The Guadiana Case

Rodrigo Maia

Key messages

- Implementation of EU WFD and EU Drought Policy
- Transboundary cooperation in Drought Planning and Management
- Development of a sound drought and scarcity indicator system
- Definition of environmental flows and establishment of a minimum flow regime (MFR) for drought periods

1. Short description of the physical and socio-economic characteristics of the case study

Drought is one of the most damaging natural hazards in the Iberian Peninsula (IP) – Figure 1 – causing varied socioeconomic and environmental impacts. In order to prevent the impacts from drought, close cooperation between Portugal and Spain is required, namely regarding water and drought planning and management, as the two countries share five river basins (Minho, Lima, Douro, Tejo and Guadiana) that cover 45 % of the Iberian territory. This issue is particularly relevant for Portugal, as 64% of its territory corresponds to shared river basins, with the Portuguese part located downstream, rendering the country extremely vulnerable to the quantity and quality of water flowing from Spain (Maia and Vicente-Serrano, 2017).

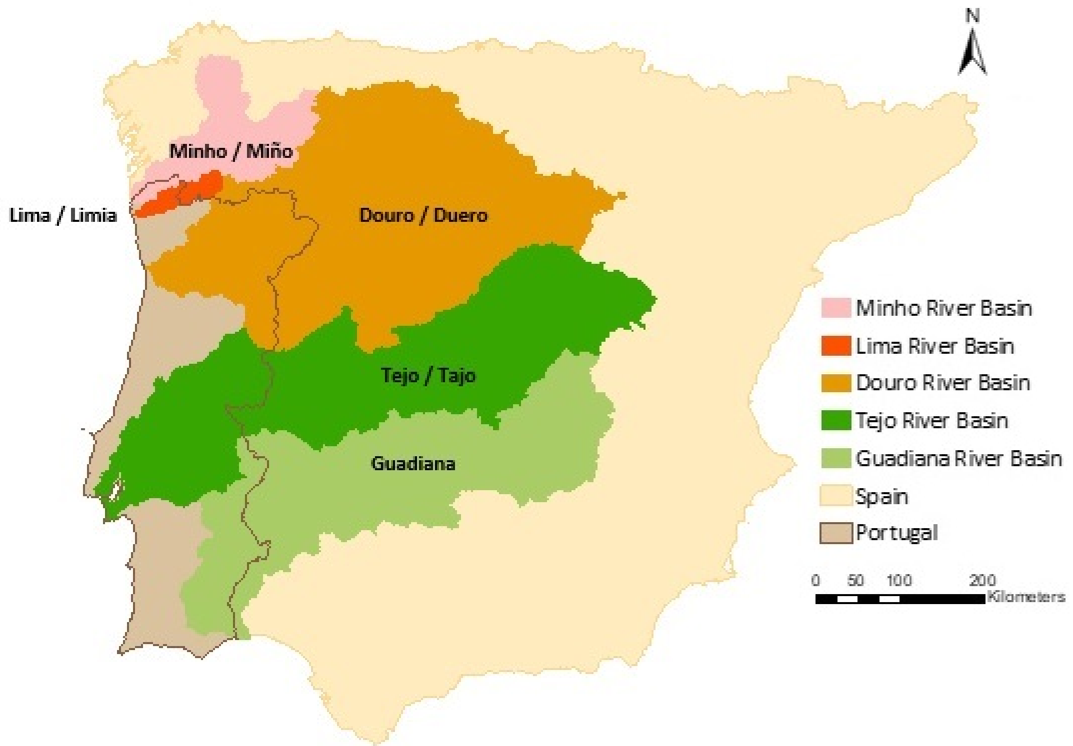

Figure 1. The five river basins shared in the Iberian Peninsula (adapted from Pulwarty and Maia 2015).

With an area of 67,200 km^2, the Guadiana River Basin is the fourth largest river basin in the Iberian Peninsula, but ranks only as the 10th in terms of average yearly flow volume. It holds a distinctive feature from other Iberian transboundary rivers, since the lower reach and the estuary of the Guadiana River serve as a natural border between Portugal and Spain, raising additional challenges for water resources management.

According to the Köppen climate classification, the region's climate is of the Csa type (hot summer Mediterranean climate). It therefore experiences hot (or very hot) and dry summers, with high evapotranspiration and mild (wet) winters. The average annual weighted precipitation over the basin is 550 mm, with about 80% of the precipitation occurring in the October – April period. The Guadiana River Basin is located within the so-called "climate change hot spot" region (Hoerling et al. 2012), and is expected to become warmer and drier, based on future climate projections (Ramos et al 2016). The inter annual irregularity (coefficient of 10.5) and the marked flow seasonality led Portugal to build the Alqueva dam, completed in 2002, whose reservoir – the largest in Europe – increased the Portuguese Guadiana basin storage capacity eightfold. Nevertheless, more than three quarters of the total existing storage capacity of the shared river basins is still located in the Spanish territory, where more than 80% of total water use occurs.

