Climate Change, Hydro-conflicts and Human Security

SEVENTH FRAMEWORK PROGRAMME

# Water vulnerability assessment to climate change in the Intercontinental Biosphere Reserve of the Mediterranean

# (Morocco-Spain)

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**Abstract**

**The Mediterranean basin has been identified as one of the regions in the world most vulnerable to global change effects. Drought trends in the Mediterranean have increased significantly in the last decades registering serious economic, social, and environmental consequences resulting in land degradation, human migrations, famine, diseases, and loss of human life. However, the impacts are unevenly distributed in the area creating a S-N gradient of decreasing intensity. Global and regional climate change scenarios foresee a growth of the average annual temperature higher than planet's mean projecting an increasing frequency of drought episodes adding to the complexity of water scarcity management and its future sustainability.**

**This study focuses on the potential water vulnerability in the Intercontinental Biosphere Reserve of the Mediterranean (IBRM), located in the western side of the Mediterranean basin between Spain (Europe) and Morocco (Africa). The vulnerability assessment was based on the use of a set of scenarios of climate change, the application of a hydro-ecological model, as well as the participation of stakeholders and local experts. This crosscutting approach identified main impacts expected in the reserve and scored their relevance.**

**The results identify the IBRM vulnerability degree to global change and propose relevant adaptation strategies and actions to local and national policy makers. These recommendations need to be introduced following an integrated implementation framework into the shared IBRM management plan and the national strategies in both countries in order to adapt to global change effects in the region.**

# 1. Introduction

The vulnerability of a system is defined as the degree to which a system is susceptible to adverse effects of a natural hazard, as a function of the exposure, its sensitivity, and its adaptive capacity (Adger 2006, Füssel 2007, IPCC 2007). Applying this concept to global change vulnerability in a regional context, it is relevant to face these questions: (1) How is the climate shifting in the specific region? (2) What are the potential impacts of climate change in the region on the different sectors? (3) What is the degree of adaptation of the specific sectors within the region to these potential impacts?

The Mediterranean basin has been identified among the regions in the world most vulnerable to climate related events (Christensen *et al.* 2007). It is very probable that the expected increase of the average annual temperature will be slightly higher than that of the world level (Hallegatte *et al.* 2007; Van Grunderbeeck and Tourre 2008). The recurrence and increasing frequency of drought episodes in the Mediterranean, further add to the complexity of water scarcity management with negative implications towards its current and future sustainability (Iglesias *et al.* 2007; Hisdal *et al.* 2001). The drought trends in the Mediterranean have increased significantly after 1970 (Iglesias and Moneo 2005; Vogt and Somma 2000; Wilhite and Vanyarkho 2000) causing huge economic damages during the last 2 decades (CRED 2010).

Apart from reduced water availability and increased drought, there are additional climate change threats that are expected to cause significant impacts in the Mediterranean Basin (IPCC 2007, Bates *et al.* 2008, EEA 2008) like severe biodiversity losses, increased forest fires, reduced summer tourism and reducing suitable cropping areas, linked to other human health and social impacts. Moreover, this region is undergoing an increasing pressure on water resources, especially in the coastal zones (Fornés *et al.* 2005). Blue Plan estimates show that regional water demand and consumption have doubled in the second half of the twentieth century, increasing the vulnerability to water scarcity. This is a result of population dynamics and growth, agricultural intensification, economic and social development, touristic pressure, and over consumption of water resources (ENPI 2007, Benoît and Comeau 2005). In addition, forecasting the highly variable seasonal and inter-annual rainfall in the region is a problem that decision makers face when fulfilling agricultural, social, and environmental targets while ensuring the sustainability of water resources. In the Mediterranean Basin, there is a growing evidence of limited capacity to cope with socio-economic and agricultural demands in extended periods of drought (Scheffran and Battaglini 2011). For example, water reserves were not able to cope with extensive droughts in the late 1990s in Spain, Morocco and Tunisia, causing many irrigation dependent agricultural systems to cease production. These conditions are already leading to significant problems due to an unbalanced distribution of water resources, conflicts among users, and between countries (Agoumi 2003, Parish and Funnell 1999, Touchan *et al.* 2010, CRED 2010).

In order to overcome these pressures and threats, the aim therefore is to find ways of adaptation, as an attempt of reducing their effects, and avoiding the occurrence of new ones. Furthermore, the development and implementation of adequate mitigation strategies, enhancing adaptive capacity to climate change gives the opportunity for a significant decrease of such vulnerability (Kallis 2008, Vogt and Somma 2000). Reducing the vulnerability of Mediterranean communities to global change will require measures that diversify livelihood options, reduce pressure on natural resources, and restore and protect ecosystems through sustainable management practices (UNDP 2008, UN-ISDR, 2006).

Causal links between environmental factors (climate and water related stressors) and conflict, cooperation and human security are studied and analysed in CLICO European project (Goulden and Porter 2010). CLICO framework focuses in human security and the interaction between conflict and cooperation within a social-ecological system, where linkages between society and environment are considered. CLICO works at multiple spatial scales showing the importance of the global or regional, national and sub-national scale economic, political and environmental contexts, focusing in eleven cases of areas where droughts or floods pose threats to human security in the Mediterranean, Middle East and Sahel. This work is one of the study cases of CLICO project.

The case study focuses on the Intercontinental Biosphere Reserve of the Mediterranean (Morocco- Spain) (hereafter IBRM), located in the western side of the Mediterranean basin between Spain (Europe) and Morocco (Africa) passing by a marine area of the strait of Gibraltar. The Reserve is a particular case where countries with different political and institutional context joint efforts to preserve the natural and cultural diversity of the region. Covering an extension of one million hectares, as well as its surroundings, the IBRM is undergoing rapid socio-economic and technological transformations resulting in changes in land uses and increasing the demographic pressure. These changes are increasing the pressure on its already structural water resource deficit and on the hydrological cycle and the limited water resources. Furthermore the registered inter-annual climatic variability in the last decades revealed water scarcity situations including extreme drought events which had direct effects on human security. These present conditions together with the climate change regional projections indicate an increased likelihood of droughts and hydro-stress in the region, and conflicts among the users, questioning by this the ability to maintain the current management philosophy of water resources in both sides of the reserve.

The main objective of this study is to assess the territorial vulnerability of water resources in the region and the future climate change effects on hydro-ecological systems and human security. The specific objectives of this study are (1) to analyse current and potential future impacts of climate change on different water-sensitive sectors (specially, water resources, agriculture, natural systems and tourism), (2) to evaluate the present degree of adaptation and the adaptive capacity of these sectors to climate change, (3) to draw conclusions on the vulnerability of the IRBM by considering potential impacts, adaptation degrees and adaptive capacity, and (4) to assess to what extent the current IBRM institutional and management framework could face challenges of human security expected in this area. In this context, the biosphere reserve figure promoted by the Man and the Biosphere Programme (MAB) of UNESCO could play a relevant role in the cooperative management of this challenge.

## 2. Study area

The Intercontinental Biosphere Reserve of the Mediterranean is located in the Western side of the Mediterranean basin shared by Spain and Morocco within the coordinates 4°41'24" W, 36°57'29" N (NW) and 5°50'25" W, 34°47'  38" N (SE). The reserve spans over two continents, Europe and Africa, passing through the marine area of the Strait of Gibraltar and covering an extension of one million hectares. It was created in 2006 under the UNESCO's Man and Biosphere Reserve Programme (figure 1).

