Aquastress D2.2.4 - Report on regional vulnerability (in different sectors) for water

E. Moors, I. van den Wyngaert, M. Manez, M. Bauer, D. Inman, P. Koundouri, Sébastien Loubier, E. Preziosi, K. Tarnacki

AquaStress

Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments

Integrated Project

D2.2-4

Report: Report on regional vulnerability (in different sectors) for water

-FINAL-

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Author(s) in alphabetic order:	*E. Moors, I. Van den Wyngaert, M. Manez, M. Bauer, D. Inman, P. Koundouri, S. Loubier, E. Preziosi, K. Tarnacki*
Contact for queries:	*E. Moors (Eddy.Moors@WUR.NL)*
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Abstract

The AquaStress project focus is mainly directed towards characterization and alleviation of current water stress experienced in a basin. In most basins, however, (changes in) water stress is just one of multiple hazards and stressors affecting the socio-ecological system (SES). In this report we describe a methodology to assess a region's vulnerability to water stress within the explicit setting of multiple interacting stresses crossing multiple scales. Emphasis is on thresholds that determine where and when negative (stabilizing) feedbacks turn into positive (disrupting) feedbacks. As a case study the method is applied to the Mértola region in the lower Guadiana river basin (Alentejo, Portugal).

A further future coping strategy would be a system to share benefits of landscape conservation (e.g. touristic value) with traditional farmers responsible for the management of these landscapes.

Some general conclusions are:

- To assess the vulnerability of a region, different scales should be taken into account,

- Thresholds determining whether feedbacks lead to stability c.q. disruption of the system can be detected/identified using a scale dependent assessment method,

- Identifying thresholds allows policymakers to focus on the most robust measures to reach their goals,

- The possibility to detect vulnerability depends largely on the ability to understand triggers or drivers that will change negative feedbacks into positive ad vice versa.

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1 Introduction

1.1 Background to the report and objectives

The worldwide increasing demand for water over the last century has meant that millions of people currently find it difficult to meet their daily domestic and food production water requirements. Rising demand has also led to a threat to the water required to maintain healthy ecosystems. In a study which examines the amount of water available for freshwater ecosystem sustainability throughout the world, Smakhtin et al (2004) calculated that existing water use already conflicts with the minimal ecological requirements in over 15% of the land surface. For many parts of the world the threat of climate change means that these pressures are set to increase in the medium and near future. Additionally to the impacts that climate change could mean, there is an increasing “institutional impact” in the water household cause mainly by policies that support the increase of water use.
AquaStress aims to develop innovative methods to diagnose and mitigate the effects of water stress based on new approaches that will integrate management, technical, economic and institutional instruments (http://environ.chemeng.ntua.gr/AquaStress/). The project is the first attempt to take a multi-sectoral and stakeholder driven approach to the problem of water stress at the European scale (http://environ.chemeng.ntua.gr/AquaStress/). Within this project much focus is directed towards characterization and alleviation of current water stress experienced in a basin. In most basins, however, (changes in) water stress is just one of multiple hazards and stressors affecting the socio-ecological system (SES). In this paper we aim to develop a methodology to assess a region’s vulnerability to water stress within the explicit setting of multiple interacting stresses crossing multiple scales. We will use the framework from Turner et al. (2003a) for a first assessment of the drivers and processes and extend it with the explicit scaling framework based on the method of Kinzig et al. (2006). As a case study we will apply the method to the Mértola region in the lower Guadiana river basin (Alentejo, Portugal).

1.2 Concepts and definitions

Planning and management of water-related risk events presupposes that such events are well defined and discernible to all. The planning needed to reduce the effects of most water-related risks is difficult because the intensity and frequency of such events are unknown. Indeed their very occurrence is extraordinarily difficult to anticipate. Through scientific expertise we can determine when floods, heavy snow falls or hurricanes could happen but significant uncertainty exists about when droughts start and finish. This lack of specificity may explain why planning for droughts and the managing of water resources during water scarce times has received less attention than it deserves.
Not only has the natural environment suffered from vulnerability regarding hydrological changes in the last decades. Social vulnerability to natural hazards such as drought and water scarcity is largely a function of the ability to predict the occurrence of the hazard, the resources available to cope with the hazard, the particular characteristics of the existing socio-economic system, and communities’ ability to adjust and adapt to change. Whilst the resilience of social networks is often challenged by conditions of water scarcity, social resilience can work to prevent degradation resulting from overexploitation of land in response to water stress. Recent advances in the theory of social adaptation has emphasized the ability (or inability) of a social entity to cope with the increasing demands caused by water scarcity, describing a second-order scarcity (Turton et al., 1999) of social resources which acts as a barrier to adaptive change.
A prerequisite for discussions about planning for water stress conditions and management of water resources in water stressed areas is some definition on what constitutes water stress. Within the Aquastress project, the definition of water stress that has been agreed upon states that water stress

occurs when the functions of water in the system do not reach the standards[1] (of policies) and or perceptions (of the population) on an appropriate quantity and quality, at an appropriate scale and the adaptability for reaching those is not given. This definition takes into account the relative perception of water stress rather than defining it as an absolute threshold (Bauer et al., 2005).
Like for water stress, many definitions exist for vulnerability, mostly coming down to the degree to which a system or system component is susceptible to and is unable to cope with an adverse effect, in this paper water stress. Vulnerability could be defined as the probability that a particular social-ecological system can experience harm from exposure to stresses associated with alterations of its societies and the environment, accounting for the process of adaptation. The key elements are the exposure to stressors of a social ecological system and its ability to cope, i.e. adaptive capacity (Adger, 2006, Turner, 2003a).

- Exposure is the nature and degree to which a system experiences environmental or anthropogenic stressors. These are characterized by magnitude, frequency, duration and real extent of the hazard.
- Sensitivity is the degree to which a system is affected or modified by the perturbations. It is built up of the different types of interactions between the components of the system, expressing positive (destabilizing) or negative (stabilizing) feedbacks. It is related to the concept of resilience from the ecological science community, which is defined as the capacity of the system to absorb disturbance and maintain essentially the same structures and functioning while undergoing change (Turner, 2003a; Kinzig, 2006).
- Adaptive capacity is the ability of a system to change in order to accommodate environmental hazards or policy or other changes in the social system and to expand the variability with which it can cope (Adger, 2006). An extensive overview of different approaches to vulnerability in general is presented in Adger (2006) and with respect to climate change in Fussel and Klein (2006).

To understand vulnerability that way, enable us to operationalise it and to asses it. Further, the assessment of vulnerability will allow us to inform decision makers about options for adapting to the impacts of water stress.

[1] Under “standard” should be understood the “level” needed for the whole ecosystem (understanding humans as a part of the ecosystem). Usually these standards are described by political bodies. Since ecosystems can not talk, the political bodies for ecosystems would be NGO as well as any scientific publication.

2 Approach to assess regional vulnerability

Vulnerabiliy assessments have been carried out from very local to global scale. Large-scale analysis are usually quantitative, calculating and mapping one or a set of "vulnerability numbers" with a varying resolution (e.g. Vörösmarty et al., 2000; Hurd et al., 1999). By deficit of a universally accepted "vulnerability measure", the analysis is usually based on a rather rigid system of indicators. The vulnerability to water stress is expressed with hydrological variables as the ratio between (sustainable) supply and demand (Vorosmarty et al., 2000), though more complete indicator systems may also take into account institutional characteristics (Hurd et al., 1999) or focus on ecological, social and/or economic system characteristics to incorporate measures for system sensitivity and adaptive capacity (water poverty index, Sullivan et al., 2003). However, the interactions between hazards, system characteristics and coping responses are very hard or even impossible to capture in these kind of analysis. This does not diminish their value, however, in giving overviews of a limited aspect of vulnerability over a large scale, illustrating relative differences between regions and making possible comparisons over regions and even continents. Whereas spatial scale is mostly well defined in these large-scale assessments, temporal scale is often implicit.

At the other end of the spectrum are community-based vulnerability assessments as described in general in Smit & Wandel (2006). The generalized conceptual framework vulnerability assessment they put forward relies heavily on community involvement and requires active participation of stakeholders, considerable effort to ensure legitimacy, information collection on community relevant phenomena and processes, the integration of information from multiple sources and the engagement of decision makers (Smit & Wandel, 2006). The methodology explicitly recognizes the interaction of various exposures, sensitivities and adaptive capacities over time (Smit & Wandel, 2006). It recognizes that sources of exposure, sensitivities and adaptive capacities function across scales, from the individual to the national. Their approach is analogue to the strong case Turner et al (2003a,b) make for the "place based" vulnerability analysis, i.e. the system analysed is a spatially continuous distinctive ensemble of human and biophysical conditions or coupled socio-ecological system with explicit scales both in time and place.

The coupling of the human and environmental system has its own dynamics, including many interactions that are influenced as well by spatial, temporal and functional scale (Cummings et al., 2006). Cummings et al (2006) even go as far as to hypothesize that many of the problems encountered by societies in managing natural resources arise because of a mismatch between the scale of management and the scale(s) of the ecological processes being managed. Without specifically addressing scale, Folke et al. (1998) describe the mismatch between institutions and the ecological resources they are managing, where stabilization of inherent ecosystem variability leads to short term success but initiates long term collapse or failure. Mismatches between institutions and ecological systems typically originate from a period of change, when the scale of one of them changes. This may be through societal changes (e.g. increased technology, the conversion of a high resolution land use (e.g. traditional farming) to a low resolution land use (large fields with monocultures),...), ecological changes or changes in the interaction between both (Cumming et al., 2006). The issue of scales in relation to vulnerability is explicitly addressed by Kinzig et al (2006) who use it to structure the large number of interactions at different scales and for different domains of the coupled human-environmental system. Taking examples from four regions, they structure the coupled human-environmental system within a matrix consisting of three domains (ecological, social and economic) and three spatial scales (small = patch, medium = farm or large = region). A regime shift[2] or drastic change in any of these domains at any of these scales may trigger one or several changes in other cells of the matrix, initiating a "cascade" of change untill a new state for the system is reached. By

[2] we define the term regime shift as any drastic change in the Properties of the system resulting from smaller perturbations or smooth changes in independent controlling variables, following Kinzig et al (2006) and similar to Muradian (2001) and Walker and Meyers (2004)

explicitly depicting the interactions among scales, they make visible what are the interaction mechanisms that cause thresholds in slowly changing variables at a specific combination of domain and scale (eg. ecological thresholds at patch scale, regional sociocultural thresholds,…) to trigger a change in the functioning of the whole system (Kinzig et al., 2006). A number of existing interdisciplinary studies and vulnerability frameworks have captured the complexities of SES (see Acosta-Michlik, 2006 for examples). However, the empirical application of the concepts remains difficult because appropriate methods are lacking (Acosta-Michlik, 2006).
In this paper we follow the vulnerability framework from Turner et al (2003) to start the analysis, and to extract key interactions across domains and scales according to Kinzig et al (2006). Turner et al (2003) identify a set of elements to be included in any vulnerability analysis aimed at advancing sustainability.