Regarding the use of water for consumptive purposes, agriculture is the main sector, displaying a greater importance when compared to urban water supply (APA, 2016; CHGuadiana, 2016). On the other hand, the weight of the primary sector in the Iberian economy has been declining during the last few decades, whilst different adaptation measures (namely dams) have reduced the vulnerability of the agricultural sector to drought.

2. Drought characteristics, management framework, risks and systemic constraints

a. Frequency and severity of droughts

Largely because of semiarid climatic characteristics and intensifying water use, the southern Europe region, and namely the IP, has historically been highly vulnerable to droughts, which have impacted both humid and dry regions (Gil and Morales 2001; Vicente-Serrano 2006, 2013). Since 1980, a dominance of dry years has been recorded in the IP, with the periods from 1981-1984 and 1991-95 being reported as the longest ones, and the driest year of the series recorded in 2005 (Maia and Vicente-Serrano, 2017). Nevertheless, the main impacts of this phenomenon are found in regions with an annual average precipitation below 600 mm (Vicente-Serrano 2007), such as the Guadiana basin.
Considering the last 30 years, the Guadiana river basin has displayed a high and increasing frequency of droughts (e.g.: 1991/1992; 1992/1993; 1994/1995; 1998/1999; 2004/2005; 2005/2006; 2008/2009; 2011/2012; 2017/2018; 2018/2019). Due to the basin's characteristics (near absence of precipitation in the dry season), the droughts usually exhibit high severity. The most severe drought period, both in terms of duration and intensity, occurred in the Spanish part of the Guadiana river basin between the years 1991 and 1995. In this period, the reduction of precipitation led to very significant decreases (over 70 %) in the mean annual runoff, with the reservoir reserves becoming limited to nearly 10 % of the total capacity. The event between

2004/2005 and 2005/2006 (extended up to 2009 in Spain) was the most severe (recorded SPI values of nearly -2), though for a shorter duration (nearly 10 months), in both countries. Regarding the future, the two (one for each country) River Basin Management Plans currently in force foresee an increase in the occurrence and severity of drought events due to climate change. That following the expected increase in temperature and the decrease of the precipitation, which shall lead to a decrease in water availability (surface and groundwater), along with an increase in water needs, particularly those arising from agriculture. (Vivas, 2011; APA, 2016; CHGuadiana, 2016, 2018; GPP, 2017; IPMA 2020).

b. Recorded and expected direct and indirect socio-economic and environmental impacts in the region and elsewhere

The socio-economic and environmental drought impacts in the Guadiana river basin have similar general characteristics in Portugal and Spain.
In Spain, in the period 1991-1995, under the so called "Megadrought", there were restrictions on water use and on the urban water supply, which were particularly severe in some cities and in systems dependent upon regulated water reservoirs. A significant reduction of agricultural output occurred (with losses of 370 million euros in 1994/1995), due to the prioritization granted to the demands related to urban water supply. Furthermore, it increased groundwater water use and aggravated problems (significant decrease of the piezometric levels) in sensible alluvial zones (Tablas del Daimiel). During that period, namely in 1994/1995, the affluences to Portugal were actually null for six months. In addition, other environmental impacts from this drought event were the observed decrease in water quality, the ignition of peat due to the overexploitation of the aquifers and the reduction the environmental flows.

This period of drought was the basis for the decision by the Spanish Water Authorities to develop a system of indicators and protocols for action for drought situations (CHGuadiana, 2018). In the Portuguese part, in this period, namely in 1992/1993, impacts on agriculture and urban water supply equally occurred due to drought. In agriculture, similarly to Spain, a reduction of production and the disruption of watering conditions for livestock was noticed. Urban water supply problems also hit some regions due to the reduction of the quantity and quality of available water. This led to urban water supply restrictions, to the search for new sources of water supply (collective hole drilling) and, in some regions, to the supply of water through auto-tanks (Vivas, 2011).

In the Spanish part, another of the most severe droughts occurred between 2005 – 2009. It should be noted that it was during this period, in 2007, that Special Drought Plans were approved. Nevertheless, the corresponding protocols and planned strategies and measures were most applied along the dry period, as the basis for those plans had already been established years before 2007 (Corominas, 2008). During this drought episode, low precipitation resulted in a marked decrease in runoff and water levels of reservoirs, with impacts on urban water supply (e.g.: application of restrictions and limitations on the use of the water, exploitation of new supply sources), on agriculture (restrictions due to supply from overexploited aquifers and dam reservoirs) and in the energy sector (reduction of the hydroelectric energy output). In terms of environmental impacts, the ignition of the peat on the "Parque Nacional de las Tablas de Daimiel", due to the reduction of the water level, was observed (CHGuadiana, 2018). Portugal was also severely affected during this drought period, but mostly in 2004/2005 and 2006/2007, where drought was most severe than in Spain. There, due to a major storage capacity, the impacts of the drought were lagged, but the drought period was longer. The drought impacts in Portugal were similar to the ones referred for the 1992/1993 period, although some more intense, namely: on agriculture, a sharp reduction of the grassland areas for livestock and water availability; on urban water supply, reduction of the supply periods. In terms of environmental impacts, the drought caused a degradation of water quality and quantity in rivers, which resulted in the reduction of conditions for flora and fauna. The increased dryness of the vegetation cover also fostered the occurrence of wildfires (Vivas, 2011; GPP, 2013, 2017).

