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57.2014

Drought Management Plans and Water Availability in Agriculture. A Risk Assessment Model for a Southern European Basin

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Climate Change and Sustainable Development
Series Editor: Carlo Carraro

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Summary

The Drought Management Plans (DMPs) are a regulatory instrument that establishes priorities among the different water uses and defines more stringent constraints to access to publicly provided water during droughts, especially for non-priority uses such as agriculture. These plans have recently become widespread across EU southern basins. Shockingly, in some of these basins the plans were approved without an assessment of the potential impacts that they may have over the economic activities exposed to water restrictions. This paper develops a stochastic methodology to estimate the expected water availability in agriculture that results from the decision rules of the recently approved DMPs. The methodology is applied to the particular case of the Guadalquivir River Basin in southern Spain. Results show that if the DMPs are successfully enforced, available water will satisfy in average 62.2% of the annual demand. This is much lower than the minimum water access reliability of 90% that the Spanish law has assured to irrigators so far.

Keywords: Agricultural Economics, Water Economics, Risk Management, Guadalquivir River Basin.

JEL Classification: Q1, Q25

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Abstract: The Drought Management Plans (DMPs) are a regulatory instrument that establishes priorities among the different water uses and defines more stringent constraints to access to publicly provided water during droughts, especially for non-priority uses such as agriculture. These plans have recently become widespread across EU southern basins. Shockingly, in some of these basins the plans were approved without an assessment of the potential impacts that they may have over the economic activities exposed to water restrictions. This paper develops a stochastic methodology to estimate the expected water availability in agriculture that results from the decision rules of the recently approved DMPs. The methodology is applied to the particular case of the Guadalquivir River Basin in southern Spain. Results show that if the DMPs are successfully enforced, available water will satisfy in average 62.2% of the annual demand. This is much lower than the minimum water access reliability of 90% that the Spanish law has assured to irrigators so far.

Keywords: Agricultural economics; Water economics; Risk management; Guadalquivir River Basin.

1. Introduction

Population growth and the improvement of living standards have increased water demand worldwide and, along with climate change, the vulnerability to drought events. This situation is to a great extent attributable to agriculture, which is the world's largest water consumer and is often believed to be wasteful (Ward and Velázquez, 2008). Consequently, policy makers in drought prone areas have called for measures to save water in this sector and thus guarantee the provision of water for priority uses, namely, drinking water and minimum environmental flows. However, the effectiveness of these measures has been burdened so far by the prevailing paradigm, which considers water demand as an exogenous variable outside the field of water policy. As a result, water policy has been mostly based on expensive supply oriented policies, such as the construction of major infrastructures or the modernization of irrigation devices, that paradoxically have ended up increasing water demand, reducing water availability and undermining the robustness and resiliency of the system and its ability to cope with future droughts (Ruttan, 2002; Anderies et al., 2004).

The high financial costs of these policies in a time of crisis and especially the limits of water supply have forced water authorities to alter their policy action. In the EU, some important legal restrictions over agricultural water demand have recently been approved to address the problem of recurrent droughts. This is the case of the Drought Management Plans (DMPs). DMPs are inspired in the drought contingency plans implemented in the US since the '80s and thus follow similar rules (NDMC, 2010). Basically, the DMPs define the precise thresholds of possible drought situations and set the water constraints that will come into force in each of these cases, with the aim of guaranteeing priority uses. The drought thresholds are obtained from the historical assessment of water supply, while the extent of the water constraints varies from one basin to other and depends largely on the ratio between water demand and water supply, being more restrictive in the more exploited basins (EC, 2008). As a result, the declaration of a drought will automatically reduce, in a predictable amount, the quantity of water delivered to the irrigation system from publicly controlled water sources.

