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DESERTIFICATION ASSESSMENT AND FUTURE SCENARIOS IN THE CONTEXT OF THE CLIMATE CHANGE INFLUENCE IN LEBANON: PLANNING FOR RESTORATION ACTIVITIES AND HYDROLOGICAL MODELING

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to qualify for the degree of **Doctor by the University of Cordoba**

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TITULO: *DESERTIFICATION ASSESSMENT AND FUTURE SCENARIOS IN THE CONTEXT OF THE CLIMATE CHANGE INFLUENCE IN LEBANON: PLANNING FOR RESTORATION ACTIVITIES AND HYDROLOGICAL MODELING*

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TÍTULO DE LA TESIS: DESERTIFICATION ASSESSMENT AND FUTURE SCENARIOS IN THE CONTEXT OF THE CLIMATE CHANGE INFLUENCE IN LEBANON: PLANNING FOR RESTORATION ACTIVITIES AND HYDROLOGICAL MODELING

DOCTORANDA: Sandra Abou Najem

INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS

La doctoranda presenta y desarrolla en su tesis un trabajo original en el campo de la evaluación de la desertificación y la restauración de zonas degradadas en ambientes semiáridos, suponiendo un trabajo novedoso en la región donde se desarrolla en estudio, el Líbano. La tesis se centra en la evaluación de la capacidad y aptitud de uso de la tierra y la modelización hidrológica para relacionar los cambios de uso del suelo y los escenarios futuros de cambio climático con la disponibilidad de recursos hídricos en la zona de estudio. Esta evaluación de la disponibilidad actual y futura de recursos hídricos se considera fundamental para una adecuada planificación territorial sostenible a nivel ambiental, social y económico, así como para el diseño de actuaciones de restauración de las áreas degradas.

Los resultados, además de su interés científico, son de aplicación en la planificación territorial y el diseño de actuaciones de restauración forestal e hidrológica en zonas semiáridas, las cuales, en numerosas ocasiones, no cuentan con la información necesaria para garantizar su éxito. Los resultados obtenidos son, por tanto, transferibles a organismos e instituciones de gestión y ejecución de actividades de gestión del territorio y los recursos hídricos y restauración de áreas degradadas.

El desarrollo metodológico es correcto y riguroso tanto en su planteamiento teórico como en su desarrollo posterior, lo cual asegura la validez de los resultados obtenidos, y permite su generalización en posteriores trabajos de investigación. En este sentido cabe destacar la innovación de las técnicas de modelización utilizadas en el contexto en el que se realiza la tesis, y su aplicación a un ámbito territorial con elevado interés ambiental y socioeconómico.

El resultado es original en el contexto de la gestión territorial y la evaluación de la capacidad y aptitud de uso de la tierra, como ha sido reconocido con la publicación de un artículo indexado "*Land Capability for Agriculture, Hermel District, Lebanon*" (Abou *et al.*, 2018; Journal of Maps, 15(2): 122-130.).

Como resultado de todo lo anterior consideramos que la tesis objeto de defensa reúne las condiciones formales y científicas para proceder a su presentación.

Por todo ello, se autoriza la presentación de la tesis doctoral.

En Córdoba, a 10 de julio de 2019.

Fdo.: Rafael Mª Navarro Cerrillo

Fdo.: Guillermo Palacios Rodríguez

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Resumen

El objetivo de esta tesis ha sido evaluar la desertificación y estudiar los efectos del cambio de uso de la tierra y el cambio climático en las variables hidrológicas de la cuenca de El Asi-Orontes (Líbano). En este trabajo se presenta un modelo validado para cartografiar la capacidad y aptitud de uso de la tierra, a una escala de 1:20.000, para el distrito de Hermel (Líbano). El modelo fue validado a través del trabajo de campo, mostrando una buena precisión general del 89%. La comparación entre el mapa de zonificación ya elaborado para el área de influencia de la ciudad de Hermel y el mapa de capacidad y aptitud de uso de la tierra demuestra un alto riesgo de desertificación ya que la planificación territorial de Hermel no está considerando el potencial y la capacidad de uso de la tierra. También se ha aplicado un modelo hidrológico (WiMMed) en la región de estudio en 2005 y 2013, para describir cómo el cambio de uso de la tierra ha afectado a los parámetros hidrológicos que definen la dinámica de la cuenca de El Asi-Orontes. Este estudio encontró que el cambio de uso de la tierra entre 2005 y 2013 tuvo efectos negativos sobre las características hidrológicas de esta cuenca disminuyendo la capacidad de infiltración y la humedad del suelo de la segunda capa en esta área. Con base en los resultados de las simulaciones, se puede concluir que en términos de escorrentía se registraron bajas diferencias en todas las estaciones entre 2005 y 2013. También se han comparado las variables hidrológicas actuales del área de estudio (infiltración, escorrentía, humedad del suelo de la segunda capa) con las variables simuladas en 2050 bajo 2 escenarios futuros, RCP 2.6 y RCP8.5, asumiendo que el uso futuro de la tierra es el mismo que el uso actual de la tierra (mapa de uso/cobertura de la tierra de 2013). Bajo las mismas condiciones de uso de la tierra, un aumento de la temperatura acompañado de una disminución de las precipitaciones resultará en una disminución de la infiltración, de la humedad del suelo de la segunda capa en todas las estaciones, y de la escorrentía durante la primavera y el invierno. Se espera que todas las variables hidrológicas dentro del área de estudio tengan disminuciones mayores bajo el escenario RCP8.5 en comparación con el RCP2.6 para todas las estaciones. Sin embargo, la influencia del cambio de uso de la tierra en la humedad del suelo de la segunda capa es mucho más significativa en comparación con la variabilidad y el cambio climático. En conclusión, los patrones de uso de la tierra de la región de estudio necesitan ser modificados de acuerdo a las clases de capacidad y aptitud de uso de la tierra identificadas para mantener las tierras productivas restantes para las

generaciones futuras. Este trabajo fue útil para evaluar la presión ejercida sobre la tierra en relación a sus usos y los estados hidrológicos de la región de estudio bajo diferentes escenarios climáticos, pero para planificar actividades de restauración adecuadas y reducir los efectos negativos del cambio en el uso de la tierra y el cambio climático, se necesitan estudios más detallados para sugerir el tipo correcto de uso de la tierra y encontrar una manera de mitigar los efectos del cambio climático en la cuenca hidrográfica de El Asi-Orontes específicamente, y en las áreas semiáridas en general.

Summary

The purpose of this study was to assess desertification and to study the effects of land use change and climate change on hydrological variables in El Asi-Orontes watershed (Lebanon). This work presents a validated model to map land capability at a scale of 1:20,000 for El-Hermel District (Lebanon). The model was validated through field work and it indicates a good overall accuracy of 89%. The comparison between the zoning map already produced for the area of influence of Hermel city and the land capability map demonstrates a high risk of desertification because the zoning map doesn't respect the capability of lands. We have also applied a hydrological model (WiMMed) in the study region in 2005 and 2013 to describe how land use change would affect the hydrological parameters. This study found that the land use change from 2005 to 2013 has negative effects on the hydrological characteristics of this watershed decreasing the infiltration capacity and the soil moisture of second layer in this area. Based on the results of the simulations, it can be concluded that in term of runoff low differences was registered in all seasons between 2005 and 2013. An attempt has been made to compare the current hydrological variables of the study area (infiltration, run-off, soil moisture of second layer) to the simulated variables in 2050 under 2 RCP future scenarios, RCP 2.6 and RCP8.5, assuming that that the future land use is the same as the current land use (2013 land use/land cover map). Under same land use conditions, a rise of temperature accompanied with a decrease of precipitation will result in a decrease of infiltration, soil moisture of second layer in all seasons, and run-off during spring and winter. All the hydrological variables within the study area are expected to have further decreases under RCP 8.5 compared to RCP2.6 for all seasons. However, the influence of land use change on soil moisture of second layer is much more significant when compared to climate variability and climate change. In conclusion, the land use patterns of the study region need to be modified according to identified land capability classes to sustain the remaining productive lands for future generations. This work was helpful to assess the stress on the land and hydrological states of the study region under different climatic scenarios, but to suggest restoration activities and to reduce the negative effects of land use change and climate change, more detailed studies are needed to suggest the correct land use type and to find a way to mitigate the effects of climate change in El Asi-Orontes watershed specifically, and semi-arid areas generally.

Chapter 1. Introduction

1.1 Introduction

Climate change and adaptation is a lead theme for the political and thematic processes, the topic of a High-Level Panel session and a focus in several documents of the regional processes (Arab Water Council, 2011). Rising fossil fuel burning and land use changes have emitted, and are continuing to emit, increasing quantities of greenhouse gases into the Earth's atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O), and a rise in these gases has caused a rise in the amount of heat from the sun withheld in the Earth's atmosphere, heat that would normally be radiated back into space. This increase in heat has led to the green house effect, resulting in climate change (UNFCCC, 2007). The arid and semi-arid regions account for approximately 30% of the world total area and are inhabited by approximately 20% of the total world population (Sivakumar *et al.*, 2005). Many impacts of and vulnerabilities to climate change occur in arid and semi-arid areas:

- Drought occurrence is one of the world's most widespread climate disasters affecting agricultural production (UNDP, 2004; Dilley *et al.*, 2005; Helmen & Hilhorst, 2006) and is therefore a determinant of world food security (Tubiello *et al.*, 2007). An increase in the intensity, duration and area affected by drought has been observed over wider areas since the 1970s, particularly in the tropics and subtropics, where rising temperature and less precipitation have contributed to enhanced drought conditions. There is now higher-confidence that climate change will increase drought-risk in drought-prone areas (IPCC, 2007; Li *et al.*, 2009).

- Arid and semi-arid areas already are quite vulnerable to extreme climate change events. Climate change and variability would exacerbate these vulnerabilities. As science indicates, we can expect longer dry seasons and more rainfall in shorter periods of time. There is a potential for drier conditions in arid and semi-arid Asia during summer which could lead to more severe droughts. (IPCC, 2007). Both droughts and floods are expected to increase in frequency and result in the displacement and migration of communities resulting in conflicts over natural resources (Trocaire, 2008).

- Climate change can affect forests in semi-arid areas by altering the intensity, frequency and timing of drought, fire, insect out breaks, windstorms or landslides. Each disturbance affects forests differently. Some cause large-scale tree mortality, whereas others affect community structure and organization without causing massive mortality (Dale *et al.*, 2001).

- Climate change is likely to cause environmental and social stress in many of Asia's rangelands and drylands (Sivakumar *et al.*, 2005).

- The combination of enhanced temperatures, changes in precipitation and sensitivity of different crops/cropping systems to projected changes have several consequences on the water balance in the arid and semi-arid areas: changes in the distribution of river and flows and groundwater recharge over space and time are determined by changes in temperature, evaporation and, crucially, precipitation (Chiew, 2007). Some climate change impacts on hydrological processes have been observed already (Rozenweig *et al.*, 2007) and further changes are projected. They vary between regions and seasons. By mid-century, annual average river runoff and water availability are projected to decrease by 10-30% over some dry regions at mid-latitudes and in the dry-topics. Many of the presently water stressed semi-arid and arid areas are likely to suffer from decreasing water resource availability due to climate change, as both river flows and groundwater recharge decline (Kundzewicz *et al.*, 2008).

The increase in atmospheric concentration of CO_2 by 31% since 1950 from fossil fuel combustion and land use change necessitates identification of strategies for mitigating the threat of the attendant global warming (Lal, 2004). Aware of the urgent need to address the high vulnerability of the population in semi-arid areas, it is so important to increase the capacity of communities to adapt to climate variability and change and to mitigate their effects. We will achieve this through many ways. The land use sector represents almost 25% of total global emissions. These emissions can be reduced however. Improved land use and management, such as low emissions agriculture, agro-forestry and ecosystem conservation and restoration could, under certain circumstances, close the remaining emissions gap by up to 25% (UNCCD, 2015).

There is a wide acceptance that Human well-being and good conditions of life are related to the land use that can provide the ecosystem services (MEA, 2005).

Governors and planners are having to re-evaluate how they retain high levels of agricultural food production while maintaining good drinking water quality, limiting greenhouse gas emissions or safe-guarding the social and economic benefits of their landscapes (Brown *et al.*, 2008). Land capability evaluation is essential for managing land resources since it helps us to know whether the resources are degraded or improved in quality (Girmay *et al.*, 2018). Land capability classification systems define and communicate biophysical limitations on land use, including climate, soils and topography. They can therefore provide an accessible format for both scientists and decision-makers to share knowledge on climate change impacts and adaptation (Brown *et al.*, 2011). Classifying lands based on their capability at region level would help decision-makers in the identification of different soil types in accordance with its capability for sustainable soil fertility management. The land capability map for agriculture could give a general orientation about the best use of the soil to increase the land productivity and mitigate the effects of the climate change in semi-arid areas. For this reason, the first step to adapt to the climate change and to reduce its effects is to achieve a sustainable land use. Therefore, the assessment of land characteristics for the present is necessary.

After the land sector, comes the water sector. Water is a critical resource in arid and semi-arid forest and rangeland environments (Clifton *et al.*, 2018). Water is also a critical element for human activities, affecting the growth of human community and the development of local economies across the landscapes (Hartter *et al.*, 2018). Hydrological modeling is one of the ways that will play a significant role in mitigating effects of climate change and early warning of climate disasters. Modeling methods have been widely used for over 40 years for a variety of purposes, but almost all modeling tools have been primarily developed for humid area applications. Arid and semi arid areas have particular challenges that have received little attention (Wheater *et al.*, 2008). Despite the critical importance of water in arid and semi-arid areas, hydrological data have historically been severely limited. It has been widely stated that the major limitation of the development of arid-zone hydrology is the lack of high-quality observations (Pilgrim *et al.*, 1988).

In recent years, there have been important developments in data availability accompanied by several more detailed studies leading us to understand the characteristics of arid and semi-arid areas. In order to solve present and possible future problems with regard to fresh water supply, an interdisciplinary and holistic approach is clearly necessary. A sustainable management of the resource can only be assured, if not only the actual state of the hydrological system is understood, but also the impacts of future climatic changes are assessed. Thus, it is imperative to understand the spatiotemporal variability of the hydrological cycle and to apply models, which are capable of quantifying the impacts of the scenarios on the system (Busche, 2013). Large-scale and complex environmental systems such as the global hydrological cycle or basin pollutant loading cannot be investigated directly through experimentation, but instead must be generalized into their component processes. The tasks for hydrological models used are diverse, and the scale of applications ranges from small catchments, of the order of a few hectares, to that of global models. Typical tasks for hydrological simulation models include:

- Modeling existing catchments for which input–output data exist, e.g., extension of data series for flood design of water resource evaluation, operational flood forecasting, or water resource management;
- Runoff estimation on ungauged basins;
- Prediction of effects of catchment change, e.g., land use change, climate change;
- Coupled hydrology and geochemistry, e.g., nutrients, acid rain;
- Coupled hydrology and meteorology, e.g., Global Climate Models (Wheater *et al.*, 2008).

Selection of appropriate hydrological model is a critical issue in climate change impact assessment. The choice of a hydrologic model for a particular case study depends on many factors: purpose of study, model and data availability have been the dominant ones. For the regional scale assessment of water resource management, monthly rainfall-runoff models are generally useful for identifying hydrologic consequences in changes of temperature, precipitation and other climatic variables. For detailed assessment of surface flow, conceptual-lumped parameters models are useful (Eslamian, 2014)

Hydrological modeling and necessary supporting data are crucial to developing arid and semi-arid areas that are usually under environmental strains. Various parameters required for the modeling will be derived using remote sensing data like digital elevation model, drainage system, soil map etc. Scientists have recently turned to satellites to search for this needed flow data (Gleason *et al.*, 2018). Remote sensing approaches and methods are important tools to properly guide spatial planning.

Satellite remote sensing is providing a systematic, synoptic framework for advancing scientific knowledge of the Earth as a complex system of geophysical phenomena that, directly and through interacting processes, often lead to natural hazards. Improved and integrated measurements along with numerical modeling are enabling a greater understanding of where and when a particular hazard event is most likely to occur and result in significant socioeconomic impact. Geospatial information products derived from this research increasingly are addressing the operational requirements of decision support systems used by policy makers, emergency managers and responders from international and federal to regional, state and local jurisdictions. This forms the basis for comprehensive risk assessments and better-informed mitigation planning, disaster assessment and response prioritization (Tralli, 2005).

Accurate modeling will require estimation of the spatial and temporal distribution of the water resources parameters. During the last decades, engineers and planners have shown the increasing interest of applying Geographic Information System (GIS) and satellite based remote sensing (RS) technologies to extract land surface parameters, which exist as a threshold in early days to approach reasonable results in hydrological modeling. With the advancement of the computer technology, GIS and RS have become efficient tools to integrate the spatial and non spatial databases for the hydrological modeling. (Gandodagamage, 2001). Hydrologists are interested in remotely sensed data because of the combination of wide spatial coverage and the frequency of measurements. An improved understanding of the hydrological cycle requires measurement of time series of data at a point, time series which vary over an area and data which do not change over the time scale of the modeling period. (Kite & Pietroniro, 2009). The modern technology of remote sensing which includes both aerial as well as satellite based systems, allow us to collect lot of physical data rather easily, with speed and on repetitive basis, and together with GIS helps us to analyze the data spatially, offering possibilities of generating various options (modeling), thereby optimizing the whole planning process. These information systems also offer interpretation of physical (spatial) data with other socio-economic data, and thereby providing an important linkage in the total planning process and making it more effective and meaningful. (Rai & Kumra, 2011).

Arid and semi-arid lands have been listed in Agenda 21 among the fragile ecosystems of the world although they are described as being important ecosystems, with unique features and resources. These ecosystems are regional in scope, as they transcend national boundaries. Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Desertification affects about 17% of the world's population, 70% of all drylands amounting to 3.6 billion hectares, and 25% of the total land area of the world (UNEP, 1992).

Lebanon (10,452 km^2) is a predominantly mountainous country with complex physical geography. Landform, climate, soils, and vegetation differ markedly within short distances. The country is characterized by four main geomorphological (physiographical) units: a narrow coastal plain and two mountainous chains (Mount Lebanon and Anti Lebanon) separated by a fertile and relatively elevated depression (700 to 1,100 m altitude) named the Bekaa Valley. Lying northeast to southwest, the two mountain chains occupy around 70% of the Lebanese territory. A major feature of Lebanese topography is the alternation of lowland and highland that run north-south (Darwish *et al.*, 2012).

Alarming rates of deforestation and climatic changes have been noted as factors for increased desertification in Lebanon during the last decades. High temperatures and low precipitation have resulted in decreased vegetation cover, and consequently favor soil erosion and degradation. According to experts in the region (Dragan *et al.,* 2005), these changes will inevitably affect all vegetation types in the long run, and potentially result in land degradation. Relief, rainfall intensity and runoff, therefore, contribute to severe water erosion and soil loss, especially where the vegetation cover is reduced or lost.

Lebanon aims to develop their arid land resources while sustaining an ecological balance and conserving the diverse biological resources there in. Combating desertification and land degradation forms the core of environmental programs of this country. For this purpose, Integrate remote sensing data with several other data types into a GIS is used to develop various models for monitoring and exploring land surface changes and degradation and for producing dynamic information since satellites have the ability to cover vast and inaccessible areas and provides long-term repetitive data. Moreover, drylands have, most of the time, a relatively cloud-free sky and consequently the area is suitable for observation by all optical systems. In Lebanon, many studies used the remote sensing techniques as a tool for the assessment and management of land degradation and desertification in dry lands. Below, is listed some applications:

- Application and validation of a desertification risk index: the paper demonstrates the efficiency of desertification index to identify areas at risk. The DRI map proved to be accurate when compared to the map of desertification prone areas produced by the Lebanese ministry of agriculture. (Dragan *et al.,* 2005).

- Assessment of vulnerability to desertification based on geo-information and socio-economic conditions: The actual state of desertification sensitivity in Lebanon was spatially assessed using site specific environmental bio-physical indicators, demographic pressure and socioeconomic conditions. Bio-physical assessment included the aridity index derived from integrated assessment of the historical data for 48 climatic stations spread throughout the country, the new detailed soil map at 1:50,000 scale, and the updated land cover/use map at 1:20,000 derived from IKONOS 2005. (Darwish *et al.,* 2012)

- Regional Landsat-based drought monitoring from 1982 to 2014: the goal of this work was to monitor the vegetation health across Lebanon in 2014 using remote sensing techniques. Landsat images datasets, with a spatial resolution of 30 m and from different platforms, were used to identify the VCI (Vegetation Condition Index) and TCI (Temperature Condition Index). The VCI was based on the Normalized Difference Vegetation Index (NDVI) datasets. The TCI used land surface temperature (LST) datasets. As a result, the VHI (Vegetation Health Index) was produced and classified into five categories: extreme, severe, moderate, mild, and no drought (Faour *et al.*, 2015).

- A research done by CNRS deals with the use of remote sensing and GIS techniques to study the mass movements in Lebanon. This research was dedicated to compare the applicability of different satellite sensors (Landsat TM, IRS, SPOT4) and preferred image processing techniques (False Color Composite “FCC”, Pansharpen, Principal component analysis “PCA”, Anaglyph) for the mapping of mass movements recognized as landslides, rock/debris falls and earth flows (Abdallah, 2006).

After reviewing existing knowledge on the application of remote sensing and hydrological modeling in the management of drylands in Lebanon, it is noticed that this field is not studied enough as it should be. Related maps and future scenarios in the context of the climate change are still lacking. This research deals with the use of the remote sensing and the application of a hydrological model (WiMMed) in the semi-arid area of Lebanon (case study: El-Hermel Region, El Asi – Orontes watershed) to mitigate the effects of climate change. Climate change mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. Protecting forests, oceans, lands and studying the capability of soils are also elements of mitigation.

Land capability is the ability to accept a type and intensity of land use permanently, or for a specified period under a certain management without long term degradation (Houghton & Charman, 1986). If you know and respect the capability of each land, you can reduce the risk of soil damage and take a step towards climate-change mitigation to help countries move towards a low-carbon society. Mapping land capability at a district level on a spatial and timely basis can present a tool to conserve and manage natural resources and therefore reduce the harmful effects of climate change. In the purpose of mapping land capability, we will present a validated modeling procedure for the assessment of land capability using available soil information and a DEM for el Hermel District. The soil map (scale 1:50,000), which is widely used for planning purposes in Lebanon was used in conjunction with a Digital Elevation Model (DEM) to derive land capability map.

The following was studied the relationship between the water balance and the land use at watershed scale. If we are able to know which land use conserve water, we will be able to mitigate the effects of climate change, maintain water balance and reduce water loss. The variables of water balance are affected by three types of parameters: soil, climate and vegetation. For a random spot at El-Hermel district, from 2005 to 2013, the soil and climatic parameters remain the same: no valuable change in the soil data and climatic data has been recorded. The considerable change is expressed by the change of vegetation cover and land use. If we calculate the hydrological parameters in 2005 and 2013 and observe how they vary in parallel with the change of the land use, we can conclude which land use conserve most the amount of water and reduce flood risk in the semi-arid area of Lebanon.

Quantification of water available to land use is very complex, due to the large number of processes involved in the water balance in the soil. Therefore, we refer to hydrological models. There are numerous hydrological models available today, corresponding to very different methodological approaches: vs aggregate distributed; vs empirical, analytical; Deterministic vs. Stochastic, etc. The choice of a particular model depends on the objective to fulfill. In this study, a physical and distributed model called WiMMed was used to obtain hydrological variables that represent the water balance in the unsaturated zone. Those results were applied to study the relationship between these variables and the land use in 2005 and 2013 in order to select the land use most suitable to the semi-arid climate and capable to conserve most the water balance, reduce water waste and mitigate the effects of climate change.

Climate change is producing profound changes in global water. A changing climate can severely perturb regional hydrology and thereby affect human societies and life in general. To assess and simulate such potential hydrological climate change impacts, hydrological models require reliable meteorological variables for current and future climate conditions. Global climate models (GCMs) provide such information (Teutschbein, 2013). In many areas, climate change is likely to increase water demand while shrinking water supplies. The amount of water in semi-arid area is already limited and demand will continue to rise as population grows. Assessing the potential impacts of climate change on hydrological variables of the Lebanese part of El Asi-Orontes watershed using 2 representative concentration pathways (RCP2.6 and RCP8.5) scenarios will help preventing the consequences of the climate change effects on the hydrological variables and developing alternative water management under future conditions. The results of this study are necessary to predict the spatiotemporal variability of hydrological parameters in order to determine policies for sustainable water resource development. And contribute in decreasing harmful effects of climate change like severe drought or flooding.

Therefore, the general and specific objectives of each chapter of this thesis are presented below:

I. The overall objective of the first part (Chapter 2) of this work was to present a methodological approach and application of land capability assessment method which is designed for use at a small catchment level, using the commonly available soil data and the DEM. The achievement of this overall objective was developed in the following specific objectives:

    - Identify and classify the specific classes of areas, their location, altitude, surface and type with information on main pedological constraints interfering with crop production.

    - Layout lands at the scale of 1:20.000 to be presented with detailed classification to identify each arable land, classify it and report on soil constraints and suitability for irrigation.

    - Map land capability of Hermel District at a scale of 1: 20.000 identifying dominant land-types, climatic zones and other features relevant to the assessment of the capabilities of the land that will facilitate the planning of future land use in the Hermel District.

II. The general objective of the second part (Chapter 3) was to study the relationship between the hydrological variables involved in the water balance at a watershed scale and the land use change in El Asi - Orontes Watershed, Lebanon between 2005 and 2013. The achievement of this general objective was developed in the following specific objectives:

- Applying a distributed physically based watershed model (WiMMed) in El Asi - Orontes Watershed for 2 years: 2005 and 2013.

- Generating, through the application of this model, the hydrological variables that define the water balance in the unsaturated zone of the soil during 2005 and 2013 in the area of study.

- Comparing the land use map of both years and detecting the changes that have been occurred in the land use in term of type and area of change.

- Studying the relationship between the hydrological variables obtained and land use changes between 2005 and 2013 in El Asi - Orontes Watershed.

- Drawing conclusions on how land use change would affect the soil moisture of second layer in a semi-arid area.

III. The general objective of the research's last part (Chapter 4) was to assess the potential impacts of climate change on hydrological variables of the Lebanese part of El Asi-Orontes watershed using $CCSM_4$ GCM model (Gent *et al*., 2011) under 2 representative concentration pathways (RCP2.6 and RCP8.5). The achievement of this general objective was developed in the following specific objectives:

- Generating the hydrological variables (infiltration, run-off and soil moisture of second layer) of el-Asi-Orontes basin using WiMMed model and the current climatic conditions as inputs.

- Projecting current climatic data according to RCP2.6 and RCP8.5 scenarios in order to simulate the hydrological characteristics of our study area under the projected climate using WiMMed hydrological model.

- Comparing the model simulations of the current and possible future hydrological characteristics.

- Drawing conclusions on how climate change would affect hydrological characteristics in a semi-arid area.

IV. Finally, a General Discussion (Chapter 5) and General Conclusions (Chapter 6) will be presented in order to summarize all the information gathered in this thesis.

1.2. References

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Chapter 2. Assess Land Capability using a Geographical Information System based model in Hermel District, Lebanon*

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Assess Land Capability using a Geographical Information System based model in Hermel District, Lebanon.

Abstract

For the purpose of mapping land capability by United States Department of Agriculture (USDA) criteria, this paper presents a validated model to map land capability at a scale of 1:20,000 using a digital elevation model and the available soil information for Hermel district (525.6 km^2) in Lebanon. The model was validated through field work and it indicates a good overall accuracy of 89% and the significance of the model for mapping land capability at a district level. The study shows that 11.5 km^2 (2.2%), 284.6 km^2 (54.2%), 66.8 km^2 (12.7%), 147.9 km^2 (28.1%) and 14.9 km^2 (2.8%) of the region were categorized in I, II, III, IV, and V land classes respectively. The comparison between the zoning map already produced for Hermel city and the land capability map demonstrates that the land use patterns need to be modified according to identified land capability classes to sustain the remaining productive lands for future generations.

Key words: Land Capability Classification; soil data; spatial analysis; Agricultural Land Use; Lebanon.

2.1. Introduction

Hermel district is the main region of the Orontes basin in Lebanon. Agrarian changes in the region increased tensions on land uses and overexploitation of irrigation water. Partial disengagement of the State in Hermel provoked adverse impacts on land and water resources. The uncontrolled use of these resources caused especially water erosion of the soil and the overexploitation of groundwater (Hamade, 2012). As of 2014, Lebanon was facing a summer drought after a record dry winter coupled by a massive influx of Syrian refugees and long-standing water management problems. This drought lowered the groundwater level and decreased the flow of the springs. A direct consequence is the threat to the agricultural sector in this country (Faour *et al*., 2015). With the increasing of human pressure on limited land resources, the analysis of land system management and soil degradation gains exclusive interest.