After 2009, in Spain, during the hydrological year of 2009/2010, a drought alert state event occurred, requiring the implementation of the corresponding planned measures, namely: restrictions to the exploitation of aquifers and restrictions on the water use, for agriculture; and transfer of water from interconnected dam reservoirs, for urban water supply (CHGuadiana, 2018).

In the Portuguese part, a significant drought occurred in 2011/2012, which particularly impacted the agriculture sector, similarly (in minor scale) to what had previously occurred in 2005, but with no significant impacts in terms of urban water supply. There was also a reduction of the hydroelectric energy output. The environmental impacts were also comparable to the ones observed in the 2005 drought (Vivas, 2011; GPP, 2013, 2017). In fact, environmental drought impacts have grown in the IP over the past two decades, in association with the climatic warming processes over the entire Mediterranean. Droughts have namely affected forest growth and caused forest decline in large areas (Camarero et al. 2015; Carnicer et al. 2011), as also contributed to land degradation processes (Vicente-Serrano et al. 2012).

Between 2016 and 2017, there was a drought (pre-alert state) event both in the Spanish and in the Portuguese parts of the Guadiana river basin. In both parts, regarding agriculture, there was a reduction of production, due to restrictions in the use of water. Additionally, in Portugal there were also impacts in the watering conditions for livestock (CHGuadiana, 2018; GPP2017a, 2018). Regarding urban water supply, supply problems occurred in both countries in some regions, that namely required some water transfers, e.g.: in Spain, from the Los Molinos dam to the Llerena dam (CHGuadiana, 2018); in Portugal, in the municipality of Redondo, from the Alqueva dam to the Vigia dam. (GPP, 2017a, 2018).

c. Cascading and compound impacts, risk of systemic failures

Spain has a decentralized political system in which regions ("*Comunidades Autónomas*") have competences over many policy domains, namely water and environment. The Spanish Water Act establishes interregional basins, whose boundaries lie within a single autonomous community, and interregional basins, shared by more than one community or State (case of Portugal). In the first ones, water is managed by regional water authorities, whereas, for the latter ones, water is managed by river management agencies (*Confederaciones Hidrográficas*), with some form of dependence/support (namely for infrastructure investment) from the central government (CG). The (intra and inter) River Basin Administrations are responsible for drought planning and operational management, under a national drought policy defined by the CG. Furthermore, water markets were introduced in Spain by a 1999 Water Act Reform that was of relevance for inter-basins water trades in the 2005-2008 drought. Interregional tensions (and/ or of the regions with the CG) may occur regarding competences over water resources and water allocations, mostly during drought and water scarcity periods. Those tensions and disputes arise, namely, from water allocations defined in the RB Management plans, the construction and operation of infrastructures and/or water transfers (Garrick et. al, 2017). The situation is different in Portugal, with a centralized political and water management system. The Portuguese Environmental Agency (Agência Portuguesa do Ambiente, APA) represents the State in water issues, holding the responsibility for national water planning and management. According to the Portuguese Water Law, as the National Water Authority, APA declares drought situations and, jointly with other organizations, manages the application of drought mitigation measures. In addition, there are no water markets in Portugal.

Following the 1991-1995 drought – when (as previously mentioned) for some months, there were no affluences from Spain –, Portugal reached an agreement with Spain on the construction of the Alqueva dam and, in the advent of the entry in force of the WFD, to rule on basin-wide bilateral cooperation under the Albufeira Convention, signed in 1998. Under this agreement, a Minimum Flow Regime (MFR) was established for all shared rivers. Nevertheless, issues of potential contention between the Iberian nations still remain, namely: i) the monitoring and application of the MFR (which is not applicable in exceptionally dry years), ii) the water abstractions of Spain in the Alqueva reservoir and in the Chança river (a Guadiana tributary), and, iii) the environmental flows releases in the lower and estuarine Guadiana river stretch. All these issues are related and examined below.

d. Minimum Flow Regime (MFR) and Environmental Flow Regime (EFR)