In spite of being relatively new and voluntary, DMPs have rapidly spread across EU southern countries, such as France, Italy, Portugal and Spain[1]. In particular, Spain has pioneered the adoption of DMPs and currently every inter-regional river basin in the country has already approved its DMP. This is particularly shocking if we consider that there are no assessments available on the potential impact of DMPs over the economic activities exposed to water restrictions. As a result, the effects of DMPs over water availability in sectors such as agriculture are basically unknown. This paper wants to help bridge this gap. We develop a stochastic methodology to estimate the expected water availability in agriculture resulting from the decision rules of the recently approved DMPs. Then we apply this method to the particular case of the Guadalquivir River Basin in Spain, using historical data and official climate change scenarios. Results show that after the implementation of the basin's DMP, available water would satisfy in average only 62.2% of the annual demand, with relevant spatial disparities. For example, in the Regulación General Sub-basin (representing 66% of the agricultural water demand in the GRB) water availability according to the DMP would satisfy *in an average year* only 50% of the existing agricultural water demand, with several extremely dry years where water availability would be below 30% of the water demand. According to the

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[1] Unlike other water management instruments such as River Basin Management Plans, DMPs are not prescriptive, although they are already available in several Southern European basins in Spain, Italy, Portugal and France, and also in Finland, Netherlands and UK.

previous legislation, River Basin Management Plans (RBMPs) have to guarantee irrigators a water access reliability of 90%. This has happened since the implementation of the first wave of RBMPs in 1998 (Berbel et al., 2012). However, if DMPs are successfully enforced, it will not be possible to guarantee a failure rate below the target of 10% -quite the contrary, this failure rate will be closer to 40%.

2. Background to the case study: The Guadalquivir River Basin (Spain)

Because most of the variables involved in the design of the DMPs are site-specific, such as water supply and risk exposure, we illustrate each step of the model with the results for the particular case of the Guadalquivir River Basin (GRB) in Southern Spain.

The GRB is a large basin (57 071 km2) located in the south of Spain (see Figure 1). Average water demand amounts to 4 016 hm3/year, while renewable resources are estimated to be 3 028 hm3/year, resulting in an overexploitation of almost 1 000 hm3/year and a water exploitation index (ratio of total freshwater abstraction over total renewable resources) of 1.22 (GRBA, 2007). More recent estimations set this ratio at 1.64 (EEA, 2009). Consequently, the GRB is regarded as a severely overexploited basin and its recurrent droughts have particularly harmful effects over the economy (EEA, 2009). In addition, strong evidence suggests that the existing water supply deficit of the last decades has been effectively covered with non-renewable groundwater resources, thus reducing the resiliency of the system to droughts and worsening the water crisis (GRBA, 2010; WWF, 2006). Overexploitation, however, is not homogeneously distributed among the 14 sub-basins that constitute the GRB. The Regulación General Sub-basin, which is the largest sub-basin and supplies most of the water in the GRB, is also the most deteriorated system. The remaining sub-basins, including Salado de Morón, Campiña Sevillana, Alto Genil, Hoya de Guadix, Alto Guadiana Menor, Bembézar-Retortillo, Viar, Almonte-Marismas, Jaén, Rumblar, Guadalmellato, Huesna and Sevilla are less overexploited (GRBA, 2010).

Agriculture is the main water user in the GRB and demands 87% of the total water consumption. Given the structural water deficit of the basin, this sector is highly vulnerable to drought events. Agriculture is also a traditional activity in the GRB, of relevance in terms of employment and income generation (Pérez et al., 2010). As a consequence, water authorities have traditionally prioritized water supply to agriculture over other uses, such as environmental flows (EEA, 2009). This has been possible because water restrictions during drought events until only a few years ago were based on the discretionary (and unpredictable) decisions taken by the water authorities. All this has changed after the implementation of the DMPs, which reduce in a predictable amount the quantity of water delivered to the irrigation systems. However, the precise impact of DMPs over the expected water supply in agriculture is still unknown. In this paper we estimate this value.

[Insert Figure 1 about here]

3. Methodology

DMPs quantify the particular situation at hand and the severity of the problem by using an objective and publicly observable drought index. Then, they restrict water use according to the drought threshold in which the drought index falls. This drought index is estimated using one or a combination of site-relevant hydrological variables, which include rainfall, runoff, groundwater stock and/or water stored in reservoirs. This combination may change from one sub-basin to other.

