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Sustainability of the innovation in Moroccan agriculture considering future climate change scenarios: The Rabat-Salé-Zemmour-Zaër case study

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Abstract

Agriculture is of primary importance for Moroccan gross domestic product and for the overall employability of the working population of the country. However, land availability for agricultural purposes is decreasing in Morocco, due to unsustainable farming practices and environmental constraints, such as harsh climatic conditions, soil erosion and water scarcity. Climate change exacerbates risk factors, and thus appropriate adaptation measures should be considered in order to cope with land degradation and depletion of resources in arid and semi-arid areas of Morocco. Only few studies have analyzed Moroccan agriculture constraints and sustainable solutions at a regional scale. Therefore, the aim of the present work is to undertake a land suitability analysis of Rabat-Salé-Zemmour-Zaër region in Central Morocco where cereals, as winter wheat, durum wheat and barley are the main cultivated crops. Conservation agriculture and in particular the practice of no-tillage has been taken as possible measure to overcome land vulnerability and increase socio-economic benefits. Since crop rotation is one of the main pillars of conservation agriculture, it is considered in the analysis as one of the indicators for the identification of lands where no-tillage may be adopted. Wheat (*Triticum* spp.) and lentil (*Lens culinaris* Medikus) rotation has been investigated in the implementation of land suitability analysis in a geographic information systems (GIS) context, with the elaboration of spatially distributed and complex land attributes. Classification, overlaying, weighting and other GIS techniques are applied to spatial data, within a multi-criteria decision analysis (MCDA) methodological framework.

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1. Introduction

1.1. General background

Land and water resources are of primary importance for agriculture. The way these resources are handled influences both food security and rural development worldwide (FAO, 2011). A mismanagement of natural resources will lead to greater undernourishment in those countries where the population is expected to considerably increase by the middle of the century. This is especially the case of arid and semi-arid regions of Sub-Saharan Africa (SSA), and West Asia and North Africa (WANA) where lands are already under degraded conditions and where water shortages cause serious damages in the agricultural sector (Duivenbooden et al., 1999; Fischer et al., 2002). Moreover, climate change is expected to exacerbate this situation in vulnerable countries. As reported by Giorgi (2006), the Mediterranean and the North Eastern European regions are the major climate change hot-spots, which means that these regions are the most sensitive to climate change. Combining these findings and considering the agricultural sector, arid and semi-arid areas of WANA countries in the Mediterranean basin result those prone to greatest risk, since they are not only highly impacted by changes in rainfall patterns and in temperature ranges due to climate change, but they are also naturally subjected to land degradation and water scarcity, as previously mentioned. According to Radhouane (2013), North African countries in particular are those more affected by climate change impacts and those presenting the highest vulnerability. Climate change in North Africa is expected to cause a decrease in precipitation between 10% and 20% jointly with an increase in temperature between 2 and 3 °C by 2050 (Karrou, 2002; Schilling et al., 2012). Poor farmers who mainly rely on rain-fed farming represent the most endangered category, since they have fewer resources to cope with unpredictable events that change land and water assets (FAO, 2011). In order to solve this problem, Duivenbooden et al. (1999) state that one important priority in arid and semi-arid regions is to improve crop yields per unit of water by increasing water storage in the rooting zone and by ameliorating soil quality and cropping systems. A great challenge consists in enhancing agriculture in a sustainable way through the adoption of good management practices and techniques that will also contribute to climate change adaptation (FAO, 2011).

Schilling et al. (2012) state that adaptation measures to climate change are of primary importance in North African countries. A combination of factors (i.e. high inter-annual precipitation variability, increase of monthly mean temperature, increase in droughts) affects agriculture and socio-economic security in the whole region. In particular, Morocco results the country with the lowest generic adaptive capacity and the highest sensitivity to climate change, as shown in Figure 1. Morocco is therefore considered the most vulnerable country in North Africa. According to Balaghi et al. (2013) this vulnerability derives from the dependence of Moroccan agriculture on precipitation. Indeed, more than 90% of arable lands relies on rainfall for water supply and, compared to other countries such as Egypt, Morocco has no proper water sources available in order to sustain the agricultural sector (Balaghi et al., 2013; Schilling et al., 2012). For this reason, water shortages stressed by climate change are extremely dangerous for agriculture and thus for the economy of the country, since the agricultural sector accounts significantly in Moroccan's gross domestic product (GDP), generating 13 up to 20% of Moroccan's GDP and providing employment to nearly half of the working population (Mrabet, 2008; Mrabet et al., 2012; Schilling et al., 2012). Therefore, in the case of Morocco, agriculture is prone to great risk, for this reason maximization of agricultural production should be replaced by its stabilization (Schilling et al., 2012). This aspect has to be deeply understood and evaluated, in order to assess future climate impacts and apply appropriate adaptation measures.

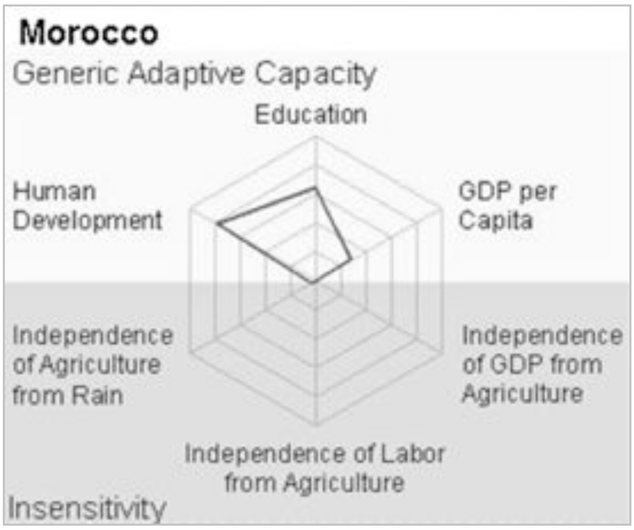

Figure 1. Generic adaptive capacity and insensitivity to climate change in Morocco (Source: Schilling et al., 2012).

Based on this premise, Morocco has been chosen as target country for the present study. The country's total land area accounts for 71.08 million hectares (M ha) of which 5.8 M ha (8%) are covered with forests, 9.2 M ha (13%) are agricultural lands and 24 M ha (30%) are rangelands (Mrabet et al., 2012). Since 1970, cultivated lands in Morocco have increased by 2.2 M ha, reaching the amount of 9.2 M ha in 2000 (Mrabet, 2008). Nevertheless, land availability for agricultural purposes is achieving its limits in Morocco, due to environmental constraints, such as harsh climatic conditions, soil erosion and water scarcity (Boughlala et al., 2011; Mrabet, 2008). These factors are both related to the natural location of the country, characterized by aridity and rainfall variability, and to climate change which exacerbates these conditions. However, not only climate change, but also conventional agricultural techniques tend to worsen soil characteristics leading to its degradation (Mrabet, 2008). In particular, traditional tillage practices, widely adopted in the country, are responsible for the increase of soil vulnerability to erosion, for the decline in soil organic matter and for the resulting reduction in soil fertility (Mrabet et al., 2012; Mrabet, 2007). Disk plough for deep tillage and crop residue removal or burning are considered by Mrabet (2007) as the main factors affecting soil quality in Morocco. Furthermore, tillage practices on soils of weak structure are likely to cause soil compaction (Mrabet, 2007). To deal with these problems, conservation agriculture (CA) has been taken as a possible solution by many researchers and farmers worldwide. Friedrich et al. (2012) report that CA principles are gaining in importance and are becoming more adopted in different countries, especially in South America, in North America, in Australia and in New Zealand. Basically, CA promotes management practices that aim at increasing agricultural productivity while protecting the environment and enhancing soil quality (Mrabet et al., 2012). Therefore, CA should be considered of primary importance in order to reach the goal of a sustainable agriculture in Morocco. The practice of no-tillage (NT) is one of the cardinal components of CA. NT technique main concept is that tillage should not be pursued in agricultural practices and mulch should always be present in the field. Moreover, crop rotation is recommended in CA to guarantee nutrients efficiency and to avoid their depletion. A series of studies conducted by the National Institute for Agricultural Research (INRA) on NT and CA underline positive results in terms of crop yields and quality of the soil. Major improvements are the protection of soil from erosion and the implementation of water retention (INRA & ICARDA, 2012; Moussadek et al., 2011). Tests and trials have been performed in different Moroccan locations and results mainly show positive effects of agriculture under NT (INRA & ICARDA, 2012). NT and CA techniques contribute in reducing negative effects due to climate constraints and in promoting sustainable agriculture through land conservation, with a reduction in costs of production and an increase in benefits for farmers (Mrabet et al., 2012). A shift in techniques is therefore required in a country as Morocco, where plowing combined with climate change tend to deteriorate arable lands. However, farmers do not always agree with a change in agricultural practices. The passage from conventional agriculture to conservation agriculture demands willingness to accept the change, therefore farmers need to deeply understand the techniques before applying them (Derpsch, 2008).

In order to manage agricultural related issues at a national level and involve local communities and especially farmers in taking proper actions to deal with these issues, the Moroccan government introduced the Green Morocco Plan (Plan Maroc Vert - PMV) in 2008. This is a strategy aimed at increasing awareness over climate change and agriculture productivity in a sustainable way. To a large extent, the main objective of the PMV is the improvement of smallholders conditions through the modernization of the agricultural sector and the enforcement of appropriate policies (Balaghi et al., 2010; Mrabet et al., 2012; Schilling et al., 2012). Results derived from the application of this strategy are expected to contribute in alleviating poverty, strengthening local economy and ameliorating the management of natural resources by 2020. To achieve this goal, actions should fall into two main pillars. Pillar I supports the development of agriculture with high added value, while pillar II focuses on reducing poverty through the enhancement of small scale farms (Balaghi et al., 2010; Schilling et al., 2012). At a regional level the national strategy is converted into 16 Regional Agricultural Plans (Plan Agricole Régionaux - PAR), one for each administrative region. This partitioning contributes in the process of identification of major actions that should be undertaken to preserve regional agricultural products. However, the complexity of the agro-ecosystem requires a remarkable amount of work and background information, in order to be defined and investigated. The understanding of regional specificity, both considering main valuable crops and their vulnerability to climate change is fundamental before taking action and prior to any local study that concerns the agricultural sector. In their work Balaghi et al. (2010) report some important findings related to Moroccan regions where agriculture will be more affected by climate change in the upcoming future. In this case, vulnerability is expressed as loss of suitable lands for agricultural purposes by 2050 under the A2[1] climate change scenario. The analysis carried out by Balaghi et al. (2010) involves two main criteria: vulnerability of agriculture to climate change and agricultural potential. The latter criterion has been chosen to represent regions where the introduction of adaptation measures will determine major benefits in terms of agricultural productivity. Table 1 shows regions particularly exposed to danger where the two criteria reach the highest values (Balaghi et al., 2010).

[1] The IPCC (Intergovernmental Panel on Climate Change) A2 emission scenario represents an heterogeneous world, with a constant increase in population during the 21st century, a slow introduction of new and more efficient technologies, a slow economic growth and an increase in [CO^2] of about 850 parts per million (ppm) by 2100 (IPCC, 2001).

Administrative region	Vulnerability to climate change (%)	Agricultural potential (mm)*	Ranking
Chaouia - Ouardigha	80	422	1
Grand Casablanca	79	408	2
Rabat - Salé - Zemmour - Zaër	37	524	3
Tadla - Azilal	33	523	4
Doukkala - Abda	51	334	5
Gharb - Chrarda - Beni Hssen	23	607	6
Marrakech - Tensift - Al Haouz	32	352	7
Fès - Boulemane	16	358	8
Oriental	14	275	9
Meknès - Tafilalet	12	313	10
Tanger - Tetouan	4	814	11
Taza - Al Hoceima - Taounate	3	489	12
Sous - Massa - Drâa	3	254	13
Guelmim - Es Semara	0	76	14
Laâyoune - Boujdour - Sakia El Hamra	0	38	15
Oued Ed Dahab - Lagouira	0	39	16

** Agricultural potential is expressed as average annual precipitation (mm), since rainfall is directly linked to crops productivity.*

Table 1. Ranking of administrative regions according to their vulnerability to climate change and agricultural potential. Regions highlighted in orange are those particularly exposed to danger. Grand Casablanca is not considered due to few agricultural lands present in the region (Source: Balaghi et al., 2010).

Considering agricultural and ecological conditions, the country is characterized by six main agro-ecological zones (Favorable, Intermediate, Unfavorable-East, Unfavorable-South, Mountain and Saharan) determined by the Ministry of Agriculture (Figure 2) (Gommes et al., 2009). Vulnerable regions identified by Balaghi et al. (2010) are those located in the north and in the center of the country, within the agro-ecological zones classified as *Favorable* and *Intermediate* for agriculture. According to Gommes et al. (2009), *Favorable* and *Intermediate* zones are those that will be more vulnerable to the impacts of climate change in the 21st century. Therefore, outcomes derived from the study carried out by Balaghi et al. (2010) are in line with those of Gommes et al. (2009). Regions that will result more affected by climate change are mainly those that at present fall into the *Favorable* and the *Intermediate* agro-ecological zones, as shown in Figure 2.

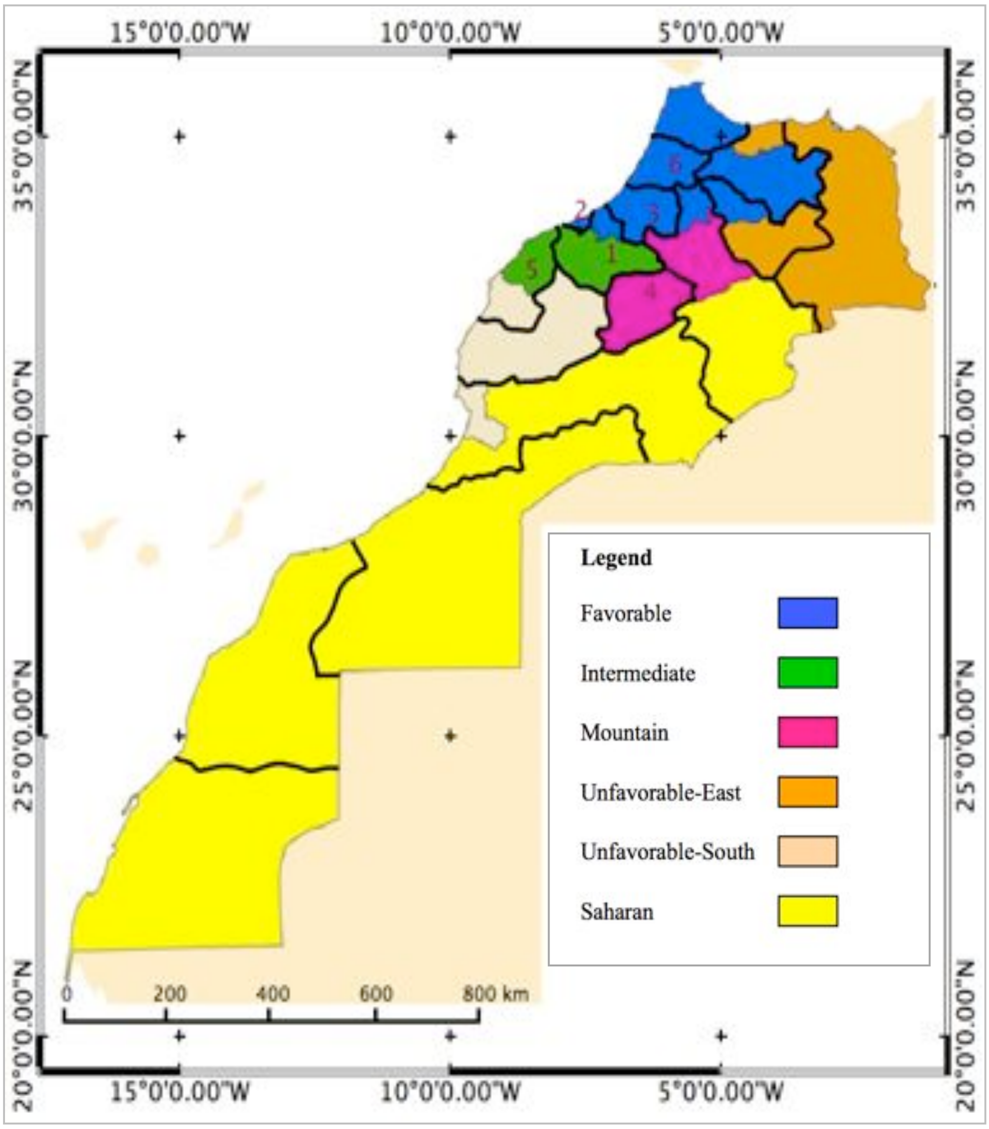

Figure 2. Moroccan agro-ecological zones (represented by colors) and administrative regions (represented by black borders). Regions are ranked based on agriculture vulnerability to climate change (see Table 1) (Source: adapted from Balaghi et al., 2010; Gommes et al., 2009).

Not only vulnerable regions, but also vulnerable crops have been identified in the study conducted by Balaghi et al. (2010). In order to determine which species are mainly impacted by climate change, other two criteria have been considered: crop vulnerability to climate change and crop importance based on the percentage of arable land occupied by crop species in each region. In this case, vulnerability is expressed as loss of agricultural productivity, considering the projection for 2050 under the A2 climate change scenario and comparing future estimates with actual productivity (Balaghi et al., 2010). Table 2 shows the ranking list of main crops affected by climate change in each of the five regions previously identified as vulnerable for agriculture. Cultivated crops that cover less than 1% of arable lands in the region are not considered (represented by white background in Table 2).

Ranking	1	2	3	4	5
	Chaouia-Ouardigha	**Rabat-Salé-Zemmour-Zaër**	**Tadla-Azilal**	**Doukkala-Abda**	**Gharb-Chrarda-Beni Hssen**
1	Barley	Winter wheat	Barley	Barley	Winter wheat
2	Winter wheat	Barley	Winter wheat	Durum wheat	Durum wheat
3	Durum wheat	Durum wheat	Durum wheat	Winter wheat	Barley
4	Corn	Oat	Olive	Corn	Sunflower
5	Broad bean	Corn	Almond	Broad bean	Broad bean
6	Lentil	Lentil	Broad bean	Olive	Chick pea
7	Olive	Olive	Corn	Oat	Olive
8	Oat	Broad bean	Lentil	Chick pea	Corn
9	Chick pea	Sunflower	Vetch	Lentil	Lentil

Table 2. Ranking of main crops affected by climate change in Moroccan most vulnerable regions. Only cultivated crops that cover more than 1% of arable land in each region are considered (green background) (Source: Balaghi et al., 2010).

Results highlight that cereals are the most impacted crops. This is a very crucial point, since the majority of agricultural production in Morocco is based on cereals. The three main species are winter wheat, durum wheat and barley. According to El Honsali (2013), the overall amount of hectares planted with cereals in the marketing year[2] 2013/2014 results in 2.24 M ha of winter wheat, 1.04 M ha of durum wheat and 1.69 M ha of barley. Therefore, the cereals sector is considered of overriding concern by PMV. Besides cereals, other crops for which appropriate measures should be undertaken in order to contrast climate change are respectively broad bean in Chaouia-Ouardigha, in Doukkala-Abda and in Gharb-Chrarda-Beni Hssen regions, lentil in Rabat-Salé-Zemmour-Zaër and in Chaouia-Ouardigha regions and olive in Tadla-Azilal region (Balaghi et al., 2010).

Once target regions and crops have been identified based on their vulnerability to climate change, adaptation and technological measures aimed at reducing harmful impacts in the agricultural sector should be investigated. Balaghi et al. (2010) underline the importance of measures such as the shift in sowing or planting date, the use of improved crop varieties, the use of NT and direct seeding, the adoption of supplemental irrigation, the use of certified seeds and the application of water gathering techniques. The choice and application of the best adaptation measure depend on the region and on the crop selected for the analysis. Considering cereals, for example, adaptation to climate change may be achieved with a shift in sowing or planting date in regions such as Chaouia-Ouardigha and Doukkala-Abda, while improved crop varieties may be used in regions where climate is more humid, such as Gharb-Chrarda-Beni Hssen and partially also in Tadla-Azilal and in Rabat-Salé-Zemmour-Zaër (Table 3).

[2] The term marketing year in agriculture refers to the 12-months marketing period after harvest (Womach, 2005).

	Improved crop varieties	Certified seeds	Sowing date planting date	NT and direct seeding	Supplemental irrigation	Water gathering
Chaouia-Ouardigha						
Barley	3		1	2		4
Winter wheat	2	5	1	3	4	6
Durum wheat	2	5	1	3	4	6
Corn	4	5	3	2	1	
Broad bean	1	2				
Lentil	2		3	1		
Olive	3	4			1	2
Oat	3		1	2		4
Chick pea	3	4	1	2		
Rabat-Salé-Zemmour-Zaër						
Winter wheat	1	5	2	3	4	6
Barley	3		1	2		4
Durum wheat	1	5	2	3	4	6
Oat	3		1	2		4
Corn	4	5	3	2	1	
Lentil	2		3	1		
Olive	3	4			1	2
Broad bean	1	2				
Tadla-Azilal						
Barley	3		1	2		4
Winter wheat	1	5	2	3	4	6
Durum wheat	1	5	2	3	4	6
Olive	3	4			2	1
Almond	3	4			2	1
Broad bean	1	2				
Corn	4	5	3	2	1	
Lentil	2		3	1		
Doukkala-Abda						
Barley	3		1	2		4
Durum wheat	2	5	1	3	4	6
Winter wheat	2	5	1	3	4	6
Corn	4	5	3	2	1	
Broad bean	1	2				
Gharb-Chrarda-Beni Hssen						
Winter wheat	1	2	3	4	5	
Durum wheat	1	2	3	4	5	
Barley	1		2	3		
Sunflower	1	2	3	4		
Broad bean	1	2				
Chick pea	1	2	3	4		
Olive	1	2			3	
Corn	1	2	3	4	5	

Table 3. Ranking of main adaptation measures to climate change in Moroccan most vulnerable regions and for most vulnerable crops. Green background indicates the most effective actions (Source: adapted from Balaghi et al., 2010).

Taking into account all the observations emerged from the study conducted by Balaghi et al. (2010), the region of Rabat-Salé-Zemmour-Zaër (RSZZ) has been considered as specific case study for the present work. Although RSZZ is ranked second in terms of priority for intervention to contrast climate change in Moroccan agricultural sector, the region has been chosen considering the higher availability of detailed regional data sets compared to other regions. Therefore, the possible choice related to the region of Chaouia, which is ranked first, has been rejected due to an overall lack of regional data sets and due to the difficulty of acquiring useful information for the purpose of this study. On the contrary, these tasks have been possible in the case of RSZZ, as a consequence of an internship held at INRA Rabat and thanks to the collaboration of local experts.

The PAR of RSZZ underlines the need of improving the agricultural and the farming sectors, focusing especially on the increase of cereals, food legume crops, vegetable crops and fruits yields on the one hand, and on the increase of poultry farming, apiculture, milk and red meat yields on the other hand (ADA, 2013). Overall, the regional PAR includes 97 projects to be accomplished by 2020. These projects aim at increasing cereals production of 147%, extending arable lands of 11%, increasing vegetable crops production of 250%, intensifying legumes production of 170%, increasing milk production of 133%, increasing red meat production of 90%, doubling honey production, tripling the agricultural sector added value and increasing the number of working days (CRI RSZZ, 2011; Mrabet et al., 2011).

In the present study, attention is focused on cereals and legumes, since these two categories of crops are of primary importance in the region of RSZZ (CR RSZZ, 2013; DRA RSZZ, 2004). Moreover, the PAR of RSZZ recommends their integration and stabilization. In particular, the plan envisages the reshaping of the total cultivated land addressed to cereals, reducing the cultivated surface and increasing profits, while in the case of legumes, the PAR promotes an increase in cultivated hectares and fosters the rotation with cereals. Indeed, considering cereals and legumes together can be extremely convenient for both crops, since if combined in rotation they can benefit from each other (Chen et al., 2012). Among cereals, wheat (*Triticum* spp.) plays a pivotal role in the region, whereas among legumes, although information in literature is scarce, lentil (*Lens culinaris* Medikus) is attested to be the main food legume in RSZZ (CR RSZZ, 2013; INRA, 2011). As reported by Balaghi et al. (2010), lentil is also the first legume crop for which adaptation measures to climate change should be undertaken in the region. Furthermore, according to local experts lentil should be adopted as valuable crop to be used in rotation with wheat in RSZZ. Wheat and lentil are therefore chosen as specific crops for the analysis carried out in this work.

In order to achieve the targets supported by the PAR of RSZZ and related to cereals and legumes, the adoption of adaptation measures to climate change is considered of primary importance. Since wheat and lentil are the two major crops considered, main adaptation measures which have a significant impact on these two crops in RSZZ are in order, improved crop varieties, shift in sowing or planting date and NT and direct seeding in the case of wheat, while in the case of lentil the best measures are in order NT and direct seeding, improved crop varieties and shift in sowing or planting date (Balaghi et al., 2010). According to Balaghi et al. (2010), NT and direct seeding allow farmers to sow or plant in advance, so as to efficiently benefit from the beginning of seasonal precipitations. Therefore, different adaptation measures can be combined. However, only NT technique and more broadly CA have been considered in this work because, even though there is clear evidence of benefits derived from their application, these systems are still characterized by low adoption in the region and in the country as a whole. Constraints related to the practice of CA and NT arise in general from: (i) lack of adequate and inexpensive machinery; (ii) misunderstanding of NT practices; and (iii) social barriers (Mrabet et al., 2012; Mrabet, 2008).

Specifically, CA is based on three main pillars that need to be considered together by farmers in order to fully take advantage of this practice. First of all, mechanical soil disturbance must be reduced to bare minimum if not completely avoided. Secondly, permanent organic soil cover made of mulch or crop residue must be present and, finally, diversification of crop species grown in rotation or associations must be induced (Friedrich et al., 2012; Kassam et al., 2012). Studies previously carried out on CA and NT techniques in the region of RSZZ report findings mainly linked to soil quality improvements obtained through NT and residue management practices. For instance, Moussadek et al. (2014) state that soil organic carbon stock (SOCs) is higher under NT than under conventional tillage (CT), especially in Vertisols and Cambisols, leading to better soil quality in the case of NT. Another example refers to a work conducted by Moussadek et al. (2011) on Vertisols in the Merchouch area, in which is reported that NT with 50% of crop residues results to considerably reduce surface runoff and soil erosion compared to CT and to the practice of NT alone (Figure 3).

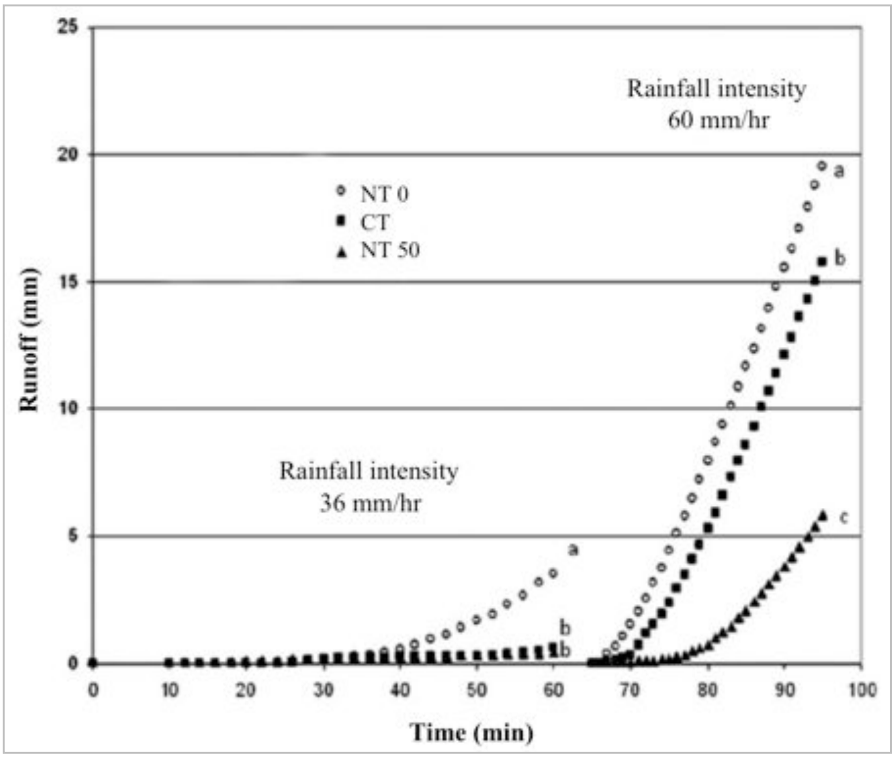

Figure 3. Effect of two rainfall intensities on runoff in conventional tillage (CT), no-tillage without residues (NT 0) and under no-tillage with 50% of the residues returned to the soil surface (NT 50) (Source: Moussadek et al., 2011).

On the other hand, studies focused on the adoption of crop rotation are rather lacking. A study carried out by Mrabet et al. (2012) describes that wheat and lentil rotation produces higher wheat yields under NT than under CT in the region of RSZZ. However, there is no clear evidence of where these two crops should be grown together in the region. Works related to the geographical identification of suitable places where crops can be combined in rotation are missing in the case of RSZZ. The purpose of this thesis is therefore the analysis of environmental factors influencing the suitability of wheat and lentil in the region of RSZZ and, especially, the attempt of assessing whether and where rotation of these two crops can be achievable. Once opportune areas for wheat and lentil rotation are identified, NT and residue management practices can be introduced as feasible adaptation measures to climate change. Rotation is therefore considered as indicator of where the other two pillars of CA may be adopted if properly introduced to the farmers. Due to time constraints, the analysis takes into account only two crops. However, the methodology followed in the present work can be applied to other crops by adjusting crop requirements used in the analysis and modifying the criteria adopted.

1.2. Problem statement

The importance of the feasibility of sustainable agriculture in countries characterized by uncertain climate and land degradation has been highlighted in many studies previously conducted in arid and semi-arid areas worldwide. To reach this goal, reconsidering current land uses is often necessary. To identify lands that are more predisposed to the cultivation of specific crops, several works have been based on Land Suitability Analysis (LSA). Overall, LSA is widely adopted in land use planning since it allows to combine criteria of different nature in order to determine the most suitable location for a defined purpose (Abbaspour et al., 2011; Mendas & Delali, 2012). In the case of Morocco, results from a work of Cesaraccio et al. (2011) have shown the capability of lands to cope with climate change scenarios. A land capability for agriculture has been performed by Cesaraccio et al. (2011) for the whole country and a LSA has been carried out for Settat province, with a focus on the response of durum wheat to climate change scenarios. The research underlines the reduction of suitable areas for the cultivation of durum wheat in Settat province in future years and, as final remarks, it highlights the need to extend the spatial scale of the analysis at a regional scale and to deeply investigate adaptation strategies to promote a sustainable agriculture, especially in other Moroccan regions with high cereals productivity, considering other crops and future climate change scenarios, in order to cope with future agricultural concerns in an opportune way (Bodini et al., 2011; Cesaraccio et al., 2011). For this reason, in the present study a LSA for wheat and lentil is investigated in the region of RSZZ, taking into account not only current climate but also future climate change scenarios. Moreover, suitable areas for the application of wheat and lentil rotation are selected, in order to define where these two crops can mutually benefit from each other and where CA could be a feasible adaptation measure in the case of wheat and lentil cultivation under the influence of climate change. To perform the LSA, different methods are integrated and this section briefly describes the procedure adopted in the present work. The whole methodology is then illustrated in details in the *methods* chapter.

A comprehensive analysis on the agricultural system in countries characterized by arid and semi-arid climate conditions should take into account interactions between climate change, environmental factors and socio-economic development. However, due to a lack of available socio-economic data sets, in the present work only the relation between climate change and environmental conditions for wheat and lentil growth has been investigated. Usually, the criteria selected for a LSA are based on data availability and there are not fixed rules for their choice, but climate data (precipitation and temperature) and soil data (drainage, depth, texture, pH, organic matter content, etc.) result those more frequently used (Akıncı et al., 2013). In this work, topographical and soil characteristics are combined with precipitation and temperature parameters, related to both current climate and climate change scenarios. Wheat and lentil crop requirements, obtained from literature, are used to assess the best conditions for crop growth and to understand where the criteria result more favorable for the development of these two crops in the region. Since all the environmental and climatic factors are connected in the agro-ecosystem, in order to identify the most suitable lands for wheat and lentil, a system-based approach is required.

In agriculture, the concept of system plays a pivotal role and involves the interaction of different components. Both physical and biological factors must be included in the analysis of an agricultural system. If one component changes, the whole system can be modified to some extent (Moore et al., 1993). For this reason, following a multidisciplinary approach is of primary importance in the analysis of agronomic and environmental issues. Moreover, since many environmental factors are involved in the system and they are spatially distributed, the analysis should carefully consider the spatial variability of these elements (Fassio et al., 2005; Giupponi & Carpani, 2006). A wide range of methodologies gives a substantial contribution for implementing awareness at different levels. These methodologies involve the integration of system-based tools, which are considered of primary importance in agricultural research because they can provide comprehensive knowledge among farmers, researchers and decision makers (Ahuja et al., 2002).

A Geographic Information System (GIS) is a computer-based system and it represents one of the most powerful tools that can be used to cope with spatial information related issues. Nowadays, GIS is a technology widely adopted for the analysis, the processing and the presentation of data sets. Results in the form of maps are the main outputs of a GIS, however, this tool reveals many additional features, especially if integrated with other methods. In particular, GIS increases its potential if combined with a multi-criteria decision analysis approach (MCDA). According to Malczewski (2006), a GIS-based multi-criteria decision analysis (GIS-MCDA) basically combines geographical and spatial data with value judgments in order to acquire useful information for decision making. This approach is included in the broad concept of Spatial Decision Support Systems (SDSS) and it is extremely convenient when dealing with spatial decision problems and when assessing alternatives characterized by several criteria, each one referring to a factor with its own unit of measurement. Alternatives, criteria and decisions are the key components of a MCDA and, in the case of a geographic multi-criteria approach, criteria are represented by map layers and alternatives by pixels or polygons, which symbolize real world features respectively in raster map and vector map formats (Bernetti & Romano, 2007; Drobne & Lisec, 2009). Usually, criteria do not represent only factors, but also constraints (e.g. urban areas, natural reserves, roads, etc.). In a GIS-MCDA approach, constraints should be taken into account in order to exclude those areas that are not considered of interest for the purpose of a specific analysis. Constraints are defined by Boolean maps in which the total area is classified only into areas that are omitted (value 0) and areas that are considered (value 1) in the evaluation (Abbaspour et al., 2011). A comprehensive description of map formats and maps used in this thesis is given in the *materials* and *methods* chapters, while in the following paragraphs focus is set on the introduction of MCDA methods and decision rules.

In a GIS-MCDA, inputs in the form of maps are generally overlaid and analyzed to produce a resultant decision (output) (Malczewski, 2004). Basically, the procedure involves criterion maps, reclassified or standardized, decision maker's preferences in the form of weights and data elaboration according to decision rules (Drobne & Lisec, 2009). Therefore, once specific factors and constraints have been identified for the purpose of the analysis, a weight should be assigned to each criterion, according to decision maker's judgments. As reported by Drobne and Lisec (2009), there are four main procedures to assign weights: (1) ranking methods, (2) rating methods, (3) pair-wise comparison methods and (4) trade-offs analysis methods. In this thesis, the focus is set on rating and pair-wise comparison methods, since these two approaches are widely used in studies related to LSA. Finally, a decision rule must be applied to perform the analysis and to identify the most suitable alternative for the final goal. As highlighted by several studies, the choice of the most suitable multi-criteria decision making (MCDM) method to combine spatial data and value judgments is not always clear, therefore, different approaches are often considered and applied to the same case study. According to Malczewski (2004), MCDM procedures, also called decision rules, define a relationship between input maps and output maps. Overall, MCDM can be classified into multi-attribute decision making (MADM) and multi-objective decision making (MODM). The two approaches mainly differ for the number of alternatives considered in the evaluation. Specifically, MADM deals with discrete alternatives, while MODM is recommended in the case of a wide number of continuous alternatives and multi-objective problems (Mendoza & Martins, 2006). Both MADM and MODM can be subsequently partitioned into individual or group decision making and into decisions under condition of certainty and uncertainty (Malczewski, 2006). In the present work, particular attention is given to MADM decision rules, such as Weighted Linear Combination (WLC), Boolean overlay operations of intersection (AND) and union (OR), Ordered Weighted Averaging (OWA), which extends and generalizes Boolean and WLC operations, and Analytic Hierarchy Process (AHP), which also establishes weights through a pair-wise comparison.

Since all these methods differ from each other, results may also vary. Therefore, a LSA for wheat and lentil is performed several times, considering the same input maps, reclassified or standardized through fuzzy membership functions and then overlaid with the application of different weights and decision rules. Output maps are finally compared and similar outcomes are highlighted.

Due to all the possible combinations between criteria and decision rules, the GIS-MCDA methodology has been increasingly adopted in order to solve spatial decision problems, especially in the last 20 years. The study carried out by Malczewski (2006) underlines the development of the GIS-MCDA approach occurred over a span of 15 years, between 1990 and 2004, revealing that the number of published works about the GIS-MCDA integration has considerably increased after 1995 (Figure 4). This escalation has been ascribed to several factors and mainly to the understanding of MCDA as a valuable tool for the improvement of many analyses in a GIS context, to the new low-cost and user-friendly technologies available and to the development of MCDA modules to be directly included into a GIS software.

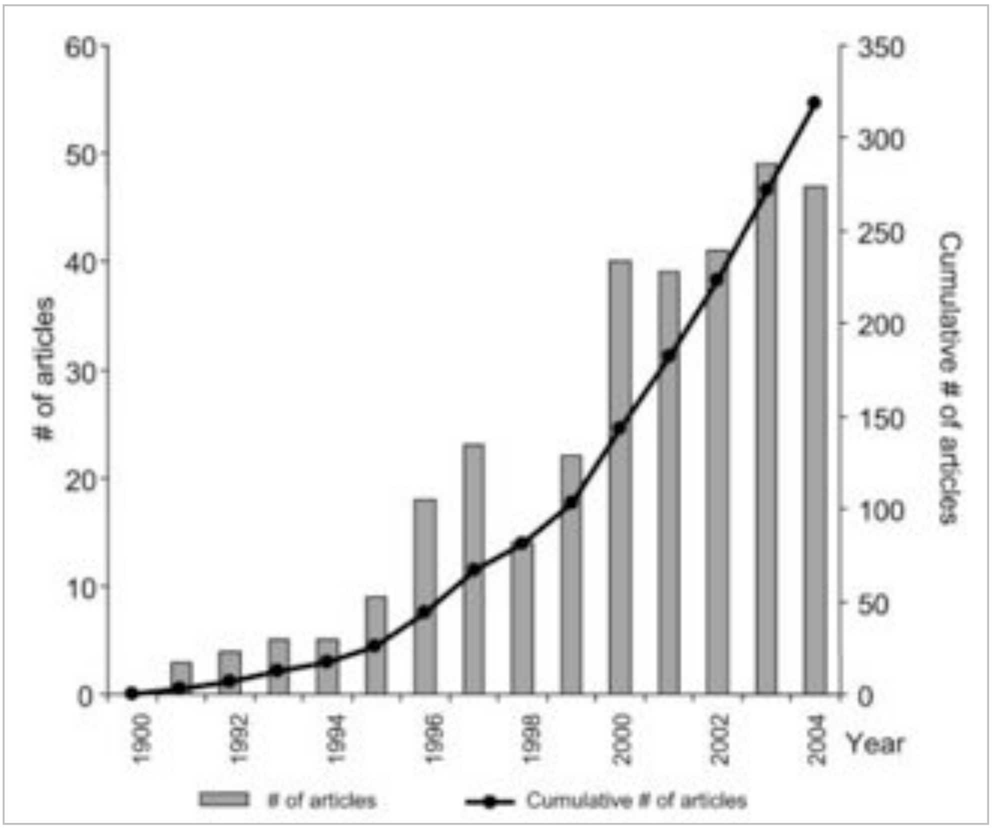

Figure 4. Total number of GIS-MCDA published works per year between 1990 and 2004 (Source: Malczewski, 2006).

In particular, the development of GIS open source software, such as QGIS (Quantum GIS) and GRASS GIS (Geographic Resources Analysis Support System), has encouraged many inexperienced users in taking advantage of GIS tools, leading to a considerable increase of possible applications. Moreover, GRASS allows expert users to modify or elaborate new modules, which can be integrated in the system. Specifically, Massei et al. (2013) developed five MCDA modules with the goal of entirely combine the MCDA approach into a GIS, so as to achieve a full efficiency of both systems through the adoption of the same database and interface. The five modules are: (1) r.mcda.electre, (2) r.mcda.fuzzy, (3) r.mcda.regime, (4) r.mcda.roughset and (5) r.mcda.ahp. In this thesis only r.mcda.fuzzy and r.mcda.ahp modules are applied, since r.mcda.electre, r.mcda.regime and r.mcda.roughset modules have been considered of scarce utility for the purpose of the study.

1.3. Research objectives and research questions

Starting from the given background, the aim of this research is to investigate the utility of an integrated approach, based on GIS and MCDA, in the case of a LSA for wheat and lentil cultivation under current and climate change scenarios in the region of RSZZ in Central Morocco. The final goal is to identify suitable lands where wheat and lentil can be grown in rotation, producing an overview of the problem of sustainable agriculture in the region taken as case study and promoting the introduction of suitable adaptation measures to cope with climate change. The level of the study is maintained at a regional scale and data sets collected are analyzed through the adoption of different GIS-MCDA techniques. First of all, criteria and constraints required for the LSA are outlined. Secondly, criteria in the form of spatial layers are reclassified or standardized according to crop requirements, while constraints are converted into Boolean maps. Thirdly, weights are assigned to each criterion based on expert's opinion. Finally, map layers representing criteria and constraints are combined according to different decision rules and analyzed into QGIS and GRASS to provide final results. Therefore, the objective of this work is to demonstrate the utility of a combination of tools for answering agronomic and environmental issues. Moreover, another important point is to make the analysis reproducible for further studies, reporting the source of data sets used, the way of gathering them and a script of main operations adopted within QGIS and in particular GRASS, which are the GIS tools used for computing the analysis.

Overall, three are the main research questions outlined in the thesis:

1. How climate change influences the cultivation of wheat and lentil crops in RSZZ?

2. Where is the rotation of wheat and lentil crops more suitable and what are the conditions for the application of CA and NT in defined areas?

3. What improvements can be obtained from the combination of GIS and MCDA tools in a multidisciplinary approach and how to make the analysis reproducible?

2. Materials

2.1. Description of the study area

2.1.1. Location and demography

The region of RSZZ is located in northwestern Morocco between latitudes 33°13′ and 34°10′N and longitudes 5°43′ and 7°06′W (Figure 5).

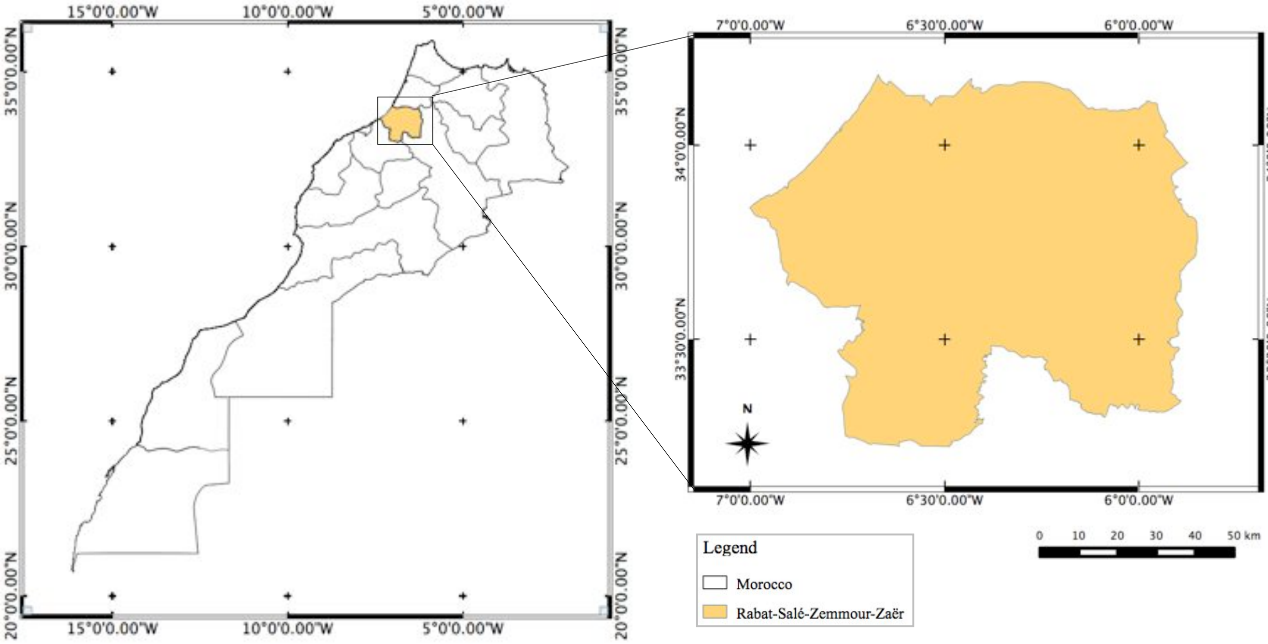

Figure 5. Location map of the study area.

Morocco is divided into 16 regions and, in particular, the study area borders the Gharb-Chrarda-Beni Hssen region to the north, the Atlantic Ocean to the west, the Meknès-Tafilalet region to the east and the Chaouia Ouardigha region to the south. The region covers 926,774 ha, corresponding to 1.3% of the total surface of Morocco and including the province of Khemisset and the three prefectures of Rabat, Salé and Skhirat-Temara. The province of Khemisset has a surface of 745,834 ha, while the prefectures of Rabat, Salé and Skhirat-Temara consist respectively of 10,570 ha, 71,657 ha and 98,713 ha. Rabat is the major city of the region and it is also the capital of the country (Figure 6). According to the last RGPH[3] of Morocco, carried out by the HCP[4], the

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[3] The last census has been carried out in 2004. A new version of the RGPH (Recensement général de la population et de l'habitat) will be available at the end of 2014.

[4] Haut-Commissariat au Plan/High Commission for Planning.

population of the region accounted for 2,366,494 inhabitants in 2004, representing the 7.9% of the overall population of the country.