Currently, for the Guadiana river basin, in accordance with the article 16 of the Albufeira Convention, in order to secure good water conditions and the current and predictable water uses, there is a need to guarantee a minimum flow regime (MFR) in two sections (Figure 2), namely at the Badajoz (weir) section, in Spain, just before the upstream river border entrance in Portugal, and at the Pomarão (Hydrometric Station) section, located in Portugal, just before the bordering Chança river junction, at the beginning of the lower, estuarine and bordering Guadiana river stretch. In these two sections an average daily flow of 2 m^3/s should be guaranteed. In addition to this, but only for the Badajoz section, minimum annual and quarterly flows are also defined, those according to the combination of two variables[1]:

- Rainfall in the hydrographic basin (Spanish part) using two meteorological stations: Talavera la Real (80%) and Ciudad Real (20%).
- Accumulated volume in the reference (Spanish) reservoirs: La Serena; Zújar; Cijara; Garcia de Sola; Orellana and Alange.

The values of the variables serve to define the amount of the referred minimum guaranteed flow volumes – depending (i) if the rainfall variable is bigger (normal year) or lower (drought year) than 65% of a reference precipitation accumulated value and (ii) of the fitting range (in four, defined for each year or trimester) of the accumulated volume in the reference reservoirs at defined yearly/trimester dates – and also the "exceptional" condition stage, in which the MFR is not defined nor applicable.

[1] Except for Guadiana, the MFR for the shared river basin is defined based only in one variable, the rainfall in referenced meteorological stations.

Figure 2: Variables used to define the minimum flow regimes of the Albufeira Convention in the Badajoz weir and Pomarão hydrometric station sections, in the Guadiana river basin.

When comparing the MFR defined in the Albufeira Convention with the EF defined in the Spanish Hydrological Plan (SHP), it is possible to verify that, in the Badajoz section, in terms of quarterly values, the EF defined in the SHP:

- In a normal year (precipitation above 65% of the reference precipitation) the EF volumes are (i) frankly higher (+56%) than those minimum defined by the Convention for the 2nd quarter, the wettest (115,18 hm^3 and 74 hm^3, respectively) but, on the other hand, (ii) much lower (-97 %) than the correspondents defined by the Convention for the 4th quarter, the driest (0,93 hm^3 compared with 32 hm^3).
- In a drought year (precipitation less than 65%), but still above the “exception” thresholds, the EF values defined (kept unchanged) are (i) frankly (and of course even more than in a normal year) higher than the ones defined by the Convention in the first 3 quarters and (ii) remain much lower (-94%) than those in the 4th quarter, despite the values defined by the Convention being between 50 and 60% of those corresponding to a normal year, in all the 4 quarters.

Table 1 presents mean daily values of monthly environmental flows defined in river stretches immediately upstream and downstream of Badajoz weir and the corresponding daily flow to be guaranteed at that control section, all values expressed in m^3/s.

Table 1 – Comparison between environmental flows defined upstream and downstream Badajoz control section (CHGuadiana 2016) with the daily MFR specified for that section.

Flow (m^3/s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Monthly Daily EF Upstream Badajoz section	1,00	4,64	10,08	9,61	11,15	10,76	7,84	2,35	1,70	0,65	0,49	0,51
Minimum Daily Flow Convention guarantee* at Badajoz section	2	2	2	2	2	2	2	2	2	2	2	2
Mean Monthly Daily EF Downstream Badajoz weir section	1,41	6,86	14,51	13,44	15,52	15,42	11,09	3,35	0,95	0,13	0,06	0,17

(*) in non-excepcional (drought/scarcity) periods

From Table 1, we can notice that:

- The monthly total and the corresponding mean daily EF values defined to be guaranteed (internally) by the Spanish RBMP (CHGuadiana, 2016) just upstream of the Badajoz section are (as expected) bigger from October to May and (unexpectedly) lower in the dry period (June to September) than the correspondent ones defined by Spain for the river stretch just downstream of that section, i.e., just before the entrance in Portugal.
- The mean monthly daily EF values correspondent to the specified by the referred Spanish RBMP just upstream of Badajoz section are not enough to guarantee the minimum daily flow to be guaranteed under the Albufeira Convention (to secure good water conditions and the current and predictable water uses downstream, i.e., in Portugal) for 5 months (June to October).

A similar analysis was performed for Pomarão control section. Upstream this section, the environmental flows defined in the Guadiana Portuguese RBMP (APA, 2016) downstream of the Alqueva-Pedrogão regulating system are considered. The corresponding ones considered downstream of Pomarão control section correspond to the environmental flows adopted by the Guadiana Spanish RBMP (CHGuadiana, 2016) for the Guadiana lower and estuarine bordering stretch (Table 2). To refer that these last almost coincide to the sum of the (just above referred) EF values considered upstream of Pomarão with those defined for the Chança tributary also by (APA, 2016).

Table 2 – Comparison between environmental flows defined upstream (APA 2016) and downstream (CHGuadiana 2016) Pomarão gauging station (control section) with the MFR specified for that section.