In our model we estimate first the probability density functions (PDFs) of these site-relevant variables. Then we use these PDFs to obtain the probability of every drought index value and we aggregate these probabilities to obtain the probability of each drought threshold (in the case of Spain, the drought thresholds are normality, pre-alert, alert and emergency). Every drought threshold has a predetermined water restriction associated, and from there we obtain the expected water availability for irrigated agriculture. In the GRB, the drought index is calculated at the beginning of the irrigation campaign in April (GRBA, 2007).

3.1. Probability density functions (PDFs)

DMPs rely on hydrological variables to assess the situation of a sub-basin. In the GRB every drought index is made up of one or a combination of the following hydrological variables: rainfall, runoff, water stored in reservoirs and the stock of groundwater. There are large data series of these variables (covering at least 50 years) available in official data bases (MARM, 2009 and 2012; AEMET, 2012; GRBA, 2012). We use these data series to estimate the PDF for all the relevant variables in the GRB's sub-basins. This way we obtain the probability of every possible state of nature. We use a Gamma PDF for the rainfall (Martin et al., 2001; McWorther et al., 1966), runoff (Gómez and Pérez, 2012) and groundwater (Pérez et al., 2011) and a Weibull PDF for the water stored in reservoirs (Gómez-Ramos et al., 2002).

3.1.1. Gamma PDF

The Gamma PDF is defined by a scale parameter (a) and a shape parameter (b)[2]. The function reaches a maximum for intermediate values, decreases according to its scale parameter and converges to a normal distribution function as the shape parameter increases. With the Gamma PDF we assign a probability p_i $(i = 1, \dots, 3)$ for every value of the variable y_i $(i = 1, \dots, 3)$:

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[2] The parameters are estimated by maximum likelihood. All the parameters for every sub-basin are significant at the 1% level.

$$p_i = z(y_i|a,b) = \frac{1}{b^a\Gamma(a)} {y_i}^{a-1}\exp(\frac{-y_i}{b}) \qquad [1]$$

Where y_1 is rainfall, y_2 the groundwater and y_3 the runoff, all of them expressed as a percentage over their maximum value in the historical data series, and p_1, p_2 and p_3 are their corresponding probabilities. Table 1 shows the best fit parameters for the Gamma function.

[Insert Table 1 about here]

3.1.2. Weibull PDF

The Weibull distribution is a continuous probability distribution with a scale parameter (c) and a shape parameter (d)[3]. The Weibull PDF assigns a probability (p_4) for every value of the water stored in reservoirs (y_4), expressed as a percentage over the maximum value in the historical data:

$$p_4 = j(y_4|c,d) = \frac{d}{c}\left(\frac{c}{d}\right)^{d-1} \exp\left(-\left(\frac{y_4}{c}\right)^{d}\right) \qquad [2]$$

Table 2 shows the best fit parameters for the Weibull function.

[Insert Table 2 about here]

3.2. Drought indexes

Now we obtain the probability of every drought index value (I_e) using the PDFs obtained above. For the simplest case in which only one variable is used, the drought index is obtained as follows (GRBA, 2007):

$$I_{e,y_i} = \begin{cases} \left[\frac{y_i - y_{i_{min}}}{2(y_{i_{av}} - y_{i_{min}})}\right], if\, y_i < y_{i_{med}} \\ \frac{1}{2}\left[1 + \frac{y_i - y_{i_{av}}}{1 - y_{i_{av}}}\right], if\ y_i \geq y_{i_{med}} \end{cases} \qquad [3]$$

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[3] The parameters are estimated by maximum likelihood. All the parameters for every sub-basin are significant at the 1% level.

Where y_i is the variable's observed value in the month of reference (April in the GRB) and $y_{i_{av}}$ and $y_{i_{min}}$ are the average and minimum values in the historical data series of that variable, respectively (all of them as a percentage over their maximum value in the historical data). The corresponding probability of this drought index would be thus p_i $(i = 1, \dots, 4)$.