One of the most important land evaluation attempts in Lebanon was during 1997-2001, when soil mapping based on modern techniques and large fieldwork was undertaken. It allowed the excavation of more than 400 profiles, which were described according to the FAO guide (1990) and sampled horizon wise (Darwish *et al*., 2005). Samples were analysed for their main physical and chemical characteristics. Soil types were classified following the Keys to Soil Taxonomy (1996), FAO-UNESCO revised Legend (1997) and World Reference Base for Soil Resources (1998) and a new soil map of Lebanon was produced (Darwish, 2006). The soil map offers a remarkable potential to constitute a tool to solve agriculture problems, in practice; however, it remains underutilized because of its complex scientific nature (Rushemuka *et al*., 2014). Soil scientists have realized the challenges of using these maps to work in a trans-disciplinary fashion (Wielemaker *et al*., 2001; Bui, 2004). The information of the soil map must be explained in an easy way that has meaning to the land-owners, decision makers and land-use managers.

Land capability classification acts as an important tool for land's better use. Classifying lands based on their capability at region level would help decision makers in the identification of different soil types in accordance with its capability for sustainable soil fertility management. Land capability is the ability to accept a type and intensity of land use permanently, or for a specified period under a certain management without long term degradation (Rees, 1995). Capability classes are groups that have the same relative degree of hazard or limitation to agricultural and non-agricultural uses. United State Department of Agriculture guidelines (USDA, 1973) have been applied to determine land capability with eight classes designated with Roman number I to VIII (Ayalew, 2015). The first four classes are suitable for agriculture in which the limitation on their use and necessity of conservation measures requires a careful management increase from I to IV (Sys *et al*., 1991), and the remaining classes are unsuitable for cultivation (Atalay, 2016). In 2004, a small-scale survey produced the land capability map of Lebanon by combining several layers related to the geomorphology and soil characteristics at a 1:200,000 scale (Darwish *et al*., 2005). At such scale, land capability classification can be used for providing a land quality inventory for Lebanon's agriculture land resource and identifying areas of agricultural interest mainly but not to plan urban and rural development, to locate the irrigation schemes and to plan transport, industrial development and telecommunication at a district level. Figure 1 shows the zoning map produced for Hermel city provided by Planning and Development Agency (PDA).

The objective of this map was to put land to the use for which it is best suited but it was done without taking into consideration the land capability of the city. This paper presents a methodological approach and application of land capability assessment method which is designed for use at a small catchment level, using the commonly-available soil data and the Digital Elevation Model (DEM). A description of the study area is presented first, followed by the methodology of land capability classification capability at a scale of 1:20,000. Results are presented after to spatially classify lands based on their capability and to assess the degree of conformance of the land use designations of specific parcels proposed by the zoning map already established for Hermel city to the output land capability map.

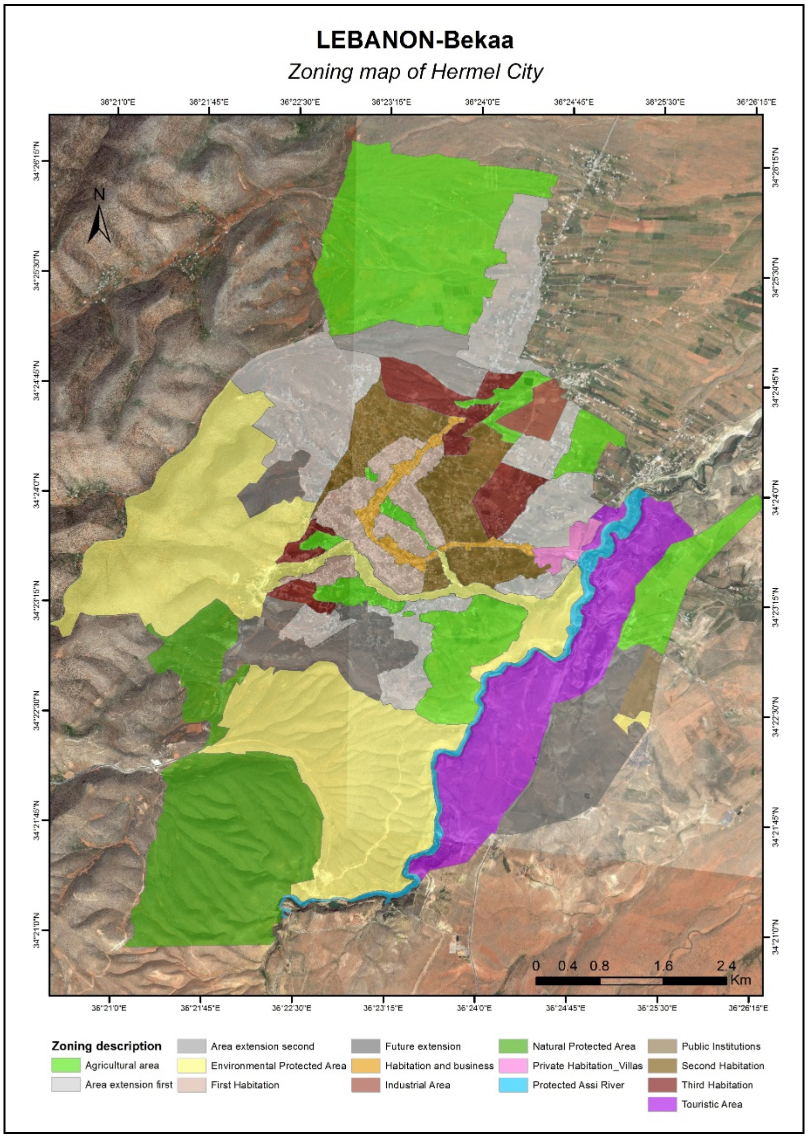

Figure 2.1. Zoning map of Hermel city

2.2. Material and methods

2.2.1. Description of the study area

Hermel district is the main area of the Orontes Basin in Lebanon. Spatial extent of Orontes Basin is ranging from latitude 34° 1´ 8" to 34° 2´ 9" North and 36° 7´ 44" to 37° 7´ 53" East. Hermel district covers a total area of 538 km^2, equivalent to 5% of the total area of Lebanon. It is located at the extreme Northern Eastern part of Lebanon (Figure 2). The study area is characterized by an altitude that varies between 500 m and 3000 m. It lies in semi-arid zone and has extreme summer with temperature reaching 40ºC. Average annual rainfall varies between 300 mm and 1300 mm, 80% of it is during the rainy season. January is the coldest month and August is the hottest month. The relative humidity varies between 62% and 70% during wet season and between 44 % and 48% during the rest of the year. The annual rate of evaporation is 1750 mm (Fonbonne, 2000).

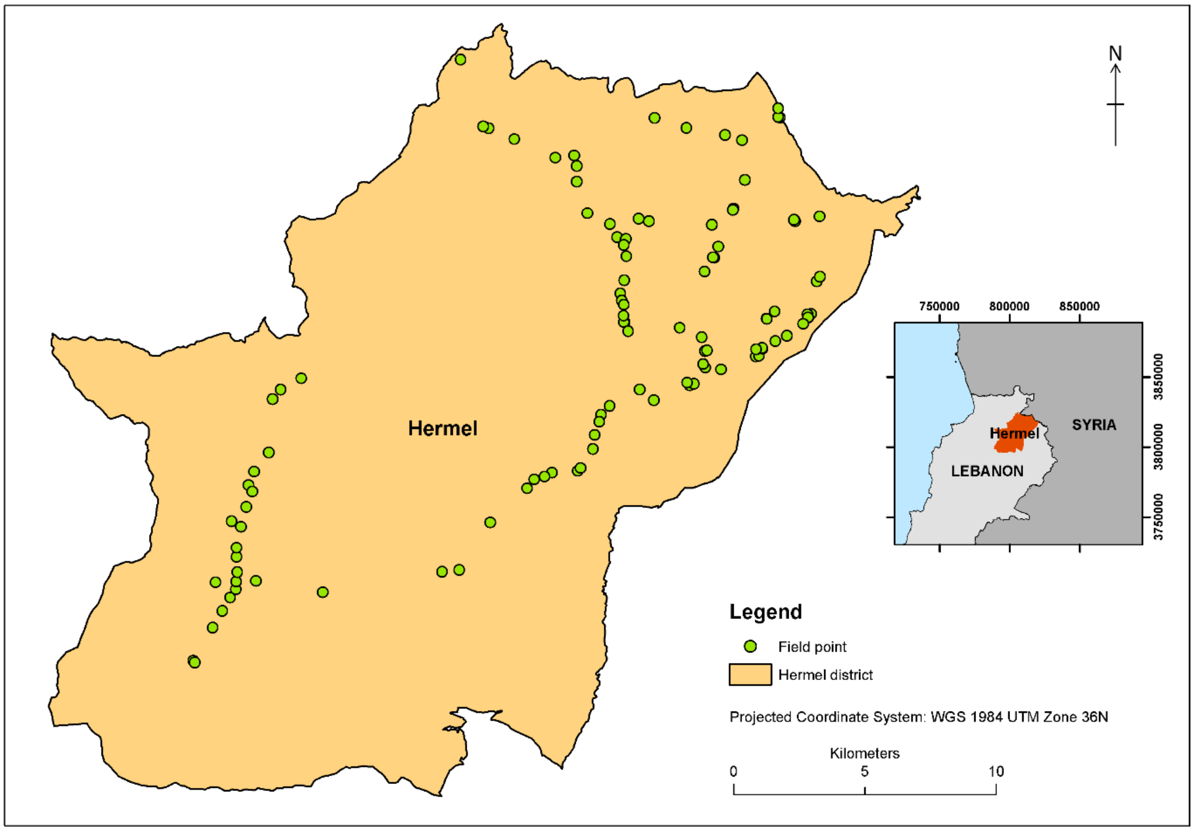

Figure 2.2. Location of Hermel District in Lebanon and locations of visited field points

2.2.2. Parameters considered for land capability mapping

The slope is the first parameter used in the equation of Land capability classification, it is a physical parameter computed from the DEM retrieved from https://earthexplorer.usgs.gov/ in ArcGIS environment. The four other parameters are measured soil parameters: soil depth, clay content, organic matter content (OM) and CaCO3, they were generated from the unified soil map of Lebanon 1/50,000 (Darwish, 2006).

2.2.2.1 Slope:

Slope is undoubtedly one of the most important factors to be considered in a capability classification. Slope gradient as a topography factor plays an important role on impacting soil erosion intensity (Zhang *et al*., 2015). Hermel district is characterized by the abundance of level and rolling lands on the eastern slopes and slopping and steep lands with slope gradient over 30% in the central part and on the west. In this study, slope is measured in percentage and recorded as one of the five slope groups categorized as follows:

- <5%: Level lands
- 5-8%: Rolling lands
- 8-15%: Slopping lands
- 15-30%: Steep lands
- >30%: Very steep lands

2.2.2.2 Soil depth

Soil depth is probably one of the most important factors in classifying land capability. Effective depth includes the total depth of the soil profile favourable for root development (Rees, 1995). Capability increases with the depth to solid bedrock. The area of study is characterized by the dominance of moderately deep and shallow soils which can reduce the area of the green cover as old and relict junipers forest is extremely rare and dispersed. Based on prevailing soil depth, this factor was classified into four classes with high positive effect on land capability classes (LCC) for soils having depth >75 cm, moderate effect for soils having a depth of 50-75 cm and low effect for soils having depth 25-50 cm, very low effect for soils having depth 10-25 cm. Soils having depth less than 10 cm were considered as non-arable.

2.2.2.3 Clay content

The clay content may be used to judge the suitability and capability of the soil because it affects the soil water content. Soils with as little as 20% clay size particles behave like a sticky clayey soil. Soils with high clay content have good water and nutrient holding capacity (Whiting *et al.*, 2015). The clay content of >30% and < 40% was attributed to the best effect on LCC due to clay positive impact on soil structure and cation exchange capacity. The moderate effect was credited to soils having clay content between 20% and 30%, low effect for soils having clay content greater than 40%. Capability of lands having clay content less than 20% is considered very low. A large part of the study area is characterized by clay and loamy soils. Soils with prevalence of silt and or sand, located to the west of the area of study, constitute a significant part of the soil types of Hermel district.

2.2.2.4 Organic matter content

The inherent capacity of soil to retain water mostly depends on specific soil parameters, such as soil texture, soil structure, and soil organic matter (SOM) content (Mudgal *et al.*, 2014). The organic content of soil greatly influences the plant, animal and microorganism populations and decomposing organic material provides many necessary nutrients to soil inhabitants (Whiting *et al.*, 2015). The slopping mountainous lands of the area of study are mainly characterized by relatively high organic matter content due to the effect of the relict forest and appropriate climatic conditions favouring natural vegetation and input of plant residues to the soil. The area of the level plains subject to cultivation and plowing showed lower level of organic matter content.

2.2.2.5 $CaCO_3$ content

$CaCO_3$ content has a significant effect on dry matter and grain yield (Patil, J.D. & Patil, N.D. 1981). The mountainous soils are characterized by low CaCO3 content which matches the prevailing climatic conditions and leaching of CaCO3 from the soil. Therefore, the soils of the low lands are characterized by enrichment in $CaCO_3$ which favours the formation of petrocalcic layer and affects the productivity of calcifuges crops.

2.2.3. Data Resources

Land capability classes were defined using information available from the unified soil map of Lebanon at a scale of 1:50,000 (soil depth, clay content, organic matter content and $CaCO_3$). This information in conjunction with slopes data taken from the 30m resolution DEM were used to define land capability.

2.2.4. LCC model, field work, model validation and results

2.2.4.1 LCC model

Table 1 displays the five LCC and the five related parameters on which the land capability model was based. The values of parameters (slope, soil depth, clay content, organic matter content, CaCO3) were generated from the unified soil map of Lebanon (1/50,000). The choice of parameters was based on previous studies on land capability classification (Panhalkar 2011; Ayalew, 2015; Slipa & Nowshaja, 2016).

Table 2.1. Categories of land capability based on slope and soil conditions

Attribute	**Land Capability Class**					**Weight**
Category	I	II	III	IV	V	**%**
	High	Moderate	Low	Very Low	Non Arable	
Slope, %	<5	5-8	8-15	15-30	>30	30
Soil depth, cm	>75	50-75	25-50	10-25	<10	25
Clay, %	30-40	20-30	>40	<20	Different	15
O.M. %	>5	3-5	1-3	<1	Different	15
Active CaCO3, %	<3	3-5	5-7	>7	Different	15

The most common factors used in previous studies were slope and soil depth. They were given the highest weights in this study: 30% was allocated to slope gradient and 25 % was allocated to soil depth. Organic matter, clay content and $CaCO_3$ were not common in previous studies; they are supposed to have less influence on land capability, they were equally assessed and given a weight of 15%. Each factor was assigned a score ranging from 1 (best land capability) to 5 (the poorest land capability). Finally, all these parameters are integrated by weighted summation to calculate land capability classes based on the equation below. Figure 3 summarizes the flow chart of the methodology used.

Equation 1:

$$(LCC = Slope \times 0.3 + Soil\ depth \times 0.25 + Clay\ content \times 0.15 + CaCO_3 \times 0.15 + OM \times 0.15)$$

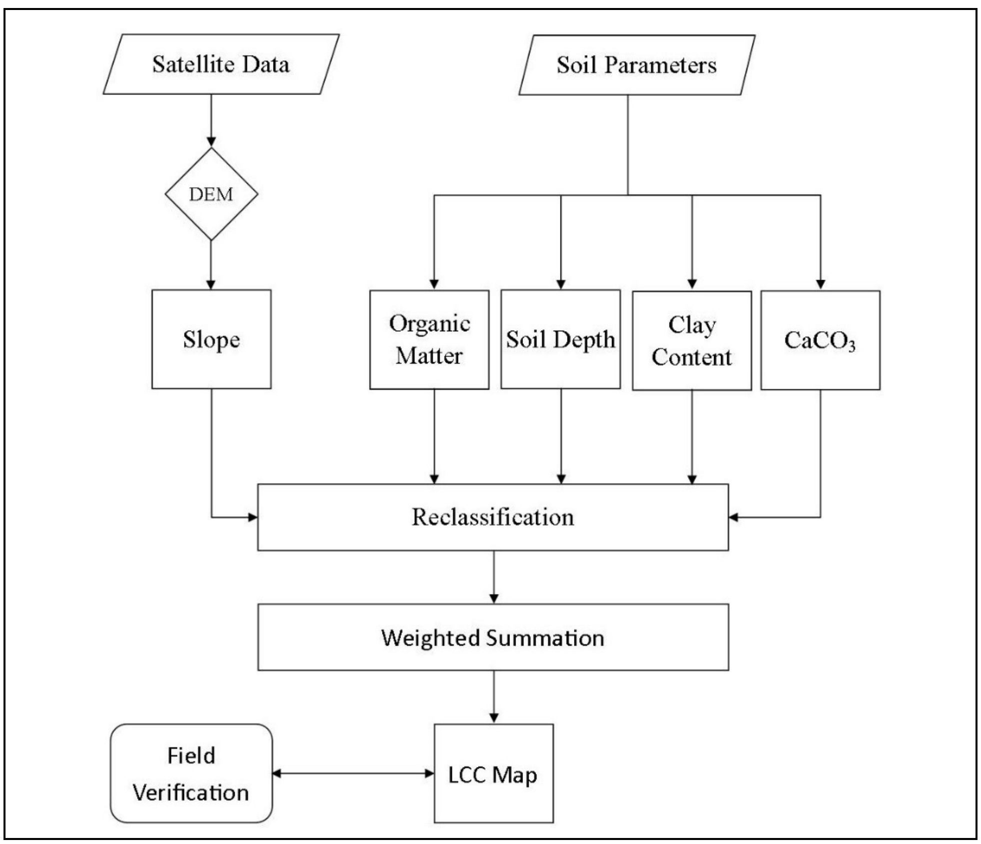

Figure 2.3. Flow chart of the methodology used

2.2.4.2 Field work

A total of 106 sample field points were used to validate the model (Figure 2). Survey points are irregularly located according to the survey team's judgment to enable the delineation of soil boundaries and checking of model output. Coordinates were registered for all field points with a real-time differential global positioning system (GNSS/GPS Systems, Leica). The error accepted for GPS measurements was limited to an EPE (Estimated Position Error) <1 m. Capability class of each point was recorded to compare it with the LCC (land capability classification) generated by the model.

2.2.5. Software

ArcmapTM (ESRI, v.10.3) was used to generate the soil parameters shapefiles and to compute the slope from the DEM (digital elevation model), including the calculation of the land capability classes and the production of the final LCC map. The 30 m spatial resolution DEM (digital elevation model) retrieved from open source (https://earthexplorer.usgs.gov/) was used to generate slope by using "Spatial Analyst Tool Surface Slope" in ArcmapTM (ESRI, v.10.3) environment. The slope and other soil parameters (soil depth, OM, clay content, CaCO3) were reclassified and grouped into 5 classes (from 1 to 5) based on their influence on land capability. Soil parameters are integrated by weighted summation using "Field calculator tool" to calculate land capability classes based on the equation 1 in ArcGIS environment. LCC Model validation and statistical analysis were performed using SPSS.

2.3. Results

2.3.1. Model validation

The validation of the land capability map is crucial for this study. Detailed observations were made during field survey to classify the 106 field points into the 5 capability classes and the results were compared with the land capability map. An accuracy analysis was then conducted and an error matrix was established between the modelling results and the field observations. It indicates a good overall accuracy of 89 % (95/106). The user's accuracy, the percentage of sites belonging to a model class correctly corresponds to field data is 82–100%, and the producer's accuracy, the percentage of sites belonging to field class correctly classified by the model is 82–93% (Table 2).

Table 2.2. Validation of land capability model

			Model predictions						
Ed(%)	**Pp(%)**	**Total**	**5**	**4**	**3**	**2**	**1**	**LCC**	
8%	**92%**	14	0	0	0	1	13	**1**	**Field observations**
8%	**92%**	26	0	0	1	24	1	**2**	
7%	**93%**	29	0	0	27	2	0	**3**	
18%	**82%**	17	0	14	2	1	0	**4**	
15%	**85%**	20	17	3	0	0	0	**5**	
		106	17	17	30	28	14	**Total**	
			100%	**82%**	**90%**	**85%**	**92%**	**Pu(%)**	
	Pt=89%		**0%**	**18%**	**10%**	**15%**	**8%**	**Ee(%)**	

Pu = user's precision; Ee = excess error (commission); Pp = producer's precision; Ed = deficit error (omission); Pt =total precision.

3.2 Land Capability for Agriculture Map of Hermel District

As main result, this work presents the Land Capability for Agriculture Map of Hermel District (Figure 4), based on the methodology described.

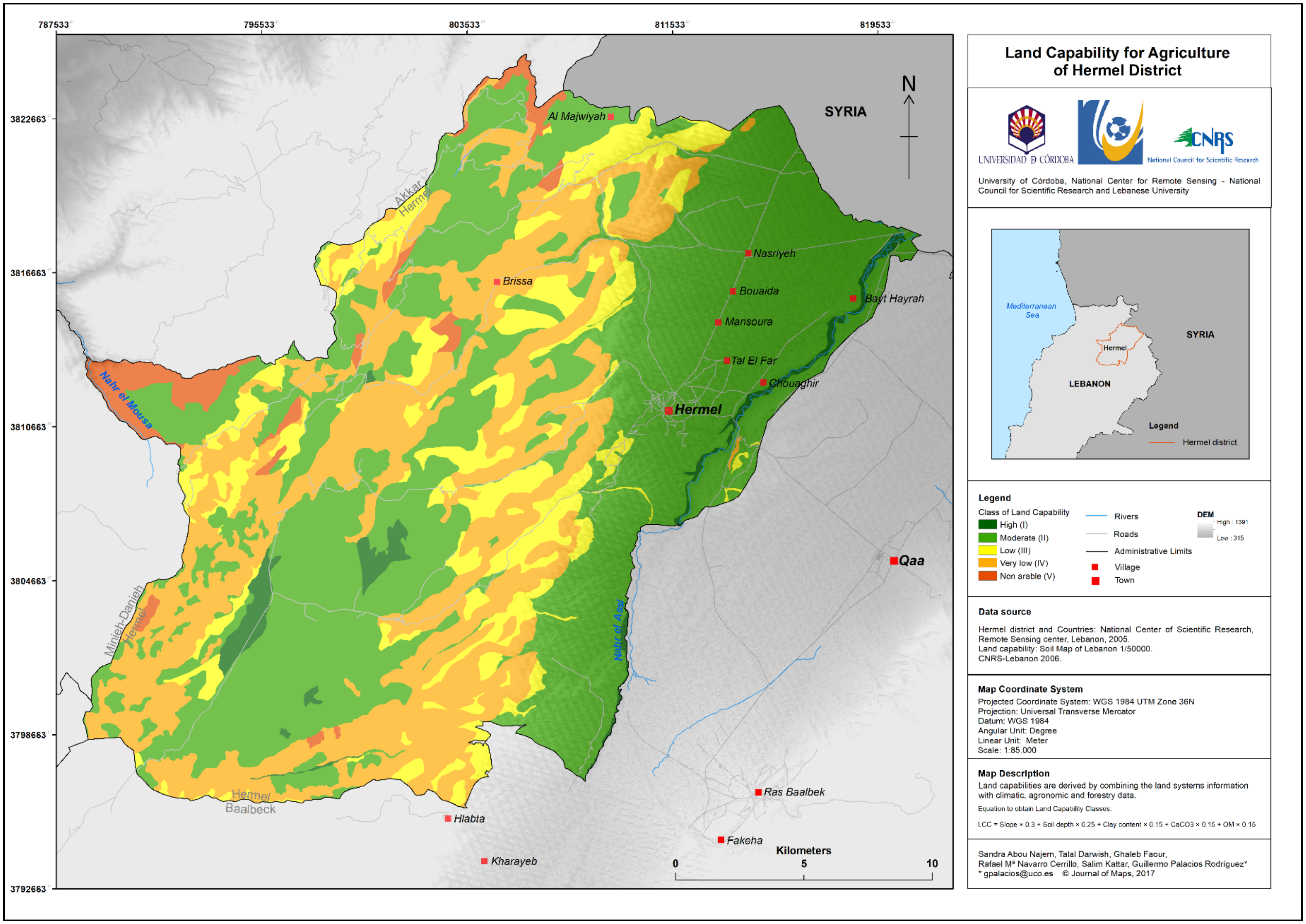

Figure 2.4. Land Capability for Agriculture Map of Hermel District

The map (Figure 4) shows five categories of lands:

(1) Class I represents lands with very minor or no physical limitations to use. These arable lands are spread in the North Eastern part of Hermel district and small patches in the Central South part. They represent 2.2% of the district total area. These soils are characterized by a suitable access for roots to moisture and a gentle slope. A wide range of crops can be grown and yields are good.

(2) Class II represents soils with minor limitations that reduce the choice of crops or require moderate conservation practices, or both. These soils are spread mainly in the East, central South and North West parts of Hermel district. The moderate capability class is large and constitutes 54.2% of the district area. Limitations may include moderate slopes, slight erosion or slightly unfavourable soil texture. A wide range of crops can be grown and winter harvested crops may not be ideal because of harvesting difficulties.

(3) Class III includes lands having limitations that require moderately intensive management practices or moderately restrict the range of crops, or both. These lands spread in the North and South central parts of Hermel district constituting 12.7% of the total area. The limitations affect the range of crops which are restricted mainly to grass, cereal and forage crops. Limitations are more difficult to correct and they include strongly sloping ground, imperfect drainage or severe climate. If terraced, they become of better productivity and thus might be planted with fruit trees.

(4) Class IV refers to land with severe limitations that restrict the choice of crops and/or require very careful management practices. The area of very low productivity lands is the largest. It constitutes 28.1% of the casa total area. This class is widespread in the central parts and West boundaries of the district. Limitations are due to very stony soils, steep

gradients and presence of petrocalcic layer: friable secondary calcium carbonate rock of 30-50 cm of thickness, found in the level lands of the eastern part of Hermel district. If these layers are removed by rippers and soils are ploughed, the land becomes class II or III as deep soil layer is found beneath the removed secondary rocks. But land reclamation requires large investment cost.

(5) Class V groups all the non-arable lands or lands with severe limitations that restrict their use to pasture, grazing, forestry and recreation. The area of non-arable lands is estimated at 14.9 km^2. It constitutes 2.8 % of the total area. These soils are spread in the West part of the district and form small patches in the North East and West boundaries of the casa. Limitations results from steep slopes, severe risk of erosion and shallow soils. The land has a wide range of capability for grazing, forestry and recreation.

2.4. Discussion

The slopes on the mountainous areas form class V lands, in general. These areas have high percentage of stoniness and steep slopes which make them unsuitable for agriculture. Only drought-resistant trees, like Juniper, are able to grow in such conditions. Generally, class IV occurs along the foothills of the mountains and the level lands of the Eastern part. This class shows the development of petrocalcic horizon which is a thick deposit that can be removed by rippers. These layers are the result of an extreme evapotranspiration reaching 1500 mm per year and restricted amount of rainfall (< 300mm). Northeastern and central South parts of the district are mainly the lands belonging to land capability classes I, II and III.

The comparison between land capability classification and the zoning map of Hermel city are presented in Table 3 to assess the degree of conformance of the lands use designations of specific parcels proposed by the zoning map to the land capability map obtained in this work.

Table 2.3. Percentage of each capability class from each zoning class

Zoning \ Capability Class	I High	II Moderate	III Low	IV Very low	V Non-arable	Total Area (Km^2)
Agricultural area	0.705204	98.6021	0.632992	0	0	9.480364
Area extension first	0	99.41552	0.584476	0	0	5.786021
Area extension second	0	100	0	0	0	0.853027
Environmental protected area	1.652527	74.96066	3.30931	17.59763	0	11.25721
First habitation	0	100	0	0	0	1.596621
Future extension	0	82.03777	16.06914	0.455867	0	3.816736
Habitation and business	0	100	0	0	0	0.498936
Industrial area	0	100	0	0	0	0.359202
Natural protected areas	0	83.30109	15.84012	0.548753	0	5.716644
Private habitations/Villas	0.145053	99.85495	0	0	0	0.238302
Protected Assi river	65.63393	21.19023	0	0.001698	0	0.786959
Public institutions	0	99.00399	0.996006	0	0	0.259997
Second habitation	0	100	0	0	0	2.281281
Third habitation	0	100	0	0	0	2.338516
Touristic area	9.378931	85.71911	0.511625	3.143368	0	4.021023
Total	2.327052	88.19887	4.075062	4.374958	0	49.28431

The results of this analysis show that the zoning map made for Hermel city did not take into consideration the soil capability of lands. Less than 1% of the classified agricultural lands are on high capability class and most of the habitations were classified within the high and moderate land capability classes.It was found that the conventional land evaluation methods suffer from limitation of spatial analysis (AbdelRahman *et al*., 2016) this implies that the poor agricultural productivity does not come from poor soil fertility but it is a result of the weak control of the land's use. Since most of the land in Hermel city is suitable for agriculture, therefore it is preferable to relocate industrial and residential structures to non arable and very low regions outside the city and give support to the agricultural sector to be an investment destination for the upcoming years.