Table 2-1: Elements of sustainability-vulnerability analysis (Turner et al., 2003)

Multiple interacting perturbations and stressors/stresses and the sequencing of them
Exposure beyond the presence of perturbation and stressor/stress, including the manner in which the coupled systems experiences hazards
Sensitivity of the coupled system to exposure
The system’s capacities to cope or respond, including the consequences and attendant risks of slow or poor recovery
The system’s restructuring after the responses taken
Nested scales and scalar dynamics of hazards, coupled systems and their responses

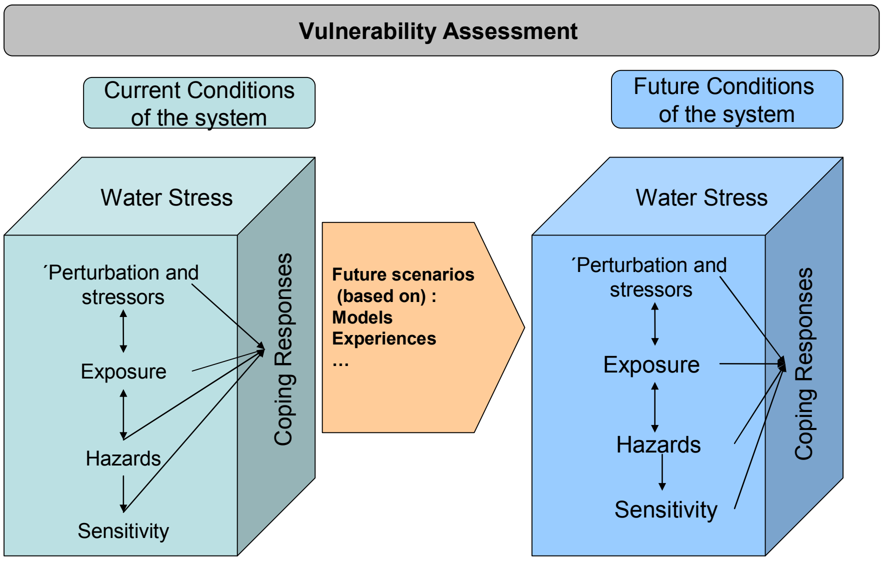

Figure 2-1: Vulnerabilty assessment model for the AquaStress Project

3 Description of the Mértola region (Portuguese Guadiana Basin)

3.1 Description of the physical system

The study region of Mértola is situated in the Baixo Alentejo, in the southern part of the Portuguese Guadiana basin. The Alentejo region is a flatted structure which is the result of the erosion of the Hercinian mountains; a mountain chain in the south separates the Alentejo from the Algarve region. Most of the area is characterized by metamorphic, eruptive and sedimentary rocks which are shaped by rivers. Soils are generally poor and thin with impermeable lithology favouring surface run-off (do Ó & Roxo, 2001). The Guadiana river is the main collector of waters of the region. The climate is typically Mediterranean, with rainy winters and hot and dry summers. Average annual precipitation at Mértola weather station is 545 mm with a standard deviation of 189 mm (Trigo & DaCamara, 2000). Untill the 60's rainfall had a bimodal distribution with a peak in December / January and one in March. (Trigo & DaCamara, 2000). Since then, there is a clear trend in decreasing March precipitation (Trigo & DaCamara, 2000; Paredes et al., 2006).

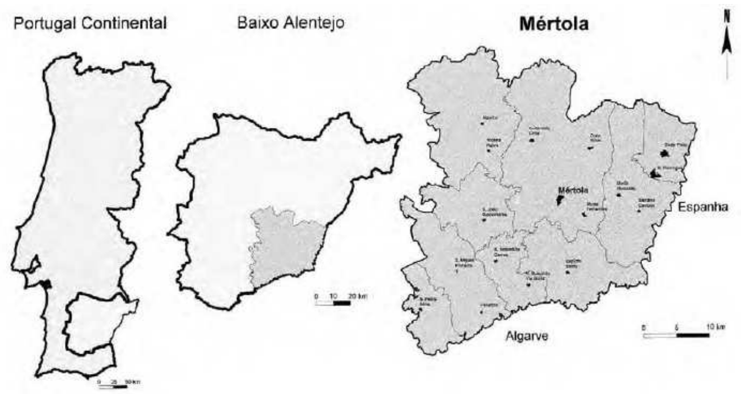

Figure 3-1: Location of the municipality of Mértola in Portugal and the Baixo Alentejo. (http://www.desurvey.net/documentation/sites/alentejo/alentejo_leaflet.pdf)

The municipality of Mértola has near to 4500 inhabitants, dispersed over 100 gatherings with populations varying between 10 to 150 inhabitants. Agriculture is the most important sector. The traditional farming system is rainfed and combines cattle raising with cultivation of cereals in so called montado systems: sparse holm or cork oaks combined with a rotation of dry cereal cultivation, pastures and fallow in the understorey (Pinto-Correia et al., 2004; Pinto-Correia & Mascarenhas, 1999).

The main water sources for agriculture, animal and human consumption are groundwater wells. Groundwater quality is locally severely impaired by waste disposal and wastewater leakage as well as fertilizer and pesticide use in agriculture, while natural background minerals in some regions are already above legal thresholds (Chambel, 2006). The old copper mines are left open resulting in a very acid pit lake containing high concentrations of sulphates and heavy metals (Costa & Duarte, 2005). There is leakage of acid water to the environment, but the extent is yet unclear (Costa & Duarte, 2005; MINEO, 2000).

Only the population in Mértola on the left bank of the Guadiana, near to 3200 inhabitants, has access to surface water supply. The surface water comes from the Enxoé dam in Serpa. Whereas the surface water quality in the Guadiana is good near Mertola (Chicharo et al., 2001), water quality situation in the reservoirs is uncertain, with some sources reporting strong eutrophication and algal blooms and cyano-bacteria.

3.2 Historical background on variability and change in the coupled system

As a consequence of the extremely variable Alentejo climate, strategies to manage the associated risks by farmers and land owners were an important force in shaping the way society was organized in Mértola.

Of old, an historical practice of risk sharing through rent decrease or acquittal in case of crop failure was in use. This was gradually abolished during the eighteenth century. Assymetrical effects of repeated crises favoured the more wealthy farmers and landlords started to select farmers on their ability to sustain an effective fixed-rent system. This restricted access of land to farmers with economic and/or social wealth and created an agrarian elite which was able to profit from both relatively low (but fixed) rents and a large class of landless labourers. This new agrarian bourgeoisie invested the accumulated capital in acquiring land when chances were provided (sell of Crown property in early 19th century, liberal land reforms) (Santos, 2004). During the 19th century average capital per household of the agrarian elite tripled, while the share of land in it more than doubled (from 29.2% to 68.2%) (values for Evora from Fonseca, 2003). Thus a rigid social stratification was created, increasing and consolidating a rural proletariat and semi-proletariat providing cheap wage labour and sharecropping rent. (Santos, 2004).

During all this time, changes in the agricultural land use were slow and relatively small. (Fonseca, 2003). This changed when the opening of the São Domingos mines in 1859 created a strong increase in population in the area with an associated demand for land (Figure 3-2). This was further aggravated when from the late 1920's on a policy towards self-sufficiency in staple cereals was adopted in Portugal, the so called "wheat campaign" focused on the Alentejo region (Vieira & Eden, 2001). The high prices paid for cereals resulted in destruction of much of the montado's and by 1950 about 90% of the area of the municipality was occupied by annual crops (Oliveira, 1998 in Pinto Correia et al.,2004). With every class of soil being sown to cereals, the wheat campaign led to exhaustion of the soil (Pinto-Correia et al., 2004) and created irreparable erosion losses (Seita Coelho, 2006).

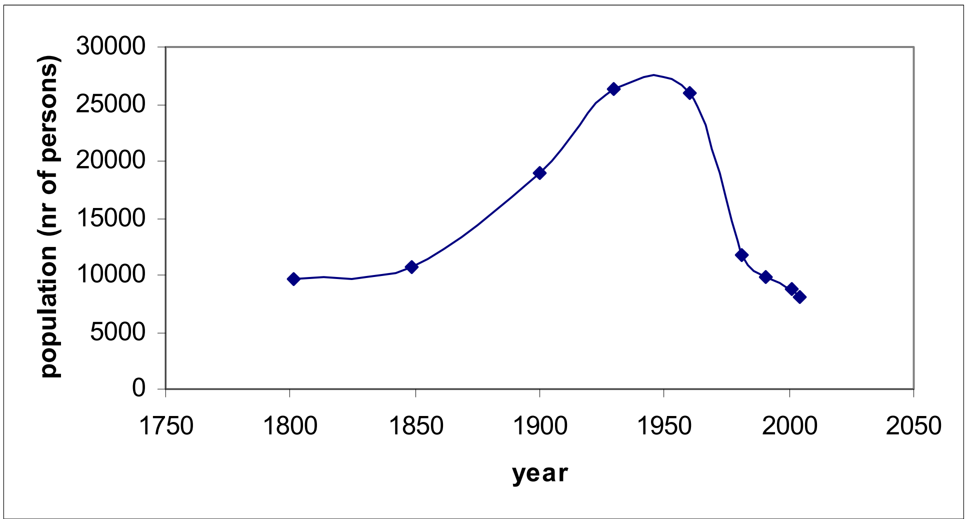

Figure 3-2: Population numbers in the municipality of Mértola

During the sixties, the attraction of the nearby coast and urban centres for employment combined with the decreasing opportunities in agriculture led to a fast population decrease (Figure 3-2) and abandonment of large previously farmed areas and a return of the extensive grazing systems ((Pinto-Correia et al., 2004). Meanwhile, the African swine fever almost wiped out the indigenous black pig that was traditionally kept in the montado's and made pig keeping in the open air (temporarily) impossible. The pigs were replaced by sheep, goats and cattle, none of which, however, was able to profit as strongly from the acorn yields as the pigs (Pinto-Correia, 1993). This reduced the incentive to return to the traditional montado system.

