Socioeconomic evaluation of drought effects.

Main principles and application to Guadiana and Algarve case studies.

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Abstract: Drought situations can have significant impacts, affecting large areas and imposing relevant restrictions on multiple economic activities. The severity of those impacts is, normally, assessed through meteorological, agricultural and/or hydrological indices or even through estimation of water deficits or reduction of production yields (for agriculture). However, those assessments usually do not represent the socioeconomic importance of the impacts and the results are not comparable for different types of impacts or distinct regions. In this context the present work enunciates the main principles of a methodology developed specifically for socioeconomic evaluation of drought effects, regarding the main characteristics of a region (water sources and associated uses) and the possible hydrological propagation of effects of drought situations. Moreover it briefly describes the application to two drought prone areas in Portugal: the Guadiana and the Ribeiras do Algarve river basin case studies. Regarding the main specificities of the referred case studies, the economic activities (and water dependent sectors) considered for this methodology were the agricultural and the urban water supply sectors. For each, specific assessment procedures where developed. Nonetheless, the final result of those procedures is, in both cases, the estimation of the economic impacts caused by the drought situation, on a certain area of analysis. The final assessment of the socioeconomic relevance of drought impacts for that region is ensured through the division of the total economic impacts estimated, by region's annual average GDP. The final result of this relation can, therefore, be compared for different regions of analysis.

Keywords: drought impacts, socioeconomic assessment, agricultural losses, urban water supply sector's increased costs, regional economic impact.

1. INTRODUCTION

Drought situations can have significant impacts, affecting large areas and imposing relevant restrictions on multiple economic activities, especially in regions with semiarid climatic characteristics and intensifying water uses, as is the case of the Southern area of Europe (DG Env EC, 2007; Iglesias et al, 2009, Strosser et al, 2012). The water dependent activities suffering from more significant impacts during drought situations are, most frequently, agriculture, urban water supply, energy production, industry and tourism (DG Env EC, 2007a; Kraemer, 2007).

The severity of drought impacts is, normally, assessed through meteorological, agricultural and/or hydrological indices (Steinemann et al, 2005; DG Env EC, 2007b; Wilhite, 2009). The importance of those impacts can also be estimated through quantification of water deficits or reduction of production yields (for agriculture). However, the referred assessments do not usually represent the socioeconomic importance of the impacts and also the obtained results are not comparable for different types of impacts or distinct regions (Kraemer, 2007; Markandya and Mysiak, 2010; Ding et al, 2011).

In this context, the present work enunciates the main principles of a methodology developed specifically for socioeconomic evaluation of drought effects, regarding the main supply and demand characteristics of a region (water sources and associated uses), as well as the hydrological ones. It should be noted that this methodology was developed envisaging the possible inclusion on a drought management and early warning system for Portugal (under development) as the basis of drought's severity assessment.

Thus, the present article will: (i) review the possible propagation of effects during drought situations (topic 2); enunciate the main principles of droughts' assessment based on economic valuation methods (topic 3); describe the methodology applied to the Guadiana and Algarve case studies (topic 4) and, finally; consider the methodology outputs for exploring the assessment and comparison of different regions and drought situations (topic 5).

2. IMPACTS OF DROUGHT SITUATIONS

Droughts are a natural phenomenon, being part of climate variability in every region. However drought impacts result from the interaction between the natural anomaly in rainfall conditions, for the area and period under analysis, and the existing dependence of human activities on water and other natural resources, in the region (Wilhite *et al*, 2007). Thus, during a drought situation (Kraemer, 2007) the impacts are:

- First, there is a reduction of rainfall conditions that, almost immediately, leads to a reduction on soil moisture.
- The first impacts appear on the agricultural sector due to soil moisture deficits. The severity of those impacts depends on: (i) the crop pattern of the area, (ii) crops' development phase, in which the water shortage occurs, (iii) the existence, or not, of water availability to compensate moisture deficits, in irrigated agriculture. Therefore, a generalized reduction of crops production and productivity can occur. On the other hand, a need to cover additional costs in order to compensate, for example, reduction of pastures for livestock husbandry (as enhanced by Pereira, 2007) can also represent significant impacts.
- In urban water supply, even though domestic water supply has, normally, legal supply priority, important problems most often occur, such as: (i) constrained supply periods, due to limited water availability, (ii) water use restrictions (for irrigation of gardens, street cleaning, car washing, etc.), or even (iii) competition for water rights with other sectors. On the other hand, additional costs may also be necessary to guarantee supply from alternative sources or reinforcement of water treatment levels.
- For energy production the main impacts correspond to the reduction of water availability for hydropower or for thermal or nuclear power plants equipment's refrigeration.
- In the industry sector, the agro-food industries are the main subsector affected, due to the reduction and/or higher cost of the available raw materials, as well as the pulp and paper industries, due to the slower development of forests vegetation or the increase of fires' risk.
- In tourism and recreation sector, the impacts of a drought situation depend on the type of tourism existing in the area and if the timing of the corresponding higher season coincides with the drought situation. Assuming summer tourism as an example, drought impacts can correspond to limitations on pool filling or golf courses irrigation, for example.

Moreover, although more difficult to identify and assess, the social impacts of drought can also be very significant, corresponding to: (i) rural population declining, (ii) unemployment increase, (iii) reduction of social cohesion, due to increase of conflicts, or even (iv) effects on individual physical and mental health, usually associated to depression and anxiety (Alston *and* Kent, 2004; Wilhite and Buchanan-Smith, 2005; Sartore *et al*, 2007).

3. MAIN PRINCIPLES OF SOCIOECONOMIC ASSESSMENT OF DROUGHTS

In order to facilitate the comparison of drought impacts on different users, regions, and/or drought situations, the relative importance of those effects shall be assessed through a common frame, as, for example, the economic valuation of impacts (Ding *et al*, 2011). In fact, the economic valuation techniques can be important tools for drought impacts' assessment, since their main goals are, as enhanced by Colby (1989) and Green (2003): (i) to facilitate decision making, using a perceptible type of information, (ii) to clarify the relative importance of the components in stake, and (iii) to set a common language for assessment and discussion among stakeholders. Although not exclusively, those valuation methods can be used, for drought assessment, at least for an estimation of impacts' economic importance. Several examples of studies involving the economic valuation of drought situations' losses on different water use sectors may be referred; Dixon *et al* (1996), Jenkins *et al* (2003), Ward *et al* (2001), (2006) and Valiñas (2006). The socioeconomic importance of drought impacts can also be compared to regional economic resilience and capacity to cope and adapt to drought situations that can be represented through regional GDP, for example (Iglesias et al, 2009), identifying the more affected regions, were interventions are more needed and urgent.

Following the inputs from the above referred studies and the reviews of the several existing methods, the production functions and the replacements cost methods were considered the more appropriate economic valuation techniques for a general socioeconomic evaluation of drought effects and comparison of different regions and drought situations (Vivas 2011, Vivas and Maia, 2013).

4. APPLICATION TO GUADIANA AND ALGARVE CASE STUDIES

In order to facilitate the evaluation of drought impacts' occurrence in a certain region, the socioeconomic assessment of droughts requires a continuous monitoring of the area, not only in what concerns rainfall anomalies and the consequent hydrological impacts (e.g. river discharge levels, volumes stored in reservoirs and aquifer systems, etc.), but also in what concerns supply of the existing water uses and identification of possible shortages. Therefore, this assessment shall regard the identification of particular problems within a region and foster the implementation of potential prevention and mitigation measures adequate to the existing problems, depending on a previous assessment of water management characteristics.

The main steps for application of the socioeconomic evaluation of drought effects to Guadiana and Algarve case studies are described below.