This analysis shows that 56.3% of the district area can be termed as lands suitable for agriculture; they have slight limitations restricting their use or reducing the choice of plants. They require few management practices to grow crops. At a smaller scale (1:200,000), the land capability map produced for Lebanon in 2005 showed that the whole Hermel district is characterized by the presence of shallow soils which represent a serious problem for agriculture (Darwish *et al*., 2005). Based on the land classification of 2005, Hermel district has been classified into class III that represents soils having severe limitations and requiring special conservation practices.

Although the land capability map of 2005 and the one published in this study used basically the same methodology, the results were different. The small scale used in 2005 classification does not show well the variability of soil characteristics as the large scale of the current study does. It should be noted that the validity of the analysis is related to the scale of the input maps. For more detail planning, more detailed input maps are required.

The model shows a good overall accuracy of 89%, this indicates that the values of weights were well chosen with slope having the highest role in determining land capability. This may be caused by the landscape of the study region that is characterized by the presence of slopping and steep lands with slope gradient over 30% especially in the Central part and on the West. Although the results were considered to be valid, the application of this model in other regions with different characteristics in term of slope and soil composition is suggested to verify the validity of this model in all types of topography. It is necessary additional factors containing detailed climatic, geomorphic and topographic parameters that have impact on land capability and environmental sustainability. This map will provide a tool for the urban master plans that are under preparation because a big part of Hermel district is among the regions not yet zoned in Lebanon.

The model, thus developed demonstrates its significance for the land capability classification and the application of this model over all Lebanon and other countries is suggested to validate the usefulness of this method in different climatic regions to discover other parameters that may be later incorporated to the model described in this paper. Finally, the results demonstrate that the land use pattern need to be oriented according to land capability classes to increase the efficient use of lands for agriculture. The results obtained indicate that in some areas the use of the land is not the most appropriate (for example, areas of high agricultural productivity are used for other purposes such as urban development, while areas with little capacity to support crops are used for agriculture, offering very poor production).

The land capability map for agriculture could give a general orientation about the use of the soil. All the high class lands could be used for agriculture because they have no limitations. All the non-arable class lands can't be used for agriculture because the cost needed to modify the soil is so high. To suggest land use activities the study of land capability is not enough, this study should be followed by land suitability study and other detailed studies to suggest correct land use for each parcel of this region. Such kind of analysis enables decision makers to develop crop managements able to increase the land productivity (AbdelRahman *et al*., 2016).

The obtained map offers more detail on the land capability for agriculture in the study area, so it can be used as a planning tool by public management bodies to contribute to more efficient land planning.

2.5. Conclusions

This work shows that GIS provides a tool to overlay multi-layer of data and to produce the land capability map. This map will certainly help decision makers to control urban expansion and follow the implementation of rules for the construction on relevant land capability classes. They have now the ability to propose fine tuning of the land use planning developed centrally based on small scale maps. Controlling land use change, land use options and urban expansion can help preventing land degradation by chaotic urban sprawl, support suitable land use, and raise awareness to hasten local governance for the protection and sustainable use of natural resources in the area. For its effective use, it is needed to increase policy maker's awareness about the capability of soils and provide land use planners with information on the land's best use. A strong communication between soil experts and decision makers is likely to increase sustainable use of lands and to help in environmental protection if earlier interventions are made.

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Chapter 3. Modeling the Hydrological Behavior of El Asi - Orontes Watershed in Lebanon and Analyzing Effects of Land Use Change on Soil Moisture Using WiMMed for the period 2005-2013

Modeling the Hydrological Behavior of El Asi - Orontes Watershed in Lebanon and Analyzing Effects of Land Use Change on Soil Moisture Using WiMMed for the period 2005-2013

Abstract

This chapter studies the relationship between the hydrological variables involved in the water balance of El Asi - Orontes watershed in Lebanon and the land use change between 2005 and 2013 in all year seasons. The distributed physically-based watershed model WiMMed, was applied in the region of study to generate the following hydrological variables for the 2 years: rainfall (mm), snow (mm), infiltration (mm), runoff (mm) and soil moisture of second layer (mm).

The results of this study show that infiltration at basin level has been reduced between 2005 and 2013. This decrease is especially important in the spring season, when infiltration was reduced to 70% compared to that recorded in the basin in the same period of 2005. It's been found similar hydrological behavior in the soil moisture of second layer, observing the largest declines in 2013 compared to 2005, in the winter (27% decrease) and spring seasons (23% decrease). This hydrological behavior is related to with the land uses changes found in the studied area. Between 2005 and 2013 there was a significant increase in Grasslands (36.58 km^2) and Fruit tree areas (33.66 km^2) in El Asi - Orontes watershed. There was also an increase in the areas destined for agriculture, with an increase of 14.77 km^2, and Low density forests, with 12.65 km^2 increment. There was also a significant reduction in Bare areas, with a decrease of 97.5 km^2. The reduction of Dense forests area was more moderate (8.31 km^2), however this reduction represents the loss of almost 93% of Dense forests in El Asi - Orontes watershed in the period 2005-2013.

Thus, it can be concluded that land use change from 2005 to 2013 in El Asi - Orontes watershed has a negative effect on the hydrological characteristics of this watershed decreasing the infiltration capacity and the soil moisture of second layer in this area.

Key words: Land use, hydrological modelling, watershed, soil moisture.

3.1. Introduction

Growing water extractions combined with emerging social demands for environment services and protection increase competition for scarce water resources worldwide, especially in arid and semi-arid regions (Kahil *et al*., 2015). The consumption of groundwater is likely to become unsustainable. Already in many parts of the world – certainly beyond the arid regions where the problem is most common – aquifer drawdown is such that future reliance cannot be placed on this resource (Arab Water Council, 2009). El Asi - Orontes Watershed in North Bekaa (Lebanon) is a semi-arid area that suffers from drought, poor agricultural productivity, loss of biodiversity, and poverty, requiring greater understanding and management of land and water resources. Furthermore, the area is increasingly affected by floods caused by surface run-off water due to torrential rains, poor soil infiltration and deteriorated vegetation cover. Aware of the urgent need to address the high vulnerability of the population in semi-arid areas (Midgley *et al*., 2012), it is so important to increase the capacity of land use management to adapt to water scarcity and to mitigate its effects. Hydrologic modeling plays a very important role in assessing the seasonal water availability, which is necessary to take decisions in water resources management (Dwarakish & Ganasri, 2015). Modeling methods have been widely used for over 40 years for a variety of purposes, but almost all modeling tools have been primarily developed for humid area applications. Arid and semi-arid areas have particular challenges that have received little attention (Wheater, 2008). Despite the critical importance of water in arid and semi-arid areas, hydrological data have historically been severely limited. It has been widely stated that the major limitation of the development of arid-zone hydrology is the lack of high quality observations (Pilgrim *et al.*, 1988). In recent years, there have been important developments in data availability accompanied by a number of more detailed studies leading us to understand the characteristics of arid and semi-arid areas. In order to solve present and possible future problems with regard to fresh water supply, an application of hydrologic model that considers spatiotemporal watershed characteristics helps in accurate prediction of dynamic water balance of a watershed. However, under the situation of lacking data, that is, the non-existing of an adequate monitoring system, and the need to know how the system would behave under conditions and/or actions different from the past sequences, physically based models are the only option that allow the simulation of non-monitored systems (Aguilar *et al*., 2010). The WiMMed model is a physically-based distributed hydrological model that allows to simulate the water and energy balance in a watershed. In this study, WiMMed model was applied in El Asi - Orontes Watershed for 2 different years (2005 and 2013) as a suitable way to compute all the processes that determine water flows throughout the watershed in semi-arid areas. The results of the model show the hydrological behavior of the watershed corresponding to the following variables: snowfall (mm), precipitation (mm), infiltration (mm), run-off(mm) and soil moisture of second layer(mm). These 5 variables were calculated for both hydrological years in summer, autumn, winter and spring times. The results analysis reveals the change of infiltration, runoff and soil moisture of second layer in the years 2005 and 2013, which is considered useful to the further understanding of the hydrological processes in El Asi - Orontes watershed. After comparing these parameters of 2005 and 2013, the relationship between land use change and soil moisture of second layer has been studied. Understanding variability and change of hydrological processes and their implications on water availability is vital for water resource planning and management (Gebremicael *et al*., 2019) The seasonality of hydrological characteristics is one of the key factors controlling the development and stability of natural ecosystems. The comparison of the different hydrological variables between different years and seasons is analyzed to interpret the long-term climatic behavior and to understand flood occurrence (Parajka *et al.,* 2009). The anthropogenic changes in land use have altered the characteristics of the Earth's surface, leading to changes in soil physic chemical properties, soil fertility, soil erosion sensitivity and content of soil moisture (Sharif *et al*., 2014). Land use change may influence a variety of natural and ecological processes, including soil nutrient, soil moisture, soil erosion, land productivity (Chen *& Pen,* 2000). Land use plays an important role in controlling spatial and temporal variations of soil moisture by influencing infiltration rates, runoff and evapotranspiration, which is important to crop growth and vegetation restoration in semi-arid environments (Niu *et al*., 2015). Soil moisture is one of the most important components which expresses the balance between incoming (precipitation) and outgoing (evapotranspiration and runoff) quantities, being also an important measure in determining crop yield. Assessment, evaluation and prediction of dry conditions which could lead to crop damage, or are indicative of potential drought, is important for amelioration efforts and forecasting potential crop yields, which in turn can serve to warn farmers, prepare humanitarian aid to affected areas, or give international commodities traders a competitive advantage. Soil moisture conditions may also serve as a warning for subsequent flooding if the soil has become too saturated to hold any further runoff or precipitation. In areas of active deforestation, soil moisture estimates help predict amounts of run-off, evaporation rates, and soil erosion (CCRS, 2002). A study of land use change of both years has been established to assess how land use transformation affects soil moisture of second layer.

Land-use and climate changes may have both immediate and long-lasting impacts on terrestrial hydrology, altering the balance between rainfall and evapotranspiration and the resultant runoff (Li *et al*., 2007). Land use changes, which are mostly induced by human activities, affect hydrological processes such as evapotranspiration (ET), interception and infiltration, resulting in alterations of surface and subsurface flows (Zangh *et al*., 2016). In the study region, no significant change in climatic and pedological conditions has been recorded between 2005 and 2013 (LARI, 2018) so the factor that affects most the water balance is the land use. The main aim of this study is to apply the WiMMed model in El Asi - Orontes Watershed to obtain the hydrological variables that represent the water balance of this area for 2005 and 2013, to compare their variation and to assess the sensitivity of the soil moisture to land use changes at a watershed scale.

The general objective of this work was to study the relationship between the hydrological variables involved in the water balance at a watershed scale and the land use change in El Asi - Orontes Watershed, Lebanon between 2005 and 2013.

The achievement of this general objective was developed in the following specific objectives:

1- Applying a distributed physically-based watershed model (WiMMed) in El Asi - Orontes Watershed for 2 years: 2005 and 2013.
2- Generating, through the application of this model, the hydrological variables that define the water balance in the unsaturated zone of the soil during 2005 and 2013 in the area of study.
3- Comparing the land use map of both years and detecting the changes that have been occurred in the land use in term of type and area of change.
4- Studying the relationship between the soil moisture obtained and land use changes between 2005 and 2013 in El Asi - Orontes Watershed.

5- Drawing conclusions on how land use change would affect the soil moisture of second layer in a semi-arid area.

3.2. Material and methods

3.2.1. Description of the study area

The study area (Fig. 3.1) consists the major part of the Orontes watershed in the Northeastern part of Lebanon. The Orontes basin covers an area of 1361 Km^2, which represents 13% of the total area of Lebanon. It is situated between the two parallels 34° 1´ 8" and 34° 2´ 9" North and 36° 7´ 44" et 37° 7´ 53" East. The study area is characterized by an altitude that fluctuates between 550 m to the South and 3000 m to the North. The Orontes basin in Lebanon is characterized by its existence between two mountain ranges, Mount-Lebanon and Anti-Lebanon (CNRS, 2004). These two chains separated by a relatively narrow depression determine the general organization of the study area. It lies in a semi-arid zone as per the Climatic Atlas of Lebanon (Meteorological Services, 1982). Average annual rainfall measures in the range of 150-1300 mm, with 72% of its area receiving an average annual rainfall between 200 and 600 mm (Hamade, 2012). In summer, the temperature often exceeds 40ºC and in winter it sometimes falls below 0ºC. January is the coldest month and August is the hottest month. The relative humidity varies between 62% and 70% during wet season and between 44 % and 48% during the rest of the year (Nimah, 1990). The annual average sunshine hour is more than 8.3 hours/day. In July it stretches up to 10 hours. In rainy days it reduces to 3-4 hours. The rate of evaporation is high over the area. Annual rate of evaporation is 1,750 mm. The winds are strong, especially in winter. In February and March, the wind’s speed could reach 382 Km/h (Nimah, 1990). Three geological formations are present in the region: Alluvium, Miocene, and Cenomanian. The alluvial deposits cover 3% of the total area of the Orontes basin in Lebanon, occupying 49 km^2. The Miocene covers 30% of the total area of the study area, which is equivalent to about 419 km^2. And finally, the Cenomanian covers about 64% of the total area of the basin, equivalent to 882 km^2. The Cenomanian is a type of rock characterized by a medium infiltration. Finally, 36% of the total area of this region is situated on a slope between 8 and 30% (Hamade, 2012).

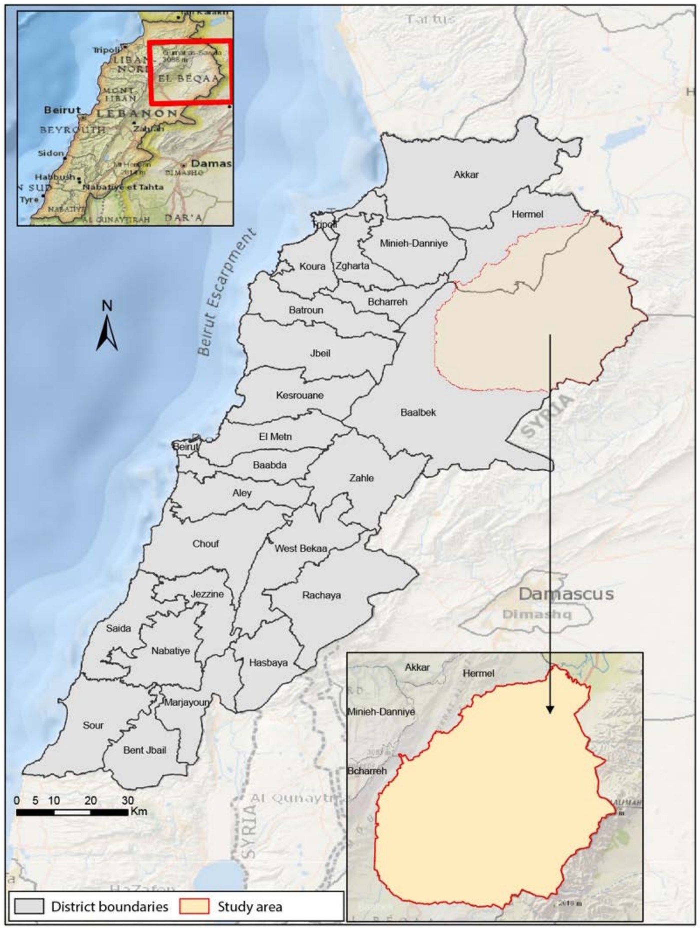

Figure 3.1. Location of El Asi – Orontes watershed in Lebanon

3.2.2. Watershed integrated hydrological model

a. Description of the model

WiMMed (Watershed Integrated Model in Mediterranean Environments) is a physically-based, fully distributed hydrologic model designed to include the variability of scales in the space and time characteristic of the Mediterranean climate in an operational suite. The model focuses on the spatial interpolation of the meteorological variables and the physical modeling of the water and energy balance at the cell scale (raster format). Characteristic aspects of Mediterranean watersheds with an influence on spatial and temporal variability (torrential rainfall events, semi-arid conditions and high risk of drought at hyper annual scales) are carefully considered, as well as processes where topography may substantially affect the results (Herrero *et al*., 2009). It is capable to connect GIS-based representations of the catchment with advanced algorithms to simulate the energy and water balance on a physical basis. The algorithms used by the model were developed taking into account the frequent shortage of input data in these areas, especially in mountainous areas, as distribution of meteorological stations, time series of recorded meteorological series or length and quality of the series (Herrero *et al*., 2014). The WiMMed model was applied in this study as it is the most suitable way to compute all the processes that determine water flows throughout the watershed in semiarid areas (Gómez-Giráldez *et al*., 2014). Also, characteristic aspects of Mediterranean watersheds with an influence on spatial and temporal variability (torrential rainfall events, semi-arid conditions and high risk of drought at hyper annual scales) are carefully considered in WiMMed, as well as processes where topography may substantially affect the results (Herrerro *et al*., 2014). WiMMed focuses on (a) the spatial interpolation of the meteorological variables at the cell scale, (b) the physical modelling of the energy and water balance at each cell, and (c) the consideration of different time scales when performing calculations, depending on the process being simulated (Egüen *et al*., 2012).

The model requires certain input data as detailed in the next section. Once the study area has been defined and the input variables introduced to the model, results on the meteorological variables can be obtained once the implicit interpolation mechanisms have been applied to each variable, state variables involved in the simulated processes and intermediate variables. The results of the obtained variables can be represented as maps for the case of distributed variables, as precipitation and infiltration, or as tables of values in the case of point variables (e.g. flow) or distributed but aggregated in space (e.g. mean precipitation of the basin or sub-basin). Depending on the needs of the study, the appropriate spatial and temporal scales are decided (Herrero *et al*., 2009).

A detailed description of each process and associate parameter characterization/calibration can be found in the cited literature. Herrero *et al*. (2011) provide the user's manual for the available WiMMed interface for Windows, and the theoretical basis of the hydrological-hydraulic model for water balance and flow calculations.

b. Input data required for modeling

A distributed water and energy balance is implemented as a cascade of reservoirs (vegetation cover, snow cover, and vadose zone of the soil) at each cell of the Digital Elevation Model of the watershed. Calculation is made on a time step of one hour under event situations (storms) or one day under non events situations (Aguilar *et al*., 2010). Different levels of simulations can be selected, according to the level of processing needed for a particular result desired, as well as different groups of resulting variables in terms of their spatial and temporal resolution. The type of simulation used in this work is the Surface Cycle simulation that performs the water balance in the unsaturated zone of the soil. To carry out this simulation the model requires several variables and input parameters. The input data are grouped into four large groups: Topography, Meteorology, Soil and Vegetation.

In the following, a short description of the data gathered for the studied watershed and its processing for the application of the model:

- Topography: The topographic input data are represented by a digital elevation model (DEM) with a horizontal resolution of 30 × 30 m and 1 m of vertical precision. The DTM downloaded from https://earthexplorer.usgs.gov// (Entity ID:SRTM1N34E036V3, Publication Date: 23/09/2014, Resolution: 1-ARC) was used to create the DEM for the application of this model. A resample from 26.2709 × 30.1783 m to 30 × 30 m was applied using Arcmap program. A projection of this raster has been done using the soil map (file +proj=utm +zone=37 +datum=WGS84 +units=m +no_defs). After that, we have extracted the DTM raster of the entire El Asi – Orontos watershed (Lebanon and Syria) and for the Lebanese part only. The DTM is the starting data for any project, since it is from this information that the extent, coordinate and accuracy (cell size) of all other maps are defined – both as input (which must coincide with it) and as output (Egüen & Herrero, 2009). The spatial resolution of 30 x 30 was chosen because it is the resolution of the Landsat images used in the characterization of the vegetation cover and because of the wide extension of the study area. It is a compromise solution between the time of execution of the Model and the levels of details required in this study. Once the DTM is introduced, the model generates the rest of the topographic variables involved in the water balance: slope, orientation, horizons, etc. (Aguilar, 2008).

- Meteorological data: The data required for the model are daily records of precipitation, mean temperature, maximum and minimum temperature, solar radiation, wind speed, vapor pressure and emissivity of the atmosphere. The meteorological information used in this study was gathered from two weather stations: El Qaa (x: 36.522961; y: 34.397645) and Machitiyeh (x: 36.085245; y: 34.15498), whose data were translated into ASCII files.txt format and manually introduced among the model inputs. The data of 2015 was used as meteorological data for both years (2005 and 2013) because of the lack of daily data in 2005 and 2013 and because no significant change in climate was recorded between 2005 and 2013 (LARI, 2018).

- Soil data: Physiochemical and hydraulic properties of the soil were estimated using the available soil map of Lebanon at 1:50,000 scale performed by Darwish (2006), providing information by soils textures (clay, clay loam, loam, sandy clay loam or sandy loam). This soil texture data has been used to generate thematic maps for the studied watershed: saturated surface conductivity (mm/h), porosity (m3/m3), Van Genuchten retention parameter (dimensionless), saturation and residual moisture values (cm3/cm3) and soil thickness of layer 1 and 2 (mm). This information has been used for the performance of WiMMed model. The soil map database provides comprehensive information related to soil physical and chemical properties, including landforms, lithology, slope gradient, drainage conditions, surface stoniness, texture, soil depth and thickness. The final soil classification system is based on US soil taxonomy, FAO UNESCO revised legend and World Reference Base (FAO, 1988).

Except soil thickness, which has been measured for all soil types in Lebanon and published with the Soil Map of Lebanon (Darwish, 2006), measured values of all these parameters are not available, so they were estimated depending on soil texture. Five different soil texture have been observed in the studied watershed (Darwish, 2006): clay, clay loam, loam, sandy clay loam and sandy loam.

Saxton and Rawls (2006) have defined the ranges of the saturated hydraulic conductivity (KSAT) and porosity for the USDA soil texture, showed in Table 3.1. Table 3.2 contains listed values for the Van Genuchten parameter n, the residual and saturated water contents for various soil textural classes compiled from the Unsaturated Soil Hydraulic Database (UNSODA) database (Leij *et al*., 1996). Results of soil thickness (upper layer 1 and lower layer 2) depending on soil type are shown in Table 3.3.

Table 3.1. Ranges of saturated hydraulic conductivity (K_{sat}) and porosity for the USDA soil textural classes (Saxton & Rawls, 2005)

USDA Soil Texture Class	K_{sat} (mm/h)	Porosity (m^3/ m^3)
Sand	0.5091 – 0.3058	0.48 – 0.46
Loamy sand	0.4464 – 0.1683	0.47 – 0.44
Sandy loam	0.3553 – 0.0744	0.47 – 0.42
Loam	0.0271 – 0.1538	0.48 – 0.46
Silt loam	0.0402 – 0.2126	0.48 – 0.46
Silt	0.0425 – 0.1068	0.49- 0.47
Sandy clay Loam	0.0128 – 0.0653	0.45 – 0.42
Clay loam	0.0122 – 0.0256	0.50 – 0.45
Silty clay loam	0.0183 – 0.0252	0.53 – 0.49
Sandy clay	0.0003 – 0.0088	0.46 – 0.43
Silty clay	0.0115 – 0.0118	0.55 – 0.50
Clay	0.0103 – 0.0056	0.56 – 0.46

Table 3.2. Van Genuchten parameter (n) including residual (Θ_r) and saturated (Θ_s) water content compiled from the UNSODA database (Leij *et al*., 1996).

Textural class	**Θ_r (cm^3/ cm^3)**	**Θ_s (cm^3/ cm^3)**	**n**
Sand	0.058	0.37	3.19
Loamy sand	0.074	0.39	2.39
Sandy loam	0.067	0.37	1.61
Loam	0.083	0.46	1.31
Silt	0.123	0.48	1.53
Silt loam	0.061	0.43	1.39
Sandy clay Loam	0.086	0.40	1.49
Clay loam	0.129	0.47	1.37
Silty clay loam	0.098	0.55	1.41
Silty clay	0.163	0.47	1.39
Clay	0.102	0.51	1.20

Table 3.3. Thickness of upper layer 1 and lower layer 2 from the Soil Map of Lebanon at 1:50,000 scale database (Darwish, 2006).

Soil type	Thickness of upper layer 1 (mm)	Thickness of lower layer 2 (mm)
Areno-eutric leptosols	500	0
Aridic leptosols	100	400
Aridic calcaric leptosols	0 – 80	80 – 500
Aridic calcisols	0 – 200	200- 650
Aridic fluvisols	0 – 120	120 – 500
Aridic regosols	0 – 100	100 - 200
Calcaric - fluvisols	0 – 200	200 – 550
Calcaric leptosols	0 – 300	300 – 450
Endocalcaro-hyperskeletic leptosols	0 – 300	300 – 350
Eutric - luvisols	0 – 600	600 – 1300
Eutric - regosols	0– 150	150 – 620
Leptic luvisols	0 – 200	200 – 400
Lithic leptosols	0 – 200	0
Petric calcisols	0 – 50	5 0– 350
Rendzic leptosols	0 – 220	0
Rhodic luvisols	0 – 200	200 – 700
Calcaric cambisols	0 – 200	200 – 550
Calcaric regosols	0 – 300	300 – 600
Calcaro- hortic anthrosols	0 – 380	380 – 650
Eutric cambisols	0 – 100	100 – 350
Eutric fluvisols	0 – 400	400 – 850
Eutric leptosols	0 – 120	120 – 250
Haplic calcisols	0 – 200	200 – 1000
Hyperskeletic leptosols	0 – 200	200 – 650
Haplic luvisols	0 – 280	280 – 420
Haplic regosols	0 – 200	200 – 650
Leptic andosols	0 – 200	0
Leptic calcisols	0 – 400	400^{+}
Skeletic regosols	0 – 400	400 – 1700
Vertic cambisols	0 – 250	250 – 450

- Vegetation data: The information related to the vegetation corresponds to the map of vegetation fraction (VF), defined as the percentage or fraction of occupation of vegetation canopy in a given ground area in vertical projection (Liang *et al.*, 2008). It is popularly treated as a comprehensive quantitative index in forest management and vegetation communities to monitor respective land cover conditions (Gómez-Giráldez *et al*., 2014). The vegetation fraction is given by (Liang *et al.*, 2008):

$$F_v = \frac{NDVI - NDVI_0}{NDVI_{100} - NDVI_0}$$

Where Fv is the vegetation fraction, NDVI is the Normalized Difference Vegetation Index (Tucker, 1979), corresponding to the cell in question, $NDVI_0$ is the vegetation index corresponding to the bare soil, and $NDVI_{100}$ is the vegetation index corresponding to a surface totally covered by vegetation.

NDVI vegetation indices were obtained using ENVI software (ITT Visual Information Solutions, Boulder, USA), using for each studied year the available corrected Landsat image (Table 3.4).

Table 3.4. Landsat images used in the calculation of Fv

Year	Platform	Sensor	Date
2005	Landsat 7	ETM+	08/23/2005
2013	Landsat 8	OLI; TIRS	07/21/2013

c. Model calibration

Since there was no gauging station in the study area, hydrograph records were not available for the calibration and validation of the model. As El Asi – Orontes watershed calibration data are not available for this study, calibration data from a similar watershed was used. Thus, the calibration parameters obtained in a semi-arid area in Spain, the

Guadalfeo river basin (Aguilar, 2008) were used (Table 3.5). El Asi – Orontes watershed in Lebanon mountain range and the Guadalfeo river basin in Sierra Nevada Mountain (Southern Spain) are both semi-arid / Mediterranean mountainous areas situated in mid-latitudes, drier and warmer, where snowmelt also constitutes the main component of the total water resources during the summer season (Polo *et al.*, 2018). Therefore, these parameters, previously calibrated and validated in similar conditions, are assumed to be valid in the study area due to the lack of information to carry out a specific complete calibration and by the relative similarity of both zones.

Table 3.5. Calibration parameters used in WiMMed.

Soil property	Parameter
Soil evaporation exponent	0.60
Soil evaporation coefficient	0.80

3.3. Results

3.3.1. Physical characteristics of the study area

As a preliminary step of the hydrological analysis, the physical characteristics of the watershed are introduced into the model, including topography, meteorology, soil and vegetation.

a) ***Topography***

It is defined by the DTM (Fig. 3.2) of the study area. The gradients of slope allow us to characterize the mountains and to have an idea about the diversity of landforms in the study area. The DEM shows that lands with the highest elevations (>1950m) are spread in the Northern Western and Southern Eastern parts of the study area. Lands with the lowest elevations (between 540 m and 900 m) spread in the Northern Eastern parts of the study area and lands with medium elevations are widespread in the central part and West boundaries of the watershed.