As a result of the 1974 revolution a brief period with minimal agricultural investments and uncertain landownership started (the “agrarian reform”), during which the main types of land use continued as in previous years (Seita Coelho, 2006). Between the late fifties and the early eighties, an increasing part of the Mértola municipilaty became covered by scrub or natural pastures with dispersed shrubs ((Pinto-Correia et al., 2004) and population numbers dropped dramatically. A socio-cultural project was started (Town Museum project) to put the rich history of Mértola to value in making the area more attractive again (Mateus, 2000).

With the accession to the European Union in 1985 and the availability of agricultural subsidies, the cereal production became profitable again, as well as cattle raising. The Common Agricultural Policy (CAP) again caused intensification of cropping system and output due to increased use of fertilizer and agri-chemicals. It also increased agricultural investments in machinery, often bigger than necessary. Old olive groves, orchards and “montados” were pulled out in order to increase areas for irrigated cereals and other annual crops such as sunflower. Erosion rates increased as well as water and soil pollution. (Seita Coelho, 2006). This lasted until the CAP reform of 1992, when cereal production lost its political priority and afforestation measures were initiated. Combined with a crisis in livestock management due to the BSE disease, which traditionally complemented cereal production, this has led to an overall extensification of farming systems (Seita Coelho, 2006). Concurrently, afforestation policies were very attractive to old farmers without successors and all land owners who have left the area or for other reasons are no full time farmers anymore. Mostly pine trees but also holm and cork oak have been planted in more than 25% of the municipality (Pinto Correia et al.,2004).

Since Portugal entered the EU in 1986, it has been the CAP that leads to the convertion of abandoned land into farming land, with cereals crops, and at this moment a general increase area of olive orchards, vineyards, tomato, melon, and sun-flowers. With the CAP revision of 1992 encouraging sustainable farming practices, set-aside areas are growing, forestry areas are increasing and intensive crops are being reduced (do Ó & Roxo, 2001)

4 Vulnerability assessment over different scales

4.1 The sustainability-vulnerability issue [in relation to water resources]

The case study Mértola is situated in one of the less favoured regions in the EU, with negative demographic, economic and social dynamics (do Ó & Roxo, 2001). Depopulation is one of the highest in Europe, and is perceived as a major problem of the region. Despite mining activity in the São Domingos mines between 1859 and 1965, agriculture is the most important sector.

Semi-environmental sector

The combination of poor and thin soils, a sloping topography, impermeable lithology favouring surface run-off and irregular rainfall pattern make the area extremely susceptible to erosion. The desertification problems associated with unsuitable land use have started with the increasing population pressure and demand for land associated with the booming of the São Domingos mines, have worsened through the new technology introduced from the British revolution and has further increased with the political backing of cereals as a priority crop during most of the 20th century. Currently, reforestation measures increase erosion in the short term, providing incentives to clear marginalized and abandoned agricultural land before actually planting trees on it (do Ó & Roxo, 2001). Trees species planted are mostly –allochthonous- Pinus pinea, with -authochthonous- Quercus ilex and Quercus suber also used. Their water requirements are very attached to the Mediterranean climate with a need of precipitation in the spring and autumn time (min. 400 mm, max 1000 mm) and a dry summer and winter. Both trees of the fagaceae family record problems regarding climate change and the inconsistent and changing raining periods. One of the proofs of that is the increase of trees affected by taphrina fungi, which increases when the water balance is disrupted (UNECE 2006).

48% of Mértola Municipality is covered by the Natural Park of the Guadiana Valley, protecting the –wet- nature associated with the river and its banks. Riparian vegetation is well developed along this zone, with *Populus alba*, *Fraxinus angustifolia*, *Salix atrocinarea*, *Tamarix sp*., *Nerium oleander* and sporadically, *Alnus glutinosa* (Chicharo et al., 2001). The biodiversity of the traditional montado's is also high,

Domestic sector

Water for drinking and other urban use is derived from the Enxoe dam, which Mértola has to share with the community of Serpa, and more than 100 groundwater sources. In normal years there is no absolute lack of water (i.e. primary scarcity), though inefficient management is recognized (i.e. secondary scarcity). While measurements in 1998 showed that water quality of the river Guadiana itself is in general good near Mértola (Chicharo et al., 2001), the water quality situation is uncertain, mainly because of cases of strong eutrophication in reservoirs. In the last years the entire water reservoir of the Enxoe Dam could not be used for domestic or even agricultural use because of an increase of the cyano bacteria. Although improvement of the reservoir management through contextualised dam management plans may improve the water quality, this is at present not the case.

Although there's no direct surface water supply source for this Municipality, half of the municipality, more specifically on the left bank of the Guadiana river, is supplied by the Enxoé reservoir.

Agricultural sector

Traditionally agriculture was mainly producing rain fed crops. The CAP reforms, caused farmers to move away from this extensive cereal production. As these high productivity crops also have a higher water demand, this reduces the amount of water available for recharge (See D2.2-2 on the Alentejo region).

In case of water shortage agricultural draws on groundwater. However, as the groundwater table in some parts of the region varies even in a normal year more than 20 m, water shortage for irrigation and

even animal consumption is often experienced. This shows the high vulnerability of the sector to variability in precipitation amounts.
Besides these quantitative issues the groundwater quality is severely impaired by waste disposal and wastewater leakage as well as fertilizer and pesticide use in agriculture, while natural background minerals in some regions are already above legal thresholds (Chambel, 2006). The old copper mines are left open resulting in a very acid pit lake containing high concentrations of sulphates and heavy metals (Costa & Duarte, 2005). There is evidence of leakage of acid water to the environment, but the extent is yet unclear (Costa & Duarte, 2005; MINEO, 2000).

In 2005, the whole country faced a severe drought situation. Because of the natural hydrological system, this was especially extreme in the municipality of Mértola. In contrast to normal years when shortage of water starts in June, in 2005 measures to fight drought were taken as early as the beginning of March.

Tourism
The biodiversity of the traditional montado's is also high, and together with the Museum Project and the arceological heritage in Mértola the landscape and biodiversity in the area is one of the main attractions to visitors. Also hunting and fishing is important in Mértola. The growing tourist business might in the future conflict with agriculture for water use, similar to the situation near the coast, but it is now unclear.

4.2 Environmental & human influences from outside

Over 95% of water demand in the Guadiana basin is for agriculture, covering 80% of the land (Apostolaki and Assimacopoulos, 2006). This illustrates the strong potential impacts of, historically, climate and climate variability, with an impact on the hydrology of the region. More recently, the impact of agricultural policies, coming in both from the national scale and from the European scale, is the decisive factor in farming practices. The development of the tourist sector on the nearby coast and its attraction to young people is the third influence considered in this region, where depopulation is one of the major problems.

Environmental effects from outside: Climate, climate change and water
The Mértola region has experienced both water scarcity and floods, though the latter are unfrequent and of low importance compared to other regions in Portugal. Flash floods occur in the tributaries with heavy and concentrated rainfall and very little escape for the water in the narrow river valleys. The resident population, however, lives far from the water lines for exactly this reason. Nevertheless, during the last flood in 1997 damage was still considerable. Progressive floods occur in the main river itself, also caused by heavy rainfall but accumulated over a large part of the basin. These types of floods are becoming more and more rare with increasing flow regulation.
The occurrence of water scarcity is an annually returning issue and dry years are not remarked by whether drought measures are applied, but by the time of year when they are applied (ref Eddy march instead of july). For Evora and Beja, two regions also situated in the province of Alentejo, there is a tendency for droughts to become more severe over the last 20 years. Other sources indicate specifically a strong reduction of rainfall in spring (37,5% reduction in March precipitation between 30 year average of 1931-1960 and 1961-1990). Though rainfall is not the only source of water, the river flow is also highly variable with inflow near Mértola varying from 0.1 to 20 m3 s-1 in summer to 200 to 600 m3 s-1 in winter (Chicharo et al., 2001). Mértola is classified in the highest category of drought susceptibility in Alentejo, whether based on rainfall or on river flow with drought occurring once in every three years (PGBRP, 2001).

Anthropogenic effects from outside: Agriculture, CAP and EU subsidies and water management policies

Since the accession in the EU in 1986 few things have been so decisive to Alentejo land use and agricultural systems as the CAP, and related measures. The period of 1986 – 1992 was characterized by high subsidies and good cereal prizes. Since the CAP reform of 1992 direct subsidies have been decreased, and complemented by agri-environmental measures. Among these is the regulation 2080/92 regulation to afforest farmland by planting new trees, one of the few measures of actual importance in the Alentejo and Mértola (Vieira & Eden, 2003; Pinto-Correia et al., 2004). The CAP reforms have caused a slow but steady increase in irrigated crops and in water use to take place in the Alentejo (Van den Wyngaert et al., 2007; Vieira & Eden, 2003).

Secondly and apart from the agricultural and environmental policies affecting water availabuility, there are also policies directly regarding water resource management, some of which are outside the influence of the municipality, some are within. As an example of overlapping policies, do Ó (2002) cites exactly the case of the municipality of Mértola, where for less than 800 inhabitants 6 Plans have colliding references and authority on drought planning: the municipal director plan (administrative local authority), the water national plan and the Guadiana Water basin plan (water basin territory), the Forestry sustainable development plan (administrative national territory) the management plan for the Guadiana national park (conservation territory) and the national action plan to combat desertification and drought, mostly ineffective at the moment (do Ó, 2002). There is a strong impact of damming and water management upstream on the water resource situation in the Mértola region. The operationalisation of the Alqueva dam will have an impact on the flow pattern of the river, but also initiate socio-economic changes in a nearby region. Indeed the influence of the Alqueva into the Enxoe Reservoir will allow to use the water of the Enxoe together with the planned Ardilla irrigation system to water the new planned irrigation perimethers in the area of Serpa-Mertola.

Anthropogenic effects from outside: Tourism coming to the region and the surrounding regions

The exposure of farmers to unpredictable weather conditions with recent droughts, declining yields and eroding soils is combined with a viable alternative at the individual level in the form of good job opportunities in the larger cities and in the tourist sector along the coast. This has created a rural exodus, affecting all other kinds of economic activities in the area. Currently, the depopulation in the area is perceived as one of the most urgent and major problems destabilizing the community.

4.3 Internal vulnerability of the human-environment system of Mértola

4.3.1 Exposure to interacting hazards

There are large differences between different population groups and different ecosystems in their exposure to influences from outside.