4.1 Main water uses considered.

Regarding the characteristics of both case studies, the most important water uses identified are the urban water supply and the agricultural sector (including livestock husbandry). It shall be referred that: (i) industry has a reduced importance in Guadiana (ARH-Alentejo, 2012) and, therefore, was not considered and (ii) the tourism sector in Algarve was considered represented through urban water use sector.

4.2 Division into spatial Units of Analysis (UA)

Drought situations normally affect an important area, not only due to a commonly wide spatial dimension of rainfall anomalies, but also due to the propagation of impacts along the hydrological cycle of a region. Regarding this last characteristic and also the goal of facilitating the identification of drought impacts within a certain river basin, aiming at the possible identification and allocation of preventive and mitigation measures, the spatial subdivision of that area for droughts' analysis, shall regard (i) the divisions into sub-basins, since those constitute the natural hydrographical limits (GWP, 2000); (ii) the location of the main water uses and of the corresponding water sources (Wilhite and Buchanan-Smith, 2005), and; (iii) the jurisdictional areas of the water management organizations (MEDROPLAN, 2007).

Regarding this, for the Portuguese area of the Guadiana river basin, was considered a division into 6 spatial units, called Units of Analysis (UA) (Figure 1b). For the Algarve case study, the Ribeiras do Algarve river basin area was subdivided into 4 UA (Figure 1c).

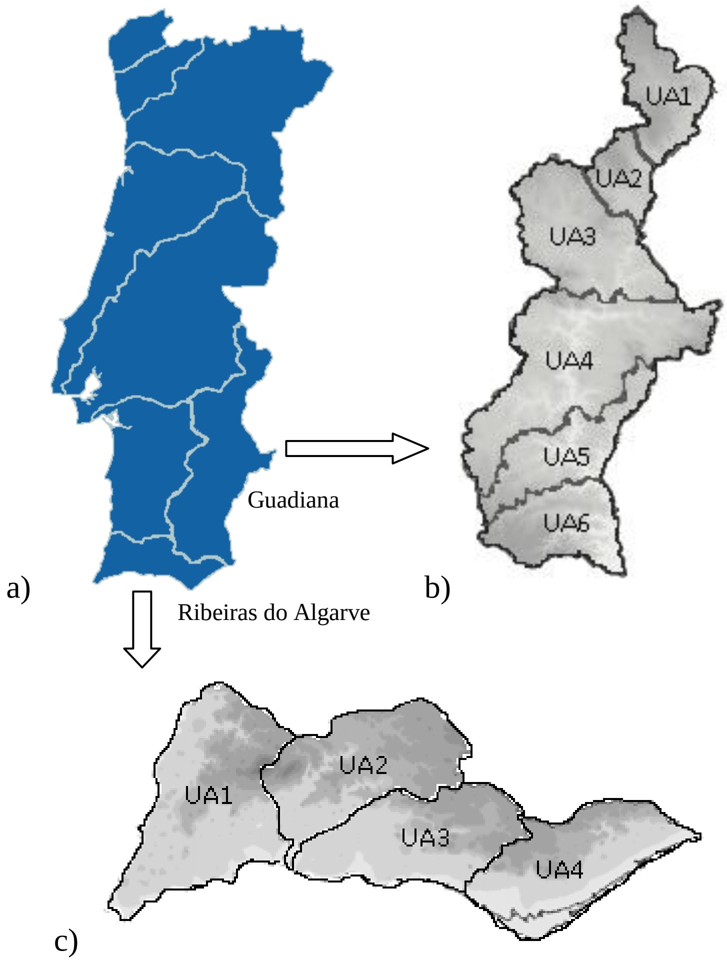

Figure 1: (a) Main Portuguese river basin areas; (b) division of Guadiana's basin area into 6 spatial units of analysis (UA); and (c) division of Ribeiras do Algarve basin area into 4 spatial units of analysis (UA)

4.3 Assessment of agricultural losses

4.3.1 Rainfed agriculture

Considering the analysis framed on the hydrological year time scale (from October to September), approximately correspondent to the agricultural year time scale, agricultural economic losses can be estimated through the reduction of annual production due to water availability limitation, compared to average production levels in normal years. Gross production estimations are based on the nation-wide official agricultural inquiries carried out by the National Institute of Statistics each ten years, the last one reporting to 2009. In rainfed agriculture the reduction of production will occur in the whole production area and will be directly related with the reduction of precipitation in the region, especially during the critical periods for crops' development.