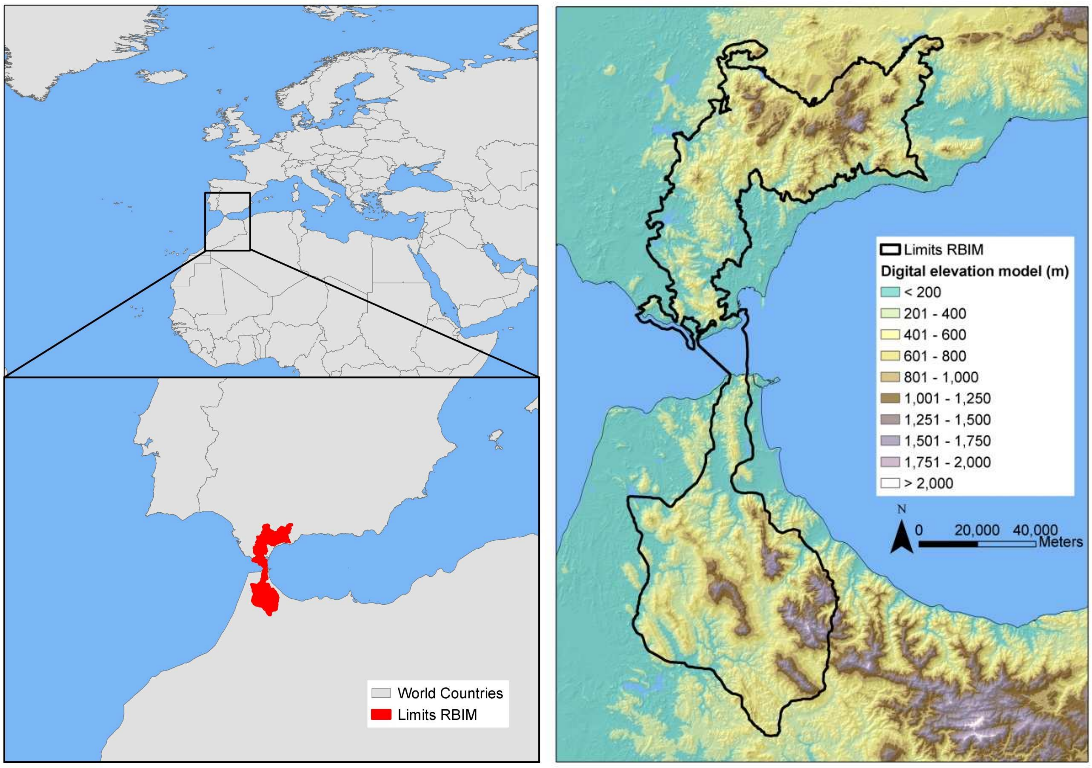

Figure 1. Location of the IBRM case study (left) and detailed zoom of the Digital Elevation Model (right)

The IBRM is located in the semi-arid zone of the Mediterranean where the climatic conditions are known for their seasonal contrasts, characterised by high annual mean variability in precipitation (500-800 mm/year) and frequent drought episodes. Due to its geographic location, the IBRM is influenced by the contrasted winds of the western Mediterranean Sea and the Atlantic wet fronts. These wet fronts enter from the Atlantic and hit both sides of the reserve discharging high amounts of annual precipitation (around 2000 mm/year) in some points of the reserve (figure 2a). In addition, the high mean annual temperature (16-19℃, figure 2b) and the high solar radiation of the region lead to an extensive evapotranspiration, especially during the summer season (WorldClim Database, Hijmans et al, 2005).

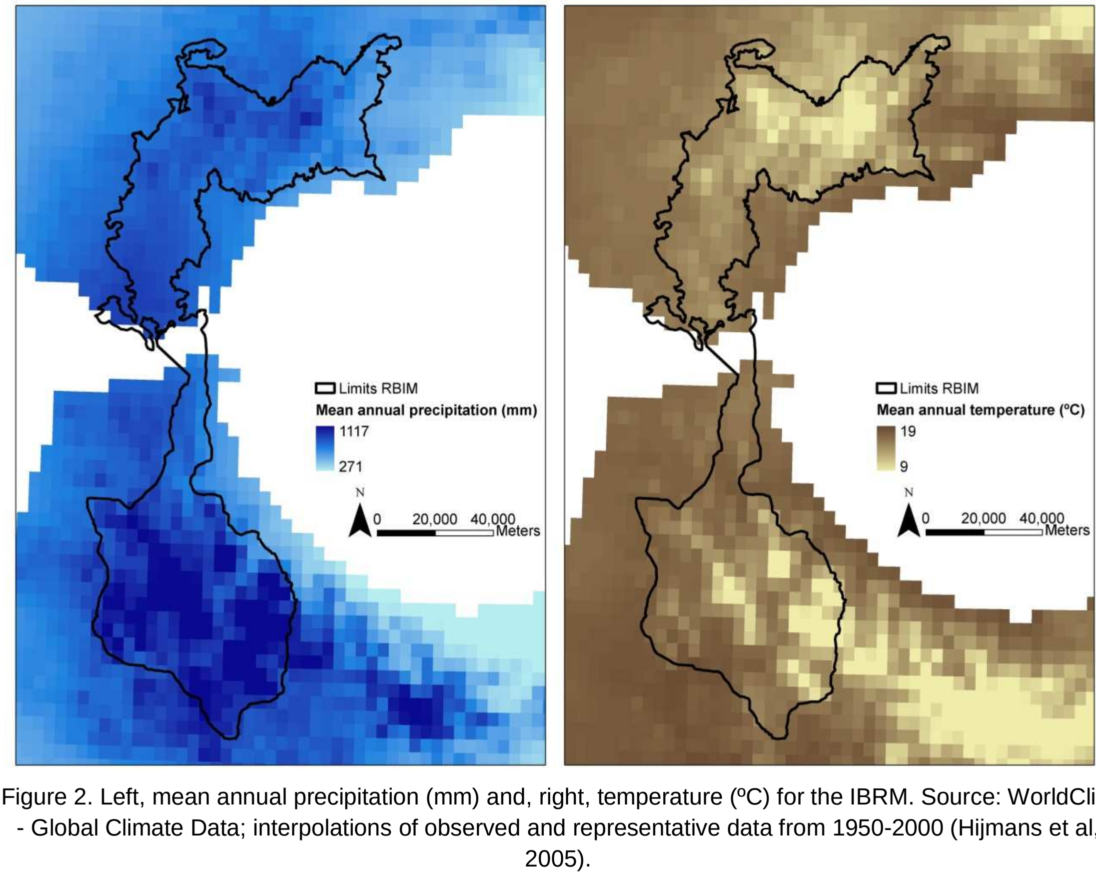


Figure 2. Left, mean annual precipitation (mm) and, right, temperature (ºC) for the IBRM. Source: WorldClim - Global Climate Data; interpolations of observed and representative data from 1950-2000 (Hijmans et al, 2005).

Although both sides of the IBRM share very similar natural and biophysical conditions, the impact of human activity resulted in a very different land cover pattern (figure 3): 80% of the Spanish side is covered by forest areas, including shrubland and pastures, whereas this land use corresponds to around 38% of the Moroccan side (Globcover V 2.2, 2005-2006). This is also mirrored in the extension of protected areas: 70% in Andalusia versus 30% in the Moroccan side (Molina and Villa 2008). In parallel, cropland covers more than 60% of the Moroccan side, being mostly rain fed, compared to less than 20% of the Spanish side which is partly irrigated (figure 3a and 3b).