Semi-environmental sector

Three types of ecosystems have particular biodiversity value in Mértola municipality: the aquatic community, especially the fishes; the riparian vegetation and the montado systems. The latter is entirely rainfall dependent, and as such exposed to changes in rainfall and rainfall patterns, but not to river flows. However, apart from rainfall, the montado systems are strongly dependent on management for their sustainability. As such they are strongly exposed to both agricultural policies at different levels and lack of labour caused by employment in the tourist sector near the coast.

Both the aquatic community and the riparian vegetation are not directly exposed to anthropogenic influences from outside related to agricultural policies and availability of labour. However, they are indirectly, by effects of agricultural practices upstream on water quality. The most important influences on both ecosystems are the amount of water and the flow pattern in the Guadiana river and its tributaries. For part of the rivers, i.e. the tributaries the influences from outside are limited to the amount and pattern of rainfall. For the Guadiana, the flow regime is determined by a combination of rainfall patterns upstream and the effects of flow regulation upstream.

Domestic sector

Part of the population, correspondent to the left margin of the Guadiana river, in the municipality of Mértola, receive drinking water from Enxoé Reservoir. The water of the Enxoé reservoir is shared between the municipalities if Serpa and Mértola and in many years, shortages already occur. Changes in (spring) precipitation would not only decrease the filling of the reservoirs but through decreased currents and volumes also increase the length of the period with eutrophication problems and algal blooms. Thus the effects of a decrease in rainfall would be aggravated by continued use of fertilisers, dumping of urban waste products, high temperatures, high poluent charge of cattle raising, high fish charge and decrease of water mass.

The rest of the population is entirely dependent on groundwater for domestic water use. The groundwater system is local, and thus mostly exposed to changes in rainfall. However, with 95% of water demand originating from agriculture, there is a strong indirect exposure of groundwater resources to agricultural policies and the resulting farming practices.

Agricultural sector

The agricultural sector is the largest in Mértola. It covers 80% of the land and takes up 95% of the total water demand. It is also most exposed to influences from outside. Being rainfed or dependent on local groundwater sources for cattle, most of the agriculture in Mértola is highly exposed to changes in (spring) rainfall and rainfall patterns. With up to 60% of the farmer's income coming from agricultural subsidies, however, farmers are even more exposed to agricultural policies determined outside the region, nowadays mostly EU CAP (medaction systhesis). Through labour shortage, especially for seasonal work, the agricultural sector is also exposed to the effects of the tourist industry near the coast. Furthermore, though few farmers are directly exposed to the increase in irrigation schemes or the reduction in river flow associated with the building of the set of dams for the Alqueva reservoir, the increase in activity in the nearby region is likely to have an effect on the Mértola municipality as well.

Tourism

The tourist sector in Mértola has its roots in the cultural attractions of Mértola as a Museum Town, as well as in ecological and landscape values associated with the more traditional farming systems. The tourism related to the cultural attraction of the region is not really exposed to any of the water-related influences from outside. On the other hand, the attraction of the landscape is strongly determined by the current agricultural practices as well as any reforestation measures. In this way, the exposure of the agricultural sector to climate change and agricultural policies also means a more indirect exposure of the more ecological tourism to these influences. As a whole, the tourist sector is exposed to changes in water availability for recreational purposes, e.g. hotel pools etc….

4.3.2 Sensitivity of the human system

The information available on the communities in the Mértola region shows two contradicting realities. On one hand, most quantitative material shows a region with negative demographic, economic and social dynamics (do Ó & Roxo, 2001; IEEP, 2006). Depopulation is one of the highest in Europe, and is perceived as a major problem of the region (IEEP, 2006).

On the other hand, since 1980 a local association strives for economic and social enhancement of the region in a sustainable way. The specific cultural and ecological worth of the region is increasingly being valued, with EU certification of local products and a growing tourist sector.

Agricultural sector & rural areas

With no dam or reservoir in the close vicinity, the agriculture is either entirely rainfed or dependent on local groundwater wells. As most of the soils are poor and shallow, and in combination with an unpredictable and variable climate, yields are often low and farming is profitable only when prices are high. These marginal conditions for farming make the agricultural sector sensitive to changes in farming conditions from outside. This is illustrated by the radical changes in farming practices that have occurred over the last century with changing policies and cereal prices as elaborated in paragraph 3.2. Land use change is not so much the result of progressive adaptations, but rather a replacement of one system by another in search of securing the minimum profit to survive (Pinto-Correia et al., 2004). There is a large impact of price fluctuations and subsidiary schemes on farming decisions (also concluded from farm interviews, see Table 4-1, Kosmas & Valsamis, 2002). For example, the higher subsidies on durum wheat in comparison with soft wheat since the last CAP reform has strongly increased the area of durum wheat in favour of soft wheat, even to the extent that the quotum of Portugal for durum wheat had been exceeded (Vieira & Eden, 2004). Due to the EU subsidies, however, the land is as yet not abandoned, though the rural community is marginalized (Pinto-Correia et al., 2004).

Table 4-1: Results of the DesertLinks questionnaire related to land use change decision making driving forces in Alentejo (Kosmas & Valsamis, 2002)

	Factors of land use change decision making	Relevant - YES (%)
1	Water irrigation	40
2	Labour availability	39
3	Main climatic characteristics	38
4	Environmental impacts	38
5	Level of possibilities of mechanisation of cultivation	35
6	Governmental implications, institutional support, subsidies	34
7	Major soil characteristics	33
8	Produced product prices	30
9	Natural hazards	28
10	Tradition, attitudes and perceptions	28
11	Tourism development	28
12	Size, shape and fragmentation of farms	27
13	Market characteristics	26
14	Technical skills	26
15	Infrastructures	25
16	Food preferences	25
17	Land tenure	20
18	Parallel employment	19
19	Migration	18
20	Household size and income	17

The traditional farming system, the montado system, depends on skilled labour for management and cork or word harvesting. The current depopulation and the good job opportunities near the coast cause a shortage in labour and typical skills needed for tree maintenance are lost. From Table 4-1 it can be seen that even more decisive than subsidies is the availability of labour. This shortage of labour is a strong impediment to a further development of valuation of the traditional systems. Still, their worth is increasingly recognized. Several of the Alentejo local products have been granted EU certificates recognizing and subsidizing the local origin of high quality products: Protected Designation of Origin (PDO), Protected Geographical Indication (PGI) and Certificate of Specificity. Among these are Mertolenga beef (PDO), Alentejo honey (PDO) and Baixo Alentejo beef (PGI) (Seita Coelho, 2006). It also includes pig meat products from local breed pigs that have foraged in montado systems (e.g. Carne de Porco Alentejano) and is smoked on Holm oak wood (e.g. Linguiça do Baixo Alentejo) (EU Publications, 2002, 2006). Producing high value products should make the sector less sensitive to changes in agricultural policies.
The afforestation and reforestation measures introduced after 1992 have made it possible to plant forest in previous farmland with no cost. This has become very attractive for land owners living far

away, working outside the region. About 25% of the municipality has been planted with mostly pine trees, but also holm oak and some cork oak trees (Pinto-Correia et al., 2004).
It can be concluded that the agricultural sector and the rural areas are extremely sensitive to price fluctuations and policies from outside if these are supported by subsidiary means. The availability of an alternative of good job opportunities in the big cities and near the coast further increases this sensitivity. It is as yet unclear what the role of a changing climate would be in this: with natural conditions already being so marginal, agriculture is not profitable without supporting subsidies. A drier and warmer climate would probably make the agricultural sector more sensitive to the other influences.

Domestic sector

Most of the people nowadays live in the town of Mértola and a few villages, while the smaller villages and hamlets become deserted (Pinto-Correia et al., 2004). Although there's no direct surface water supply source for the municipality of Mértola, half of the municipality, more specifically on the left bank of the Guadiana river, is supplied by the Enxoé reservoir. Considering the very small part of domestic water demand in the total, and the high priority given to domestic water use in case of droughts, the sector is not very likely to experience real water shortage.

Tourism & cultural attraction

Since 1980 the ADPM (Association for Defence of the Patrimonium of Mértola) is active in the region to enhance economic, social and cultural development in a sustainable way. Current projects comprise the organisation of workshops on biological agriculture in Alentejo, the development of an educational program on Environmental Citizenship, … The ADPM was also one of the driving forces behind the initiation of the Natural Park of the Guadiana Valley. An increasing number of visitors, both scientists and tourists, is attracted to the region of Mértola, due to a very old and rich history of human occupation and its extreme location with a high biodiversity. (Pinto-Correia et al,2004; Seita Coelho, 2006). Hunting tourism is developing rapidly. There are more than 400 hunting zones for tourists, occupying an area of 600,000 hectares. Possible game is thrush, pigeon, turtle dove, duck, rabbit, hare, partridge, deer and wild boar. Despite its remoteness there are several musea in Mértola and the number of commercial businesses and houses has gradually risen. The major attraction, the Islamic Ceramic Exhibition receives around 17.000 visitors per year. The old São Domingos mines will also be transformed into a touristic attraction. It is currently not very clear to what extent this sector is sensitive to influences from outside related to water resources, like climate change. However, the ecological inspired tourism is sensitive to any changes in the agricultural system that impact the landscape and land use at larger scale.

4.3.3 Sensitivity of the environmental system

The past century has seen very large changes in land use in the Mértola area (Pinto-Correia et al., 2004). A large part of the area of the municipality of Mértola is nowadays protected as the Natural Park of the Guadiana Valley. High biodiversity is mainly associated with riparian vegetation, which is well developed with high floristic value in this area, and the oak plantations, also traditionally well represented in the Mértola municipality (Figure 4-1). Agricultural areas have a decreasing importance for priority species with increasing intensity, and (sub)urban zones have the lowest amount of priority species. Intensive forestry has about the same habitat value for protected species as (sub)urban zones. The sustainability of the different habitats is described in relation to current and past threats, with special focus on the identification of thresholds for positive and negative feedbacks within the system at different scales.