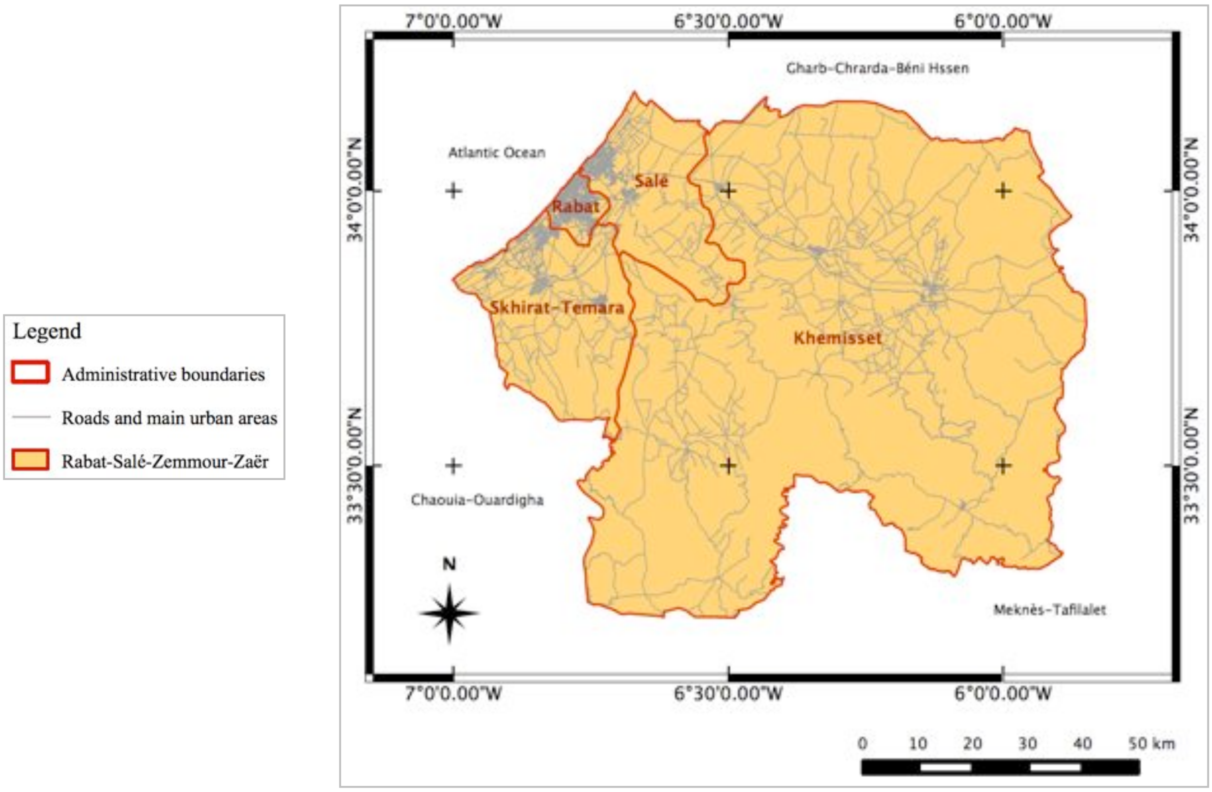


Figure 6. Administrative boundaries and main urban areas of RSZZ.

The value estimated for the year 2012 was approximately of 2,655,000 inhabitants, with an urban rate of 84.4% while the rural rate was of 15.5% (HCP, 2012). Data sets collected and estimated by the HCP show an increase in the urban population compared to the rural population between year 2004 and 2012. Nevertheless, in both cases, the province of Khemisset is mainly rural, while the prefectures of Rabat, Salé and Skhirat-Temara include most of the urban population (Table 4).

	2004			2012*			2014
	Urban	Rural	Urban+Rural	Urban	Rural	Urban+Rural	
Khemisset	219,018	302,797	521,815	271,000	295,000	566,000	NA
Rabat	627,932	-	627,932	652,000	-	652,000	NA
Salé	769,500	53,985	823,485	897,000	27,000	924,000	NA
Skhirat-Temara	302,872	90,390	393,262	422,000	91,000	513,000	NA
Total	**1,919,322**	**447,172**	**2,366,494**	**2,242,000**	**413,000**	**2,655,000**	NA

* *Data estimated*

Table 4. Population by area of residence and province/prefecture (Source: HCP, 2010, 2012).

2.1.2. Physiography

The topography of the study area ranges from flat surfaces to hilly and mountainous areas. The elevation varies from 0 to 1,300 meters above sea level (m a.s.l.), increasing from the Atlantic Coast to the Oulmes plateau, located at the border with the Middle Atlas ridge. The two major watersheds of RSZZ are the Bouregreg basin and the Sebou basin, characterized by the presence in the region of two dams: respectively the Sidi Mohammed Ben Abdellah dam and the El Kansera dam. The main rivers are the Oued Bouregreg, the Oued Grou, the Oued Mechra, the Oued Korifla and the Oued Beht (Figure 7).

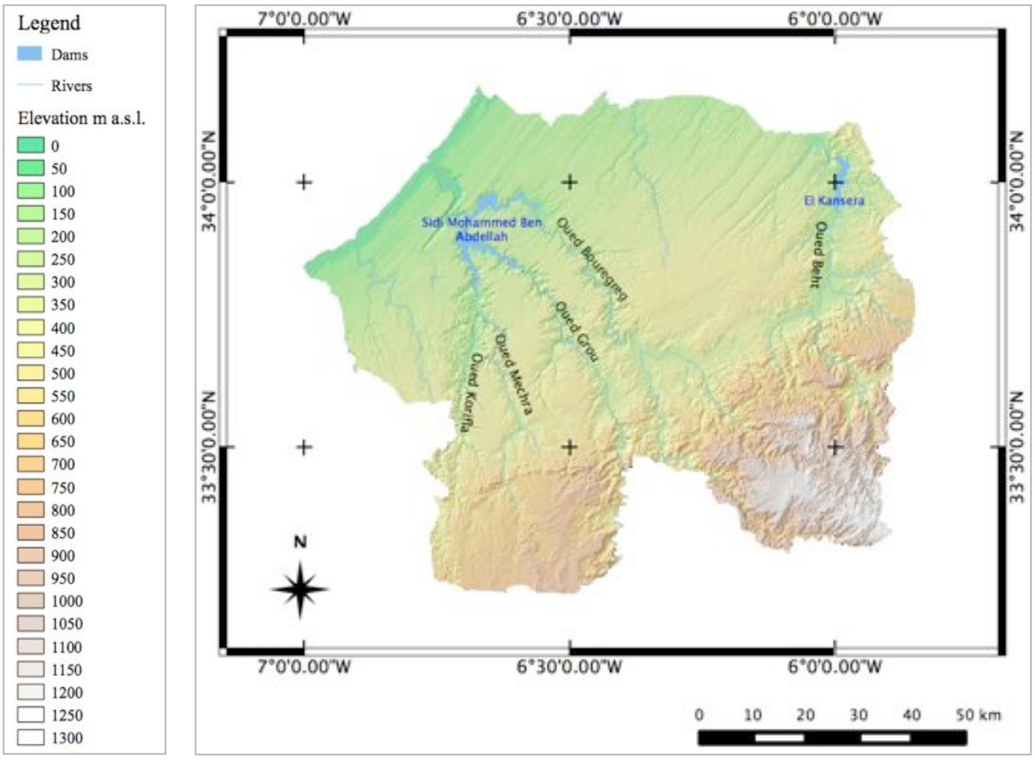


Figure 7. Digital elevation model, main rivers and dams of the study area.

According to Akıncı et al. (2013), slope affects agriculture both directly and indirectly, influencing soil development and limiting agricultural practices where too steep. In the region slope is largely suitable for crop production. Unsuitable slope (>30%) prevails in the mountainous area around Oulmes and along rivers. Only 10% of the study area is covered by unsuitable slopes, while most of the territory is characterized by slopes ranging from 0 to 15% and therefore suitable for agriculture and mechanization (Figure 8). The digital elevation model (DEM) used to derive slope has been downloaded from the U.S. Geological Survey (USGS) EarthExplorer database in raster format and subsequently elaborated in a GIS environment with GRASS and QGIS. A more detailed explanation of slope analysis is available in the *data source and collection* section.

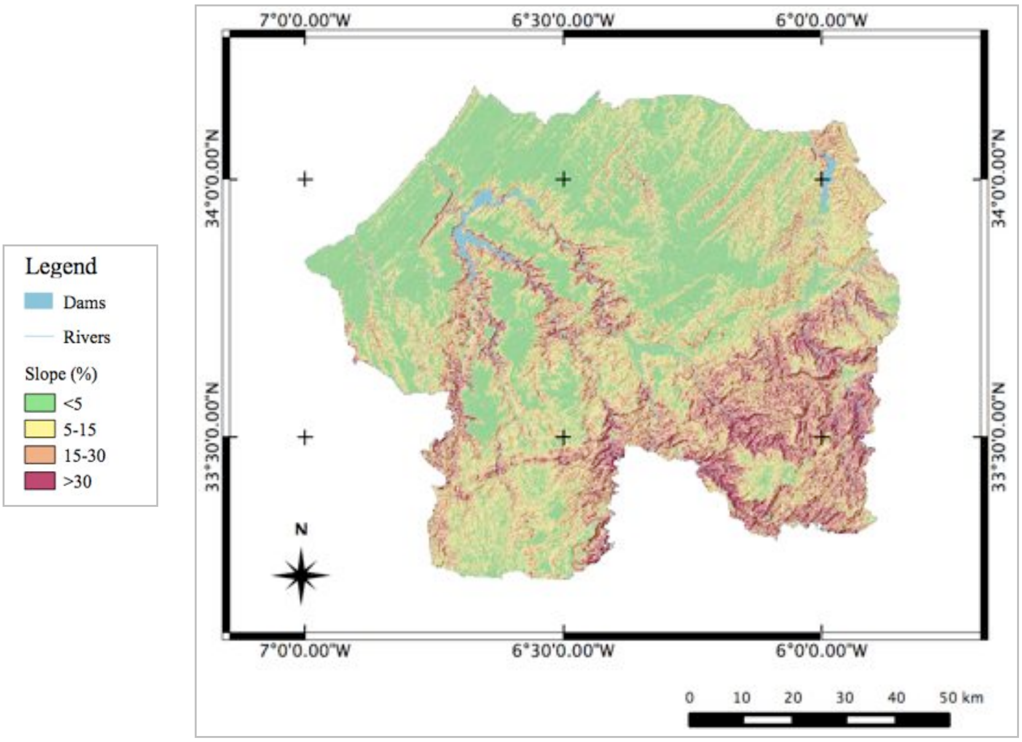


Figure 8. Slope map of the study area.

2.1.3. Current climate

Knowledge on climate is of primary importance for agriculture activities, especially for regions characterized by arid and semi-arid climate conditions under rainfall variability and unpredictable extreme events. Rainfall and temperature are considered as the main variables influencing climate as a whole. The study area belongs to semi-arid and sub-humid regions, with mild winters and dry summers (DRA RSZZ, 2004a; Iaaich, 2009a). In terms of rainfall June, July, August and September are the driest months, while precipitation occurs from October to May, showing highest values in November and December and, in some areas, even around March. Temperatures in the RSZZ region are higher in summer, between June and September and lower in winter, reaching the minimum in January (Figure 9). Four weather stations at different altitudes and latitudes have been chosen to represent a set of rainfall and temperature trends in the region. Data sets in the form of maps and weather stations coordinates have been downloaded from "WorldClim" and from "Data Basin" websites and subsequently elaborated. WorldClim time series (~1950-2000) related to average monthly precipitation and average monthly minimum, mean and maximum temperature have been imported into QGIS and used to define and extrapolate the climate trend of the region. Results are in agreement with the reviewed literature of the study area (DRA RSZZ, 2004b; Iaaich, 2009b). The weather stations considered are Rabat-Salé, Tiflet, Rommani and Oulmes (Table 5). Rainfall trends in the four locations change accordingly to the elevation gradient and distance from the ocean. As shown in Figure 10, the mountain location of Oulmes has higher annual rainfall compared to the others, while the location of Rommani presents a low precipitation peak in winter with a second rainfall peak in spring. Tiflet has a trend similar to Rommani but with higher precipitation in winter, while the oceanic location of Rabat-Salé after a rainfall peak in winter receives less precipitation in spring.

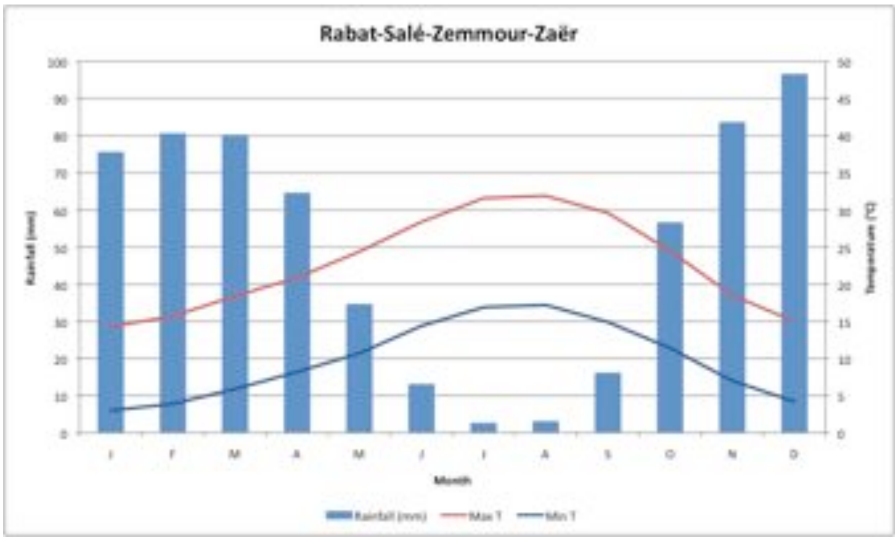


Figure 9. Average monthly precipitation and average monthly maximum and minimum temperature of RSZZ (Data source: WorldClim time series ~1950-2000).

STATION	ALT (m a.s.l.)	LONG	LAT
Rabat-Salé	75	6°46'W	34°03'N
Tiflet	368	6°18'W	33°53'N
Rommani	394	6°35'W	33°31'N
Oulmes	1,167	6°00'W	33°25'N

Table 5. Altitude and coordinates of weather stations considered.

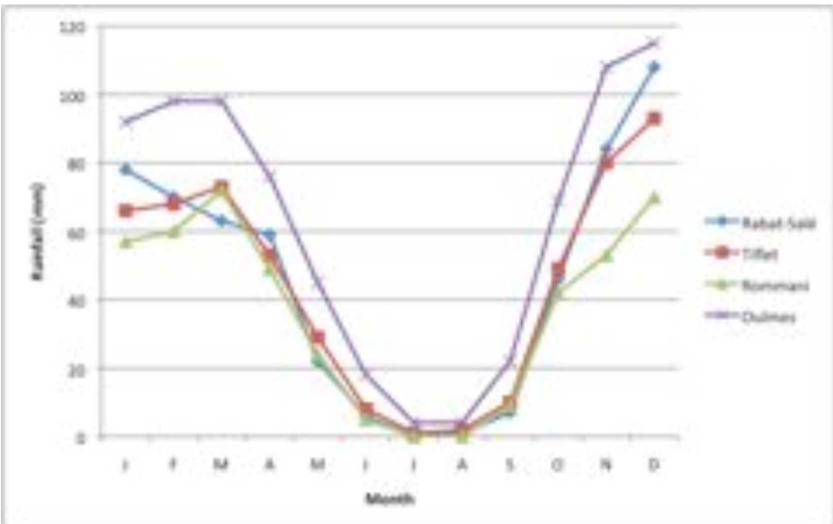


Figure 10. Average monthly precipitation in four different weather stations located in RSZZ (Data source: WorldClim time series ~1950-2000).

The total average annual rainfall calculated over a period of 50 years (~1950-2000) at Oulmes station is 749 mm with a minimum of 4 mm in July and August and a maximum of 115 mm in December. For Rommani station the total average annual rainfall is 441 mm with a minimum of 0 mm in July and August, a maximum of 70 mm in December and another maximum of 72 mm in March. Tiflet station has a total average annual rainfall of 532 mm with a minimum of 1 mm in July and 2 mm in August and a maximum of 93 mm in December and a slighter peak of 70 mm in March, while the weather station of Rabat-Salé reports a total average annual rainfall of 544 mm with a minimum of 0 mm in July and 1 mm in August and a maximum of 108 mm in December.

As for rainfall trends, temperature trends in the four locations change accordingly to the elevation gradient and distance from the ocean. Figure 11 represents the average monthly mean temperature in the four weather stations considered for a period of 50 years (~1950-2000). The mountain location of Oulmes has the lowest average mean temperature with a mean of 13.7°C, a minimum of 5°C in January and a maximum of 23.3°C in July. Rommani and Tiflet stations follow a very similar trend but Rommani has a lower average mean temperature compared to Tiflet. Rommani station has a mean of 17.4°C, a minimum of 10.1°C in January and a maximum of 25.7°C in August, while the location of Tiflet has a mean of 18.0°C, a minimum of 10.8°C in January and a maximum of 26.5°C in August. Moreover, Tiflet station has the highest average mean temperatures in summer compared to the other three stations. The oceanic location of Rabat-Salé is characterized by mild temperature in winter and moderately high temperature in summer. The annual mean is of 17.8°C, with a minimum of 12.3°C in January and a maximum of 23.4°C in August.

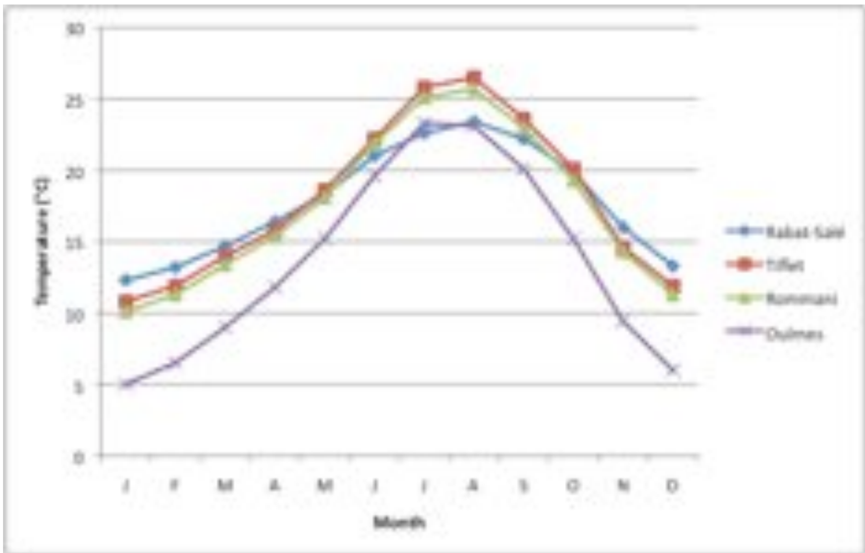


Figure 11. Average monthly mean temperature in four different weather stations located in RSZZ (Data source: WorldClim time series ~1950-2000).

2.1.4. Soil

According to the Soil Science Society of America (2008), soil is defined as:

« (i) The unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral or organic matter on the surface of the Earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. »

Understanding soil characteristics is fundamental in agriculture. Therefore, information related to soil properties needs to be as complete and detailed as possible. This task becomes more difficult if the study area is defined at a local scale and in a country with scattered data sets. In the present work, soil analyses have been possible thanks to the collaboration with INRA Rabat that has provided a series of data sets on soil classes, drainage, depth, texture, pH and organic matter content of the study area in the form of shapefiles. Based on the WRB[5] classification, the main classes of soils found in the study area are: Arenosols, Cambisols, Chernozems, Kastanozems, Leptosols, Luvisols, Regosols, Solonchaks and Vertisols. As shown in Table 6, Arenosols represent the major soil class of the region and they are mainly found in the northern and southeastern part of RSZZ. They are sandy soils with coarse texture typically of arid and semi-arid environments. Despite their low nutrient storage capacity and high permeability, Arenosols have a moderately good agricultural potential, especially in areas where annual precipitation is more than 300 mm (FAO & IUSS, 2007). Cambisols are distributed in the northwestern and in the southwestern part of the study area. They typically present different structures, colors and clay or carbonate contents in the subsurface. Cambisols agricultural properties vary widely, based on the topography, slope and pH, but they are generally good soils (FAO & IUSS, 2007). Chernozems are present in the central part of the region, where climate has continental characteristics, with cold winters and hot summers. Chernozems are rich in organic matter content and they represent a valuable resource for agricultural uses (FAO & IUSS, 2007). Kastanozems soils are mainly found in the southwestern and northern part of the study area. They are characterized by a thinner humus-rich horizon compared to Chernozems soils, but they have great potential for agriculture if soil moisture is not limited (FAO & IUSS, 2007).

[5] World Reference Base for Soil Resources.

Leptosols are distributed in the southeastern part of the region, mainly in the mountainous area. They are shallow and gravelly soils. Therefore, Leptosols are most suitable for grazing and forests (FAO & IUSS, 2007). Luvisols are present along the Atlantic Coast and in the southwestern part of the region. They are characterized by lower clay content in the topsoil and higher clay content in the subsoil due to a pedogenetic process. Luvisols are fertile soils, for which agricultural constraints occur when erosion takes place on steep slopes (FAO & IUSS, 2007). Regosols represent the second major class of soils in the region where they are wide spread with the exception of northern areas. They are weakly developed soils and commonly found in arid environments. Since Regosols profile is not well developed, agriculture on these soils is generally unsuitable and they are mainly used for grazing (FAO & IUSS, 2007). Solonchaks soils are found only in a small portion of the study area in the southern part of the region. They are typical soils of arid and semi-arid environments. Solonchaks are not very suitable for agriculture due to high concentration of soluble salts (FAO & IUSS, 2007). Vertisols are distributed in the central and northeastern part of the region. They are characterized by high swelling clay content, forming cracks when dry. Good management practices focused on water control and soil fertility are essential for agriculture on these soils (FAO & IUSS, 2007). Calcisols and Gleysols soils are also described, since they are found in combination with major soil classes in the region. Calcisols are present especially in the southwestern and central part of the study area. They are soils with substantial accumulation of secondary lime and they are usually found in arid and semi-arid environments. Agriculture has some limitation on Calcisols, therefore they are preferably used for grazing or for drought-tolerant crops (FAO & IUSS, 2007). Finally, Gleysols are distributed in northwestern, southwestern and southeastern areas. Gleysols are usually saturated by groundwater for long periods. Therefore, they need to be drained for agricultural purposes (FAO & IUSS, 2007).

As reported by FAO & IIASA (2007), while considering the overall quality of a soil and its suitability to agriculture, many criteria are involved. A mere soil classification is thus integrated with a comprehensive description of other regional soil characteristics. Physical soil properties, as drainage, depth and texture are therefore presented followed by chemical soil properties as pH and organic matter content (OMC).

A qualitative drainage classification, made by INRA soil scientists, divides the RSZZ region into Excessively well drained, Well drained, Moderately well drained, Poorly drained and Very poorly drained zones. Table 6 shows that most of the soils in the region are characterized by good drainage. However, also poorly drained and very poorly drained soils occupy a considerable area.

Only moderately well drained soils do not exceed the coverage amount of 100,000 ha. Drainage related constraints mainly occur in the northwestern, southwestern and central areas of the region, where drainage is classified as poor and very poor. On the contrary, the northern and most of the southern parts of the region are characterized by excessively well drained and well drained soils. Another classification is made considering soil depth. This is an important parameter for cultivated crops, since it determines the limit at which roots can reach nutrients and water. As shown in Table 6, the overall soil depth of the region varies from 100 cm to 40 cm, but most of the study area is included in the range 80-100 cm, with very few parts corresponding to or being below 60 cm, which are mainly located around the Oulmes plateau and close to the Sidi Mohammed Ben Abdellah dam. Therefore, the study area is not affected by extreme constraints related to soil depth. Texture classification, based on the proportion of sand, silt and clay in the soil, follows rules expressed in the textural triangle (Figure 12). In the case study, texture is classified as: Clay, Sandy clay, Loam, Sandy loam, Loamy sand and Sand. In the region, clay texture mostly characterized Vertisols, while sandy clay texture is partly found in Kastanozems soils. Loam texture is prerogative of Chernozems, while sandy loam texture is present in Leptosols and Regosols. Loamy sand texture is typical of Cambisols and part of Kastanozems, while sand texture primarily characterized Arenosols. Table 6 shows that sand texture is also the predominant texture class in RSZZ, jointly with sandy loam and loamy sand textures.

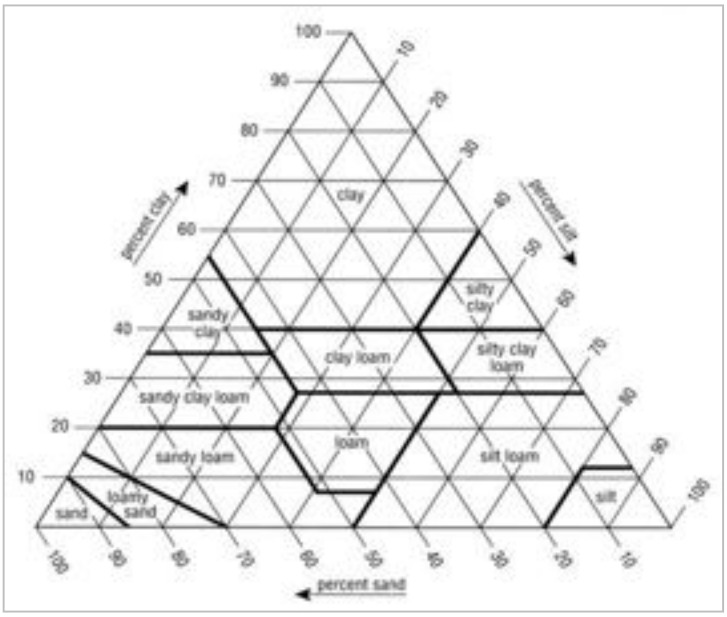


Figure 12. Textural triangle expressing relative proportion of sand, silt and clay (Source: USDA, 1993).

Soils can also be classified based on their chemical properties. Soil pH is an important parameter for agriculture, since it affects nutrients availability (Sys et al., 1991). Acid soils, neutral soils and alkaline soils are present in different areas of RSZZ. Respectively, acid soils are concentrated in the upper and lower part of the region, alkaline soils in the middle and neutral soils in between the two extremes. Based on regional coverage, acid soils are the most common soils, while neutral soils are the less common (Table 6). OMC is another important criterion considered in terms of soil characteristics. Based on available data sets, there are not many areas characterized by high percentages of OMC. The few parts of the region with more than 3% of OMC are mainly located between the eastern and western borders of the study area. The region is mostly characterized by OMC between 2% and 1%, while only a small fraction of northern soils presents OMC ranging from 1% to less than 0.5%.

A more detailed description of soil data sets used in this work is available in the *data source and collection* section.

WRB	Area (ha)	Area (%)
Arenosols	283,509	30.59
Cambisols	76,259	8.23
Chernozems	75,343	8.13
Kastanozems	115,560	12.47
Leptosols	62,946	6.79
Luvisols	102,362	11.05
Regosols	127,992	13.81
Solonchaks	6,001	0.65
Vertisols	63,655	6.87
Dam	7,584	0.82
Urban Area	5,546	0.60

Depth (cm)	Area (ha)	Area (%)
40	0.2	0.00
45	8,439	0.91
60	42,917	4.63
70	74,407	8.03
80	244,656	26.40
90	262,688	28.34
100	271,615	29.31
NA	8,905	0.96
Dam	7,584	0.82
Urban Area	5,546	0.60

Drainage	Area (ha)	Area (%)
Excessively well drained	204,075	22.02
Well drained	428,460	46.23
Moderately well drained	63,655	6.87
Poorly drained	107,235	11.57
Very poorly drained	110,202	11.89
Dam	7,584	0.82
Urban Area	5,546	0.60

Texture	Area (ha)	Area (%)
Clay	79,804	8.61
Sandy Clay	47,170	5.09
Loam	75,343	8.13
Sandy Loam	167,267	18.05
Loamy Sand	110,202	11.89
Sand	433,841	46.81
Dam	7,584	0.82
Urban Area	5,546	0.60

OMC (%)	Area (ha)	Area (%)
< 0,5	11,956	1.29
0,5 - 1	95,680	10.33
1 - 1,5	169,057	18.25
1,5 - 2	287,094	30.99
2 - 2,5	230,218	24.85
2,5 - 3	80,589	8.70
3 - 3,5	27,934	3.02
3,5 - 4	13,352	1.44
4 - 4,5	9,296	1.00
4,5 - 5	1,186	0.13

pH	Area (ha)	Area (%)
< 5,5	232,307	24.93
5,5 - 6	217,510	23.34
6 - 6,5	150,344	16.13
6,5 - 7	80,969	8.69
7 - 7,5	59,388	6.37
7,5 - 8	124,493	13.36
8 - 8,5	61,459	6.59
Urban Area	5,546	0.60

Table 6. RSZZ soil classes and soil parameters (depth, drainage, texture, omc, pH) coverage area, expressed in hectares and percentage.

2.1.5. Crops productivity

An easy way to determine the overall growing season of one region is to consider both the average annual rainfall and the average annual mean temperature combined in an ombrothermic diagram (Gaussen & Bagnouls, 1957). Figure 13 shows the ombrothermic diagram of RSZZ. The general rule to identify the growing period is to consider months where the average rainfall value (mm) double exceeds the average mean temperature value (°C). Thus, the growing season of RSZZ results to cover the period between October and April/May.

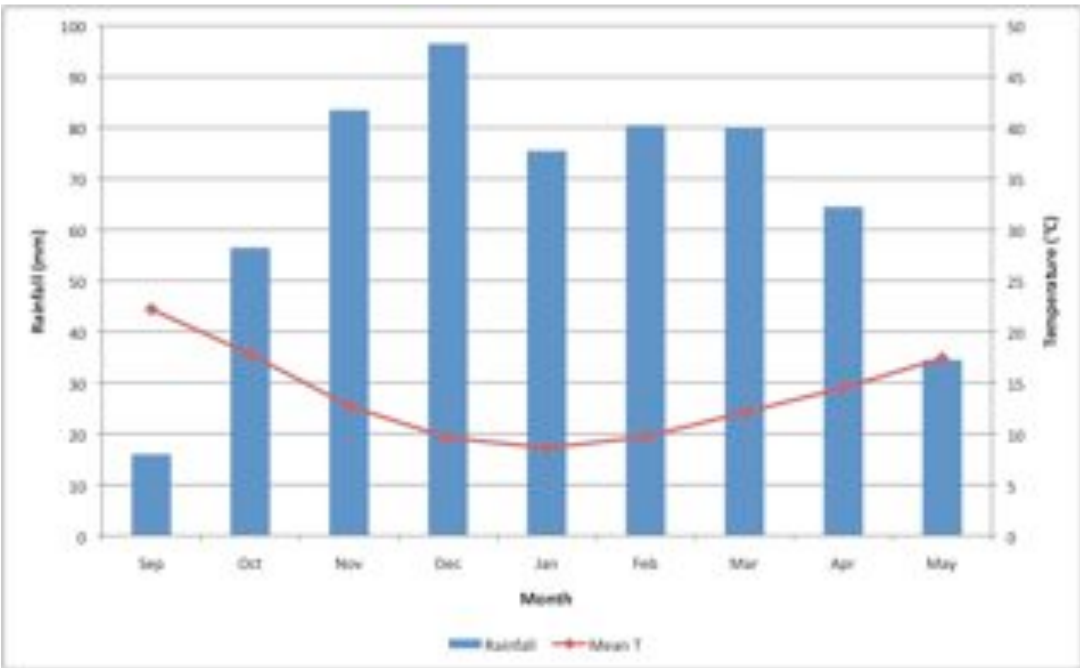


Figure 13. Ombrothermic diagram of the RSZZ region (Data source: WorldClim time series ~1950-2000).

According to HCP (2010), cultivated areas in RSZZ amount to 442,674 ha, of which 427,027 ha are rain-fed lands. Main cultivated crops in the region are cereals, legumes, oleaginous plants, vegetable and fodder crops. Tables 7 and 8 show respectively the total cultivated land (ha) and the total yield (q) for each crop in the province of Khemmiset and in the prefectures of Salé and Skhirat-Temara in the reference year 2008-2009. The prefecture of Rabat is not included in the analysis, since its contribution to regional agriculture is marginal.

		Salé	Skhirat-Temara	Khemmiset	Total
Cereals	Durum wheat	2,130	600	25,150	27,880
	Winter wheat	8,200	13,490	139,400	161,090
	Barley	4,832	6,300	60,050	71,182
	Corn	-	-	9,250	9,250
	Others	-	-	3,400	3,400
Total		**15,162**	**20,390**	**237,250**	**272,802**
Legumes	Broad bean	1,595	100	9,000	10,695
	Pea	415	-	3,800	4,215
	Chick pea	80	-	4,050	4,130
	Lentil	-	-	10,900	10,900
	Others	-	-	150	150
Total		**2,090**	**100**	**27,900**	**30,090**
Oleaginous plants	Sunflower	-	-	1,270	1,270
	Olive	NA	NA	NA	20,000
Total		NA	NA	NA	**21,270**
Vegetable crops	Tomato	115	94	195	404
	Potato	1,035	640	1,700	3,375
	Onion	-	-	217	217
	Turnip	-	-	99	99
	Green bean	270	120	12	402
	Carrot	-	-	114	114
Total		**1,420**	**1,033**	**6,366**	**4,611**
Fodder crops	Oat	570	3,650	NA	NA
	Barley	800	700	NA	NA
	Triticale	-	200	NA	NA
	Vetch	-	-	NA	NA
	Fodder corn	200	-	NA	NA
	Lupin	200	-	NA	NA
	Clover	-	65	NA	NA
	Alfalfa	-	60	NA	NA
	Rye	270	-	NA	NA
	Sorghum	-	45	NA	NA
Total		**2,040**	**4,720**	**28,770**	**35,530**

Table 7. Total cultivated land (ha) for main crops of the study area in the reference year 2008-2009 (Data source: DRA RSZZ, 2004; HCP, 2010).

		Salé	Skhirat-Temara	Khemmiset	Total
Cereals	Durum wheat	39,008	10,800	226,350	276,158
	Winter wheat	150,160	196,780	1,394,000	1,740,940
	Barley	87,701	157,500	480,400	725,601
	Corn	-	-	46,250	46,250
	Others	-	-	40,800	40,800
Total		**276,869**	**365,080**	**2,187,800**	**2,829,749**
Legumes	Broad bean	3,286	1,200	45,000	49,486
	Pea	6,640	-	15,200	21,840
	Chick pea	640	-	32,400	33,040
	Lentil	-	-	92,650	92,650
	Others	-	-	-	-
Total		**10,566**	**1,200**	**185,250**	**197,016**
Oleaginous plants	Sunflower	-	-	11,430	11,430
	Olive	NA	NA	NA	180,000
Total		NA	NA	NA	**191,430**
Vegetable crops	Tomato	49,450	49,000	340,000	438,450
	Potato	301,500	115,200	35,100	451,800
	Onion	-	-	34,720	34,720
	Turnip	-	-	11,800	11,800
	Green bean	21,600	9,600	960	32,160
	Carrot	-	-	11,400	11,400
Total		**372,550**	**173,800**	**433,980**	**980,330**
Fodder crops	Oat	18,240	116,800	NA	NA
	Barley	25,600	8,900	NA	NA
	Triticale	-	7,000	NA	NA
	Vetch	-	-	NA	NA
	Fodder corn	19,500	-	NA	NA
	Lupin	5,000	-	NA	NA
	Clover	-	7,800	NA	NA
	Alfalfa	-	15,000	NA	NA
	Rye	40,500	-	NA	NA
	Sorghum	-	15,750	NA	NA
Total		**108,840**	**171,250**	**484,487**	**764,577**

Table 8. Total yield (q) for main crops of the study area in the reference year 2008-2009 (Data source: DRA RSZZ, 2004; HCP, 2010).

Data sets obtained from reports of HCP (2010) and DRA RSZZ (2004) are not fully completed and missing information is therefore indicated as not available (NA). Nevertheless, some considerations can be formulated. In terms of location, the province of Khemmiset results to be the most predisposed to agriculture, while in terms of crops, cereals and especially winter wheat play a major role in regional agriculture. Winter wheat has the highest values in terms of cultivated land and yield. Legumes also hold an important position in terms of cultivated land, but yields are modest apart from lentil. On the other hand, considerable yields are found in vegetable crops, while the area covered by these crops is the lowest of the region. Concerning fodder crops, they present a total cultivated area slightly higher than legumes and a total yield that has one of the highest values of the region after cereals and vegetable crops. However, information on fodder crops is not precise for the province of Khemmiset for which only total values are available.

2.1.6. Land Cover

Identifying the current land cover of the study area is an important step for further investigation on agricultural properties and characteristics of the region. Figures 14, 15 and 16 illustrate portions of the land cover map of RSZZ derived from the GlobCover 2009 global database. According to the GlobCover classification, the region is characterized by mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%), mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%), rain-fed croplands and forests. The land cover map showing forests is the result of a combination of different classes of the GlobCover database. Therefore, the layer includes: closed (>40%) broadleaved deciduous forest (>5m), closed (>40%) needleleaved evergreen forest (>5m), mosaic forest or shrubland (50-70%) / grassland (20-50%), mosaic grassland (50-70%) / forest or shrubland (20-50%), closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m) and sparse (<15%) vegetation. Moreover, since data on forests total coverage derived from the GlobCover 2009 database was not conformed to data presented by Iaaich (2009) and to satellite images explored with the Google satellite plugin in QGIS, additional information on forests has been gathered from Geofabrik and integrated with GlobCover 2009 using QGIS. A more comprehensive description of data sources adopted and adjustments operated in QGIS are outlined in the *data source and collection* section.

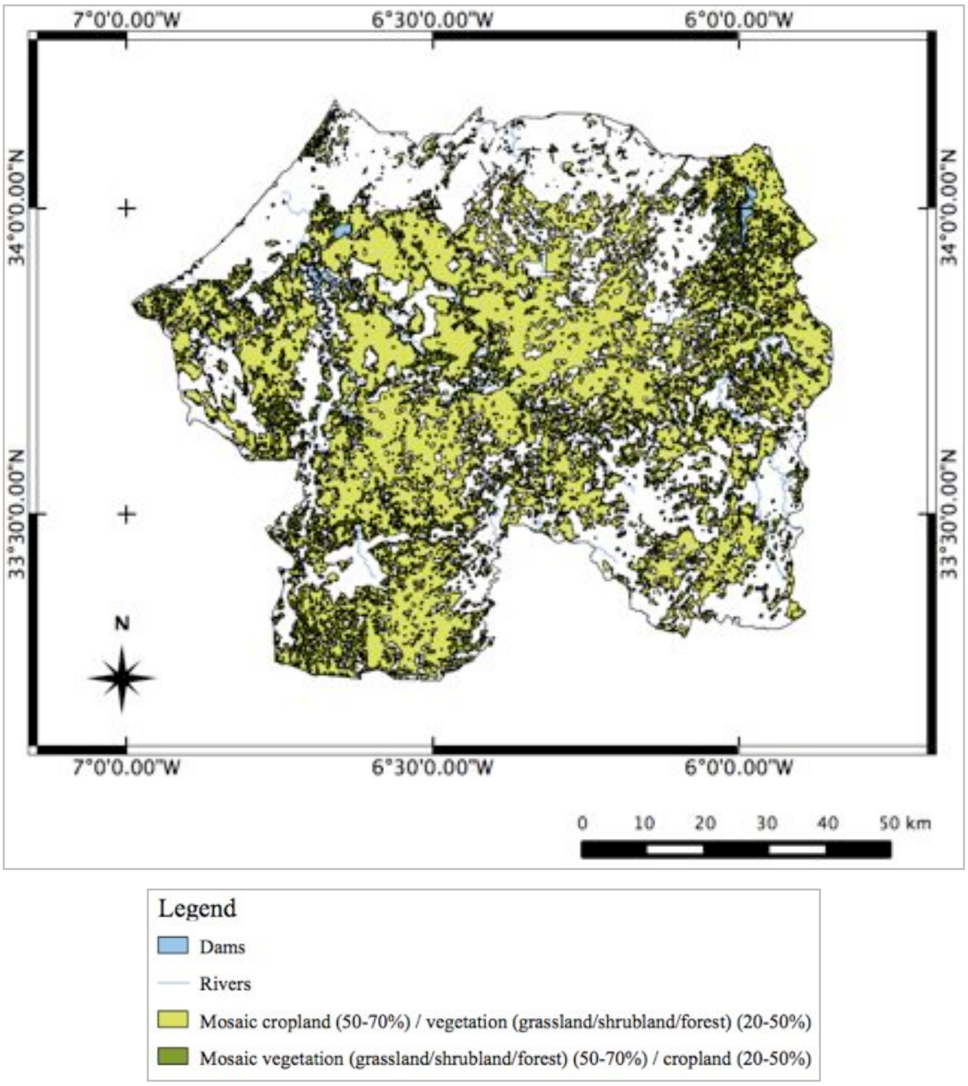


Figure 14. Land cover map showing mosaic cropland and mosaic vegetation of the study area (Source: GlobCover 2009).

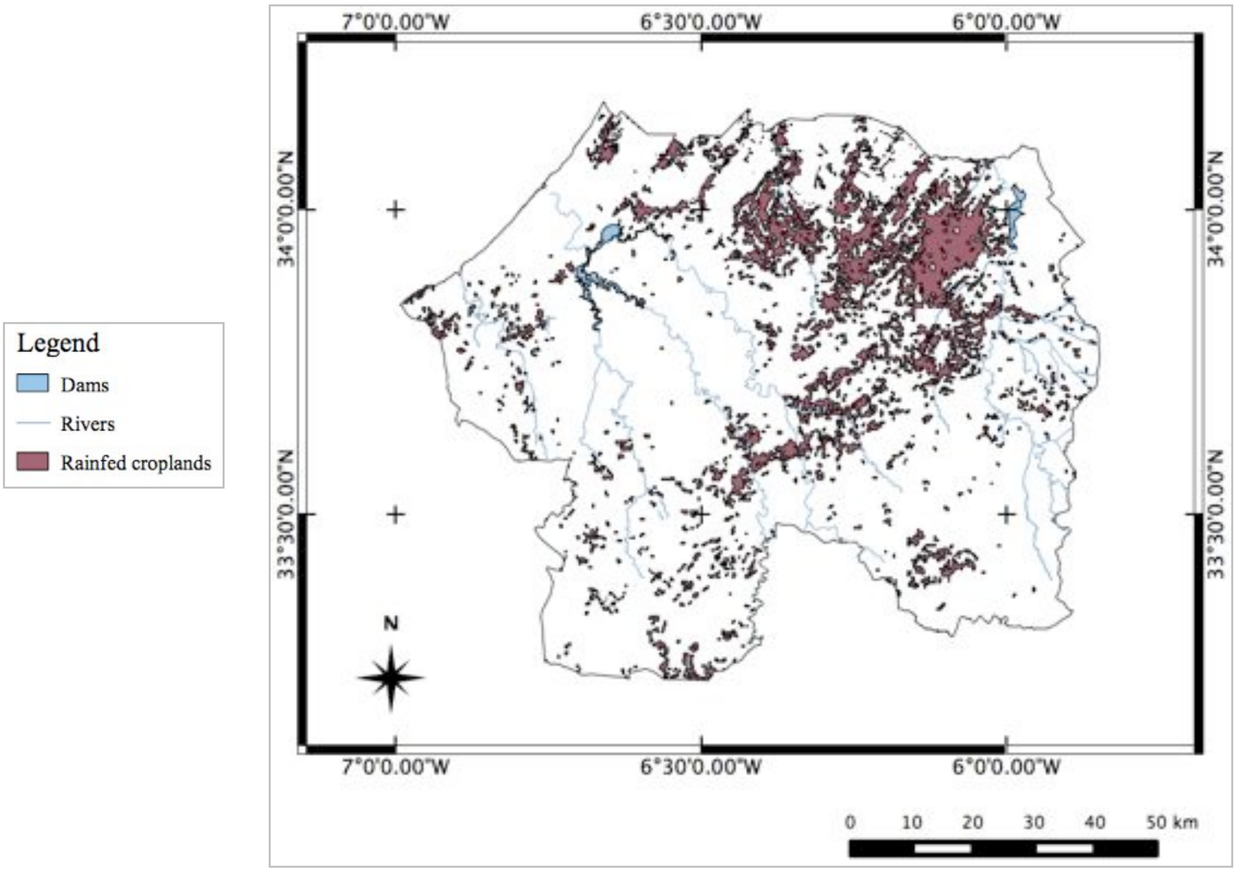


Figure 15. Land cover map showing rain-fed croplands of the study area (Source: GlobCover 2009).

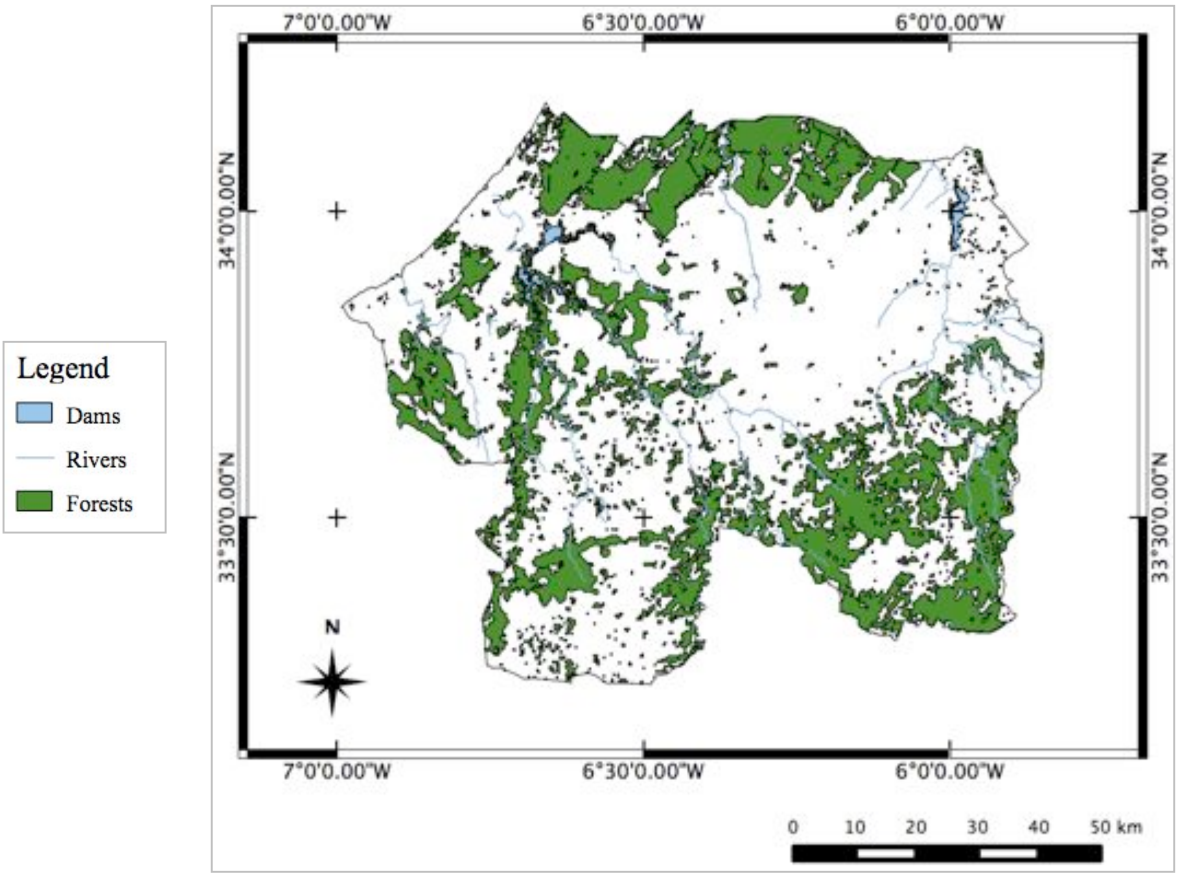


Figure 16. Land cover map showing forests of the study area (Source: GlobCover 2009 and Geofabrik).

2.2. Climate change scenarios

Arid and semi-arid Moroccan regions are particularly susceptible to climate change. As reported by Schilling et al. (2012), recent climate trends of Morocco are characterized by an overall increase in mean temperature, especially in summer and autumn, and a decrease in precipitation in the winter season, leading to comprehensive warmer and drier climate conditions compared to the past. Trends observed in the 20th century are likely to continue in the future (Born et al., 2008; Schilling et al., 2012). In particular, extreme events, such as droughts, are expected to be more frequent in the 21st century, due to higher temperatures and lower precipitations, which cause longer dry spells that influence plant growing cycles (Schilling et al., 2012). For this reason, crop productivity in Morocco is predicted to decrease by 30% prior to 2080 (Giannakopoulos et al., 2009; Schilling et al., 2012). As reported by Giannakopoulos et al. (2009), if adaptation measures are not undertaken in order to cope with climate change impacts in Morocco, cereals and legumes will respectively decrease in productivity of about 15% and 40% in the second half of the 21st century (Figure 17).