In fact, it was concluded that rainfed agriculture, in both case study regions, has two main critical periods that must be assessed in order to estimate possible losses of productivity due to drought: (i) November to February and (ii) March to April. The assessment of corresponding impacts is based on the evaluation of representative crops of different crop groups (cereals for grain, pulses, fodder and temporary pastures, etc.). For each individual crop, a water productivity function was defined, on the basis of the total precipitation occurring in the critical periods of analysis, to obtain the correspondent annual production levels. The agricultural losses due to drought are, then, generally quantified by means of the reduction in productivity (considered a function of rainfall reduction on critical periods), and depending on the areas allocated to each representative crop. For pastures, however, the agricultural losses are quantified differently, since these do not correspond to a commercial product, namely through the additional costs resulting from the need to acquire hay and concentrate feed for livestock production, due to the reduction of pastures' productivity.

4.3.1 Irrigated agriculture

In what regards irrigated crops, the socioeconomic assessment of impacts due to droughts is also based on the reduction of annual production. In this case, the assessment requires the comparison of the available water (attending to possible use of water to complement rainfall shortages) in the hydrological year timescale, with crop demand needs estimated for each representative crop group considered (corn/spring cereals, sunflower/oilseeds, wheat/winter cereals, tomato/industrial vegetables, rice, permanent pasture, olive groves, orchards, vineyards). These total needs, correspondent to the average needs for crops production in normal years, are estimated based on the areas allocated to each crop group, on average water demand needs quantified for each group and on the efficiency of the typical irrigation methods used. Then, the quantification of the reduction on production due to droughts, for permanent crops, will be based on water productivity models (FAO proposed or derived from those), attending to water availability in sources, at annual level) for permanent crops. On the other hand, for annual crops, the reduction in production will be estimated attending to the restriction of the irrigated areas, according to water availability in the existing sources, and not on the reduction of water productivity.

The water available for irrigation is defined according to the type of water source in use for the irrigated area. According to case study characteristics, three main types of water sources can be identified: (i) public water reservoirs, (ii) private small water reservoirs, (iii) private groundwater abstractions.

In the first case, the estimation of water availability is achieved through hydrological model balance developed specifically for each of the main public water reservoirs, attending to monthly real water storage volumes, provided by a national information system on water resources (INAG, 2011), and to inflows and outflows of those same reservoirs. The inflows are estimated in order to approximate the existing water volumes stored in each reservoir, according to the precipitation occurred, the discharges rules identified for each reservoir, the evaporation losses and the water consumptions dependent on the referred reservoir.

In what regards small private reservoirs, the main difference to public reservoirs is that the stored volumes are not monitored. Therefore availabilities have to be estimated based on the known reservoir's capacities, and assuming that, in a regular year, full capacity is always reached. In dry years, the available volume is a function of the regular runoff reduction given by hydrological models calibrated to simulate natural runoff generation in the area.

For irrigated areas relying on groundwater abstractions, the procedure for estimation of water availabilities differed with the type of bedrock formation supporting the storage of water volumes from which water is extracted:

- In the so called non-differentiated area (NDA) that corresponds to a major part of the study regions, small storage capacity does exist due to the fractured nature of the ground systems, and there is no groundwater monitoring. Therefore, a balance was assumed to exist between the water demand needs quantified as associated to these areas and the natural recharge in normal years. In drought years, the reduction in the available water is defined based on the reduction in precipitation when compared to the median for the region.
- For water abstractions located in delimited aquifer systems, a hydrologic balance model is used to simulate the evolution of groundwater table records on the referred aquifer. The model takes into account existing water uses, losses due to evaporation, springs and flow discharges to rivers and other aquifer systems and estimates the necessary recharge that, according to the precipitation levels

and aquifer porosity, approximates the spatial average levels of groundwater tables. Water availability in each aquifer system is, then, quantified according to the saturated height correspondent to the difference between groundwater table levels and the average abstraction depths, taking into account the average ground porosity in the area.