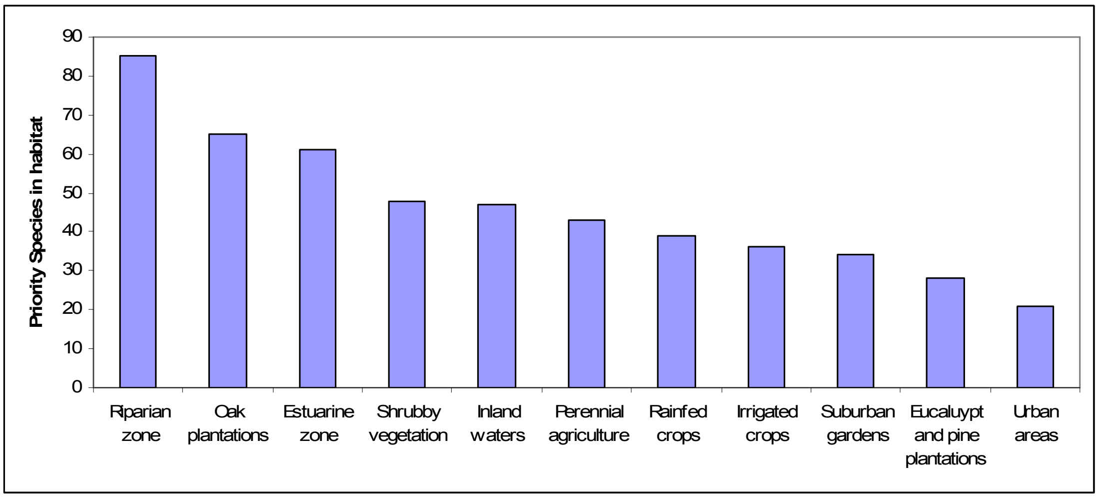

Figure 4-1: Occurrence of priority species in different habitats in the Portuguese Guadiana basin (PGRBP, 2001).

Aquatic and riparian systems

The fish fauna of the Guadiana contains species of high biological value, which through their specific needs also are a good indicator of other aquatic resources' conservation status. The Guadiana stretch form Mértola to the mouth of the river is of special importance and is now dependant on Alqueva's system discharges through Pedrógão Dam (Apostolaki & Assimacopoulos, 2006). The main threats to the aquatic fauna and flora are the degradation of water quality and the lentic conditions created by dams, both of which interact with each other and Mediterranean climatic conditions to cause strong eutrophication, algal blooms and cyanobacteria dominance (e.g. Chicharo et al., 2006)). Chicharo et al. (2006) simulated that for the current ecological flow (1-2 $m^3 s^{-1}$) cyanobacteria blooms would occur throughout their 60 days simulation period. At 5 $m^3 s^{-1}$, the effects depend to a large extent on frequency and amplitude of discharge events, while a weekly pulse of 50 $m^3 s^{-1}$ effectively excludes cyanobacterial dominance. As the actual occurrence is determined by the local combination of nutrients and temperatures, algal blooms and cyanobacteria dominance are results of feedback loops at small (patch) to intermediate scale, especially in reservoirs.

The stable lentic conditions and the reduction of floods associated with dam construction also favour exotic fish species (Clavero et al., 2004; Bernardo et al., 2003). The aquatic communities in Mértola are protected to a certain extent, as damming is not allowed in the Natural Park (Apostolaki & Assimacopoulos, 2006), but many dams have been constructed upstream and minimal ecological flow is not well defined (PRBPG, 2001). Bernardo et al. (2003) found a reduction of native species from 96% to 17.2% during a 15 year long period with mainly low river flows (1980-1995) in the Portuguese Guadiana, coinciding with an increase of the exotic pumpkinseed to 81,3% of the fish community. After the return of high flows with a series of wet years, native non-rheophilous species recovered after one year, while recovery was significant only after the third year for rheophilous species (Bernardo et al., 2003). The changes in fish community structure are the resultant of manifold responses to habitat quality at a small ("patch") scale. However, through the realized stream flow and through population dynamics effects, the different river patches are highly interconnected and interdependent. Therefore, the resulting fish community is considered an effect on a regional scale.

Agro-silvicultural systems

The oak plantations or montado systems are the traditional agricultural system of the region, with pruned trees providing wood and acorns in the case of *Quercus ilex/Quercus rotundifolia* and wood and cork in the case of *Quercus suber*. The trees depend on pruning and the undergrowth depends on grazing, rotational agricultural use and in general extensive (manual) management to prevent shrub encroachment. Rotation lengths are typically between 2 and 12 years (Pinto-Correia & Mascarenhas, 1999; Eichhorn et al., 2006). The system is entirely rainfall and groundwater dependent and water use depends on the relative proportions of tree and grass cover. Combining different locations with wet and dry years, Joffre and Rambal (1993) found a strong dependence of annual evapotranspiration on precipitation for the grass component leading to rather stable water yields across years, while evapotranspiration for the tree (including the grass directly below the tree) was not significantly affected by annual precipitation. Thus, below 570mm no water was lost from the tree covered part of the system. On a longer time span, there appears to be a functional equilibrium between tree density and average precipitation (Joffre et al., 1999). Decreases in (spring) precipitation through climate change or increased drought frequency will in the long term lead to decreased tree densities, realized through a higher tree mortality in existing montado's. In this sense, the increase of trees affected by taphrina fungi is symptomatic (UNECE 2006), as is the mentioning of tree mortality by more than half of the farmers in a questionnaire held in Mertola (Vierira and Eden, 2004).

*Table 4-2: Relation between annual evapotranspiration and precipitation (Pr) and water yields and precipitation (Joffre & Rambal, 1993) * relation not statistically significant*

	Evapotranspiration	Water yield
Grass component	0.305 * Pr + 174	0.695 * Pr - 174
Tree-grass component	0.122 * Pr + 500 *	0.878 * Pr - 500

The main threats to the montado ecosystem are changes in management and decreased water availability (decreasing groundwater levels and a reduction in spring rainfall through climate change).
Management decisions are taken at farm level, but the effects on the montado system are results of feedbacks at patch scale. Both land intensification and extensification may result in abandonment through different feedback systems (Pinto-Correia, 1993; Pinto-Correia & Mascarenhas, 1999). Deep ploughing for cereals, high stocking rates, especially of heavy cattle breeds, or shrub clearing using heavy machinery, all lead to root damage and increased erosion (Shakesby et al., 2002; Pinto-Correia, 1993). A survey in Mertola showed that most cork and holm oak montados are located on soils that are susceptible to erosion because of low soil quality and/or slopes. In the 80's, heavy machinery was commonly used, and no attention was paid to save regenerating trees by careful driving (Vieira and Eden, 2004).
While mechanical shrub clearing damages the trees and the soil, manual clearing has become too expensive with increasing labour wages. The absence of management and consequential shrub encroachment, increases water use by the understorey and decreases productivity of the main *Quercus* trees (Montero et al., 2004). The most common understorey shrub is *Cistus spp*., a very drought resistant shrub which through allelopatic substances is able to dominate the fields.
The main products of montados are animal products (mostly meat), fuelwood and for cork montados the cork, which is the most valuable output product of the system.

Pure agricultural systems

More than 80% of the Mértola area has been classified as without capability for agriculture by the Ministry of Agriculture (Pinto-Correia et al., 2004). The agro-silvo-pastoral montado systems were a type of extensive land use adapted to the thin soils and sloping topography of the regions. Periods in the history of Mértola of intensified land use and tilling of unsuitable soils are typically characterized by high erosion and loss of top soil. This has led to an increased problem of desertification in the area. The high environmental sensitivity of the area to erosion is mainly determined by the following biophysical characteristics (http://www.unibas.it/desertnet/dis4me/):

- a sloping topography, with average angles between 10-25% favouring surface run-off
- a dense drainage network, allowing fast and efficient sediment transport

- a highly irregular rainfall regime, a high frequency of very intense rainfall events with maximum erosive capacity
- absence of rainfall during the hot season, reducing vegetative cover and thus soil protection
- soil types with impermeable lithology, especially schist, favouring surface run-off and allowing minimal infiltration
- shallow, poorly developed soils (up to 20-30 cm only), with low organic matter content and fine structure (low permeability)

Including the montado's, four different basic types of agriculture can be found in the Alentejo (Vieira & Eden, 2004):

- montado's
- permanent pastures (no rotation with cereals nor managed tree cover), usually spontaneous grassland and native shrubs
- areas sown with arable crops, mostly used for dryland cereals but recently also increasing in sunflower
- permanent crops like olive grove and vineyards.

A fifth one, not mentioned in Vieira and Eden (2004) is irrigated agriculture. Though it is not a new phenomenon in Mertola, it was lost during periods of depopulation and is now returning (Table 4-3).The water is drawn mostly from local surface reservoirs (small dams and ponds) as the groundwater reserve is extremely limited (Roxo & Casimiro, website).

Table 4-3: Area of irrigated cultivation (ha) in Mértola Municipality (http://www.unibas.it/desertnet/dis4me/issues/issue_irrigation.htm)

Cultures	1989	1999
Orchards	-	57.04
Citrus	-	67.78
Olive	-	54.90
Fodder cultures	-	32.91

The combination of biophysical characteristics and land use determines the actual susceptibility to erosion, with all arabale lands classified as critically sensitive (see also par on damages). It is clear that this makes the agricultural systems extremely sensitive to the type of cultivation practices employed.

There is, however, also a high sensitivity to climate change, as less rainfall, more extremes and a longer dry and hot period is expected. This directly affects the occurrence and force of erosive events, but also makes the soil more sensitive to all kind of disturbances. In more arid soils the water regulating function is mainly regulated by dispersion of clay minerals. Dispersion conditions are frequently found in soils that contain low amounts of slat but where a large proportion on this consists of sodium. The clay dispersion is a climatesensitive process. A climatological threshold above or below of which the soil being either flocculated or disperse has been proposed for southern Europe (Lavee et al.,1996). Where the annual precipitation is below about 400 mm yr^{-1} dispersion is the key process regulate infiltration. The areas of soil affected by dispersion vary both temporally according to the amount of rainfall and spatially, anywhere salt accumulates in soil.

Pure forestry systems

A relatively new phenomen in the area is the large scale planting of forests on previous farmland, utilizing EU regulation 2080/92 subsidizing reforestation of agricultural land. Though *Quercus* species are also used, *Pinus pinea* is favoured by land owners because it grows faster and the revenues per hectare are higher. Harvested products are wood, but also the valuable pine nuts. According to legislation from 2001, the *Pinus pinea* could be faced like species which aims the multiple production, protection and soil recovery in areas with high susceptibility to desertification, supported by governmental subsidies like Agro and Ruris. However, the risks for fire are much higher than for the montado systems and *Quercus* forests. The afforestation with *Pinus pinea* is one of the reasons a strong increase in forest fires is expected in the South of Portugal.(www.fire.uni-freiburg.de/iffn/country/pt/pt_6.htm) This is further aggravated as afforestation is especially popular with land owners living far away and applying little to no management.

(Sub)urban zones

The only type of land use that could classify as (sub)urban zones are situated in the municipality of Mertola itself. The environmental sensitivity of these areas is not considered in this report.