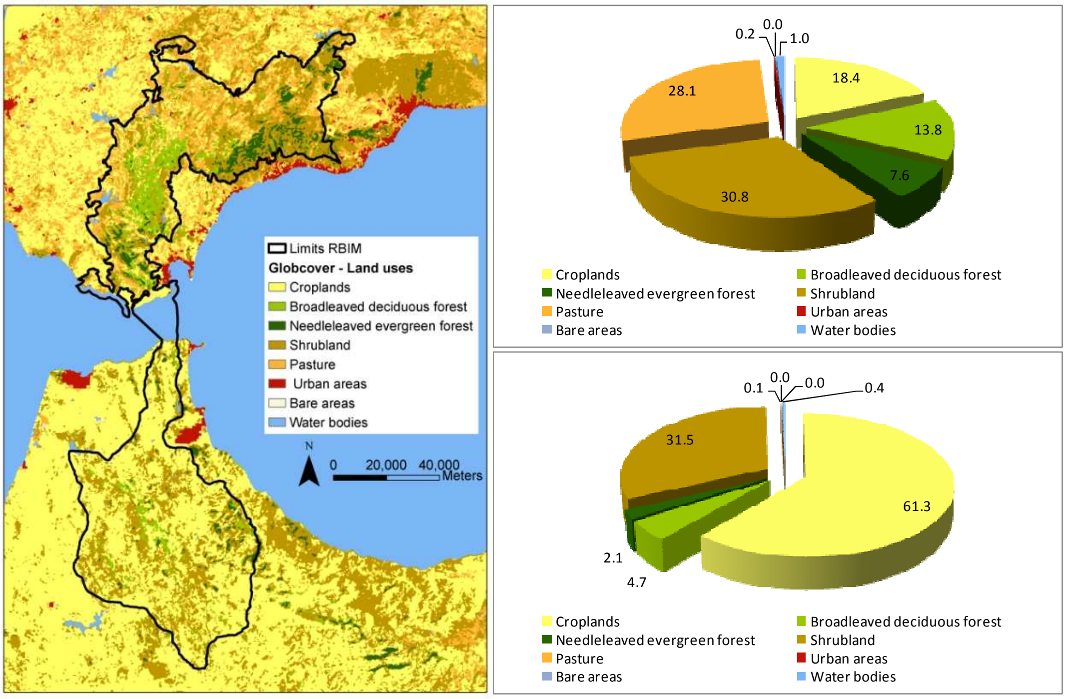


Figure 3. Figure 3a (left) land-use map for the region and figure 3b (right) the percentage distribution of land-use categories. Source: Globcover V 2.2, 2005-2006.

Both sides of the IBRM count around 556.359 inhabitants inside its limits (Molina and Villa 2008). However, when neighbouring towns surrounding the IBRM borders are considered, the population is almost three times higher (approximately 1.442.059 inhabitants). The Eastern side of the IBRM is the most exposed to external pressures in terms of population. Inside the IBRM a different pattern emerges between Spain and Morocco following a decreasing South – North pattern and where Morocco counts with a predominant presence of mid-low size towns (figure 4).

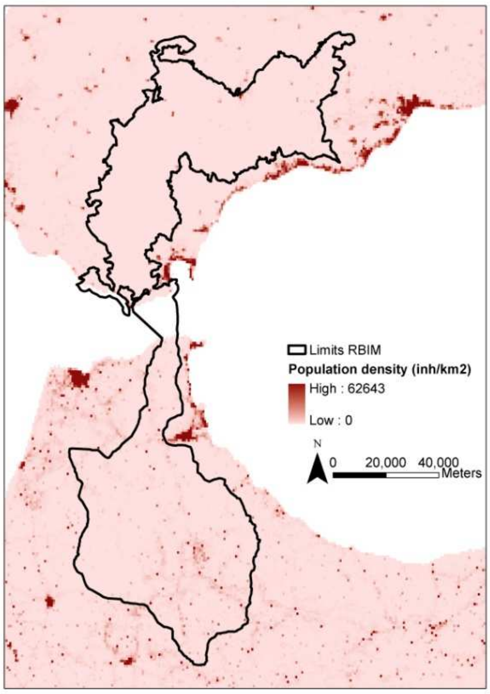


Figure 4. Population density in the IBRM and surrounding areas (inhabitants/km$^2$). LandScan Global Population Database 2008.

Table 1 shows the marked socio-economic contrast between Spain and Morocco which reflects, specially, the greater dependency on natural resources in Morocco than in Spain.

Table 1. Socio-economic indicators for Morocco and Spain.

| Indicators | Morocco | Spain |
|---|---|---|
| GDP / per capita in US Dollar (2009 est.)[6] | 4,600 | 33,700 |
| **Per capita – by occupation**: [7] | | |
| • agriculture: | 18.8% | 3.4% |
| • industry: | 32.6% | 26.9% |
| • services: | 48.6% (2009 est.) | 69.6% (2009 est.) |
| **Labour force – by occupation**: [8] | | |
| • agriculture: | 44.6% | 4% |
| • industry: | 19.8% | 26.4% |

6 http://www.theodora.com/wfbcurrent
7 http://www.theodora.com/wfbcurrent
8 http://www.theodora.com/wfbcurrent

| | | |
|---|---|---|
| • services: | 35.5% (2006 est.) | 69.5% (2008 est.) |
| **Population living in rural areas** (%) | 47 | 22.4 (in Andalusia) |
| **Population living in Rural area in IBRM** (%) | 93 | -- |
| **Land ownership (**average farm side in ha.**)** | 2-3 | 35 |
| **Use of total water resources** (%)[9] | 43 | 32 |
| **Water resources per capita** (m3 / person/ year)[10] | 895 | 2557 |
| **Water use for agriculture** (%) | 86 | 70 |
| **Water use for tourism** (%) | -- | 13 |
| **Irrigated agriculture** (%) | 10 | 90 |

Drought is the major threat in the IBRM area known to have prolonged effects in time, which have shown a significant increasing trend in frequency the last decades (Karaky 2002, INE 2008).

In Morocco, the periodic drought episodes and significant rainfall variability greatly affect agriculture production (Karaky 2002), livestock and, as consequence, their contribution to overall gross national product has decreased (GDP) (Touchan *et al.* 2010). After the 1970's, the decreasing trend in precipitation provoked water deficiency in many areas (Ouassou *et al.* 2005) and affected drastically the production of cereals (e.g. from 9.5 million tons in 1994 to 1.6 million tons in 1995) (Skees *et al.* 2001). In the Rif region, recent studies also demonstrate that the latter half of the twentieth century was one of the driest in the last nine centuries causing net declines of dam's water reserves, deficits in groundwater resources and limitations in drinking water and irrigation water supply (Agoumi 2003, Parish and Funnell 1999, Touchan *et al.* 2010). Moroccan population have taken two main exits to overcome these worsening of their living means in last decades: 1) the development of unsustainable agricultural practices (overgrazing, illegal cannabis crop in higher gradient slopes, forest overexploitation) with a high environmental impact in terms of soil degradation (Moore *et al* 1998, Barrow and Hicham 2000); and 2) the rural exodus to coastal cities (Bennis and Tazi Sadeq 1998).

In Andalusia, some examples include the major drought of mid 1990s which affected over 6 million people in Spain and had severe effects on the agricultural economy (CRED 2010). Recurrent droughts involve serious losses and injuries in forestry, cropping and pastoral sectors (Mestre Barceló 1995, Roberts 2002). In particular cereal crops, vines, and olive trees are ones of the most affected. Droughts affect the amount of irrigated land and rural industry sectors. In parallel, shortages in water supply to

9 Millenium Development Goal indicators 2000
10 http://earthtrends.wri.org

numerous villages affect touristic sector adding to the effect of increased summer extreme temperatures (Méndez 2008).

The less favourable scenario for the IBRM, according to CLICO Climate Outlooks (Bruggeman *et al.*, 2010), shows a maximum rainfall decrease of 24-25% in 2040-2069, compared to 1961-1990, where summer and autumn periods would be more affected (A1B IPCC scenario). The same scenario projects a temperature increase of 2.4-2.5 ℃ for the same period. Even under the lower emission B1 scenario, the projected temperature increase is expected to be between 1.7-1.8 ℃. These climatic stresses are expected to deeply affect water resources availability by decreasing water runoff and aquifer recharge. The same patterns and order of magnitude are found in other regional projections sources (Moreira and Ribalaygua 2007, AEMET 2009).