In the case where the drought index is made up of a combination of hydrological variables, it is obtained as follows (GRBA, 2007):

$$I_e = \sum_{i=1}^{4} b_i * I_{e,y_i} \qquad [4]$$

Where b_i is a weighting coefficient predetermined by the river basin authority that ranges between 0 (the variable is no relevant in the calculation of the index) and 1 (the same situation as in [3]), with $\sum_{i=1}^{4} b_i = 1$. The probability of the mixed drought index is:

$$\prod_{i=1}^{4} h(p_i) \qquad [5]$$

where:

$$h(p_i) = \begin{cases} 1, if \;\; b_i = 0 \\ p_i, if \; b_i > 0 \end{cases} \qquad [6]$$

3.3. Drought thresholds and expected water availability

We finally aggregate the indexes into the four drought stages (normality, pre-alert, alert and emergency) to obtain the probability of every drought stage. First we define a set of dummy variables:

$$n_{I_e} = \begin{cases} 1, if \; I_e > I_{e,z} \\ 0, if \; I_e \leq I_{e,z} \end{cases} \qquad [7]$$

$$z_{I_e} = \begin{cases} 1, if \; I_{e,a} < I_e \leq I_{e,z} \\ \quad 0, otherwise \end{cases} \qquad [8]$$

$$a_{I_e} = \begin{cases} 1, if \; I_{e,e} < I_e \leq I_{e,a} \\ \quad 0, otherwise \end{cases} \qquad [9]$$

$$e_{I_e} = \begin{cases} 1, if \; I_e \leq I_{e,e} \\ 0, if \; I_e > I_{e,e} \end{cases} \qquad [10]$$

Where $I_{e,z}$, $I_{e,a}$ and $I_{e,e}$ are the pre-alert, alert and emergency thresholds, respectively.

Next we obtain the probability of every drought stage (q_k) in the sub-basins of the GRB. For example, the probability for the stage of *normality* (q_n) is obtained as follows:

$$q_n = \int_{y_1=0}^{max_{y_1}} \int_{y_2=0}^{max_{y_2}} \int_{y_3=0}^{max_{y_3}} \int_{y_4=0}^{max_{y_4}} \left(n_{I_e} * \prod_{i=1}^{4} h(p_i) \right) \; [11]$$

Where max_{y_i} is the value of the variable y_i that makes the cumulative density function equal to 1 (i.e., the probability of any value above this limit is zero).

Similarly, the probability for the stages of *pre-alert* (q_{pa}), *alert* (q_a) and *emergency* (q_{em}) are obtained as follows:

$$q_z = \int_{y_1=0}^{max_{y_1}} \int_{y_2=0}^{max_{y_2}} \int_{y_3=0}^{max_{y_3}} \int_{y_4=0}^{max_{y_4}} \left(z_{I_e} * \prod_{i=1}^{4} h(p_i)\right) \quad [12]$$

$$q_a = \int_{y_1=0}^{max_{y_1}} \int_{y_2=0}^{max_{y_2}} \int_{y_3=0}^{max_{y_3}} \int_{y_4=0}^{max_{y_4}} \left(a_{I_e} * \prod_{i=1}^{4} h(p_i)\right) \quad [13]$$

$$q_e = \int_{y_1=0}^{max_{y_1}} \int_{y_2=0}^{max_{y_2}} \int_{y_3=0}^{max_{y_3}} \int_{y_4=0}^{max_{y_4}} \left(e_{I_e} * \prod_{i=1}^{4} h(p_i)\right) \quad [14]$$

Finally we use the water allotments specified in the DMP for every drought stage (R_k) to estimate the expected water availability in agriculture ($EWirr$). In the GRB the plan establishes the following four drought thresholds and their corresponding allotments (GRBA, 2007): i) when water stored levels are regarded as normal ($I_e > I_{e,z}$), there are no restrictions ($R_k = 1$); ii) water for irrigation is reduced by 5% ($R_k = 0.95$) when available water falls below the prealert threshold ($I_{e,a} < I_e \leq I_{e,z}$); iii) if the alert limits are exceeded ($I_{e,e} < I_e \leq I_{e,a}$), water for irrigation is reduced by 30% ($R_k = 0.7$); and iv) in emergency situations ($I_e \leq I_{e,e}$), water for irrigation is drastically reduced by 70% ($R_k = 0.3$). $EWirr$ is obtained for every sub-basin in the GRB as a percentage over the amount of water allotted in a normal year ($R_k = 1$).