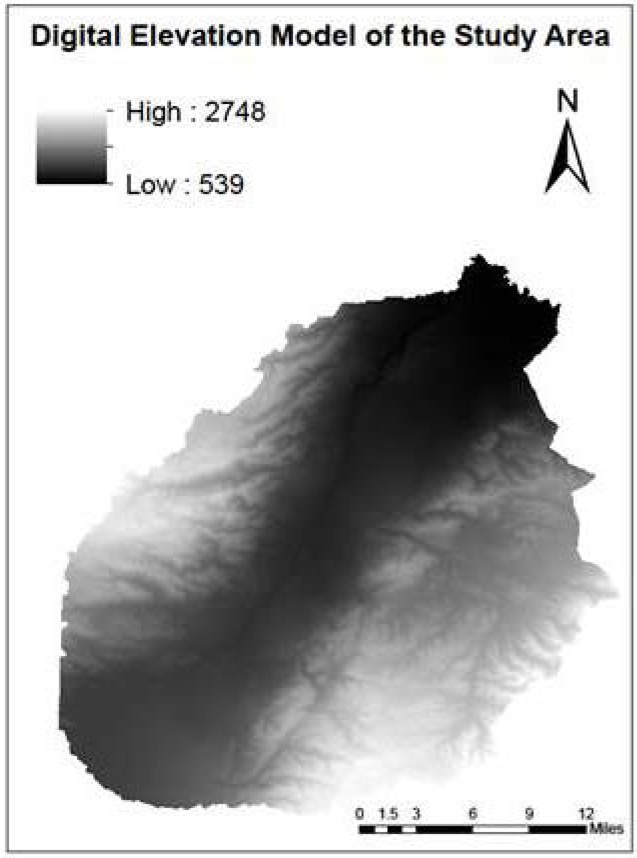

Figure 3.2. Digital elevation model of the study area

b) ***Meteorology***

The meteorology of the study area can be defined with the total monthly precipitation (Fig. 3.3) and the mean monthly temperature (Fig. 3.4). It can be observed that the total annual precipitation of the zone is 147.4 mm taking March as the wettest month (43.4 mm) and May, June, July, August, September, October and November as the driest ones (0.00 mm). As for temperature, the warmest month is August (23.84 °C) and the coldest month is January (2.6 °C).

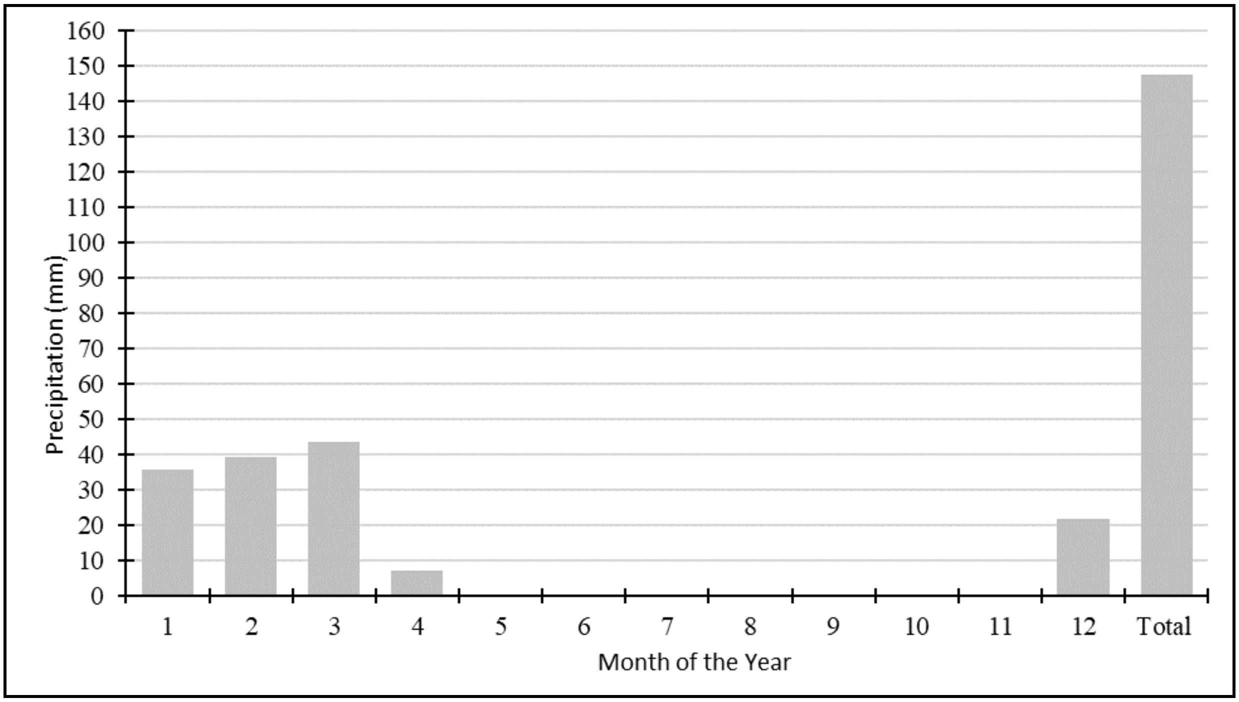

Figure 3.3. Total monthly precipitation of the study area

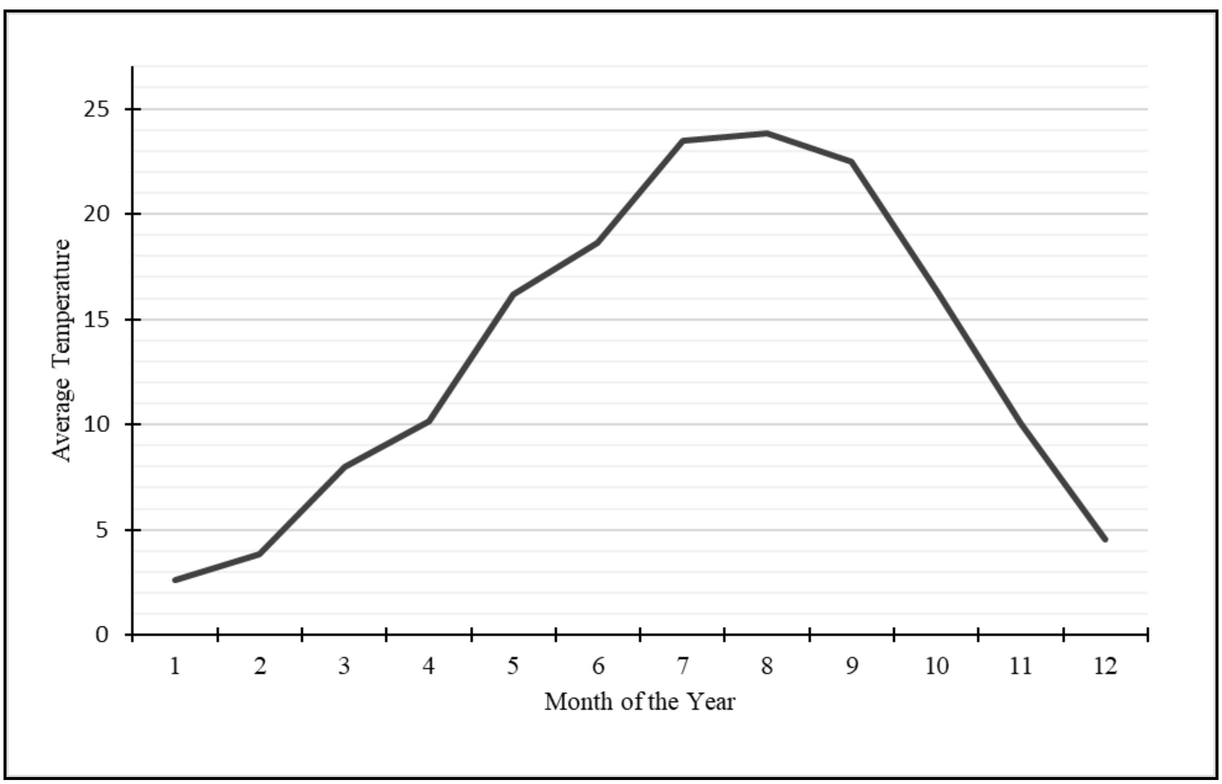

Figure 3.4. Average monthly temperature of the study area

c) Soil

Some soil properties, like saturated hydraulic conductivity, are influenced by the topographic gradients, while others, such as soil depth, are affected by the segmentation of the geological units (Gómez-Giráldez, 2014). Figures 3.5 and 3.6 show the soil properties necessary for the execution of the WiMMed model.

Saturated Hydraulic conductivity of soil in the Upper and lowest layers are the lowest in the Northern and Southern West while the highest values of the saturated hydraulic conductivity of soil is found in the Central Western part and some patches along the Eastern part.

The highest values for n of Van Genuchten are spread in the Southern Eastern part and some patches in the Central Western part while the lowest values are found in the Northern Eastern and the Southern Eastern parts of the study area.

The lowest values of the matric potential are found in the Southern Eastern part and few patches in the Western Central part while the highest values of matric potential are spread along the Eastern part of the study area.

The distribution of the residual and saturation moisture are similar. The highest moisture values are found along the Eastern part of the study area while the medium and low values are spread in the Western part. Few patches of low, residual and saturation, moisture spread in the Western part of the watershed.

The thickness of soil upper layer varies significantly among the area of study. The thickest layers are found along the Southern Eastern part while the Central North and the center of the study area appear to have thin soil upper layers.

Most of the study area (Central, Eastern and Western parts) seem to have thin soil second layer. Small patches of the Central Eastern and the Southern Western parts have high values for the thickness of soil second layer.

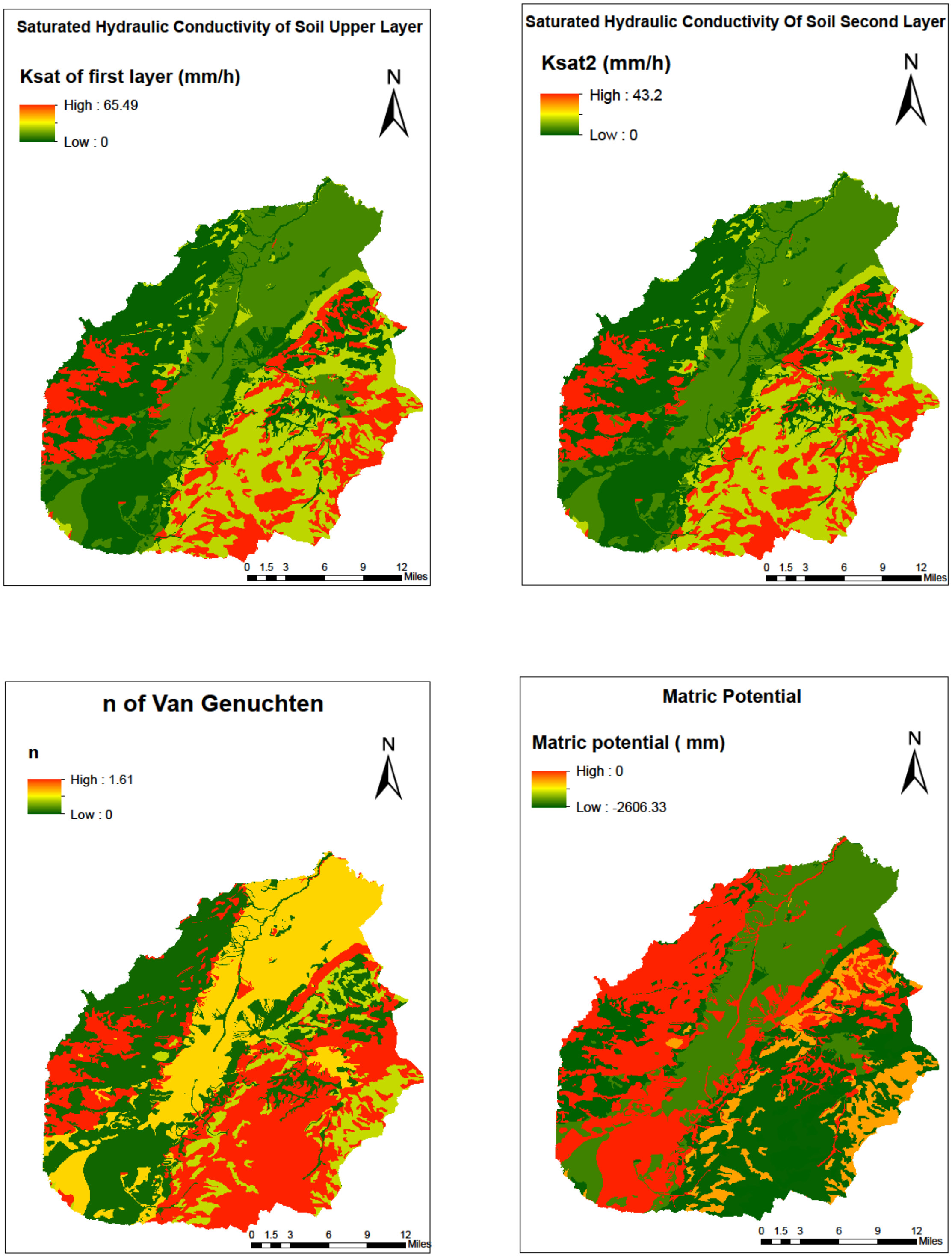

Figure 3.5. Soil parameters of the study area: Saturated Hydraulic Conductivity of soil upper layer, Saturated Hydraulic Conductivity of soil second layer, N of Van Genuchten and Matric potential

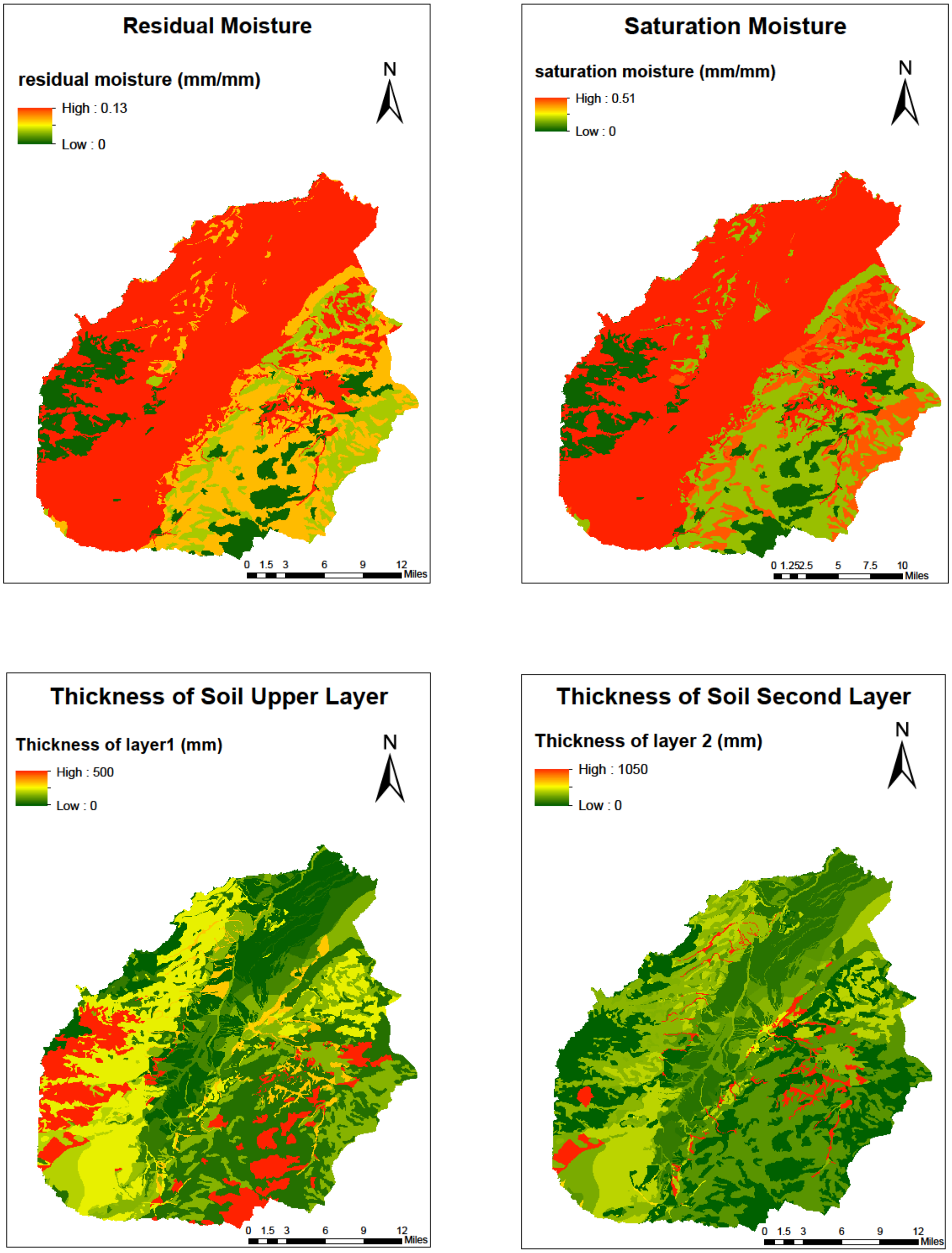

Figure 3.6. Soil properties of the study area: Residual moisture, Saturation moisture, Thickness of soil upper layer and Thickness of soil second layer

d) ***Vegetation***

The vegetation status in the study area was defined by the vegetation fraction (F_v). Figure 3.7 shows the vegetation fractions of 2005 and 2013 years. It can be observed how the cover varies within the same image between neighboring cells and between images of 2005 and 2013.

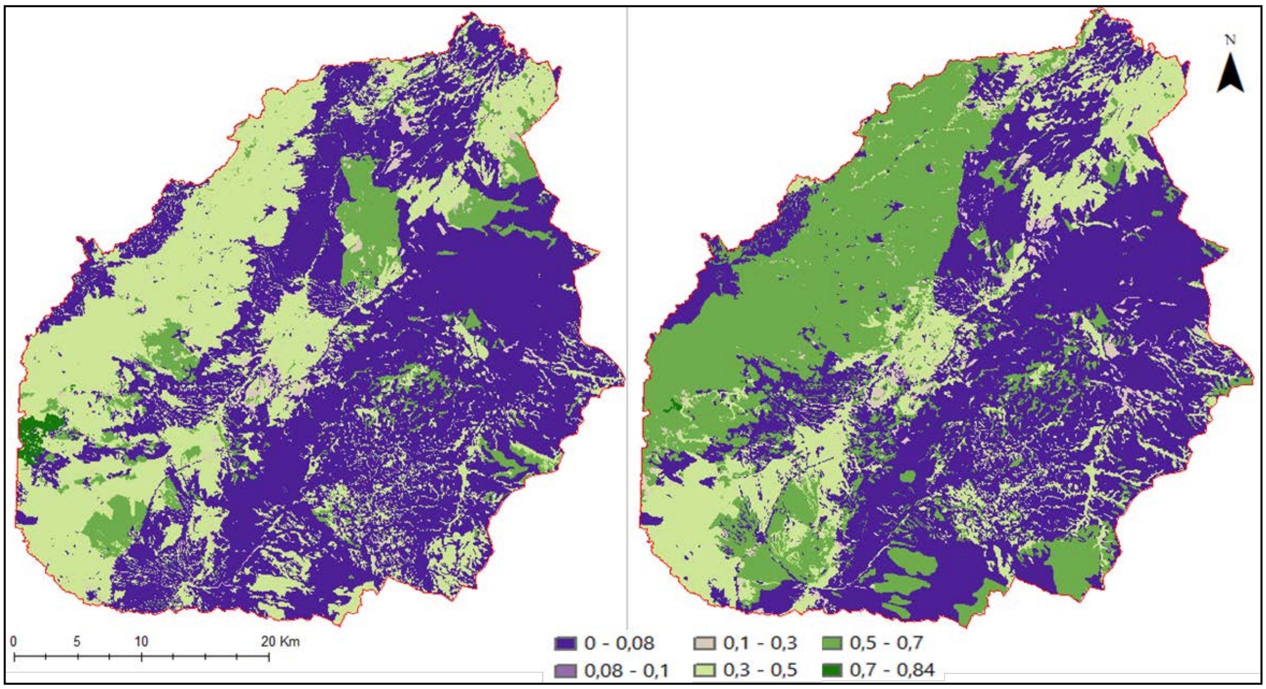

Figure 3.7. Vegetation fraction (F_v) in the study area in 2005 and 2013

3.3.2. Hydrological behavior of the study area

The WiMMed model generated a set of raster maps with a spatial resolution of 30 x 30 m^2 corresponding to 5 variables calculated. All the variables were generated for each season (Autumn, Winter, Spring, Summer) of each hydrological year (2005 and 2013).

The variables were grouped in 3 categories for interpretation: state variables, intermediate variables and meteorological variables. State variables have been calculated as the instantaneous value that this variable takes at the last day of the analyzed station, while the results of the intermediate and meteorological variables represent the average of the accumulated value for the analysis period (Herrero *et al*., 2011).

As intermediate variables, infiltration (mm) and runoff (mm) were obtained. The outputs variables of the model reflected appreciable changes within the same image between neighboring cells, as a result of the spatial variability of the input data (Figures 3.8 and 3.9). About state variables, the soil moisture of second layer (mm) was calculated (Figure 3.10), and as meteorological variables, rainfall (mm) and snow (mm) were obtained (Figures 3.11 and 3.12).

Comparing the results obtained for 2005 and 2013, the hydrological properties of the territory in the study area have changed and clear differences can be observed between the analyzed years.

Since the main aim of this study is to evaluate the effect of land use change on hydrological behavior, the changes of hydrological variables will be compared in the following section by season between both years 2005 and 2013 as vegetation status (morphological and physiological) varies a lot between the different seasons of each year: summer, autumn, winter and spring.

The results show that big difference can be observed in infiltration (Table 3.6; Figure 3.8), mainly in spring season with a reduction of almost 70% in 2013 compared to 2005, that determine the complex hydrological behavior of the zone and highlights the distributed nature of the model applied in the calculation of the water balance (Gómez-Giráldez, 2014).

Table 3.6. Average data of Infiltration (mm) by season for 2005 and 2013 in the study area.

INFILTRATION	**Autumn 2005**	**Autumn 2013**	**Winter 2005**	**Winter 2013**	**Spring 2005**	**Spring 2013**	**Summer 2005**	**Summer 2013**
Mean	2.57	2.43	30.17	29.66	81.23	23.88	0	0
Standard Deviation	2.22	2.22	13.92	13.89	16.76	10.8	0	0
Maximum	7.06	7.06	74.82	74.16	143.47	67.82	0	0
Minimum	0	0	0	0	2.66	0	0	0

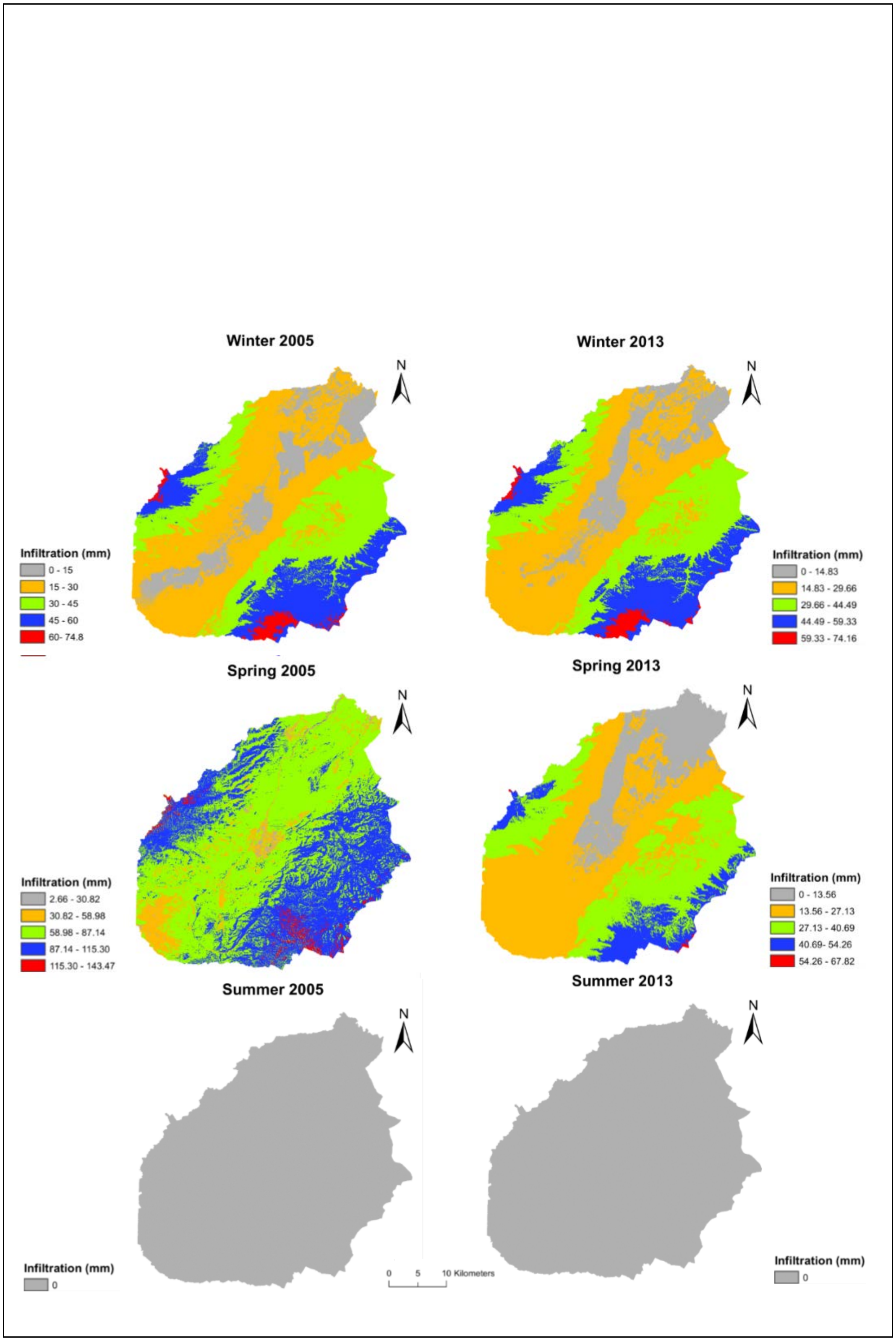

Figure 3.8. Spatial distribution of the Infiltration depending on the season in 2005 and 2013.

Runoff in the study area has also decreased in 2013 compared to 2005 (Table 3.7; Figure 3.9), although this was less than in the infiltration, and observing the greatest difference in the autumn season.

Table 3.7. Average data of Runoff (mm) by season for 2005 and 2013 in the study area.

RUNOFF	Autumn 2005	Autumn 2013	Winter 2005	Winter 2013	Spring 2005	Spring 2013	Summer 2005	Summer 2013
Mean	0.109	0.033	1.43	1.39	3.6	3.56	0	0
Standard Deviation	0.87	0.27	7.17	7.09	10.42	10.35	0	0
Maximum	20.78	6.92	74.35	73.68	76.81	78.28	0	0
Minimum	0	0	0	0	0	0	0	0

It's been found similar hydrological behavior in the soil moisture of second layer, the state variable modelled for the entire study area (Table 3.8; Figure 3.10), observing the largest declines in 2013 compared to 2005, in the winter (27% decrease) and spring seasons (23% decrease).

Table 3.8. Average data of Soil Moisture of the Second Layer (mm) by season for 2005 and 2013 in the study area.