In parallel, the demand for freshwater services in the IBRM region and the neighbouring areas is high and is likely to continue in the future due to an ongoing increase in economic and demographic development. The over-exploitation of water resources is resulting from excessive abstraction for tourism and irrigation (Llamas and Martinez-Santos 2005, Garrido and Iglesias 2006) causing a cycle of unsustainable socio-economic developments within the region, influencing energy and food security. As a result, Spain's Mediterranean basins are in already very high stress, and will have to meet a growing part of their demand from "unconventional" sources by 2025, such as the water re-use and desalination processes (Blinda *et al.* 2006). Actually, Andalusia is reusing approximately 21 $hm^3$/year, and desalinating 23 $hm^3$/year, the 1.9% and the 2.1% respectively of the total available resources within the region (AAA, 2010). During the same period, Morocco will still be within its limits of using their resources but may experience local or exceptional stress (Blinda *et al.* 2006). In this area, the vulnerability of the local population is linked to climate and its fluctuation, since the main economic activities (agriculture, tourism, and coastlines) depend highly on water availability (Agoumi 2003).

## 3. Methodology of the vulnerability assessment to Climate Change

The vulnerability assessment is based on a multi-disciplinary approach implying the use of a set of scenarios of climate change, the application of a hydro-ecological model, as well as the participation of stakeholders and local experts.

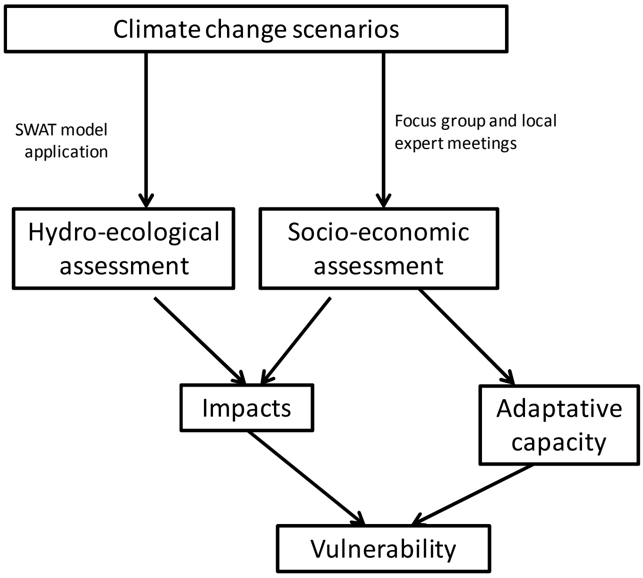


Figure 5, Conceptual framework of vulnerability assessment applied in IRBM

### *3.1 Climate change scenarios*

The scenarios are based on the CLICO Climate Outlooks (Bruggeman *et al.*, 2010). These outlooks provide an ensemble median from several different Global Circulation Models (GCMs) of change projections in average annual precipitation and temperature under different IPCC scenarios (Nakicenovic and Swart 2000) for different sites in the Mediterranean Basin, the Middle East and the Sahel. IPCC has described four scenarios families (A1, A2, B1 and B2) depending on the induced effect of carbon emissions, defined by the demographic, economic and technologic development (IPCC, 2007). The projections for the A2 and B1 scenarios were selected for this work. The A2 scenario implies a high anthropogenic emissions level in a more economic and regional development, while the B1 scenario represents a low emissions level in a more environmental and global development (IPCC, 2007). CLICO Climate Outlooks include the climate change signal for average annual temperature and precipitation for the period 2040-2069 relative to 1961-1990. These selected projections point out an average precipitation decrease of 17-18% for the A2 scenario and 16% for the B1 for the mentioned periods, and an increment in annual temperature of 2.3-24 ºC (A2 scenario) and 1.7-1.8 ºC (B1 scenario).

Future climate series were constructed considering this climate change signal using the weather generator developed under GOTILWA+ model system (Gracia *et al.* 1999, Keenan 2010; http://www.creaf.uab.es/GOTILWA+). It generates daily climate series (1961 to 2070) with the same statistical pattern of observed climate data and allows overlay different climate change scenario signals. Obviously, the uncertainties related to future climate projections linked to modeling purposes must be considered and be in mind when results are discussed because of cumulative uncertainties in Global Circulation Models projections, in downscaling procedures, in land-use assumptions, or in models used (Ewen *et al.* 2006; Beven 2011).

### *3.2 Hydro-ecological assessment*

The Soil and Water Assessment Tool (SWAT, Arnold *et al.*, 1998, Neitsch et al 2002) was used to simulate the hydro-ecological response to climate change. This is a physically based, semi-distributed hydrological model that estimates surface and subsurface flow, erosion and sediment deposition and nutrient movement within the basin at a daily time step. SWAT has been widely used throughout the world for many water resources applications but scarcely in studies focused on climate change impacts in Mediterranean watersheds (Nunes *et al.* 2008).

In order to adequately simulate hydrologic processes, the basin is divided into subbasins through which streams are routed. The subunits of the subbasins are referred as hydrologic response units (HRU's) being the unique combination of slope, soil and land use characteristics being considered hydrologically homogeneous. The model calculations are performed at a HRU basis. In IRBM case study, the basins which totally or partially contain the reserve were selected. The results are shown at subbasin level.

In a first phase, the model is calibrated and validated with measured climatic and flow discharge data. In a second phase, the calibrated model is used to evaluate climate change impact on water resources. In this phase generated climate and climate projections are used for the period 1961 to 2070.

SWAT input data used on the calibration includes:

- SRTM digital elevation model for Andalusia (90 m spatial resolution) developed by NASA and;
- ASTER global digital elevation model for Morocco (ASTER GDEM, 30m) developed by the Earth Remote Sensing Data Analysis Center;
- the soil map created from the Andalusian Soil Map (1: 400.000) developed by the Andalusian Agricultural Regional Ministry and CSIC and the Moroccan Geomorphological map (1:100.000) developed by Mohamed V University in Rabat(both adapted to the aim of this research);

- land use data from the Andalusia Use and Land Cover Map (2007 version, 1:25.000) developed by the Andalusian Environmental Regional Ministry and from Globcover V (2005-2006 version, 300m) developed by ESA GlobCover Team; and
- climatic series from meteorological stations located on the watersheds (AEMET - Spanish Meteorological Agency and Loukkos Hydrological Basin Agency)[11].

The model calibration was based on measured stream flow values along the watersheds. In these specific watersheds, flow series were often scarce, incomplete and with bad quality. Initially, a 26 years period (1983-2009 in Andalusia and 1981-2007 in Morocco) was chosen to calibrate and validate the model, the longest time slice in which both climatic and flow data were available. Within this time slice, calibration was made with shorter periods, depending on the quality data of the gauging station. Calibration was carried out at a monthly time step to target three main objectives: (1) simulated curves similar to measured ones, (2) mean flow values and total contributions similar between simulated and measured data, and (3) good statistics of Nash and Sutclife efficiency coefficient (NSE) and RMSE-observations standard deviation ratio (RSR) (Moriasi *et al.* 2007).

Figure 6 and Table 2 show calibration and validation outputs in some gauging station within the RBIM. The graphical comparison between simulated and measured data shows a good adjustment, as well as mean daily values. Statistics NSE and RSR show a satisfactory adjustment in the majority of the gauging stations.

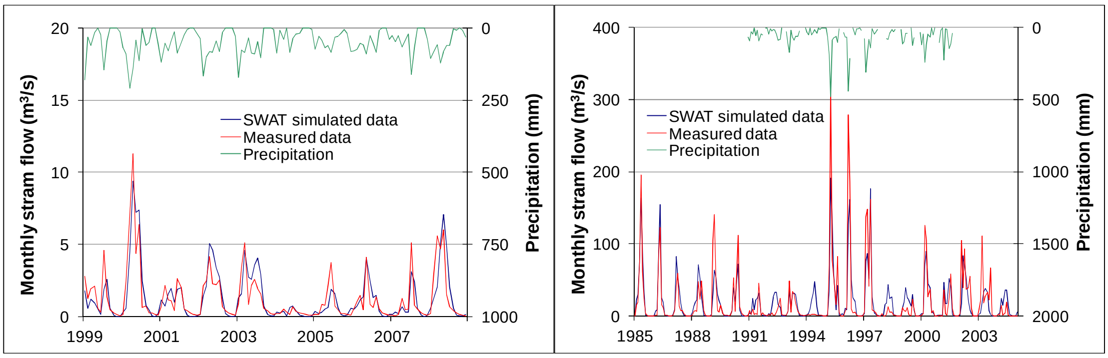


Figure 6. Calibration results: measured and simulated daily discharge in Guadiaro river in Andalusia (6030 gauging station) (left graph) and in Barrage Oued El Makhazine in Morocco (5764 gauging station)(right graph).