$$EWirr = \sum_k q_k * R_k \qquad [15]$$

3.4. Climate change scenarios

So far we are assuming that the dynamics of the renewable water resources are endogenous and there is no external shock. However, there is evidence that renewable water resources in Spanish basins have been decreasing during the last years (MARM, 2000 and 2011). Climate change is regarded as the main cause and consequently it has become a matter of concern, especially in overexploited southern basins such as the GRB (GRBA, 2007 and 2010). Therefore, national and regional authorities have commissioned several reports on the effects of climate change over water supply in the GRB. The alternative scenarios provided by these reports are compiled in MARM (2011). In this paper we use *synthetic indexes* that are obtained from a weighted average of the alternative climate change scenarios (see MARM, 2011). *Synthetic indexes* are available for the periods 2011-2040, 2041-2070 and 2071-2100. We use these indexes to adjust the historical data series of the hydrological variables and then we repeat the methodology above to assess the effects of climate change over water availability in agriculture in the medium-long term. We consider three climate change scenarios (2011-2040, 2041-2070 and 2071-2100), all of them showing a decrease of renewable resources. The *synthetic indexes* show that water availability falls between 7.5% and 12% in the period 2012-2040, between 12.5% and 20% in 2041-2070 and between 19% and 33.5% in 2071-2100, depending on the water source, as compared to the historical data series (MARM, 2011).

4. Results

The historical overexploitation of the GRB has reduced the robustness and resiliency of the basin and has made it gradually more exposed to drought events. According to our model, a drought is declared almost one in two years and the probability of suffering an extreme drought (with water restrictions for agriculture of 70%) is approximately 14%. Consequently, the implementation of the DMP will result in an expected water availability for agriculture of 62.2% (much lower than the 90% specified in the previous legislation), although there are relevant differences among sub-basins.

Regulación General is the largest sub-basin in the GRB and represents 66% of agricultural water demand. It is also the most affected sub-basin by the water restrictions specified in the DMP, with an expected water availability only slightly above 50% in an average year. The Jaén Sub-basin (4% of the agricultural water demand) also has a low expected water availability of 67%. On the other hand, the sub-basins of Alto Genil, Hoya de Guadix, Alto Guadiana, Bembézar-Retortillo, Viar and Almonte Marismas, which together represent 20% of the agricultural water demand in the GRB, have an expected water availability over 80%. The remaining sub-basins also show positive results, with expected water availability above 75%, although most of these sub-basins are located upstream and have a marginal relevance for irrigation (10% of the agricultural water demand) (Figure 2).

[Insert Figure 2 about here]

4.1. Climate change scenarios

Now we use the official climate change estimations to introduce an exogenous shock that reduces the amount of renewable water resources in the system. Our results show that expected water availability for agriculture in the GRB is reduced in average by 4% in 2012-2040, by 7% in 2041-2070 and by 12% in 2071-2100 as compared to the values in the simulation with no climate change.

As before, there are relevant differences among sub-basins. In the Regulación General Sub-Basin the expected water availability for agriculture is reduced by 12% throughout the century, from 50% to 38%, revealing a scenario in which a large share of the irrigated land in the GRB would be unsustainable. Expected water availability in the Alto Genil Sub-Basin, which supplies 9% of the agricultural water demand, is reduced by almost 20%, from 84% to 66%. Also the Alto Guadiana (from 84% to 69%), Guadalmellato (from 78% to 67%) and Sevilla (from 80% to 61%) sub-basins show expected water availability values for agriculture under 70% in the end of the century. Finally the Salado de Morón (from 75% to 58%) and Jaén (from 67% to 55%) sub-basins show expected water availability values for agriculture under 60% in 2100. All the results are displayed in the Figure 3:

[Insert Figure 3 about here]

5. Discussion and conclusions

In this paper we develop a model to assess the impact of the DMPs over water availability for agriculture. The methodology is general and can be implemented in any basin with a DMP in force. We apply the methodology to the particular case of the overexploited GRB in Spain. Results show that, provided that the DMP is effectively enforced, the effects over water availability in agriculture are significant. Water availability is reduced in average to 62.5% of the water demand, a much lower figure than the water access reliability of 90% that the previous legislation foresaw. In some areas, the impact may be even larger. For example, expected water availability is halved in the Regulación General Sub-basin, which comprises most of the irrigated lands in the GRB, including the most productive areas. If we introduce climate change simulations in our model, water restrictions are deepened and more frequent.