Flow (m3/s)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean Monthly Daily EF Downstream of Alqueva-Pedrogão System	9.26	18.90	19.68	19.68	18.13	19.68	13.12	13.50	9.26	6.17	6.17	6.17
Minimum Daily Flow Convention at Pomarão section	2	2	2	2	2	2	2	2	2	2	2	2
Mean Monthly Daily EF at the Guadiana Estuarine Stretch	9,41	19,87	19,97	19,97	20,28	19,6	13,7	13,63	9,72	6,42	6,42	6,64

From Table 2 one can conclude that the mean monthly daily EF specified by the Portuguese RBMP upstream of Pomarão (i) is by large far enough to guarantee the minimum daily flow to be guaranteed under the Albufeira Convention as also (ii) is in accordance and guarantees the larger EF daily monthly EF specified by Spain, in accordance with upstream EF values defined by Portugal, for the lower and bordering estuarine stretch.

4. Existing and/or potential management/mitigation and adaptation options:

a. Drought policies and legislation. Drought management plans

Spain and Portugal fully occupy the IP and are neighbors for centuries, the first being a federal state monarchy and the second a national republic. Nevertheless, although a large part of the two countries' territory, namely in the shared river basins, have similar natural and climatic conditions, their sectoral water use (namely in agriculture), water policy and institutions developed in a different way. Both countries joined the EU at the same time (in 1986). The Water Framework Directive (WFD) set a common European water policy framework based on river basin approach and management plans (RBMP's) to achieve a good ecological status of water bodies. It states the possibility of complementing RBMPs through special programs and management plans to deal with specific water issues, namely to mitigate the effects of droughts. On the other hand, if exceptional conditions occur, such as prolonged droughts, the WFD foresees the possible and temporary non-compliance with its environmental requirements.
The second cycle (2016-2021) RBMPs were approved in 2016 for all the Portuguese RBDs and for most Spanish RBDs, namely those that correspond to international river basins. However, although the two countries are at a similar stage in what regards WFD mandatory RBMPs' implementation, they still do not yet share a common or coordinated framework in what concerns drought management (Maia and Vicente-Serrano, 2017).

Unlike Portugal, which only approved a national drought plan (NDP) in 2017 (GPP, 2017), Spain has approved and implemented drought plans in all the River Basin Districts since 2007 (Estrela and Sancho, 2016). The 2007 Spanish drought plans have already been revised and approved in 2018 (BOE, 2018). In the 2018 versions (e.g. CHGuadiana, 2018), two types of indicators are defined: a prolonged drought indicator (PDI) and a water scarcity indicator (SI), the last one being an operational indicator to enable the postponement or avoidance of the occurrence of scarcity, mitigating adverse impacts on the different water uses (MITECO, 2017; Hervás-Gámez and Delgado, 2019). According to Article 18 of the Spanish Hydrological Planning Regulation (BOE, 2007), a Prolonged Drought situation allows the justified reduction of the environmental flows of water bodies as established in RBMPs.

As stressed before (in 3.), the DMPs have been much useful in Spain, namely already for the drought period 2004-2009, as the DMP nationwide operational procedures were already being prepared since the last severe drought period (in 1995-1999) and/or were in a phase of approval, and have been in force in that period (formally only after 2007) and in sequent drought periods. Although Portugal is lagging in this respect, with a NDP approved in 2017, a DMP for each River Basin District has been announced in 2019 as envisaged.

b. Steps taken to mitigate droughts in case of an event

Current drought management measures have contributed to reduced vulnerability and impacts in agriculture and livestock sectors, and improved water management during critical drought periods (Maia and Vicente-Serrano, 2017). The Spanish DMP's includes drought diagnosis (by means of monitoring indicators), program of measures and management options and a follow up system (MITECO, 2017). The foreseen Portuguese DMP's frame, in accordance with the NDP, shall be similar. Following new regulation of water markets in 2005 and legislation changes triggered by the 2004-2009 drought, water trading, supported by the creation of public water banks, is currently used in Spain in drought situations (Berbel and Esteban, 2019); no water markets exist in Portugal. A large governmental program for the modernization of irrigation systems began in Spain in 2002, water-saving techniques being considered the main irrigation management initiatives in the implementation of the WFD and the RBMPs in southern Spain (Berbel et al. 2019). That, together with a rain-fed insurance based on a public-private partnership and re-insurance systems enabled Spain to shift from crisis response and subsidies to support farmers to a more pro-active risk-based approach (Berbel and Esteban, 2019).

Although Spain drought management is currently at an advanced stage and more integrated with the WFD frame compared to Portugal, both countries have been working together since 2000 under the Albufeira Convention agreement, namely (Article 19) to "coordinate actions to prevent and control drought and water scarcity situations, setting the exceptional mechanisms to mitigate consequent effects and define the nature of exceptionality to the general regime established in the present Convention...".