Table 2. Calibration results: mean daily discharge values from both simulated and measured data and adjust statistics in each basin. G.s. means gauging station. Compared period: 1983-2009 in Andalusia and 1981-

[11] Climatic series included precipitation and minimum and maximum temperature in nine points in Andalusia and fifteen in Morocco. These series were filled and corrected by the effects of orography on precipitation and temperature with SWAT equations.

2007 in Morocco. NSE: Nash–Sutcliffe efficiency, RSR: RMSE (root mean square errors) to observations standard deviation ratio.

| | | Simulated mean daily discharge ($m^3/s$) | Observed mean daily discharge ($m^3/s$) | Statistics | |
|---|---|---|---|---|---|
| | | | | NSE | RSR |
| Andalusia (Spain) | **Guadiaro river (g.s. 6030)** | 1.3 | 1.3 | 0.7 | 0.5 |
| | **Guadiaro river (g.s. 6028)** | 2.6 | 2.6 | 0.6 | 0.7 |
| | **Guadalete river (g.s. 5148)** | 3.0 | 2.2 | 0.5 | 0.7 |
| | **Palmones river (g.s. 6083)** | 0.3 | 0.4 | 0.6 | 0.6 |
| | **Guadalhorce river (g.s. 6093)** | 1.0 | 0.9 | 0.6 | 0.6 |
| | **Guadalhorce river (g.s. 6011)** | 1.2 | 1.2 | 0.5 | 0.7 |
| Morocco | **M'douar (g.s. 612/04)** | 12.0 | 11.7 | 0.4 | 0.7 |
| | **BOEM (g.s. 5764)** | 20.0 | 19.2 | 0.8 | 0.5 |
| | **Khrofa (g.s. 1373/03)** | 5.7 | 5.5 | 0.2 | 0.9 |

### *3.3 Socio-economic assessment*

At the socio-economic level, the exposure of the IBRM communities to climate change effects and water scarcity is analysed through a series local experts and stakeholders meetings and focus-groups. Two stakeholders' meetings (May 2011) and two focus group meetings (February 2012) were developed in Andalusia (Spain) and Morocco respectively. The aim of the stakeholders meetings was to identify the present most sensitive water-dependent areas and sectors in the IBRM. Based on these outputs, future hydro-climatic and water use scenarios were drawn and were used in the focus group meetings. In the focus group, different actors analysed the potential impacts of climate change and their implications on human security (hydro-security) and future water uses within the region through a structured dialogue among them. The focus group followed the methodology proposed by Goulden and Porter (2011). Four scenarios for year 2040 were presented and adapted to local conditions of each side of the IBRM (Table 3). Each scenario was a combination of a hydro-climatic scenario (mentioned in the 3.1 section) and water use scenario. The participants identified potential impacts based on their expert knowledge and field experience. These identified impacts were scored according to the community/sector adaptative capacity and, consequently, their vulnerability. The results of this assessment were partially compiled in Abdul Malak *et al* 2012.

Table 3. Scenarios proposed for the IBRM case study

| | | | Hydro-climatic scenarios | |
|---|---|---|---|---|
| | | | Low change scenario | High change scenario |
| **Water use scenarios** | **Resources adaptation** | Equitable distribution of water resources | ***A scenario*** | ***B scenario*** |
| | **Water use prioritization** | Prioritization of water use for a specific economic sector (tourism in Andalusia and non-sustainable agriculture in Morocco) | ***C scenario*** | ***D scenario*** |

## 4. Results and discussion

According to the assessment described in section 3.3, four main categories of impacts were identified by stakeholders as the most relevant in IBRM (hydrological and climate impacts, impacts on rural population, impacts on touristic sector and impacts on natural systems). For each impact category, a summary of the results of the socio-economic assessment jointly with the contrasted outputs of the hydro-ecological assessment are presented.

### *4.1 Hydrological and climate impacts*

Despite the uncertainty linked to the degree of change of the future climate scenarios, the main concern in the region is the impact of more extreme conditions, specially, the effects on water availability and quality. The stakeholders consider that demand for freshwater services in the IBRM region and the neighbouring areas is high and is likely to continue in the future due to an ongoing increase in economic and demographic development. The results of hydrological modelling attempt to quantify these trends and perceptions.

Climate projections show an increased aridity in the future within the IBRM, resulting on the combination of lower precipitation and higher annual temperature. Results are analyzed for the time slice 2041-2070 and compared with the results for the reference period (1961-1990). Figure 7 shows the evolution of the water deficit index which relates water availability (precipitation, P) with vegetation potential evaporative demand (potential evapotranspiration, PET) through the equation ((P-ETP)/ETP)*100. Negative indexes mean limitations in water availability for covering vegetation requirements. Reference period shows already a deficit in water availability in the whole IBRM, following a decreasing gradient with altitudes. Figure 7 shows that low altitudes and coast range are already more stressed in the baseline scenario, and lower in mountainous and humid areas, like Grazalema mountains in Spain (with 2.000mm mean annual precipitation). Future trends show a higher aridity expected in coastal and low altitude areas, while no changes are forecasted in mountainous areas (figure 7 right). These trends could affect actual species distribution, leading to losses of climatically suitable areas for several species (Tuiller *et al.* 2005, Serra-Diaz *et al.* 2012). At the same time, lower altitude areas are those with higher density of population. Consequently, there is a clear spatial segregation of ecological and social impacts: higher altitudes will be less affected and changes in species composition may be relevant for biodiversity, but not for human activities. On lower altitudes and coastal areas there will be a higher pressure on water demand for different uses and, at the same time, a higher water deficit.

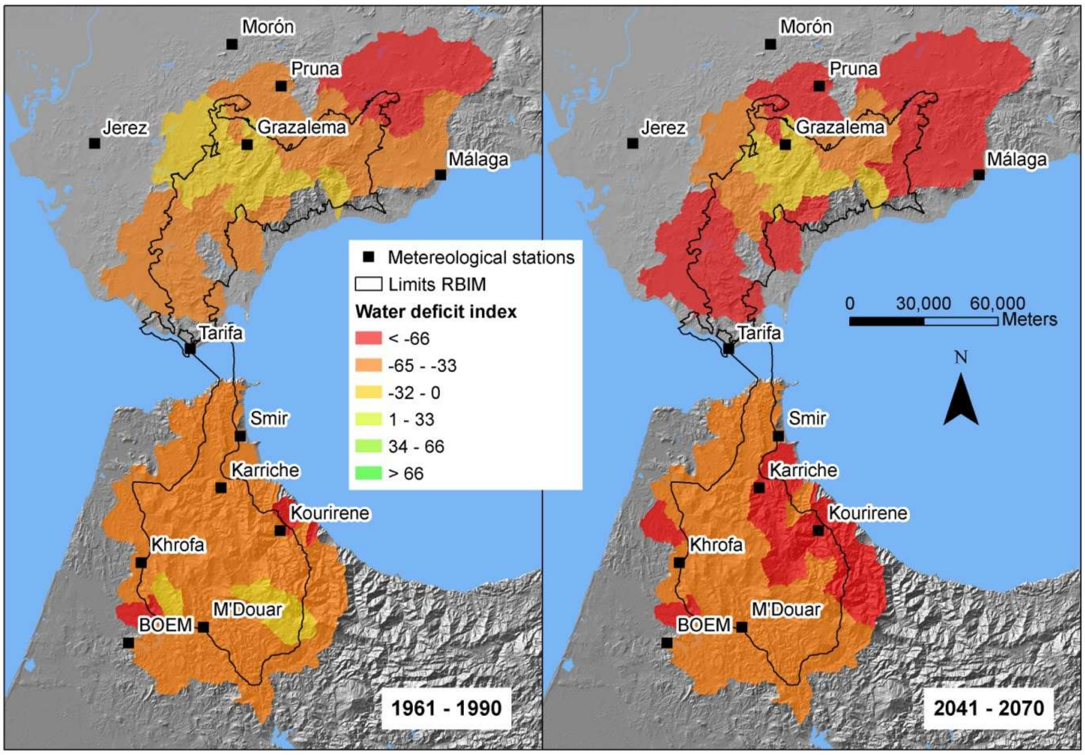


Figure 7. Water deficit index (mm) in the IBRM subbasins for the baseline time slice (left) and the 2041-2070 period (right)