4.3.4 Damages

In the previous paragraphs several influences from outside and responses within the system have been mentioned. In the following paragraphs it is not aimed to make an exhaustive list of all possible chains leading to damage that could be set in motion with any of the influences from outside changing. Two major issues from recent times, where information from the region was most available, have been chosen to discuss the damages and coping responses in relation to water-related hazards: soil degradation and the changes relating to the montado system.

Soil degradation

The area of Mertola has lived with varying degrees of soil degradation for at least three centuries (Roxo et al., 1999). Periods in history with massive soil degradation and erosion are related to increases in agricultural areas to include unsuitable soils. This was found in periods with high population density (e.g. exploitation of the Sao Domingo mines between 1858 and 1968), during the wheat campaign (from 1930 on) and after accession to the EU (1985 – now) and the uncoupling of yields and incomes through subsidies. As yield was not the primary determinate of farmer's income, there was little incentive for fallow or any other mechanism to protect the soil. Between 1985 and 2001, i.e. after the accession to the European Union, there was a threefold increase in the area with discontinuous vegetation cover up to 15% of the total area. The area with discontinuous herbaceous cover represents either overgrazed area, very degraded or recently abandoned fields. All have a severe risk for erosion associated to them (Casimiro & Roxo, 2006).

Table 4-4: Land cover (in %) from 1985 till 2001 as derived from a supervised classification of the Municipality of Mertola, based on Landsat TM images (Casimiro & Roxo, 2006 adapted from Casimiro, 2002)

	1985	1995	2001	Sensitivity to erosion
Shrubs	52.13	33.26	19.5	
Herbaceous continuous	14.73	23.61	32.91	Fragile
Herbaceous discontinuous	5.72	11.23	15.42	Critical
Cereals	7.69	4.39	5.95	Critical
Rock rose (Cistus)	4.72	3.21	9.18	Critical
Dense Scrubland	3.3	9.94	4.53	Fragile
Montado	1.84	1.1	2.22	Fragile
Eucalyptus	1.21	0.6	1.01	

Pine trees	0.08	0.02	1.57	
Riparian vegetation	0.1	0	1.9	
Mineral	5.65	12.21	3.79	Critical
Burned	2.34	0.12	1.2	Critical
Water	0.48	0.31	0.81	

Based on an indicator methodology, the Medalus project (1991-1999) classified and mapped the Environmentally Sensitive (to desertification) Areas in the Mertola Municipality. They distinguish 3 types of critically sensitive areas (C1-C3) and three types of fragile areas (F1-F3) as being affected, apart from potentially sensitive (14.3%) and not sensitive areas (2.6%) (Roxo et al., 1999). The critically sensitive areas cover over one third of the total surface of Mertola and range from very steep slopes with severely eroded soils or no soil left at all (C3, 7.2%) over arable land on poor , stony and shallow soils (C2, 23.3%) to arable soils on more gentle slopes (C1, 5.6%). All arable land currently or recently used is included as critically sensitive, illustrating the large impact of ploughing in combination with the soil and climatic conditions of Mertola.

The fragile areas cover together almost half of the total surface of Mertola and include former intensively used areas which were abandoned for 5-10 years, grazing land and fallow (F1, 31%), as well as areas under continuous vegetation cover on steep slopes with shallow soils (F2, 7.1%), and evergreen *Quercus* forests on good soils and gentle slopes (F1, 9%). The classification further illustrates the high importance of land use for desertification and soil degradation, as found on the Vale Formosa Erosion Experimental Centre (e.g. Kosmas et al., 1997).

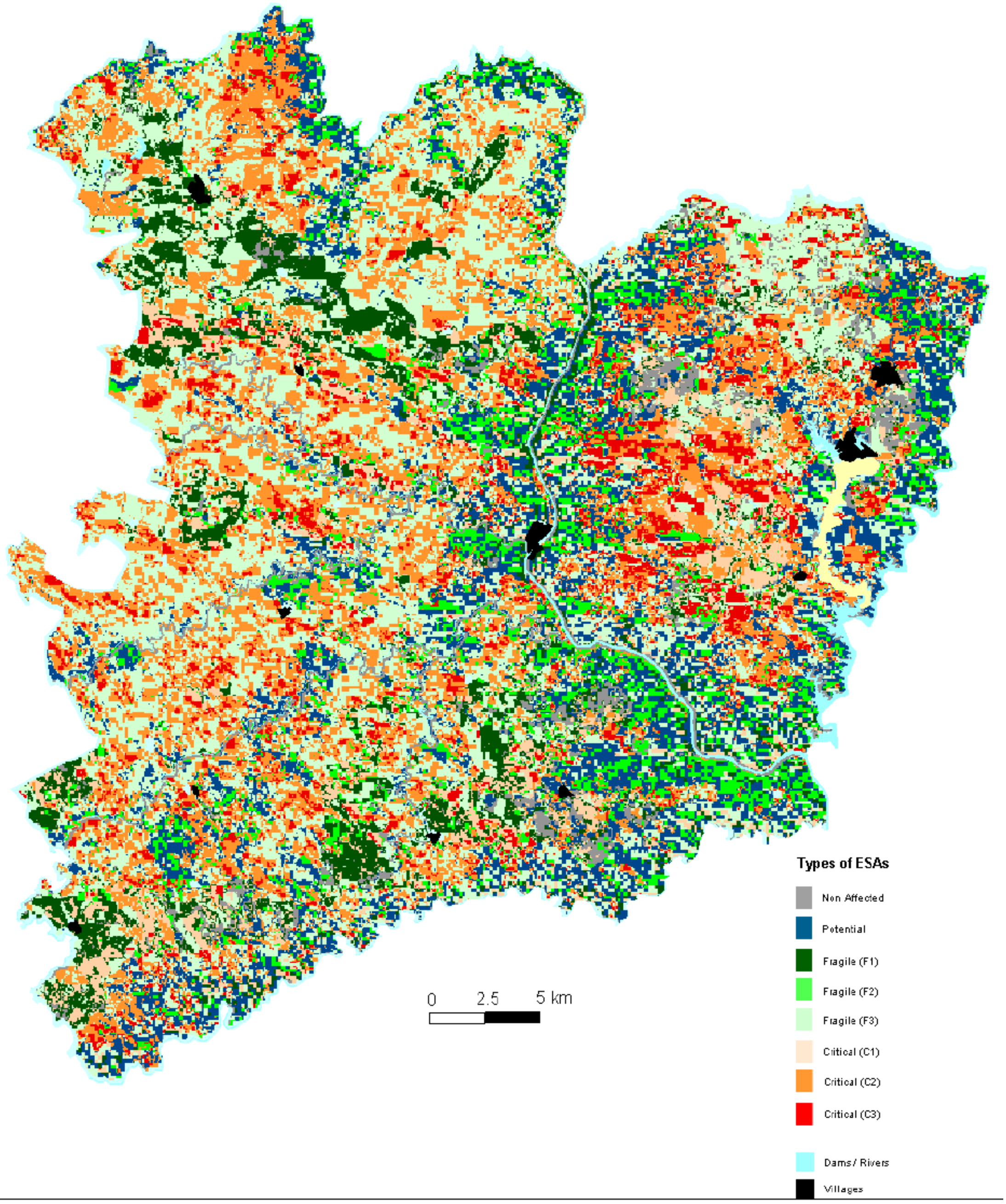

Figure 4-2: Map of environmentally sensitive areas to desertification or the Mertola municipality derived in the Medalus project (Roxo et al., 1999)

Threatening the rural landscape: loss of the montado systems

The traditional agricultural system in the Alentejo region is the montado system, plantations of *Quercus ilex/Quercus rotundifolia* or *Quercus suber* with very low tree density and a rotation of wheat cultivation and extensive grazing between the trees. The actual and historical occurrence of montado systems in Mertola Municipality is difficult to asses: values are generally low, land cover delineation is arbitrary and estimates differ to a large extent (Casimiro & Roxo, 2006; Van Doorn and Pinto-Correia, 2007). Whereas Table 4-4 shows values between 1% and 2.5% based on Landsat images, Van Doorn and Pinto-Correia (2007) found a land cover of 43% based on aerial photographs for a 44 km^2 study area in the north of Mertola. A comparison with the National COS'90 database showed large discrepancies, with 39%, 22% and 12% respectively of montado land cover classes (with ascending

tree densities) classified as grassland or arable land, and some of the higher density montado's classified as forests or scrublands (Van Doorn and Pinto-Correia, 2007). Testimony of the importance and decline of montado systems is thus given in words rather than proven by figures. However, many of the touristic web sites do mention the landscape, if not by name then by description ("dispersed solitary Holm oak trees"). With tourism perceived as one of the most promising options for a future development in the area (see), the quality of the landscape goes beyond aesthetics.
Similarly, the certification of a number of pig meat products (e.g. 'Carne de Porco Alentejano', 'Linguiça do Baixo Alentejo') is linked to pigs kept in montado systems (EU Publications, 2002, 2006). The success of certified products depends on a minimal critical mass to actually deliver the product. The further loss of these systems would thus not only be a loss for culture and biodiversity, both values which are extremely hard to quantify, but also affect things like getting paid for good quality meat.

4.3.5 Coping responses

In this paragraph a number of coping responses are discussed that are linked to the damages described in paragraph 4.3.4. A distinction is made between local coping strategies (i.e. that originate from the community itself) and coping strategies from outside.

Soil degradation

Local coping strategies

The farmers of Mertola are aware of the problems related to soil degradation: they acknowledge that desertification is occurring in the region and that soil erosion is one of the important factors causing it. Still, 38% mentioned it was not occurring on their land. On the other hand, 15% mentioned soil erosion problems and lack of water as causes for desertification on their own land (synthesis medaction). Of the farmers which were sent a questionnaire, one third did not reply, one third did not act against desertification and only 10% of farmers claimed to have adapted their way of soil cultivation (
Table 4-5). Between 1985 and 2000, from the 1241 ha of arable land in the case study in Amoendeira, only 35% remained arable. However, only 4% of the arable land was really abandoned (Van Doorn and Bakker, 2007). Van Doorn and Bakker (2007) also showed that land use changes of arable land into other use classes (montado, reforestation) could be best explained by socio-economic factors, while the abandonment of arable land was slightly better explained by bio-physical variables. Abandoned land was situated on steeper slopes, poorer soils and further away from infrastructure. However, in the perception of the local population "all land has a use" and due to unsuitability for agriculture, patches of scrub have always been part of the mosaic and have a function for hunting and honey (Pinto-Correia et al., 2004). The abandonment of land allows a recovery of soil conditions as natural vegetation reappears. Experimental results obtained in Medalus II revealed a clear improvement in organic matter content and drainage conditions as well as a better development of the soil vertical profile after between 5 and 25 years of abandonment (www.unibas.it/desertnet/dis4me)
For many farmers, however, the exposure to unpredictable weather conditions, recent droughts and eroding soils, combined with a viable alternative at the individual level in the form of job opportunities in the larger cities, have been enough reasons to leave or to have their children leave the area. This has created a rural exodus, affecting all other kinds of economic activities in the area.