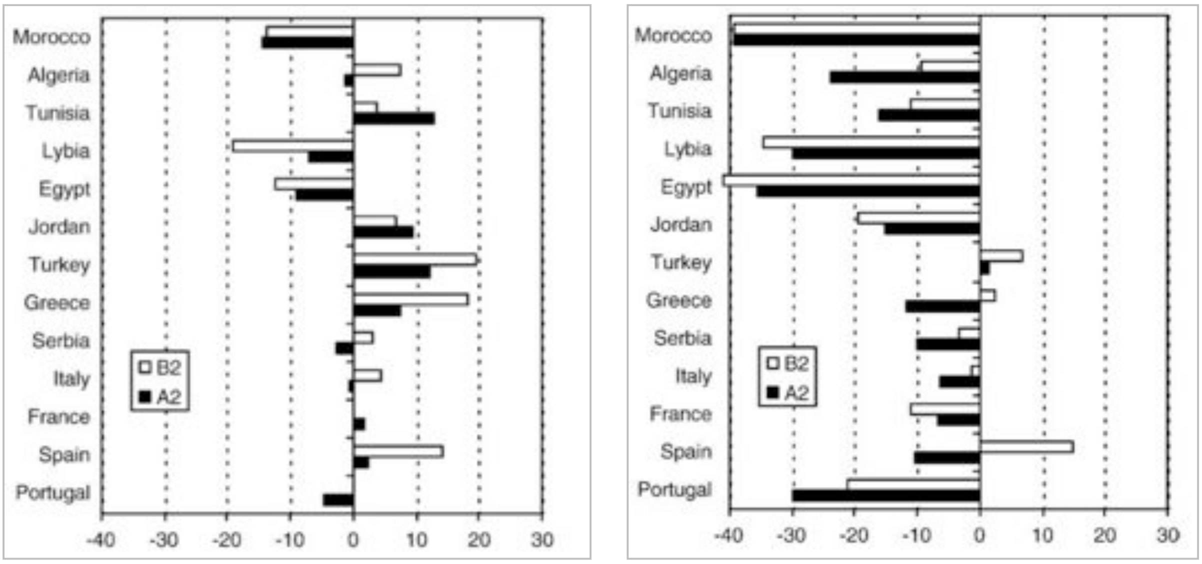


Figure 17. Consequences of climate change on cereals (left) and legumes (right) productivity expressed in percentage. Values underline different future yields (considering SRES A2 and B2) compared to the present (Source: Giannakopoulos et al., 2009).

Considering Morocco, the study conducted by Giannakopoulos et al. (2009) also reports that no substantial differences are present between the two SRES (Special Report on Emission Scenarios) A2 and B2[6] climate change scenarios in terms of cereals and legumes future productivity.

[6] The IPCC B2 emission scenario represents a world focused on local solutions to economic, social and environmental sustainability, with a constant increase in population during the 21st century (lower than A2), an intermediate economic development and an increase in $[CO^2]$ of about 620 ppm by 2100 (IPCC, 2001).

Therefore, due to time constraints, in the present thesis it was decided to apply only one of the possible climate change scenarios and specifically the A2 scenario, since wide adopted in other studies related to climate change in Morocco. Moreover, the A2 scenario represents one of the most negative scenarios in terms of temperature and precipitation changes. For this reason, results from a LSA where this scenario is applied should be able to show the worst projection possible, allowing the understanding of where adaptation measures should be allocated in the upcoming future. If measures are undertaken to adapt to the worst scenario, the same measures will be useful also in the case of climate change scenarios with lower impacts.

Not only climate change scenarios, but also several Atmosphere-Ocean General Circulation Models (AOGCMs) have been analyzed by different studies focused on the Mediterranean region. According to Giannakopoulos et al. (2009), the analysis carried out considering the Hadley Center Coupled Model version 3 (HadCM3) revealed that mean temperature in the Mediterranean basin is expected to increase by 2 °C in winter and spring and 4 °C in summer by the end of the 21st century. In this case, the General Circulation Model (GCM) HadCM3 refers to the SRES A2 scenario. However, values differ between studies, depending on models and scenarios considered in the evaluation of future climate. For instance, Paeth et al. (2009) report that temperature in Northern Africa is predicted to rise between 1.5 °C and 2.5 °C based on the Regional Climate Model (REMO) referring to the A1B[7] SRES scenario, while the range in the B1[8] SRES scenario is estimated to be 1 °C lower than the A1B scenario. Regarding rainfall, variation in precipitation patterns is considered to be of extreme importance for agricultural productivity in Morocco, where the sector plays a pivotal role in the GDP of the country. Giannakopoulos et al. (2009) state that precipitation may decrease of 10-20% in the Mediterranean basin towards the 21st century. In the case of the B2 climate scenario, a slightly increase in precipitation in winter is reported and according to Schilling et al. (2012) this is probably due to changes in circulation patterns. On the other hand, the A2 scenario only reports a decrease in precipitation. Overall, these predictions are characterized by significant uncertainties which are related to intra- and inter-annual variabilities (Giannakopoulos et al., 2009). In order to cope with uncertainties, several GCMs and climate scenarios should be therefore considered in studies that involve climate change projections.

[7] The IPCC A1B emission scenario describes a world of rapid economic growth, a rapid development of new and efficient technologies, with a peak of population growth by the middle of the 21st century, a balance across energy sources and an increase in [CO^2] of about 715 ppm by 2100 (IPCC, 2001).

[8] The IPCC B1 emission scenario describes a world with a peak of population growth by the middle of the 21st century, an increase in service and information economy, a rapid development of clean and efficient technologies and an increase in [CO^2] of about 550 ppm by 2100 (IPCC, 2001).

2.2.1. Climate change scenarios and general circulation models

With the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), released between 2013 and 2014, a new set of future climate scenarios has been identified. The Representative Concentration Pathways (RCPs) basically differ from the old SRES because they primary consider radiative forcing (W/m^2) resulting from atmospheric concentration of greenhouse gases (GHG) instead of emissions and socioeconomic processes (Jubb et al., 2013). RCP2.6 represents the mitigation scenario with the lower radiative forcing, a peak before 2100 and then a decline. RCP4.5 and RCP6 are medium scenarios with stabilization of radiative forcing after 2100, while the RCP8.5 indicates the higher scenario. However, since RCPs scenarios are a new product, their use is not wide spread in literature. Moreover, data sets in the form of maps, related to the RCPs and found on the "Downscaled GCM Data Portal" website, are extremely large in terms of required storage capacity on a computer, while data sets related to SRES scenarios can be downloaded by tile and therefore they have no storage related problems, although they are still quite large files. For this reason, attention is required, in order to perform the analysis with the most suitable data set, both in terms of reliability and accessibility. As previously stated, only the A2 climate scenario has been chosen to perform the analysis in the present work, due to time constraints and because it represents the worst scenario possible, together with the A1FI[9] scenario. On the other hand, findings from a study carried out by Navarra (2007) led up to the choice of four GCMs with which to perform the LSA in the present work. The four models have been chosen also because made by different institutes in the world and because they present different outputs both concerning precipitation and temperature patterns, as shown in Figure 18 and 19.

[9] The IPCC A1FI emission scenario describes a world of rapid economic growth, a rapid development of new and efficient technologies, with a peak of population growth by the middle of the 21st century, with an intense use of fossil sources and an increase in [CO^2] of about 970 ppm by 2100 (IPCC, 2001).

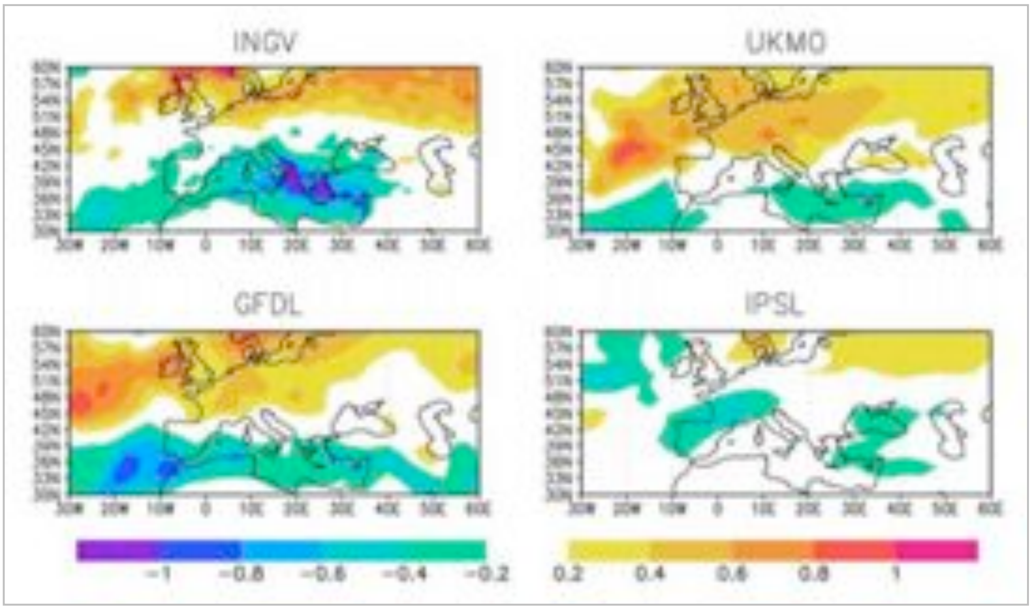


Figure 18. Four different GCMs for winter precipitation (JFM) for the A1B scenario (2061-2099) considering the INGV model, the UKMO model, the GFDL and the IPSL model (Source: Navarra, 2007).

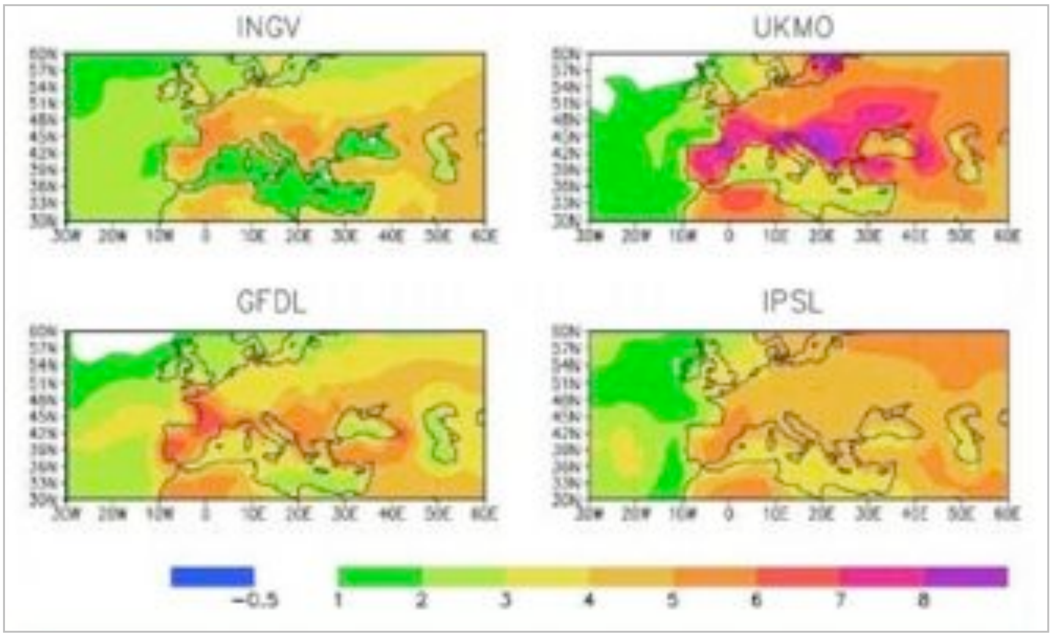


Figure 19. Four different GCMs for summer temperature (JAS) for the A1B scenario (2061-2099) considering the INGV model, the UKMO model, the GFDL and the IPSL model (Source: Navarra, 2007).

The GCMs chosen for this study are therefore the INGV (Istituto Nazionale di Geofisica e Vulcanologia) fourth-generation European Center Hamburg Atmospheric General Circulation Model (INGV-ECHAM4), the Geophysical Fluid Dynamics Laboratory Coupled Model 2.0 (GFDL-CM2.0), the UK Met Office HadCM3 (UKMO-HadCM3) and the Institute Pierre Simon Laplace Coupled Model version 4 (IPSL-CM4), since these specific models are among the GCMs available on the Downscaled GCM Data Portal.

In the *data sources and collection* section, information is given on the acquisition of GCMs in the form of maps and on the subsequently processing through QGIS before the final elaboration.

2.3. Data sources and collection

The collection of spatial data sets and the generation of a complete database for a LSA is a priority of the present work. In the case of Morocco, and specifically in the case of RSZZ region, data sets availability is the main problem for the purpose of this research, and if this issue is overcome and data sets are found accessible they can result coarse, scattered or incomplete as well, therefore data quality is another focal point. Once collected, all spatial data sets are described in the form of metadata, as explained in the INSPIRE European Directive of 2007. This Regulation has been adopted in order to cope with scattered spatial information at a European level. A set of metadata elements is outlined and used to identify each data set. Resources are classified according to their availability, geographical location, temporal reference, quality and validity, conformity, constraints related to access and use, and organization responsible for the source (EC, 2008). The implementation of a common methodology for metadata classification of spatial information allows and facilitates cooperation and collaboration between countries in an international context. Since the main concept is that information is stored and made available for all potential users, this approach should be pursued in other countries worldwide, not only at the European level. In the present study, metadata of spatial data sets on Morocco and RSZZ are stored according to the INSPIRE framework, to be easily described and to make them available for future studies (Annex I).

In this section, the methodology pursued for gathering all the data needed is illustrated, since it represents a significant effort in the current work.

2.3.1. Administrative boundaries

A first step in any GIS analysis is the collection of basic data sets, such as administrative boundaries of the country, region and case study area considered. This information can be obtained directly from regional offices or through Internet search. Both the ways are usually imperfect and they require subsequent elaboration to make data acceptable for the final goal. The acquisition of administrative boundaries data for this study has been initially carried out through Internet search.

Administrative boundaries of Morocco have been gathered from the database of Global Administrative Areas (GADM). Finding the right administrative boundaries of the country has caused time-consuming problems, due to missing boundaries update, then solved with an adjustment operated in QGIS. In practice, two different shapefiles, the one of North Morocco and the one of South Morocco, have been merged together with the "union" tool. Afterward, the merged files have been modified with the QGIS "dissolve" tool, in order to make them uniform, based on a common attribute of both features. Residual lines not linked to boundaries have been deleted with the "delete ring" tool. Concerning boundaries of Moroccan regions, data sets have been downloaded from "Natural Earth" website in the form of shapefile and then overlaid with country boundaries. Regional boundaries have been used for a mere representation of the study area location in geographical terms. The region of RSZZ is the area considered in the present work, therefore boundaries need to be as precise as possible, because every GIS analysis will be based on these boundaries throughout the study. Defining the province of Khemmiset and the three prefectures of Rabat, Salé and Skhirat-Temara is also required for an accurate analysis. In this case, local experts at INRA Rabat have been contacted and asked for the availability of detailed boundaries of RSZZ region. Files received consist of a vector layer with polygon areas (region and municipalities) and a vector layer with lines delimiting provinces. These two files have been also processed and adjusted in QGIS. Polygons related to municipalities have been deleted and only the overall regional boundary has been kept. The procedure used in QGIS is the same analyzed above, with both "dissolve" and "delete ring" tools. Concerning provinces, the process of adjustment has been slightly more complicated, since it involved the union of two different vector features. The problem has been overcome using the older version of QGIS (v. 1.8) that allowed the use of the "polygonizer" plugin. In particular, the plugin permits to generate polygons from areas delimited by new lines.

2.3.2. Topography

Elevation and derived slope data are of primary importance for a LSA and for other GIS analyses. Valuable sources for collecting these data sets can be easily found through Internet search. There are many international organizations providing files in raster format of Digital Elevation Model (DEM) at different resolution. An important source for this kind of data is the U.S. Geological Survey (USGS) EarthExplorer database. Within the case study area, five raster files have been imported previous free registration to the database. These files are extrapolated from the Shuttle Radar Topographic Mission (SRTM) at a resolution of 3 arc-seconds (90 meters). Once collected, SRTM rasters have been merged in QGIS with the “merge” tool and then clipped using administrative boundaries of RSZZ as mask layer. The resulting DEM of the region has been transferred into GRASS to derive and reclassify slope, as previously shown in the *description of the study area* section. In particular, passages in GRASS have been: Raster > Terrain Analysis > Slope and Aspect (command r.slope.aspect) with further selection of the elevation raster map to be analyzed and choice between slope and other analyses. The command r.slope.aspect also permits to select the format for reporting the slope (degree or percent). In this case, the percent format has been preferred to facilitate reclassification according to literature data on suitable slope for agriculture. According to Akıncı et al. (2013) and INRA experts judgment, slope suitability can be classified based on limits of agricultural practices, such as mechanization, irrigation and appropriate management measures. Slopes lower than 5% are very suitable for agriculture, while slopes greater than 30% are usually unsuitable for many crops. Slopes between 5 and 15% generally do not present any particular constrain, while slopes varying from 15 to 30% may show problems related to mechanization. Taking into account this classification, slopes can be reclassified into four classes: <5%, 5-15%, 15-30% and >30%. This second step can be obtained through the following passages into GRASS: Raster > Change category values and labels > Reclassify (command r.reclass). The raster map to be reclassified and the name of the new output raster need to be specified. Then, a file containing reclass rules should be added, alternatively values can be entered manually following a specific procedure. Another useful analysis that can be performed from a DEM into GRASS is the shaded relief. This analysis permits to present maps in a more realistic way, as shown in the *description of the study area* section while introducing topography. In this case, the DEM layer has been overlaid with the shaded relief layer to underline the elevation profile. Running this analysis is easy into GRASS, and passages are the following: Raster > Terrain analysis > Shaded relief (command r.shaded.relief). To make the command work it is necessary to specify the input elevation map and the output raster name. Moreover, the scale factor for converting horizontal units to vertical units need to be set differently when a latitude-longitude projection is used with an elevation map measured in meters (e.g. SRTM) or feet (GRASS Development Team, 2012). In the case of meters, the scale factor must be set at the value 111120, while in the case of feet, the scale factor must be set at the value 370400. For a more detailed and complete description of GRASS commands used in this work see Annex II.

2.3.3. *Current climate*

Climate contributes greatly in defining agricultural characteristics of a determined area and is a key element in a LSA. Information on temperature (°C) and precipitation (mm) has been gathered through the Internet. A first approach considered the acquisition of monthly minimum and maximum temperatures and mean precipitation data from weather stations located in the region, with the purpose of carrying out an interpolation analysis within QGIS or GRASS. However, this solution was not feasible due to scattered or missing information on weather stations and time series. For example, data sets obtainable from the Climatic Research Unit (CRU) of the University of East Anglia result to be incomplete as, for precipitation data, only the weather station of Rabat-Salé is available in the database, while other stations considered by CRU are located outside the region. Regarding precipitation data for this single station, time series quality is acceptable, but in some years information is scarce or absent. In addition, the CRU temperature database for Morocco only includes five weather stations and none in RSZZ. Hence, another approach is required, based on a reliable source of information. A solution to the problem can be achieved in the opposite way, looking for available thematic maps of the area and then extracting temperatures and precipitation for the analysis through points and coordinates. This procedure has been applied to the WorldClim database, a source freely available online which includes average monthly minimum, mean and maximum temperature, average monthly precipitation and bioclimatic variables related to the 1950-2000 period. The database covers the whole world (apart from Antarctica) and it has been generated from a wide range of worldwide climate sources. ANUSPLIN is the software used by Hijmans et al. (2005) in the WorldClim database to interpolate climate surfaces, in particular, the analysis applies a thin-plate smoothing spline algorithm. Resulting raster files can be downloaded by tile, according to the area of interest. A choice can be also made between different resolutions, from 10 arc-minutes to 30 arc-seconds. Working at a regional level, the highest resolution of 30 arc-seconds (1 km) has been chosen for the present study. Once raster files for temperature, precipitation and bioclimatic variables have been collected, data sets related to weather stations used by WorldClim have been searched since not present in the mean database. A shapefile with vector point features related to WorldClim global weather stations has been downloaded from Data Basin and used in the analysis after adaptation. The shapefile has been clipped in QGIS with the “clip” tool, using Morocco and then RSZZ as clip layers. This operation permitted to obtain only national and regional weather stations from the global database. The total amount of points representing Moroccan weather stations is of 165 of which 7 are located in the RSZZ region. Subsequently, extrapolated points have been used in combination with national and regional raster layers obtained for both precipitation and temperature, in order to extract information on country and regional monthly climate conditions. This process has been possible using the QGIS plugin "point sampling tool". The layer containing sampling points and the layer from which to get values need to be specified, as well as the new output vector layer. As shown in the *description of the study area* section, 4 out of 7 weather stations have been taken into consideration for the description of regional climatic trends based on their latitude and elevation and therefore presenting spatial variability. Furthermore, climate data have been extracted for all 165 stations and a complete representation of extrapolated data for average monthly minimum, mean and maximum temperature and average monthly precipitation for the whole country can be found in Annex III, where weather stations are ordered according to latitude values.

Regarding climate data used in the LSA carried out in this work, WorldClim maps related to average annual precipitation and to average monthly mean temperature were adopted, considering the length of the growing season for wheat and lentil in the region of RSZZ. This choice has been made based on the study conducted by Costantini (2006), which refers to crop and climate requirements for several crops, including wheat and lentil. In particular, climate requirements are reported as mean temperature during the growing cycle (°C) and average annual precipitation (mm). Moreover, Balaghi et al. (2013) state that summer months are generally dry in Morocco, therefore, the amount of rainfall in the growing cycle (October-May) correspond to the amount of total annual rainfall. Hence, the bioclimatic variable "bio12", which refers to average annual precipitation, has been downloaded from WorldClim in raster format and subsequently clipped with regional administrative boundaries, whereas concerning mean temperatures of the growing cycle, months from October to May have been considered. A map for each one of the 8 months has been gathered and then all the 8 maps have been added together and divided by 8, in order to obtain a single map that shows the average mean temperature for the growing cycle. Finally, the map has been clipped with regional administrative boundaries.

2.3.4. Soil

Information on soil is essential in a LSA, since agriculture mainly relies on soil properties for its development and production potential (FAO & IIASA, 2007). A first attempt to collect reliable soil data sets on the case study area has been made through Internet search. At a global level, the Harmonized World Soil Database (HSWD ver. 1.2) provides a raster file on soil classes and properties at a resolution of 30 arc-seconds (1 km) and at a scale of 1:1,000,000 to 1:5,000,000 depending on the country. However, after having verified the possible application of these data sets for the specific purpose of this work, the scale resulted too coarse and unsuitable for a study at a regional level. Conclusions have underlined the need for local and more accurate data sets. Thus, local soil scientists at INRA Rabat have been involved at this stage. Five shapefiles on relevant soil classes and soil properties of the region have been made available for this study at a scale of 1:500,000. Every considered shapefile has vector features in the form of polygons. In the *description of the study area* section, files content has been already partially illustrated, therefore in this section focus is set on soil data sets description. The shapefile named "sols_rszz_500_000" includes soils classes based on the WRB soil classification and soil parameters such as soil depth expressed in cm and shallow and deep infiltration rates expressed in cm/hour. Information in the attribute table is divided by 30 rows, each one containing information on soil classes, soil depth and shallow and deep infiltration rates. The urban area of Rabat and the Sidi Mohammed Ben Abdellah dam are also included. These two features, jointly with one feature related to Leptosols, have no data values in their rows, therefore they are excluded from the analysis. Also infiltration rates are not considered for the LSA, since information on drainage is included in another file. Moreover, adjustments have been made in QGIS using the "dissolve" tool, both for soil classes and depth. Soil classes have been grouped accordingly to main classes present in the region, as discussed in the *description of the study area* section, while a new map with soil classification based on depth has been produced for further analyses. The shapefile named "drainage_500_000" presents qualitative information about soil drainage in the region. The attribute table counts 5 rows related to soils that are classified as: Excessively well drained, Well drained, Moderately well drained, Poorly drained and Very poorly drained. The urban area of Rabat and the Sidi Mohammed Ben Abdellah dam are also included in the attribute table, which therefore counts a total of 7 rows, but they are not considered in the LSA because they have no values. The shapefile named "texture_500_000" contains information on soil texture of the region. The attribute table of this file consists of 8 rows, two of which refers to the urban area of Rabat and to the Sidi Mohammed Ben Abdellah dam, that also in this case do not have any value related to the parameter and are therefore excluded. As shown by the textural triangle in the *description of the study area* section, texture classification is based on the proportion of sand, silt and clay in the soil, hence, resulting texture found in the case study area are: Clay, Sandy clay, Loam, Sandy loam, Loamy sand and Sand. Regional soils are thus classified according to these main texture types characterizing RSZZ. The shapefile named "ph" provides soil pH values for the whole region. The attribute table presents 8 rows, including the row that refers to the urban area of Rabat, while the Sidi Mohammed Ben Abdellah dam is not included in the database, but the area is excluded from the LSA, since it is present in other layers. Classification of regional soils is based on the following pH values and ranges, for which soils can be divided into acidic, neutral and alkaline: <5.5, 5.5 – 6, 6 – 6.5, 6.5 – 7, 7 – 7.5, 7.5 – 8, 8 – 8.5. The last shapefile provided by INRA is the one named “omc” which stands for organic matter content. According to Sys et al. (1991), the organic matter content is a valuable parameter to asses the overall fertility of a soil. In this case, the attribute table includes 10 rows, one for each value expressing the percentage of organic matter content in regional soils. The urban area of Rabat and the Sidi Mohammed Ben Abdellah dam are not included in the database, but areas are excluded from the analysis as explained before. Values and ranges used in the classification are: <0.5%, 0.5 – 1%, 1 – 1.5%, 1.5 – 2%, 2 – 2.5%, 2.5 – 3%, 3 – 3.5%, 3.5 – 4%, 4 – 4.5%, 4.5 – 5%.

In order to make a reliable LSA, polygons where values are absent are automatically excluded from the analysis to avoid mismatch in the overlaying procedure.

2.3.5. Land cover

Undertaking a LSA requires prior knowledge on the land cover of the location considered so as to identify current cultivated lands, forests, water bodies, urban areas, etc. As shown in the *description of the study area* section, RSZZ appears to be prevalently characterized by cultivated lands. Information has been obtained from the GlobCover 2009 Global Land Cover Map database which is freely available online. GlobCover 2009 is a project realized by the European Space Agency (ESA) based on ENVISAT satellite mission and in particular on the 300 m MERIS sensor (Defourny et al., 2011). The downloaded file consists of a global raster layer with a resolution of 10 arc-seconds (300 meters). The file has then been imported in QGIS where it has been clipped using regional administrative boundaries as mask layer. After this first step, the raster layer has been converted into vector format through the “polygonize (raster to vector)” tool available in Raster > Conversion > Polygonize (raster to vector). This operation of format conversion has been made to allow a subsequent analysis jointly with data sets on forest coverage collected from the Geofabrik website in the form of shapefile. Geofabrik also provides shapefiles on roads, waterways, water bodies and urban areas, with the latter resulting more accurate and up dated compared to data extrapolated from the GlobCover database. These files have also been downloaded and then used in map representation after having been clipped according to regional boundaries. However, Geofabrik only reports data originated from OpenStreetMap project concerning common information such as roads, forests, rivers and lakes location, thus the database is incomplete for specific GIS analyses and it requires to be combined with other data sets providing technical information. Vector files from Geofabrik have been imported into QGIS and incorporated with GlobCover converted files.

The “union” and “dissolve” tools have been used to make a single layer for forests, which in turn has been used as layer to omit forest areas previously not included in the mosaic cropland (50-70%) / vegetation (20-50%), mosaic vegetation (50-70%) / cropland (20-50%) and rain-fed croplands data sets. This adjustment has been possible thanks to the vector “difference” tool, considering the forests layer as difference layer and other layers as input vector layers. The same approach has been followed in order to produce the Boolean map related to the constraints for the analysis. After the roads and the waterways layers have been buffered through the “buffer” tool in QGIS, they have been combined with forests, water bodies, urban areas and Leptosols layers. Subsequently, the “difference” tool has been used and the jointed layer has been subtracted from the RSZZ regional layer to provide a mask layer. The final passage has been to convert the mask layer from a vector format to a raster format, through the command Raster > Conversion > Rasterize (raster to vector), choosing the input vector file, the attribute field (in this case corresponding to value 1) and the output file for the rasterized vector. The resulting raster map assigns value 1 to areas that are included in the analysis and value 0 to areas that are excluded (Figure 20).

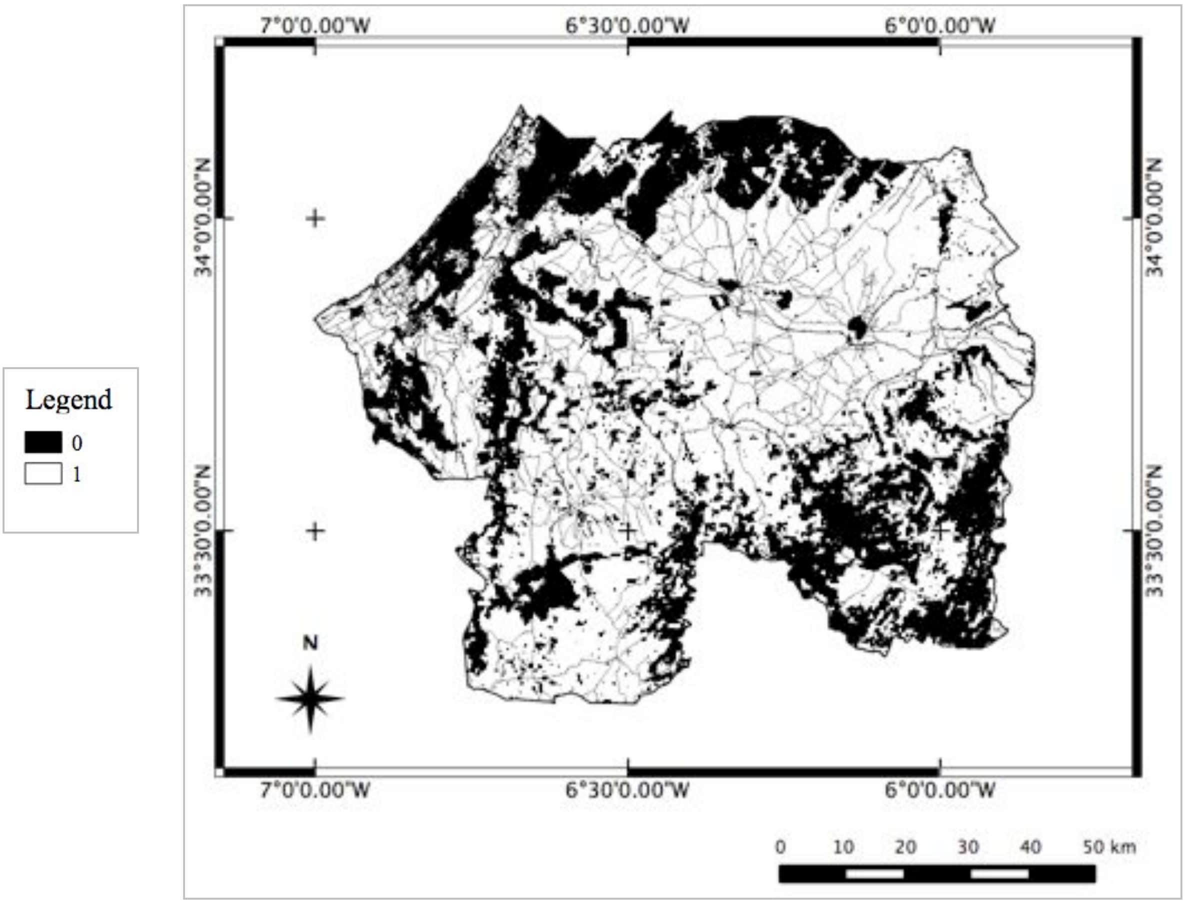


Figure 20. RSZZ constraints map with considered (value 1) and omitted (value 0) areas.

2.3.6. Climate change scenarios

As previously stated, information on climate is fundamental to determine what crops can be grown in a defined area. Not only current climate, but also climate change should be considered in countries where agriculture is prone to great risk due to land degradation and climate change impacts. In the present study, data sets on climate change scenarios in the form of maps have been gathered through the Downscaled GCM Data Portal. The SRES A2 climate change scenario has been considered, referring to the time slice 2079-2099 (denoted 2080s) and taking into account four different GCMs. The four GCMs differ from each other in terms of outputs and institute that has generated them. Maps downloaded from the Downscaled GCM Data Portal have been collected in ASCII[10] grid format for both average annual precipitation and average monthly mean temperature at a resolution of 30 arc-seconds (1 km). The same approach has been used to collect current climate maps, as previously described. However, in this case, the process has required a considerable amount of space to store data sets in the computer hard drive, due to the map format. Therefore, once collected in ASCII format, maps have been clipped with RSZZ regional boundaries previous conversion into GeoTIFF[11] format, so as to reduce files size.

[10] ASCII: American Standard Code for Information Interchange.

[11] GeoTIFF: Geographic Tagged Image File Format.

3. Methods

In order to answer the research questions outlined in this thesis, outputs and maps resulting from a LSA of wheat and lentil are a valuable support. Both current climate and climate change scenarios are considered in the LSA carried out for the region of RSZZ. In general terms, LSA is a very useful technique for assessing appropriate locations for future land uses, based on spatial data, specific requirements, preferences or predictors (Malczewski, 2004). This technique has been used in other studies for different purposes, such as urban planning, forests conservation, identification of habitat for animal species, etc. In the present work, the analysis has been applied in the context of sustainable agriculture, which is defined by Mendas & Delali (2012) as: « productive and profitable agriculture that protects the environment and that is socially equitable ». In the analysis of agricultural systems, identifying the dimension in which operate and defining suitable indicators is fundamental. The assessment of agro-ecosystems is therefore provided by the observation, description and measurement of variables that can be subsequently processed and transformed into indicators. After this step, indicators need to be organized for being used in the analysis selected for the specific objective of the research. This is essential in the study and modeling of agro-ecosystems and other environmental systems, where reality needs to be simplified (Giupponi & Carpani, 2006). Since a LSA requires variables, which are spatially distributed on a territory, the use of GIS simplifies the work needed for the visualization and analysis of data sets and the screening of results. Decision maker judgments and alternatives preferred can be also added into a LSA through a MCDA. Thus, the application of an integrated GIS-MCDA approach is extremely useful in environmental studies, such as in the case of land suitability that aims at identifying the most suitable lands for a specific purpose, including factors and value judgments otherwise of difficult evaluation. Moreover, a GIS-MCDA allows the allocation of policy measures where is required, without losing focus and efforts (Fassio et al., 2005).

Once the opportune criteria for a LSA are determined and data sets in the form of map layers or attributes are collected and predisposed for further investigation, the second phase includes data reclassification or standardization, weighting and final maps overlay based on defined rules. Firstly, each criterion map is reclassified or standardized according to values derived from specific requirements or preferences. For this study, wheat and lentil crop requirements have been considered and applied to land and climate parameters, in order to classify quantitative or qualitative data of each criterion based on their positive or negative effect on wheat and lentil growth. According to Qiu et al. (2013), reclassification or standardization of criteria can be made using crisp sets or fuzzy sets. In crisp sets raw values, ranges or qualitative data are reclassified through a categorical ranking. However, this approach is rather limited because it considers sets that are strictly defined, leading to a misrepresentation of the continuous nature of environmental criteria. This limit can be overcome with the application of fuzzy sets, which rate the criteria into a real number scale (0-1) or a byte scale (0-255) based on membership functions, allowing partial membership of values into classes (Abbaspour et al., 2011; Drobne & Lisec, 2009; Qiu et al., 2013). After this step, since criteria accounted in a LSA do not have the same degree of importance, weights need to be assigned according to the role played by each criterion in the final evaluation (Akıncı et al., 2013; Malczewski, 2004). Since there is not a single method to assign importance weights and results may vary, in this study two techniques have been chosen. Rating and pair-wise comparison are the methods selected. A detailed description of the two methods is provided in the *criteria weighting* section. Once importance weights are produced through different techniques, they are used in combination with several decision rules. Indeed, reclassified or standardized criteria, subsequently weighted based on their importance for the purpose of the analysis, are combined following specific decision rules. MCDM methods to solve spatial decision problems include compensatory, non-compensatory and partially compensatory decision rules (Bernetti & Romano, 2007; Greene et al., 2011; Guitouni & Martel, 1998). This distinction introduces the concept of compensation between criteria once they are overlaid. Basically, in compensatory methods the low performance of one criterion can be compensated by the higher performance of another criterion. One example is the WLC method. On the contrary, non-compensatory methods do not consider any degree of compensation or trade-off and they base the final decision on the lowest or the highest values of the overall criteria. Minimum (MIN) or maximum (MAX) functions, which correspond respectively to the Boolean intersection (AND) and union (OR) operators, are example of non-compensatory methods. Finally, partially compensatory methods refer to methods where the low performance of one criterion can be partially counterbalanced by the high performance of other criteria. This is the case of the OWA method, which includes not only importance weights but also order weights that control the degree of trade-off, going from a full trade-off approach to a no trade-off approach, considering all the possible variations in between (Greene et al., 2011; Qiu et al., 2013; Riccioli, 2008).

In this thesis, five combinations of criteria, weights and decision rules are analyzed and they consist of: (1) criteria reclassified based on crisp sets and combined with the MAX function, (2) criteria reclassified based on crisp sets and combined with a WLC without preference weights, (3) criteria reclassified based on crisp sets and combined with a WLC with preference weights assigned through rating technique, (4) criteria reclassified based on fuzzy sets and combined with the OWA method with preference weights assigned through rating technique and order weights and (5) criteria reclassified based on fuzzy sets and combined with the AHP method with preference weights assigned through pair-wise comparison. These five approaches and decision rules are discussed later in this chapter, while main concepts of GIS and phases of the LSA are now described.

3.1. Geographic Information System and spatial data analysis

3.1.1. GIS concepts

Nowadays, complex GIS analyses are possible because of the improvement in computer technology and spatial science occurred in the last 40 years (Malczewski, 2004). The core of the present work is the spatial analysis with GIS open-source tools, such as QGIS and GRASS. As demonstrated by the open-source philosophy, GIS is constantly evolving, both in terms of technology and software release, but also in the accessibility of applications for a wide range of users. This significant advancement has been dictated by a progress in planning procedures and communication needs, shifting from a strictly scientific point of view to a wider political one (Malczewski, 2004). The interaction among scientists, policymakers and stakeholders has lead to more user-friendly technologies in order to bridge the gap between these categories. Therefore, the flexibility of a GIS is fundamental in combining data sets derived from different sources, both in form of map layers or attribute data. Data collection and database quality are thus considered as crucial points for any GIS analysis. According to Malczewski (2004), since data are the key concept, every GIS system can be seen as made by the following components: data input, data storage and management, data manipulation and analysis, data output. The first step consists in the identification, acquisition and adjustments of data sets needed for the specific goal of the research. Hence, raw data are formatted based on requirements for further use. The second step refers to the ability of a GIS in organizing a functional database that can be implemented and updated at any time throughout the process. The third step plays a pivotal role in GIS and it refers to its potential in computing specific analyses of spatial and attribute data. The final step is the result of previous operations where GIS products are usually presented and displayed in the form of maps reporting the outcomes of the analysis that has been run. In a GIS, data processed have typically two formats: vector or raster, jointly with attribute data. Each format is described in details in the next part of this chapter, while in this section other important characteristics of data sets are presented.

Data gathered for GIS analyses usually come with their own map projections and coordinate reference system (CRS) in order to represent the Earth's surface in two dimensions for illustration purposes and define the relation between map projection and real places (Sutton et al., 2009). The choice of the opportune projection depends on the goal of the study and on the scale of the map used. A particular projection may be suitable for a detailed study at a large scale, but may produce distortions in the case of a whole continent. Basically, projections can be classified into three groups: planar projections, cylindrical projections and conical projections. However, each projection shows some distortions in terms of angular conformity, distance or area (Sutton et al., 2009). Thus, a map projection needs to be accurately selected based on the purpose of the analysis. Not only projections, but also coordinate reference systems can be classified into groups: geographic coordinate reference systems and projected coordinate reference systems. The former is the most popular and it is represented by degree of latitude and longitude, divided into minutes (′) and seconds (′′), while the latter is expressed by x, y and z axes, with the z axis defining the third dimension (Sutton et al., 2009). Because of this heterogeneity in coordinate reference systems, while operating within GIS, it is possible to activate the on-the-fly projection that allows map sets in different CRS to be shown accordingly to the reference system chosen by the user. However, to manipulate data sets, combining and analyzing maps together, all the different layers should present the same CRS. To actually reproject maps into a new CRS there are two different ways, according to the map format. If the map is in vector format, once it has been opened in QGIS, the "save as" option should be chosen right-clicking with the mouse on the file in the layers list and, after having selected the "selected CRS" option, the desired CRS and the name of the output file need to be specified before the new file is finally generated. If the map to be reprojected is in raster format, the procedure is slightly different. Once the raster map has been opened in QGIS, to reproject it in the desired CRS the path Raster > Projections > Warp (Reproject) should be followed. Reprojection is indispensable for the final overlaying phase if original maps do not have the same CRS. In the present work, each map used in the analysis has been reprojected based on the CRS World Geodetic System 1984 (WGS84) since the majority of maps downloaded had this reference system already, such as temperature, precipitation, DEM and land cover maps. Therefore, reprojection focused on maps with other CRS. Specifically, maps that needed to be converted where those related to soil parameters, since their original CRS was Merchich/Nord Maroc. However, before reprojection, these maps were used in their original CRS to derive information on areas, as shown in Table 6 in the *materials* chapter.

Another important concept that should be considered before dealing with map overlay and analysis is represented by spatial resolution. In this thesis, raster maps used in the analysis have been set at a spatial resolution of 3 arc-seconds, which corresponds approximately to grid cells of 90 x 90 meters. The choice has been made considering that the LSA has been carried out at a regional scale, therefore a suitable spatial resolution was required. Only the original DEM had a resolution of 3 arc-seconds and, as a result, also the map of slope obtained from the DEM. However, all the other files needed a preprocessing phase, since their resolution was lower than the one chosen. In particular, the conversion has been carried out on raster files, setting the pixel cell size to 0.0008333 degrees, which corresponds to 3 arc-seconds resolution (~90 m). It is important to notice that, even though resolution has changed, pixels appear to have the same original shape due to the lower resolution of the original raster. This is the case of temperature and precipitation maps, which may add a coarse aspect in some parts of the final overlay. Concerning maps in vector format that have been subsequently rasterized, the spatial resolution has been set before the conversion into raster, therefore files obtained showed already a resolution of 3 arc-seconds.

After this first overview related to general vector and raster characteristics, both formats are now presented in details, followed by a description of QGIS and GRASS software adopted for GIS analyses in the present work.

3.1.2. Vector data

Vector is one of the two map formats typically used in any GIS. In this case, entities of the real world are described by geometric features, such as points, lines and polygons. Thus, vector represents the object view of the real world. Information regarding each feature is reported by attributes as text or numbers. Moreover, features characterized by topology are identified through coordinates x, y and in some cases z (Malczewski, 2004; Sutton et al., 2009). Data are stored in layers and each layer contains only one kind of feature. Therefore, in order to obtain information from different entities, layers must be combined together. To perform complex analyses, the vector format is not appropriate. Common issues in the use of this format typically refer to the overlay procedure and spatial analysis. For this reason, the vector format is more suitable for data representation. However, other problems can emerge in terms of slivers polygons, overshoots or undershoots of lines (Sutton et al., 2009). To overcome these problems topological editing may be required. Another issue that can affect vector data is the scale at which information is gathered. Hence, the right choice between a large scale and a small scale should be carefully considered depending on the goal of the analysis.

3.1.3. Raster data

Raster is the second important map format used in a GIS and it represents the field view of the real world. Graphical elements are made of a two-dimensional matrix of pixels or cells, each one containing a single value representing the characteristic of the land in that point. Points are thus delineated by single pixels, areas are identified by adjacent pixels with the same value, while lines are made by single pixels with the same value linked together in one-cell thick line (Malczewski, 2004; Sutton et al., 2009). This format is typically used to describe pictures such as satellite images or continuous information that changes throughout a surface, which otherwise would be too simplified by vector features. As for vector, raster data are stored in layers but, in this case, each layer may contain both pixels representing points, lines or areas. The resolution of a raster layer is given by the cell size. Smaller the cells size for a defined portion of land, higher the resolution. Another difference between vector and raster format is that more information can be include in the latter, leading to a predisposition of raster layers for spatial analysis.

3.1.4. QGIS

QGIS is a GIS open source software and project realized by the Open Source Geospatial Foundation (OSGeo). In the present study the version 2.0 Dufour of QGIS has been used as one of the main tools to perform the analysis in a GIS context. In some cases, due to constraints related to the new QGIS release, the old version 1.8 Lisboa has been adopted. QGIS can be easily run on many operating systems, such as Linux, Windows and Mac OSX, making this software a very adaptable tool for different working conditions (QGIS Project, 2014). One of the most important characteristics of QGIS is its user-friendly graphical user interface (GUI) combined with its GNU General Public License that makes QGIS freely available and modifiable. GIS functionalities in QGIS can be also increased through plugins, allowing the integration of tools not available in the basic interface. Moreover, the community of users can realize useful plugins to be incorporated into QGIS thanks to the Python programming language.

3.1.5. GRASS

GRASS is another GIS open source software, which has been initially developed by the U.S. Army Construction Engineering Research Laboratories (USA-CERL) for environmental management and it subsequently became a project of the OSGeo and a very useful tool for a wide range of applications (GRASS Development Team, 2012). In this thesis the version 6.4 of GRASS has been used for computing the spatial analysis. As for QGIS, GRASS can be run on many operating systems, including Windows or Unix-like systems. This software is more complex than QGIS, but still user-friendly. Moreover, GRASS is released under the GNU General Public License that allows users to develop new modules, which improve the software capabilities. In particular, two modules developed by Massei et al. (2013) are investigated in the present work. The two modules are r.mcda.fuzzy and r.mcda.ahp, which have been used respectively to elaborate the OWA analysis and the AHP pair-wise comparison and further WLC. These modules are described in the *ordered weighted averaging* and in the *analytic hierarchy process* sections. Furthermore, to make the analysis easily reproducible and to show the main passages and operations made in GRASS, the macro language of GRASS commands used in this work has been provided in Annex II.

3.2. Land suitability analysis

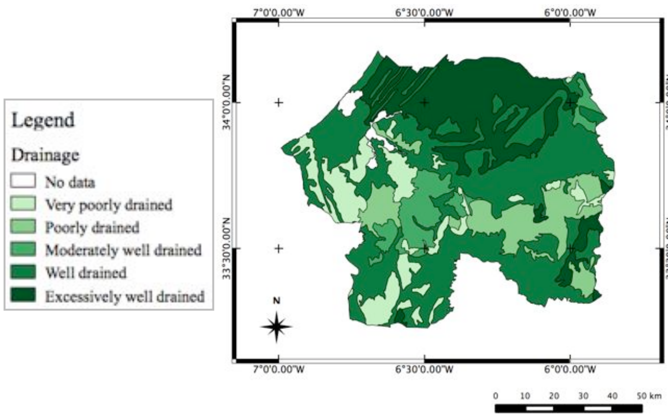
3.2.1. General framework and selection of criteria

Identifying suitable lands for different purposes is a valuable approach that can be used for defining appropriate practices leading to sustainable agriculture (Rabia & Terribile, 2013). A LSA can be achieved through a GIS after a series of passages involving (1) problem definition, (2) a preprocess of spatial data acquired for the analysis, (3) the definition of the chosen model through a flowchart and (4) the application of this model (Malczewski, 2004).