Figure 8 shows changes in mean annual temperature increment between 2041-2070 period and reference period (1961-1990). More than two degrees increase is expected throughout the Reserve. Potential and real evapotranspiration (PET and ETr) are estimated by Penman-Monteith equation incorporated in the hydrological model. Results show an 8.5% to 9.5% PET-increment by 2070 due to the expected temperature increment. A 4.5% to 7.5% real evapotranspiration reduction is predicted because of the expected precipitation reduction (table 4).

Temperature increase along XXI Century will impact in natural and agricultural ecosystems, affecting vegetation phenology and advancing or retarding the processes of the vegetation annual cycle such as flowering, pollination or fructification. Phenological changes together with a lower water availability may lead to changes in crop species and varieties, modifying agronomical techniques and agronomic calendar (Moriondo and Bindi 2007, Giannakopoulos *et al.* 2009).

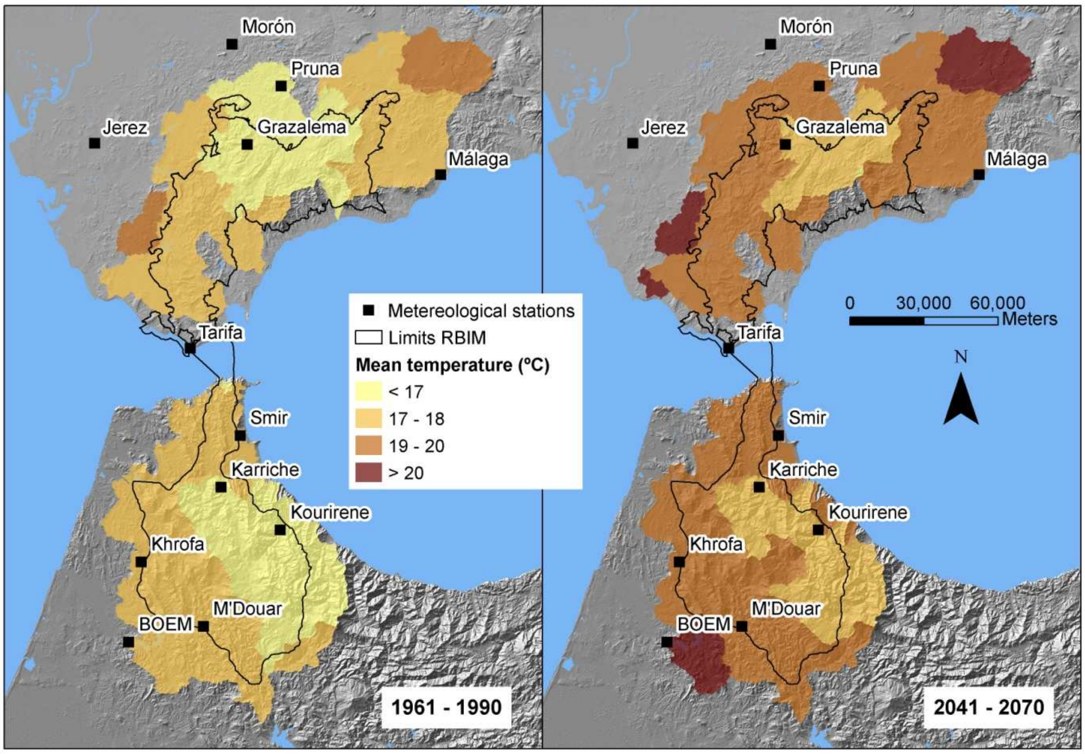


Figure 8. Mean temperature (ºC) in IBRM subbasins for the baseline time slice 1961-1990 (left) and the 2041-2070 period (right)

Table 4. Predicted potential and real evapotranspiration variation (%) in IBRM subbasins comparing the 2041-2070 period related to baseline (1961-1990)

| | Potential evapotranspiration | Real evapotranspiration |
|---|---|---|
| **Andalusia (Spain)** | + 9.6 % | - 7.5% |
| **Morocco** | + 8.6 % | - 4.5% |

Hydrological simulations with climate projections show a generalized stream flow and real evapotranspiration reduction. Figure 9 shows the percentage of stream flow reduction per A2 climate scenario at the IBRM, with a 30% mean stream flow reduction. The highest reductions are observed in the Spanish Atlantic slope, corresponding to Barbate watershed. Consequently there will be an increased seasonality on water streams. However, the probability of extreme events will tend to increase, keeping high the risk of erosion during those events (Moore *et al.* 1998, Agoumi 2003, Ruiz Sinoga *et al.* 2009).

In an ecological sense, expected stream flow reduction would imply longer periods in which stream flow will be lower, affecting stream environment quality conservation. Riparian ecosystems would be deeply affected in some parts of the Reserve. At the same time, decreases in soil water availability and changes in intranual variability could impact on woodland development and suitability of some forest species and on water supply for agricultural and urban uses (Schröter *et al.* 2005).

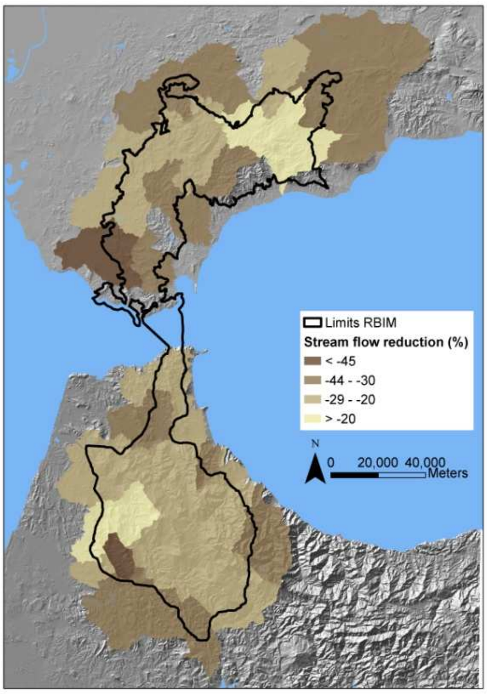


Figure 9. Water runoff changes (%) in IBRM subbasins comparing the 2041-2070 period related to baseline (1961-1990)

*4.2 Impacts on rural population*

Agriculture and livestock are identified as the main exposed and sensitive economic sector to climate change, especially in the Moroccan side. Unfavourable weather conditions are the main sources of risk on subsistence farming systems, especially in marginal land, where drought years can affect directly farmer's income. Traditional agriculture and extensive farming are still the main subsistence means for a great part of the population living on the Moroccan side of the Reserve. In Andalusia, recurrent droughts involve serious losses and injuries in cropping and pastoral sectors, but the affected surface is lower. In particular cereal crops, vines, and olive trees are the most affected crops. Furthermore, recurrent droughts affect the amount of irrigated land and rural industry sectors mostly.