Meanwhile, the same document states that both sides should "undertake joint studies of drought and water scarcity situations to define measures to be applied and define the criteria and indicators of the exceptional regime…". That was foreseen in 2003, under the CADC (Commission for the Albufeira Convention Implementation) (by then) specific workgroup on droughts that agreed on a two-phase work, aiming at: the establishment of an indicator's system and respective trigger values; the identification of the main uses to be assured under special circumstances. That is still currently pending. And still the provisory MFR that is only applicable to non-exceptional periods is active.

From 2005/2006 to 2017/2018, the following periods with exceptional droughts conditions were reported in the Guadiana river basin, under the Albufeira Convention provisions (CADC, 2020):

- 1st quarter of 2009/2010 (precipitation less than 65% and volume between 2350 and 2850 hm^3);
- 2017/2018 year (precipitation less than 65% and volume between 2650 and 3150 hm^3);
- 2nd quarter of 2017/2018 (precipitation less than 65% and volume of 3020 hm^3).

Figure 3 shows the PDI and SI indicators in the Spanish Guadiana Basin part for (almost) the same period of analysis (2005-2017) as defined in the 2018 SDP. The referred 2009 exception period is confirmed by both the PDI and the SI indicators. The 2017/2018 exception periods can´t be confirmed by means of the SI and PDI indicators due to lack of values on those, although both correspondent values by October 2017 are just above the normal drought and scarcity conditions. Nevertheless, it shall be noticed that during the full period of analysis (2005-2017) the Scarcity indicator evolution did not signal any emergency or alert situation for the Guadiana Basin Spanish Part.