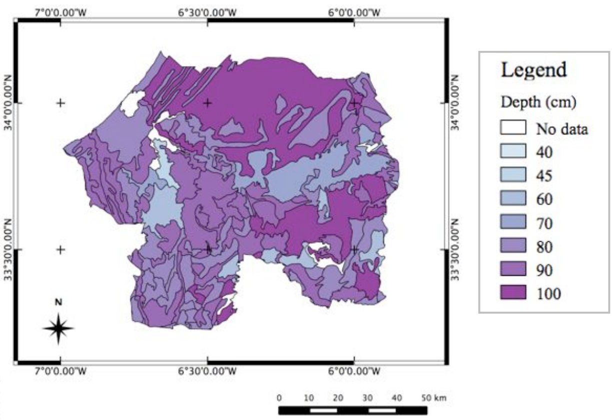
First of all, according to Malczewski (2004) a LSA should be considered both as a site selection or a site search problem. The former refers to the identification of the best site for one specific purpose once the possible sites have been identified, while the latter is applied when no potential sites have been identified. Both concepts consider that there is a specific area where the study is carried out and this area is represented by units of observations (e.g. polygons, raster grid cells, etc.) classified based on their suitability for a defined purpose or activity (Cova & Church, 2000; Malczewski, 2004). In the present work, a LSA is the approach followed to detect where the rotation of wheat and lentil may be feasible and where CA may be adopted in the region of RSZZ. Therefore, the region of RSZZ represents the area considered in the analysis, while units of observations are represented by pixels or grid cells, since they are the typical features of the raster map format that is used for the overlay of criteria considered in the analysis carried out in this thesis. Rabia and Terribile (2013) state that a LSA is basically a multi-criteria problem, defined by the function:

$$S = f\ (x_1, x_2, \ldots, x_n)$$

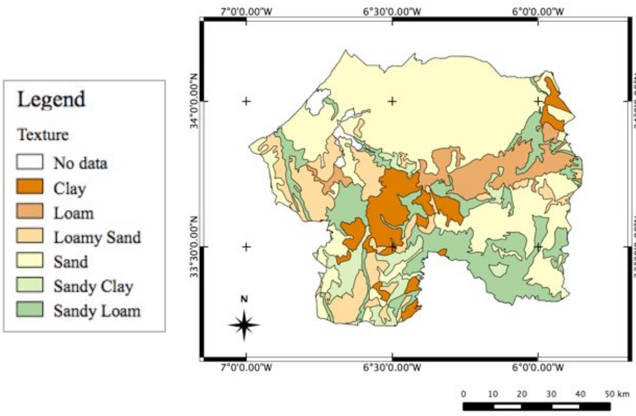
where S refers to the suitability level and x_1, x_2, …, x_n are the parameters or criteria affecting land suitability. Therefore, land suitability should consider several criteria that need to be evaluated. For this reason, criteria are chosen taking into account the role of each parameter in defining lands for wheat and lentil growth, and considering data availability. Usually, in a LSA that involves the definition of suitable lands for specific crops, data such as temperature, precipitation, soil characteristics and topographic parameters are considered (Akıncı et al., 2013; Kamkar et al., 2014). In the present study, the parameters selected in order to compute a LSA based on data required for the purpose of the analysis and based on data available at a regional level are drainage, soil depth, texture, pH, OMC, slope, average annual precipitation and average mean temperature of the growing cycle. Furthermore, temperature and precipitation data have been gathered for both current climate and for four GCMs referring to the A2 climate change scenario. As described in the previous chapter, these data have been collected in the form of raster or vector maps with the latter converted into rasters at a resolution of 3 arc-seconds. Figure 21 shows soil parameters used in this work, classified according to their original values and ranges, while Figure 22 and 23 show climate parameters, respectively average annual precipitation expressed in mm and average mean temperature of the growing cycle expressed in °C. In order to underline the differences between climate data, the minimum and the maximum value has been taken considering the five maps together, so as to build a legend that reports changes within the four GCMs chosen. Climate scenarios derived for the region and compared with current climate highlight a slight difference in the amount of rainfall for the IPSL and INGV models compared to current rainfall, while in the UKMO and GFDL models, the contrast is clearly evident. In the case of temperature, the four GCMs are similar to each other and they all show higher temperatures compared to the current temperature parameter. These statements can be confirmed looking back at Figures 18 and 19, which underline the differences of future climate compared to the current situation.



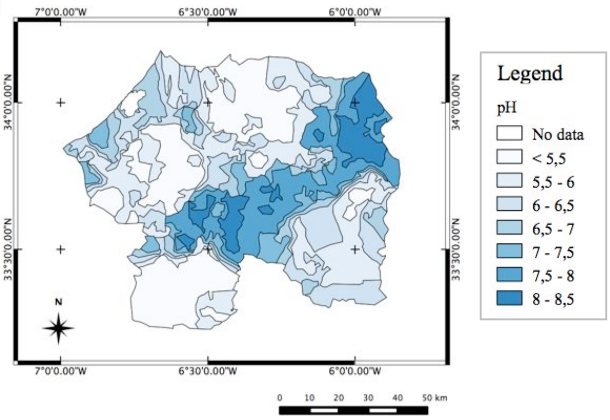
(a)



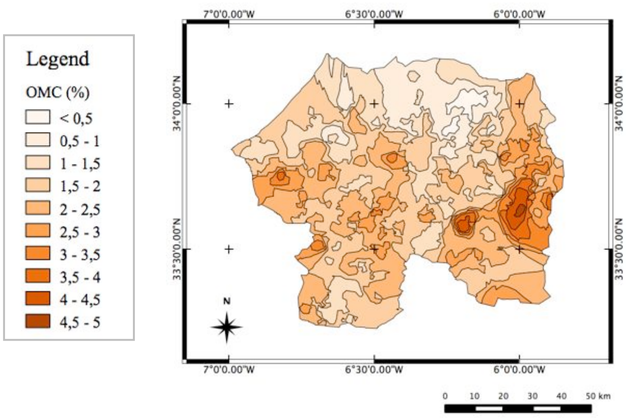
(b)



(c)

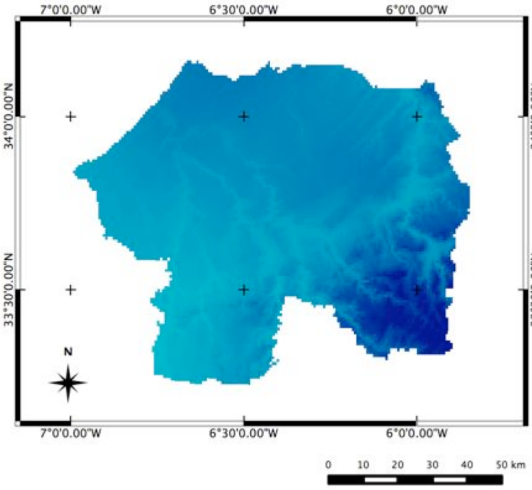


(d)

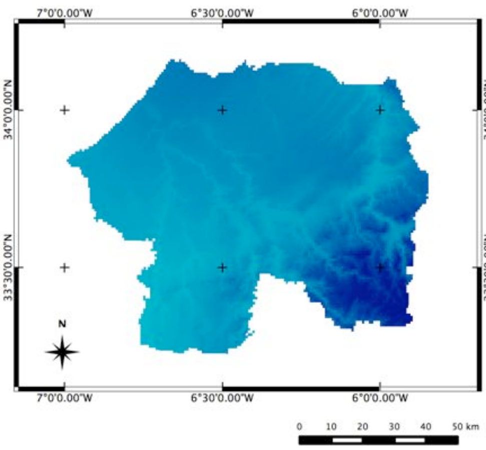


(e)

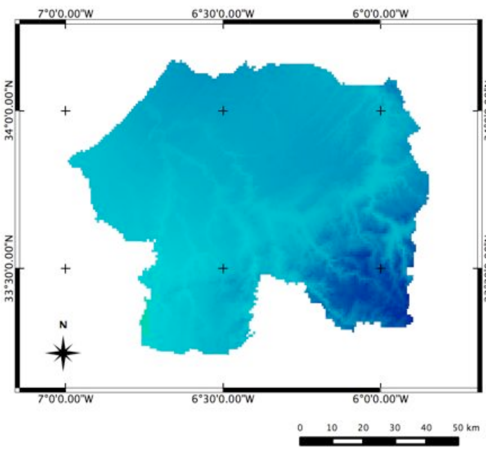
Figure 21. Soil parameters used for the LSA of wheat and lentil in RSZZ: (a) drainage, (b) soil depth (cm), (c) texture, (d) pH and (c) OMC (%).



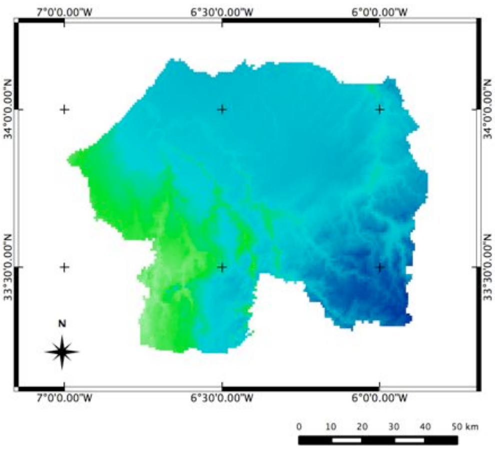
(a)



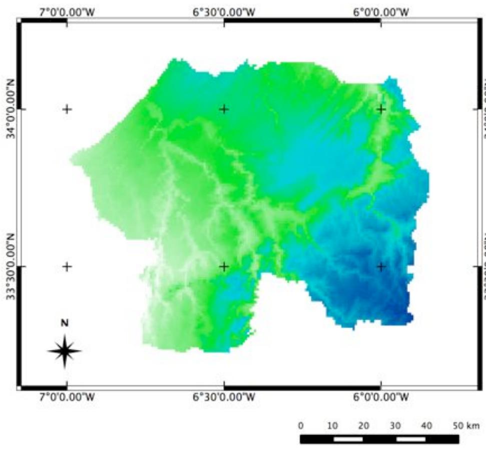
(b)



(c)



(d)



(e)

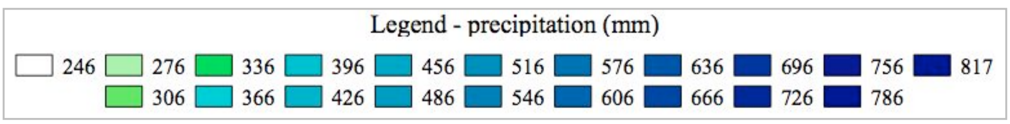


Figure 22. Average annual precipitation for (a) current climate and A2 climate change scenario in (b) IPSL-CM4, (c) INGV-ECHAM4, (d) UKMO-HadCM3 and (e) GFDL-CM2.0 models.

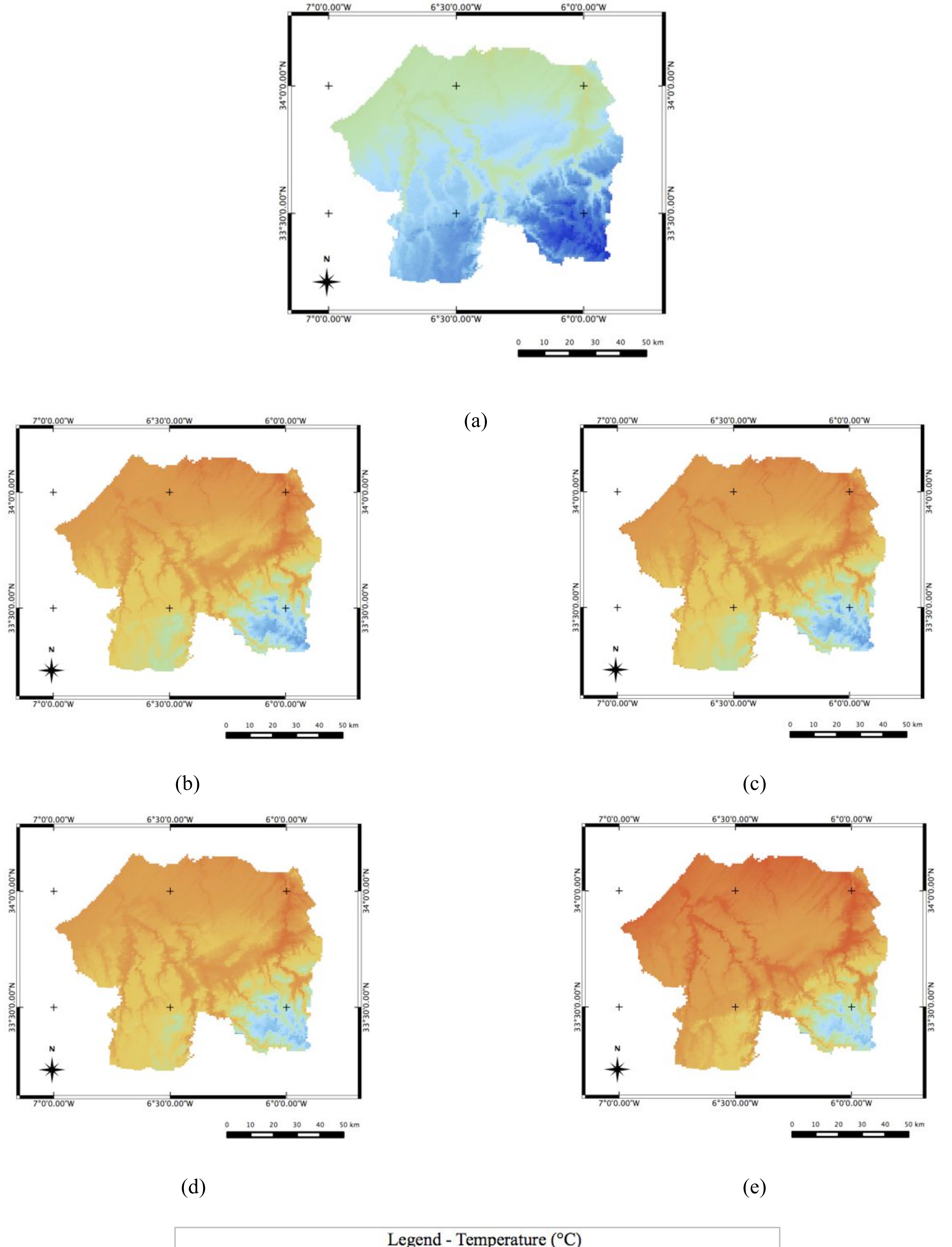


Figure 23. Average mean temperature of the growing cycle for (a) current climate and A2 climate change scenario in (b) IPSL-CM4, (c) INGV-ECHAM4, (d) UKMO-HadCM3 and (e) GFDL-CM2.0 models.

Since slope has been already illustrated in the previous chapters, it will be considered in the LSA as reported in Figure 8, with a classification based on the limitation of agricultural practices and mechanization due to extreme slopes.

The second step of a LSA requires not only the identification of criteria, but also their reclassification or standardization based on crop requirements. This step allows the integration into a GIS of parameters that present various units of measurement. In order to reclassify the criteria two approaches are considered in the present work. The first approach refers to the basic FAO land suitability framework, in which each criterion is reclassified into four classes based on the suitability of its original values for the defined purpose. S1, S2, S3 and N are the four classes described by FAO, where S1 corresponds to the highest suitability, S2 to moderate suitability, S3 to marginal suitability and N to the unsuitability of lands for the activity or the use considered (Caprara & Martelli, 2011; Costantini, 2006; FAO, 1976). Values given to the reclassified criteria in order to combine maps into a GIS range from 1 to 4. However, because of the limitation of the first approach that defines crisp sets, the second approach results more appropriate due to the definition of fuzzy sets, which respect the natural continuity of criteria. Fuzzy sets are established following specific membership functions. In this work the r.fuzzy command in GRASS has been used to standardize the criteria with values ranging from 0 to 1, where 1 indicates the highest suitability (full membership) and 0 the unsuitability (no membership), while values in between represent intermediate degrees of suitability. In the following sections crop requirements and reclassification techniques are outlined.

3.2.2. Crop requirements, matching tables and fuzzy membership functions

Wheat and lentil are the two crops considered in the present work. Their soil, topographic and climate requirements are therefore investigated. Table 9 shows wheat and lentil crop requirements based on the traditional land suitability classification, while Figure 25 shows fuzzy membership functions and values used to generate fuzzy sets of the same criteria. Matching tables and fuzzy sets have been defined based on literature review and experts opinion, taking into account optimal and unsuitable conditions for each parameter that affects wheat and lentil growth. In particular, the work of Costantini (2006) resulted to be of primary importance for the identification of main limits or optimal ranges of each criterion for both wheat and lentil. However, regarding climate parameters, limits have been slightly modified, according to the values found in a study carried out by INRA (2007), while in the case of slope, suitable ranges have been defined based on the work of Iaaich

(2009) and, concerning OMC values, they have been obtained from Duguma (2010). As already mentioned, the FAO approach defines crisp classes. For the classification adopted in the analysis, each criterion has been divided into ranges of suitability and then a value from 1 to 4 has been given to each range according to the degree of suitability expressed, as illustrated in Table 9.

Crop	Factor	Range of suitability			
		S1	**S2**	**S3**	**N**
		New values			
		1	**2**	**3**	**4**
Wheat	Texture (class)	C, L, SC	-	SL, LS	S
	Drainage (class)	W	MW	E	P, VP
	Depth (cm)	> 60	40 - 60	20 - 40	< 20
	pH	6 - 8	5.5 - 6 8 - 8.5	-	< 5.5 > 8.5
	OMC (%)	> 3	2.5 - 3	1 - 2.5	< 1
	Slope (%)	0 - 5	5 - 15	15 - 30	> 30
	T (°C)	12 - 23	10 - 12 23 - 25	5 - 10	< 5 > 25
	P (mm)	350 - 1250	250 - 350 1250 - 1500	1500 - 1600	< 250 > 1600
Lentil	Texture (class)	L	C, SL, SC	LS, S	-
	Drainage (class)	W	MW	E	P, VP
	Depth (cm)	> 60	40 - 60	30 - 40	< 30
	pH	5.5 - 7	5 - 5.5 7 - 7.5	4.5 - 5 7.5 - 8.2	< 4.5 > 8.2
	OMC (%)	> 3	2.5 - 3	1 - 2.5	< 1
	Slope (%)	0 - 5	5 - 15	15 - 30	> 30
	T (°C)	23 - 25	15 - 23 25 - 27	6 - 15	< 6 > 27
	P (mm)	700 - 800	600 - 700 800 - 1000	300 - 600 1000 - 2400	< 300 > 2400

Table 9. Wheat and lentil crop requirements. Texture: C = Clay, SC = Sandy Clay, L = Loam, SL = Sandy Loam, LS = Loamy Sand, S = Sand. Drainage: E = Excessively well drained, W = Well drained, MW = Moderately well drained, P = Poorly drained, VP = Very poorly drained (Source: adapted from Costantini, 2006; Duguma, 2010; Iaaich, 2009; INRA, 2007).

Nevertheless, this approach is clearly restricted, since only four classes are defined and the intrinsic complexity of each parameter is therefore reduced. To overcome this issue and to take into account the continuous nature of environmental factors, fuzzy logic is a valuable solution. The fuzzy approach allows to consider the whole set of values for each criterion. In this work, the establishment of fuzzy sets has been carried out through the r.fuzzy command available in GRASS (Figure 24).

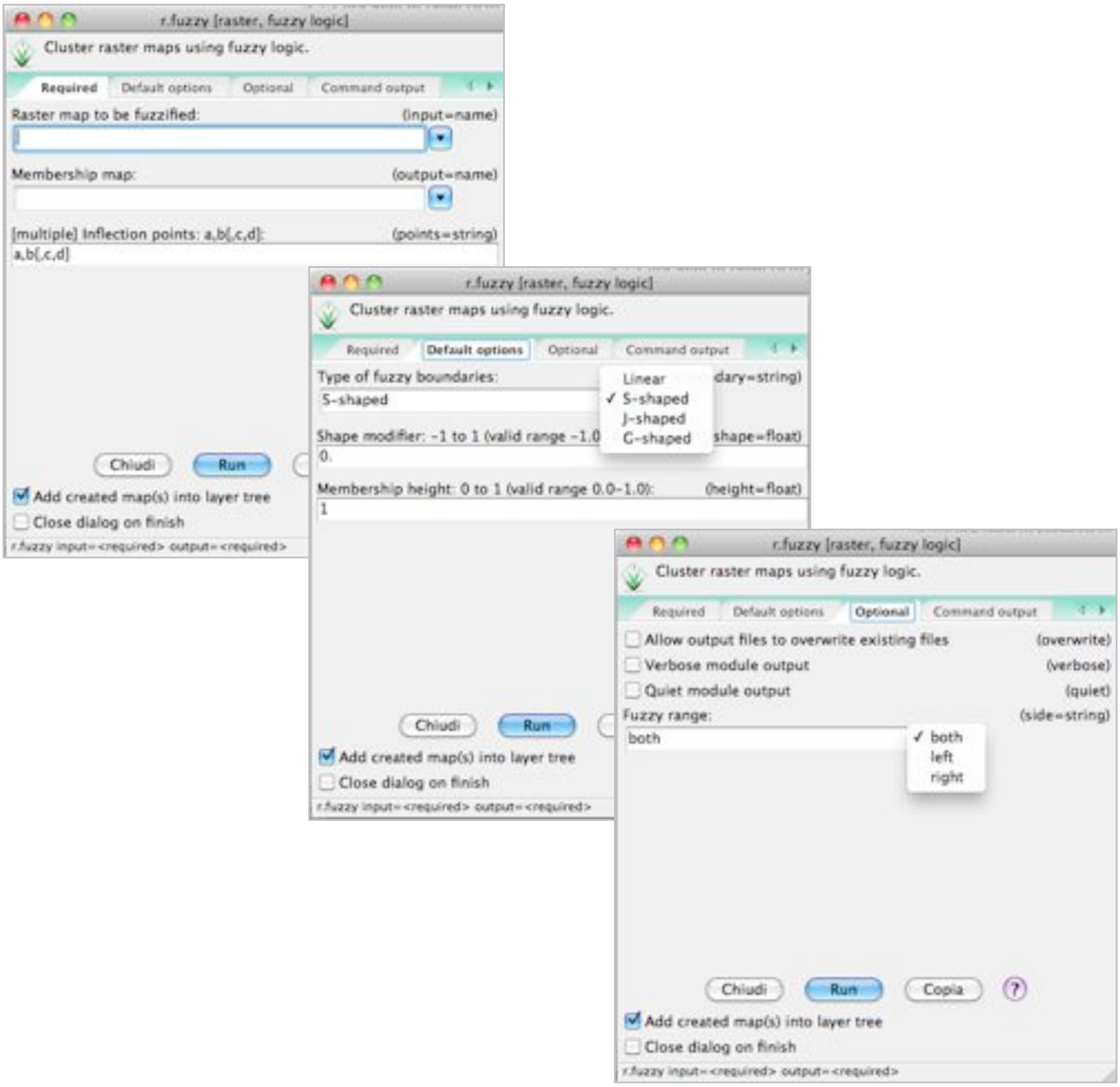
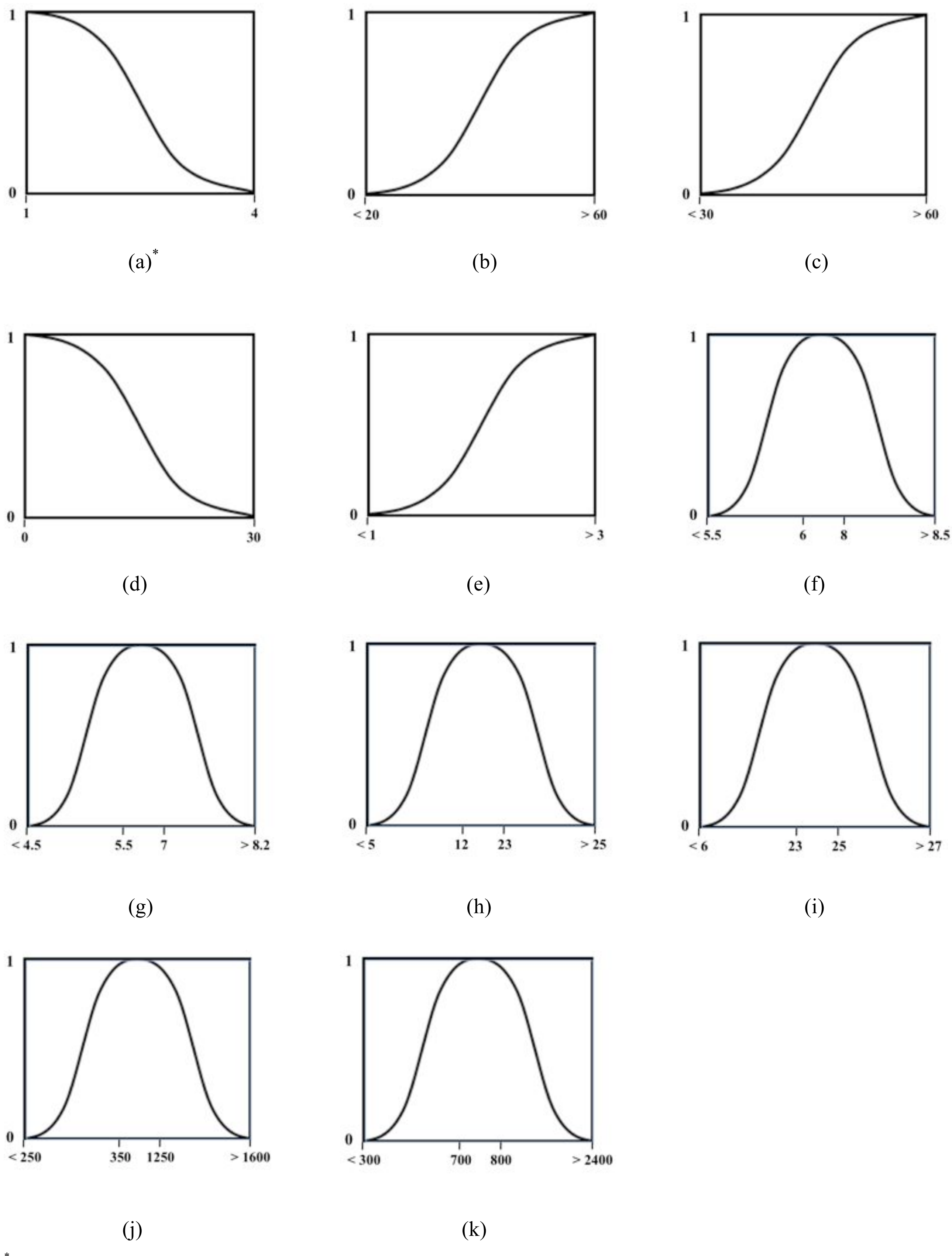


Figure 24. The interface of the r.fuzzy command in GRASS.

The r.fuzzy command consists of a series of passages and choices that need to be made before running the module. First of all, the input raster map with raw values to be fuzzified is required. Secondly, the name of the output map is chosen and a list of 4 (a,b,c,d) or 2 (a,b) points defining set boundaries need to be specified, based on the fuzzy range selected (both, left or right). Moreover, the shape of fuzzy boundaries must be decided, choosing between linear, s-shaped, j-shaped and g-shaped. The default fuzzy boundary and the most adopted is the s-shaped (GRASS Development Team, 2012). Therefore, the s-shaped has been used for the fuzzification of the considered parameters, changing values and fuzzy ranges, based on the optimum and minimum/maximum values of wheat and lentil crop requirements, as shown in Figure 25, where fuzzy membership functions are represented with the aim of simply illustrating the concept of fuzzy sets.



*wheat and lentil drainage and texture have been previously reclassified into a 1-4 range, since these two parameters were qualitative.

Figure 25. Fuzzy membership functions of (a) wheat and lentil drainage and texture, (b) wheat soil depth, (c) lentil soil depth, (d) wheat and lentil slope, (e) wheat and lentil OMC, (f) wheat pH, (g) lentil pH, (h) wheat mean temperature of the growing cycle, (i) lentil mean temperature of the growing cycle, (j) wheat average annual precipitation and (k) lentil average annual precipitation crop requirements.

The application of points that define set boundaries is outlined in the r.fuzzy module described in Annex II. It should be noted that in the macro language of the r.fuzzy command, in some cases points are set differently, in order to reproduce “less than” and “more than” values (e.g. < 20, > 60). Moreover, since temperature data in raster maps are expressed as °C * 10, in the r.fuzzy module values such as 120 or 130 represent 12.0 or 13.0 °C. Finally, pH and OMC maps have been fuzzified based on values given to each range, since rasterizing pH and OMC vector maps with more than one value per pixel is not allowed by conversion tools in GIS.

Figures 26 and 27 show wheat and lentil criteria maps reclassified according to the FAO approach, while Figures 28 and 29 show wheat and lentil criteria maps standardized based on fuzzy membership functions.

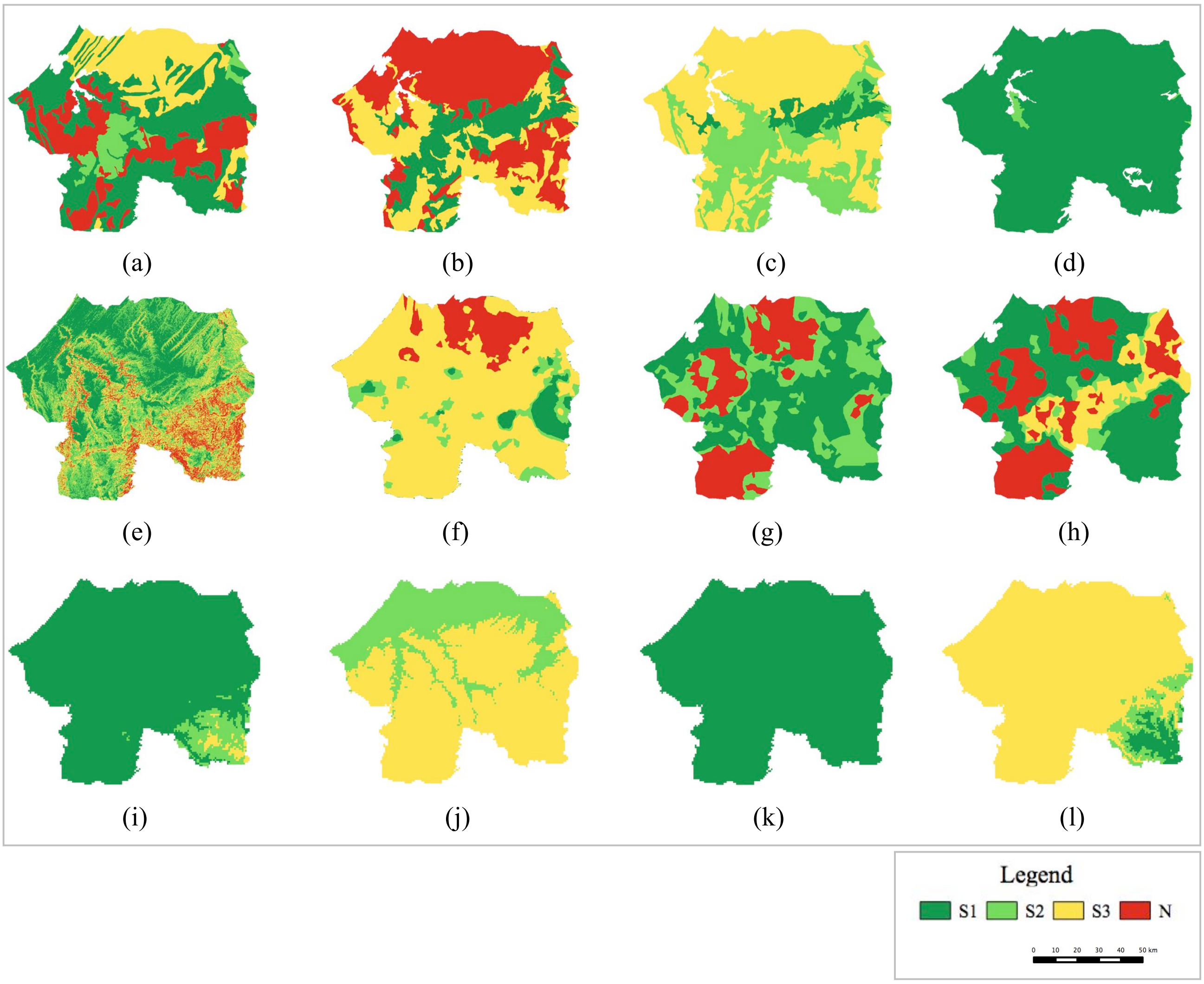


Figure 26. Reclassification based on 4 classes (S1, S2, S3, N) according to the FAO approach. Reclassified criteria are in order (a) wheat and lentil drainage, (b) wheat texture, (c) lentil texture, (d) wheat and lentil soil depth, (e) wheat and lentil slope, (f) wheat and lentil OMC, (g) wheat pH, (h) lentil pH, (i) wheat mean temperature of the growing cycle, (j) lentil mean temperature of the growing cycle, (k) wheat average annual precipitation and (l) lentil average annual precipitation. Climate parameters refer to current climate conditions.

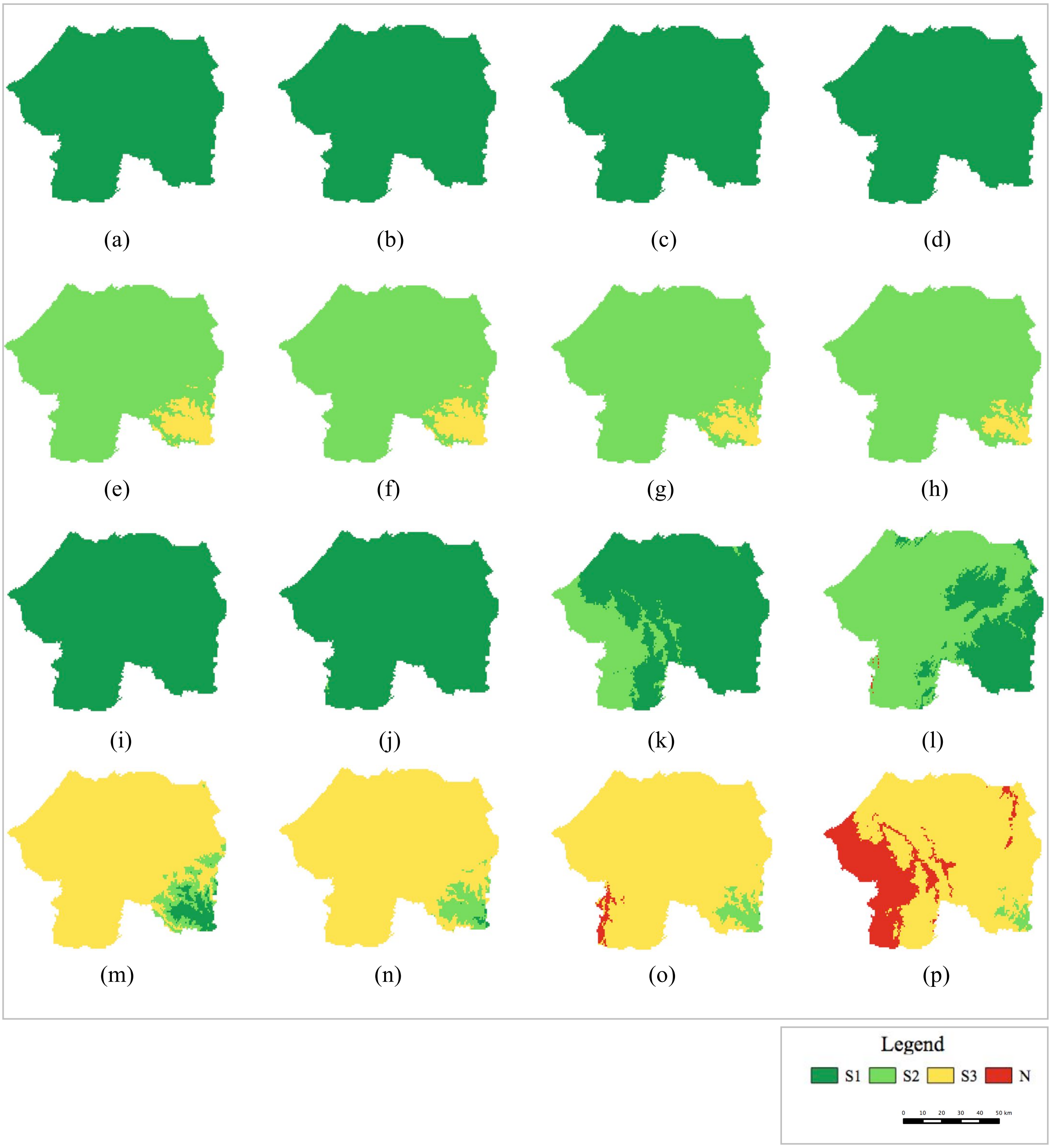


Figure 27. Reclassification based on 4 classes (S1, S2, S3, N) according to the FAO approach. Reclassified criteria are in order wheat mean temperature of the growing cycle, lentil mean temperature of the growing cycle, wheat average annual precipitation and lentil average annual precipitation for (a,e,i,m) IPSL-CM4, (b,f,j,n) INGV-ECHAM4, (c,g,k,o) UKMO-HadCM3 and (d,h,l,p) GFDL-CM2.0 models.

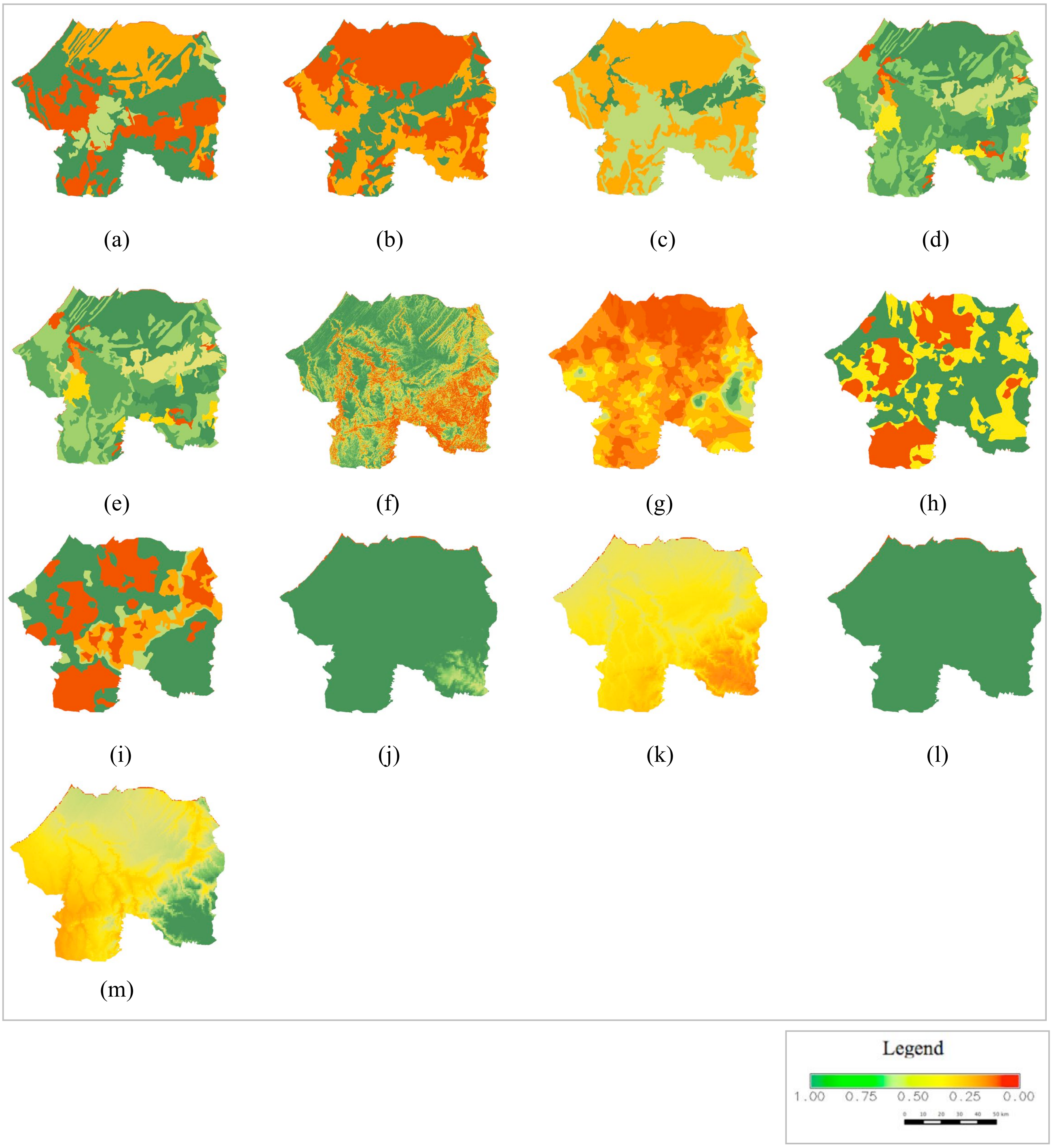


Figure 28. Standardization based on fuzzy membership functions. Standardized criteria are in order (a) wheat and lentil drainage, (b) wheat texture, (c) lentil texture, (d) wheat soil depth, (e) lentil soil depth, (f) wheat and lentil slope, (g) wheat and lentil OMC, (h) wheat pH, (i) lentil pH, (j) wheat mean temperature of the growing cycle, (k) lentil mean temperature of the growing cycle, (l) wheat average annual precipitation and (m) lentil average annual precipitation. Climate parameters refer to current climate conditions.

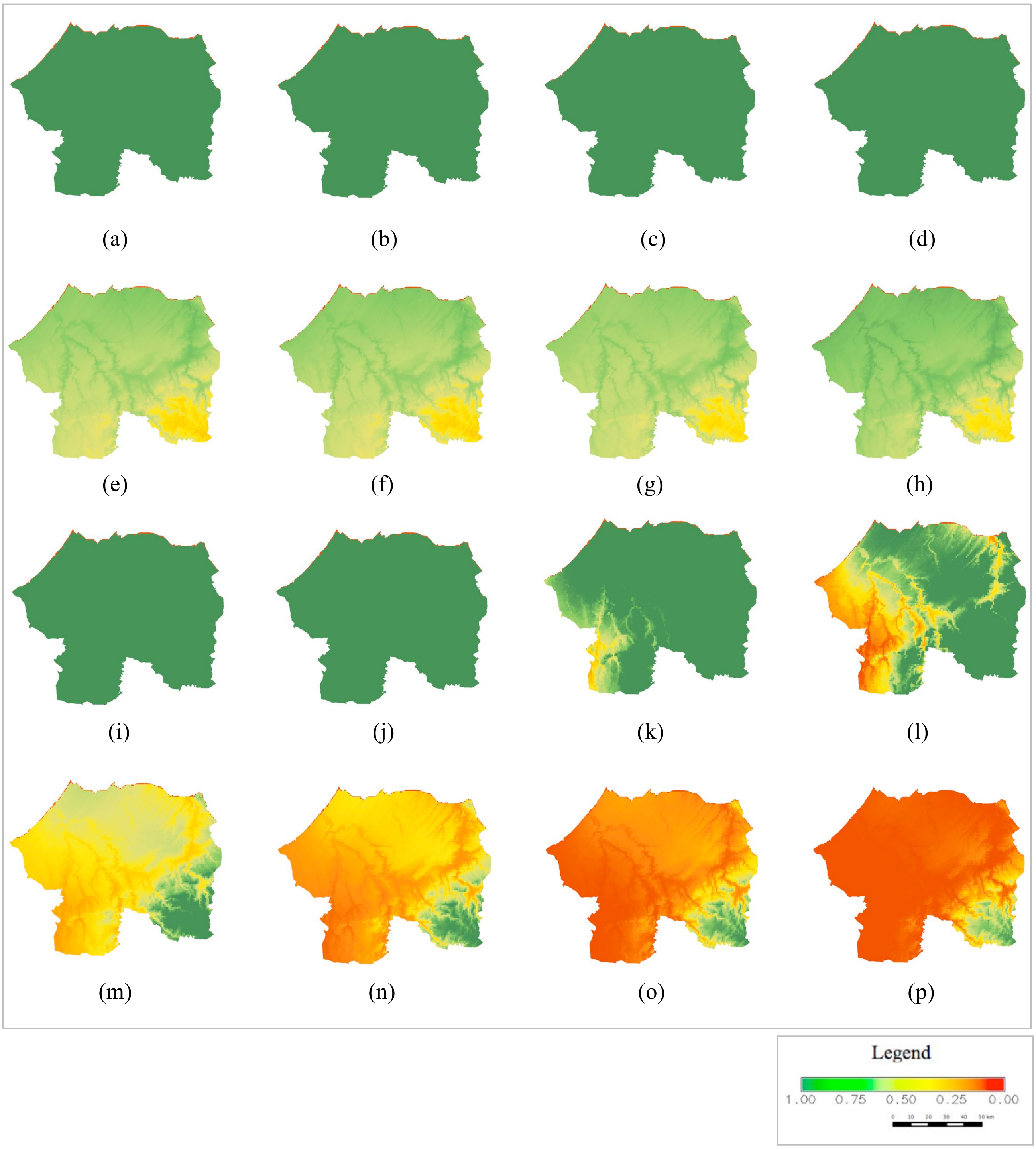


Figure 29. Standardization based on fuzzy membership functions. Standardized criteria are in order wheat mean temperature of the growing cycle, lentil mean temperature of the growing cycle, wheat average annual precipitation and lentil average annual precipitation for (a,e,i,m) IPSL-CM4, (b,f,j,n) INGV-ECHAM4, (c,g,k,o) UKMO-HadCM3 and (d,h,l,p) GFDL-CM2.0 models.

3.2.3. Criteria weighting

Once all the parameters required in a LSA have been preprocessed, they should be weighted based on their importance for the computation of the final analysis. Indeed, the criteria presented in the previous sections do not play the same role in the definition of suitable lands for wheat and lentil growth. Therefore, weights need to be assigned to each criterion. This step involves the opinion of experts in order to determine the relative importance of each criterion used in the LSA. At this point of the analysis, the intervention of experts or decision makers is fundamental in determining opportune weights. According to Drobne and Lisec (2009), the weight of one criterion expresses the relative importance of the criterion itself compared to the other criteria considered. Higher its weight, higher the importance of one criterion in the final evaluation. In order to assign weights to n criteria, a general rule is expressed as follows:

$$w = (w_1, w_2, \ldots, w_n), \text{ and}$$
$$\sum w_j = 1$$

where the weight w_j is assigned to the j-th criterion in all the locations considered (Rinner & Malczewski, 2003). Moreover, weights are normalized so that their sum is equal to 1 (Drobne & Lisec, 2009). In a study carried out by Greene et al. (2011) four methods are outlined to assign weights. These methods are (1) ranking, (2) rating, (3) trade-off analysis and (4) AHP. In this work, a local expert of INRA-Rabat has been contacted and asked to establish weights according to the rating and AHP methods, so as to have the opportunity to compare two different methods for the assignment of weights and to identify different aspects of the two approaches. If the rating method is considered, the decision maker or the expert involved in the analysis rates directly all the criteria, based on a common scale (e.g. values between 0 and 1) or point allocation (Greene et al., 2011). Point allocation basically allocates a number of points among the considered criteria based on their importance. The point allocation technique allows the decision maker to assign points following for example a 0-100 scale, giving higher scores to the criteria which have greater importance in the analysis and lower scores to the less influential criteria. Points are allocated taking into consideration that the sum of weights must be 100 in the case of a 0-100 scale. Weights obtained in this way are then divided by 100, in order to get values the sum of which gives 1. Table 10 illustrates wheat and lentil criteria weights obtained through point allocation.

	wheat	lentil
CRITERION	WEIGHT (0-100)	WEIGHT (0-100)
Drainage	5	15
Depth	5	5
Texture	5	5
pH	5	5
OMC	5	5
Slope	10	5
Temperature	15	10
Precipitation	50	50
Total	**100**	**100**

→

CRITERION	wheat	lentil
Drainage	0,05	0,15
Depth	0,05	0,05
Texture	0,05	0,05
pH	0,05	0,05
OMC	0,05	0,05
Slope	0,1	0,05
Temperature	0,15	0,1
Precipitation	0,5	0,5
Total	**1**	**1**

Table 10. Wheat and lentil criteria weights obtained through rating method (point allocation).