The results of the hydro-ecological assessment show a future general increase in crop and pasture water demand (figure 10). Water demand includes the supplementary water needed by crops and pastures to maintain actual production standards. This indicator is soil water related and it is a good integrated estimator of crop and pasture sensitivity to climate changes (Pla and Pascual 2012). In order to homogenise the analysis for the whole IRBM, the irrigated and rainfed crops are considered together. A specific analysis for irrigated crops could show higher values due to the fact of the great water-dependency of these systems. Linking crop water demand increase with water availability reductions (figure 9) could help to identify the most vulnerable areas within the reserve, where adaptative strategies must be focused on first and foremost.

It is worthwhile to note the different crop pattern between Spain and Morocco which have different consequences for their management. On the Spanish side, low crop activity within the protected area contrast with a higher agricultural pressure on the neighbouring areas outside the IBRM. On the Moroccan side, no significant distribution on the crops inside and outside the IBRM is noted, with a higher demand on water resources in the neighbouring areas of the Reserve.

According to Globcover classification, pastures are only relevant in the Spanish side and are widely spread within the IBRM. Higher water demand is expected outside the Reserve limits, meanwhile pastures inside the IBRM might be considered as rainfed.

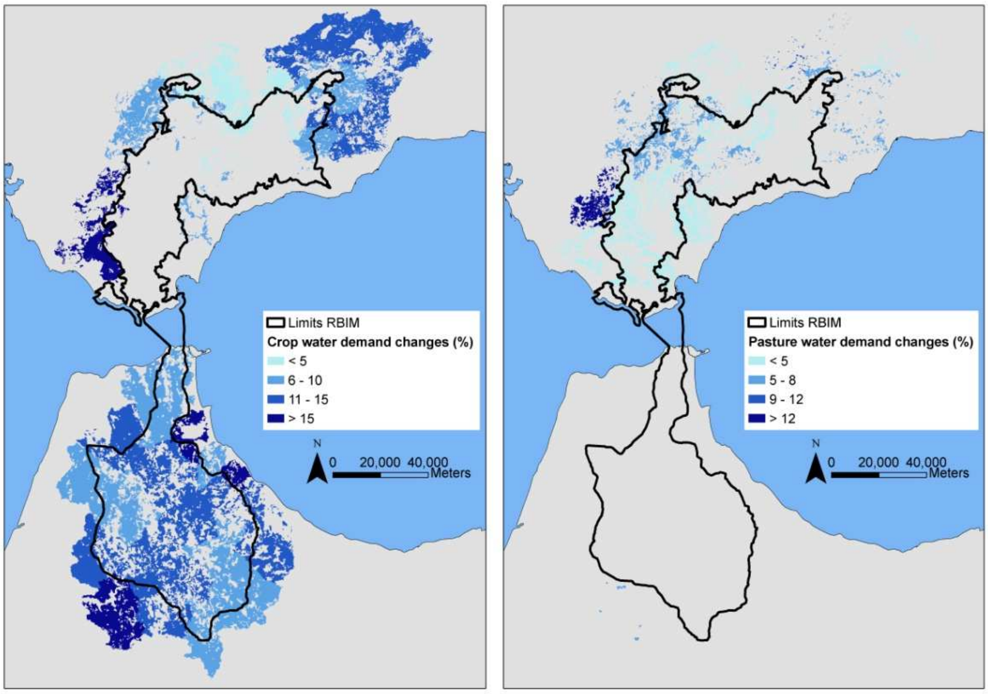


Figure 10. Left: Crop water demand changes (%) in IBRM crop areas comparing the 2041-2070 period related to baseline (1961-1990). Right: Pasture water demand changes (%) in IBRM pasture areas comparing the 2041-2070 period related to baseline (1961-1990).

*4.3 Impacts on touristic sector*

The touristic sector is identified as a very sensitive to climate related impacts. There is a concern about the effects of higher temperatures on the suitability of the region for tourism. In parallel, likely shortages in water supply could affect specially the sector.

In this sector, the hydro-ecological assessment has focused on future higher temperature impacts on some comfort indicators: number of hot days (Tmax > 30ºC), number of very hot days (Tmax > 35ºC) and number of tropical nights (Tmin > 21 ºC). The analysis was performed for several points within the IBRM. The results for Malaga, an Andalusian coast city, show an increase of 39 days per year of hot days, 46 days per year of tropical nights and a slight increase of very hot days (4 days per year) at the end of the simulated period (2040-2070).

Climate change basically increases the number of hot days by a similar amount for both urban and rural situations. However, the number of additional hot nights is larger in cities than in the countryside. The urban fabric stores more heat during the day than greener rural areas and releases this heat during the night. The so-called 'Urban Heat Island' (UHI) describes the increased temperature of the urban air compared to its rural surroundings. The temperature difference can be up to 10℃ or more (Oke, 1982). The difference is in particular high at night time. Also relatively small towns can experience a considerable UHI (Steeneveld *et al.*, 2011). Basically, urbanization, urban development and human activities alter the balance between the energy from the sun absorbed by surface and its partitioning between storage in surface elements, warming of the air and evaporative cooling. Most notably, the cooling effect of vegetated surfaces is replaced by storage of heat in impervious engineered surfaces.

An increased mortality is the most drastic impact of hot days and tropical nights; however, exposure to hot weather can have various other impacts on human health and well-being, ranging from "bad mood", feeling discomfort and getting sick. In addition, socio-economic and behavioural factors enhance the sensitivity to heat at the community level. Such factors include gender, social isolation, homelessness, lack of mobility, alcohol use, being dressed inappropriately, intensive outdoor labour and low income or poverty (e.g., Kovats and Hajat, 2008; Hajat *et al.*, 2010). In many cases and in particular in cities a number of these factors act together. For example, the elderly people are more likely to be socially isolated, to be less mobile and to suffer from chronic disease, while also having reduced physiological responses (Luber and McGeehin, 2008; Hajat and Kosatsky, 2010).

People can acclimatize to heat to a certain extent. Initial physiological acclimatization is quite fast and may occur within a couple a days through increased sweating, for example (Haines *et al.*, 2006). However, even with a more comprehensive and long term acclimatization and change of habits, above a certain (locally and individually) threshold pose a stress on people and can have health implications.

Projected changes in climatic conditions will result a decrease on the Tourist Climatic Index[12], on the Spanish side of the IBRM in 50-60 years perspective (Ciscar et al,, 2009). It will have a major impact on summer period and, consequently, it is expected that tourism will be diverted to other parts of Europe –at least for the summer period. While it may have a positive consequence by decreasing water demand, it will have an impact on the economy. These results highlight the need to look for a long term strategy regarding tourism. There is no information for the Moroccan side, but one could expect similar results.

### *4.4 Impacts on natural systems*

The increase of environmental aridity has a direct impact on forest and other natural ecosystems functioning, with a likely loss in ecosystem integrity and biodiversity. Forest decline (Jump *et al.* 2006, Sarris *et al.* 2007) and forest fire (Moriondo *et al.* 2006) are two of the most relevant expected impacts. In turn, the existence of some water bodies that are at risk of not meeting the environmental objectives of the European Water Framework Directive (2000/60/EC) is identified (Iglesias *et al.* 2007, Benejam *et al.* 2010).

Forest land and shrublands are the most extensive and representative natural system present in the IBRM. The selected indicator to assess climate change impacts on natural systems is the change in the amount of water stored in soil (figure 12). It is an integrative parameter related with forest health status, forest sensitivity to mortality and fire risk.

Forests areas show a higher reduction of water stored in soil than shrublands areas, remarking a potential higher vulnerability of forest to future climatic trends. Forests in Moroccan side might be more sensible to future conditions than the Spanish ones. Contrariwise, shrublands arise as more adapted to arid conditions than forests, promoting the expansion of its distribution range along the region.

[12] The tourist climatic index is based on the notion of 'human comfort' and consists of a weighted index of maximum and mean daily temperature, humidity, precipitation, sunshine and wind.