SOIL MOISTURE SECOND LAYER	Autumn 2005	Autumn 2013	Winter 2005	Winter 2013	Spring 2005	Spring 2013	Summer 2005	Summer 2013
Mean	40.02	37.07	65.93	47.89	65.28	50.47	42.21	37.73
Standard Deviation	168.74	147.7	22.47	18.53	163.92	135.67	168.76	147.84
Maximum	293	279.9	150.13	118.9	297.7	205.13	333.81	279.93
Minimum	0	0	0	0	0	0	0	0

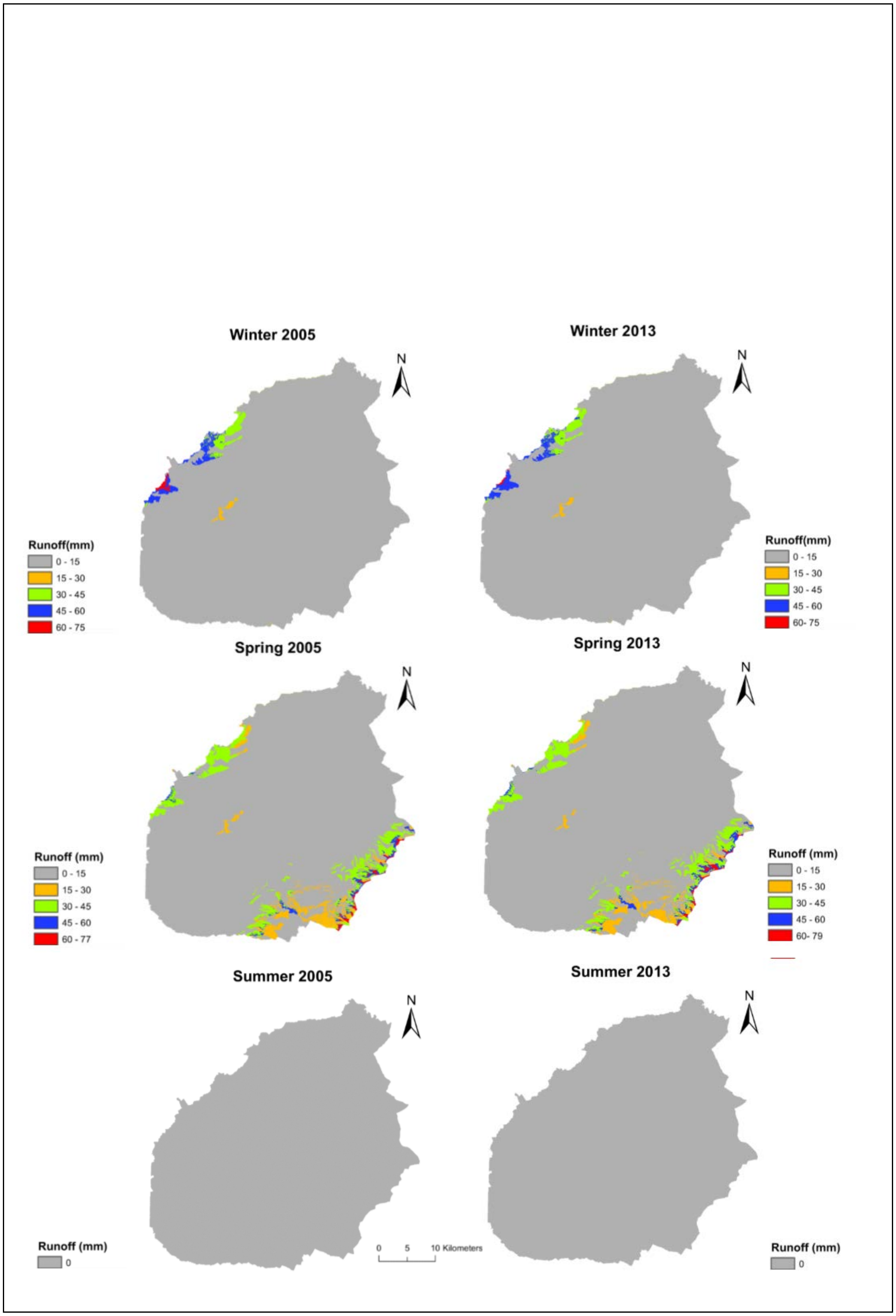

Figure 3.9. Spatial distribution of the Runoff depending on the season in 2005 and 2013.

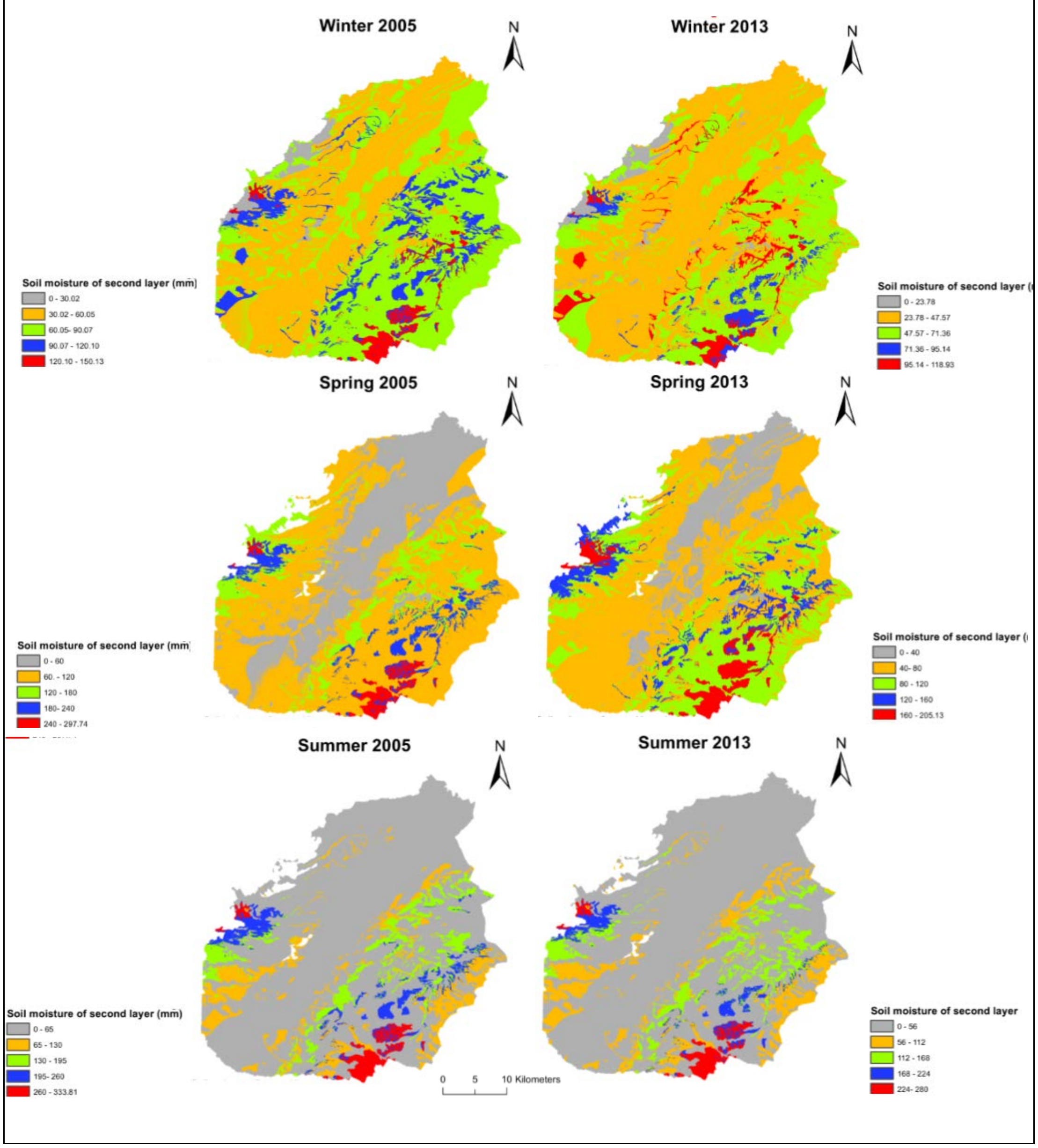

Figure 3.10. Spatial distribution of the Soil Moisture of the Second Layer depending on the season in 2005 and 2013.

As expected, no variation in the rainfall (Table 3.9) and snowfall (Table 3.10) values of 2005 and 2013 was noticed for all seasons as the climatic dataset for both simulations were the same because of the unavailability of meteorological data for both years. The marked seasonality of the area is evident in the lack of episodes of rain in the summer months (Figure 3.11). Snowfall is limited to the highest areas of the study area (Figure 3.12).

Table 3.9. Average data of Rainfall by season for 2005 and 2013 in the study area.

RAINFALL	**Autumn 2005**	**Autumn 2013**	**Winter 2005**	**Winter 2013**	**Spring 2005**	**Spring 2013**	**Summer 2005**	**Summer 2013**
Mean	3.44	3.44	32.73	32.73	25.90	25.90	0	0
Standard Deviation	2.30	2.30	13.17	13.17	9.97	9.97	0	0
Maximum	7.06	7.06	74.2	74.2	55.11	55.11	0	0
Minimum	0	0	15.2	15.2	11.05	11.05	0	0

Table 3.10. Average data of Snowfall by season for 2005 and 2013 in the study area.

SNOWFALL	**Autumn 2005**	**Autumn 2013**	**Winter 2005**	**Winter 2013**	**Spring 2005**	**Spring 2013**	**Summer 2005**	**Summer 2013**
Mean	0	0	9.11	9.11	0.69	0.69	0	0
Standard Deviation	0	0	10.08	10.08	2.08	2.08	0	0
Maximum	0	0	46.06	46.06	24.55	24.55	0	0
Minimum	0	0	0.46	0.46	0	0	0	0

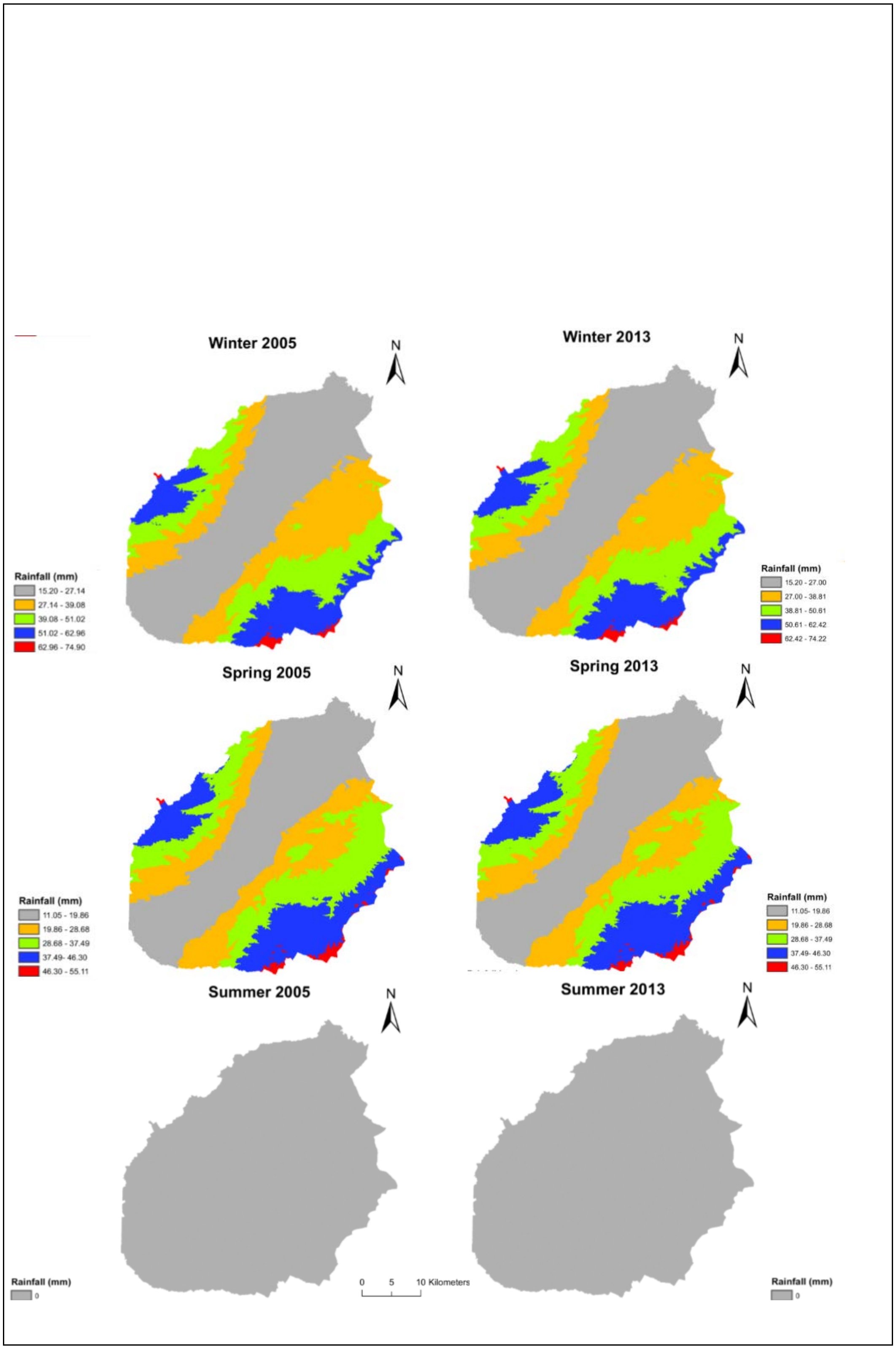

Figure 3.11. Spatial distribution of the Rainfall depending on the season in 2005 and 2013.

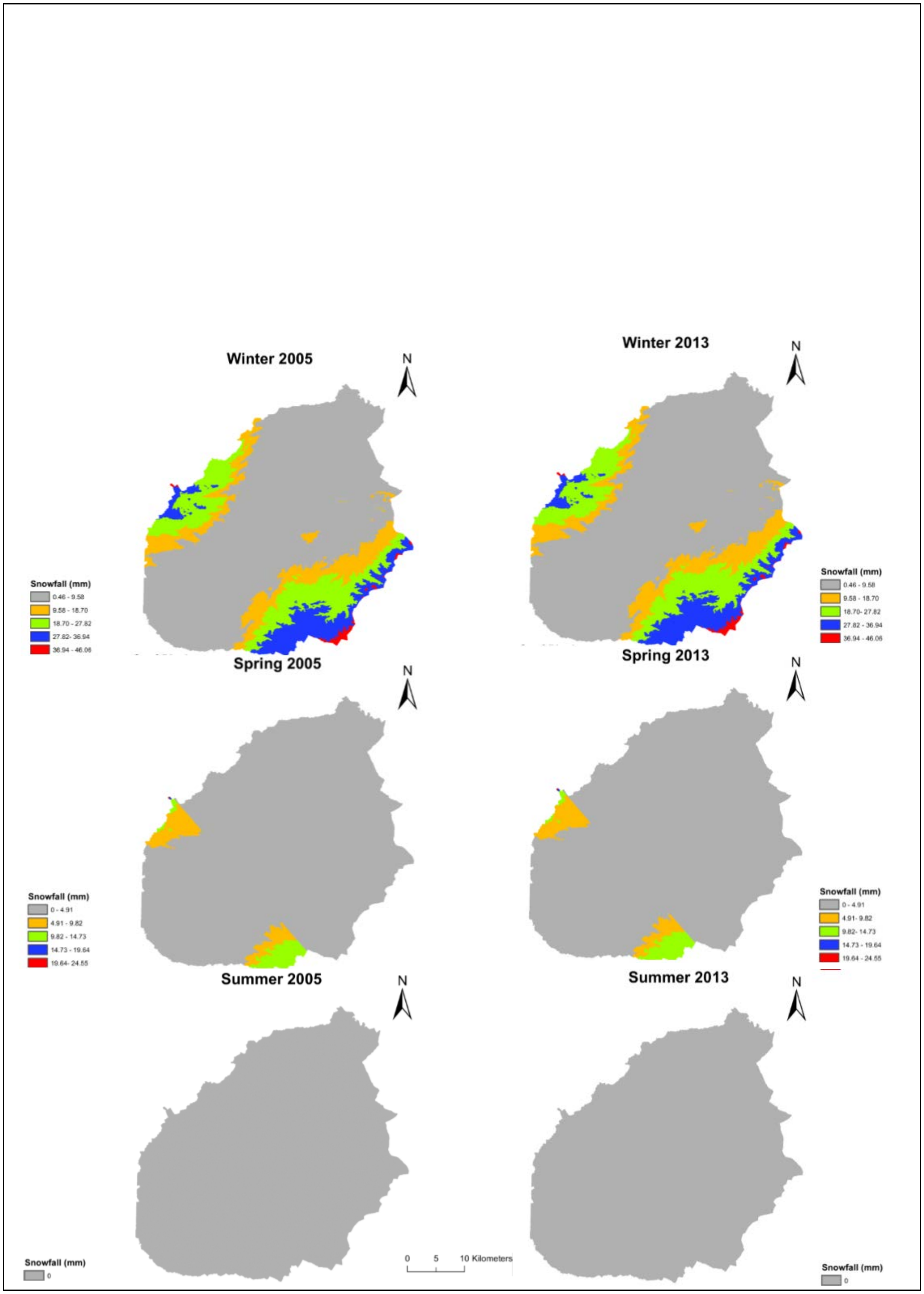

Figure 3.12. Spatial distribution of the Snowfall depending on the season in 2005 and 2013.

3.3.3. Land use change in El Asi - Orontes watershed

The land use map of El Asi - Orontes watershed has been provided by the National Council for Scientific Research (CNRS) of Lebanon. As the CNRS land use classification contained more than 40 categories, making it difficult to interpret changes in land use, these were grouped and reclassified into 9 categories. New categories include Urban areas, Agricultural areas, Grasslands, Fruit trees areas, Shrublands, Low density and Dense forests, Bare Areas and Rivers, lakes and wetlands (Figure 3.13).

Between 2005 and 2013 there was a significant increase in Grasslands (36.58 km^2) and Fruit tree areas (33.66 km^2) in El Asi - Orontes watershed (Table 3.10). There was also an increase in the areas destined for agriculture, with an increase of 14.77 km^2, and Low density forests, with 12.65 km^2 increment. There was also a significant reduction in Bare areas, with a decrease of 97.5 km^2. The reduction of Dense forests area was more moderate (8.31 km^2), however this reduction represents the loss of almost 93% of Dense forests in El Asi - Orontes watershed in the period 2005-2013.

Table 3.10. Land Use change in El Asi - Orontes watershed for the period 2005 – 2013.

Classes	Area in 2005 (km^2)	Area in 2013 (km^2)	Change Area (km^2)	Change Area (%)
Urban areas	28.05	38.87	10.82	38.57
Agricultural areas	252,72	267,49	14,77	5,84
Grasslands	96.15	132.73	36.58	38.04
Fruit trees areas	96.45	130.11	33.66	34.90
Shrublands	46.31	45.68	-0.63	-1.36
Low density forests	224.36	237.01	12.65	5.64
Dense forests	8.95	0.64	-8.31	-92.85
Bare Areas	792.55	695.05	-97.5	-12.30
Rivers, lakes and wetlands	0.59	0.65	0.06	10.17

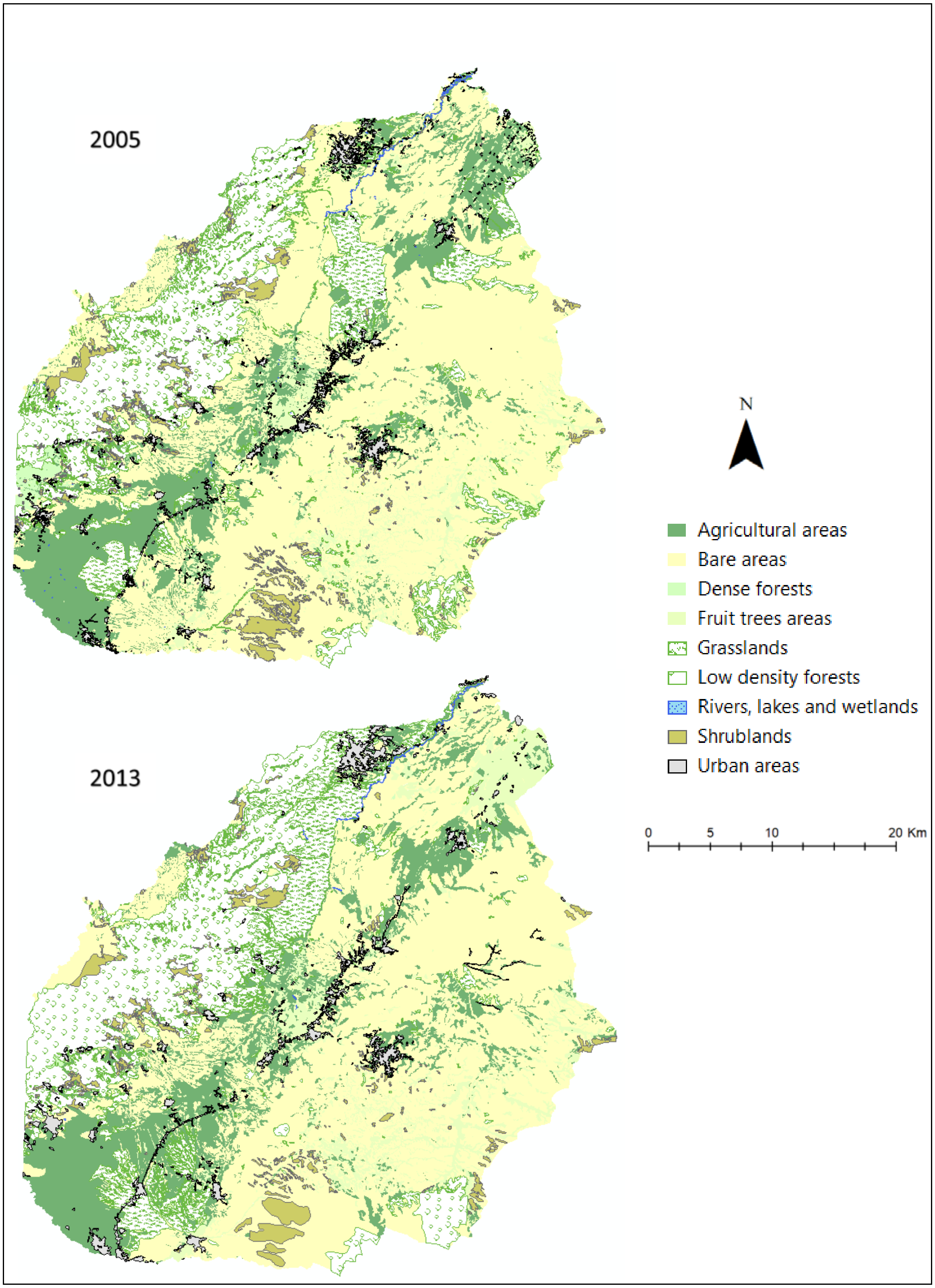

Figure 3.13. Land use map of El Asi – Orontes watershed in 2005 and 2013.

3.4. Discussion

Changes in the land use in a watershed can affect water quality and supply (Turner *et al*., 2001). Thus, the assessment of land use patterns and their changes at the watershed level is crucial to planning and management of water resources and land use of a particular watershed (Butt *et al*., 2015). In Lebanon. the status of the land cover/land use has been characterized by a continuous change over the last decades. The lack of land management plans and/or adequate urban regulations has strongly affected the natural and built environment. This has facilitated unplanned urban sprawl at the expense of natural landscapes (MoE & UNDP, 2011).

The present study is concerned with the application of a hydrological model (WiMMed) in a semi-arid area in Lebanon El Asi – Orontes watershed to compare the hydrological behavior of this region in the period 2005-2013 and to assess the impact of land use changes on infiltration, run-off and soil moisture of second layer at water basin scale under same climatic conditions.

Land use change may influence a variety of natural and ecological processes, including soil nutrient, soil moisture, soil erosion, land productivity (Chen *& Pen.* 2000). Land use plays an important role in controlling spatial and temporal variations of soil moisture by influencing infiltration rates, runoff and evapotranspiration, which is important to crop growth and vegetation restoration in semi-arid environments (Niu *et al*., 2015). Soil moisture is one of the most important components which expresses the balance between incoming (precipitation) and outgoing (evapotranspiration and runoff) quantities. The anthropogenic changes in land use have altered the characteristics of the Earth's surface, leading to changes in soil physic chemical properties, soil fertility, soil erosion sensitivity and content of soil moisture (Sharif *et al*., 2014). El Asi - Orontes watershed is a semi-arid area requiring greater understanding and management of land and water resources.

Previous studies have shown that the second layer of soil was wetter in dense forests than low density forests, shrublands, grasslands or agricultural areas, sorted from highest to lowest humidity (Dwarakish & Ganasri, 2015). This is due to the greater post rainfall loss of moisture under grass and crops sites than forest and shrubs (Wang *et al*., 2013), and bare soils were associated with consistently lower soil moisture values than the other land use types.

Effect of land use change on infiltration:

The results of this work show that infiltration at basin level has been reduced between 2005 and 2013. This decrease is especially important in the spring season, when infiltration was reduced to 70% compared to that recorded in the basin in the same period of 2005. Spring infiltration includes the effects of precipitation (rain and snow) both of the spring season itself and those occurred in the winter season, which is why the effect is the most important.

Infiltration capacity of grasslands and pasture is higher than the infiltration capacity of outcrops and bare rocks. The loss of dense forest in favor of grasslands, fruit tree plantations or bare rocks, impacts infiltration by affecting surface crusting, compaction and soil organic matter reduction. Without a protective vegetative or residue cover, bare soil is subject to direct impact and erosive forces of raindrops that dislodge soil particles. Dislodged soil particles fill in and block surface pores, contributing to the development of surface crusts which restrict water movement into the soil (Li *et al*., 2007).

Effect of land use change on run-off

Although a reduction in runoff has also been found between 2005 and 2013, it has been much less than in the case of infiltration. Regarding run-off, it is in the autumn season when the greatest differences are shown, although these are of an order of magnitude very low, since the presence of rain and snow is this time of year in the study area is very low.

The increase in runoff seems to be related to the decrease in the area of dense forests, which lost almost 98% of their surface area during the study period, especially when they were in the upper areas of the basin. However, there has also been a decrease in the area of vacant land of around 12% (97.5 km^2), which has been transformed into agricultural areas, pastures or fruit crops, which seems to have mitigated the effect on runoff.

The run-off shows an important seasonal variation being higher in spring and winter when compared to the other seasons. This could be related to soil saturation after winter precipitations. In addition to the loss of water resources for the vegetation that the runoff supposes, this one has an important influence in the erosion (Hou *et al*., 2013), which causes serious environmental problems in the zone of study and makes difficult the restoration options of the most degraded zones.

Effect of land use change on soil moisture of second layer:

The results obtained show that soil moisture of second layer is strongly affected by the change of land use type as important differences in these variables were observed between 2005 and 2013. The study reveals that the changes of land use in El Asi - Orontes watershed from 2005 to 2013 result in a decrease of the soil moisture of second layer.

The soil moisture of second layer of any type of forests is greater than the soil moisture of shrubland or agricultural areas, as these land uses cannot protect the soil surface from the water loss via evapotranspiration as much as forests do, which has also been observed in other studies (Wang *et al*., 2013). Other authors previously conclude that soil moisture of forests was significantly higher than the soil moisture of grasslands and field crops in large areas, this is due to the greater post rainfall loss of moisture under grass and crops sites than forest and shrubs (Mu. *et al*., 2002). For the same reason, the results showed that dense forest have higher values of soil moisture than low density forests because the open surface leads to greater daily water losses in the low density mixed forest. Deboodt (2008) conducted another study showing how low density forest of *Juniper spp*. utilizes available moisture and how removal of stands may provide improved water availability for forage production, livestock and wildlife water and increased ground water for down slope uses. Echeverria *et al*. (2001) also concluded that soil moisture is always higher in the dense pine forests in comparison with low density oak forests.

3.5. Conclusions

In the present study, has been compared the hydrological behavior of the study area between 2005 and 2013 by considering land use change as major influencing factor. An important decline in area coverage of Dense forests in El Asi - Orontes watershed was observed in during 2005-2013 period by almost 93% of area loss. The main reason for this decreasing trend is the frequency and the intensity of forest fires that form a real threat of the sustainability of the forest ecosystems in semi-arid regions of Lebanon. In addition, Hermel region, where El Asi - Orontes watershed is located, is one of the areas that are mainly affected by dryland degradation and desertification as Climate Change effects, and overgrazing pressure is common in this area.

In addition to soil erosion and degradation the partial disengagement of the state in Hermel region pushed the local farmers to adopt independent agricultural and livestock farming strategies to raise their incomes and meet their needs, which may be the reason for the significant increase in Grasslands and Fruit trees areas. Aldo the augmentation of area covered by urban sprawl and sites was clear at the expense of green areas.

This study found that the land use change from 2005 to 2013 has a negative effect on the hydrological characteristics of this watershed decreasing the infiltration capacity and the soil moisture of second layer in this area. Based on the results of the simulations, it can be concluded that in term of runoff low differences was registered in all seasons between 2005 and 2013. The lack of proper management and land use planning is a limiting factor responsible for further loss in forest areas in the future. Hence proper management of this region is required or else these resources will soon be lost and no longer be able to play their role in the development of the area.

Therefore, the results of this study can contribute to define adequate policies and strategies for territorial management and planning, in terms of land use. Adequate spatial planning aimed at productive and sustainable development in this region of Lebanon should consider the influence that possible changes in land use could have on available water resources.

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Chapter 4. Evaluating climate change impacts on hydrological variables under RCP scenarios for the Lebanese Part of el-Asi - Orontes watershed

Evaluating climate change impacts on hydrological variables under RCP scenarios for the Lebanese Part of el-Asi - Orontes watershed.

Abstract

Water management at the scale of a watershed is generally a complex issue not only because of the multiple interactions between the hydro-physical and socio-economic-political systems. *In the present study, an attempt has been made to compare the current hydrological variables of the study area using WinMed hydrological model (infiltration, run-off, soil moisture of second layer) to the simulated variables in 2050 under 2 RCP scenarios: RCP 2.6 and RCP8.5 assuming that* that the future land use is the same as the current land use (2013 land use/land cover map). Since the study region has highly variable precipitation for each season due to the existence of 4 seasons and the influence of topographical variation, seasonal variations of hydrological variables (infiltration, runoff and soil moisture of second layer) due to future climate change were observed. *Under same land use conditions, a rise of temperature accompanied with a decrease of precipitation will result in a decrease of infiltration, soil moisture of second layer in all seasons, and run-off of second layer during spring and winter.* All the hydrological variables within the study area are expected to have further decreases under RCP 8.5 compared to RCP2.6 for all seasons. However, the influence of land use change on soil moisture of second layer is much more significant when compared to climate variability and climate change, *decreasing the drought sensitivity and the erosion risk. Being aware of these facts offers possibilities for the elaboration of efficient measures for adaptation to the predicted climate change scenarios preventing, or at least moderating their unfavorable consequences*. Therefore, the results of this study are necessary to predict the spatiotemporal variability of hydrological parameters in order to determine policies for sustainable water resource development.