If the AHP method is considered, more complex elaborations are required. This method is widely adopted in literature to assign weights based on a pair-wise comparison matrix. In the established matrix, criteria are disposed both on rows and columns in the same order and then compared together two at a time. In this case, one criterion is directly compared to another and values are given according to Saaty (1980) scale of importance (Table 11). Once values have been allocated by the expert at INRA-Rabat, they have been used as raw input data in the r.mcda.ahp module in GRASS. This module automatically generates weights that are applied to each criterion and the final result is a map showing a WLC with AHP weights. However, in this work, another way to obtain weights from the pair-wise comparison matrix has been carried out, in order to show how the approach works. The procedure is now illustrated, while the r.mcda.ahp module is presented in the *analytic hierarchy process* section.

Intensity of importnace	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared to activity j, then j has the reciprocal value when compared with i	

Table 11. Scale of importance for pair-wise comparison (Source: Saaty, 1980).

First of all, in the AHP procedure, a pair-wise comparison matrix is established, taking into consideration that the number of comparisons for *n* criteria corresponds to *n(n - 1)/2* (Akıncı et al., 2013). In the present study, 8 criteria have been considered, therefore the number of comparisons is given by *8(8 - 1)/2 = 28*. For this reason, since the procedure has been developed within Microsoft Excel 2008, only the grey part of Table 12 has been filled in with values according to expert's judgment, while the white part has been automatically completed with reciprocals of values of the upper diagonal. Table 12 shows the pair-wise comparison matrices realized for wheat and lentil.

WHEAT	Drainage	Depth	Texture	pH	OMC	Slope	Temperature	Precipitation
Drainage	1	2	3	4	4	3	3	2
Depth	0,5	1	2	5	5	2	2	2
Texture	0,333333333	0,5	1	5	7	2	2	2
pH	0,25	0,2	0,2	1	2	2	2	2
OMC	0,25	0,2	0,142857143	0,5	1	2	2	2
Slope	0,333333333	0,5	0,5	0,5	0,5	1	3	2
Temperature	0,333333333	0,5	0,5	0,5	0,5	0,333333333	1	2
Precipitation	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1

LENTIL	Drainage	Depth	Texture	pH	OMC	Slope	Temperature	Precipitation
Drainage	1	5	3	5	5	3	3	2
Depth	0,2	1	3	5	5	3	3	2
Texture	0,333333333	0,333333333	1	5	7	2	3	2
pH	0,2	0,2	0,2	1	5	2	3	2
OMC	0,2	0,2	0,142857143	0,2	1	2	2	2
Slope	0,333333333	0,333333333	0,5	0,5	0,5	1	3	2
Temperature	0,333333333	0,333333333	0,333333333	0,333333333	0,5	0,333333333	1	2
Precipitation	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1

Table 12. Pair-wise comparison matrix of wheat and lentil.

Once the pair-wise comparison matrix has been completed, the next step is the normalization of values contained in the matrix itself. This passage is done by dividing each value of the pair-wise matrix by the sum of its column. Table 13 shows the normalized matrices for wheat and lentil.

WHEAT	Drainage	Depth	Texture	pH	OMC	Slope	Temperature	Precipitation
Drainage	0,285714286	0,37037037	0,382513661	0,235294118	0,195121951	0,233766234	0,193548387	0,133333333
Depth	0,142857143	0,185185185	0,255009107	0,294117647	0,243902439	0,155844156	0,129032258	0,133333333
Texture	0,095238095	0,092592593	0,127504554	0,294117647	0,341463415	0,155844156	0,129032258	0,133333333
pH	0,071428571	0,037037037	0,025500911	0,058823529	0,097560976	0,155844156	0,129032258	0,133333333
OMC	0,071428571	0,037037037	0,018214936	0,029411765	0,048780488	0,155844156	0,129032258	0,133333333
Slope	0,095238095	0,092592593	0,063752277	0,029411765	0,024390244	0,077922078	0,193548387	0,133333333
Temperature	0,095238095	0,092592593	0,063752277	0,029411765	0,024390244	0,025974026	0,064516129	0,133333333
Precipitation	0,142857143	0,092592593	0,063752277	0,029411765	0,024390244	0,038961039	0,032258065	0,066666667

LENTIL	Drainage	Depth	Texture	pH	OMC	Slope	Temperature	Precipitation
Drainage	0,322580645	0,632911392	0,345773875	0,285171103	0,204081633	0,21686747	0,162162162	0,133333333
Depth	0,064516129	0,126582278	0,345773875	0,285171103	0,204081633	0,21686747	0,162162162	0,133333333
Texture	0,107526882	0,042194093	0,115257958	0,285171103	0,285714286	0,144578313	0,162162162	0,133333333
pH	0,064516129	0,025316456	0,023051592	0,057034221	0,204081633	0,144578313	0,162162162	0,133333333
OMC	0,064516129	0,025316456	0,016465423	0,011406844	0,040816327	0,144578313	0,108108108	0,133333333
Slope	0,107526882	0,042194093	0,057628979	0,02851711	0,020408163	0,072289157	0,162162162	0,133333333
Temperature	0,107526882	0,042194093	0,038419319	0,019011407	0,020408163	0,024096386	0,054054054	0,133333333
Precipitation	0,161290323	0,063291139	0,057628979	0,02851711	0,020408163	0,036144578	0,027027027	0,066666667

Table 13. Normalized matrix of wheat and lentil.

Subsequently, row values are summed together and divided by the number of criteria and average values obtained are the final weights, also called priority vectors (Akıncı et al., 2013). Table 14 reports weights obtained for wheat and lentil following the procedure described.

WHEAT	weight
Drainage	0,253707793
Depth	0,192410159
Texture	0,171140756
pH	0,088570096
OMC	0,077885318
Slope	0,088773596
Temperature	0,066151058
Precipitation	0,061361224

LENTIL	weight
Drainage	0,287860202
Depth	0,192310998
Texture	0,159492266
pH	0,10175923
OMC	0,068067617
Slope	0,078007485
Temperature	0,054880455
Precipitation	0,057621748

Table 14. Weights related to wheat and lentil criteria following the AHP method.

As for the rating method, the sum of weights is equal to 1, but in this case, other criteria result to have higher importance, therefore the final overlay is expected to be different compared to the one obtained with weights derived from the rating method.

Carrying out a pair-wise comparison between several criteria may lead to some level of inconsistency when assigning values in the pair-wise matrix, for this reason the consistency of the analysis should be checked through a consistency ratio (CR) (Akıncı et al., 2013; Drobne & Lisec, 2009). The CR is expressed as:

$$CR = \frac{CI}{RI}$$

where CI is the consistency index and RI the random index. The evaluation made by the expert or the decision maker is consistent if the result of the ratio is less than 0.1 (Drobne & Lisec, 2009). CI is expressed as:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where n is the number of criteria and $\lambda_{\max}$ is the average of the consistency vector that can be calculated through the Excel's matrix multiplication function MMULT() taking each row of the pair-wise matrix and the whole column of generated weights and dividing the function by each single weight. In the case of wheat and lentil $\lambda_{\max}$ is respectively 9.19 and 9.7 and the derived CI is

0.17 and 0.24. Finally, since the RI has been determined by Saaty (1977) in relation to the number of criteria compared, the RI that corresponds to 8 criteria is 1.41 (Table 15).

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 15. Random index (Source: Saaty, 1977).

The CR for both wheat and lentil is then calculated:

$$CR_{wheat} = \frac{0.17}{1.41} = 0.12 \qquad CR_{lentil} = \frac{0.24}{1.41} = 0.17$$

Results show how the final CR is greater than 0.1 in both cases and therefore the evaluation made by the expert is inconsistent in some parts and it should be revised. However, due to time constraints and due to the purpose of illustrating the AHP approach and especially the application and functionality of the r.mcda.ahp module in GRASS, pair-wise values have been maintained as given by the expert.

After criteria and weights have been defined, the next and final phase is their overlay and combination following specific decision rules. In the last part of this chapter a detailed description of MCDM methods and the GIS-MCDA approach used in this thesis is provided.

3.3. Multi-Criteria Decision Analysis

MCDM methods allow the elaboration of comparative evaluations and the classification of a series of alternatives through the adoption of defined decision rules (Massei, 2010). In a MCDA, decision rules are all the procedures required for the establishment and the definition of a valuable solution, therefore MCDM methods are decision rules that produce a relationship between input and output data sets in order to obtain a resultant outcome that provides useful information (Drobne & Lisec, 2009; Massei, 2010). In particular, the adoption of a GIS-MCDA approach enables the integration of geographic data sets with experts or decision maker’s judgments when the computation of the acquired information is necessary to produce a useful result for decision making.

In a MCDA, the criteria chosen to represent the elements of the analysis and the weights or preferences given by experts or decision makers can be combined in different ways. There is not a specific decision rule to be applied in order to answer a particular issue, but many decision rules can be used for the same problem. Therefore, the present work takes into account and makes a comparison between five possible combination of criteria, weights and decision rules. These approaches are applied in a GIS context and they consider in order: (1) criteria reclassified based on crisp sets and combined with the MAX function, (2) criteria reclassified based on crisp sets and combined with a WLC without preference weights, (3) criteria reclassified based on crisp sets and combined with a WLC with preference weights assigned through rating technique, (4) criteria reclassified based on fuzzy sets and combined with the OWA method with preference weights assigned through rating technique and order weights and (5) criteria reclassified based on fuzzy sets and combined with the AHP method with preference weights assigned through pair-wise comparison.

As mentioned at the beginning of this chapter, non-compensatory, compensatory and partially compensatory decision rules have been considered in the application of the five approaches outlined above. A description of these methods and their use in combination with criteria and weights is presented in the following sections. Methods range from the simplest approach that takes into account the concept of the most limiting factor to more complex approaches such as the OWA method.

3.3.1. Minimum and maximum operators

A simple analysis that can be made in a GIS is the overlay of previously rasterized and reclassified or standardized criteria according to the minimum or the maximum value they present in each single pixel. Basically, the final value of a pixel, after MIN or MAX operators are applied, is the minimum or the maximum value possible for that pixel, considering all the criteria involved. In this study, this approach has been applied to the criteria reclassified based on the FAO system, where value 1 represents the highest suitability and value 4 represents the unsuitable conditions for wheat and lentil growth in each criterion. Therefore, in this case, a MAX operator has been used, so as to underline where values reach the lowest degree in the suitability analysis. The approach has been applied considering both current climate and climate change scenarios by simply modifying the input criteria in the case of average mean temperature of the growing cycle and average annual precipitation, while maintaining all the other criteria for both wheat and lentil. Moreover, since the

LSA is made with the aim of identifying suitable lands for wheat and lentil rotation, the MAX operator has been applied also when wheat and lentil maps have been combined in order to show limitations for both crops. The decision rule adopted in the approach described is:

$$MAX\ ([raster_1], [raster_2], [raster_3], \ldots, [raster_n]) * \prod C_j$$

where $\prod C_j$ is the product of Boolean constraints that is represented in this study by the constraints map of Figure 20.

If criteria are standardized according to the fuzzy logic approach, then the worst conditions for each factor are represented by the value 0. In this case the MIN operator is used to outline unsuitable areas. However, in the analysis carried out, only results concerning the MAX operator used with criteria containing crisp sets are shown in the *results and discussion* chapter when this non-compensatory approach is illustrated, since the MIN and MAX operators are also discussed in the OWA method, where they assume the meaning of AND and OR operators. Specifically, the AND operator represents the MIN operator applied to fuzzy sets and it is therefore presented in the *ordered weighted averaging* section. For further information, GRASS commands, containing an example of the adopted criteria in the application of the MAX operator, are reported as macro language in Annex II.

3.3.2. Weighted linear combination

A second approach refers to the WLC or simple additive weighting, which is a compensatory method that includes criteria weights. In this case, the low performance of one criterion can be compensated by the high performance of another criterion (Bernetti & Romano, 2007). The criteria used in this method are those reclassified according to the FAO classification (S1, S2, S3, N). However, as for MIN and MAX operators, the same approach can be applied to criteria standardized based on fuzzy sets. Since the WLC is also a particular result of the OWA in which fuzzy criteria are considered, the WLC with fuzzy criteria is discussed in the *ordered weighted averaging* section. In both cases, the general decision rule to compute a WLC can be described as:

$$\sum w_i x_i * \prod C_j$$

where w_i is the weight assigned to criterion *i*, x_i is the criterion score of factor *i* and $\prod C_j$ is the product of Boolean constraints (Eastman, 1999). This approach has been applied to both current climate and climate change scenarios, as described in the first approach. Moreover, the analysis has been carried out in two ways that differ for the adoption of weights. On the one hand, the first analysis does not consider weights, so that the WLC results in a mere sum of criteria, while on the other hand, in the second analysis weights obtained from the rating method have been applied to each criterion as shown in Table 10 in the *criteria weighting* section. In both cases, the new resulting rasters have been reclassified according to the FAO classification, in order to represent the final outcome as the input raster maps.

The WLC carried out without preference weights results in a raster where the value in each pixel is the sum of the criteria scores related to that pixel, therefore, considering 8 criteria and values from 1 o 4, the minimum value possible in one pixel is 8 and the maximum value possible is 32. The reclassification of this raster map has been made taking into account that an area with a defined class of suitability can tolerate a certain number of criteria with values falling in the lower class. This number generally considers a maximum of two criteria, therefore values from 8 to 10 fall in class S1, values from 11 to 18 in class S2, values from 19 to 26 in class S3 and values from 27 to 32 in class N. A similar approach has been applied in the case of the WLC carried out with weights obtained from the rating method. However, the reclassification has been made differently, taking into account the importance assigned to the criteria. Since weights are normalized so that they sum to 1 and they are multiplied by values from 1 to 4 and then summed together, in the final rasters produced with this WLC, the minimum value possible in one pixel is 1, while the maximum value possible is 4, therefore these new values result to have the same range of values of the input criteria (Drobne & Lisec, 2009). However, if all the criteria fall in class S1 except for one of those with higher importance, then the total sum ranges from 1.05, in the case of a criterion weighted 0.05 that falls in class S2, to 1.5 in the case of a criterion weighted 0.5 that falls in class S2. 1.1 is the value obtained in the case of a criterion weighted 0.1 that falls in class S2 and 1.15 is the value obtained in the case of a criterion weighted 0.15 that falls in class S2. For this reason and considering the importance of criteria, if the value of one pixel is 1.05 or 1.1 is considered of class S1, while values from 1.1 to 2.1 are reclassified in class S2, values from 2.1 to 3.1 in class S3 and values greater than 3.1 in class N. The reclassified maps for wheat are then summed together with the corresponding reclassified maps for lentil and the final combined maps show values ranging from 2 to 8, where 2 is considered as S1, 4 as S2, 6 as S3 and 8 as N for both crops. Intermediate values are considered as intermediate suitability classes, so that 3 corresponds to S1/S2, 5 corresponds to S2/S3 and 7 corresponds to S3/N. The r.reclass and the r.recode modules of GRASS have been used for the two reclassifications outlined in this section and they are described together with the procedure adopted as macro language in Annex II.

3.3.3. Ordered weighted averaging

Another approach used in the present work is the OWA, which considers not only criteria and criteria weights, but also order weights. In particular, order weights play a pivotal role in the OWA method, since they determine the level of criteria trade-off and the degree of AND/ORness related to risk-averse or risk-taking solutions (Drobne & Lisec, 2009; Greene et al., 2011). This concept is better explained in Figure 30.

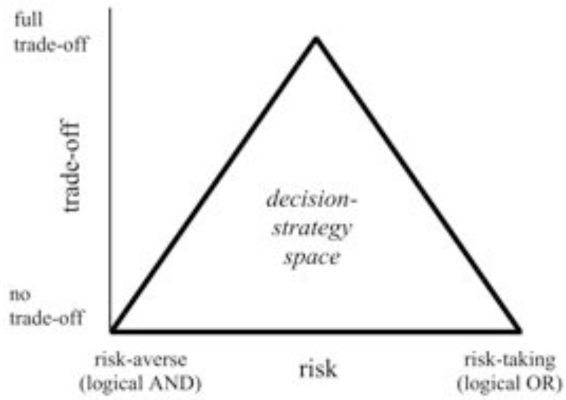


Figure 30. Triangular decision-strategy space (Source: Drobne & Lisec, 2009).

Basically, different order weights can lead to different solutions along the triangle decision-strategy space. Order weights are given following the rule:

$$v = (v_1, v_2, \ldots, v_n), \text{ and}$$
$$\sum v_j = 1$$

while the general decision rule of the OWA method is expressed as:

$$\sum v_j z_{ij}$$

where the order weight v_j is associated with criteria values on a pixel-by-pixel basis and where $z_{i1} \geq z_{i2} \geq \ldots \geq z_{in}$ is the sequence obtained by reorganizing criteria values $x_{i1}, x_{i2}, \ldots x_{in}$ in a descending order (Malczewski et al., 2003; Rinner & Malczewski, 2003). In the case of the intersection operator AND, all possible weight is assigned to the criterion with the minimum value, while in the case of the union operator OR, all possible weight is assigned to the criterion with the maximum value and, in the case of a WLC, equal order weights are assigned to each criterion and the result falls in between AND and OR (Drobne & Lisec, 2009). The set of solutions ranges from a non-compensatory approach to a full compensatory approach, as underlined by the degree of trade-off. Indeed, the AND and OR operators, which correspond to the MIN and MAX operators, do not allow trade-off, while full trade-off is possible if the WLC with equal order weights is considered. In the OWA, intermediate solutions are also possible by changing order weights values. However, in the r.mcda.fuzzy module used in this work to compute the OWA, the order weights are automatically applied by the module itself, therefore results obtained refer only to the three solutions AND, OR and WLC. Even though this module may appear limited, considering the potential of the OWA method in GIS, it can be used to easily obtain three different maps with a single operation. Moreover, the module has been applied to criteria standardized according to the fuzzy logic approach, therefore final maps should not be confused with the ones obtained with criteria reclassified based on crisp sets. Outcomes derived from this module are illustrated and compared with other results in the *results and discussion* chapter. The r.mcda.fuzzy module interface is shown in Figure 31.

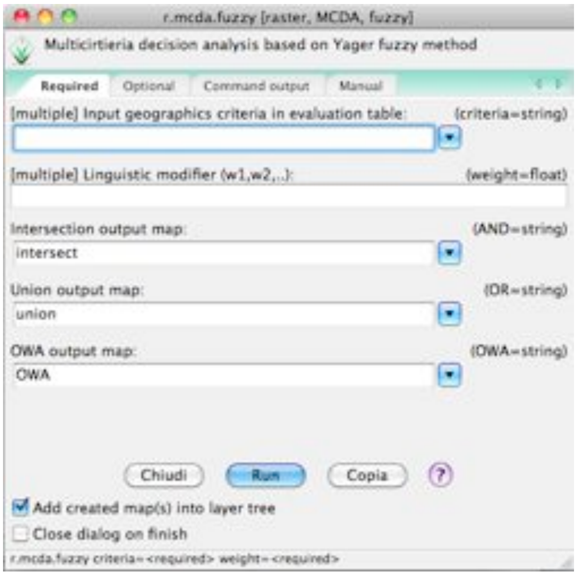


Figure 31. The interface of r.mcda.fuzzy command in GRASS.

The input required by the module is the list of rasterized and standardized criteria, followed by the list of criteria weights, also called linguistic modifiers that are included following the same order of criteria, while the output of the module is respectively the intersection, the union and the OWA maps, which refers to the AND and OR operators and to a WLC with equal order weights (Massei, 2010). The way in which the module computes the analysis is based on the use of criteria weights as exponents applied to the values of criteria in each pixel. This choice has been made by Massei (2010) in order to produce a result that considers the higher importance of some criteria. For example, in the case of the AND operator, with the adoption of exponents, the overall score of alternatives (pixels) with low performance in important criteria is reduced, while the overall score of alternatives in less important criteria increases. Therefore, criteria of higher importance play a major role in the definition of degree of membership (Massei, 2010). Final maps have been produced for both current climate and climate change scenarios, as reported in previous approaches. Moreover, wheat and lentil maps have been combined to define best places for the rotation of these two crops. Results obtained with the OWA method are then multiplied by $\prod C_j$ in order to exclude all the constraints.

3.3.4. Analytic Hierarchy Process

The last method that has been adopted in carrying out the analysis is the AHP method, which has been applied to fuzzy criteria, considering both current climate and climate change scenarios, as for the other approaches. The AHP approach has been previously described as a valuable way to assign criteria weights based on decision maker or expert's opinion, therefore in this section, only the r.mcda.ahp module used to compute the elaboration in GRASS is illustrated. The r.mcda.ahp interface is shown in Figure 32.

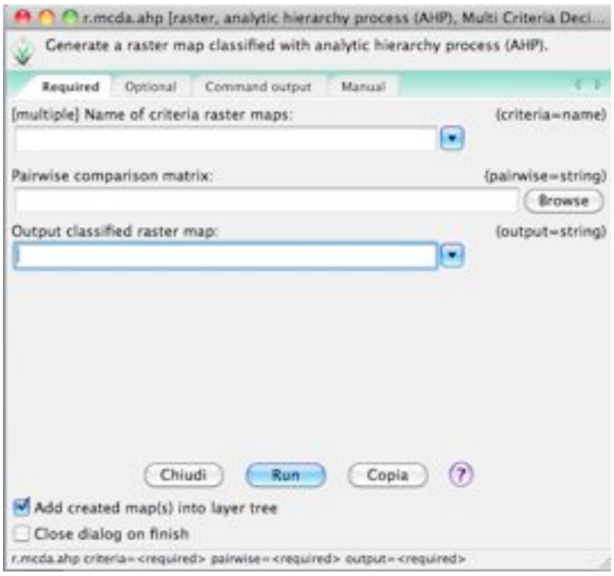


Figure 32. The interface of r.mcda.ahp command in GRASS.

As for the r.mcda.fuzzy module, the input required by the r.mcda.ahp module is the list of rasterized and standardized criteria, but in this case, a file containing the pair-wise comparison matrix must be chosen instead of defined weights. Then, the output map should be specified before running the command. The utility of this module is that it automatically generates weights from the pair-wise comparison matrix and it also computes the CR. This information is available in a separate file named log.txt once the module has been run. The files generated for both wheat and lentil are reported in Figure 33, in order to compare the results with values obtained manually in the *criteria weighting* section.

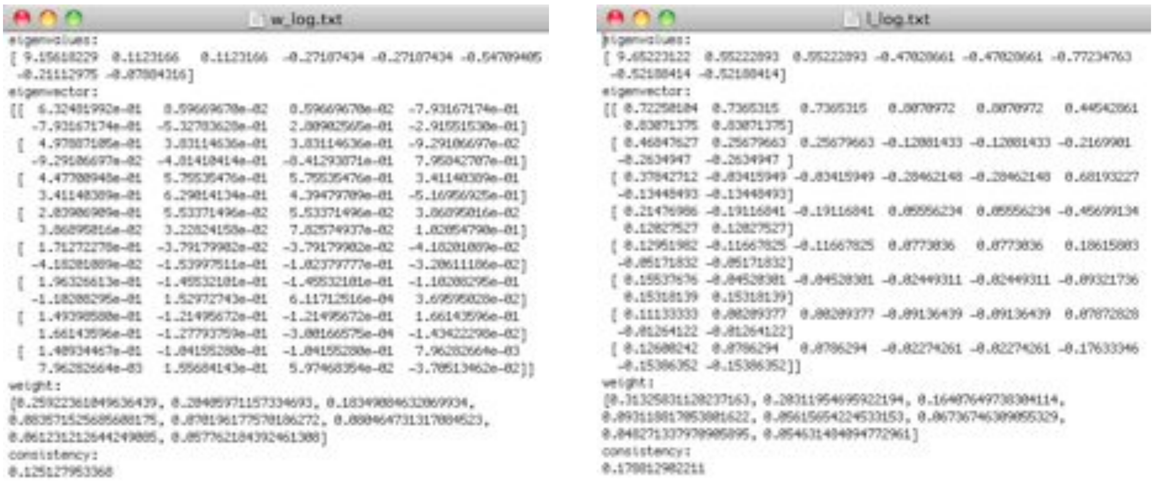


Figure 33. r.mcda.ahp automatically generated files with information on weights and CR for wheat (left) and lentil (right).

Results derived from the automatically generated files are basically the same of those obtained in the *criteria weighting* section. Weights change slightly, but CR values are the same. Therefore, the adoption of this tool in GRASS allows the user to save time when the analysis requires the elaboration of maps that involve pair-wise comparison matrices built by the experts. The r.mcda.ahp module in GRASS produces a result that corresponds to a WLC with weights obtained from a pair-wise comparison. As already mentioned, the CR results to be slightly inconsistent, but final maps are presented anyway in the *results and discussion* chapter, so as to show what possible changes in weighting methods may lead to.

All the methods described above range from the simplest approach to the more complex, none has been excluded from the final representation, in order to define the variation that results may present. Even the simplest approach should be considered, since it can provide useful information at the beginning of the evaluation.

4. Results and discussion

Outcomes derived from the application of the MCDM methods outlined in the previous chapter are now presented. Results in the form of maps are illustrated and discussed for each combination of criteria, weights and decision rules, taking into account both pros and cons of each approach. A flowchart summarizing the analysis is provided for each method before showing final output maps. Wheat and lentil suitability is reported both in terms of single crops and in terms of crop rotation, combining wheat and lentil maps together in order to highlight what degree of suitability can be reached in the case these two crops are adopted in sequence. A general overview, considering main differences between wheat and lentil cultivation under current climate and under climate change scenarios is given. Moreover, a direct comparison is made between maps showing wheat and lentil suitability for rotation under current climate and maps showing wheat and lentil suitability for rotation under the worst scenario possible, which turned out to be the one described by the GFDL-CM2.0 model. The comparison is made considering the total available area for each suitability class and positive or negative differences between the current situation and climate change based on the GFDL-CM2.0 model. The GRASS module used for the computation of the area is r.report (Annex II). Finally, areas where wheat and lentil rotation is feasible are selected, in order to present possible places for the application of opportune adaptation measures, such as CA and NT, so as to contribute in preserving land suitability of the two crops considered in the case of future climate change.

4.1. Land suitability analysis based on MAX operator

The method of the MAX operator consists in a simple overlay that basically takes only the highest value of each cell or pixel to build the final map. The reason for the choice of the MAX operator has been already explained in the previous chapter, what should be noted here is that the approach provides results characterized by a low level of risk in terms of choices related to the selection of suitable lands, since the approach only considers the worst value of each pixel. Indeed, results derived from this method, which is applied to crisp sets in ascending order where the higher value is applied to N class, are in line with results obtained from the operator of intersection (AND) in the OWA approach, applied to fuzzy sets in descending order where the lower value is the one applied to N class. These methods represent a form of limiting factor analysis, so that the suitability of a location is determined by its worst quality (Eastman, 1999). Figure 34 shows the MAX operator flowchart that summarizes the procedure adopted.

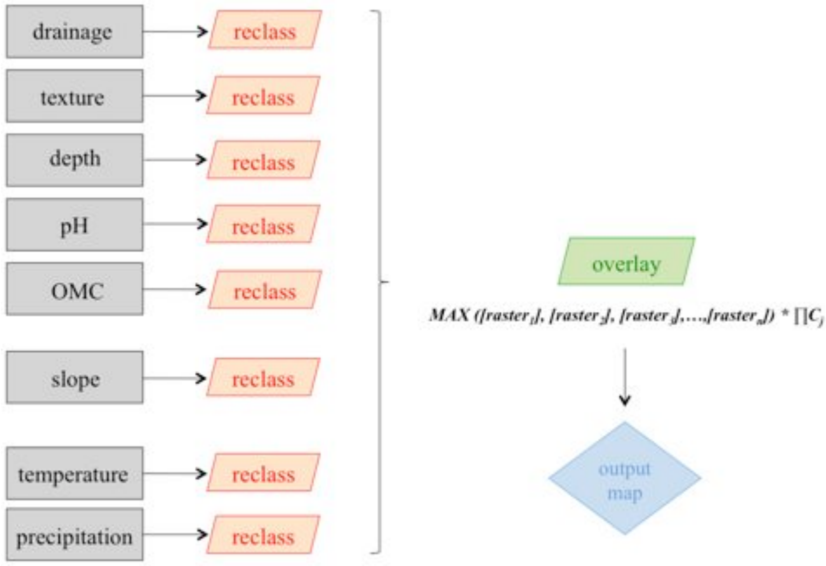


Figure 34. The MAX operator flowchart.

Output maps derived from the MAX operator approach are shown below. Figure 35 reports land suitability maps of wheat and lentil cultivation and the land suitability map for wheat and lentil rotation in the region of RSZZ, considering current climate conditions, whereas Figure 36 illustrates the same outcomes but under the SRES A2 climate change scenario in the four GCMs considered.

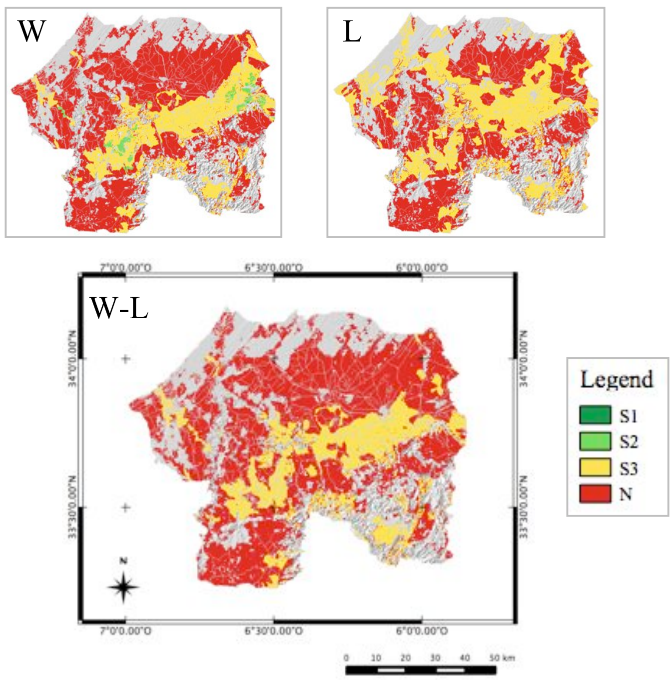


Figure 35. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under current climate conditions (MAX operator).

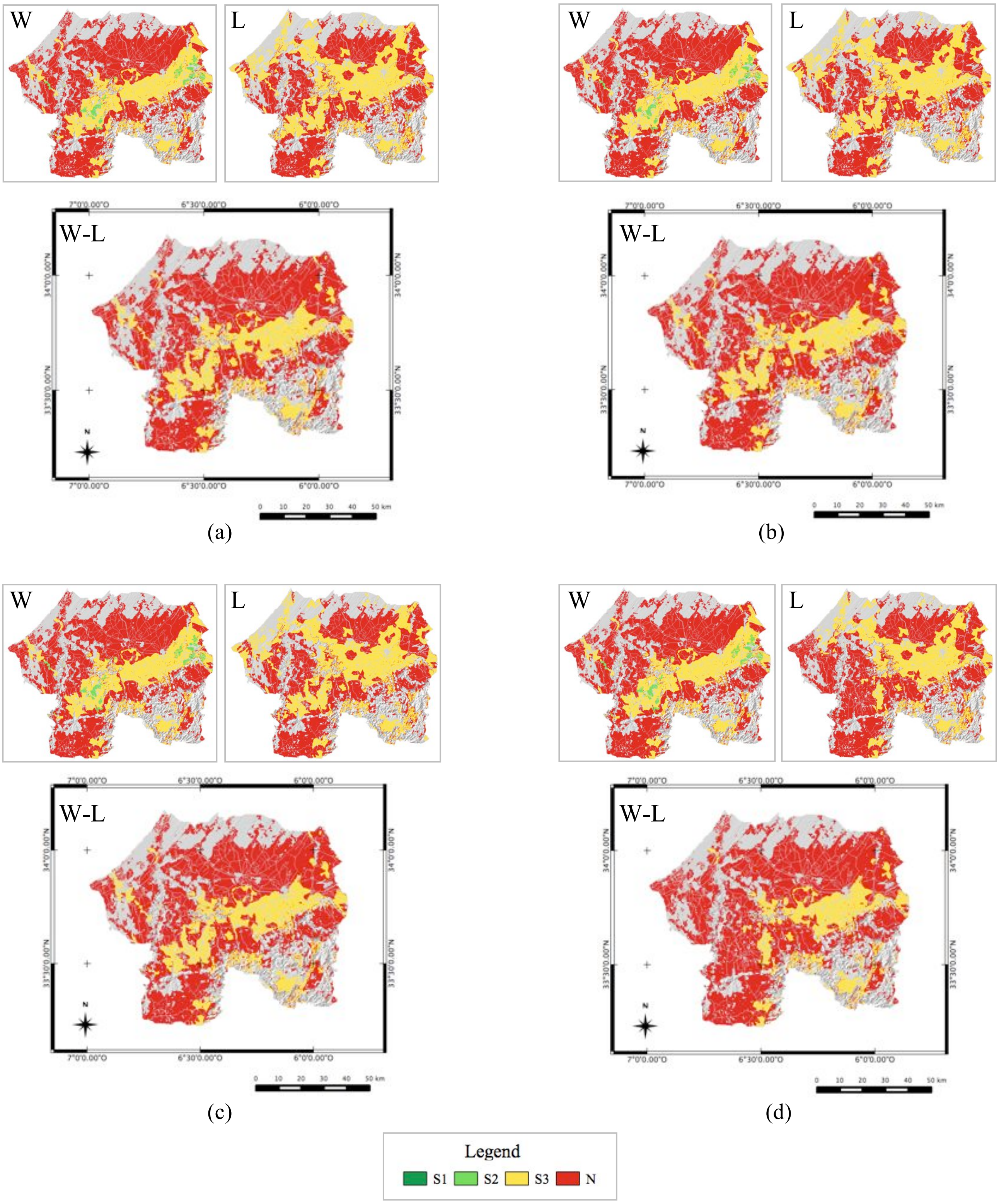


Figure 36. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario in (a) IPSL-CM4, (b) INGV-ECHAM4, (c) UKMO-HadCM3 and (d) GFDL-CM2.0 models (MAX operator).

Since the approach followed does not allow compensation between criteria, results can be easily interpreted. The N class is the one with the highest percentage of coverage. Criteria that mainly influence this result are wheat and lentil drainage, wheat texture, wheat and lentil slope, wheat and lentil OMC, wheat pH, lentil pH and, in the case of the GFDL-CM2.0 model, lentil average annual precipitation (see Figure 26 and 27). In the output maps related to wheat, S1 and S2 classes are presents in very few parts of the central zone of the region, whereas in maps related to lentil and in maps showing rotation of the two crops there are not lands classified in S1 and S2 classes, due to the lower performance of lentil pH in the case of lentil suitability. Areas where the two crops can be combined are mainly located in the central and southern parts of the region, in the province of Khemisset and in few areas located in the prefecture of Skhirat-Temara. Maps related to the IPSL-CM4, INGV-ECHAM4 and UKMO-HadCM3 models show null or slight differences if compared to the maps in Figure 35. Only the GFDL-CM2.0 model reports a significant difference that refers to lentil suitability, due to the negative performance of the average annual precipitation parameter. A comparison is made between land suitability maps for wheat and lentil rotation under current climate conditions and under climate change based on the GFDL-CM2.0 model, taking into account the total available area for agriculture, expressed both in hectares and in percentage for each suitability class (Figure 37).

Suitability class	Area (ha)	Area (%)
S1	-	-
S2	-	-
S3	154,193.14	25.52
N	450,089.83	74.48

Suitability class	Area (ha)	Area (%)
S1	-	-
S2	-	-
S3	117,874.96	19.51
N	486,383.72	80.49

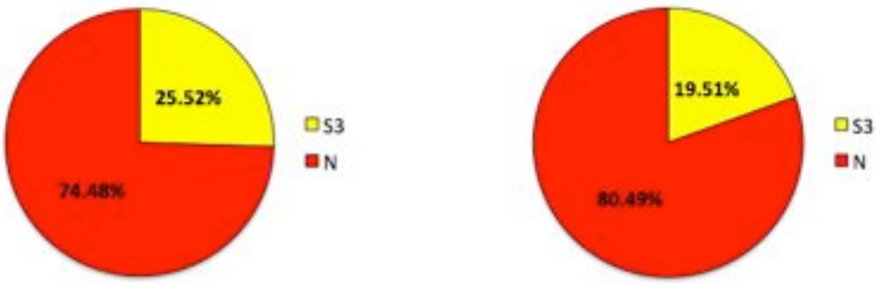


Figure 37. Land suitability area for wheat and lentil rotation under current climate (left) and under climate change based on the GFDL-CM2.0 model (right) (MAX operator).

Results only show marginally suitable and unsuitable lands, with an increase in unsuitable lands under climate change scenario based on the GFDL-CM2.0 model. Suitable and moderately suitable lands are not present in final maps because they are overcome by higher values given by S3 and N classes. A difference map, reporting positive differences between the two extreme outcomes is realized and presented in Figure 38.

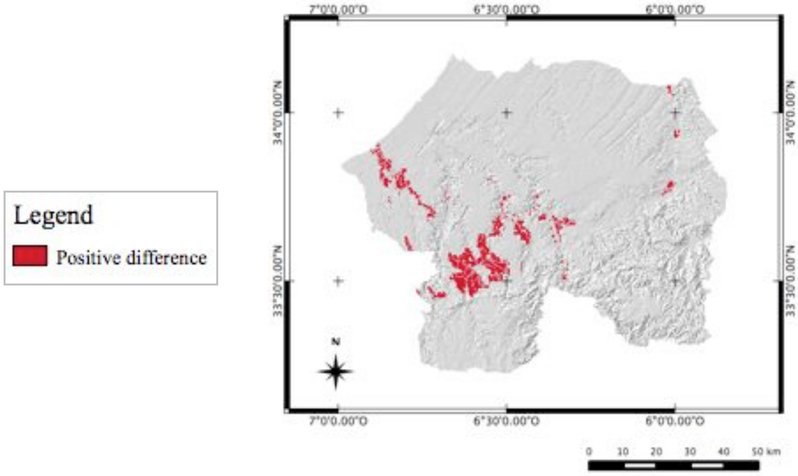


Figure 38. Difference map of the suitability of wheat and lentil rotation obtained from the map (d) in Figure 36 and the map in Figure 35. Red areas show a positive difference and therefore a worsening of land suitability under climate change.

A general worsening of land suitability is likely to occur before the end of the 21st century. The A2 climate change scenario based on the GFDL-CM2.0 model reports higher impacts on the cultivation of lentil and on the rotation of wheat and lentil compared to land suitability under current climate. However, further analyses based on other approaches are made to confirm or deny this statement. Overall, the MAX operator should be considered as a valuable starting point in a LSA, so as to identify the lower degree of suitability that can be achieved in a defined area.

4.2. Land suitability analysis based on weighted linear combination

The second approach followed to compute the LSA is the WLC. The method has been applied in two different ways. First of all, preference weights assigned to the criteria have been excluded in order to have a simple sum of reclassified criteria. In the second case, preference weights obtained from rating have been applied to each criterion, based on expert's judgment. This choice has been made in order to illustrate how the introduction of preference weights affects final results. Wheat and lentil maps resulting from the two analyses have been reclassified as explained in the *weighted linear combination* section and final land suitability maps related to wheat and lentil rotation have been generated from the simple sum of single crops maps. Figure 39 illustrates the WLC flowchart that summarizes the general procedure adopted. However, where preference weights are not included, w_j is not considered in the decision rule. Moreover, it should be noted that unlike the MAX operator, in the WLC method output wheat and lentil maps are reclassified. Output maps derived from the WLC approach are presented and discussed in the following sections.

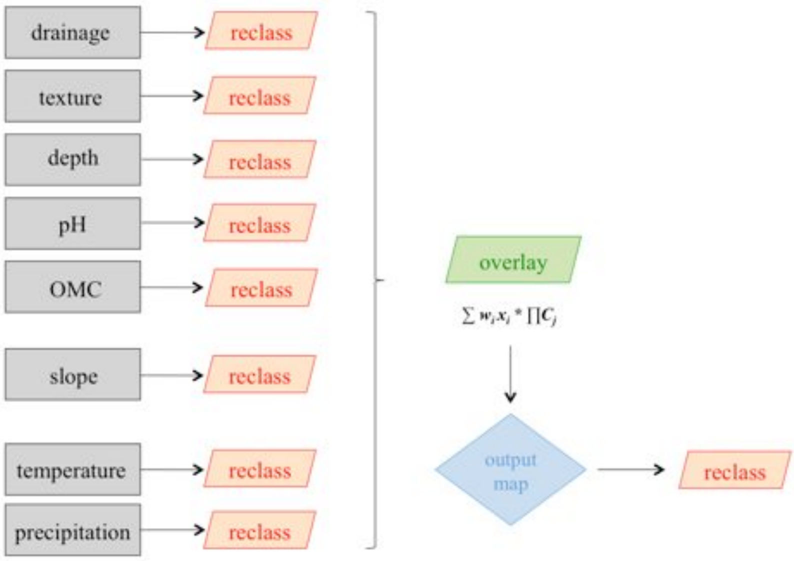


Figure 39. The weighted linear combination flowchart.

4.2.1. Weighted linear combination without preference weights

Output maps determined by a simple sum of reclassified criteria without preference weights are shown in Figure 40 and in Figure 41. Maps are presented in the same order as for the MAX operator, with outcomes related to the application of the WLC method under current climate conditions and under the SRES A2 climate change scenario in the four GCMs considered.

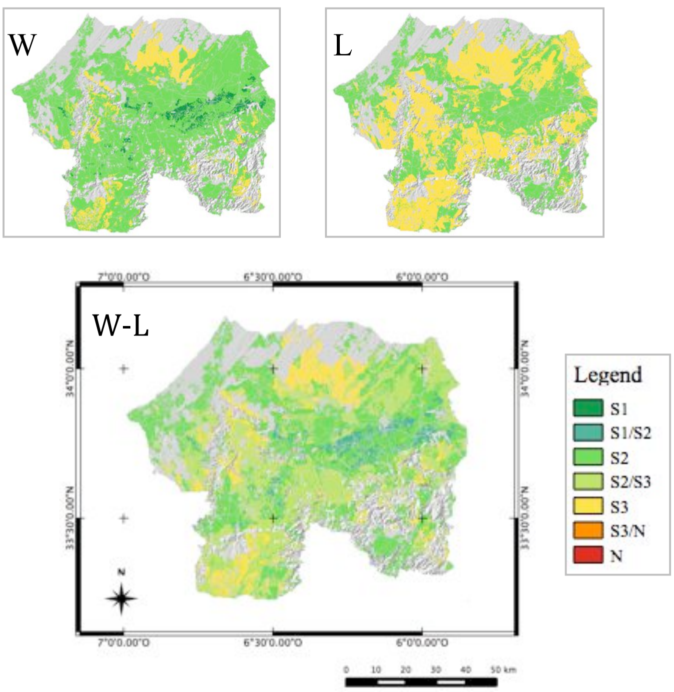


Figure 40. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under current climate conditions (WLC without preference weights).

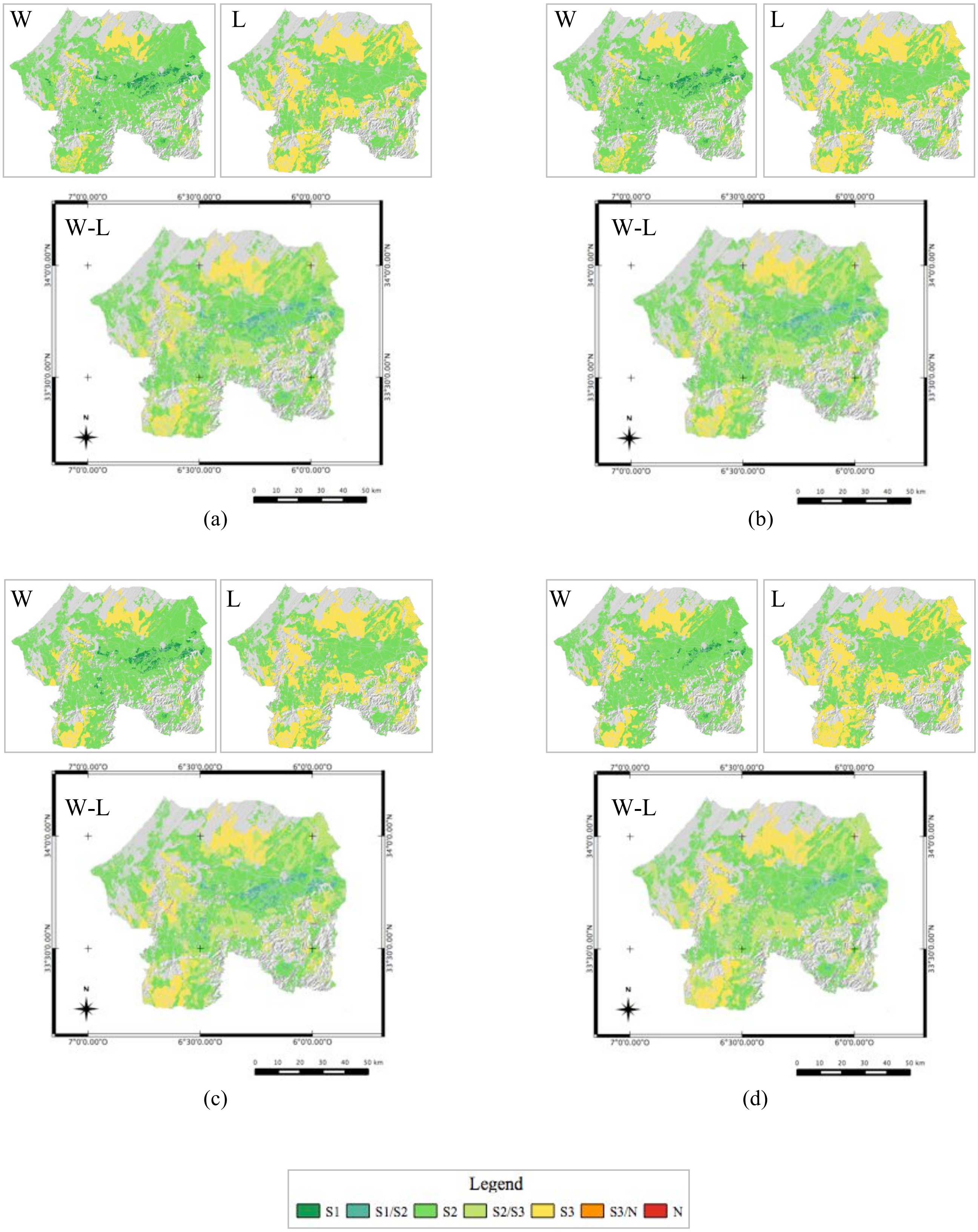


Figure 41. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario in (a) IPSL-CM4, (b) INGV-ECHAM4, (c) UKMO-HadCM3 and (d) GFDL-CM2.0 models (WLC without preference weights).

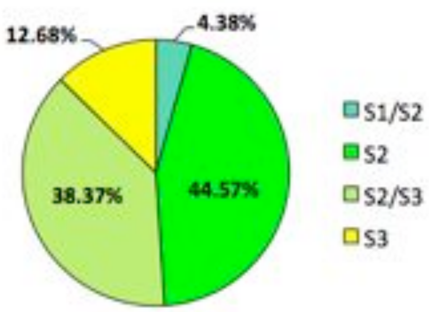
Since wheat and lentil maps are reclassified with values ranging from 1 to 4, the sum of these values in final maps produces a range from 2 to 8, which has been maintained with no further reclassification. Intermediate suitability classes have been introduced in final maps and they represent the combination of two different classes derived from wheat and lentil maps. If compared with results obtained from the MAX operator, the present WLC does not show unsuitable lands. This is due to the compensatory nature of the approach, compared to the non-compensatory MAX operator. For this reason, more realistic output maps are produced with the WLC approach.