4.4 Assessment of urban water supply sector's increased costs

As previously referred, important limitations can occur in urban water supply, during a drought situation, especially for areas relying on limited water sources' capacity and on systems with low or no flexibility for management of different water sources' availabilities. In that case, the socioeconomic effects of drought in this sector can be estimated through quantification of the additional costs necessary to offset water shortages with alternative sources. The economic conceptual basis is further described in Vivas (2011) and Vivas and Maia (2013).

Assuming that a water supply system is composed by an abstraction, water transport pipes, and the final distribution network, it was possible to identify two main types of water systems in both case study regions: (i) the, so-called, autonomous systems (AS), dependent only on one type of water source (storage reservoir, aquifer system or non-differentiated area, NDA), as well as (ii) the, so-called, integrated systems (IS) served by more than one type of water sources. The water needs calculation, allocated to each water supply system, makes use of a Portuguese national inventory of water supply and wastewater drainage systems (INSAAR) database (INAG, 2009) for determining the volumes of water abstracted from each source. It shall be referred that taking into account the emergency nature of a drought situation, a reduction of 5% on urban water consumptions, during that period, was assumed as effective, by means of savings as response due to public awareness.

The available water in each of the water supply systems, on a hydrological time scale (compatible with the assessment of agricultural losses), is estimated in accordance with the type of water source(s) on which they depend, similar to the procedure described before (4.3.1).

Nonetheless, in what concerns the integrated systems, the referred assessment shall also take into consideration the global needs of the system, and those having to be compared with the total availabilities of the correspondent sources, thereby simulating the management flexibility of those systems. On the other hand, in what concerns the autonomous systems, it was assumed that those were designed with a certain supply margin in a normal situation, given by availabilities from extra boreholes, dedicated to emergency situations, if existent, or via a safety gap in comparison with a regular year (of about 20%), for the remaining situations.

Both in the autonomous and the integrated systems, the water shortage volumes, corresponding to the difference between the water demand needs (reduced in 5%) and the total availabilities of water sources, will be used for defining the socioeconomic effects on this sector. This calculation is done through the estimation of the additional costs derived from the compensation of the water volumes in deficit, taking, as a reference method, the usage of emergency water supply through water tank, for smaller volumes, and, alternatively, for larger volumes, the execution of new, complementing, boreholes. For both cases, regional characteristic average costs (of m^3 for water supplied by water tank and of meter for borehole execution, the number of boreholes determined assuming identical productivity to other boreholes in the region) were considered. In order to ensure the proximity to reality of those assumptions, a limited volume of supply through water tanks was considered.

5. DROUGHT SEVERITY ACROSS REGIONS AND DROUGHT SITUATIONS

The annual economic impacts of drought, estimated according to the previously described methodologies, for a particular hydrological year, can, at the end, be aggregated: (i) by user sector, for a certain region, and (ii) by region, as a sum of the impacts for all sectors.

In the first case, the economic impacts obtained for each agricultural subsector can be summed and compared with the total income of the agricultural sector for the same region (obtained through the sum, for that region, of total agricultural production of each crop, for normal years, multiplied by the corresponding average sale price and the extra cost associated with the livestock feeding), so as to obtain one single value representative of the agricultural drought impacts severity in the area.

Similarly, for urban water supply, the sum of economic impacts due to drought, in a certain region, correspondent to the additional costs needed to overcome systems' limitations, must be compared with the total costs of water supply, in the same area, quantified as the total volume of water use in normal years, multiplied by the average total costs of water supply, per m^3, following INSAAR data (INAG, 2009).