Key words: Land use*, hydrological modelling,* WIMMED*, watershed, soil moisture, climatic change.*

4.1. Introduction

Water management at the scale of a watershed is generally a complex issue not only because of the multiple interactions between the hydro-physical and socio-economic-political systems, but also between the components of the two systems that are further encumbered by many uncertainties. The Orontes River basin is undoubtedly complex. The Lebanese section of the Orontes River basin, the northern Beqaa valley, is a semi-arid area viewed as poor and marginal. However, it is an area where large private investments in irrigation development have been made in the past three decades (Kibaroglu & Jaubert, 2016). The future impacts of climate change may pose serious implications on water resources and soil conditions. Soil and water conservation are interrelated; methods that control and conserve water on hillsides also conserve the soil and control erosion. In the arid and semi-arid regions; all rainfall must be retained by techniques that reduce storm-water runoff, improve infiltration and increase the water storage capacity of the soil (FAO, 1993). Improvements in soil conditions and soil-water regime to optimize crop production can be accomplished by runoff and infiltration management techniques. The choice of management requires the study of these parameters variation (infiltration, run-off and soil moisture).

The previous chapter assessed the impact of land use change on hydrological variables of this watershed but not a single study has been conducted yet to assess the impact of climate change on hydrological variables in the Lebanese part of el-Asi Orontes watershed. Assessment that also accounts for climate change is therefore critical for planning and management of future water allocations (Dlamini *et al.*, 2017). Modeling the hydrologic impacts of global climate change involves the calculation of climatic variables under future scenarios of climate change and their integration in the hydrological model for the prediction of their future behavior (Jiang *et al.*, 2007).

There is a long-standing concern that increases in the concentrations of greenhouse gases and aerosols from human activity will lead to substantial changes in Earth's climate in the 21st century (Nazarenko *et al.*, 2015). Therefore, the change in climate conditions is expected to significantly affect hydrological and ecological components (Basheer *et al.*, 2016). Climate change is a global phenomenon exhibited by three prominent signals, that is: (1) global average temperatures are gradually increasing; (2) changes in global rainfall patterns; and (3) rising of sea levels. One of the major impacts of this phenomenon is on local water resource availability, whose impact will be felt by many sectors, including agriculture (Dlamini *et al.,* 2017). Global warming due to increasing concentration of greenhouse gases is likely to have a significant impact on precipitation, run-off processes and water resources (Yan *et al.,* 2015). Over the next century is expected severely impact on water resources, and arid and semi-arid areas are particularly more vulnerable to that change and are projected to suffer from water shortage due to precipitation reduction (Tavakoli & De Smedt, 2011; Setegn *et al.,* 2011).

In order to evaluate the effect of climate change on hydrological variables at a watershed scale, further studies should be conducted with the context of water management. One of the best tools for simulating current and future prediction of climate change scenarios is a global circulation model. Global atmospheric general circulation models (GCMs) have been developed to simulate the present climate and used to predict future climatic change (Xu, 1999). GCMs are currently the most credible tools available for simulating the response of the global climate system to increasing greenhouse gas concentrations. They provide estimates of climate variables, such as air temperature, precipitation, incoming radiation, vapor pressure and wind speed among others, for the whole world (Prudhomme *et al.,* 2003). One of the most important issues in studying the climate change is the uncertainties that accompany GCM models. These uncertainties will finally affect the impact assessment results (Ashofteh & Massah, 2003). The uncertainty in GCM projections comes from uncertainty in future greenhouse gas emission scenarios, as well as in the way GCMs respond to changes in atmospheric forcing, which is associated with model structure, parameterization, and spatial resolution (Teng *et al.,* 2011). Kite *et al.* (1994) have shown that land-phase parameterizations in current GCMs do not agree on predictions of most hydrological variables, even when all atmospheric forcing are identical. Many gaps in the relationship between hydrologic modeling and climate modeling exist. To circumvent the problems and narrow the gaps between GCMs ability and hydrology needs, several ways could be undertaken. Statistical downscaling is often used to bridge the scale gap in linking GCM outputs with hydrological models because it does not require significant computing resources and can more directly incorporate observations into method (Fowler *et al.,* 2007). However, the absence of long data series and the low quality of these series in the study area make the use of this method impossible in our case study. Methods of simple alteration of the present conditions are widely used by hydrologists. Various hypothetical climate scenarios have been adopted and climate predictions for "double CO_2" conditions have become standard (Loaiciga *et al.,* 1996).

It was reported in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change that a warming climate in the past half century has occurred in almost every region across the world, especially in the mid-latitudes of the northern hemisphere (IPCC, 2013). Few analyses have been done on the Mediterranean basin. Ragab & Prudhomme (2002) developed temperature and precipitation variation maps for the whole Mediterranean basin; they show for 2050 an increase in temperature from 1.5 ºC to 3 °C and a decrease in the mean precipitation from 3% to 15%. But those global values mask significant variations within the regional distribution with increases or decreases, uncertain interannual variations, and various seasonal evolutions (Hreiche *et al*., 2005).

In Lebanon, climate change policies are still underway due to limited local studies. Effective adaptation measures require good understanding of local changes taking into account the projections provided by global climate models (Dlamini *et al.,* 2017). Estimating average annual changes in precipitation and temperature under representative concentration pathways RCP2.6 and RCP8.5 is used in this study to adjust the historic temperature and precipitation series by adding ΔT for temperature values and, for precipitation, by multiplying the values by $(1 + \Delta P/100)$. For the distribution of these annual changes during the year, we assumed constant distributions of climatic changes, multiplied historical precipitation records by constant factors and adjusted historical temperatures by constant increments (Ng & Marsalek, 1992). In the climatic part, we apply 2 RCP scenarios under CCSM4 model and in hydrology, we use WIMMED model. The GCM derived climate perturbations can be used as model input. A variety of response to climate change scenarios can hence be modeled (Jiang *et al.,* 2007).

The general objective of this work was to assess the potential impacts of climate change on hydrological variables of the Lebanese part of el Asi-Orontes watershed using CCSM4 GCM model (Gent *et al*., 2011) under 2 representative concentration pathways (RCP2.6 and RCP8.5). The achievement of this general objective was developed in the following specific objectives:

1- Generating the hydrological variables (infiltration, run-off and soil moisture of second layer) of el-Asi-Orontes basin using WIMMED model and the current climatic conditions as inputs.

2- Perturbing the historical time series of climatic data according to RCP2.6 and RCP8.5 scenarios.
3- Simulating the hydrological characteristics of our study area under the perturbed climate using the calibrated hydrological model.
4- Comparing the model simulations of the current and possible future hydrological characteristics.
5- Drawing conclusions on how climate change would affect hydrological characteristics in a semi-arid area.

4.2. Material and methods

4.2.1. Description of the study area

The study area (Figure 1) consists the major part of the Orontes watershed in the Northeastern part of Lebanon. The Orontes basin covers an area of 1,361 Km^2, which represents 13% of the total area of Lebanon. It is situated between the two parallels 34° 1´ 8" and 34° 2´ 9" North and 36° 7´ 44" et 37° 7´ 53" East. The study area is characterized by an altitude that fluctuates between 550 m to the South and 3000 m to the North. The Orontes basin in Lebanon is characterized by its existence between two mountain ranges, Mount-Lebanon and Anti-Lebanon. These two chains separated by a relatively narrow depression determine the physiographic organization of the study area. It lies in a semi-arid zone as per the Climatic Atlas of Lebanon. Average annual rainfall measures in the range of 150-1300 mm, with 72% of its area receiving an average annual rainfall between 200 and 600 mm (Fayad *et al.*, 2017). In summer, the temperature often exceeds 40ºC and in winter it sometimes falls below 0ºC. January is the coldest month and August is the hottest one. The relative humidity varies between 62% and 70% during wet season and between 44 % and 48% during the rest of the year. The annual average sunshine hour is more than 8.3 hours/day. In July it stretches up to 10 hours. In rainy days it reduces to 3-4 hours. The rate of evaporation is high over the area. Annual rate of evaporation is 1750 mm. The winds are strong; especially in winter. Three geological formations are present in the region: Alluvium, Miocene and Cenomanian. The alluvial deposits cover 3% of the total area of the Orontes basin in Lebanon, occupying around 49 km^2. The Miocene covers 30% of the total area of the study area, which is equivalent to about 419 km^2. And finally, the Cenomanian covers about 64% of the total area of the basin, equivalent to 882 km^2. The Cenomanian is a type of rock characterized by a medium infiltration. Finally, 36% of the total area of this region is situated on a slope between 8 and 30%.

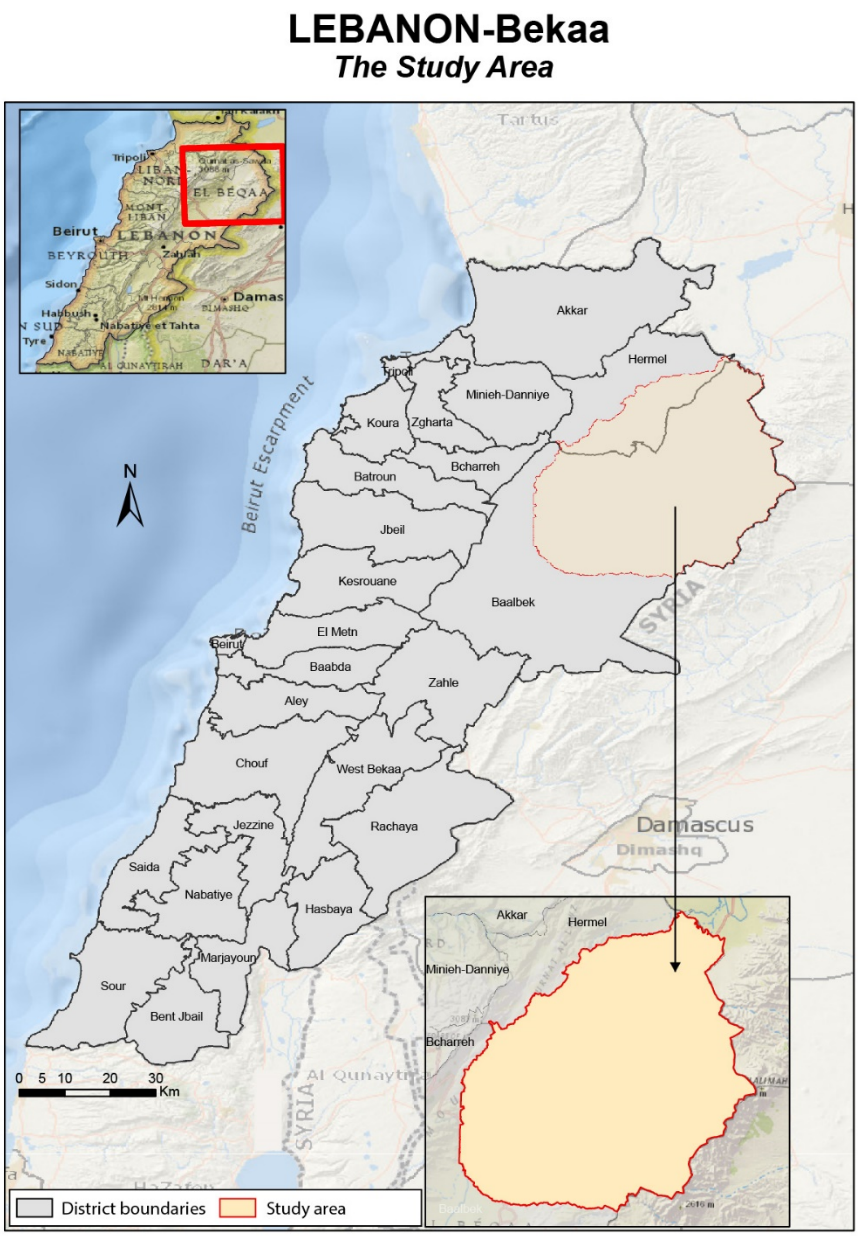

Figure 4.1. Location of El-Hermel Watershed in Lebanon

4.2.2. Watershed integrated hydrological model

a. Description of the model

Several hydrological models have been developed for application in hydrologic systems and water resources management. One such model utilized is WiMMed (Watershed Integrated Model in Mediterranean Environments) which is a physically based, fully distributed hydrologic model designed to include the variability of scales in the space and time characteristic of the Mediterranean climate in an operational suite (Herrero *et al*., 2014). It is capable of connecting GIS-based representations of the catchment with advanced algorithms to simulate the energy and water balance on a physical basis. The algorithms used by the model were developed taking into account the frequent shortage of input data in these areas, especially in mountainous areas (e.g. distribution of meteorological stations, time series of recorded meteorological series, length and quality of the series. The WiMMed model was applied in this study as it is the most suitable way to compute all the processes that determine water flows throughout the watershed in semiarid areas (Gómez-Giráldez *et al*., 2014) and because characteristic aspects of Mediterranean watersheds with an influence on spatial and temporal variability (torrential rainfall events, semi-arid conditions and high risk of drought at hyper annual scales) are carefully considered, as well as processes where topography may substantially affect the results (Herrerro *et al*., 2014).

WiMMed focuses on (a) the spatial interpolation of the meteorological variables at the cell scale, (b) the physical modelling of the energy and water balance at each cell, and (c) the consideration of different time scales when performing calculations, depending on the process being simulated (Eugen *et al*., 2012). Interception by the vegetation cover is estimated using the Rutter and Gash models from Landsat data analysis of cover fraction and the available forest and crop cartography (Polo *et al*., 2011). During rainfall events, the infiltration fluxes are calculated by the Green and Ampt equation, where redistribution is approximated by means of a lag time (Aguilar, 2008); during nonevents, the slow drying of the vegetation and soil is calculated by a combination of the Penman-Monteith and Hargreaves equations (Aguilar *et al.*, 2011). Water excess in every cell for each time step is routed as runoff down the hill slopes (Aguilar *et al*., 2016).

The model requires certain input data as detailed in the next section. Once the study area has been defined and the input variables introduced to the model, results on the meteorological variables can be obtained once the implicit interpolation mechanisms have been applied to each variable, state variables involved in the simulated processes and intermediate variables. The results of the obtained variables can be represented as maps for the case of distributed variables (precipitation, infiltration, etc.) or as tables of values in the case of point variables (e.g. flow) or distributed but aggregated in space (The mean precipitation of the basin or sub-basin), depending on the needs of the study, the appropriate spatial and temporal scales are decided (Herrero *et al.*, 2009). A detailed description of each process and associate parameter characterization/calibration can be found in Herrero *et al.* (2011).

Since there was no gauging station in the study area, hydrograph records were not available for the calibration and validation of the model. On the other hand, the type of simulation performed was of surface cycle, since this type of simulation provides the results of the water balance in the unsaturated zone of the soil without performing the surface circulation in the necessary channel where the calibration process is carried out through hydrographs. Thus, the calibration parameters obtained in a semi-arid area in Spain, the Guadalfeo river Basin (Table 1; Aguilar, 2008) were used. These parameters, previously calibrated and validated, are assumed to be valid in the study area due to the lack of information to carry out a specific complete calibration and by the relative similarity of both zones.

Table 4.1. Calibration parameters used in WIMMED.

Soil property	Parameter
Soil evaporation exponent	0,60
Soil evaporation coefficient	0,80

b. Input data required for modeling

A distributed water and energy balance is implemented as a cascade of reservoirs (vegetation cover, snow cover and vadose zone of the soil) at each cell of the Digital Elevation Model of the watershed. Calculation is made on a time step of one hour under event situations (storms) or one day under nonevents situations (Aguilar *et al.*, 2010). Different levels of simulations can be selected, according to the level of processing needed for a particular result desired, as well as different groups of resulting variables in terms of their spatial and temporal resolution. Due to the calculation needs of this work, the simulations carried out in this watershed are the type of Surface Cycle simulations that perform the water balance in the unsaturated zone of the soil. To carry out this simulation the model requires several variables and input parameters. The input data are grouped into four large groups: Topography, Meteorology, Soil and Vegetation.

In the previous chapter, a description of the data gathered for our watershed and its processing for the application of the model was gathered.

4.2.3. Future climate scenarios selection

This chapter examines the effects of projected changes in mean temperature and precipitation on run-off, infiltration and soil moisture for the Lebanese part of el-Asi Orontes watershed through a comparison of the spatial distribution of these variables under current climatic conditions with that under future climatic scenarios (Bou-Zeid & El-Fadel, 2002). On this study, the Representative Concentration Pathways (RCPs) were selected to support the research on impacts and potential policy responses to climate change (Moss *et al*., 2010). As a set, the RCPs cover the range of forcing levels associated with emission scenarios (van Vuuren *et al*., 2011). In general, RCPs predict increases in mean annual temperature and decreases in mean annual precipitation for the whole Mediterranean region. The first scenario used in this study was RCP2.6. The RCP2.6 emission and concentration pathway is representative of the literature on mitigation scenarios aiming to limit the increase of global mean temperature to 2°C. This scenario forms the low end of the scenario literature in terms of emissions and radiative forcing (van Vuuren *et al*., 2011). This scenario version shows CO_2 emissions declining from 2020. In North Bekaa of Lebanon the RCP2.6 scenario predicts increases of approximately 2 °C and decreases of 10% in precipitation. The second scenario used was RCP8.5 which corresponds to the worst case scenario that does not include any specific climate mitigation target (Fisher *et al*., 2007; IPCC, 2008), and hence also to the upper bound of the RCPs (Riahi *et al*., 2011). The RCP8.5 scenario predicts increases in temperature of approximately 5°C in the study area and decreases in precipitation of 20% are predicted.

4.3. Results

4.3.1. Impact of climate change on hydrological variables

Since the study region has highly variable precipitation for each season due to the existence of 4 seasons and the influence of topographical variation, predicting seasonal variations of hydrological variables (infiltration, runoff and soil moisture of second layer) due to future climate change is very important. Therefore, this study compared these hydrological variables for the Lebanese part of El Asi-Orontes watershed simulated for 2050s under RCP 2.6 and 8.5 scenarios with the hydrological variables of 2013 assuming that the future land use is the same as current land use (2013 land use/land cover map). The results showed that the influence of future climate change on hydrological variables in the study area has distinctive characteristics for each season (see also Annex A1).

It is seen in table 2 that during autumn, the values of infiltration (mean) and soil moisture of second layer were 2.4 mm and 57.6 mm respectively in 2013. They decreased by 9.5%-21.25% (for infiltration) and 5.06%-10% (for soil moisture) under RCP2.6 and RCP8.5 scenarios respectively. Run-off value in autumn 2013 was null, it increased slightly under RCP2.6 to 0.03 mm and to 0.025 under the RCP8.5.

Table 4.2. Hydrological behavior of the study area in autumn under control year and climatic change scenarios

	Infiltration (mm)		**Runoff (mm)**		**Snowfall (mm)**		**Rainfall (mm)**		**Soil Moisture 2 (mm)**
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
2013	2.4	7.3	0.0	0.1	0.0	0.0	3.5	10.4	57.6
RCP2.6	2.17	6.50	0.03	0.09	0	0	3.12	9.35	54.68
RCP8.5	1.89	5.68	0.025	0.075	0	0	2.76	8.3	51.84

The findings showed that the values of infiltration, run-off and soil moisture of second layer were 24 mm, 3.5 mm and 74.5 mm respectively in spring 2013 and decreased under RCP2.6 scenario by 11.7%-40%-8.6% showing further decreases by 22.4%, 71.1% and 17.4% respectively under the RCP8.5 scenario (Table 3).

Table 4.3. Hydrological behavior of the study area in spring under control year and climatic change scenarios

	Infiltration (mm)		**Runoff (mm)**		**Snowfall (mm)**		**Rainfall (mm)**		**Soil Moisture 2 (mm)**
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
2013	24.0	72.0	3.6	10.8	0.7	2.1	26.0	78.0	74.5
RCP2.6	21.17	63.53	2.16	6.49	0.10	0.30	23.38	70.16	68.04
RCP8.5	18.61	55.85	1.04	3.13	0.000022	0.000066	20.79	62.37	61.58

During the summer (dry season), no precipitation was registered under current conditions or RCP scenarios. This can justify that the total and mean values of infiltration and run-off are null in 201, under RCP2.6 and RCP8.5 scenarios. The only variable that shows difference between the current conditions and the RCP scenarios is the soil moisture of second layer. This parameter was reduced by 5.6% under RCP 2.6 and 10.9% under RCP 8.5 (Table 4).

Table 4.4. Hydrological behavior of the study area in summer under control year and climatic change scenarios

	Infiltration (mm)		**Runoff (mm)**		**Snowfall (mm)**		**Rainfall (mm)**		**Soil Moisture 2 (mm)**
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
2013	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.5
RCP2.6	0	0	0	0	0	0	0	0	55.23
RCP8.5	0	0	0	0	0	0	0	0	52.12

Reductions in hydrological variables were also seen in winter season. Table 5 shows that the mean values of infiltration decreased by 11.3%-22.1%, the mean run-off values decreased by 24.2%-37.8% while the soil moisture of second layer decreased by 4.5%-8.5% under the RCP2.6 and 8.5 scenarios respectively.

Table 4.5. Hydrological behavior of the study area in winter under control year and climatic change scenarios

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
2013	29.8	89.4	1.4	4.2	9.2	27.6	32.7	98.0	48.1
RCP2.6	26.41	79.24	1.06	3.19	4.42	13.27	29.40	88.22	45.92
RCP8.5	23.19	56.59	0.87	2.61	1.29	3.87	26.13	78.40	43.25

4.3.2. Cartography of hydrological variables

For the 3 simulated scenarios, in March and April there is precipitation in the form of snow for the year 2013 and for scenario RCP2.6. Under the conditions of the RCP8.5 scenario, snow would only appear during the month of March, in such a small quantity and area that it cannot even be seen in the raster classification (Figure 2).

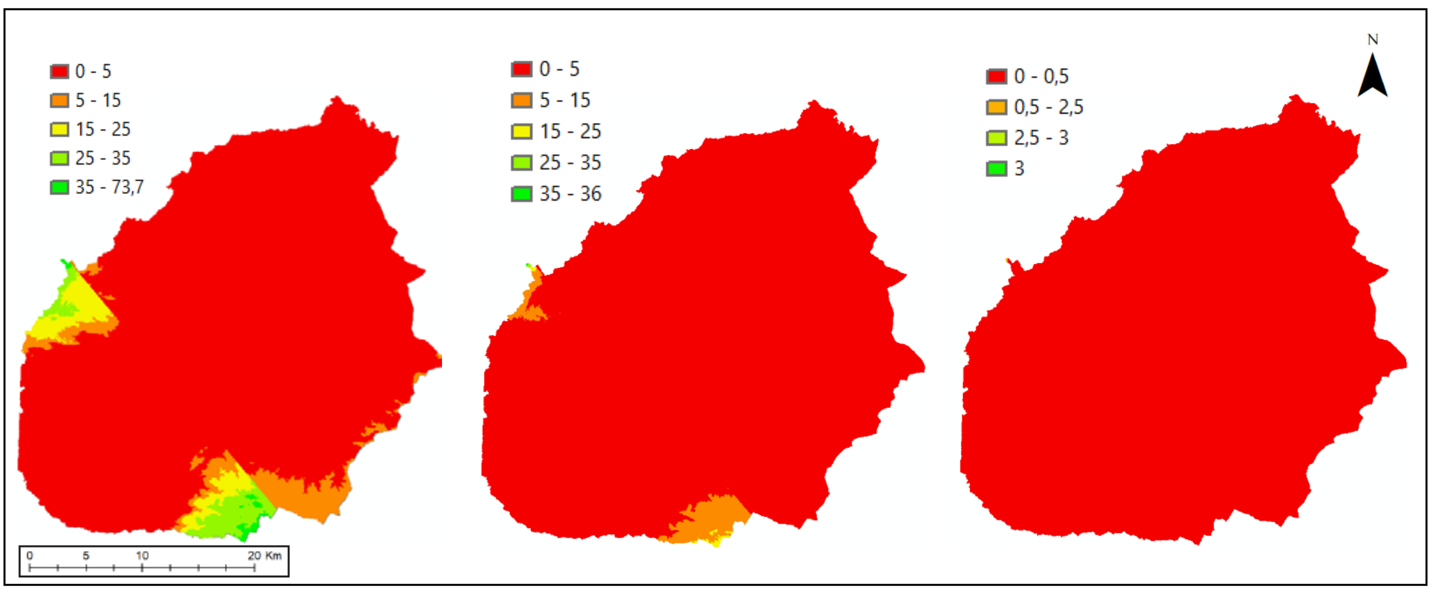

Figure 4.2. Simulation of total snowfall in spring 2013 and for scenarios RCP2.6 and RCP8.5 (from left to right)

In the same way, for the 3 simulated scenarios, significant changes are observed in the precipitation and in the water available in the soil (Figures 3 and 4). It is observed that the surface where the infiltration in spring exceeds 125 mm is considerably reduced in the RCP scenarios simulated with respect to 2013.

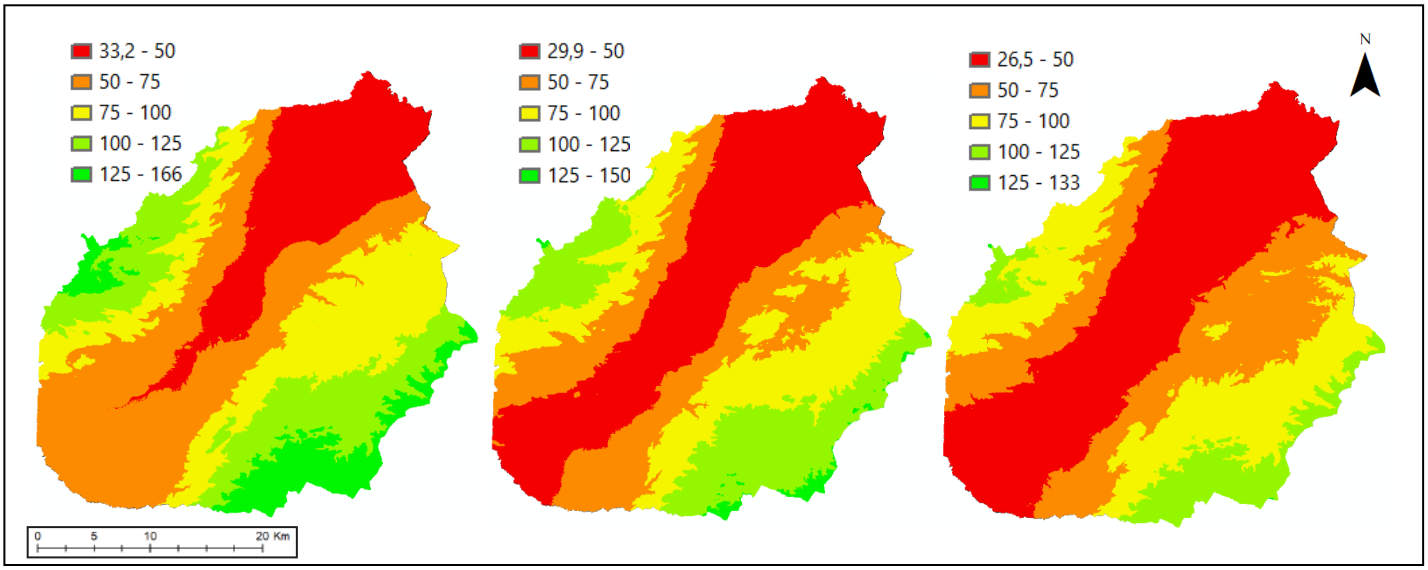

Figure 4.3. Simulation of total rainfall in spring 2013 and for scenarios RCP2.6 and RCP8.5 (from left to right)

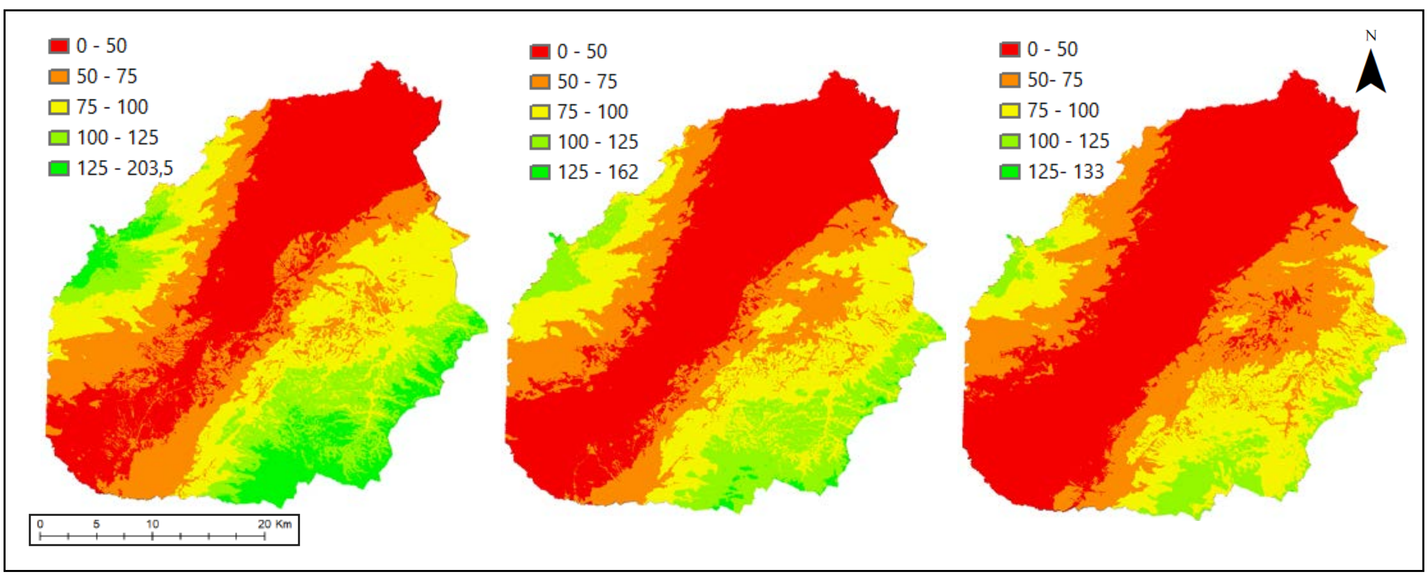

Figure 4.4. Simulation of total infiltration in spring 2013 and for scenarios RCP2.6 and RCP8.5 respectively

The behavior of the rest of the hydrological variables follows a similar pattern for runoff and second soil layer moist, with important values reductions in the scenarios of climate change (Figure 5 and 6).

