case-study examined. The run method is used to determine the characteristics of the drought phenomenon and to identify drought periods. As expected the RDI index shows more frequent events of drought in the Northern regions than in the South of Italy where the droughts is a structural condition. In the South the agricultural system has a more robust coping capacity and is more prepared to deal with water scarcity. This information is extremely useful for the evaluation of drought risk through mitigation measures with the appropriate management of water resources.

Key words: agricultural drought, drought indices, Reconnaissance Drought Index (RDI), drought assessment, mediterranean crops, drought mitigation measures

1. INTRODUCTION

The mitigation of drought impacts is one of the most important challenges in the management of water resources and can only be properly realized through an integrated management of this phenomenon. The term drought indicates “a natural, temporary and casual situation of strong reduction in water availability compared to normal values for a significant period of time and over a wide area” (Yevjevich, 1967).

This phenomenon is generally due to a series of natural causes such as high pressure, the localized subsidence, the lack of precipitation, the absence of the moist air flows. The causes of water scarcity can also be attributed to anthropogenic factors such as population growth, climate change and the resulting global warming, degradation of soil resources, pollution of water resources, which reduces the availability (Pickup, 1998).

As it is widely known, drought can be classified into four different types (Dracup, 1980; Wilhite and Glantz, 1985): meteorological, agricultural, hydrological and socio-economic.

Particularly the phenomenon of drought is basically of meteorological nature and it is identified as a precipitation deficit. The soil moisture deficit (agricultural drought), and the runoff deficit in surface and groundwater bodies (hydrological drought) are determined as a result of meteorological drought. The phenomenon is serious and complex. The consequences that it produces can give rise to multiple types of impacts on environment, economic and social sector (Yevjevich, 1967). According to Tsakiris (2016) the methodology DPSIR (Driver-Pressure-State-Impacts-Response) can be applied to analyze the drought phenomenon in its complexity.

Applying this scheme, in this study the drought phenomenon is analyzed, providing an overview at national level. The meteorological drought [Driver] creates the hydrological and agricultural
droughts [Pressure]. The drought phenomena produce water scarcity [State], this presents unavoidable negative consequences on various sectors (economic, social and environmental) [Impacts]. The last step of this analysis involves identifying measures to prevent and monitor the negative consequences of the drought [Response] by applying appropriate water policies at National level.

Many authors have proposed indices for assessing the drought phenomena. However, taking into account the drought as a water deficit, the Reconnaissance Drought Index (RDI) was considered more appropriate to assess the drought phenomenon throughout Italy (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007).

This index is based on the relationship between the precipitation (P) and potential evapotranspiration (PET), it represents the intensity of water consumption in a given system, which varies in time and space but is entirely independent by crops, by the characteristics of the soil and also easily determined (only climatic parameters). For this reason the index is more suitable to monitor the agricultural drought (Rossi, 2007). The aim of this study is the agricultural drought characterization through RDI implementation at regional scale. The proposed methodology could be used by the Italian Government of Water to develop measures and strategies finalized to combat drought in the agricultural sector especially.

2. MATERIALS AND METHODS

The meteorological data considered in this investigation were taken from Agro-climatic Observatory of the Ministry of Agriculture. The weather and climate statistics published are estimated with data of daily time series of meteorological stations of the National Agro-meteorological network (RAN). The estimate of weather and climate statistics of the areas of interest or geographic domain names is performed with a non-stationary geostatistical model that takes into account the location of the stations of both the trend and the geographical correlation of climatic factors.

For each Italian region, the annual rainfall and potential evapotranspiration data were used from 2006 to 2015 and their long-term climatic averages for each station.

An initial value of the Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis 2005; Tsakiris et al., 2006, 2007) was calculated for each year of the period considered:

\[ RDI = \alpha_y = \frac{P_i}{PET_i}, \ i = 1 \text{ to } N \]  

where \( P_i \) e PET\(_i\) are the precipitation and potential evapotraspiration of the \( i\)th year and \( N \) is the total number of years of the available data.

A second expression, the Normalized RDI (RDI\(_{norm}\)) was calculated for each year, using the following equation:

\[ RDI_{norm} = \frac{\alpha_y}{\bar{\alpha}_{avg}} - 1 \]  

where the parameter \( \alpha_y \) is the annual average value and \( \bar{\alpha}_{avg} \) is the average value calculated for all \( N \) years of data. The RDI\(_{norm}\) was used to determine the critical value below which define the drought "severe", so the negative values below the average were used to identify drought events.

The Run Method (Yevjevich, 1967; Rossi, 2007) was applied directly on RDI\(_{norm}\) for identifying drought periods and average intensity.

Therefore a drought period was identified by the number of consecutive years in which RDI\(_{norm}\) assumed negative values. While for each drought period, the average intensity (severity) was calculated from the relationship between cumulative RDI\(_{norm}\) and the number of years of drought.
3. RESULTS OF RDI APPLICATION

This application tested the scenario of drought events of the past decade. The Run Method was applied to identify droughts periods for each Italian Region. For the sake of brevity, the results for three Italian Regions are presented in Figure 1 (a northern region, Lombardy, a central region, Lazio, and a southern region, Sicily).

As expected, the RDI$_{\text{norm}}$ shows more frequent drought events in the Northern region, Lombardy. As illustrated in Figure 1a, the negative values show the dry years and, as a result, four dry periods are identified: the first long 4 years, the second two years and the third one year only (even if it is the upper limit of the analyzed time series) and all of four present a certain severity. A different situation was found in the southern Region, in Sicily, as the dry periods are only two (one year each one), as well as presenting a lower severity (Fig. 1c). The central region, Lazio, presents intermediate results (Fig. 1b).