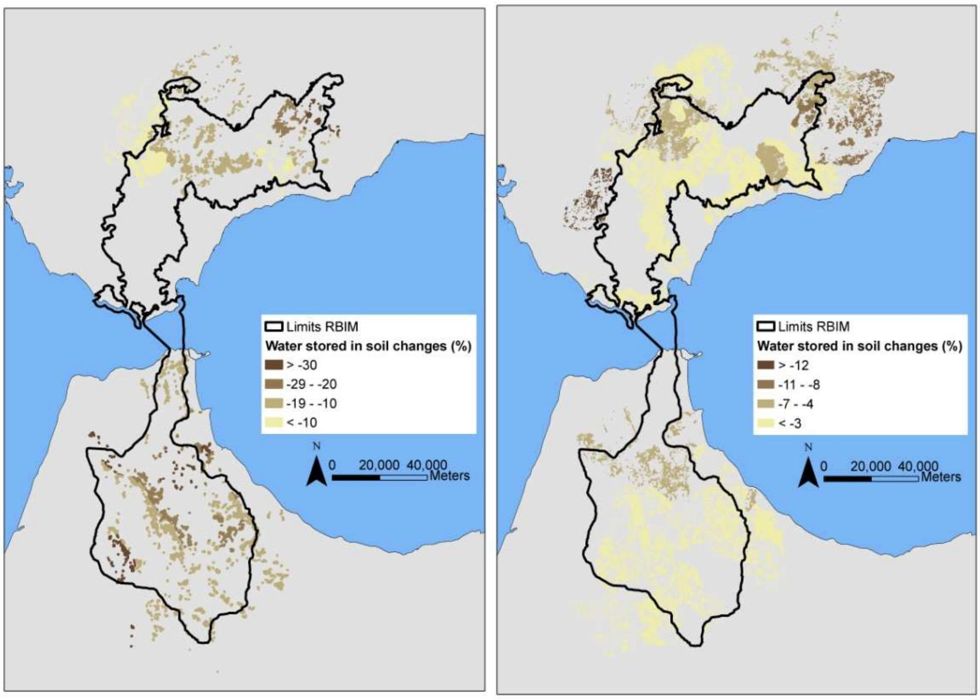


Figure 12. Left: Water stored in soils changes (%) in IBRM forests comparing the 2041-2070 period related to baseline (1961-1990). Forest spots are remarked to make them visible. Right: Water stored in soils changes (%) in IBRM shrublands comparing the 2041-2070 period related

### *4.5 Adaptative capacity and vulnerabilities*

The IBRM adaptative capacity to face the mentioned impacts, and therefore the vulnerabilities of each assessed system and sector, was tackled in the focus group sessions. In general, for the lowest climate change scenario (B1), there is an agreement that the region, as a whole, has the capacity to face negative impacts without having major effects on the local community. In this sense, full implementation of current policies and tools would be the priority (table 5).

Table 5. Summary of adaptation measures for the IBRM. Based on Abdul Malak et al 2012.

| **IBRM** | **Spanish side** | **Moroccan side** |
|---|---|---|
| - **Fulfilment of current laws** | - **Improve the management of** | - **Integrate local knowledge in** |

| | | |
|---|---|---|
| **and normative and enforce their accomplishment.**<br>- **Encourage public participation and population co-responsibility in water management**<br>- **Promote more efficient water technologies and solutions**<br>- **Improve the link between research, public sector and private sector.**<br>- **Introduce touristic taxes and effective water pricing**<br>- **Strengthen the IBRM common institutions**<br>- Promote ex ante adaptive measures rather than ex post measures (crisis management rather than catastrophe management) | **natural and forest areas**<br>- **Improve the existing infrastructures**<br>- **Take into account the need of monitoring networks**<br>- **Consider alternative water sources**<br>- **Improve the technical level of the public administration** | **development planning (empowerment of civil society)**<br>- **Implement reforestation plans and natural systems preservation**<br>- **Promote the change to low water consumption irrigation systems**<br>- **Use alternative water sources in extreme scenarios, such as desalinization and reuse of wastewater**<br>- **Change to crop species and varieties well-adapted to drought conditions**<br>- Reinvest economic benefits of water sector in the conservation and protection of natural resources. |

Adaptative measures could be strengthened if the climatic conditions get worsen (A2) but, despite of that, some systems and scenarios couldn't be able to maintain their integrity and to provide services sustainably.

Water management adaptation is the most developed sector. Water demand strategies, water pricing, water efficiency techniques and the use of alternative sources of water are feasible measures in IBRM. Water bodies need to reduce human pressure in order to face increased climate-related risks (lowering of the water table, salinisation, eutrophication, species loss). This would involve stimulating water saving in agriculture, relocating intensive farming to less environmentally sensitive areas and reducing diffuse pollution, increasing the recycling of water, increasing the efficiency of water allocation among different users, favouring the recharge of aquifers and restoring riparian vegetation, among others (IPCC 2007).

Forests in the region could have greater difficulty in adapting to climate change. Management options conducting to less water stressed systems and fire protection will be important in Mediterranean. They include the replacement of highly flammable species, regulation of age-class distributions, and widespread management of accumulated fuel. Public education, development of advanced systems of forest inventories, and forest health monitoring are important prerequisites of adaptation and mitigation.

Agriculture adaptation may include changes in crop species and varieties, modifying agronomical techniques and taking into account phenological changes.

In the IBRM, the likely reduction of tourism during the hotter summer months may be compensated by promoting changes in the temporal pattern of seaside tourism, for example by encouraging visitors during the cooler months (Amelung and Viner, 2006). Another adaptive measure for European tourism, is promoting new forms of tourism such as eco-tourism or cultural tourism.

Present institutions and policies are considered adequate and enough to ensure climate change adaptation but efforts shall be done in the fulfilment of the current laws and normative and in the enforcement of their accomplishment. Another key issue for political measures success is the encouragement and promotion of the civil participation and population co-responsibility in water management.

## 5. Conclusions

Nowadays, the majority of studies related to global change impacts has been conducted for separated sectors and therefore integrated projects need to be carried out in the future in order to have a global overview of cumulative global change effects (IPCC 2007). This work tries to match hydro-ecological vulnerability assessment with the social dimension of the water use and its management. Besides, the work helps local stakeholders to manage the territory based in the output of a scientific research and aims to improve the link between research, public sector and private sector.

Future scenarios draw a more arid climate for the IBRM with more frequent water scarcity phenomena as shown in the hydro-ecological assessment conducted in this work. The greatest challenge is the implementation of water resources in a way that ensures sustainability of natural systems, which is an asset of IBRM and neighbouring catchments, and supports human activities in the Reserve (agriculture, farming and rural tourism) in strong competition with the neighbouring areas (coastal tourism and some major urban areas).

Water availability reduction (around 30% in stream flow) jointly with higher temperature (around 2ºC) and potential evapotranspiration (between 8.5% to 9.5%) by 2070 might lead to a higher aridity and water scarcity within the region. In this context, crops and forest might be potentially more vulnerable to future conditions than pastures and shrublands.

Present institutions and policies are considered adequate to ensure human security in the future scenarios. But, efforts shall be done in the fulfilment of the current laws and normative and the reduction of duplicities among institutions. In this context, the creation of the IBRM is considered an opportunity for promoting cooperation between Spain and Morocco and for ensuring the sustainable development within the region. However, the Reserve needs to be provided with more economic resources and common adaptive measures. Local knowledge could help in the development of those measures.

Public participation and population co-responsibility in water management needs to be strengthened and more effective. The awareness and responsibility of the civil society in water uses could reinforce and ensure the success of the adaptive measures. In this sense, participation platforms where all the stakeholders are involved should be reinforced and promoted. In particular, it is recommended to extend the activity of focus groups under the CLICO project as a permanent forum where both sides of the IBRM are represent.

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