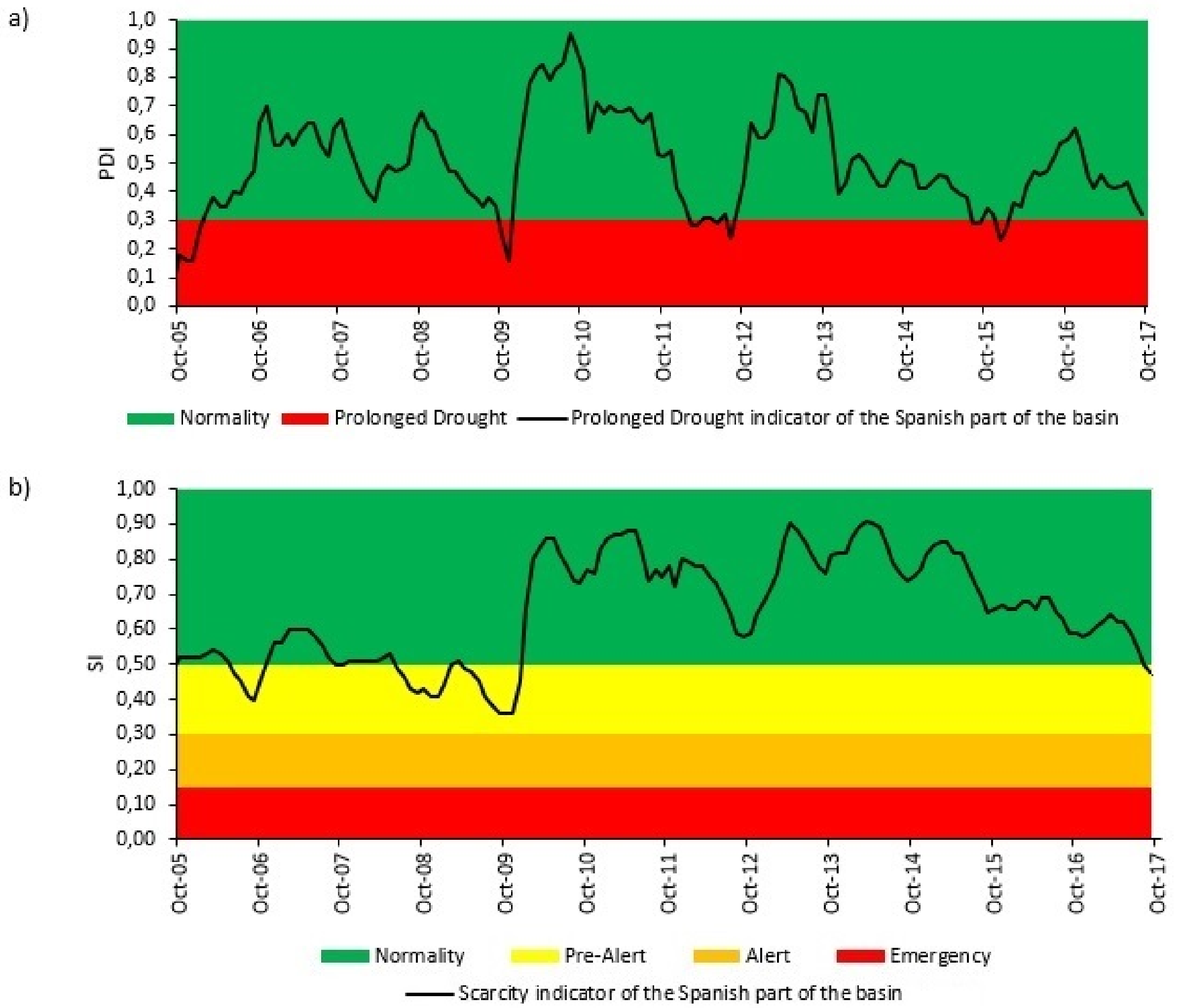

Figure. 3: a) Prolonged Drought and b) Scarcity indicators in the Spanish part of the Guadiana river basin.

In fact, although the Convention MFR values for the Guadiana basin are defined taking into account potential scarcity situation levels (as those values are dependent on storage capacity in Spain), the “exceptional condition” periods definition is not in accordance with (and is more severe than) internal (Spanish) drought and scarcity indicator´s levels.

c. Possible options/pathways to increase the resilience and minimize the risk from droughts (now and in the future)

It is aimed and expected that both countries will implement effective drought monitoring and early warning systems, to anticipate and predict drought occurrence. It is foreseen that, concerning shared rivers, both countries enforce best practices on drought management policy (WMO 2012) framed on EU and regional bilateral agreements, namely (Maia and Vicente-Serrano, 2017):

- The promotion of standard and common approaches in coordinated and/or possible joint drought planning and management of the shared RBDs, under the frame of the WFD and of the Albufeira Convention.
- The development of a sound common indicators system, hopefully including

ecological ones.

In fact, as previously mentioned, environmental drought impacts have grown in the IP over the past two decades, rendering it necessary to reinforce DMPs and indicators that correspond to environmental droughts (Maia and Vicente-Serrano, 2017). Nevertheless, prior to that, a common plan and agreement on environmental flows definition, implementation and monitoring should also be achieved. That also in order to facilitate and enable fostering the required redefinition of the current (provisory) MRF, that shall:

- take into account a common and/or joint and/or agreed definition of the environmental flow regime for the water bodies upstream of and downstream of the control sections, to secure good water conditions, in accordance with WFD requirements;
- take into account current and future water uses and basic needs, and;
- include no “periods of exception/exemption”.

References

APA (2016). Portuguese River Basin Management Plan 2016-2021 (2nd cycle) of Guadiana River Basin District (RBD7), 2nd Part – Characterization and diagnosis (in

Portuguese). https://apambiente.pt/_zdata/Politicas/Agua/PlaneamentoeGestao/PGRH/2016-2021/PTRH7/PGRH7_Parte2.pdf. Accessed April 2020.

Berbel, J,, Esteban, E. (2019) Droughts as a catalyst for water policy change. Analysis of Spain, Australia (MBD), and California. Global Environmental Change 58

Berbel, J., Expósito, A., Gutiérrez-Martin, C. (2019) Effects of the irrigation modernization in Spain 2002-2015. Water Resources Management 33, 1835-1849

BOE (2007) Boletin Oficial del Estado (Spanish Official State Journal) 162. Decree-Law 907/2007.Regulation of Hydrological Planning (in Spanish). https://www.boe.es/eli/es/rd/2007/07/06/907/com. Accessed April 2020.

BOE (2018) Boletin Oficial del Estado (Spanish Official State Journal) 311. Order TEC/1399/2018. Drought Special Plans (In Spanish). https://www.boe.es/diario_boe/txt.php?id=BOE-A-2018- 17752. Accessed April 2020

CADC (2020). Hydrometeorological Reports of the Flow Regime (in Portuguese). http://www.cadc-albufeira.eu/pt/documentos/

Camarero, J. J., A. Gazol, G. Sanguesa-Barreda, J. Oliva, and S. M. Vicente-Serrano (2015). To die or not to die: Early warnings of tree dieback in response to a severe drought. Journal of Ecology 103: 44–57.

Carnicer, J., M. Coll, M. Ninyerola, et al. (2011). Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. Proceedings of the National Academy of Sciences of the United States of America 108(4): 1474– 1478.

CHGuadiana (2016). Hydrological Plan 2016-2021 (2nd cycle) of the Spanish Part of the Guadiana River Basin District, Memory – Part I (in Spanish).https://www.chguadiana.es/sites/default/files/2019-10/RPH_01_1Rev-T1_Memoria_PHC_parteI_vf.pdf. Accessed April 2020.

CHGuadiana (2018). Special Drought Plan of the Guadiana River Basin District. https://www.chguadiana.es/sites/default/files/2018-12/PESCHGn.pdf. Accessed April 2020.