Each of these final numbers will express the drought impacts' relevance, according to the economic dimension of the agricultural or water supply sectors for that area, and may be used to picture drought severity maps for each sector, for a particular hydrological year.

Nonetheless, in the second case referred above, a final aggregation may also be obtained for each unit of analysis or, even, for the river basin's level. For that, a sum of the economic impacts of the various sectors and subsectors can be performed, in order to compare those with an estimation of the Gross Domestic Product (GDP) of the corresponding area (the unit of analysis or the whole river basin area). The final result will be representative of the expected final aggregated impact for that region.

Since all of these assessments are based on the relative comparison of the estimated impacts with the economic importance of the subsector, sector or region, it is possible to compare, directly, the relevance of drought impacts in each sector, or also of the overall impacts in different regions, or drought situations.

Moreover, in both cases (analysis of impacts for each sector, or overall impacts for the region), specific drought severity classes can be defined, according to the importance of the impacts, and the priority objectives of decision making. For the referred case studies, it was considered the application of the drought severity classes (with indicative trigger values) presented: in Table 1a, for the assessment of the agricultural sector and subsectors; in Table 1b, for the assessment of the urban water supply sector, and; in Table 2, for the assessment of regional overall impacts.

Table 1: Classification scales of the socioeconomic drought assessments for the (a) agricultural sector and subsectors and (b) urban water supply sector, by reduction of income or increasing of cost, respectively

a)

Scale used for agriculture (% € - Income)	
Regular	0 a 15%
Mild Drought	15 a 30%
Severe Drought	30 a 50%
Extreme Drought	50 a 100%

b)

Scale used for urban water supply (% € - Costs)	
Regular	0 a 5%
Mild Drought	5 a 10%
Severe Drought	10 a 25%
Extreme Drought	25 a 100%

Table 2: Classification scales of the socioeconomic drought assessment of regional overall impacts as a % of region's GDP

Scale used for regional impacts (% € - GDP)	
Regular	0 a 1,5%
Mild Drought	1,5 a 3,0%
Severe Drought	3,0 a 5,0%
Extreme Drought	> 5,0 %

Based on the classification presented, the assessment of drought situations for each of the case study regions can be performed. Figure 2 depicts an example of the drought severity maps for the Guadiana region, for the 2004/05 hydrological year (a very significant and recent drought situation in Portugal), for each of the analysed sectors and subsectors. In Figure 3 a drought severity map for the overall impacts, for the same region and drought situation, is presented

It is possible to verify that for each sector, there are some UAs more affected than others and also that, for that particular drought situation and case study region (Guadiana) the rainfed agricultural subsector was the most affected. Globally, from Figure 3, it is observed that the UA number 5 was the most affected area of the entire Guadiana basin, being coherent with reality (CPS, 2005).