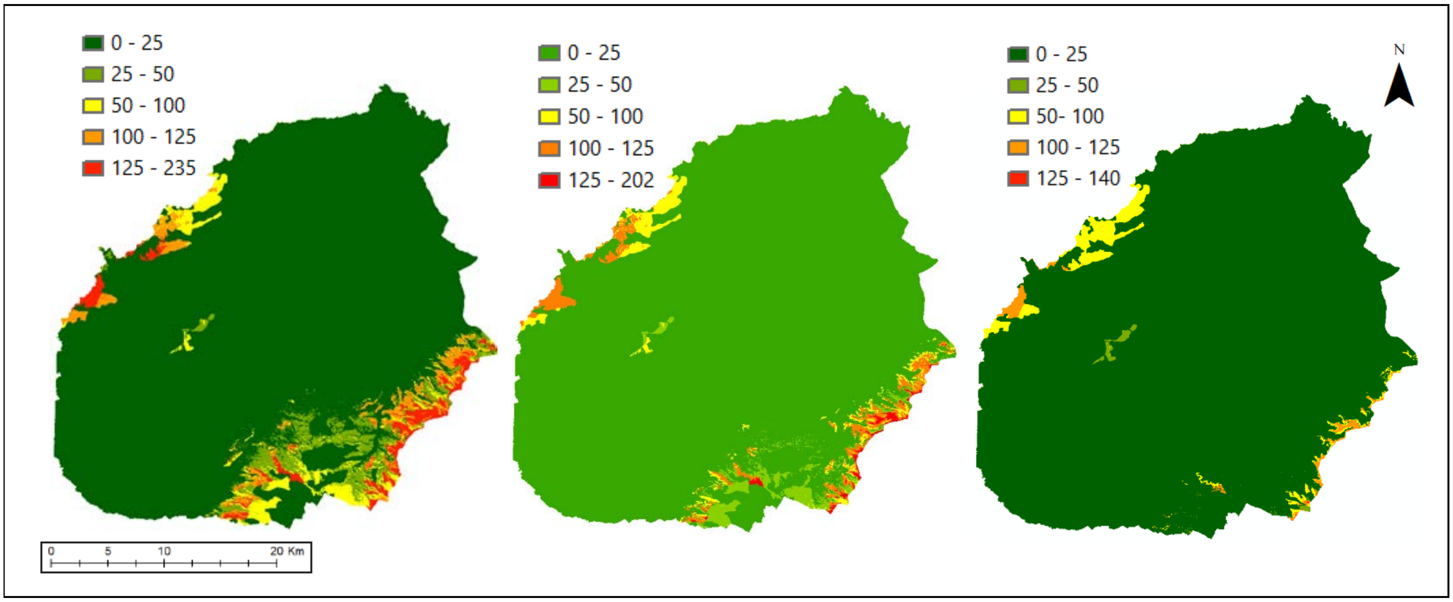

Figure 4.5. Simulation of total runoff in spring 2013 and for scenarios RCP2.6 and RCP8.5 respectively

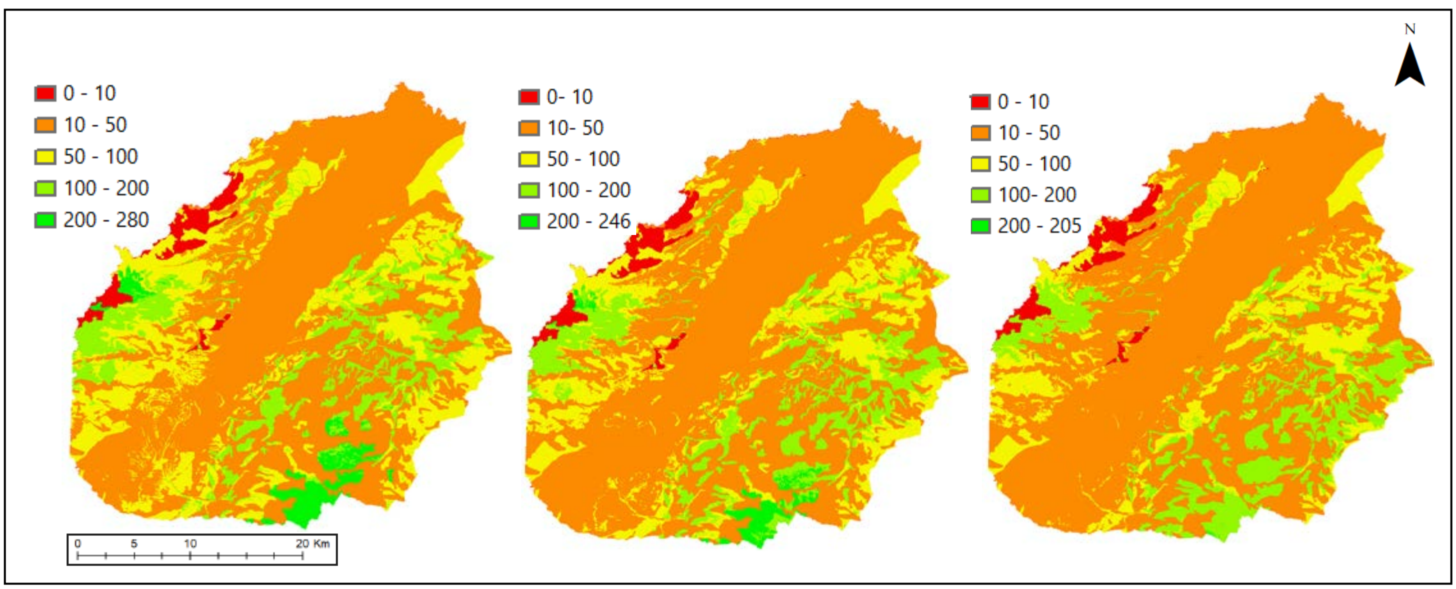

Figure 4.6. Simulation of total runoff in spring 2013 and for scenarios RCP2.6 and RCP8.5 respectively

A runoff in the spring season greater than the amount of total rainfall (Figures 5 and 6) is due to the snow melting process accumulated during winter. During the summer, the only variables undergoing significant changes is total second soil layer moist, with a strong reduction in the two climate change scenarios (Figure 7).

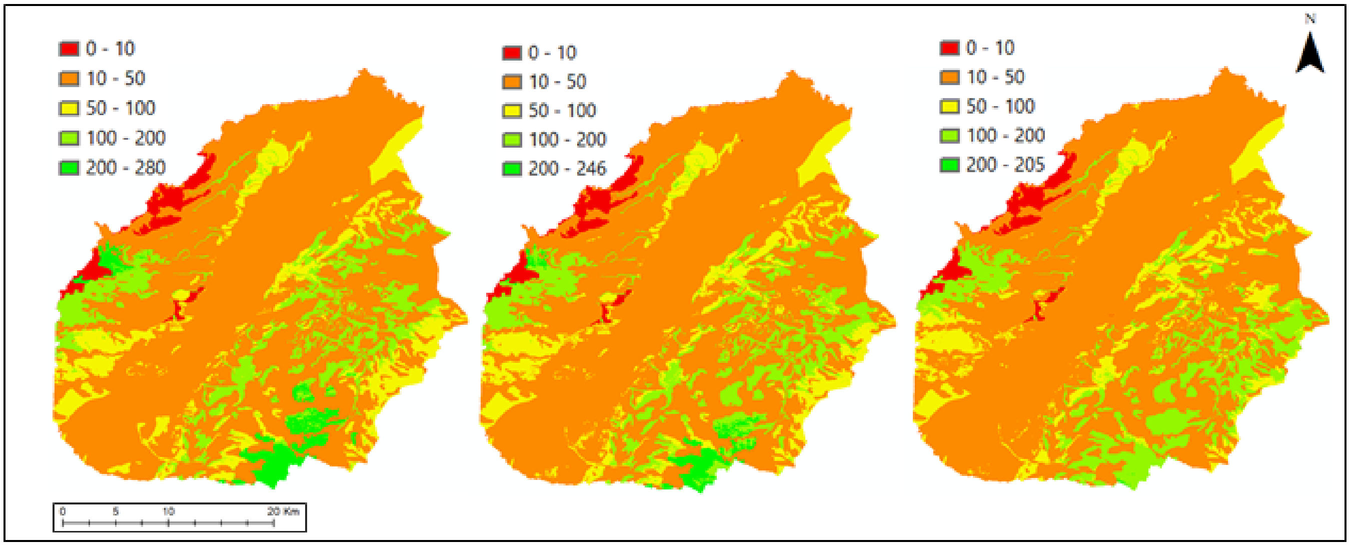

Figure 4.7. Simulation of total second soil layer moist in summer 2013 and for scenarios RCP2.6 and RCP8.5 respectively.

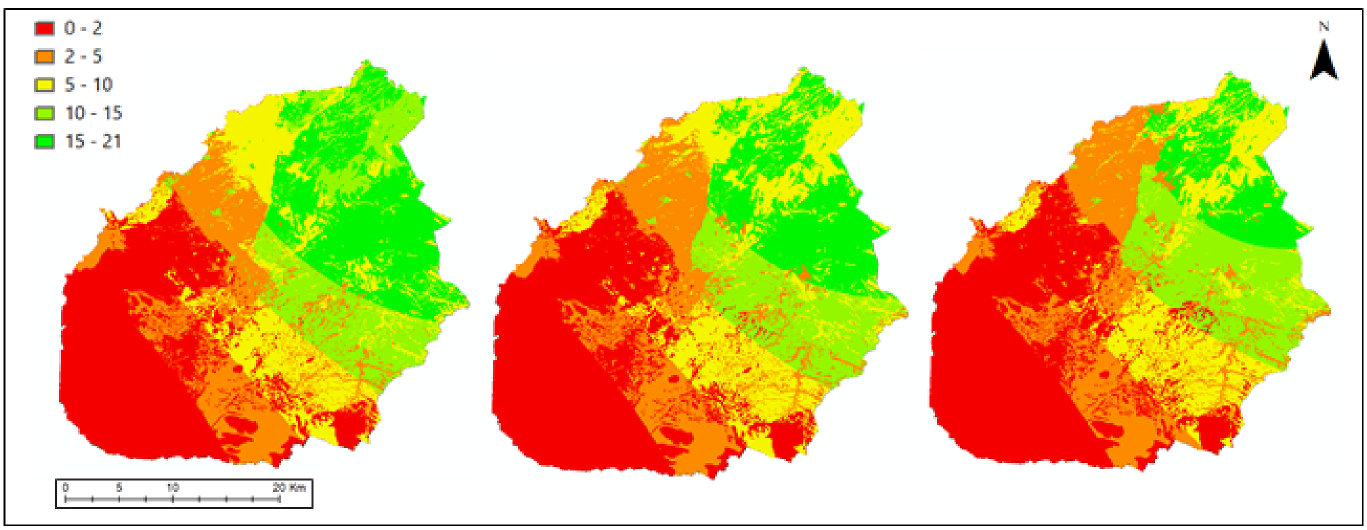

Figure 4.8. Simulation of total infiltration in autumn 2013 and for scenarios RCP2.6 and RCP8.5 respectively.

The response of the hydrological variables in autumn show a similar pattern to spring, observing the most important changes for total infiltration (Figure 8), runoff (Figure 9) and the second soil layer (Figure 10).

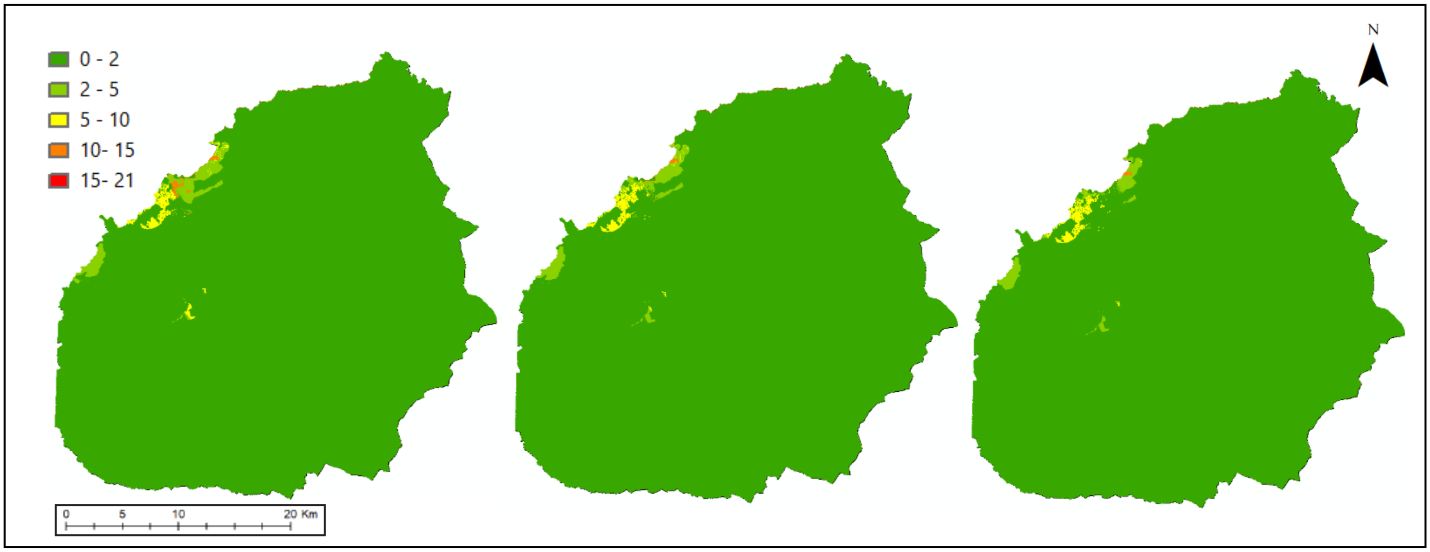

Figure 4.9. Simulation of total runoff in autumn 2013 and for the RCP2.6 and RCP8.5 scenarios respectively

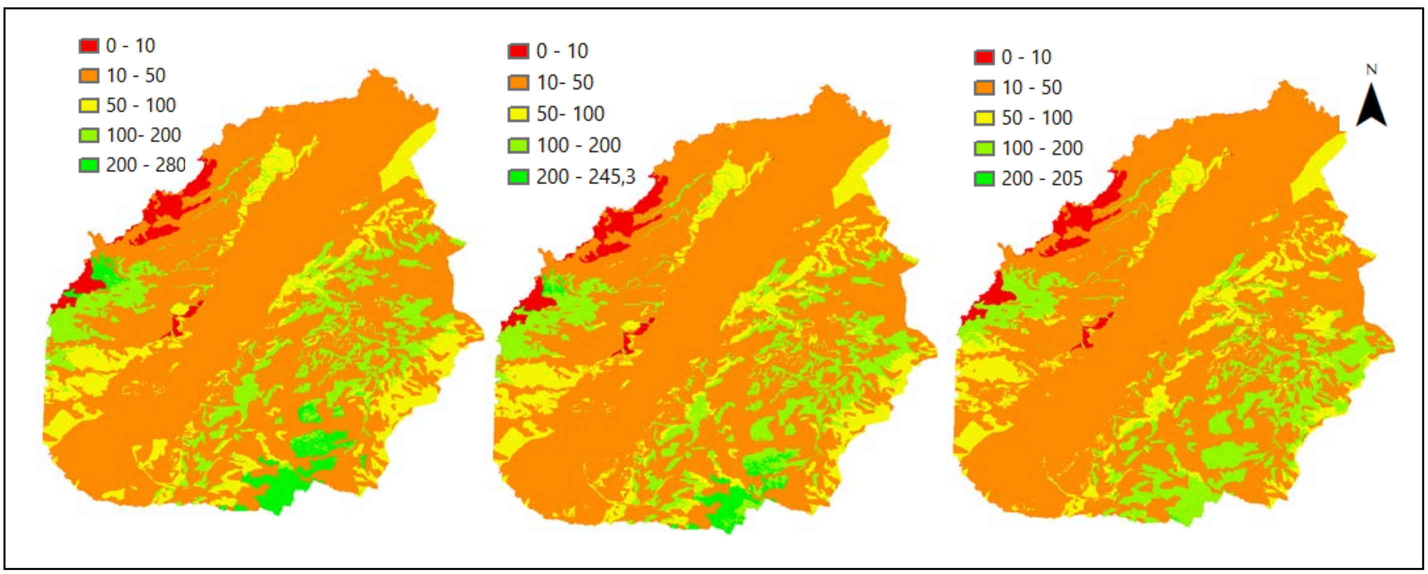

Figure 4.10. Moisture of the second soil layer in autumn 2013 and for scenarios RCP2.6 and RCP8.5 respectively.

During the winter, although in 2013 and in the scenario RCP2.6 there is snowfall distributed throughout the basin, for scenario RCP8.5, snow would not appear during the winter (Figure 11).

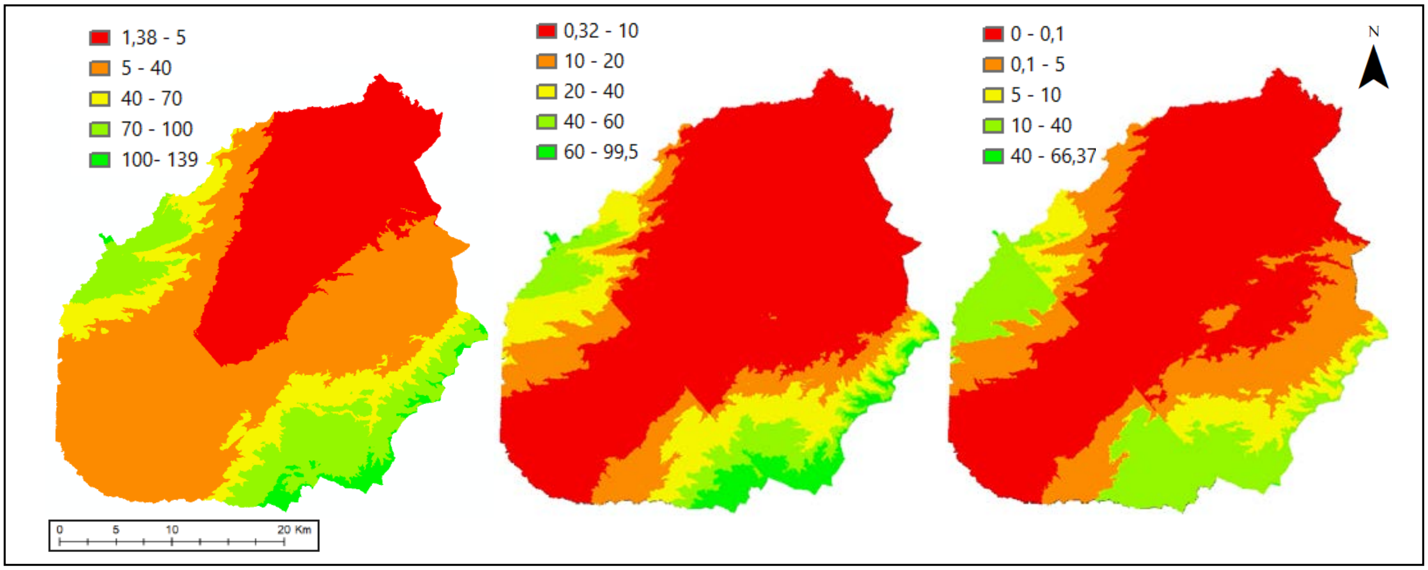

Figure 4.11. Simulation of total snowfall in winter 2013 and for scenarios RCP2.6 and RCP8.5 respectively.

Also, in winter, there are important changes in rainfall (Figure 12) and moisture of the second soil layer (Figure 13), of the climate change scenarios with respect to the reference scenario in 2013

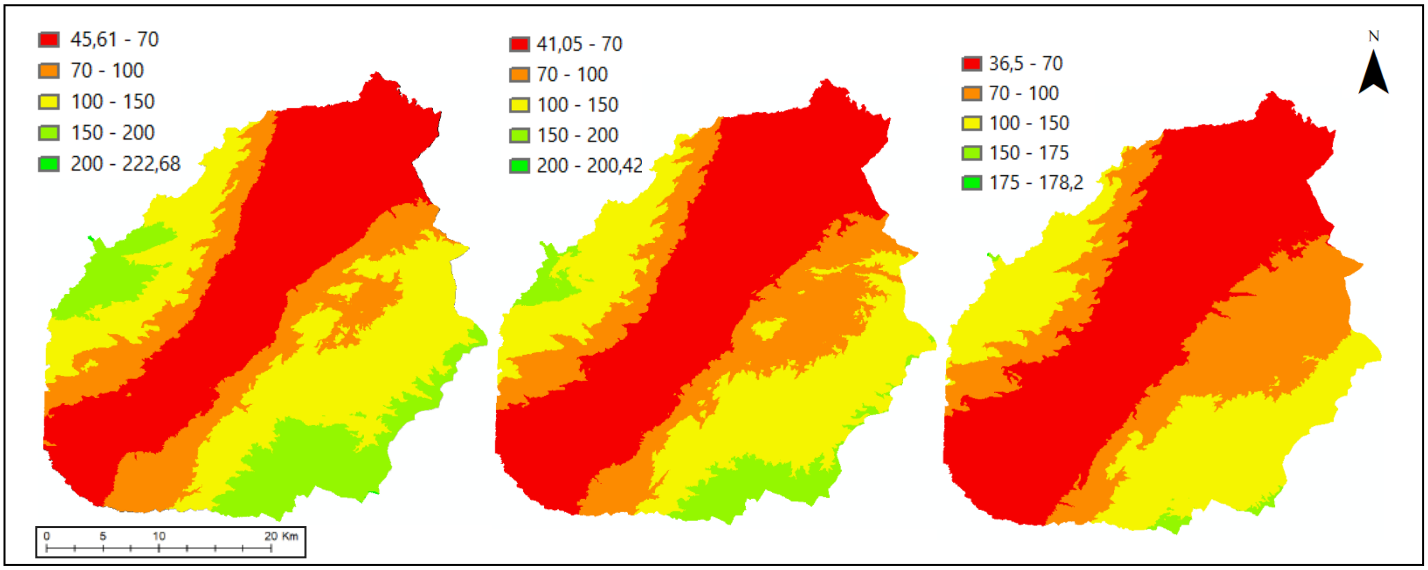

Figure 4.12. Simulation of total rainfall in winter 2013 and for scenarios RCP2.6 and RCP8.5 respectively

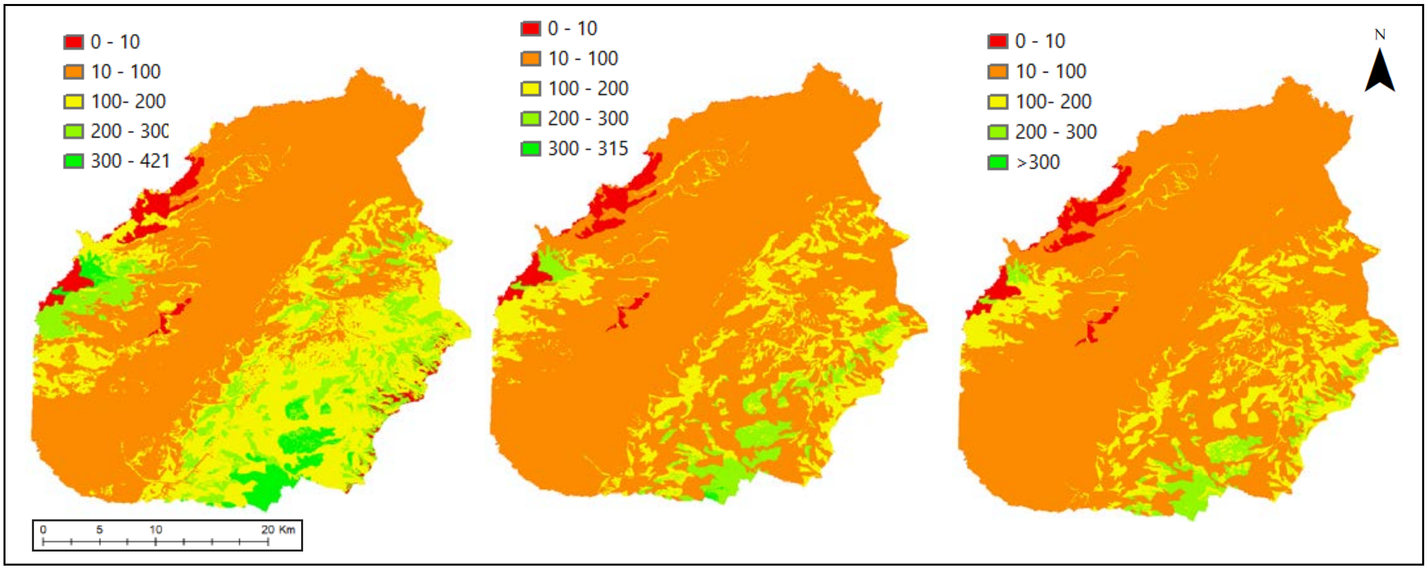

Figure 4.13. Moisture of the second soil layer in winter 2013 and for scenarios RCP2.6 and RCP8.5 respectively

Although the moisture of the second soil layer at the end or the summer season is lower than the winter and spring seasons humidity, there are areas where this humidity is higher than 200 and it can be seen that they are clearly related to the presence of snow during the winter and spring seasons (Figures 2, 11 and 14).

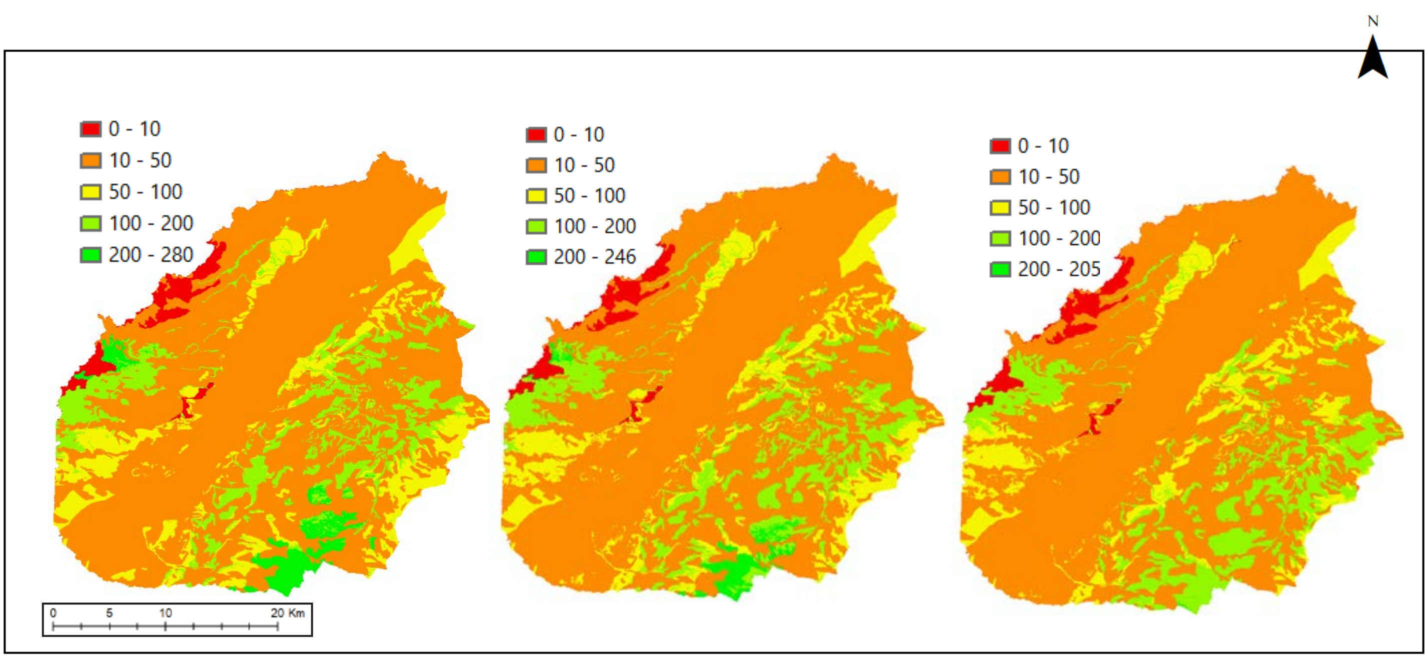

Figure 4.14. Moisture of the second soil layer in Summer 2013 and for scenarios R.C.P. 2.6 and R.C.P. 8.5 respectively.