The severity of these water restrictions is largely determined by the strict water constraints imposed by the DMPs in order to guarantee household supply and minimum environmental flows. These constraints are a function of the water demand to water supply ratio. In basins suffering a severe water deficit, such as the GRB, water constraints are tighter and thus have a higher effect over agriculture. Thus, we would expect a policy aimed towards reducing and adapting water demand to water supply. This policy would make possible a relaxation in the water constraints of the DMP and would make the agricultural activity more sustainable. However, unlike the US contingency plans, EU DMPs do not use complementary economic instruments (such as water markets or water pricing) to curb water demand. As a result, water demand in the GRB is expected to remain in similar levels (GRBA, 2010), though water availability will be drastically reduced according to our model.

It is also important to consider that in this model we have assumed a perfect enforcement of the DMP. Without complementary instruments to reduce water demand, a likely collateral effect of *command and control* policies in drought prone agricultural areas is the overexploitation of uncontrolled groundwater resources (Gómez and Pérez, 2012). Consequently, the final outcome of the DMPs could be the substitution of the publicly provided water by illegal groundwater abstractions. This may raise environmental as well as inequality issues, as those who have no access to groundwater would be the ones actually facing the consequences of water restrictions.

In order to avoid a disproportionate impact over agriculture and at the same time guarantee water demand for priority uses, additional instruments need to be in place. Without complementary policies, DMPs may change water availability but not agents' incentives. Consequently, DMPs should not be regarded as a panacea, but rather as a part of an institutional change towards a sustainable water management. A comprehensive policy mix can find the way to make the reduction of water scarcity compatible with the maintenance of a sound agricultural sector. DMPs are a first step and an opportunity, but the transition towards a sustainable water use relies on building better institutions and putting the effective incentives in place.

Acknowledgements:

The research leading to these results has received funding from the European Union's Seventh Framework Program (FP7/2007-2013) under grant agreement n° 265213 (EPI-WATER - Evaluating Economic Policy Instruments for Sustainable Water Management in Europe). The authors also acknowledge the support of the Spanish Association of Agrarian Insuring Firms (Agroseguro S.A.).

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Table 1: Gamma function. The dependent variable is the percentage of rainfall (x_1), groundwater (x_2) or runoff (x_3) over their maximum value in the historical data.

		Coefficient	
Sub-basin	Variable type	a (Scale)	b (Shape)
Campiña Sevillana	x_1	10.699*	0.057*
		(0.764)	(0.005)
Alto Guadiana Menor	x_1	11.327*	0.049*
		(0.755)	(0.004)
Almonte-Marismas	x_1	16.452*	0.032*
		(1.371)	(0.003)
Alto Genil	x_2	7.719*	0.062*
		(0.858)	(0.010)
Viar	x_3	1.679*	0.193*
		(0.316)	(0.025)
Huesna	x_3	1.263*	0.324*

Estimated maximum likelihood. Standard errors in parentheses.

Source: Authors' elaboration from MARM, 2009 and 2012; AEMET, 2012 and GRBA, 2012.

* Significant at the 1% level.

Table 2: Weibull function. The dependent variable is the percentage of dam-stored water over dam storage capacity (x_4).

	Coefficient	
Sub-basin	a (Scale)	b (Shape)
Salado de Morón	0.500*	1.684*
	(0.036)	(0.153)
Alto Genil	0.597*	1.683*
	(0.040)	(0.129)
Hoya de Guadix	0.818*	5.109*
	(0.068)	(0.426)
Alto Guadiana Menor	0.720*	3.062*
	(0.080)	(0.510)
Bembézar-Retortillo	0.711*	2.397*
	(0.178)	(0.184)
Jaén	0.549*	1.698*
	(0.110)	(0.170)
Rumblar	0.743*	2.538*
	(0.106)	(0.195)
Guadalmellato	0.589*	1.924*
	(0.059)	(0.275)
Sevilla	0.731*	2.137*
	(0.061)	(0.194)
Regulación General	0.347*	1.484*
	(0.035)	(0.212)

Estimated maximum likelihood. Standard errors in parentheses.