A general overview of wheat and lentil suitability maps produced with the WLC decision rule is now provided. Overall, land suitability maps of wheat show few areas classified as S1 in the central zone of the region, while in land suitability maps of lentil this class is not present. Other classes represented are S2 and S3. As already mentioned, there are not unsuitable lands. Considering wheat, land suitability decreases in the UKMO-HadCM3 and GFDL-CM2.0 models compared with the current situation, but an increase in suitability is recorded in the Oulmes plateau. The worsening is due to the lower performance in the average annual precipitation for both UKMO-HadCM3 and GFDL-CM2.0, while an increase in mean temperature leads to better conditions in the Oulmes area. Concerning IPSL-CM4 and INGV-ECHAM4 models, there is not a significant difference compared to the current situation, there is rather a slight improvement due to the better performance of wheat mean temperature in the Oulmes area. In the case of lentil, land suitability is worse in the current situation, due to a lower suitability of lentil mean temperature, which increases in the future leading to better performances in terms of temperature requirements. Therefore, lentil suitability increases in every model considered for the future, but not in the western part of the region in the GFDL-CM2.0 model, since it records a considerable loss in precipitation. Final maps that integrate wheat and lentil suitability report values ranging from the S1/S2 class to the S3 class. Both S1 and N classes are missing. Results show that the most suitable area for wheat and lentil rotation is the central zone of the region, located in the province of Khemisset and some areas located in the prefecture of Skhirat-Temara and in the southern part of the region (Oulmes plateau).

Outcomes derived from the WLC without preference weights result to be more positive compared to results obtained with the MAX operator. In Figure 42 a direct comparison is made between land suitability maps for wheat and lentil rotation under current climate conditions and under climate change based on the GFDL-CM2.0 model, taking into account the total available area for agriculture, expressed both in hectares and in percentage for each suitability class. An increase in lands classified as S2 is reported, opposed to a decrease of the S2/S3 class in maps derived from the GFDL-CM2.0 model and compared to the final map that considers current climate. This is due to the difference observed in the lentil suitability map and related to mean temperature. On the other hand, the decrease in precipitation leads to a reduction of the S1/S2 class and an increase in lands classified as S3.

Suitability class	Area (ha)	Area (%)
S1	-	-
S1/S2	26,440.89	4.38
S2	269,304.37	44.57
S2/S3	231,884.44	38.37
S3	76,626.18	12.68
S3/N	-	-
N	-	-

Suitability class	Area (ha)	Area (%)
S1	-	-
S1/S2	10,968.58	1.82
S2	327,608.19	54.21
S2/S3	149,947.42	24.82
S3	115,719.54	19.15
S3/N	-	-
N	-	-



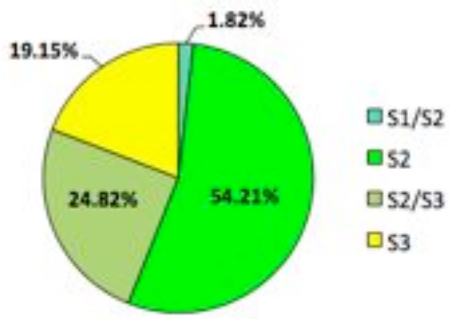


Figure 42. Land suitability area for wheat and lentil rotation under current climate (left) and under climate change based on the GFDL-CM2.0 model (right) (WLC without preference weights).

Therefore, in the WLC approach it should be underlined that not only a worsening of land suitability is possible between the current situation and the future scenarios described by the models, but also some degree of improvement, linked to better performances of lentil in the case of future mean temperature projection. Both negative and positive differences are highlighted in the difference map below, respectively in red and blue tones (Figure 43).

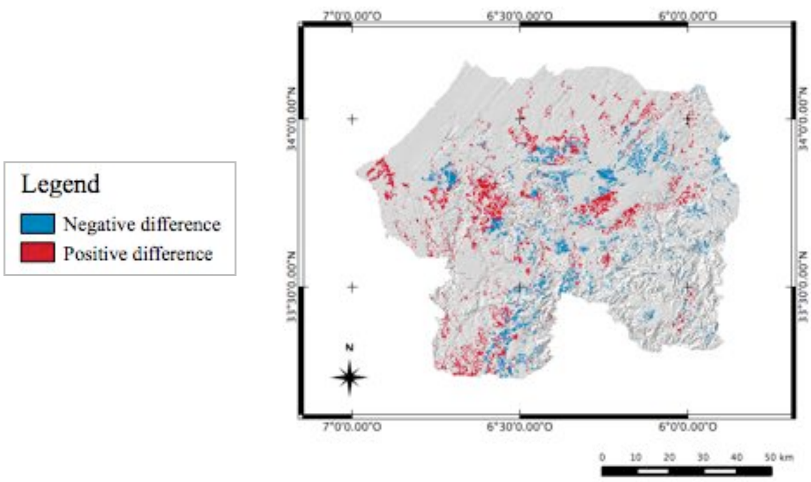


Figure 43. Difference map of the suitability of wheat and lentil rotation obtained from the map (d) in Figure 41 and the map in Figure 40. Red areas show a positive difference and therefore a worsening of land suitability under climate change, while blue areas represent a negative difference that corresponds to an improvement in land suitability under climate change.

Compared to the MAX operator difference map, in the WLC positive differences are widespread in the region and negative differences are present. However, western boundaries of RSZZ are still those more affected by a worsening under the GFDL-CM2.0 model, jointly with some areas located in the central part of the region.

The introduction of preference weights in the WLC leads to the definition of the influence that weights have in the overlay.

4.2.2. Weighted linear combination with preference weights

Output maps obtained with the application of preference weights are shown below. Weights adopted in this analysis are those produced through the rating technique (see Table 10). Figure 44 reports land suitability maps of wheat and lentil cultivation and the land suitability map for wheat and lentil rotation in the region of RSZZ, considering current climate conditions, whereas Figure 45 illustrates the same outcomes but under the SRES A2 climate change scenario in the four GCMs considered.

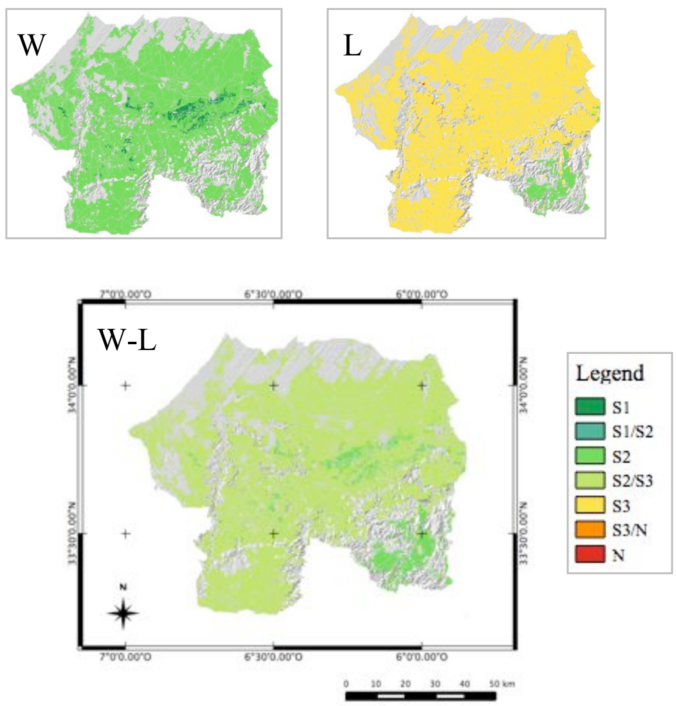


Figure 44. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under current climate conditions (WLC with preference weights).

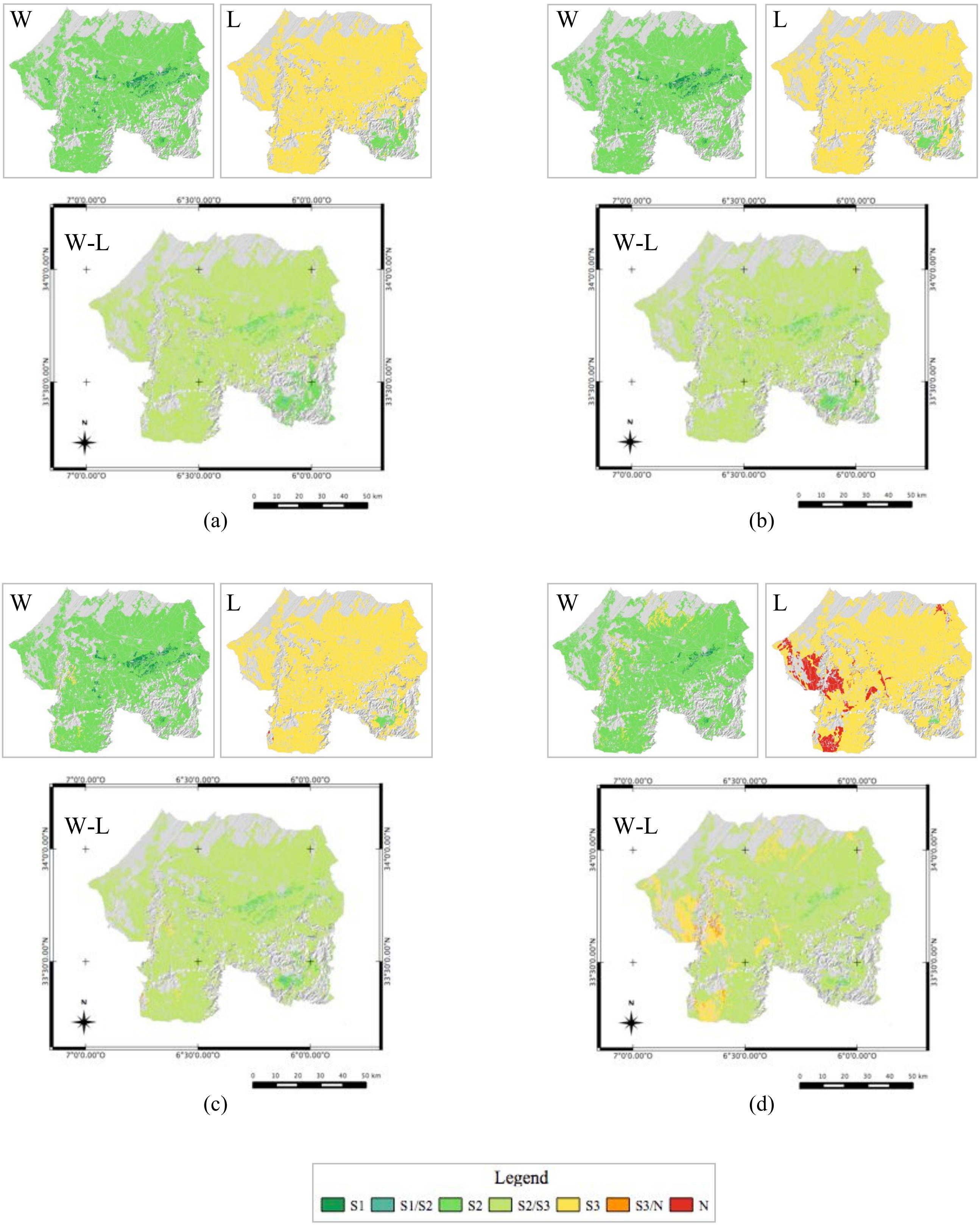


Figure 45. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario in (a) IPSL-CM4, (b) INGV-ECHAM4, (c) UKMO-HadCM3 and (d) GFDL-CM2.0 models (WLC with preference weights).

As reported in the WLC carried out in the previous section, wheat and lentil suitability maps have been reclassified with values ranging from 1 to 4, while final maps have been maintained without further reclassification, with values ranging from 2 to 8 and the establishment of intermediate suitability classes. The reclassification procedure has been illustrated in the *weighted linear combination* section and the explanation of the r.recode module that has been used is provided in Annex II.

A first consideration can be made comparing output maps with those related to the WLC without preference weights. The effect of preference weights is evident, especially if the output maps are analyzed taking into account the original reclassified criteria of Figures 26 and 27. In particular, precipitation is the criterion with the highest importance and it greatly affects final results. Temperature is the second criterion, in order of importance, influencing wheat suitability, whereas in the case of lentil, the second most important criterion is drainage. An overall reduction of land suitability is attested for lentil and this leads to a worsening of suitability in final outcomes, in which wheat and lentil are combined to assess their performances when grown in sequence. On the other hand, wheat suitability increases if compared with the first WLC, due to the lower influence of criteria such as drainage, texture and pH that show the lowest suitability performances. Indeed, land suitability maps of wheat are highly characterized by the predominance of the S2 class and few areas, in the central zone of RSZZ, falling into the S1 class, whereas in land suitability maps of lentil the S3 class prevails with few areas located in the Oulmes plateau falling into the S2 class and also few areas classified as unsuitable in the case of the analysis based on the GFDL-CM2.0 model. Considering final land suitability maps related to wheat and lentil rotation, the S2/S3 class generally prevails and results show that the most suitable areas for the cultivation of wheat and lentil are located in the central zone of the region and in the Oulmes plateau, within the Khemisset province. The IPSL-CM4 and INGV-ECHAM4 models do not show significant differences compared with the current situation and there is only a slight decrease in suitability in the Oulmes area in the case of the INGV-ECHAM4 model. On the contrary, the UKMO-HadCM3 model and especially the GFDL-CM2.0 model show not only a decrease in suitability in the Oulmes plateau, but also the increase of marginally suitable areas in the western part of the region. For this reason, the GFDL-CM2.0 model is considered to be the worst projection possible also in this case and a direct comparison with the current situation is therefore made, as shown in previous approaches. Figure 46 reports the comparison between land suitability maps for wheat and lentil rotation under current climate conditions and under climate change based on the GFDL-CM2.0 model, taking into account the total available area for agriculture, expressed both in hectares and in percentage for each suitability class.

Suitability class	Area (ha)	Area (%)
S1	-	-
S1/S2	33.50	0.01
S2	51,071.62	8.45
S2/S3	552,573.99	91.46
S3	499.11	0.08
S3/N	-	-
N	-	-

Suitability class	Area (ha)	Area (%)
S1	-	-
S1/S2	-	-
S2	10,294.57	1.7
S2/S3	515,170.30	85.27
S3	74,180.00	12.28
S3/N	4,507.91	0.75
N	-	-

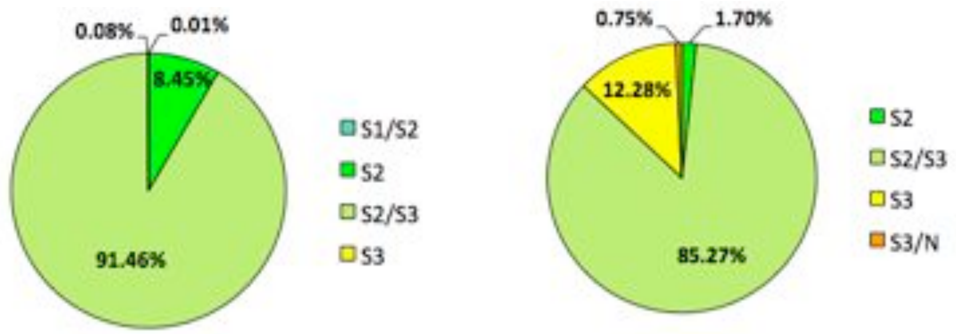


Figure 46. Land suitability area for wheat and lentil rotation under current climate (left) and under climate change based on the GFDL-CM2.0 model (right) (WLC with preference weights).

The predominance of the S2/S3 class is clearly evident and, unlike the WLC carried out without preference weights, in this case the future scenario only describes a decrease in the overall suitability of wheat and lentil combined. Positive differences are highlighted in the difference map in Figure 47.

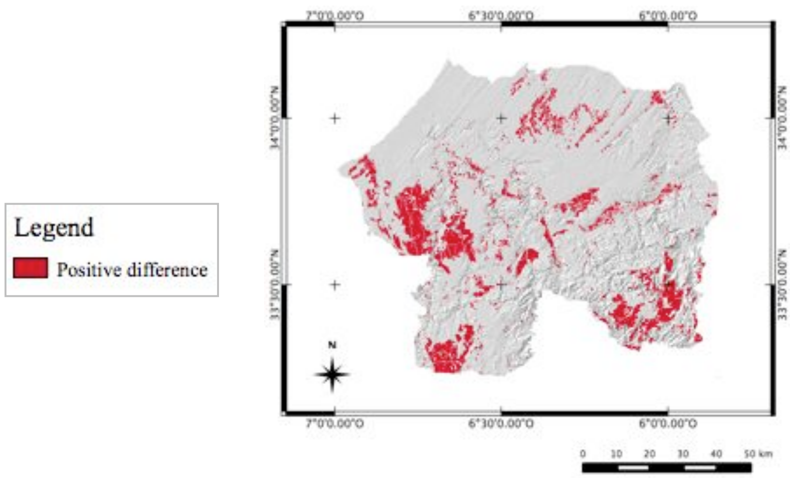


Figure 47. Difference map of the suitability of wheat and lentil rotation obtained from the map (d) in Figure 45 and the map in Figure 44. Red areas show a positive difference and therefore a worsening of land suitability under climate change.

The difference map derived from the WLC with preference weights presents some similarities if compared with difference maps previously discussed. In particular, a worsening in land suitability is expected to occur in western areas, but also in the Oulmes plateau and in some areas located in the center of the region. Results related to positive differences are in line with findings derived from the other two approaches previously described, with the exception of changes in the Oulmes plateau, which are not present in the first WLC and in the MAX operator.

4.3. Land suitability analysis based on ordered weighted averaging

The third approach adopted in the present work to compute a LSA of wheat and lentil is the OWA method. As already mentioned, criteria standardized according to fuzzy membership functions are adopted instead of criteria reclassified based on crisp sets. In this way, the continuous nature of environmental parameters and their spatial variability is taken in consideration. The adoption of criteria based on fuzzy sets should be preferred in a LSA, however, methods previously illustrated should not be excluded, since they produce a first useful evaluation to detect main areas where the cultivation of wheat and lentil is feasible. As mentioned in the *ordered weighted averaging* section, the OWA approach may generate several outputs, based on order weights. Nevertheless, in the r.mcda.fuzzy module used to compute the analysis, order weights are automatically included. The module produces three different outputs: (1) intersection (AND operator), (2) union (OR operator) and (3) OWA. The intersection, or AND operator, considers the worst value in each pixel that, in the case of fuzzy criteria, is a value equal or close to 0. Outcomes obtained with the AND operator and fuzzy criteria gives similar results to those obtained with the MAX operator and crisp sets. As previously mentioned, the AND operator and the MAX operator used in the present work represent a form of limiting factor analysis, so that the suitability of a location is determined by its worst quality (Eastman, 1999).

Output maps shown in this section refer only to the AND operator and the OWA since, concerning the OR operator, results obtained with the r.mcda.fuzzy module do not present any difference in the scenarios examined. Indeed, the union operator (OR) considers the most positive value in each pixel that, in the case of fuzzy criteria, is a value equal or close to 1. In the present study, maps derived from the OR operator reported a value equal to 1 for the whole region and for both wheat and lentil in each scenario. Therefore, this result is not presented, due to the fact that the OR operator determines a high level of risk in terms of choices related to the selection of suitable lands, since the approach only takes into account the most positive values and does not include less performing criteria and it does not allow trade-off between criteria. Regarding OWA outcomes, output maps derive from the average of weighted and summed criteria, therefore the approach corresponds to a

WLC that considers equal order weights for the criteria. Since the criteria in the present analysis are 8, the order weight assigned automatically to each parameter by the r.mcda.fuzzy module is 0.125. The OWA and the AND operator derived from the GRASS module adopt preference weights as linguistic modifiers and, for this reason, according to Massei (2010), weights are not multiplied to criteria, but they are used as exponents of criteria. As described in the *ordered weighted averaging* section, this approach in the AND operator allows to identify the actual minimum value in each pixel, taking into account the relative importance of criteria. The OWA is computed in the same way, but all values are used, not only the minimum or the maximum value, leading to a full trade-off between criteria.

Besides these observations, it should be noted that final outputs derived from the OWA approach are not reclassified as in the WLC previously described, but maps are maintained as direct results of the overlay of fuzzy criteria, in order to represent the continuous nature of the parameters involved. Most suitable lands are therefore identified based on values equal or close to 1.

The flowchart of the OWA method that summarizes the procedure adopted in the present work is shown below, followed by output maps related to the AND operator and the OWA.

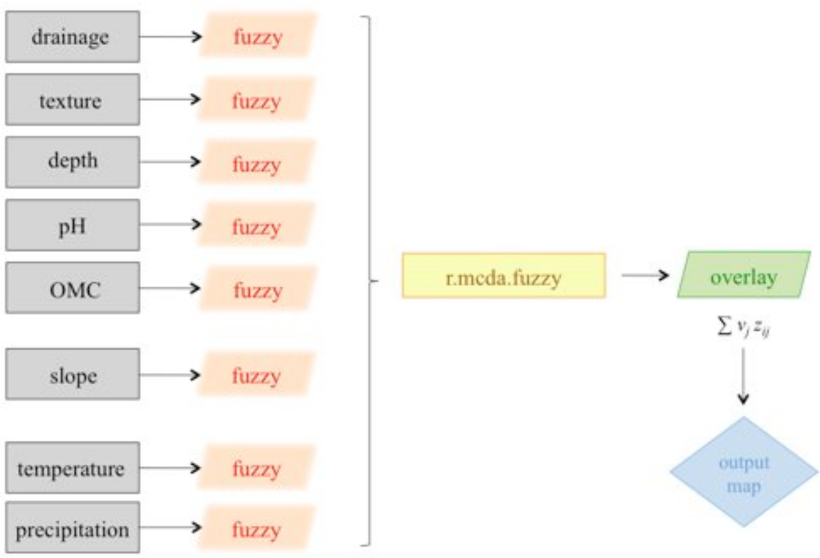


Figure 48. The ordered weighted averaging flowchart.

Figure 49, 50 and 51 report land suitability maps for wheat and lentil cultivation and for the two crops combined in rotation in the region of RSZZ, considering current climate conditions and the A2 climate change scenario in the four GCMs considered. Maps on the left derive from the AND operator, while maps on the right are originated from the OWA.

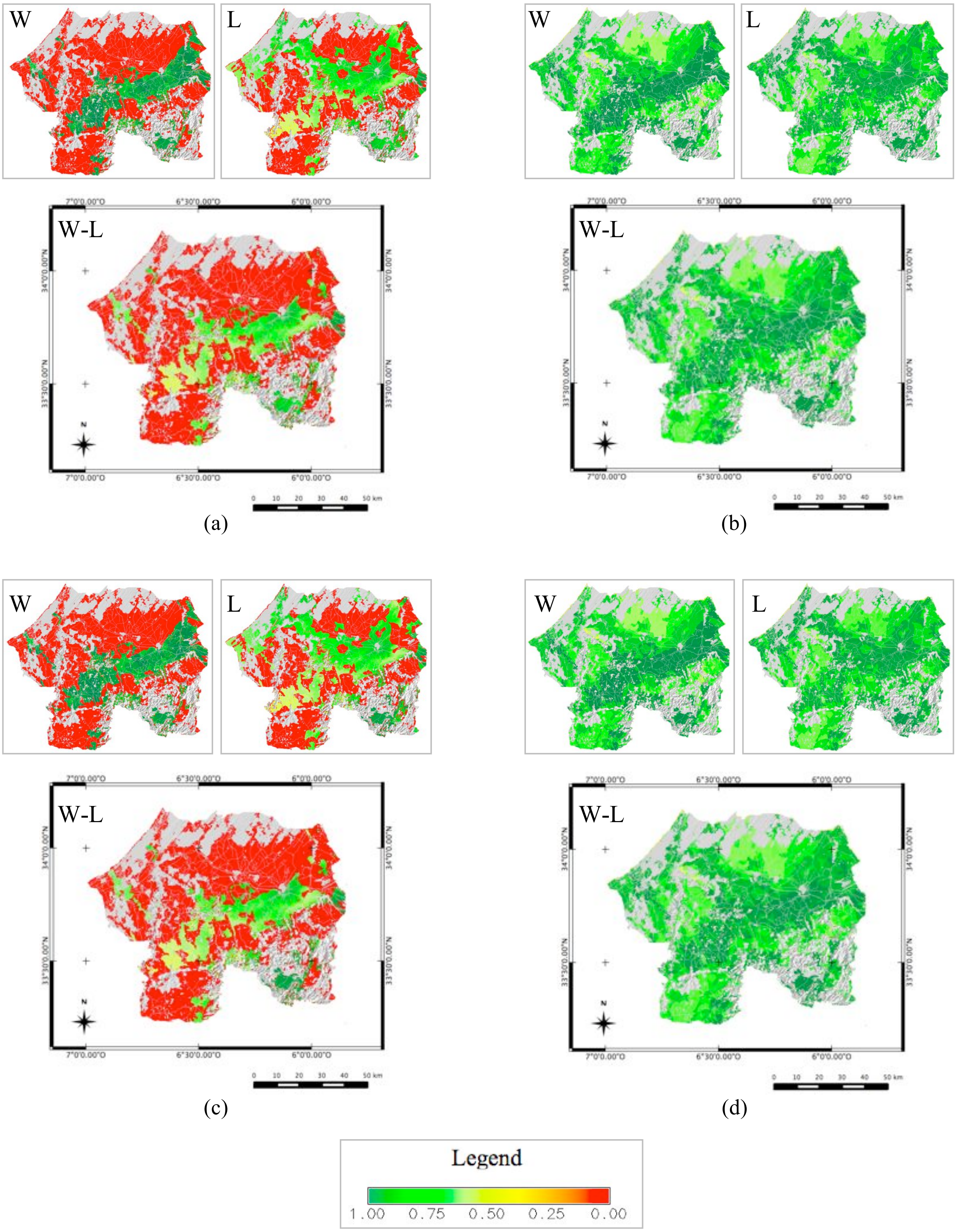


Figure 49. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under current climate (a,b) and under the SRES A2 climate change scenario based on the IPSL-CM4 model (c,d). AND operator (left) and OWA (right).

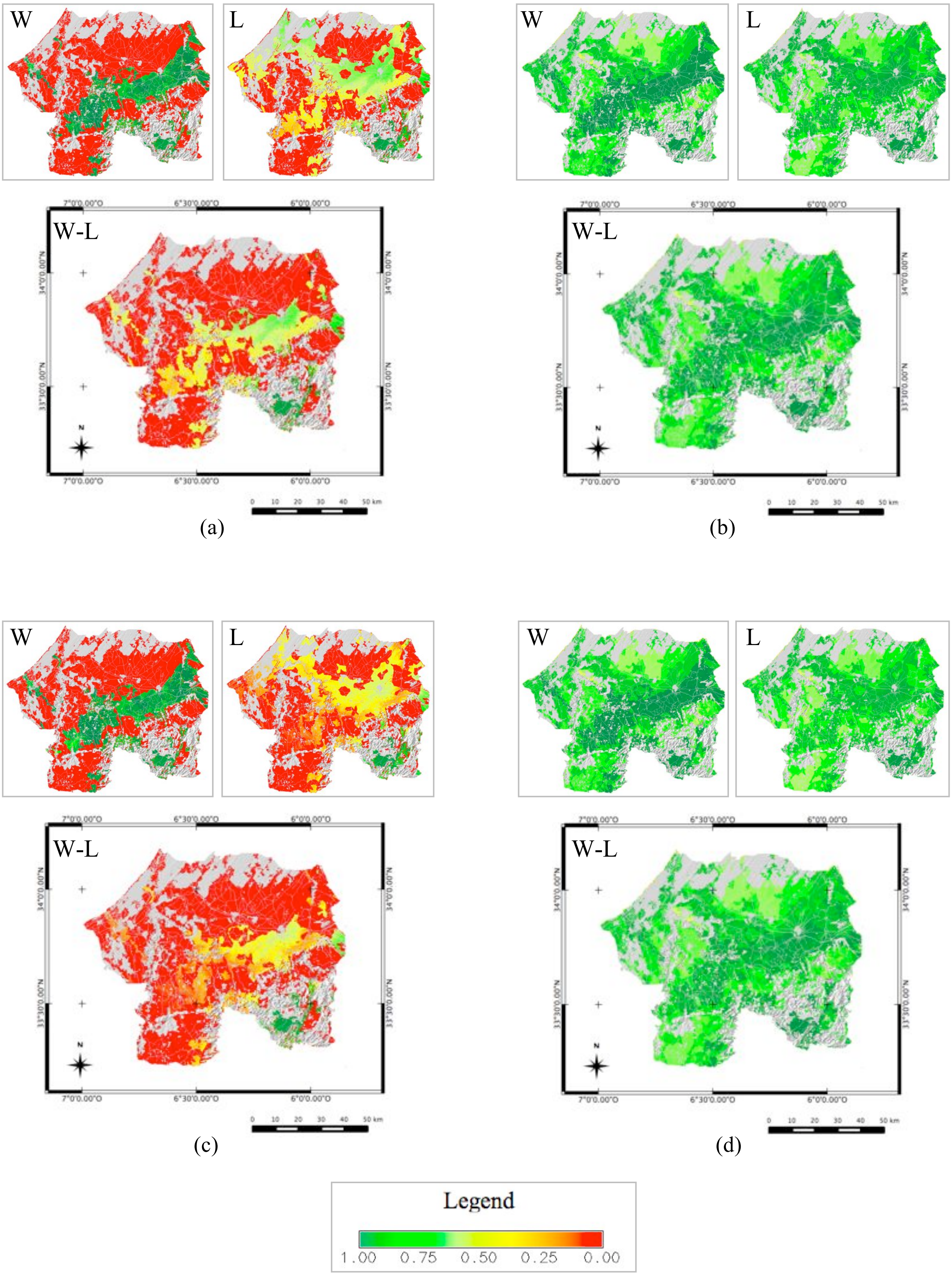


Figure 50. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario based on the INGV-ECHAM4 (a,b) and the UKMO-HadCM3 (c,d) models. AND operator (left) and OWA (right).

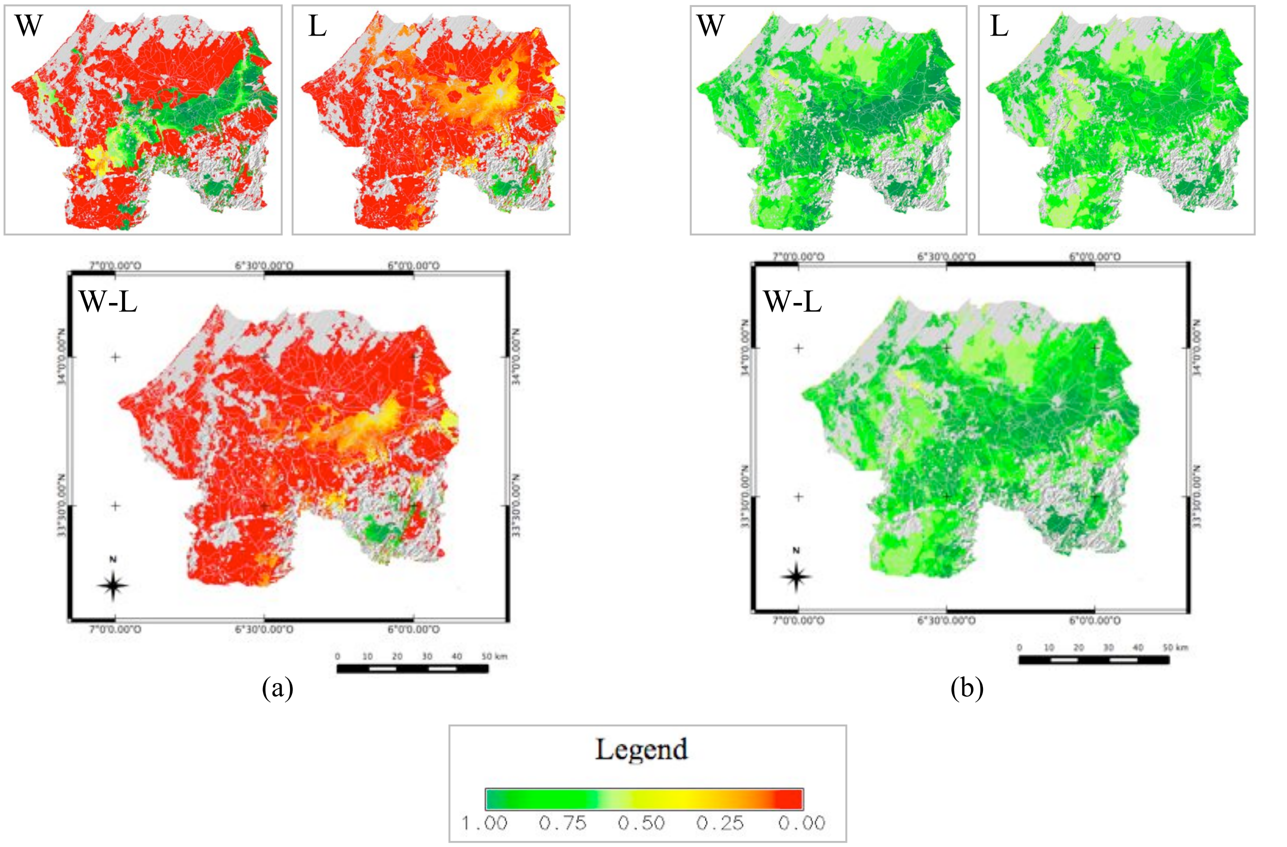


Figure 51. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario based on the GFDL-CM2.0 model (a,b). AND operator (left) and OWA (right).

Output maps that represent the application of the AND operator can be compared with maps derived from the MAX operator and maps showing the OWA with maps derived from the WLC. A first consideration can be made on the effect that fuzzy criteria and the subsequent elaboration in GRASS through the r.mcda.fuzzy module produce. Concerning the AND operator, higher variability is described by the use of fuzzy criteria and final outcomes generally show more differences between scenarios than in the case of the MAX operator. Even though the area characterized by value 0 is the same as in the first approach, in this case, land suitability of the central part of the region varies widely, from the highest degree of suitability in current climate, to the lowest under climate change based on the GFDL-CM2.0 model. Overall, the AND operator reveals the prevalence of medium-low values compared to the theoretical range [0,1], indeed green tones that corresponds to the maximum level of suitability for wheat and lentil are present only in few areas of the region. Concerning the OR operator, results are the opposite. Most of the values fall in the upper range. In this case, all maps realized with the OR operator resulted to be identical and represented by the highest value. In the present work, maps obtained with the OR operator are not represented, as previously explained. Maps resulting from the OWA operator are instead characterized by spread values and full trade-off. If maps derived from the OWA operator are compared with maps obtained from the WLC, there are both similarities and differences that can be underlined. Outcomes of the OWA approach are more in line with outcomes of the WLC without preference weights than with the second WLC approach. This is due to the different use of preference weights in the OWA compared to the WLC with preference weights, indeed, preference weights in the OWA play a less important role than order weights and, for this reason, their influence is reduced over the final output map. Overall, maps reclassified in the WLC approaches showed lower land suitability than maps resulting from the OWA method. Nevertheless, final results show higher suitability in the central part of RSZZ for both WLC and OWA and lentil is attested to have worse performances compared to wheat both under current climate and under climate change scenarios, as shown in previous approaches. A last consideration can be made comparing land suitability maps for wheat and lentil rotation under current climate with the land suitability maps for wheat and lentil rotation related to climate change based on the GFDL-CM2.0 model. It should be noted that a direct comparison related to the amount of hectares linked to the degree of suitability is not possible without further reclassification, therefore only difference maps are illustrated (Figure 52).

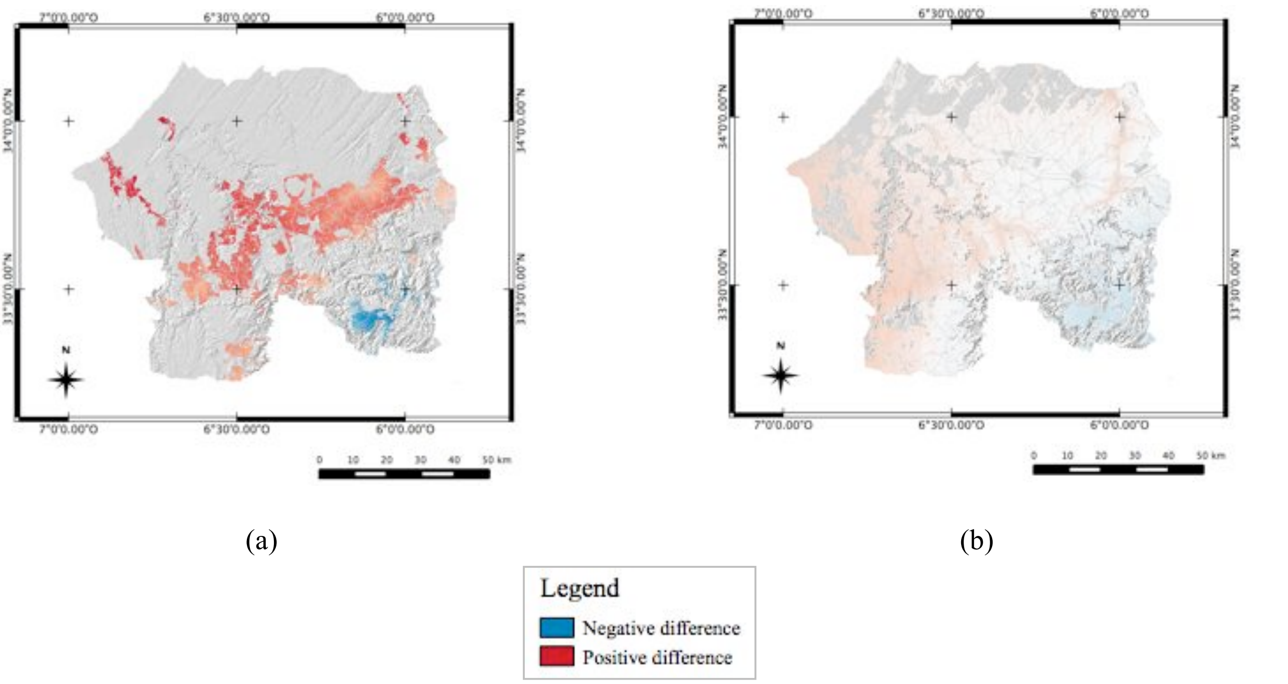


Figure 52. Difference maps of the suitability of wheat and lentil rotation obtained from the two maps (a,b) in Figure 49 and the two maps (a,b) in Figure 51. Red areas show a positive difference and therefore a worsening of land suitability under climate change, while blue areas represent a negative difference that corresponds to an improvement in land suitability under climate change. White areas show values in between the two categories. AND operator (left) and OWA (right).

The difference map related to the AND operator (a) reports stronger differences compared to the difference map of the OWA (b). The AND operator shows higher differences in the central part of the region compared to the OWA. However, a worsening of conditions is attested to likely occur close to the western hedge of the region in both cases, whereas in the Oulmes plateau an improvement in land suitability is recognized. These results appear to have some discrepancies compared to outcomes obtained from the approaches previously analyzed, but the overall worsening of land suitability in important locations for the cultivation of wheat and lentil is a common output of the different models used in the analysis.

A final approach is now illustrated to present another GIS-MCDA module in GRASS and to show changes related to the use of other preference weights.

4.4. Land suitability analysis based on analytic hierarchy process

The AHP method includes the use of preference weights obtained through a pair-wise comparison. As explained in the previous chapter, the allocation of values in the pair-wise comparison matrix resulted to be slightly inconsistent, with a CR > 0.1. However, for the purpose of the present work, values given by the expert at INRA-Rabat have been used anyway, in order to show what a change in preference weights may lead to. Moreover, the r.mcda.ahp module in GRASS, which has been developed by Massei (2010), is adopted to compute the LSA. The module allows running the analysis without prior definition of final weights, since it automatically generates them from the pair-wise matrix. Figure 53 shows the AHP flowchart that summarizes the procedure used in this study. The decision rule applied is the same as for the WLC method, since the r.mcda.ahp module simply produces a WLC with weights derived from a pair-wise comparison.

In the AHP approach criteria standardized based on fuzzy membership functions have been used and, as for the OWA approach, final results have been maintained without further reclassification. Subsequently, output maps have been compared to detect discrepancies and similarities and to identify suitable lands for wheat and lentil rotation.

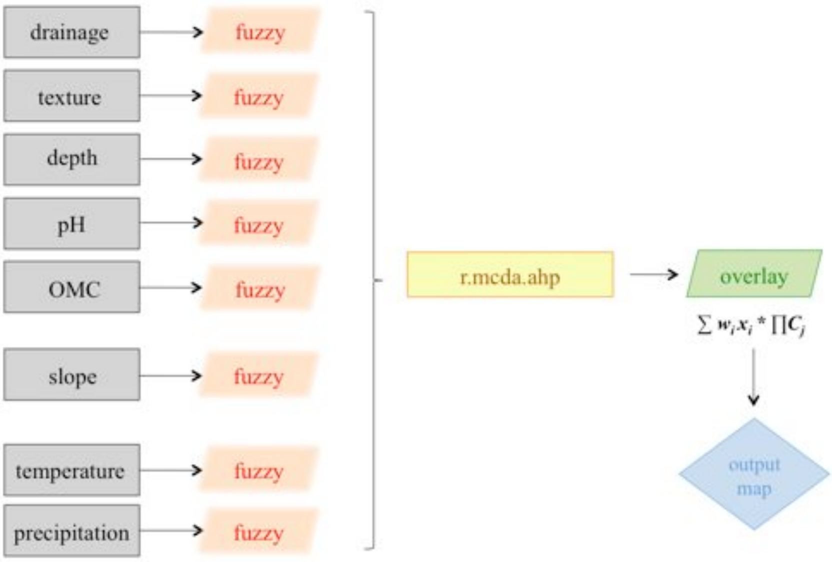


Figure 53. The analytic hierarchy process flowchart.

Results derived from the application of the AHP module are shown below. Figure 54 and Figure 55 describe land suitability maps for wheat and lentil cultivation and for the two crops combined in rotation in the region of RSZZ, considering current climate conditions and the A2 climate change scenario in the four GCMs models.

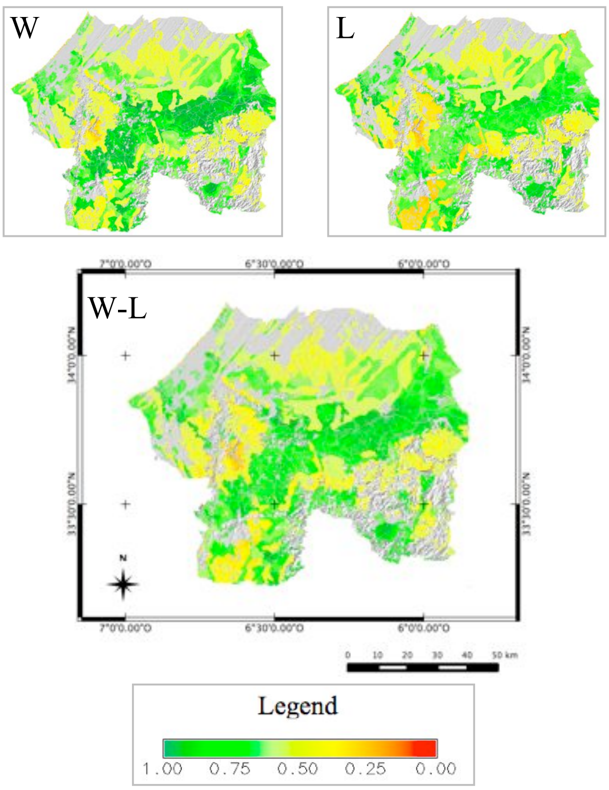


Figure 54. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under current climate conditions (AHP).

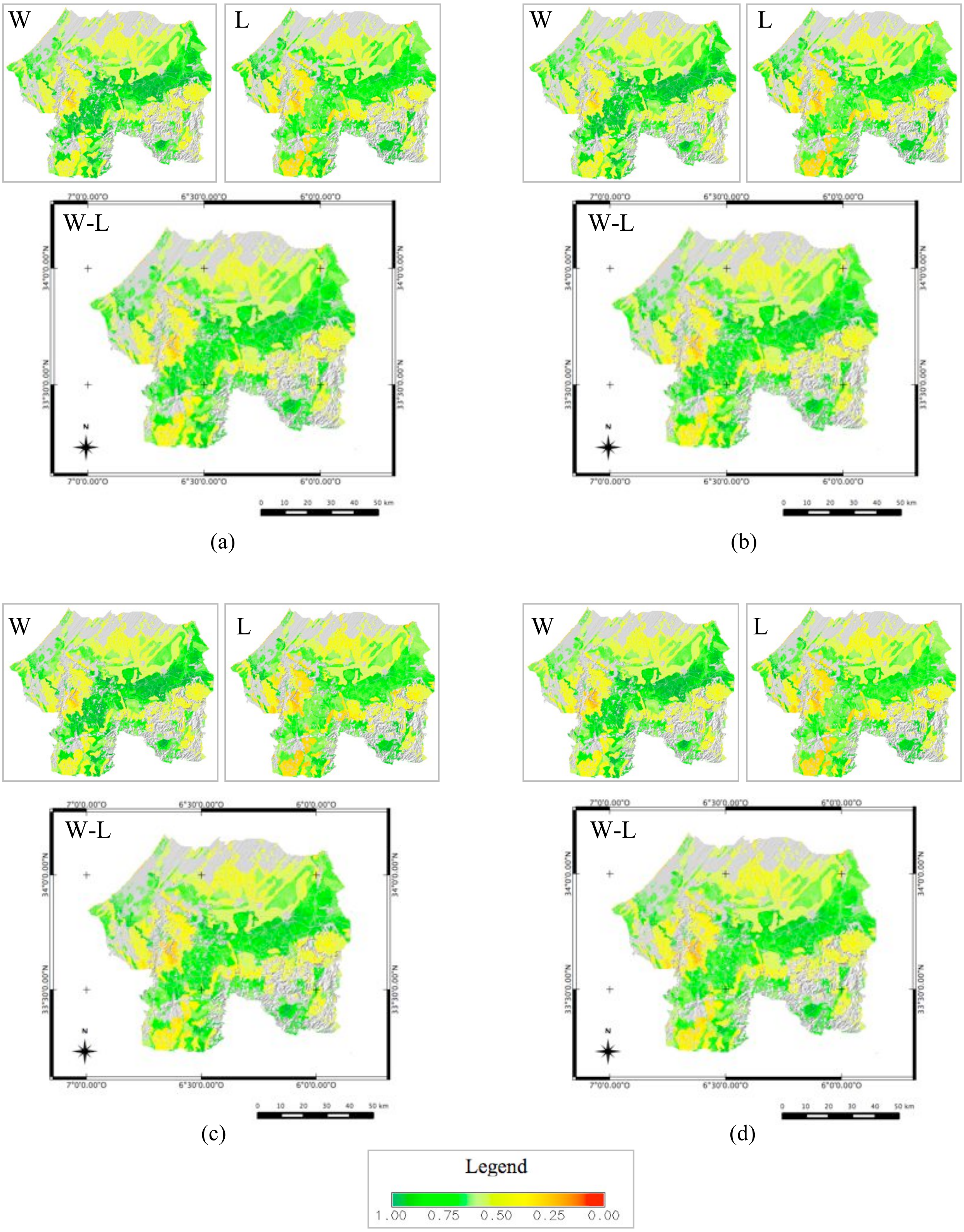


Figure 55. Land suitability map of wheat (W) and lentil (L) cultivation and land suitability map for wheat and lentil (W-L) rotation in RSZZ under the SRES A2 climate change scenario in (a) IPSL-CM4, (b) INGV-ECHAM4, (c) UKMO-HadCM3 and (d) GFDL-CM2.0 models (AHP).