Corominas, J. (2008). Modernización o reconversión de regadíos? Dimensiones socio- económicas, ambientales y territoriales. VI Congreso Ibérico sobre Gestión y Planificación del Agua. Vitoria, December 2008. 15 pp. https://fnca.eu/congresoiberico/documentos/p0302.pdf

EC (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, L 327, 22.12.2000, p. 1. http://eur-lex.europa.eu/resource.html?uri= cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF.

Estrela, T., Sancho, T. (2016) Drought management policies in Spain and the European Union: from 445 traditional emergency actions to Drought Management Plans. Water Policy 18:153–176

Garrick, Dustin E., De Stefano, L. and Connel, D. (2017) Managing Drought and Water Scarcity in Federal Political Systems In: Wilhite, D. and Pulwarty, R. (ed) Drought and Water Crises: Integrating Science, 453 Management, and Policy, 1st ed. Taylor & Francis Group, pp 369-384.Gil, A., and A. Morales (2001). Causas y consecuencias de las sequías en España. Interniversitario de Geografia. Universidad de Alicante, ISBN: 84-7908-600-9. Spain. GPP (2013). 2012 Drought – Report balance. https://www.gpp.pt/images/Agricultura/Seca/Relatorio_Balanco_GTSeca2012_v1.p df. Accessed April 2020

GPP (2017). Prevention, Monitoring and Contingency Plan for Drought Situations (in Portuguese). https://www.gpp.pt/images/Agricultura/Seca/Plano-Monitorizao-Preveno-e- Contingncia-SECA.pdf. Accessed April 2020.

GPP (2017a). Agrometeorological and Hydrological Monitoring - September 30, 2017 (Hydrological year 2016/2017) (in Portuguese). https://www.gpp.pt/images/Agricultura/Seca/Relatorio_Monitorizaco_30-SETEMBRO_2017.pdf. Accessed April 2020

GPP (2018). Agrometeorological and Hydrological Monitoring - September 30, 2018 (Hydrological year 2017/2018) (in Portuguese). https://www.gpp.pt/images/Agricultura/Seca/Relatorio_Monitorizaco_30_de_setembro_de_2 018.pdf. Accessed April 2020.

Hervás-Gámez C., Delgado F. (2019) Drought Management Planning Policy: From Europe to Spain. Sustainability 11, 1862. https://doi.org/10.3390/su11071862.

Hoerling, M., J. Eischeid, J. Perlwitz, X. Quan, T. Zhang, and P. Pegion (2012). On the increased frequency of Mediterranean drought. Journal of Climate 25: 2146–2161.

IPMA (2020). Drought Monitoring (in Portuguese). http://www.ipma.pt/pt/oclima/observatorio.secas/. Accessed April 2020.

Maia, R., Vicente-Serrano. S. (2017) Drought Planning and Management in the Iberian Peninsula. In: Wilhite, D. and Pulwarty, R. (ed) Drought and Water Crises: Integrating Science, Management, and Policy, 1st ed. Taylor & Francis Group, pp 481-505.

MITECO (2017) Technical Instruction for the Elaboration of the Special Drought Plans and the definition of the global system of indicators of prolonged drought and scarcity (in Spanish). Ministry for the Ecological Transition (MITECO). https://www.miteco.gob.es/images/es/pp-orden-instruccion-tecnica-elaboracion-planes-458 especiales-sequia-nov2017_tcm30-434700.pdf. Accessed April 2020.

Morales, A., J. Olcina, and A. M. Rico (2000). Diferentes persepciones de la sequia en Espana: Adaptacion, catastrofismo e intentos de correccion. Investigaciones Geográficas 23: 5–46.

Ramos V., Maia R., Formigo N., Oliveira B. (2016) Assessment of Ecological Risk Based on Projected Hydrological Alteration. Environmental Processes, 3: 569 -587. doi 10.1007/s40710-016-0164-0

Vicente-Serrano, S. M. (2006). Spatial and temporal analysis of droughts in the Iberian Peninsula (1910–2000). Hydrological Sciences Journal 51(1): 83–97.

Vicente-Serrano, S. M. 2007. Evaluating the impact of drought using remote sensing in a Mediterranean, semi-arid region. Natural Hazards 40: 173–208.

Vicente-Serrano, S. M. 2013. Spatial and temporal evolution of precipitation droughts in Spain in the last century. Adverse weather in Spain, Madrid, WCRP Spanish Committee, pp. 283–296.

Vicente-Serrano, S. M., A. Zouber, T. Lasanta, and Y. Pueyo (2012). Dryness is accelerating degradation of vulnerable shrublands in semiarid Mediterranean environments. Ecological Monographs 82: 407–428.

Vivas, E. (2011). Avaliação e Gestão de Situações de Seca e Escassez. Aplicação ao caso do Guadiana (PhD Thesis). FEUP.

WMO. 2012. Science Document: Best Practices on National Drought Management Policy. World Meteorological Organization. High Level Meeting on National Drought Policy (HMNDP). Geneva: CICG.