Source: Authors' elaboration from MARM, 2009 and GRBA, 2012.

* Significant at the 1% level.

Figure 1: Location of the Guadalquivir River Basin in the Iberian Peninsula and detail of its sub-basins.

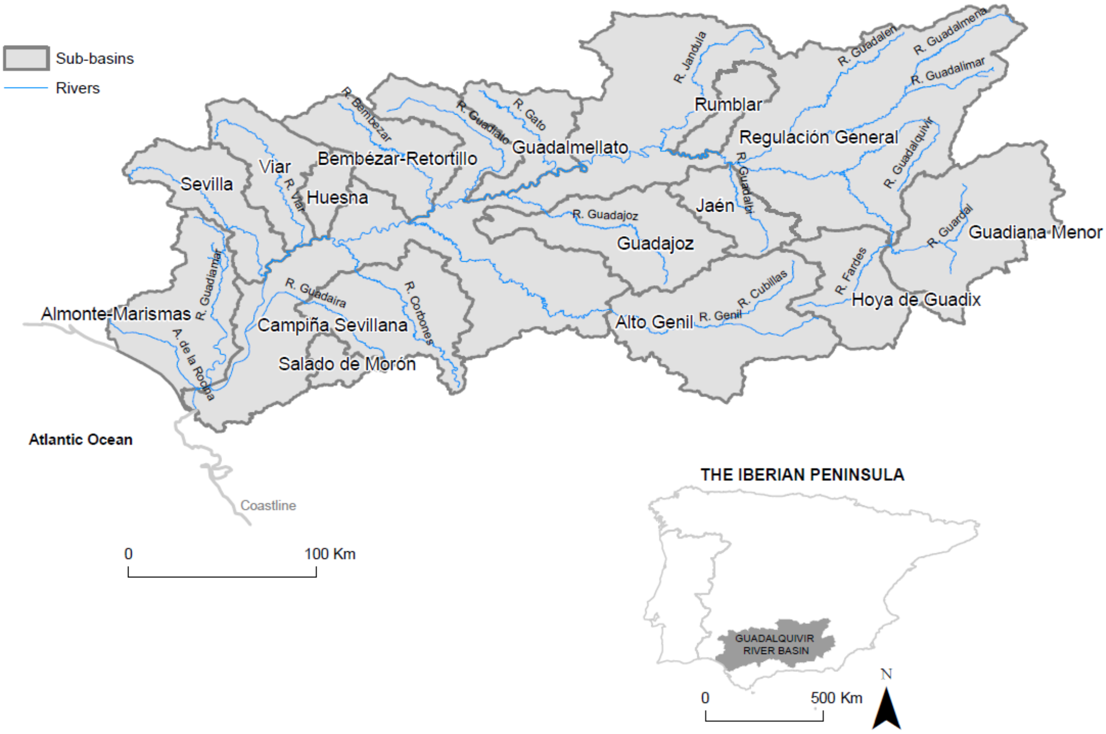


Figure 2: Expected water allocation for agriculture, GRB.