Compared to outcomes previously illustrated, the main clear difference is the predominance of other criteria in the final LSA. Indeed, preference weights obtained with the pair-wise comparison approach reveal that the highest importance is assigned to drainage, followed by soil depth and texture. Concerning precipitation and temperature parameters, weights assigned to these two criteria are the lowest. For this reason, the variation between wheat and lentil maps under current climate conditions and under climate change scenarios is not evident, since the only factors that change among the criteria are temperature and precipitation and these are also the less affecting criteria in the AHP approach. Nevertheless, the model that deviates the most from the present situation is the GFDL-CM2.0, as reported also in all the previous methods adopted.

Regarding the overall degree of suitability, the central part of the region is the one with the highest score. Therefore, the province of Khemisset results to be the province with most of the suitable lands for wheat and lentil cultivation. Suitable lands are also partially present in the prefecture of Skhirat-Temara. As reported in the outcomes derived from the other approaches, wheat generally presents higher suitability compared to lentil, but in this case there are not extreme differences between the two crops. Considering climate change scenarios, a worsening in the degree of suitability is attested to likely occur in the western part of the region, as shown by the low level of suitability reached in some areas close to the border with Chaouia. To better understand this change, a last observation can be made comparing the land suitability map for wheat and lentil rotation under current climate conditions, with the map obtained under the A2 climate scenario described by the GFDL-CM2.0 model. Due to the use of fuzzy criteria, no further reclassification has been computed to define hectares corresponding to suitability classes, therefore only the difference map is provided (Figure 56).

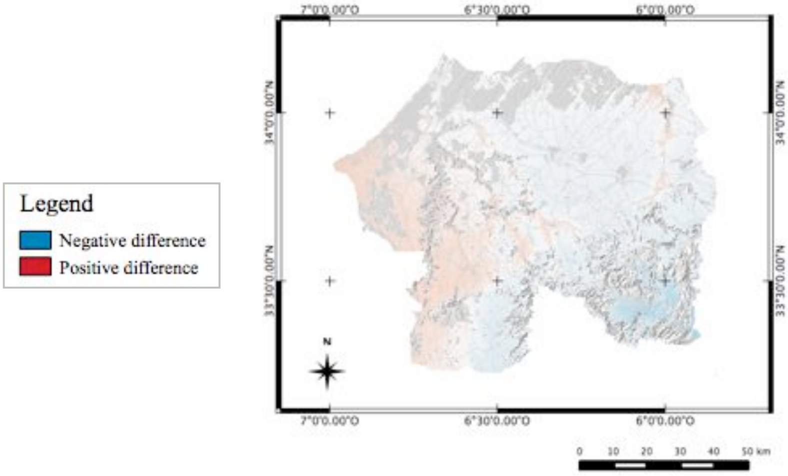


Figure 56. Difference map of the suitability of wheat and lentil rotation obtained from the map in Figure 54 and the map (d) in Figure 55. Red areas show a positive difference and therefore a worsening of land suitability under climate change, while blue areas represent a negative difference that corresponds to an improvement in land suitability under climate change. White areas show values in between the two categories.

The difference map generated almost corresponds to the difference map illustrated in the OWA approach, but differences outlined here are slightly more negative than in the OWA.

The last section of the *results and discussion* chapter aims at locating a possible vulnerable area to climate change in the region of RSZZ, where the introduction of adaptation measures such as CA and NT will increase crops productivity, preserving soil from erosion and enhancing water retention, in order to cope with the worsening in land suitability projected for wheat and lentil.

4.5. Application of conservation agriculture in vulnerable areas

Through a simple overlay of difference maps obtained from the approaches followed in this study, the area of Merchouch-Rommani-Ain Sbit has been considered as particularly vulnerable to climate change for the cultivation of wheat and lentil (Figure 57). According to INRA (2011), these two crops play a pivotal role in the area and the area itself results to be characterized by high levels of suitability for these two crops, as shown in the LSA carried out in the present work. However, the projected reduction in precipitation has been attested to highly influence the land suitability of the western part of the region, where this area is located. For this reason, the Merchouch-Rommani-Ain Sbit area is taken as an example for strategies that should be selected and applied in order to cope with predicted changes.

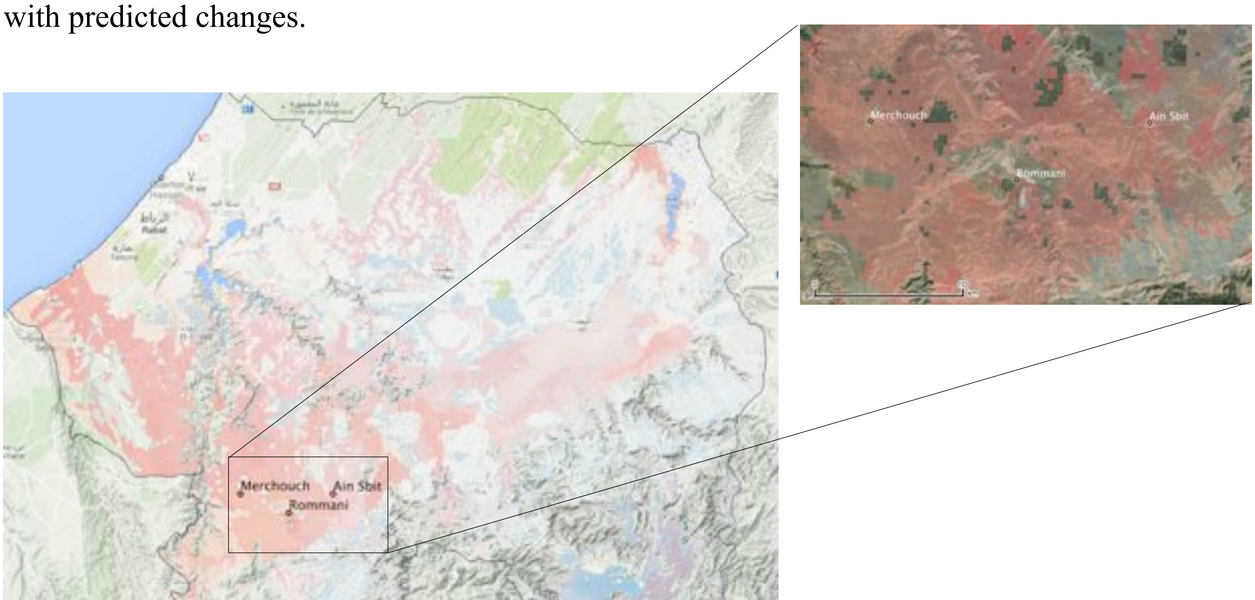


Figure 57. The area of Merchouch-Rommani-Ain Sbit and difference maps combined.

Opportune adaptation measures, such as CA and NT have been identified as valuable solutions in the area of Merchouch-Rommani-Ain Sbit. However, the application of these measures requires a deep knowledge on means and techniques to be adopted. According to Boughlala et al. (2011), farmers often come across problems in front of the decision of choosing CA, since they may reveal lack of knowledge in the fundamentals of this technique or they may need appropriate resources in order to adopt CA and NT. To improve this knowledge and to support cooperation between farmer cooperatives, INRA conducts strategies for intervention to promote CA. These strategies include the planning of both theoretical and practical meetings on the opportune application of CA. The participation of all the stakeholders involved (e.g. farmers, scientists, decision makers, etc.) is of primary importance for the success of the organized training. Figure 58 show moments of CA process disclosure with the presentation of the direct seed drill, which is a special seeder to be used under NT conditions. Concerning this point, Mrabet (2000) states that the improvement in direct drill design should be the focus of the mechanization sector in Morocco. Moreover, another important point is residue management in CA and the area of Merchouch-Rommani-Ain Sbit results to have the chance of improving soil cover in the fields, since according to local experts, in the area the amount of livestock that may reduce the residue left on the field due to overgrazing is minimal.

The same effort here described should be promoted in other communities, other vulnerable locations and for other economically relevant crops, in order to preserve local products and biodiversity for future generations and therefore reach a sustainable agriculture in areas that will be likely affected by climate change.

Figure 58. Strategies for intervention to promote CA include the plan of both theoretical and practical public meetings on the opportune application of CA, with the participation of all possible stakeholders.

5. Conclusions and recommendations

The purpose of the present work has been the analysis of the utility of an integrated approach, based on GIS and MCDA, in the case of a LSA for wheat and lentil cultivation under current and climate change scenarios in the region of RSZZ in Central Morocco. Suitable lands where wheat and lentil can be grown in rotation have been identified. Difference maps for the five followed approaches have been produced, in order to underline where climate change is more likely to occur. The introduction of CA and NT as suitable adaptation measures to cope with climate change has been described as a possible solution in vulnerable areas, where crops suitability reaches the highest level and where climate change is expected to cause major problems in the cultivation of wheat and lentil.

Another important point has been to make the analysis reproducible for further studies, reporting the source of data sets used, the way of gathering them and a script of main operations adopted within GRASS, which is the GIS tool used for computing the analysis.

The following research questions have been answered:

1. How climate change influences the cultivation of wheat and lentil crops in RSZZ?

Results obtained from the LSA with the application of GIS techniques highlight an overall worsening of wheat and lentil suitability in the western part of the region of RSZZ. The weighted linear combination without preference weights, the ordered weighted averaging and the analytic hierarchy process also show a slight improvement of the overall suitability in some areas, especially in the Oulmes plateau. This improvement is linked to an increase in mean temperature in the mountain regions.

2. Where is the rotation of wheat and lentil crops more suitable and what are the conditions for the application of CA and NT in defined areas?

Output maps derived from the application of different methods to compute the LSA reveal similar outcomes in terms of wheat and lentil suitability. These outcomes show that the central part of the region of RSZZ, corresponding to the province of Khemmiset, results the most favorable for these two crops, both under current climate conditions and under climate change scenarios. However, suitability is highly reduced under the A2 climate change scenario described by the GFDL-CM2.0 model. To deal with this worsening, the adoption of CA and NT is a suitable solution. Opportune knowledge, means and resources are needed for the application of these techniques. The dissemination of information has been promoted by INRA as an important step to reach the adoption of CA and NT by farmers. Meetings and training sessions with all the stakeholders involved aim at describing all the required passages for a full comprehension of CA and NT.

3. What improvements can be obtained from the combination of GIS and MCDA tools in a multidisciplinary approach and how to make the analysis reproducible?

The methodology followed in the present work showed how GIS-MCDA approaches are a powerful tool when geographical data sets and expert or decision maker's judgments need to be combined to solve spatial decision problems. Five different interactions of criteria, weights and decision rules have been considered and none has been excluded from the final representation, in order to define the variation that results may present. Even the simplest approach has been considered, since it can provide useful information at the beginning of the evaluation. All the data sets used in the LSA have been described and detailed information is available in the form of metadata in Annex I. GIS operations and main commands used in GRASS to compute the analysis are also made available in Annex II. In this way, further analyses may be carried out based on the approaches followed and data sets used in this work.

The present work has highlighted the potential of the integration between GIS and MCDA techniques, underling the utility of this approach in supporting decision making in a clear way, thanks to the presentation of final results in the form of thematic maps. Therefore, GIS-MCDA techniques provide a first valuable support for subsequent analyses of higher detail. Possible limits related to GIS-MCDA are mainly data availability, data accessibility and data preprocess prior to the final use, since these steps are all crucial points and they must be carefully considered.

Future improvements of the present research may consist in the selection of more detailed data sets to compute the analysis at a district level. Moreover, the suitability of other relevant crops may be investigated in the region of RSZZ or in other vulnerable regions of Morocco. Different climate change scenarios can be also used (e.g. RCPs when easily available for download) and socio-economic data integrated for further considerations on the adoption of CA and NT compared to CT.

6. References

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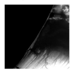
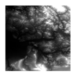
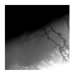
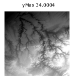
ANNEXES

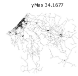
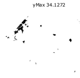
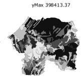
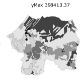
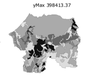
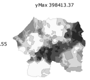
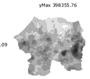
ANNEX I - METADATA

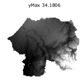
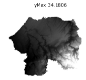
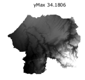
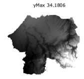
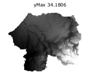
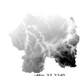
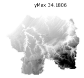
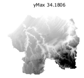
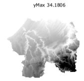
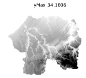
	IDENTIFICATION					
	Resource title	Resource abstract	Resource type	Resource locator	Unique resource identifier	Resource language
ADMINISTRATIVE BOUNDARIES	MAR_adm	GADM database of Global Administrative Areas. Countries and lower level subdivisions. GADM describes where administrative areas are and it provides attributes. The current version is 2.0 (January 2012).	dataset	GADM web site http://www.gadm.org/	NA	English
ADMINISTRATIVE BOUNDARIES	ESH_adm	GADM database of Global Administrative Areas. Countries and lower level subdivisions. GADM describes where administrative areas are and it provides attributes. The current version is 2.0 (January 2012).	dataset	GADM web site http://www.gadm.org/	NA	English
ADMINISTRATIVE BOUNDARIES	ne_10m_admin_1_states_provinces_lines	Natural Earth is a public domain map dataset of free vector and raster map data available at 1:10m, 1:50m, and 1:110 million scales.	dataset	Natural Earth http://www.naturalearthdata.com/	NA	English
ADMINISTRATIVE BOUNDARIES	decoupage_adm_rszz	NA	dataset	INRA Rabat	NA	French
ADMINISTRATIVE BOUNDARIES	rabat_lim_prov	NA	dataset	INRA Rabat	NA	French
DIGITAL ELEVATION MODEL	n34_w007_3arc_v2	The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude.	dataset	USGS Earth Explorer http://earthexplorer.usgs.gov/	SRTM3N34W007V2	English
DIGITAL ELEVATION MODEL	n34_w006_3arc_v2	The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude.	dataset	USGS Earth Explorer http://earthexplorer.usgs.gov/	SRTM3N34W006V2	English
DIGITAL ELEVATION MODEL	n33_w008_3arc_v2	The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude.	dataset	USGS Earth Explorer http://earthexplorer.usgs.gov/	SRTM3N33W008V2	English
DIGITAL ELEVATION MODEL	n33_w007_3arc_v2	The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude.	dataset	USGS Earth Explorer http://earthexplorer.usgs.gov/	SRTM3N33W007V2	English
DIGITAL ELEVATION MODEL	n33_w006_3arc_v2	The Shuttle Radar Topography Mission (SRTM) is a partnership between NASA and the National Geospatial-Intelligence Agency (NGA). Flown aboard the NASA Space Shuttle Endeavour (11-22 February 2000), SRTM fulfilled its mission to map the world in three dimensions. The USGS is under agreement with NGA and NASA's Jet Propulsion Laboratory to distribute the C-band data. SRTM utilized dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer to successfully collect data over 80 per cent of the Earth's land surface, everything between 60 degrees North and 56 degrees South latitude.	dataset	USGS Earth Explorer http://earthexplorer.usgs.gov/	SRTM3N33W006V2	English

	CLASSIFICATION OF SPATIAL DATA AND SERVICES		KEYWORD		GEOGRAPHIC LOCATION
Resource title	Topic category (ISO 19115 category)	Spatial data service type	Keyword value	Originating controlled vocaulary	Geographic bounding box
MAR_adm	003 boundaries	Download	National boundary, sub-national boundary	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 35.9226 xMin -13.1679  xMax -0.997406 yMin 27.6701
ESH_adm	003 boundaries	Download	National boundary, sub-national boundary	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 27.6831 xMin -17.1054  xMax -8.67001 yMin 20.7696
ne_10m_admin_1_states_provinces_lines	003 boundaries	Download	National boundary, sub-national boundary	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 35.1996 xMin -15.0004  xMax -1.24445 yMin 21.5814
decoupage_adm_rszz	003 boundaries	NA	National boundary, sub-national boundary	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1807 xMin -7.11886  xMax -5.73244 yMin 33.224
rabat_lim_prov	003 boundaries	NA	National boundary, sub-national boundary	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.9285 xMin -7.4251 xMax -5.70658 yMin 32.6387
n34_w007_3arc_v2	010 imageryBaseMapsEarthCover	View, download	NASA, NGA, Shuttle Radar Topography Mission, 90-meter resolution- 3 arc second of the world, Elevation, SRTM, Mapping, Topography, DTED		yMax 35.0004 xMin -7.0004  xMax -5.9995 yMin 33.9995
n34_w006_3arc_v2	010 imageryBaseMapsEarthCover	View, download	NASA, NGA, Shuttle Radar Topography Mission, 90-meter resolution- 3 arc second of the world, Elevation, SRTM, Mapping, Topography, DTED		yMax 35.0004 xMin -6.0004  xMax -4.9995 yMin 33.9995
n33_w008_3arc_v2	010 imageryBaseMapsEarthCover	View, download	NASA, NGA, Shuttle Radar Topography Mission, 90-meter resolution- 3 arc second of the world, Elevation, SRTM, Mapping, Topography, DTED		yMax 34.0004 xMin -8.0004  xMax -6.9995 yMin 32.9995
n33_w007_3arc_v2	010 imageryBaseMapsEarthCover	View, download	NASA, NGA, Shuttle Radar Topography Mission, 90-meter resolution- 3 arc second of the world, Elevation, SRTM, Mapping, Topography, DTED		yMax 34.0004 xMin -7.0004  xMax -5.9995 yMin 32.9995
n33_w006_3arc_v2	010 imageryBaseMapsEarthCover	View, download	NASA, NGA, Shuttle Radar Topography Mission, 90-meter resolution- 3 arc second of the world, Elevation, SRTM, Mapping, Topography, DTED		yMax 34.0004 xMin -6.0004  xMax -4.9995 yMin 32.9995

	TEMPORAL REFERENCE					QUALITY AND VALIDITY	
Resource title	Temporal extent	Date of publication	Date of last revision	Date of cration	Acquisition date	Lineage	Spatial resolution
MAR_adm	NA	NA	NA	NA	NA	NA	country
ESH_adm	NA	NA	NA	NA	NA	NA	country
ne_10m_admin_1_states_provinces_lines	NA	NA	NA	NA	NA	NA	regions
decoupage_adm_rszz	NA	NA	20-Dec-13	NA	NA	NA	districts
rabat_lim_prov	NA	NA	NA	NA	NA	NA	provinces
n34_w007_3arc_v2	NA	1-Oct-12	17-Apr-13	NA	11-Feb-00	SRTM data at 1 arc second (30 meter) is currently available for the United States, its territories and possessions. SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. Raster size is 1 degree tiles. The data is expressed in geographic coordinates (latitude/longitude) and is horizontally referenced to WGS84 and vertically referenced to the EGM96 Geoid.	3 arc-seconds GDT_Int16 - Sixteen bit signed integer
n34_w006_3arc_v2	NA	1-Oct-12	17-Apr-13	NA	11-Feb-00	SRTM data at 1 arc second (30 meter) is currently available for the United States, its territories and possessions. SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. Raster size is 1 degree tiles. The data is expressed in geographic coordinates (latitude/longitude) and is horizontally referenced to WGS84 and vertically referenced to the EGM96 Geoid.	3 arc-seconds GDT_Int16 - Sixteen bit signed integer
n33_w008_3arc_v2	NA	1-Oct-12	17-Apr-13	NA	11-Feb-00	SRTM data at 1 arc second (30 meter) is currently available for the United States, its territories and possessions. SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. Raster size is 1 degree tiles. The data is expressed in geographic coordinates (latitude/longitude) and is horizontally referenced to WGS84 and vertically referenced to the EGM96 Geoid.	3 arc-seconds GDT_Int16 - Sixteen bit signed integer
n33_w007_3arc_v2	NA	1-Oct-12	17-Apr-13	NA	11-Feb-00	SRTM data at 1 arc second (30 meter) is currently available for the United States, its territories and possessions. SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. Raster size is 1 degree tiles. The data is expressed in geographic coordinates (latitude/longitude) and is horizontally referenced to WGS84 and vertically referenced to the EGM96 Geoid.	3 arc-seconds GDT_Int16 - Sixteen bit signed integer
n33_w006_3arc_v2	NA	1-Oct-12	17-Apr-13	NA	11-Feb-00	SRTM data at 1 arc second (30 meter) is currently available for the United States, its territories and possessions. SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. Raster size is 1 degree tiles. The data is expressed in geographic coordinates (latitude/longitude) and is horizontally referenced to WGS84 and vertically referenced to the EGM96 Geoid.	3 arc-seconds GDT_Int16 - Sixteen bit signed integer

	CONSTRAINT RELATED TO ACCESS AND USE		ORGANISATIONS RESPONSIBLE FOR THE ESTABLISHMENT, MANAGEMENT, MAINTENANCE AND DISTRIBUTION OF SPATIAL DATA SETS AND SERVICES		METADATA ON METADATA			
Resource title	Conditions applying to access and use	Limitation on public access	Responsible party	Responsible party role	Metadata language	Distribution format	Data type	Reference system
MAR_adm	Data are freely available for academic and other non-commercial use. Redistribution, or commercial use, is not allowed without prior permission.	Public	Robert Hijmans: rhijmans@ucdavis.edu Nell Garcia, Arnel Rala, Aileen Maunahan (International Rice Research Institute) John Wieczorek, Julian Kapoor (Univeristy of California, Berkeley, Museum of Vertebrate Zoology)	Point of contact	English	.shp	vector	WGS84
ESH_adm	Data are freely available for academic and other non-commercial use. Redistribution, or commercial use, is not allowed without prior permission.	Public	Robert Hijmans: rhijmans@ucdavis.edu Nell Garcia, Arnel Rala, Aileen Maunahan (International Rice Research Institute) John Wieczorek, Julian Kapoor (Univeristy of California, Berkeley, Museum of Vertebrate Zoology)	Point of contact	English	.shp	vector	WGS84
ne_10m_admin_1_states_provinces_lines	All versions of Natural Earth raster + vector map data found on the website are in the public domain. You may use the maps in any manner, including modifying the content and design, electronic dissemination, and offset printing. The primary authors, Tom Patterson and Nathaniel Vaughn Kelso, and all other contributors renounce all financial claim to the maps and invites you to use them for personal, educational, and commercial purposes. No permission is needed to use Natural Earth. Crediting the authors is unnecessary.	Public	Nathaniel Vaughn Kelso: nathaniel@naturalearthdata.com Project Manager	Point of contact	English	.shp	vector	WGS84
decoupage_adm_rszz	NA	Limited	Hamza Iaaich: hamza.iaaich@gmail.com INRA Rabat	Point of contact	English	.shp	vector	WGS84
rabat_lim_prov	NA	Limited	Rachid Moussadek: rachidmoussadek@yahoo.fr INRA Rabat	Point of contact	English	.shp	vector	NAD27
n34_w007_3arc_v2	There is no guarantee of warranty concerning the accuracy of these data. Users should be aware that temporal changes may have occurred since the data was collected and that some parts of these data may no longer represent actual surface conditions. Users should not use these data for critical applications without a full awareness of their limitations. Acknowledgement of the originating agencies would be appreciated in products derived from these data. Any user who modifies the data set is obligated to describe the types of modifications they perform. User specifically agrees not to misrepresent the data set, nor to imply that changes made were approved or endorsed by the U.S. Geological Survey.	Public	lta@usgs.gov U.S. Geological Survey Earth Resources Observation and Science (EROS) Center	Long Term Archive (LTA) User Services Point of contact	English	.tif Band Interleaved by line (BIL) Digital Terrain Elevation Data (DTED)	raster GeoTIFF	WGS84
n34_w006_3arc_v2	There is no guarantee of warranty concerning the accuracy of these data. Users should be aware that temporal changes may have occurred since the data was collected and that some parts of these data may no longer represent actual surface conditions. Users should not use these data for critical applications without a full awareness of their limitations. Acknowledgement of the originating agencies would be appreciated in products derived from these data. Any user who modifies the data set is obligated to describe the types of modifications they perform. User specifically agrees not to misrepresent the data set, nor to imply that changes made were approved or endorsed by the U.S. Geological Survey.	Public	lta@usgs.gov U.S. Geological Survey Earth Resources Observation and Science (EROS) Center	Long Term Archive (LTA) User Services Point of contact	English	.tif Band Interleaved by line (BIL) Digital Terrain Elevation Data (DTED)	raster GeoTIFF	WGS84
n33_w008_3arc_v2	There is no guarantee of warranty concerning the accuracy of these data. Users should be aware that temporal changes may have occurred since the data was collected and that some parts of these data may no longer represent actual surface conditions. Users should not use these data for critical applications without a full awareness of their limitations. Acknowledgement of the originating agencies would be appreciated in products derived from these data. Any user who modifies the data set is obligated to describe the types of modifications they perform. User specifically agrees not to misrepresent the data set, nor to imply that changes made were approved or endorsed by the U.S. Geological Survey.	Public	lta@usgs.gov U.S. Geological Survey Earth Resources Observation and Science (EROS) Center	Long Term Archive (LTA) User Services Point of contact	English	.tif Band Interleaved by line (BIL) Digital Terrain Elevation Data (DTED)	raster GeoTIFF	WGS84
n33_w007_3arc_v2	There is no guarantee of warranty concerning the accuracy of these data. Users should be aware that temporal changes may have occurred since the data was collected and that some parts of these data may no longer represent actual surface conditions. Users should not use these data for critical applications without a full awareness of their limitations. Acknowledgement of the originating agencies would be appreciated in products derived from these data. Any user who modifies the data set is obligated to describe the types of modifications they perform. User specifically agrees not to misrepresent the data set, nor to imply that changes made were approved or endorsed by the U.S. Geological Survey.	Public	lta@usgs.gov U.S. Geological Survey Earth Resources Observation and Science (EROS) Center	Long Term Archive (LTA) User Services Point of contact	English	.tif Band Interleaved by line (BIL) Digital Terrain Elevation Data (DTED)	raster GeoTIFF	WGS84
n33_w006_3arc_v2	There is no guarantee of warranty concerning the accuracy of these data. Users should be aware that temporal changes may have occurred since the data was collected and that some parts of these data may no longer represent actual surface conditions. Users should not use these data for critical applications without a full awareness of their limitations. Acknowledgement of the originating agencies would be appreciated in products derived from these data. Any user who modifies the data set is obligated to describe the types of modifications they perform. User specifically agrees not to misrepresent the data set, nor to imply that changes made were approved or endorsed by the U.S. Geological Survey.	Public	lta@usgs.gov U.S. Geological Survey Earth Resources Observation and Science (EROS) Center	Long Term Archive (LTA) User Services Point of contact	English	.tif Band Interleaved by line (BIL) Digital Terrain Elevation Data (DTED)	raster GeoTIFF	WGS84

	IDENTIFICATION						CLASSIFICATION OF SPATIAL DATA AND SERVICES		KEYWORD		GEOGRAPHIC LOCATION	TEMPORAL REFERENCE					QUALITY AND VALIDITY		CONSTRAINT RELATED TO ACCESS AND USE		ORGANISATIONS RESPONSIBLE FOR THE ESTABLISHMENT, MANAGEMENT, MAINTENANCE AND DISTRIBUTION OF SPATIAL DATA SETS AND SERVICES		METADATA ON METADATA			
	Resource title	Resource abstract	Resource type	Resource locator	Unique resource identifier	Resource language	Topic category (ISO 19115 category)	Spatial data service type	Keyword value	Originating controlled vocaulary	Geographic bounding box	Temporal extent	Date of publication	Date of last revision	Date of cration	Acquisition date	Lineage	Spatial resolution	Conditions applying to access and use	Limitation on public access	Responsible party	Responsible party role	Metadata language	Distribution format	Data type	Reference system
LAND COVER	GlobCover - Land Cover (v2.3)	GlobCover is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 - June 2006 and January - December 2009. The GlobCover 2009 land cover map is delivered as one global land cover map covering the entire Earth. Its legend, which counts 22 land cover classes, has been designed to be consistent at the global scale and therefore, it is determined by the level of information that is available and that makes sense at this scale.	dataset	ESA - European Space Agency http://due.esrin.esa.int/globcover/	GlobCover 2009	English	010 imageryBaseMapsEarthCover	Download	Land cover, landcover, MERIS, ESA, Glob, GlobCover, forest (theme)		yMax 90.0014  xMin -180.001 xMax 179.998 yMin -64.998	NA	21-Dec-10	NA	NA	NA	NA	10 arc-seconds GDT_Byte - Eight bit unsigned integer	The GlobCover products have been processed by ESA and by the Université catholique de Louvain. They are made available to the public by ESA for educational and/or scientific purposes, without any fee. © ESA 2010 and UCLouvain	Public	Olivier Arino olivier.arino@esa.int European Space Agency (ESA)	Point of contact	English	.tif .lyr .jpg	raster GeoTIFF	WGS84
	morocco-latest	Geofabrik was created out of the conviction that free geodata created by projects like OpenStreetMap will become increasingly attractive for commercial uses. Free, community-maintained data like that produced by the OpenStreetMap project is a real alternative to the offerings of the trade's top players. Such data is not only free of charge, but also comes with fewer license restrictions than other offers. Geofabrik GmbH was incorporated in late 2007 by Jochen Topf and Frederik Ramm. Both have been working as software engineers and consultants in the Internet industry for many years. Frederik Ramm and Jochen Topf regularly give talks and workshops about OpenStreetmap or neogeography in general. In February 2008, their German OpenStreetMap book was published by Lehmanns. An English version is planned.	dataset	Geofabrik http://www.geofabrik.de/index.html	natural	English	010 imageryBaseMapsEarthCover	View, download	Land cover, natural areas	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1703  xMin -7.07372 xMax -5.78536 yMin 33.2308	NA	NA	NA	NA	NA	NA	region	Data available free of charge and free of restrictive licensing terms.	Public	Geofabrik GmbH info@geofabrik.de	Point of contact	English	.shp	vector	WGS84
	morocco-latest	Geofabrik was created out of the conviction that free geodata created by projects like OpenStreetMap will become increasingly attractive for commercial uses. Free, community-maintained data like that produced by the OpenStreetMap project is a real alternative to the offerings of the trade's top players. Such data is not only free of charge, but also comes with fewer license restrictions than other offers. Geofabrik GmbH was incorporated in late 2007 by Jochen Topf and Frederik Ramm. Both have been working as software engineers and consultants in the Internet industry for many years. Frederik Ramm and Jochen Topf regularly give talks and workshops about OpenStreetmap or neogeography in general. In February 2008, their German OpenStreetMap book was published by Lehmanns. An English version is planned.	dataset	Geofabrik http://www.geofabrik.de/index.html	waterways	English	010 imageryBaseMapsEarthCover	View, download	Land cover, natural areas	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1529  xMin -7.02354 xMax -5.73433 yMin 33.2906	NA	NA	NA	NA	NA	NA	region	Data available free of charge and free of restrictive licensing terms.	Public	Geofabrik GmbH info@geofabrik.de	Point of contact	English	.shp	vector	WGS84
	morocco-latest	Geofabrik was created out of the conviction that free geodata created by projects like OpenStreetMap will become increasingly attractive for commercial uses. Free, community-maintained data like that produced by the OpenStreetMap project is a real alternative to the offerings of the trade's top players. Such data is not only free of charge, but also comes with fewer license restrictions than other offers. Geofabrik GmbH was incorporated in late 2007 by Jochen Topf and Frederik Ramm. Both have been working as software engineers and consultants in the Internet industry for many years. Frederik Ramm and Jochen Topf regularly give talks and workshops about OpenStreetmap or neogeography in general. In February 2008, their German OpenStreetMap book was published by Lehmanns. An English version is planned.	dataset	Geofabrik http://www.geofabrik.de/index.html	roads	English	010 imageryBaseMapsEarthCover	View, download	Transport networks	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1677  xMin -7.10903 xMax -5.73269 yMin 33.2241	NA	NA	NA	NA	NA	NA	region	Data available free of charge and free of restrictive licensing terms.	Public	Geofabrik GmbH info@geofabrik.de	Point of contact	English	.shp	vector	WGS84
	morocco-latest	Geofabrik was created out of the conviction that free geodata created by projects like OpenStreetMap will become increasingly attractive for commercial uses. Free, community-maintained data like that produced by the OpenStreetMap project is a real alternative to the offerings of the trade's top players. Such data is not only free of charge, but also comes with fewer license restrictions than other offers. Geofabrik GmbH was incorporated in late 2007 by Jochen Topf and Frederik Ramm. Both have been working as software engineers and consultants in the Internet industry for many years. Frederik Ramm and Jochen Topf regularly give talks and workshops about OpenStreetmap or neogeography in general. In February 2008, their German OpenStreetMap book was published by Lehmanns. An English version is planned.	dataset	Geofabrik http://www.geofabrik.de/index.html	landuse	English	010 imageryBaseMapsEarthCover	View, download	Land use, urban environment	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1272  xMin -7.07223 xMax -5.92592 yMin 33.4198	NA	NA	NA	NA	NA	NA	region	Data available free of charge and free of restrictive licensing terms.	Public	Geofabrik GmbH info@geofabrik.de	Point of contact	English	.shp	vector	WGS84
SOIL DATA SETS	sols_rszz_500_000	NA	dataset	INRA Rabat	NA	French	008 geoscientificInformation	NA	Soil, soil type	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 398413.37  xMin 340958.47 xMax 469211.52 yMin 292114.42	NA	NA	20-Dec-13	NA	NA	NA	region	NA	Limited	Hamza Iaaich: hamza.iaaich@gmail.com INRA Rabat	Point of contact	English	.shp	vector	Merchic/Nord Maroc
	drainage_500_000	NA	dataset	INRA Rabat	NA	French	008 geoscientificInformation	NA	Soil, soil type	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 398413.37  xMin 340958.47 xMax 469211.52 yMin 292114.42	NA	NA	28-Feb-14	NA	NA	NA	region	NA	Limited	Rachid Moussadek: rachidmoussadek@yahoo.fr INRA Rabat	Point of contact	English	.shp	vector	Merchic/Nord Maroc
	texture_500_000	NA	dataset	INRA Rabat	NA	French	008 geoscientificInformation	NA	Soil, soil texture	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 398413.37  xMin 340958.47 xMax 469211.52 yMin 292114.42	NA	NA	28-Feb-14	NA	NA	NA	region	NA	Limited	Rachid Moussadek: rachidmoussadek@yahoo.fr INRA Rabat	Point of contact	English	.shp	vector	Merchic/Nord Maroc
	ph	NA	dataset	INRA Rabat	NA	French	008 geoscientificInformation	NA	Soil, soil type	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 398413.37  xMin 341107.55 xMax 469267.59 yMin 292114.42	NA	NA	20-Dec-13	NA	NA	NA	region	NA	Limited	Hamza Iaaich: hamza.iaaich@gmail.com INRA Rabat	Point of contact	English	.shp	vector	Merchic/Nord Maroc
	omc	NA	dataset	INRA Rabat	NA	French	008 geoscientificInformation	NA	Soil, soil profile, organic matter	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 398355.76  xMin 340986.09 xMax 469330.86 yMin 292145.72	NA	NA	28-Feb-14	NA	NA	NA	region	NA	Limited	Rachid Moussadek: rachidmoussadek@yahoo.fr INRA Rabat	Point of contact	English	.shp	vector	Merchic/Nord Maroc

	IDENTIFICATION						CLASSIFICATION OF SPATIAL DATA AND SERVICES		KEYWORD		GEOGRAPHIC LOCATION	TEMPORAL REFERENCE					QUALITY AND VALIDITY		CONSTRAINT RELATED TO ACCESS AND USE		ORGANISATIONS RESPONSIBLE FOR THE ESTABLISHMENT, MANAGEMENT, MAINTENANCE AND DISTRIBUTION OF SPATIAL DATA SETS AND SERVICES		METADATA ON METADATA			
	Resource title	Resource abstract	Resource type	Resource locator	Unique resource identifier	Resource language	Topic category (ISO 19115 category)	Spatial data service type	Keyword value	Originating controlled vocaulary	Geographic bounding box	Temporal extent	Date of publication	Date of last revision	Date of cration	Acquisition date	Lineage	Spatial resolution	Conditions applying to access and use	Limitation on public access	Responsible party	Responsible party role	Metadata language	Distribution format	Data type	Reference system
PRECIPITATION DATA SETS	bio_15_tif	WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer. The data can be used for mapping and spatial modeling in a GIS or with other computer programs.The current version is Version 1.4.	dataset	WorldClim http://www.worldclim.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	This dataset is freely available for academic and other non commercial use. Redistribution, or commercial use is not allowed without prior permission.	Public	Robert J. Hijmans: rhijmans@ucdavis.edu	Point of contact	English	.tif .bil .esri	raster GeoTIFF	WGS84
	gfdl_cm2_0_sres_a2_2080s_bio_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float64 - Sixty four bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ingv_echam4_sres_a2_2080s_bio_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float64 - Sixty four bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ipsl_cm4_sres_a2_2080s_bio_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float64 - Sixty four bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ukmo_hadcm3_sres_a2_2080s_bio_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float64 - Sixty four bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
TEMPERATURE DATA SETS	tmean_15_tif	WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer. The data can be used for mapping and spatial modeling in a GIS or with other computer programs.The current version is Version 1.4.	dataset	WorldClim http://www.worldclim.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	This dataset is freely available for academic and other non commercial use. Redistribution, or commercial use is not allowed without prior permission.	Public	Robert J. Hijmans: rhijmans@ucdavis.edu	Point of contact	English	.tif .bil .esri	raster GeoTIFF	WGS84
	gfdl_cm2_0_sres_a2_2080s_tmean_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ingv_echam4_sres_a2_2080s_tmean_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ipsl_cm4_sres_a2_2080s_tmean_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
	ukmo_hadcm3_sres_a2_2080s_tmean_30s_tile_a3_asc	Data Provided by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data distributed are in ARC GRID, and ARC ASCII format, in decimal degrees and datum WGS84. CCAFS and its partners have processed this data to provide seamless continuous future climate surfaces.	dataset	GCM data portal http://www.ccafs-climate.org/	NA	English	004 climatologyMeteorologyAtmosphere	View, download	Climate, climatic factor	GEMET - GEneral Multilingual Environmental Thesaurus http://www.eionet.europa.eu/gemet/	yMax 34.1806 xMin -7.11886  xMax -5.73244 yMin 33.2240	NA	NA	NA	NA	NA	NA	30 arc-seconds Float32 - Thirty two bit floating point	Users are prohibited from any commercial, non-free resale, or redistribution without explicit written permission from CCAFS or the data-developing institutions.	Public	Héctor Tobón: h.f.tobon@cgiar.org	Point of contact	English	.asc	raster ASCII	WGS84
PLACES	WorldClim: Global weather stations	The points in this shapefile represent locations of the weather stations assembled for use in devloping the WorldClim dataset. WorldClim was developed by Robert J. Hijmans, Susan Cameron, and Juan Parra, at the Museum of Vertebrate Zoology, University of California, Berkeley, in collaboration with Peter Jones and Andrew Jarvis (CIAT), and with Karen Richardson (Rainforest CRC).	dataset	Data Basin http://databasin.org/	NA	English	013 location	View, download	Worldclim, weather stations		yMax 35.8 xMin -15.95  xMax -1.9 yMin 23.72	NA	NA	6-Aug-10	NA	NA	NA	world	This work is licensed under a Creative Commons Attribution 3.0 License.	Public	databasin@consbio.org	Point of contact	English	.shp	vector	WGS84

ANNEX II – GRASS 6.4 MACRO LANGUAGE

r.slope.aspect

elevation=DEM_usgs_rszz slope=RSZZ_slope_srtm format=percent

r.shaded.relief
map=DEM_usgs_rszz shadedmap=dem_hillshade scale=111120

MAX OPERATOR

r.mapcalc

MAX - WHEAT

class1_w_current = max (RSZZ_slope_srtm_reclass, drainage_wheat_lentil, depth_wheat_lentil, omc_wheat_lentil, pH_wheat_2, texture_wheat_2, tempmean_current_w, bio12_current_w) * MAP_NO_DATA

MAX - LENTIL

class1_l_current = max (RSZZ_slope_srtm_reclass, drainage_wheat_lentil, depth_wheat_lentil, omc_wheat_lentil, pH_lentil, texture_lentil, tempmean_current_l, bio12_current_l) * MAP_NO_DATA

→ MAX - TOTAL

class1_tot_current = max (class1_w_current, class1_l_current)

WLC (no weights)

r.mapcalc

WLC (no weights) - WHEAT

class2_w_current = (drainage_wheat_lentil + depth_wheat_lentil + omc_wheat_lentil + RSZZ_slope_srtm_reclass + pH_wheat_2 + texture_wheat_2 + tempmean_current_w + bio12_current_w) * MAP_NO_DATA

WLC (no weights) - LENTIL

class2_l_current = (drainage_wheat_lentil + depth_wheat_lentil + omc_wheat_lentil + RSZZ_slope_srtm_reclass + pH_lentil + texture_lentil + tempmean_current_l + bio12_current_l) * MAP_NO_DATA

r.reclass

input=class2_w_current output=class2_w_current_reclass

rules=
8 thru 10 = 1
11 thru 18 = 2
19 thru 26 = 3
27 thru 32 = 4
* = NULL

r.mapcalc

→ WLC (no weights) - SUM

class2_current_union = (class2_w_current + class2_l_current)

WLC (weights)

r.mapcalc

WLC (weights) - WHEAT

class3_w_current = ((drainage_wheat_lentil * 0.05) + (depth_wheat_lentil * 0.05) + (texture_wheat_2 * 0.05) + (pH_wheat_2 * 0.05) + (omc_wheat_lentil * 0.05) + (RSZZ_slope_srtm_reclass * 0.1) + (tempmean_current_w * 0.15) + (bio12_current_w * 0.5)) * MAP_NO_DATA

WLC (weights) - LENTIL

class3_l_current = ((drainage_wheat_lentil * 0.15) + (depth_wheat_lentil * 0.05) + (texture_lentil * 0.05) + (pH_lentil * 0.05) + (omc_wheat_lentil * 0.05) + (RSZZ_slope_srtm_reclass * 0.05) + (tempmean_current_l * 0.1) + (bio12_current_l * 0.5)) * MAP_NO_DATA

r.recode

input=class3_w_current output=class3_w_current_reclass

rules=
1:1.11:1
1.11:2.11:2
2.11:3.11:3
3.11:3.90:4

r.mapcalc

→ WLC (weights) - SUM

class3_current_union = (class3_w_current + class3_l_current)

OWA

r.fuzzy

drainage - wheat/lentil
input=drainage_wheat_lentil output=drainage_wheat_lentil_fuzzy points=1,4 side=right

texture - wheat
input=texture_wheat_2 output=texture_w_fuzzy points=1,4 side=right

texture - lentil
input=texture_lentil output=texture_l_fuzzy points=1,4 side=right

depth - wheat
input=depth_w_l output=depth_w_fuzzy points=19,100 side=left

depth - lentil
input=depth_w_l output=depth_l_fuzzy points=29,100 side=left

slope - wheat/lentil
input=RSZZ_slope_srtm output=RSZZ_slope_srtm_fuzzy points=0,31 side=right

omc - wheat/lentil
input=omc_w_l output=omc_w_l_fuzzy points=1,5 side=left

pH - wheat
input=ph_w_l output=ph_w_fuzzy points=5.5,6.5,8,9

pH - lentil
input=ph_w_l output=ph_l_fuzzy points=5.5,6,7,8.5

temperature - wheat
input=Temp_mean_current_average output=temp_mean_current_w_fuzzy points=51,120,230,251

temperature - lentil
input=Temp_mean_current_average output=temp_mean_current_l_fuzzy points=61,230,250,271

precipitation - wheat
input=bio12_rszz_current output=bio12_rszz_current_w_fuzzy points=249,350,1250,1601

precipitation - lentil
input=bio12_rszz_current output=bio12_rszz_current_l_fuzzy points=299,700,800,2401

r.mcda.fuzzy

OWA FUZZY (weights) - WHEAT

criteria = drainage_w_l_fuzzy, depth_w_fuzzy, texture_w_fuzzy, ph_w_fuzzy, omc_w_l_fuzzy, RSZZ_slope_srtm_fuzzy, temp_mean_current_w_fuzzy, bio12_rszz_current_w_fuzzy
weight = 0.05, 0.05, 0.05, 0.05, 0.05, 0.1, 0.15, 0.5
AND=**intersect_w_current** OR=**union_w_current** OWA=**OWA_w_current**

OWA FUZZY (weights) - LENTIL

criteria = drainage_w_l_fuzzy, depth_l_fuzzy, texture_l_fuzzy, ph_l_fuzzy, omc_w_l_fuzzy, RSZZ_slope_srtm_fuzzy, temp_mean_current_l_fuzzy, bio12_rszz_current_l_fuzzy
weight = 0.15, 0.05, 0.05, 0.05, 0.05, 0.05, 0.1, 0.5
AND=**intersect_l_current** OR=**union_l_current** OWA=**OWA_l_current**

r.mapcalc

→ AND - TOTAL (MIN operator)

intersect_tot_current = min(intersect_w_current, intersect_l_current)

→ OWA - SUM

OWA_tot_curremt = (OWA_w_current + OWA_l_current) / 2

AHP

r.mcda.ahp

WLC FUZZY **AHP** (weights) - WHEAT

criteria = drainage_w_l_fuzzy, depth_w_fuzzy, texture_w_fuzzy, ph_w_fuzzy, omc_w_l_fuzzy, RSZZ_slope_srtm_fuzzy, temp_mean_current_w_fuzzy, bio12_rszz_current_w_fuzzy
pairwise = browse > ahp_grass_w.csv
output = **class5_w_current**

weight:
[0.25922361049636439, 0.20405971157334693, 0.18349084632069934, 0.083571525685608175, 0.070196177570186272, 0.080464731317084523, 0.061231212644249085, 0.057762184392461308]
consistency:
0.125127953368