Table 4-5: Measures to correct desertification problems

Average	Answer
33 %	don't reply
32 %	have done nothing
7 %	new water bores

10 %	minimal or no cultivations
4 %	better conditions for the workers

Coping strategies from outside
Farming is the main factor of management of the landscape and has shaped it over centuries. Policies affecting farming systems are the most important factors affecting land use and desertification. After its accession to the European Community, the Common Agricultural Policy has been one of the major determinants for land use in Portugal. Since 1989 the European Community has funded a number of research projects addressing desertification and land degradation as well as sustainable water use across Southern Europe. Between then and now, several international projects have included the Alentejo and Mertola as test areas or case studies (e.g. Medalus, Medaction, Desertlinks,…). Simultaneously, the Common Agricultural Policy has been updated in 1992 and 2000, one of the goals being to limit its causing or enhancing environmental problems linked to soil erosion and unsustainable water use. The agri-environmental measures are ranked not very high in this list, considering that several of them were designed to combat erosion, such as extensification of cereals and livestock, minimal cultivations or direct drilling, as well as restrictions on cultivations on slopes, and encouraging a winter green cover crop. However, the premiums are considered too low by farmers and very few farms are taking them up. Despite this, just the publicity associated with the agri-environmental measures has already increased awareness and thereby had a positive effect. (Vieira and Eden, 2004).

Table 4-6: European regulations with most influence on farmers' decision making in the Mertola region (Vieira and Eden, 2004)

EU Regulation	Type of aid	Take-up	% Farmers
797/85	farm improvement aid	most farms	17
2328/91	improvement aid	most farms	17
1257/99	rural development regulation	most farms	10
465/86	less favoured areas	most farms	36
1094/88	set-aside	cereal farms	20
Several	co-finance cereals	cereal farms	17
2078/92	agri-environmental measures	farms	42
2309/97	durum wheat quotas	cereal farms	28
2366/98	olive oil CMO	olive farms	21
2467/98	sheep and goat CMO	farms	12
1254/99	cattle CMO	farms	8
1493/99	wine CMO	vineyards	4

At the national level, a "National Plan to Combat Desertification" has been developed. However, its impact is limited, as 79% of all respondents from Mertola say they do not know of the plan, and more than 90% of the people say they do not know of any action of the plan. (Roxo, 2002).

Loss of montado systems

Local coping strategies

The past two decades have seen a re-valuation of the montado system. Similar to many traditional extensive agricultural systems in other parts of Europe it has a high biodiversity, provides habitat for endemic species and is of high aesthetic value, contributing to the attraction the region has for tourism (Pinto-Correia, 2000). Local projects, in cooperation with (inter)national organizations, are being set up to restore montados (www.nandoperettifound.org). An important role is there for the ADPM, the Association for the Defence of the Patrimonium of Mértola. This association stimulates sustainable local development, and the montado system is considered as being one good option for that. They are running a pilot tree nursery of cork and holm oak in the National Park of the Guadiana Valley (www.nandoperettifound.org). Montado farmers themselves are currently more actively managing their estates, with most of them managing to allow natural regeneration. Also pruning is done more regularly, which is important for the health of the tree. Table 4-7 gives the current status of management practices in the montado systems in Mertola. The higher value of cork compared to holm oak is translated in a better management of the cork montados. There, less exploitation for cereals or other cultures and less grazing occurs, along with more regeneration and better pruning (Table 4-7). New montados are being planted under the 2080/92 regulation (conversion of arable land to forest) of the European Community (see also next paragraph). The certification of pork meat from montado origin is one of the examples where recognition of the quality of the products should lead to a better economic incentive to conserve the system.

Table 4-7 Frequency of farming practices on the montado (Vieira and Eden, 2004)

Montado Farm practices	**(% of montado farmers)**	
	Cork oak montado	**Holm oak montado**
Allow regeneration	77%	45%
Regular pruning	77%	69%
Sow legumes	11%	31%
Sow cereals	11%	24%
Graze livestock	77%	86%

Coping strategies from outside

Along with a growing awareness of the value of all traditional and extensive land use systems, there has been a growing interest in the montado system. Montados are now protected under Portuguese law, European certification of montado products is occurring and touristic websites propagate the landscape. New montados are being planted under the 2080/92 European Regulation (conversion of arable land to forest, with montados being recognized as forests). They replace the large area that have been destroyed during the successive wheat campaigns between the 1930's and the end of the 1980's. Under the 2080/92 regulation the farmers are paid to plant, and they receive an income to substitute income losses from the areas for the first 20 years, during which they cannot use the land. However, the costs per ha are quite high, so the total area that can be planted each year is limited. (Vieira and Eden, 2004).

Possibilities for future coping responses

Current coping strategies are based on experiences in the past. As it is known that water availability will change in the next decades, a future coping strategy taking these changes into account could consist of the following:
Water use under standard and extreme weather conditions will be known for different land use types, cropping patterns and forest types (including tree density, shrub invasion or control etc). Using this information a fictional water balance for the region can be optimized for land use. As farmers greatly rely on subsidies, policy changes with associated subsidy changes have a high impact on farmers' decisions and changes in farmers' behaviour can be guided through further policy changes. The lack of application of many agro-environmental measures illustrates that the financial incentive needs to be high enough (or a system of penalties of too high water use should be implemented).

A further future coping strategy would be a system to share benefits of landscape conservation (e.g touristic value) with traditional farmers responsible for the management of these landscapes.
This highlights the necessity to stimulate young people to stay in their homeland, trough the improvement of employment conditions for the people who lives from agriculture activities. The problem is that the farmers are at this moment essentially old people, whose sons have already moved away looking for better conditions of live, and many of them will not return, so these lands will be abandoned one day.

4.3.6 Scenarios for the future

In a landscape scenario study for the Mertola region by Ramos (2006), four different landscape scenarios were distinguished. In table Table 4-8 the internal and external drivers as identified for this scenario analysis are summarized. The four scenarios were named: "Living the idyllic countryside", "Fashion wilderness", "Environmental technocracy" and "Oasis recreated". The last scenario was considered the most desired by the local population, while the "Fashion wilderness" was the most likely to happen. The scenario desired by the local population had the following characteristics: Expansion of Urban areas, Recreation facilities, Health infrastructures, Traditional crop mosaic – livestock "Montado", Water bodies, Patches of forest. Although scenarios are by definition not reflecting the actual state, they do reflect the ideas of the people involved in the construction of the scenarios on a possible future as envisaged at the time of the construction of the scenarios. They also show a qualitative measure of the uncertainties regarding the development of the region. The scenarios presented here are mainly driven by internal and external socio-economic factors. Figure 4-3 shows the role of agriculture in the construction of the scenarios. Not surprising Table 4-8 shows that the most important driver in nearly every scenario are the CAP subsidies. These subsidies will, together with the development of the economic value of the agricultural products drive the future of the region. The present increase in the demand for bio-fuels may alter the most likely scenario and shift it towards "Environmental technocracy". Although for such a relatively small region the effect of mitigation options towards climate change will have little effect on the local weather, the effect of climate change on the region and thus the feasibility of these mainly socio-economic driven scenarios may be large.

Table 4-8: Four scenarios for the future of Mertola (Ramos, 2006)

	Living the idyllic countryside	Fashion wilderness	Environmental technocracy	Oasis recreated
Drivers at regional to global scale	Coupled CAP subsidies Maintenance of the less favoured areas concept Agri-environmental measures focused on traditional landscape Support for transformation of agricultural product Reinforcement of Food Quality Assurance and Certification schemes (PDO, PGI)	Abolishment of CAP pillar 1 Concentration RD support in Nature 2000 areas, Agri-environmental measures focused on promotion of biodiversity Abolishment of the less favoured areas concept	CAP support focused on energy crops and production of biomass Support for research and development to increase productivity Support for modernization of farms	Abolishment of CAP pillar 1 Agri-environmental measures focused landscape Abolishment of the less favoured areas concept
Drivers at local to regional scale	Discomfort with urban life style New residents: with initiative Public investment in infrastructures and networks in remote areas Public support for culture and landscape Second housing	No public investment in infrastructures in remote areas Urban concentration Social disparities Available private capital Demand for evasion - “wilderness” Liberalization of world trade Food security problem	Rising fuel prices Public investment in alternative renewable energy sources CAP support for energy crops and forest Public and private partnerships for infrastructure Funding of local administrations based on GHG emission	Increasing senior population in Europe Sun and nature Private investment in health care Available urban infrastructures Public investment in a regional airport and hospital