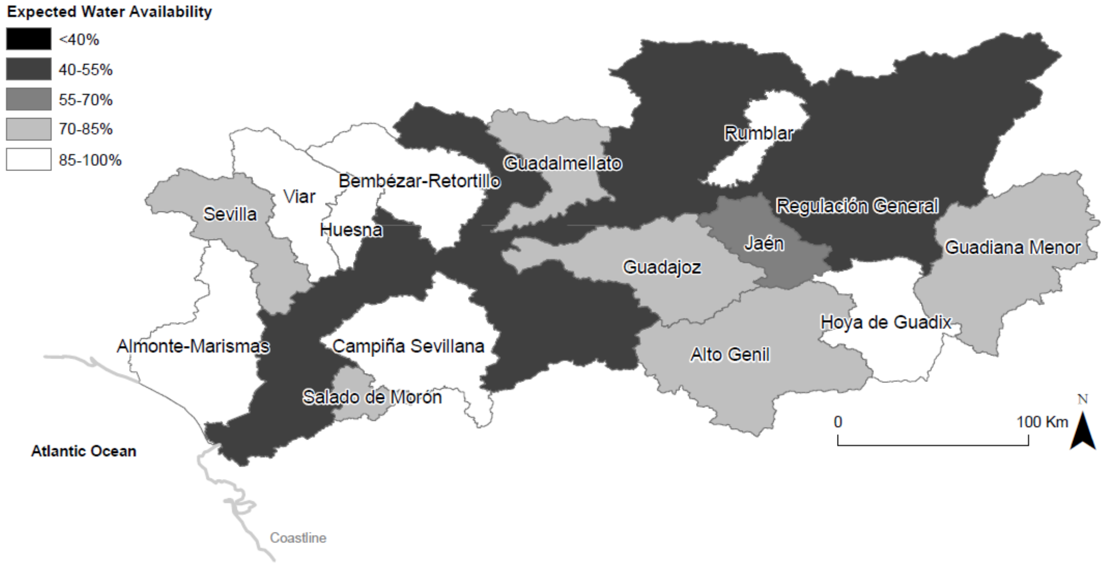
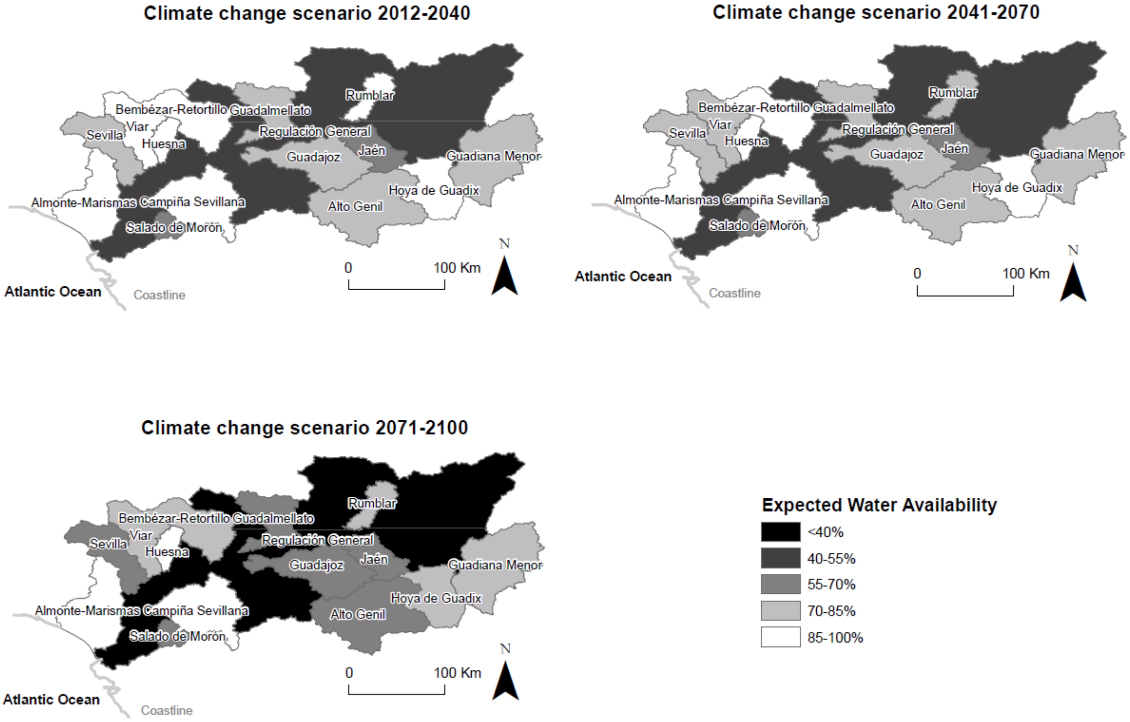


Figure 3: Expected water allocation for agriculture, GRB. Climate change simulations (2012-2040, 2041-2070 and 2071-2100).


Climate change scenario 2012-2040

Climate change scenario 2041-2070

Climate change scenario 2071-2100

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