WLC FUZZY **AHP** (weights) - LENTIL

criteria = drainage_w_l_fuzzy, depth_l_fuzzy, texture_l_fuzzy, ph_l_fuzzy, omc_w_l_fuzzy, RSZZ_slope_srtm_fuzzy, temp_mean_current_l_fuzzy, bio12_rszz_current_l_fuzzy
pairwise = browse > ahp_grass_l.csv
output = **class5_l_current**

weight:
[0.31325831120237163, 0.20311954695922194, 0.16407649738304114, 0.093118817053801622, 0.05615654224533153, 0.06736746309055329, 0.048271337970905895, 0.054631484094772961]
consistency:
0.178812902211

r.mapcalc

→ WLC FUZZY **AHP** (weights) - SUM

class5_current_union = (class5_w_current + class5_l_current) / 2
class5_current_union * MAP_NO_DATA

r.report

-n map = <required> units = h,p

ANNEX III – WEATHER STATIONS AND CLIMATIC VARIABLES

Minimum temperature

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
NA	171	147	114	94	82	83	101	117	133	162	178	187
Tanger	174	152	116	96	85	85	103	119	136	166	184	189
Tanger	174	150	116	94	84	85	103	119	135	166	184	190
Melusa	165	135	103	77	58	61	84	103	119	155	177	184
Tanger(Aerodrome)	177	154	118	98	88	89	106	121	138	168	187	189
Tangiers	174	151	117	94	81	82	102	118	135	167	185	189
Rincon Medik	172	146	116	91	74	75	96	113	132	162	186	190
Jemis Anyera	177	148	117	89	75	79	102	120	140	173	197	200
Malalien	175	148	119	94	77	81	100	115	135	165	189	193
Zagora	174	151	119	96	82	85	105	122	137	168	185	186
Tetouan	168	138	109	83	61	64	87	108	125	156	182	185
Tetuan	179	150	121	97	79	83	101	117	137	168	191	197
Tetuan Sania Ramel	179	150	121	97	79	83	101	117	137	168	191	197
Tetuan	179	150	121	97	79	83	101	117	137	168	191	197
Tetuan Sania Ramel	179	150	121	97	79	83	101	117	137	168	191	197
Dar Chaui	172	149	117	92	76	78	102	119	134	166	185	186
Tanger	170	139	109	80	58	65	90	111	127	163	187	190
Ben Karrich	177	149	116	91	72	77	98	119	138	168	194	196
Rgaia	167	140	110	81	60	65	92	111	124	162	182	187
R'gaia	151	118	88	58	36	41	67	89	102	143	169	172
Arcila	162	138	112	85	68	73	96	115	127	162	172	171
Fondak	158	129	100	72	49	51	78	97	112	147	174	179
Tzelata Beni Ide	174	143	110	82	61	69	94	115	132	165	192	192
Tzenin Sidi Jama	164	139	111	83	62	69	95	114	128	162	179	179
Zoco Arbaa	155	124	95	66	43	45	73	92	105	145	174	177
Ali Telat	144	109	83	54	32	32	59	82	95	135	164	167
Sidi Ali	169	138	106	71	52	63	95	114	128	167	194	192
Talambot	137	99	73	45	25	26	52	77	94	130	158	160
Zoco Sebt	169	144	110	80	57	71	98	117	128	163	187	186
Tzelata Raixana	163	130	108	77	51	70	92	114	128	158	177	177
Puerto Capaz	167	140	110	90	71	76	95	115	133	160	178	185
Larache	159	132	108	79	61	71	94	117	128	156	168	166
Einzorem	176	147	116	90	68	73	94	111	133	163	189	197
Punta Nador	157	130	107	78	61	69	93	116	127	154	165	162
Budinar	179	144	113	86	64	71	94	109	135	167	195	202
Chauen	156	123	95	67	45	52	78	100	118	154	181	184
Villa Nador Aero	188	154	117	97	78	84	99	116	144	174	203	212
Bab Tazza	128	82	54	27	8	12	38	70	89	125	152	151
Monte Arruit	186	152	117	95	74	82	99	114	142	172	200	209
Mexerah	173	150	111	79	61	72	97	119	133	171	195	188
Taatof	167	152	111	82	62	72	97	116	126	165	187	176
Ben Tieb	177	137	105	79	55	64	88	96	131	163	193	198
Rabat	174	148	115	89	79	84	98	115	135	165	180	186
Alcazarquivir	171	145	109	79	58	69	97	121	131	165	184	181
Dar Drius	177	139	107	80	58	67	91	102	131	162	191	196
Bab Berret	145	104	78	54	35	40	65	94	113	148	172	172
Zaio	190	153	115	87	71	73	94	109	141	173	205	217
Zaio	184	148	112	83	67	70	90	105	137	168	200	212
NA	125	96	72	45	22	28	48	70	89	129	151	157
Chaib Tarquist	125	96	72	45	22	28	48	70	89	129	151	157
Berkane	183	146	109	72	64	70	90	108	137	170	200	210
Llano Amarillo	83	55	24	3	-19	-15	8	46	59	87	113	116
Ouezzene	160	125	90	56	38	46	73	100	115	157	185	183
Arbaoua	166	138	102	71	55	64	89	118	126	160	181	182
Oujda	158	116	85	55	47	51	71	84	116	148	177	185
Souk Larbat	170	138	100	70	58	67	90	117	131	159	182	189
Rhafsai	161	119	89	65	48	55	79	112	131	166	192	190
Oujda	159	115	84	57	47	52	70	84	115	148	175	183
Aknoul	157	120	83	58	36	45	69	82	113	150	178	186
Souk El Arba	174	140	96	68	59	67	88	114	132	156	185	195
NA	153	114	77	48	37	45	64	78	114	148	178	188
Oudjda	153	114	77	48	37	45	64	78	114	148	178	188
Ain Guenfouda	131	98	59	34	17	24	45	59	93	127	155	165
Taourirt	149	128	106	77	63	72	92	103	119	140	147	154
El Morhrane	197	159	120	93	82	89	108	133	151	189	217	221
Port Lyautey	181	151	112	86	75	83	102	119	142	174	191	194
Sidi Kacem	182	150	112	81	72	80	101	122	138	173	194	201
Tissa	183	144	99	71	57	69	92	120	146	182	210	211
Port Lyautey (Kenitra ?)	180	151	111	85	75	82	101	119	142	174	192	196
Kenitra	195	158	119	94	81	89	107	130	150	188	217	221
Slimane	176	146	108	77	68	75	97	117	133	169	185	193
Sidi Slimane	175	146	109	83	76	81	99	117	138	168	185	192
Guercif	182	142	91	65	49	64	89	109	142	178	205	216
Port Lyautey	165	133	93	64	54	61	82	103	122	156	182	187
Sidi Kacem	173	140	102	72	62	69	90	110	130	164	189	194
Taza	174	129	79	51	37	50	74	92	122	169	200	207
Taza	170	126	78	50	35	48	72	90	119	166	196	204
Touahar	175	131	87	57	41	53	80	97	121	172	201	206
Rabat Sale	170	145	111	85	75	81	94	111	132	161	175	182
Fes	160	128	84	56	40	51	78	96	118	152	177	182
Khouribga	149	112	63	41	33	34	51	66	94	131	161	169

Oued Zem	149	108	50	30	19	24	41	61	93	131	169	172
Settat	158	120	82	55	42	49	65	80	108	140	166	176
Fes	153	119	77	48	33	42	69	89	111	146	172	176
Ain Taoujdate	153	123	82	53	38	48	73	91	112	144	169	175
Tiflet	168	137	91	67	56	62	81	97	121	156	183	191
Meknes	151	121	80	52	41	50	70	87	109	141	165	172
Midelt	102	66	24	-3	-22	-13	12	44	61	105	131	136
Casablanca	175	145	112	85	75	79	96	112	136	164	185	190
Ben Slimane	160	131	98	69	59	64	80	94	120	149	171	176
Casablanca	174	143	109	83	72	76	93	110	134	162	184	189
Rommani (Marchand)	161	127	85	56	45	52	71	86	115	152	174	184
Rommani	158	125	85	56	44	51	70	86	112	148	172	179
Rommani	155	121	80	52	41	47	65	81	108	144	168	175
Ifrane	85	55	12	-23	-44	-27	-3	33	48	94	123	123
Azrou	105	71	22	-4	-22	-12	11	42	62	106	135	139
Oulmes	118	81	31	1	-13	-1	22	48	78	115	138	140
Nouasseur	164	129	98	69	60	64	83	94	124	151	174	179
Nouasseur	164	129	98	69	60	64	83	94	124	151	174	179
Nouasseur	164	129	98	69	60	64	83	94	124	151	174	179
Ourat Oulad	146	108	55	23	10	18	57	78	108	148	151	176
Berrechid	164	127	95	64	54	59	80	92	118	151	178	180
Averroes	161	127	95	64	54	60	77	90	116	149	173	178
El Jadida	168	145	112	89	76	76	93	108	131	159	177	189
Mazagan	168	145	111	89	75	75	92	108	131	159	176	188
El Jadida	168	144	112	88	75	75	92	107	131	159	176	188
Settat	165	128	95	64	54	58	79	92	118	151	178	181
Melilla	184	149	113	92	73	78	95	110	138	168	198	208
Azilal	118	75	23	1	-12	-1	18	39	63	98	142	153
Er Rachidia	136	113	63	29	14	32	60	95	128	176	211	208
Khenifra	132	100	60	28	15	26	50	69	90	127	150	153
NA	151	115	61	43	34	35	52	67	95	132	163	172
Khouribga	151	115	61	43	34	35	52	67	95	132	163	172
Oued Zem	165	121	61	40	31	36	51	72	106	145	189	189
Khouribga	152	114	63	43	34	35	51	68	95	132	165	173
Midelt	127	84	43	17	1	11	33	61	82	129	162	162
Midelt	127	84	43	17	1	11	33	61	82	129	162	162
Midelt	134	92	50	22	7	18	41	70	93	139	169	171
Bennour	178	148	105	74	65	74	89	107	138	174	192	202
El Ksiba	148	112	68	35	22	34	56	77	102	141	171	173
Souk El Had	175	146	106	76	65	73	91	110	136	169	190	196
Kasba Tadla	172	132	86	51	39	50	71	93	122	162	195	198
Kasba Tadla	172	132	86	51	39	50	71	93	123	163	195	198
Bouarfa	158	115	59	11	13	26	51	72	158	168	209	210
Bouarfa	158	115	59	11	13	25	51	72	158	169	209	211
Souk El Tleta	166	129	83	53	45	51	72	89	115	151	180	186
Kasba Tadla	170	131	86	49	37	48	71	92	121	161	194	196
Beni Slimane	165	114	55	17	10	27	56	88	136	170	202	205
NA	152	120	85	46	36	48	71	89	109	145	166	169
Beni Mellal	152	120	85	46	36	48	71	89	109	145	166	169
Beni Mellal	150	117	79	41	32	43	66	85	106	143	167	170
Safi	197	169	129	105	90	98	113	132	160	189	206	218
Benguerir	163	132	87	55	47	55	76	94	121	153	177	184
Ben Guerir	172	141	96	64	54	65	85	103	134	160	188	195
El Kelaa	169	132	84	50	43	55	78	100	126	158	187	195
Azilal	130	88	39	17	2	14	33	52	77	109	153	164
Bou Denib	186	129	64	26	20	44	69	107	153	190	231	226
Ksar Es Souk	141	124	74	38	25	44	72	109	142	190	226	222
Sidi Mbarek	189	156	114	83	69	81	104	125	153	182	204	212
El Alleb	187	154	110	75	64	77	102	122	151	180	204	212
Demnate	137	103	62	24	11	27	54	74	97	131	155	161
Demnate	129	92	47	13	0	15	40	62	86	120	149	156
Sidi Rahhal	151	118	76	38	26	41	68	89	112	143	168	174
Marrakech	172	138	94	57	44	61	88	109	138	164	192	199
Chichaoua	185	149	97	61	50	66	93	112	146	171	202	211
Ain Er Reggada	173	138	91	55	42	58	85	105	136	161	188	197
Boumalne Du Dade	120	78	24	-9	-26	-8	17	46	73	117	150	156
Amizmiz	130	98	53	16	1	17	46	65	92	118	140	151
Imi N Tanoute	128	96	60	24	9	23	50	68	92	119	137	146
Ouarzazate	163	114	70	21	9	32	63	93	124	165	197	203
Ouarzazate	163	113	69	21	10	32	62	93	125	165	197	203
NA	185	154	130	84	65	86	115	133	146	172	197	205
Sidi Larbi	141	92	46	0	-13	8	40	68	100	136	172	179
Taroudant	185	154	130	84	67	86	116	134	146	172	196	204
Taroudant	185	154	130	84	65	86	115	133	146	172	197	205
Taroudant	185	155	132	86	67	87	117	136	148	173	198	206
Agadir	176	155	127	88	76	87	112	133	149	169	181	186
NA	200	152	107	56	40	61	97	132	172	215	252	253
Tiznit	98	208	133	169	155	92	190	214	116	90	112	168
Tiznit	96	205	131	167	152	90	188	211	116	87	111	166
Sidi Ifni	121	179	140	168	159	119	179	183	147	115	133	172
Tan Tan	107	181	143	162	161	113	181	186	142	104	136	172
Assa	71	224	138	163	174	70	204	226	113	58	107	202
El Aaium	102	180	134	166	153	108	175	184	154	100	123	165
Ad Dakhla	144	184	156	182	161	139	194	189	172	133	150	171

Mean temperature

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
NA	221	189	156	131	119	124	139	156	178	208	228	237
Tanger	225	192	158	131	121	126	141	158	180	212	234	240
Tanger	224	194	158	133	122	126	140	158	181	211	234	239
Melusa	220	182	148	118	101	107	128	147	168	207	235	241
Tanger(Aerodrome)	227	196	160	135	124	130	144	160	183	214	237	239
Tangiers	226	195	160	133	119	125	141	158	182	215	237	241
Rincon Medik	223	191	160	132	117	120	138	155	179	211	239	243
Jemis Anyera	229	193	162	130	116	124	144	162	187	222	250	253
Malalien	226	193	164	135	119	126	143	158	182	214	241	246
Zagora	228	197	164	137	122	129	146	163	185	218	239	240
Tetouan	224	186	156	125	106	111	132	153	176	210	242	244
Tetuan	231	196	166	139	122	128	144	160	185	218	245	251
Tetuan Sania Ramel	231	196	166	139	122	128	144	160	185	218	245	251
Tetuan	231	196	166	139	122	128	144	160	185	218	245	251
Tetuan Sania Ramel	231	196	166	139	122	128	144	160	185	218	245	251
Dar Chaui	229	198	164	135	119	125	146	162	184	219	243	244
Tanger	229	189	157	124	103	113	136	157	179	219	249	251
Ben Karrich	233	198	163	134	117	124	143	163	188	222	252	254
Rgaia	227	191	159	126	106	114	139	156	176	218	244	249
R'gaia	215	172	138	103	84	91	116	137	156	203	236	238
Arcila	223	193	163	132	116	123	144	160	179	219	232	232
Fondak	220	181	149	116	97	101	127	145	166	207	241	245
Tzelata Beni Ide	234	194	159	126	107	118	141	162	185	222	254	254
Tzenin Sidi Jama	227	194	163	131	111	120	145	160	182	221	242	243
Zoco Arbaa	219	178	145	111	92	96	122	142	160	206	243	245
Ali Telat	227	191	155	130	114	120	136	152	181	213	245	252
Sidi Ali	210	163	134	99	82	84	110	133	152	198	236	237
Talambot	232	192	157	118	100	114	144	161	182	227	259	257
Zoco Sebt	204	153	124	90	76	79	104	129	152	194	232	232
Tzelata Raixana	234	201	163	129	108	124	149	165	183	224	253	252
Puerto Capaz	229	190	163	129	104	125	146	163	184	221	243	244
Larache	224	189	159	133	118	125	142	163	186	217	240	246
Einzorem	226	195	165	134	117	128	150	167	184	221	234	235
Punta Nador	227	193	162	131	113	119	139	158	182	214	244	250
Budinar	225	193	164	134	118	127	150	166	184	219	231	231
Chauen	229	190	158	126	108	116	139	155	183	218	250	254
Villa Nador Aero	222	178	147	113	95	104	129	151	175	217	252	254
Bab Tazza	233	198	159	137	120	127	141	160	189	220	251	257
Monte Arruit	199	139	108	74	61	67	93	125	149	193	231	228
Mexerah	233	197	160	136	117	126	142	160	188	220	251	257
Taatof	238	207	164	128	111	125	149	170	191	234	264	257
Ben Tieb	234	211	165	132	114	127	151	167	184	230	257	246
Rabat	230	185	151	120	101	111	134	145	182	216	252	253
Alcazarquivir	225	202	164	137	127	135	151	168	186	213	230	237
Dar Drius	238	206	164	131	111	125	152	172	189	230	253	251
Bab Berret	229	187	153	121	103	113	137	150	181	214	248	249
Zaio	213	159	131	100	87	94	118	148	172	214	248	245
Zaio	244	203	161	132	117	121	141	160	191	225	262	271
NA	239	199	158	128	113	118	138	157	188	222	259	267
Chaib Tarquist	192	151	124	89	74	82	101	125	148	195	227	229
Berkane	192	151	124	89	74	82	101	125	148	195	227	229
Llano Amarillo	237	198	155	126	111	120	138	159	187	221	256	264
Ouezzene	157	113	79	49	36	42	65	104	121	157	197	196
Arbaoua	230	184	144	105	90	101	128	154	176	225	261	258
Oujda	235	200	158	123	108	120	144	170	186	226	253	255
Souk Larbat	229	180	136	107	100	107	126	150	179	212	251	256
Rhafsai	237	199	155	122	110	123	146	169	190	224	251	259
Oujda	228	175	142	112	100	109	132	167	191	233	268	264
Aknoul	232	180	135	108	100	109	126	151	179	213	251	255
Souk El Arba	220	174	133	102	86	97	120	137	170	212	248	253
NA	241	201	151	119	110	122	143	167	192	220	255	266
Oudjda	226	178	129	98	90	102	120	145	179	214	255	261
Ain Guenfouda	226	178	129	98	90	102	120	145	179	214	255	261
Taourirt	206	161	111	82	70	81	102	126	159	195	234	239
El Morhrane	211	184	156	125	113	125	145	161	177	200	214	217
Port Lyautey	251	214	171	141	130	141	161	183	204	241	271	276
Sidi Kacem	227	202	162	133	122	133	153	168	191	219	235	239
Tissa	252	212	166	130	121	134	157	178	203	241	271	278
Port Lyautey (Kenitra ?)	252	202	154	120	111	125	147	179	210	252	289	288
Kenitra	227	203	161	132	122	133	152	168	191	220	237	243
Slimane	249	213	170	142	128	141	160	181	204	240	272	277
Sidi Slimane	245	208	161	126	116	128	153	173	198	236	262	270
Guercif	244	207	161	131	122	134	154	173	203	234	261	268
Port Lyautey	245	198	143	113	100	118	143	166	201	240	274	282
Sidi Kacem	239	197	149	114	106	117	140	163	189	229	266	269
Taza	246	204	157	122	113	125	147	169	197	237	271	275
Taza	241	186	133	99	91	106	130	151	184	236	277	280
Touahar	238	183	132	98	88	104	128	149	181	233	273	278
Rabat Sale	243	188	142	106	95	109	136	156	184	240	279	281
Fes	222	199	160	133	123	132	147	164	183	210	226	234
Khouribga	238	191	143	107	97	111	138	160	188	231	268	271

Oued Zem	235	190	129	105	100	105	124	145	176	216	257	262
Settat	235	184	116	94	86	94	114	138	174	217	268	267
Fes	231	191	143	115	102	115	132	152	180	212	245	253
Ain Taoujdate	230	182	136	100	91	102	129	153	181	225	263	264
Tiflet	230	188	141	105	94	107	133	155	182	223	259	263
Meknes	236	201	146	119	108	119	140	158	186	222	258	265
Midelt	226	188	137	104	95	107	130	151	178	219	252	257
Casablanca	181	128	85	50	40	51	76	108	128	179	222	223
Ben Slimane	221	197	162	135	125	132	149	163	182	208	226	234
Casablanca	222	195	155	124	115	124	141	157	181	209	234	239
Rommani (Marchand)	219	194	159	133	122	129	145	160	179	205	224	231
Rommani	232	194	143	113	102	113	135	153	183	222	252	260
Rommani	230	193	143	113	101	113	134	154	181	219	251	257
Ifrane	228	190	139	110	100	110	130	150	178	216	248	253
Azrou	167	118	76	34	24	42	64	97	113	168	216	212
Oulmes	186	136	85	53	44	55	79	107	130	182	228	228
Nouasseur	201	152	94	60	50	65	90	118	152	196	233	231
Nouasseur	223	191	155	124	114	123	143	156	182	208	233	238
Nouasseur	223	191	155	124	114	123	143	156	182	208	233	238
Ourat Oulad	223	191	155	124	114	123	143	156	182	208	233	238
Berrechid	218	170	113	77	67	79	119	144	177	220	233	254
Averroes	227	192	153	121	110	121	143	157	180	212	243	244
El Jadida	231	196	156	123	114	125	143	161	184	217	246	249
Mazagan	213	193	159	136	122	125	142	156	176	201	221	234
El Jadida	214	194	158	136	121	124	141	155	177	202	220	233
Settat	213	192	159	134	121	123	141	154	177	202	220	233
Melilla	230	194	154	121	111	120	142	158	182	214	245	247
Azilal	207	152	93	69	62	74	96	122	151	193	247	252
Er Rachidia	212	182	127	92	79	99	131	170	208	258	301	295
Khenifra	214	172	124	90	79	93	120	142	168	211	246	247
NA	237	193	127	108	101	106	126	147	178	219	260	267
Khouribga	237	193	127	108	101	106	126	147	178	219	260	267
Oued Zem	251	198	127	105	98	106	124	150	188	233	288	285
Khouribga	238	192	129	108	101	106	125	148	178	219	263	268
Midelt	203	149	105	74	60	73	101	132	158	207	252	248
Midelt	203	149	105	74	60	73	101	132	158	207	252	248
Midelt	209	157	112	79	66	80	108	140	168	216	257	256
Bennour	234	202	156	124	115	127	143	161	193	228	251	261
El Ksiba	233	188	134	100	89	104	128	154	185	230	271	270
Souk El Had	236	204	159	128	117	129	148	168	197	228	256	262
Kasba Tadla	257	209	151	118	106	120	143	171	205	251	295	296
Kasba Tadla	257	209	151	118	106	119	143	171	207	252	295	296
Bouarfa	233	177	122	70	73	94	117	146	230	243	291	286
Bouarfa	233	177	122	70	73	93	117	146	230	244	291	287
Souk El Tleta	250	206	149	118	112	121	145	168	197	237	276	279
Kasba Tadla	255	209	152	116	104	118	144	170	205	251	294	294
Beni Slimane	238	179	116	78	73	93	123	160	209	245	284	284
NA	237	197	151	113	104	119	145	168	193	235	265	266
Beni Mellal	237	197	151	113	104	119	145	168	193	235	265	266
Beni Mellal	236	195	146	109	102	114	141	165	191	234	268	268
Safi	236	210	171	147	132	141	155	172	200	225	246	258
Benguerir	236	196	145	111	103	116	140	160	193	226	261	266
Ben Guerir	247	206	154	121	111	127	150	170	209	235	274	280
El Kelaa	251	205	148	114	108	124	149	176	207	243	282	286
Azilal	219	166	109	86	77	90	111	135	166	204	258	263
Bou Denib	259	196	127	90	86	112	139	180	229	267	314	306
Ksar Es Souk	217	193	138	101	91	112	144	184	222	272	316	308
Sidi Mbarek	244	208	165	134	121	134	157	178	206	235	264	270
El Alleb	247	210	164	129	120	134	159	179	209	239	271	276
Demnate	225	180	132	94	86	103	132	157	186	225	258	258
Demnate	218	169	117	83	77	91	118	146	175	216	253	253
Sidi Rahhal	236	193	143	105	98	114	143	168	196	233	267	268
Marrakech	252	209	158	121	112	129	158	183	213	246	286	288
Chichaoua	243	204	150	115	107	123	149	168	202	228	266	273
Ain Er Reggada	237	197	147	112	103	119	145	166	197	225	260	266
Boumalne Du Dade	208	155	95	61	52	69	97	131	164	214	253	253
Amizmiz	207	167	117	81	72	87	116	138	166	198	229	234
Imi N Tanoute	192	155	117	82	73	85	111	130	154	184	210	214
Ouarzazate	250	192	143	96	94	114	145	181	217	265	298	296
Ouarzazate	250	191	143	96	95	114	144	182	218	265	298	295
NA	244	214	189	147	133	153	178	195	205	232	260	266
Sidi Larbi	227	169	119	74	70	90	121	155	190	233	272	271
Taroudant	242	213	188	146	134	152	178	195	204	230	257	262
Taroudant	244	214	189	147	133	153	178	195	205	232	260	266
Taroudant	242	214	190	149	135	153	179	197	206	231	260	265
Agadir	222	208	181	148	142	150	169	185	195	211	224	229
NA	283	231	180	131	122	143	178	220	264	312	351	345
Tiznit	232	217	166	150	145	147	163	181	198	208	250	255
Tiznit	231	215	166	148	142	146	163	180	195	207	247	252
Sidi Ifni	211	206	188	162	156	162	174	177	191	201	209	213
Tan Tan	232	218	199	162	159	167	187	192	204	215	226	239
Assa	264	226	174	134	123	139	171	205	237	269	291	290
El Aaium	234	223	202	153	160	167	180	187	204	214	235	241
Ad Dakhla	230	224	211	183	175	183	192	195	200	210	220	227

Maximum temperature

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
NA	272	232	198	169	157	166	177	195	223	254	279	287
Tanger	276	235	200	169	158	167	179	197	226	258	285	290
Tanger	275	236	200	170	159	168	178	197	226	257	285	289
Melusa	275	229	194	160	144	153	172	192	218	260	293	298
Tanger(Aerodrome)	278	239	203	173	161	171	182	199	229	260	288	289
Tangiers	279	239	203	172	158	168	181	199	229	263	290	294
Rincon Medik	274	236	205	174	160	166	181	198	227	260	292	296
Jemis Anyera	281	239	207	171	158	169	186	205	234	271	303	307
Malalien	278	239	210	177	162	171	186	201	230	264	294	300
Zagora	282	244	209	178	163	173	187	204	233	268	294	295
Tetouan	281	235	203	168	151	159	177	198	227	264	302	304
Tetuan	283	243	212	181	165	174	188	204	234	268	299	305
Tetuan Sania Ramel	283	243	212	181	165	174	188	204	234	268	299	305
Tetuan	283	243	212	181	165	174	188	204	234	268	299	305
Tetuan Sania Ramel	283	243	212	181	165	174	188	204	234	268	299	305
Dar Chaui	286	247	212	178	162	172	190	206	234	273	301	302
Tanger	289	240	205	168	149	162	183	203	231	275	311	313
Ben Karrich	290	247	211	178	162	172	189	208	239	276	311	313
Rgaia	288	243	208	171	152	163	186	202	228	275	306	311
R'gaia	279	226	189	148	133	142	166	186	211	264	303	305
Arcila	284	248	214	180	164	174	193	206	232	277	293	294
Fondak	283	233	199	161	145	152	176	194	221	267	308	311
Tzelata Beni Ide	294	246	209	171	154	168	189	209	238	279	317	317
Tzenin Sidi Jama	291	250	215	180	160	172	195	207	236	281	305	307
Zoco Arbaa	283	232	196	156	141	147	172	192	216	268	312	313
Ali Telat	271	234	197	168	155	162	178	195	225	259	292	296
Sidi Ali	277	218	186	145	133	137	162	185	210	262	309	308
Talambot	295	247	208	165	149	165	193	209	237	287	324	323
Zoco Sebt	272	208	176	136	127	132	156	182	210	259	306	304
Tzelata Raixana	299	259	217	179	159	177	201	213	239	286	319	319
Puerto Capaz	296	251	218	182	157	180	200	212	240	285	310	312
Larache	281	239	208	177	166	174	190	212	239	274	303	308
Einzorem	294	258	223	190	173	186	206	217	241	287	301	304
Punta Nador	278	240	208	173	159	165	185	205	232	266	300	303
Budinar	293	257	222	190	175	185	207	217	241	285	298	300
Chauen	280	237	203	167	153	162	184	202	232	269	305	306
Villa Nador Aero	288	234	199	160	146	157	181	203	233	281	324	325
Bab Tazza	278	242	202	178	162	170	184	204	234	267	300	303
Monte Arruit	270	197	162	121	115	123	148	181	210	261	311	305
Mexerah	281	243	204	177	161	170	186	206	235	268	302	305
Taatof	304	265	217	177	162	178	202	221	249	298	334	327
Ben Tieb	302	271	220	183	166	182	205	218	243	295	327	317
Rabat	283	234	197	161	147	158	181	195	233	270	311	309
Alcazarquivir	277	256	214	186	175	187	205	221	238	262	281	289
Dar Drius	306	267	220	183	164	181	207	224	248	295	323	322
Bab Berret	281	235	199	162	149	160	183	199	231	267	305	303
Zaio	281	215	184	146	139	148	171	202	232	280	324	319
Zaio	298	254	207	178	163	169	188	211	242	278	320	326
NA	295	251	204	174	160	167	186	209	240	276	318	323
Chaib Tarquist	260	206	176	134	127	136	155	181	208	261	303	302
Berkane	260	206	176	134	127	136	155	181	208	261	303	302
Llano Amarillo	291	251	202	180	159	171	186	211	237	273	312	319
Ouezzene	231	171	134	95	91	99	122	163	183	228	281	276
Arbaoua	301	244	199	154	143	157	183	208	237	293	338	334
Oujda	304	262	214	176	162	177	200	223	246	293	325	328
Souk Larbat	301	245	187	159	153	164	182	216	242	277	326	328
Rhafsai	305	261	211	175	163	179	202	222	250	289	321	330
Oujda	296	232	195	159	152	163	186	222	252	300	344	338
Aknoul	305	246	187	159	154	166	183	218	243	278	327	328
Souk El Arba	283	228	184	146	136	149	172	192	228	274	319	320
NA	308	262	206	170	161	177	199	220	253	285	325	337
Oudjda	300	243	181	148	144	159	177	213	244	280	333	334
Ain Guenfouda	300	243	181	148	144	159	177	213	244	280	333	334
Taourirt	281	225	164	130	124	139	160	194	225	264	313	314
El Morhrane	273	240	207	174	164	179	198	219	235	260	281	281
Port Lyautey	305	269	223	190	178	193	214	234	258	294	326	332
Sidi Kacem	273	254	212	181	170	184	205	217	240	264	279	285
Tissa	322	274	220	180	170	188	213	235	269	310	349	355
Port Lyautey (Kenitra ?)	322	260	209	169	165	181	203	238	274	322	368	366
Kenitra	275	255	211	180	170	184	204	217	241	266	282	290
Slimane	304	269	222	190	176	193	213	233	259	293	327	333
Sidi Slimane	315	270	214	175	164	182	209	230	264	303	339	347
Guercif	313	269	214	180	169	187	210	230	269	300	337	344
Port Lyautey	308	254	195	162	152	172	197	224	260	302	344	348
Sidi Kacem	313	261	205	165	158	173	198	223	256	303	350	351
Taza	319	268	212	173	164	181	205	229	264	310	354	357
Taza	309	243	188	148	145	162	186	210	247	303	354	354
Touahar	307	241	187	147	142	160	184	208	244	301	351	352
Rabat Sale	312	246	197	155	149	166	192	216	247	309	357	356
Fes	274	253	210	182	171	183	201	217	234	259	278	286
Khouribga	316	254	202	159	155	171	198	225	259	311	360	360

Oued Zem	321	269	195	170	167	177	198	225	258	302	354	355
Settat	321	261	182	158	153	165	187	216	256	304	367	363
Fes	305	262	205	175	163	181	200	224	252	285	324	331
Ain Taoujdate	308	246	195	153	149	163	190	218	251	304	354	353
Tiflet	308	253	200	158	151	167	194	220	252	303	350	351
Meknes	305	265	201	172	161	176	200	220	251	289	333	339
Midelt	302	255	195	157	150	164	190	215	247	297	340	342
Casablanca	261	191	146	104	102	115	141	172	196	254	314	310
Ben Slimane	267	250	213	186	175	185	202	214	229	252	267	278
Casablanca	285	259	212	180	171	184	203	221	242	270	298	303
Rommani (Marchand)	264	246	210	184	173	182	198	210	225	248	264	274
Rommani	304	262	202	170	159	174	199	221	252	292	330	337
Rommani	303	261	202	170	159	175	199	222	251	291	330	335
Ifrane	302	260	199	168	159	174	196	220	249	289	329	332
Azrou	250	182	140	91	92	111	132	161	179	242	309	301
Oulmes	268	201	149	110	111	123	147	173	198	258	322	318
Nouasseur	284	223	157	119	114	131	159	188	226	278	328	323
Nouasseur	282	254	212	180	169	183	203	219	241	266	293	298
Nouasseur	282	254	212	180	169	183	203	219	241	266	293	298
Ourat Oulad	282	254	212	180	169	183	203	219	241	266	293	298
Berrechid	290	232	172	132	125	140	181	211	246	292	315	333
Averroes	291	258	212	178	167	183	206	223	243	274	308	309
El Jadida	301	266	217	183	174	190	210	232	253	285	320	321
Mazagan	259	242	207	183	168	174	191	204	222	244	265	279
El Jadida	260	243	206	183	167	173	190	203	223	245	265	279
Settat	259	241	206	181	167	172	190	202	223	245	264	279
Melilla	295	260	213	178	168	183	206	225	246	278	312	314
Azilal	297	229	163	138	137	150	174	205	240	288	352	351
Er Rachidia	289	251	192	155	145	167	203	246	288	340	392	382
Khenifra	297	244	188	152	144	160	190	216	246	296	343	341
NA	324	271	194	173	169	178	200	227	261	306	358	362
Khouribga	324	271	194	173	169	178	200	227	261	306	358	362
Oued Zem	337	276	193	171	165	177	198	229	271	321	387	382
Khouribga	325	271	195	173	169	178	200	228	262	307	361	363
Midelt	279	214	168	131	120	135	169	203	235	286	342	335
Midelt	279	214	168	131	120	135	169	203	235	286	342	335
Midelt	284	222	174	136	125	142	176	211	244	294	346	342
Bennour	290	257	208	175	165	180	198	216	249	282	311	321
El Ksiba	319	264	200	166	157	174	201	232	268	319	371	368
Souk El Had	298	262	213	181	170	186	206	227	258	288	322	328
Kasba Tadla	343	287	217	185	173	190	216	250	289	341	395	394
Kasba Tadla	343	287	217	185	173	189	216	250	291	342	396	395
Bouarfa	308	239	185	130	134	162	184	220	302	319	373	363
Bouarfa	308	239	185	130	134	162	184	220	302	319	373	363
Souk El Tleta	334	283	215	184	179	192	218	247	280	324	373	373
Kasba Tadla	341	287	218	184	172	189	217	249	289	341	394	392
Beni Slimane	311	245	178	139	136	160	191	232	283	320	367	363
NA	322	275	218	181	173	190	219	248	278	325	365	363
Beni Mellal	322	275	218	181	173	190	219	248	278	325	365	363
Beni Mellal	323	273	213	178	172	186	216	245	277	325	369	366
Safi	276	251	214	190	174	184	198	213	240	261	286	298
Benguerir	310	261	203	168	160	178	205	227	266	300	345	349
Ben Guerir	322	272	213	178	169	189	216	238	284	311	360	365
El Kelaa	334	278	213	179	174	194	221	252	289	328	377	378
Azilal	309	244	179	155	153	166	190	219	255	300	363	363
Bou Denib	332	264	190	154	152	180	209	254	306	345	398	387
Ksar Es Souk	294	263	203	165	157	180	216	260	303	355	406	395
Sidi Mbarek	299	261	216	185	174	188	210	231	259	288	324	328
El Alleb	308	267	218	184	176	191	216	237	267	299	339	341
Demnate	313	258	202	164	162	179	210	241	275	320	361	355
Demnate	307	247	188	153	154	168	197	230	264	312	357	351
Sidi Rahhal	321	268	211	173	170	187	218	248	281	324	367	362
Marrakech	332	280	223	186	181	198	228	257	288	329	381	377
Chichaoua	302	259	204	170	164	180	206	225	258	286	331	335
Ain Er Reggada	301	257	204	170	164	180	206	228	258	290	333	335
Boumalne Du Dade	296	233	167	131	130	147	178	217	256	311	357	350
Amizmiz	284	236	181	146	143	157	186	211	241	279	318	317
Imi N Tanoute	257	215	175	141	137	148	172	193	216	250	283	283
Ouarzazate	337	270	217	171	180	196	228	270	311	365	400	389
Ouarzazate	337	270	217	171	180	196	227	271	311	365	400	388
NA	303	274	248	210	202	220	241	258	265	292	324	327
Sidi Larbi	313	246	192	148	154	172	202	242	280	331	373	363
Taroudant	299	272	247	209	202	219	240	256	262	288	319	321
Taroudant	303	274	248	210	202	220	241	258	265	292	324	327
Taroudant	300	274	249	212	204	220	241	258	264	290	322	324
Agadir	268	261	236	209	209	214	226	237	241	254	268	273
NA	367	310	253	206	204	226	260	308	356	409	450	437
Tiznit	275	266	217	203	200	203	215	230	241	249	292	296
Tiznit	274	264	216	200	198	202	215	229	239	249	290	294
Sidi Ifni	244	245	229	203	197	205	215	215	224	230	240	244
Tan Tan	284	274	257	217	214	221	239	241	247	259	272	292
Assa	325	290	236	197	188	209	235	273	301	336	358	354
El Aaium	293	281	251	204	220	226	238	240	255	264	290	298
Ad Dakhla	267	267	250	222	217	228	234	234	239	250	256	266

Precipitation

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
NA	17	67	121	147	110	106	113	54	35	11	0	3
Tanger	17	66	123	149	110	107	120	51	35	11	0	3
Tanger	17	66	123	149	109	106	117	51	35	11	0	3
Melusa	17	58	109	146	149	138	143	53	34	6	0	3
Tanger(Aerodrome)	16	65	117	140	103	97	88	58	34	12	0	3
Tangiers	17	65	116	148	117	106	108	57	35	10	0	3
Rincon Medik	14	43	80	114	112	111	96	47	25	6	0	3
Jemis Anyera	15	50	92	131	126	130	116	55	30	6	1	2
Malalien	14	43	78	113	108	110	90	51	24	7	0	3
Zagora	16	62	105	141	115	102	96	61	32	9	0	3
Tetouan	14	49	91	133	141	125	134	47	29	6	0	3
Tetuan	13	44	79	116	108	108	90	54	24	8	0	3
Tetuan Sania Ramel	13	44	79	116	108	108	90	54	24	8	0	3
Tetuan	13	44	79	116	108	108	90	54	24	8	0	3
Tetuan Sania Ramel	13	44	79	116	108	108	90	54	24	8	0	3
Dar Chaui	15	55	93	141	129	118	112	60	31	6	0	2
Tanger	14	55	95	153	156	140	146	54	32	6	0	2
Ben Karrich	13	47	81	129	128	112	122	51	27	6	0	2
Rgaia	15	56	96	153	147	139	135	57	33	6	0	3
R'gaia	17	65	118	169	166	168	170	65	40	9	1	3
Arcila	14	49	88	131	119	114	94	50	28	7	0	3
Fondak	14	49	95	137	147	137	147	52	32	7	0	3
Tzelata Beni Ide	13	51	87	147	149	128	136	55	30	7	0	2
Tzenin Sidi Jama	14	51	88	146	134	135	112	56	29	6	0	2
Zoco Arbaa	14	52	103	143	151	149	158	58	35	7	0	3
Ali Telat	14	24	31	47	56	36	33	40	23	6	2	3
Sidi Ali	17	58	113	142	155	159	166	71	41	10	1	3
Talambot	14	55	91	163	153	135	124	65	33	7	0	2
Zoco Sebt	18	62	118	135	157	161	168	76	43	11	1	3
Tzelata Raixana	14	53	90	159	142	137	109	61	30	7	0	2
Puerto Capaz	13	47	85	146	135	125	102	52	28	7	0	2
Larache	13	30	49	71	64	57	66	45	26	9	1	3
Einzorem	12	42	79	137	117	98	87	46	25	7	1	3
Punta Nador	10	16	21	41	46	41	44	43	27	7	0	2
Budinar	12	42	80	138	117	95	87	46	25	7	1	3
Chauen	11	18	25	56	47	56	47	51	28	4	1	3
Villa Nador Aero	13	52	101	145	155	140	151	64	36	9	0	2
Bab Tazza	16	23	25	46	51	37	37	43	23	7	1	3
Monte Arruit	21	74	138	141	176	185	189	91	52	14	2	3
Mexerah	16	22	21	40	46	35	35	44	24	7	1	3
Taatof	12	55	95	138	138	142	117	65	33	8	0	1
Ben Tieb	13	59	96	131	139	149	115	61	34	8	0	1
Rabat	13	20	18	44	47	41	40	51	29	5	2	4
Alcazarquivir	7	43	79	104	75	66	60	55	21	5	0	1
Dar Drius	11	55	93	122	121	132	86	58	29	10	0	1
Bab Berret	14	20	17	35	43	34	32	49	26	5	1	3
Zaio	17	54	101	111	121	118	125	72	43	12	1	3
Zaio	17	24	20	37	47	33	35	47	28	7	1	3
NA	17	24	20	37	48	33	35	48	28	7	1	3
Chaib Tarquist	21	36	58	68	62	51	54	58	36	12	2	6
Berkane	21	36	58	68	62	51	54	58	36	12	2	6
Llano Amarillo	20	31	31	45	43	42	32	44	30	8	1	3
Ouezzene	28	73	148	156	153	145	144	94	49	20	4	7
Arbaoua	14	64	122	178	165	171	158	81	43	12	1	2
Oujda	12	60	102	135	112	110	93	65	34	12	0	1
Souk Larbat	16	30	36	42	38	36	44	44	33	12	2	3
Rhafsai	10	52	91	123	97	87	74	57	31	8	0	1
Oujda	15	58	106	133	109	119	116	77	45	14	1	2
Aknoul	16	30	36	42	38	36	44	44	33	12	2	3
Souk El Arba	15	32	31	63	44	51	37	54	31	9	3	4
NA	9	50	87	118	91	80	71	56	31	7	0	1
Oudjda	17	30	41	45	39	35	42	40	35	15	2	3
Ain Guenfouda	17	30	41	45	39	35	42	40	35	15	2	3
Taourirt	20	23	38	41	42	28	44	37	34	11	3	4
El Morhrane	16	21	19	21	20	24	22	30	27	11	2	3
Port Lyautey	10	56	100	114	71	68	66	50	27	7	0	1
Sidi Kacem	9	52	97	115	80	74	65	49	25	6	0	1
Tissa	10	46	75	87	72	63	64	52	29	8	0	1
Port Lyautey (Kenitra ?)	11	45	72	90	58	69	79	60	38	13	0	1
Kenitra	9	52	97	114	78	73	64	50	25	6	0	1
Slimane	10	56	99	113	70	67	65	49	27	8	0	1
Sidi Slimane	9	44	73	85	67	57	57	46	27	7	0	1
Guercif	8	40	76	84	71	56	59	42	24	6	0	1
Port Lyautey	15	22	20	19	18	23	23	36	26	11	2	3
Sidi Kacem	13	55	90	108	87	83	82	64	36	11	1	2
Taza	12	52	86	102	80	75	75	60	34	10	1	2
Taza	15	40	59	97	80	90	89	69	41	12	3	3
Touahar	15	39	57	93	77	85	85	68	41	12	3	4
Rabat Sale	15	40	59	96	80	76	86	65	42	10	2	3
Fes	7	46	84	108	78	70	63	59	22	6	0	1
Khouribga	13	47	69	76	61	71	75	67	37	16	2	3

Oued Zem	12	35	50	70	58	58	55	49	21	6	2	2
Settat	13	40	57	71	63	56	65	53	26	9	2	5
Fes	8	35	48	66	53	56	47	40	17	4	1	0
Ain Taoujdate	14	47	66	73	61	68	73	65	38	16	2	3
Tiflet	13	49	73	74	59	65	66	60	36	13	2	3
Meknes	10	49	80	93	66	68	73	53	29	8	1	2
Midelt	15	51	76	92	77	76	73	65	37	12	2	3
Casablanca	24	36	40	25	25	23	32	46	42	21	7	7
Ben Slimane	6	33	65	81	64	53	48	36	17	4	1	2
Casablanca	8	36	60	86	69	60	57	43	21	4	1	1
Rommani (Marchand)	6	34	66	78	62	53	49	36	18	5	1	3
Rommani	9	42	54	70	57	59	70	49	23	5	0	0
Rommani	9	42	53	70	57	60	72	49	24	5	0	0
Ifrane	10	42	52	70	59	62	69	48	24	5	0	0
Azrou	34	96	119	140	95	112	113	103	65	33	8	10
Oulmes	31	84	110	124	85	99	101	96	60	28	8	9
Nouasseur	22	69	108	115	92	98	98	76	45	18	4	4
Nouasseur	8	34	56	74	59	52	56	30	19	3	0	1
Nouasseur	8	34	56	74	59	52	56	30	19	3	0	1
Ourat Oulad	8	34	56	74	59	52	56	30	19	3	0	1
Berrechid	19	20	17	10	8	13	14	24	23	11	5	4
Averroes	9	36	53	67	54	51	47	32	18	3	0	0
El Jadida	9	36	53	68	54	52	49	34	18	3	0	0
Mazagan	7	34	66	74	50	49	41	32	16	4	0	1
El Jadida	7	34	67	76	50	49	41	33	16	4	0	1
Settat	7	34	67	77	51	50	42	33	16	4	0	1
Melilla	8	36	52	65	53	52	46	33	17	3	0	0
Azilal	22	46	62	87	70	64	91	72	34	13	4	7
Er Rachidia	18	19	18	14	10	6	11	14	11	4	3	6
Khenifra	18	57	88	97	65	83	84	72	43	18	4	6
NA	12	36	52	71	59	58	56	51	22	7	2	3
Khouribga	12	36	52	71	59	58	56	51	22	7	2	3
Oued Zem	12	40	57	70	61	54	65	53	25	9	2	5
Khouribga	12	36	53	72	59	58	57	52	22	7	2	3
Midelt	24	29	30	24	14	22	26	36	28	13	7	8
Midelt	24	29	30	24	14	22	26	36	28	13	7	8
Midelt	22	24	24	19	11	18	21	30	24	12	7	7
Bennour	6	34	55	53	42	40	39	29	15	3	0	1
El Ksiba	11	55	94	113	79	105	107	90	43	14	4	6
Souk El Had	6	31	53	56	44	40	44	32	14	3	0	0
Kasba Tadla	10	35	71	78	55	63	85	64	31	10	2	4
Kasba Tadla	10	35	72	79	56	64	86	65	32	10	2	5
Bouarfa	19	25	27	25	16	17	25	23	15	7	3	8
Bouarfa	19	25	27	25	16	17	25	22	15	7	3	8
Souk El Tleta	9	46	75	92	59	66	64	50	25	8	0	2
Kasba Tadla	9	35	73	79	55	66	89	67	33	10	2	5
Beni Slimane	13	24	33	51	38	37	39	31	18	7	4	4
NA	7	39	71	69	48	69	78	61	33	12	1	4
Beni Mellal	7	39	71	69	48	69	78	61	33	12	1	4
Beni Mellal	8	41	72	73	52	71	82	65	34	12	2	5
Safi	4	34	57	61	53	48	39	33	14	4	0	0
Benguerir	8	22	30	47	30	36	36	26	16	5	2	1
Ben Guerir	8	21	28	43	28	35	34	25	16	5	2	1
El Kelaa	9	23	39	37	27	35	40	38	18	7	1	1
Azilal	19	43	61	84	66	64	96	73	34	13	3	6
Bou Denib	14	15	10	4	4	5	8	11	12	13	10	11
Ksar Es Souk	18	20	18	19	8	5	8	9	8	4	3	6
Sidi Mbarek	4	32	43	44	38	36	38	29	16	4	1	1
El Alleb	6	29	36	38	34	34	32	27	17	5	1	1
Demnate	13	37	53	59	46	51	69	63	30	11	2	4
Demnate	17	41	58	70	57	59	86	81	37	14	2	5
Sidi Rahhal	7	33	47	49	36	44	52	51	25	8	2	3
Marrakech	7	22	35	28	29	35	32	33	20	5	1	2
Chichaoua	9	26	36	33	32	30	29	23	16	5	1	1
Ain Er Reggada	13	31	40	50	43	60	36	36	24	7	1	2
Boumalne Du Dade	17	28	27	15	10	6	12	7	8	2	3	6
Amizmiz	18	39	54	47	43	53	59	66	37	13	2	4
Imi N Tanoute	13	31	58	45	44	45	50	48	29	14	2	1
Ouarzazate	12	24	25	17	16	12	14	11	10	3	1	5
Ouarzazate	12	24	25	16	16	11	13	10	10	3	1	5
NA	7	19	33	50	39	35	30	18	4	1	0	0
Sidi Larbi	10	36	55	63	46	40	44	33	16	6	1	1
Taroudant	7	19	33	49	39	34	30	18	4	1	0	0
Taroudant	7	19	33	50	39	35	30	18	4	1	0	0
Taroudant	7	19	33	45	37	33	29	18	4	1	0	0
Agadir	4	19	41	51	43	34	27	17	3	1	0	0
NA	6	13	15	7	4	3	5	1	2	1	1	3
Tiznit	5	12	26	30	29	20	18	15	4	2	0	0
Tiznit	6	12	26	29	29	19	18	15	4	2	0	0
Sidi Ifni	3	10	15	29	25	25	13	12	2	2	2	1
Tan Tan	2	10	20	32	11	15	6	4	1	0	1	0
Assa	10	7	18	16	6	4	4	3	1	0	1	1
El Aaium	0	4	7	8	3	2	1	1	0	1	0	0
Ad Dakhla	15	3	4	15	2	1	1	1	1	0	1	4