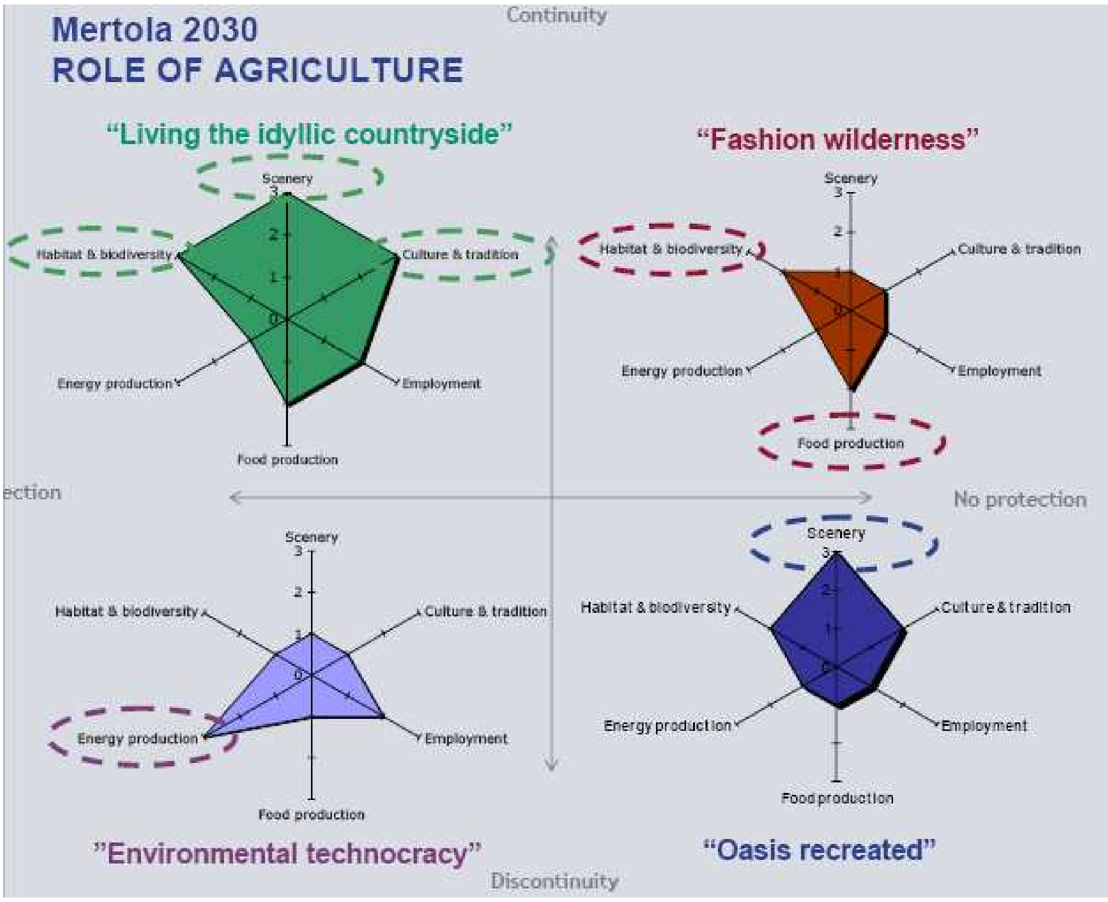

Figure 4-3: Visualisation of the four developed scenarios for the future (Ramos, 2006)

In the summary of the Fourth Assessment Report of the IPCC on Climate Change Impacts, Adaptation and Vulnerability it is stated for Southern Europe: "climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability: increased risk to health due to heat waves, more wildfires, reduced water availability and hydropower potential and lower crop yields". These predicted impacts also apply for the Mertola region and are mainly related to a predicted decrease in water availability and an increase in the variability of precipitation.

The IPCC report on the physical system (Christensen et al., 2007) presented regional averages of temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario. The resulting changes between the periods 1980-1999 and the period 2080-2099 showed as median values for the four seasons (winter, spring, summer and autumn): -6%, -16%, -24%, -12% decrease in precipitation and 2.6, 3.2, 4.1, 3.3 ^{0}C increase in temperature. This shows the likely increase of the risk of summer drought. Besides the decrease in precipitation it is also expected that evaporation will be enhanced in spring and early summer, which may lead to a further reduction of available soil moisture.

Combining the effects of the socio-economic scenario with the climate change prediction of IPCC shows the increased vulnerability of the region towards shortage of water. To reduce this vulnerability land-use changes that will require more water should be avoided. Even if the production of bio-fuels may reduce the expected climate change, this will take years before it becomes effective. While, the year of 2005, which caused drought measures already to start in March, instead of June as happens in normal years, may be considered as a preview of situations that will be encountered more frequently in the coming decades.

5 Major driving interactions & their scales

To structure the set of interacting effects as described in the sections above in such a way that makes them visible across scales and domains, but also in a way that shows that some regime shifts are occurring next to each other and may actually have the same effect (e.g. land abandoned after too much intensification or due to bush encroachment after lack of management) we adopted the scheme as suggested by Kinzig et al. (2006).

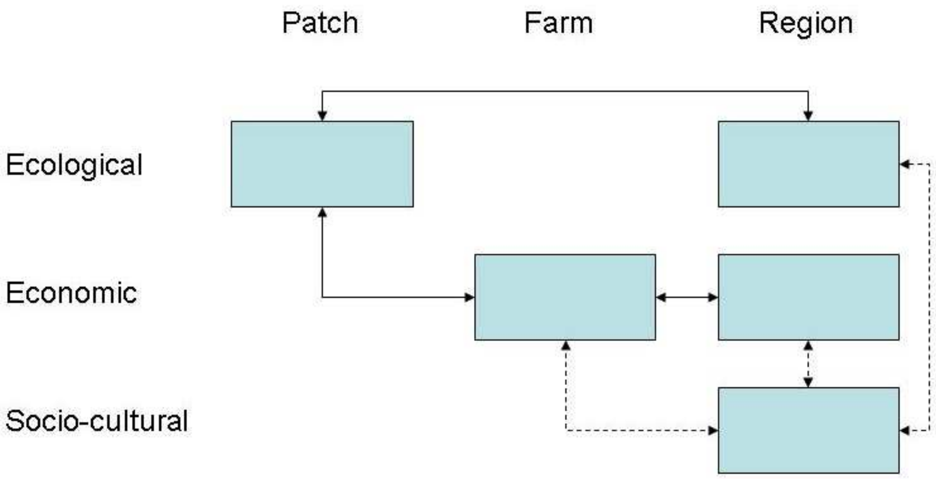

Figure 4: Scheme adapted from Kinzig et al. (2006) with critical interactions from their example case studies.

Regime shifts at the ecological level are largely limited by bio-physical boundaries. These shifts have the biggest impact at the patch scale. At the other levels other sectors become more and more important. Interactions between the sectors agriculture, industry, domestic water supply, tourism will play a role. At these larger scales people's behavior when faced with choices, stress, change in people's environmental and socio-economic values, consequences of soil loss and land use change on the water balance of the area, consequences of the management of the Alqueva and other dams on river flow under droughts all interact and influence the choices being made and as such influence the final outcome.

The drivers indicated in the earlier sections may cause certain shifts. The regime shifts below are examples at the three scales, mainly described as consequences at the ecological level.

Regime shifts at *patch* level (ecological):

- Higher temperatures;
- Shrub encroachment with extensive management (especially in cork oak montado's)
- Soil erosion and yield loss with very intense use of montado's for cereal cultivation, tree death due to mechanical soil preparation (especially in holm oak montado's)
- Increased erosion due to increase in precipitation intensities

- Soil topography with average slope angels between (10 to 25%), and impermeable lithology leads to soil destruction and degradation by erosion;
- Irregularity of the rainfall regime, combined with natural water resources over-exploitation, leads to deficient aquifer recharge, water quality and quantity problems;
- Decrease of water mass;
- Algal blooms at reservoir level with increased nutrient loading and/or decreased flow;
- High fish charge.

Although these shifts in the ecological system will mainly take place at the smallest scale, they will effect the farm and the region and because of feedback mechanism even trigger further shifts in the biophysical system.

Regime shifts at *farm* level:

- Full time farming practices viable, land “well managed” <> full time farming not viable, emigration outside the area and land use as “absentee farmer” or reforestation;
- Different agricultural practices and cultures (cereals, vegetables, and pastures);
- Excessive use of fertilizers, and overexploitation of the soil, leads to a decrease of soil fertility, and contamination of the natural water resources;
- Poor water management in irrigation leads to an overexploitation of the aquifers, decreasing the capability of recharge;
- Agriculture practices are becoming less profitable and have bad employment conditions, so young people are moving away from these practices and the elderly people are discouraged to continue and improve the agriculture practice and irrigation management;
- Pinus Pinea plantation is being encouraged by government policies in order to soil recovery and, to bind people to their land.

Regime shifts at *regional* level:

- Certification of local products (gives added value to traditional production methods);
- Natural Park of Guadiana Valley protects biodiversity, points it out to tourists (Natural Park allows hunting) <> no protection of natural values, loss of biodiversity, no systems left to protect;
- Natural park prohibits dam building, irrigation difficult, conservation of landscape values etc <> damming of tributaries, irrigated agriculture, loss of landscape values;
- Mértola Municipality is facing problems, just like others municipalities in the region, of high analphabetism rate, ancient population, and low economics dynamic. Regarding these situation there are rising in the region social structures to help old people, and economic incentives for the people that want to stay in this municipality.

The major question to mange the system and derive at the state of a desired scenario, for example “Fashion wilderness”, is: “Which regime is sustainable in view of biophysical limitations and expected socio-economic drivers?”. Improving the attractiveness of the region for tourists by stimulating reforestation among others by restoring the Mercado systems may be a socio-economic attractive option and fits well in the EU policy to improve biodiversity (Natural habitat of community-wide interest, European Union Habitat Directive 92/43). However, if this is also sustainable in terms of the water cycle in view of expected climate changes is not certain.

Based on knowledge of water use by Mercado systems such as presented in Table ?? and measured in the MIND project (EU-FP5) and knowledge on sustainable tree density for certain precipitation regimes (Joffre, 1999) enables estimates of tree densities in view of expected climate changes. Using predictions based on the A1B scenario (see section 4.3.6) shows decreases in precipitation varying between 6% and 24% for the different seasons. Extrapolating the reported relations between tree density and precipitation shows that the present average precipitation rate for the region of 470 mm y^{-1}, may decrease by 10% and still support an average tree density of 10 trees ha^{-1}. However, any further decrease in precipitation will only allow a sustainable Mercado system with reduced tree densities.

6 Conclusions

The general conclusions are:

- To assess the vulnerability of a region different scales need to be taken into account;
- Thresholds determining whether feedbacks lead to stability c.q. disruption of the system can be detected/identified using a scale dependent assessment method;
- Identifying thresholds allows policymakers to focus on the most robust measures to reach their goals.
- The possibility to detect vulnerability depends largely on the ability to understand triggers or drivers that will change negative feedbacks into positive and vice versa.

Explicit results from the Mertola region are:

Since the closing of the mines the region has no main independent sources of income. As such the economic livelihood is highly dependent on national and European subsidies. As these subsidies are often not region specific, they may function as incentives for changes that disturb the equilibrium at the smaller scale (i.e. patch to farm). Besides these socio-economic drivers also bio-physical drivers such as climate induced changes in precipitation amounts may determine the thresholds for sustainable eco-systems. The increased inter-annual variability in precipitation amounts even further augment the uncertainty of available water resources. This will also influence the available water for domestic use, especially as the water quality for the region is not assured at present. The development in Portugal to connect all water systems will strongly improve the reliability of the water supply of the Mertola region. Making the region attractive by restoring the montado system, could attract newcomers, not only from the larger region, but also from other EU countries. While this may be the only way to sustain the montado systems economically, this may totally change the social equilibrium in the region and also the domestic water demand.

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