The total number of drought years were obtained for each Italian Region that correspond to negative values of calculated RDI$_{\text{norm}}$ (Fig. 2a). For each drought period the corresponding severity (average intensity) was calculated (Fig. 2b).

Figure 1. Application of the Run Method for three Italian Region: (a) Lombardy, (b) Lazio and (c) Sicily.

Figure 2. The total number of drought years for each Italian Region (a) and the corresponding average severity (b).
As illustrated in Figure 2 the longest drought events occur in the North of Italy showing also a greater severity while in the south of Italy a less worrisome condition occurs.

This is due to the fact that, over the past decade, the Mediterranean climate showed a significant trend toward the so-called phenomenon of climate extremes showing more and more frequent and sensitive deviations from historical trends of climate parameters. In fact deviations from the climate average are more evident in the North. This analysis demonstrates that rainfall is the primary factor that controls the drought whereas other climatic factors such as high temperatures and relative humidity may amplify its intensity.

4. THE RESPONSE: PROACTIVE STRATEGIES AGAINST DROUGHT IN ITALY

The impacts caused by the drought are well known. The consequences that it produces may give rise to a multiple types of impacts, in particular on the environment, economic and social sector. The magnitude of the impact depends on the vulnerability of the different sectors affected.

Particularly at the level of water supply systems, the risk of water scarcity is also connected to the structural measures, management, administrative actions, economic support, which are adopted both proactive measures and emergency reactive measures, that is, when the phenomenon has already manifested. During 2016, the Italian Government of Water identified measures to prevent and monitor the negative consequences of drought. According Water Framework Directive (WFD), the National Observatories of Water Uses (OWU) were established. The OWUs were included among the measures provided in the River Basin Management Plans for each Italian River Basin Districts (Fig. 3). Members of the OWU are the public water authorities:

- Water district authorities;
- Ministry of Agriculture (MIPAAF);
- Ministry of Environment (MATTM);
- Civil Protection Agency;
- Regional Administrations;
- Italian National Institute for Environmental Protection and Research (ISPRA);
- Council for Agricultural Research and Economics (CREA);
- Italian National Institute of Statistics (ISTAT).

Figure 3. Extent of the River Basin Districts in Italy.
The observatories are operating bodies in charge of monitoring the water uses and coordinating the management responses in case of drought events. For the identification of different levels of severity of the drought phenomenon, the World Meteorological Organization (WMO) defines the specific indexes related to some of the cumulative effects of a prolonged and abnormal moisture deficiency. Identifying appropriate indices and triggers (specific values that can define a level of a drought plan and associated management responses) based upon the local climate and data availability is a critical aspect of drought management. The WMO defines three levels of severity as well as the resulting measures to implement for each of these levels. In Table 1, the aspects involving the irrigation sector are outlined.

Table 1. Relations between levels of drought and measures for risk management

<table>
<thead>
<tr>
<th>Drought severity level</th>
<th>Definition</th>
<th>Measures for irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal situation</td>
<td>No drought</td>
<td>• Monitoring water usage/volumes in the water district</td>
</tr>
<tr>
<td></td>
<td>water demand is fulfilled but drought indices and weather forecasts show a clear worsening</td>
<td>• definition of impact scenarios for agricultural sector</td>
</tr>
<tr>
<td>Mild drought</td>
<td>water demand is fulfilled but drought indices and weather forecasts show a clear worsening</td>
<td>• evaluation of drought mitigation strategies/measures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• notices on climatic situation, its evolution and related risks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ex-post analysis of the drought events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ex-post evaluation of strategies/measures adopted</td>
</tr>
<tr>
<td>Moderate drought</td>
<td>water demand is not fulfilled, river flows and reservoirs are lower than the average. Economic losses are foreseen</td>
<td>Same of the mild drought but having a higher intensity and a higher frequency</td>
</tr>
<tr>
<td>Severe drought</td>
<td>Crops are suffering damages. State of calamity</td>
<td>Support the civil protection in the event management</td>
</tr>
</tbody>
</table>

The drought indices which mark the severity levels are defined by a Technical Committee (TC) at national level. TC has been established last October and is currently working on the indices definition and a common format for the notices provided by the OWU during the drought events.

5. CONCLUDING REMARKS

At the present study, the drought occurrences have been identified in Italy during the decade 2006-2015. For this purpose the RDI index (Tsakiris and Vangelis, 2005; Tsakiris et al., 2006, 2007) was implemented at regional scale. The proposed methodology provide an overview of drought phenomena at national level. As expected, this application shows more frequent events of drought in the Northern regions than in the South of Italy where the droughts is a consolidated condition. The results have shown that the drought has a more severe impact on the regions of northern Italy.

The management of drought impacts is one of the major challenges in water management. An important element to implement an effective drought management strategy is to identify in advance the measures to be taken to prevent the adverse effects on the water supply system, the productive sectors and the environment. These strategies must be based on a preventive approach. Moreover, the planning tools for risk management must be identified and the combination of better short- and long-term measures should be selected.

The Italian Government of Water identified measures to prevent and monitoring the negative consequences of drought. During 2016, the National Observatories of Water Uses (OWU) were established. At this moment the observers are in operation and are implementing the risk management policies with a proactive approach for effectively dealing the consequences of the drought in Italy.

It has been shown that The Reconnaissance Drought Index is a useful tool to improve the management of water resources. It can also be used by OWUs for drought monitoring. In fact this analysis is the starting point of further investigation.
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