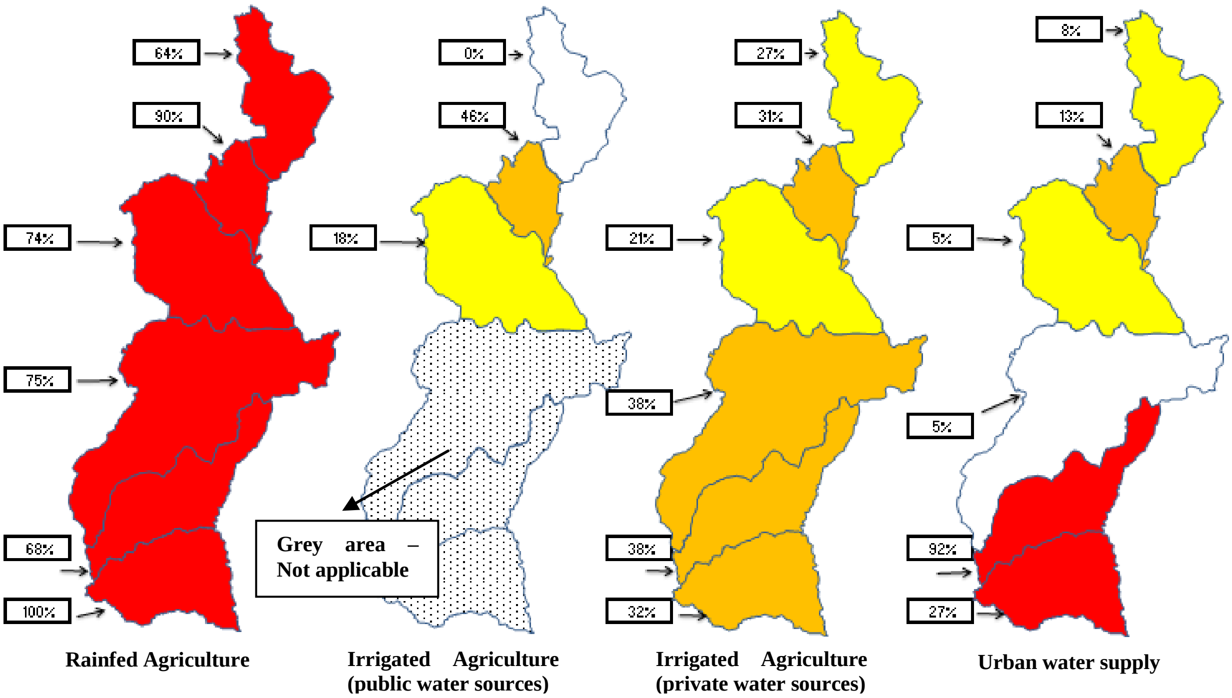

Figure 2: Results for the different sectors and subsectors of the socioeconomic assessment of drought, for Guadiana, on the 2004/05 hydrological year.

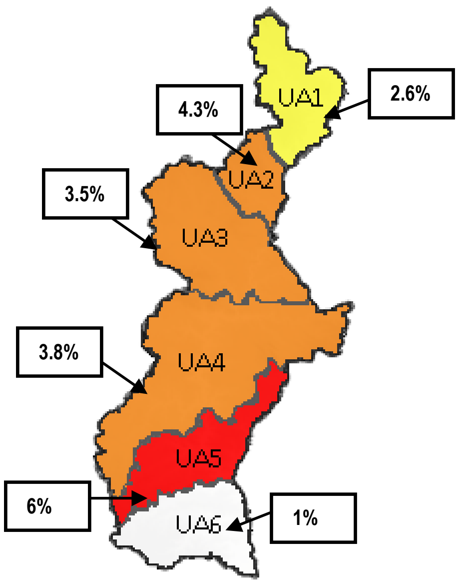

Figure 3: Results for the socioeconomic assessment of overall drought impacts for each UA, for Guadiana, on the 2004/05 hydrological year.

Moreover, it should be enhanced that although the analysis presented is based on real past data (of precipitation and water volumes in sources), the same assessment can be applied considering possible future scenarios of rainfall, at annual scale, and the corresponding simulation of water availabilities in sources. The corresponding results can, then, be used for identification of the most probable affected areas or the areas where drought preventive and/or mitigating measures need to be adopted, fostering the envisaged support for application on a drought management and early warning system (still under development for Portugal).

6. CONCLUSIONS

The procedure developed was based on the assessment of potential impacts on agriculture and urban water supply sectors, since these were considered the more significant water users in the case study regions. For agriculture, the procedure (distinguishing rainfed and irrigated crops production) is based on assessing the decrease on framers' income compared to a normal year. For urban water supply the evaluation method regards the estimation of additional costs of using alternative water sources to avoid water shortages.

As a result of the present work, it is possible to conclude that the socioeconomic evaluation of drought effects can be used for drought severity assessment. This type of procedure can improve the identification of drought impacts in a certain region, linking the possible reduction of rainfall to effective impacts in different water uses and regions, as well with different drought events. Moreover, it enables the comparison of results for different sectors and distinct regions, since it relates the importance of drought impacts with the economic relevance and support of the sector or region.

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