4.4. Discussion

This study analyzes how changes in climate under the representative concentration pathways (RCP) scenarios affect infiltration, run-off and soil moisture of second layer within the Lebanese part of el-Asi- Orontes watershed. This study used RCP2.6 and 8.5 scenarios assuming that the future land use is the same as the current land use (2013 land use/land cover map). The changes in mean and total infiltration, run-off and soil moisture of second layer for the period 2013-2050 were calculated under RCP2.6 and 8.5 scenarios. Our results show that climate change affect all of these variables but within different rates. Consequently, this watershed will very likely be exposed to a variety of negative effects. First, both RCP2.6 and 8.5 showed decreases of the mean values of infiltration, run-off and soil moisture of second layer in all seasons compared to the current values of these hydrological parameters.

Effect of climate change on infiltration:

Compared to the current conditions, the monthly precipitation is projected to decrease by 10% under RCP2.6 and by 20% under RCP8.5. An increase of temperature of 2°C is predicted under RCP2.6 while RCP8.5 scenario predicts an increase of 5 °C in the mean temperature of the study area. Under RCP2.6 scenario, infiltration showed a decrease pattern for the period 2013-2050 in all seasons. It decreased by a maximum of 11.7% during Spring season and a minimum of 9.5% during Autumn season. Under RCP8.5 scenario, infiltration showed further decreases for the same period in all seasons. It decreased by a maximum of 22.4% during Spring season and a minimum of 21.25% during Autumn season. The simulated infiltration depending on climate change showed a decreasing trend for all seasons under both RCP scenarios. The results showed that the mean infiltration within the study area is expected to have further decreases under RCP 8.5 compared to the mean infiltration under RCP2.6 for all seasons. Seasonal variation for infiltration showed similar patterns of decrease in all seasons under both scenarios. This can be explained by the decrease of precipitation and the increase of temperature, therefore, the increase of evaporation rate under RCP scenarios. After comparing the results of RCP2.6 and 8.5 the findings showed that when precipitation is reduced by half (a decrease of 10% under RCP2.6 compared to a decrease of 20% under RCP8.5) the percentage of infiltration change clearly decreased by half in all seasons. The variation of infiltration means has a similar pattern to that of future precipitation change under RCP2.6 and RCP8.5 scenarios which means that infiltration is very sensitive to precipitation. Varallyay (2010) had the same conclusion; he has proved that a rise in temperature accompanied by low precipitation decreases the water infiltration.

Effect of climate change on run-off

As noted before, the run-off mean and total values are negligible in Autumn and Spring seasons in the current conditions and under both RCP scenarios. Under both scenarios, run-off showed a decrease pattern for the period 2013-2050 in Winter and Spring. Under RCP2.6 scenario, it decreased by a maximum of 40% during Spring season and a minimum of 24.2% during Winter season. Under RCP8.5, run-off means values decreased by a maximum of 71.1% during Spring season and a minimum of 37.8% during Winter season. The simulated run-off depending on climate change showed a decreasing trend during Spring and Winter seasons under both RCP scenarios. The results showed that the mean run-off values within the study area are expected to decrease more under RCP8.5 than RCP2.6 scenario. The similar pattern of decrease that affects run-off under both scenarios can be explained by the predicted decrease of precipitation. After comparing the current run-off with the values of run-off under RCP2.6 and RCP8.5, the results demonstrate that when precipitation decreases more, run-off values decrease further. Other researchers demonstrated the same results. Varallyay (2010) found that the decrease in atmospheric precipitation and the rise in temperature will result in decrease of surface run-off. A review done by Roudier *et al*., (2014) summarizes the impact of climate change on run-off in West Africa: a correlation analysis revealed that run-off changes are tightly linked to changes in rainfall (R=0.49), and to a smaller extent also to changes in potential evapotranspiration. To study the potential future run-off evolution in view of climate change, we found that the future tendency of run-off changes is affected by the future precipitation changes. Therefore, the run-off means could decrease in the study region during the wet season because a decrease in precipitation pattern is predicted under RCP2.6 and 8.5 scenarios. The seasonal variation of run-off is clear: higher average and total run-off values are registered in Spring when compared to Winter values under both scenarios. The high Spring run-off potential can be justified by a saturated soil after Winter precipitation. The same conclusion was obtained by Ho *et al*., (2013). They have demonstrated that run-off and erosion in Spring are higher than in Winter.

Effect of climate change on soil moisture of second layer:

Under both scenarios, soil moisture of second layer showed a decrease pattern for the period 2013-2050 in all seasons. Under RCP2.6 scenario, it decreased by a maximum of 8.6% during Spring season and a minimum of 4.5% during Winter season. Under RCP 8.5 scenario, it decreased by a maximum of 17.4% during Spring season and a minimum of 8.5% during Winter season. The simulated soil moisture of second layer depending on climate change showed a decreasing trend in all seasons under both RCP scenarios. The results showed that the soil moisture of second layer is expected to decrease more under RCP8.5 than under RCP2.6. the similar pattern of decrease that affects soil moisture under both scenarios can be explained by the predicted decrease of precipitation and the predicted rise of temperature. After comparing the current soil moisture of layer 2 with the values of soil moisture of second layer under RCP2.6 and RCP8.5 scenarios, the results show that no significant difference is registered under RCP2.6: the decrease percentage of soil moisture recorded in all seasons is less than 10% while a significant decrease of soil moisture of second layer is recorded in all seasons except winter (a decrease of 8.5%) under RCP8.5 scenario. In our case study, a decrease of 10% in precipitation and an increase of 2 °C in the mean temperature do not affect significantly the soil moisture of second layer. It is only under RCP8.5 scenario, after decreases in precipitation of 20% and a rise in temperature of 5 °C, when significant decreases of soil moisture of layer 2 are recorded. This study has shown that the influence of land use change (previous chapter results) on soil moisture of second layer is much more significant when compared to climate variability and climate change. The results show that climate and land use each exerts a control on soil moisture (Amir *et al.,* 2016). Their effects vary depending on the land use change and on the level of projected climate change. A 20% precipitation reduction accompanied with 5°C of temperature increase is projected to decrease the soil moisture of second layer in a significant way.

4.5. Conclusions

In the present study, an attempt has been made to compare the current hydrological variables of the study area (infiltration, run-off, soil moisture of second layer) to the simulated variables in 2050 under 2 RCP scenarios: RCP2.6 and RCP8.5 assuming that that the future land use is the same as the current land use (2013 land use/land cover map). Based on this study, the following important points are highlighted. Under same land use conditions, a rise of temperature accompanied with a decrease of precipitation will result in a decrease of infiltration, soil moisture of second layer in all seasons, and run-off of second layer during spring and winter. All the hydrological variables within the study area are expected to have further decreases under RCP8.5 compared to RCP2.6 for all seasons. However, the influence of land use change on soil moisture of second layer is much more significant when compared to climate variability and climate change.

These direct influences of the climate change on hydrological variables could cause unfavorable consequences in the study region. for groundwater replenishment, we depend largely on recharge (water moving from the surface to the groundwater) from infiltration of the precipitation (VADEQ, 2010). In other hand, the decrease of surface run-off consequently decreases water erosion hazard but increases the risk of wind erosion for dry surfaces (Varallyay, 2010). The projected decrease of soil moisture of second layer may affect the water supply of plants, influences the biological activity and plant nutrient status of the soil, it will also decrease the drought sensitivity and the cracking and erosion risk. Being aware of these facts offers possibilities for the elaboration of efficient measures for adaptation to the predicted climate change scenarios preventing, or at least moderating their unfavorable consequences (Harnos & Csete, 2008). As noted above, the hydrological variables within the Lebanese part of El-Asi-Orontes watershed is expected to have higher variations due to climate change. Therefore, the results of this study are necessary to predict the spatiotemporal variability of hydrological parameters in order to determine policies for sustainable water resource development.

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Annex A1. Hydrological variables

Table 4.A1. Hydrological behavior of the study area in autumn 2013

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	15.3
Maximum	7.1	21.2	6.9	20.8	0.0	0.0	7.1	21.2	231.0
Range	7.1	21.2	6.9	20.8	0.0	0.0	7.0	21.1	215.7
Mean	2.4	7.3	0.0	0.1	0.0	0.0	3.5	10.4	57.6
STD	2.2	6.7	0.3	0.8	0.0	0.0	2.3	6.9	53.3

Table 4.A2. Hydrological behavior of the study area in autumn under RCP2.6 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	0.02	0.06	0.00
Maximum	6.36	19.08	6.23	18.7	0	0	6.36	19.08	245.27
Range	6.36	19.08	6.23	18.7	0	0	6.34	19.02	245.27
Mean	2.17	6.50	0.03	0.09	0	0	3.12	9.35	54.68
STD	2.0	6.0	0.25	0.74	0	0	2.08	6.23	47.08

Table 4.A3. Hydrological behavior of the study area in autumn under RCP8.5 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	0.02	0.06	0
Maximum	5.65	16.96	5.53	16.62	0	0	5.65	16.9	204.93
Range	5.65	16.96	5.53	16.62	0	0	5.63	16.9	204.93
Mean	1.89	5.68	0.025	0.075	0	0	2.76	8.3	51.84
STD	1.78	5.34	0.21	0.64	0	0	1.84	5.53	42.39

Table 4.A4. Hydrological behavior of the study area in spring 2013

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	11.1	33.2	18.0
Maximum	67.8	203.5	78.3	234.9	24.6	73.7	55.3	165.9	220.1
Range	67.8	203.5	78.3	234.9	24.6	73.7	44.2	132.7	202.1
Mean	24.0	72.0	3.6	10.8	0.7	2.1	26.0	78.0	74.5
STD	10.8	32.4	10.4	31.2	2.1	6.3	10.0	29.9	42.9

Table 4.A5. Hydrological behavior of the study area in spring under RCP2.6 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	9.95	29.8	0
Maximum	53.83	161.5	67.17	201.53	11.98	35.9	49.76	149.29	217.23
Range	53.83	161.5	67.17	201.53	11.98	35.9	39.81	119.44	217.23
Mean	21.17	63.53	2.16	6.49	0.10	0.30	23.38	70.16	68.04
STD	9.26	27.79	7.68	23.04	0.52	1.57	8.97	26.9	36.5

Table 4.A6. Hydrological behavior of the study area in spring under RCP8.5 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	8.84	26.5	0
Maximum	44.24	132.74	46.59	139.79	0.94	2.83	44.23	132.71	188.10
Range	44.24	132.74	46.59	139.79	0.94	2.83	35.39	106.18	188.10
Mean	18.61	55.85	1.04	3.13	0.000022	0.000066	20.79	62.37	61.58
STD	8.22	24.68	5.2	15.62	0.002	0.0089	7.97	23.93	35.69

Table 4.A7. Hydrological behavior of the study area in summer 2013

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	`5.3345
Maximum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	231.0
Range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	215.7
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.5
STD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.4

Table 4.A8. Hydrological behavior of the study area in summer under RCP2.6 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	245.26
Range	0	0	0	0	0	0	0	0	245.26
Mean	0	0	0	0	0	0	0	0	55.23
STD	0	0	0	0	0	0	0	0	47.11

Table 4.A9. Hydrological behavior of the study area in summer under RCP8.5 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	204.9
Range	0	0	0	0	0	0	0	0	204.9
Mean	0	0	0	0	0	0	0	0	52.12
STD	0	0	0	0	0	0	0	0	42.43

Table 4.A10. Hydrological behavior of the study area in winter 2013

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0.0	0.0	0.0	0.0	0.5	1.4	15.2	45.6	0.0
Maximum	74.2	222.5	73.7	221.1	46.1	138.2	74.2	222.7	118.9
Range	74.2	222.5	73.7	221.1	45.6	136.8	59.0	177.1	118.9
Mean	29.8	89.4	1.4	4.2	9.2	27.6	32.7	98.0	48.1
STD	13.9	41.7	7.1	21.4	10.1	30.3	13.2	39.5	18.6

Table 4.A11. Hydrological behavior of the study area in winter under RCP2.6 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0.1	0.32	13.68	41.05	0
Maximum	68.47	205.42	68.40	205.21	33.16	99.48	66.80	200.41	116.64
Range	68.47	205.42	68.40	205.21	33.06	99.16	53.12	159.36	116.64
Mean	26.41	79.24	1.06	3.19	4.42	13.27	29.40	88.22	45.92
STD	12.61	37.84	6.22	18.62	6.02	18.07	11.85	35.56	17.67

Table 4.A12. Hydrological behavior of the study area in winter under RCP8.5 scenario

	Infiltration (mm)		Runoff (mm)		Snowfall (mm)		Rainfall (mm)		Soil Moisture 2 (mm)
	Average	*Total*	*Average*	*Total*	*Average*	*Total*	*Average*	*Total*	
Minimum	0	0	0	0	0	0	12.16	36.48	0
Maximum	60.07	180.21	5.36	180.29	7.42	22.27	59.38	178.15	116.33
Range	60.07	180.21	5.36	180.29	7.42	22.27	47.22	141.67	116.33
Mean	23.19	56.59	0.87	2.61	1.29	3.87	26.13	78.40	43.25
STD	10.89	32.65	60.10	16.08	1.29	3.87	10.53	31.59	17.12

Chapter 5. General Discussion

5.1. General Discussion

This research aims to assess desertification to study the influence of climate change in El Asi – Orontes watershed in Lebanon. To evaluate desertification and climate change effects, two sectors were studied: land and water.

The first step to assess desertification is to evaluate the land use planning. The land capability map of El Hermel District produced during the first part of the work can be used as a planning tool by governors and planners to increase the efficiency of the land use and to decrease the stress on the soil. The results of land use classification show that the slopes on the mountainous areas form class V lands, in general. These areas have high percentage of stoniness and steep slopes which make them unsuitable for agriculture. Only drought-resistant trees, like Juniper, are able to grow in such conditions. So, these areas could be used for grazing or ecotourism activities. Generally, class IV occurs along the foothills of the mountains and the level lands of the Eastern part. This class shows the development of petrocalcic horizon which is a thick deposit that can be removed by rippers. These layers are the result of an extreme evapotranspiration reaching 1500 mm per year and restricted amount of rainfall (< 300mm), people can investigate in agriculture in these areas but it costs more than planting in the Northeastern and central South parts of the district which are mainly the lands belonging to land capability classes I, II and III. They are suitable for agriculture with few or no limitations.

The definition of desertification is the process by which fertile lands become desert, typically as a result of drought, deforestation, or inappropriate agriculture. Therefore, assessing the degree of conformance of the lands use designations of specific parcels proposed by the zoning map to the land capability classification obtained in this work is a tool to evaluate the stress applied on each parcel of land and to predict the possible desertification of each piece of land. The results of this comparison between the land capability classification and the zoning map shows that the zoning map made for Hermel city did not take into consideration the soil capability of lands. Therefore, we can predict a high possible risk of desertification in this area. The reason of this prediction is that less than 1% of the classified agricultural lands are on high capability class and most of the habitations were classified within the high and moderate land capability classes. It was found that the conventional land evaluation methods suffer from limitation of spatial analysis (AbdelRahman *et al*., 2016) this implies that the poor agricultural productivity does not come from poor soil fertility, but it is a result of the weak control of the land's use. Since most of the land in Hermel city is suitable for agriculture, therefore it is preferable to relocate industrial and residential structures to non-arable and very low regions outside the city and give support to the agricultural sector to be an investment destination for the upcoming years.

This study shows also the importance of the large scale when studying land use and land capability. This analysis demonstrates that 56.3% of the district area can be termed as lands suitable for agriculture; they have slight limitations restricting their use or reducing the choice of plants. They require few management practices to grow crops. At a smaller scale (1:200,000), the land capability map produced for Lebanon in 2005 showed that the whole Hermel district is characterized by the presence of shallow soils which represent a serious problem for agriculture (Darwish *et al*., 2005). Based on the land classification of 2005, Hermel district has been classified into class III that represents soils having severe limitations and requiring special conservation practices. Although the land capability map of 2005 and the one published in this study used basically the same methodology, the results were different. The small scale used in 2005 classification does not show well the variability of soil characteristics as the large scale of the current study does. It should be noted that the validity of the analysis is related to the scale of the input maps. For more detail planning, more detailed input maps are required.

The model takes into consideration 5 parameters: slope, organic matter, soil depth, $CaCO_3$ and clay content. It shows a good overall accuracy of 89%, this indicates that the choice of parameters and the values of weights were well chosen with slope having the highest role in determining land capability. This may be caused by the landscape of the study region that is characterized by the presence of slopping and steep lands with slope gradient over 30% especially in the Central part and on the West. Although the results were considered to be helpful to assess desertification because it gives an overview about the stress applied on land. Studying land capability of land is not enough to assess desertification. It is necessary to evaluate additional factors containing detailed climatic, geomorphic and hydrological parameters that have impact on desertification and environmental sustainability. First restoration activity suggested for this region is to elaborate an urban master plan. This plan needs to be oriented according to land capability classes to increase the efficient use of lands for agriculture. The results obtained indicate that in some areas the use of the land is not the most appropriate (for example, areas of high agricultural productivity are used for other purposes such as urban development, while areas with little capacity to support crops are used for agriculture, offering very poor production). The land capability map for agriculture could give a general orientation about the use of the soil. All the high class lands could be used for agriculture because they have no limitations. All the non-arable class lands can't be used for agriculture because the cost needed to modify the soil is so high. To plan for restoration activities and suggest land use, the study of land capability is not enough, this study should be followed by land suitability study and other detailed studies to suggest correct land use for each parcel of this region. The obtained map offers more detail on the land capability for agriculture in the study area, so it can be used as a planning tool by public management bodies to contribute to more efficient land planning.

Assessing desertification using land capability classification is followed by the application of hydrological modeling to assess how land use and future climatic scenarios would affect the water balance in the study region. We have used a hydrological model (WiMMed) to compare the hydrological variables in El Asi- Orontes watershed between 2005 and 2013 to understand how a change in land use will affect the hydrological variables. Water quantity and quality are affected by changes in the land use. Evaluating land use changes is essential to manage water resources. In Lebanon. the status of the land cover/land use has been characterized by a continuous change over the last decades. The lack of land management plans and/or adequate urban regulations has strongly affected the natural and built environment. This has facilitated unplanned urban sprawl at the expense of natural landscapes (MoE & UNDP, 2011).

The present study is concerned with the application of a hydrological model (WiMMed) in a semi-arid area in Lebanon El Asi – Orontes watershed to compare the hydrological behavior of this region in the period 2005-2013 and to assess the impact of land use changes on infiltration, run-off and soil moisture of second layer at water basin scale under same climatic conditions.

The results of this work show that infiltration at basin level has decreased between 2005 and 2013. This reduction is especially important in the spring season, when infiltration was reduced to 70% compared to that recorded in the basin in the same period of 2005. Spring infiltration includes the effects of precipitation of Spring and Winter. This can explain why the change of infiltration is the most during Spring.

The runoff doesn't show a remarkable change between 2005 and 2013, it is only during Autumn season where the greatest differences are shown, Although the change is low, since the presence of rain and snow is this time of year in the study area is very low. The increase in runoff seems to be related to the decrease in the area of dense forests, which lost almost 98% of their surface area during the study period, especially when they were in the upper areas of the basin. However, there has also been a decrease in the area of vacant land of around 12% (97.5 km^2), which has been transformed into agricultural areas, pastures or fruit crops, which seems to have mitigated the effect on runoff.

The run-off is one of the hydrological parameters that shows an important seasonal variation being higher in spring and winter when compared to the other seasons. This could be related to saturation of soil after winter precipitation. In addition to the loss of water resources for the vegetation that the runoff supposes, this one has an important influence in the erosion (Ho *et al*., 2013), which causes serious environmental problems in the zone of study and makes difficult the restoration options of the most degraded zones.

The study reveals that the changes of land use in El Asi - Orontes watershed from 2005 to 2013 result in a decrease of the soil moisture of second layer in all seasons.

Land use change affects many hydrological variables like soil moisture, infiltration rates, runoff, evapotranspiration and others. Soil moisture is one of the most important components which express the balance between incoming (precipitation) and outgoing (evapotranspiration and runoff) quantities. The anthropogenic changes in land use have altered the characteristics of the Earth's surface, leading to changes in soil physic chemical properties, soil fertility, soil erosion sensitivity and content of soil moisture (Sharif *et al*., 2014). El Asi - Orontes watershed is a semi-arid area requiring greater understanding and management of land and water resources.

In the present study, the hydrological behavior of the study area has been compared between 2005 and 2013 by considering land use change as major influencing factor. An important decline in area coverage of Dense forests in El Asi - Orontes watershed was observed in during 2005-2013 period by almost 93% of area loss. The main reason for this decreasing trend is the frequency and the intensity of forest fires that form a real threat of the sustainability of the forest ecosystems in semi-arid regions of Lebanon. In addition, Hermel region, where El Asi - Orontes watershed is located, is one of the areas that are mainly affected by dryland degradation and desertification as Climate Change effects, and overgrazing pressure is common in this area.

In addition to soil erosion and degradation the partial disengagement of the state in Hermel region pushed the local farmers to adopt independent agricultural and livestock farming strategies to raise their incomes and meet their needs, which may be the reason for the significant increase in Grasslands and Fruit trees areas. Also, the augmentation of area covered by urban sprawl and sites was clear at the expense of green areas.

After comparing the runoff, the infiltration and the soil moisture of second layer rates between 2005 and 2013, our aim was to describe how these variables respond to land use change.

When studying the effect of land use change on infiltration between 2005 and 2013 we found that Infiltration capacity of grasslands and pasture is higher than the infiltration capacity of outcrops and bare rocks. The loss of dense forest in favor of grasslands, fruit tree plantations or bare rocks, decreases infiltration by affecting surface crusting, compaction and soil organic matter reduction. Without a protective vegetative or residue cover, bare soil is subject to direct impact and erosive forces of raindrops that dislodge soil particles. Dislodged soil particles fill in and block surface pores, contributing to the development of surface crusts which restrict water movement into the soil (Li *et al*., 2007).

The soil moisture of second layer of any type of forests is greater than the soil moisture of shrubland or agricultural areas, as these land uses cannot protect the soil surface from the water loss via evapotranspiration as much as forests do, which has also been observed in other studies (Wang *et al*., 2013). Other authors previously conclude that soil moisture of forests was significantly higher than the soil moisture of grasslands and field crops in large areas, this is due to the greater post rainfall loss of moisture under grass and crops sites than forest and shrubs (Mu *et al*., 2002). For the same reason, the results showed that dense forest have higher values of soil moisture than low density forests because the open surface leads to greater daily water losses in the low density mixed forest. Deboodt (2008) conducted another study showing how low density forest of *Juniper spp*. utilizes available moisture and how removal of stands may provide improved water availability for forage production, livestock and wildlife water and increased ground water for down slope uses. Echeverria *et al*. (2001) also concluded that soil moisture is always higher in the dense pine forests in comparison with low density oak forests.

This study found that the land use change from 2005 to 2013 has a negative effect on the hydrological characteristics of this watershed decreasing the infiltration capacity and the soil moisture of second layer in this area. Based on the results of the simulations, it can be concluded that in term of runoff low differences was registered in all seasons between 2005 and 2013. The lack of proper management and land use planning is a limiting factor responsible for further loss in forest areas in the future. Hence proper management of this region is required or else these resources will soon be lost and no longer be able to play their role in the development of the area.

Therefore, the results of this study can contribute to define adequate policies and strategies for territorial management and planning, in terms of land use. Adequate spatial planning aimed at productive and sustainable development in this region of Lebanon should consider the influence that possible changes in land use could have on available water resources.

Water balance is affected by both : land use and climate, after highlighting the land uses that are more efficient for the water balance and increase the soil moisture of the soil, this study analyzes how changes in climate under the representative concentration pathways (RCP) scenarios affect infiltration, run-off and soil moisture of second layer within the Lebanese part of el-Asi- Orontes watershed. This study used RCP2.6 and 8.5 scenarios assuming that the future land use is the same as the current land use (2013 land use/land cover map). The changes in mean and total infiltration, run-off and soil moisture of second layer for the period 2013-2050 were calculated under RCP2.6 and 8.5 scenarios. Our results show that climate change affect all of these variables but within different rates. Consequently, this watershed will be very likely exposed to a variety of negative effects. First, both RCP2.6 and 8.5 showed decreases of the mean values of infiltration, run-off and soil moisture of second layer in all seasons compared to the current values of these hydrological parameters.

Effect of climate change on infiltration:

Compared to the current conditions, the monthly precipitation is projected to decrease by 10% under RCP2.6 and by 20% under RCP8.5. An increase of temperature of 2°C is predicted under RCP2.6 while RCP8.5 scenario predicts an increase of 5 °C in the mean temperature of the study area. Under RCP2.6 scenario, infiltration showed a decrease pattern for the period 2013-2050 in all seasons. It decreased by a maximum of 11.7% during Spring season and a minimum of 9.5% during Autumn season. Under RCP8.5 scenario, infiltration showed further decreases for the same period in all seasons. It decreased by a maximum of 22.4% during Spring season and a minimum of 21.25% during Autumn season. The simulated infiltration depending on climate change showed a decreasing trend for all seasons under both RCP scenarios. The results showed that the mean infiltration within the study area is expected to have further decreases under RCP 8.5 compared to the mean infiltration under RCP2.6 for all seasons. Seasonal variation for infiltration showed similar patterns of decrease in all seasons under both scenarios. This can be explained by the decrease of precipitation and the increase of temperature, therefore, the increase of evaporation rate under RCP scenarios. After comparing the results of RCP2.6 and 8.5 the findings showed that when precipitation is reduced by half (a decrease of 10% under RCP2.6 compared to a decrease of 20% under RCP8.5) the percentage of infiltration change clearly decreased by half in all seasons. The variation of infiltration means has a similar pattern to that of future precipitation change under RCP2.6 and RCP8.5 scenarios which means that infiltration is very sensitive to precipitation. Varallyay (2010) had the same conclusion; he has proved that a rise in temperature accompanied by low precipitation decreases the water infiltration.

Effect of climate change on run-off

As noted, before, the run-off mean and total values are negligible in Autumn and Spring seasons in the current conditions and under both RCP scenarios. Under both scenarios, run-off showed a decrease pattern for the period 2013-2050 in Winter and Spring. Under RCP2.6 scenario, it decreased by a maximum of 40% during Spring season and a minimum of 24.2% during Winter season. Under RCP8.5, run-off means values decreased by a maximum of 71.1% during Spring season and a minimum of 37.8% during Winter season. The simulated run-off depending on climate change showed a decreasing trend during Spring and Winter seasons under both RCP scenarios. The results showed that the mean run-off values within the study area are expected to decrease more under RCP8.5 than RCP2.6 scenario. The similar pattern of decrease that affects run-off under both scenarios can be explained by the predicted decrease of precipitation. After comparing the current run-off with the values of run-off under RCP2.6 and RCP8.5, the results demonstrate that when precipitation decreases more, run-off values decrease further. Other researchers demonstrated the same results. Varallyay (2010) found that the decrease in atmospheric precipitation and the rise in temperature will result in decrease of surface run-off. A review done by Roudier *et al*., (2014) summarizes the impact of climate change on run-off in

West Africa: a correlation analysis revealed that run-off changes are tightly linked to changes in rainfall (R=0.49), and to a smaller extent also to changes in potential evapotranspiration. To study the potential future run-off evolution in view of climate change, we found that the future tendency of run-off changes is affected by the future precipitation changes. Therefore, the run-off means could decrease in the study region during the wet season because a decrease in precipitation pattern is predicted under RCP2.6 and 8.5 scenarios. The seasonal variation of run-off is clear: higher average and total run-off values are registered in Spring when compared to Winter values under both scenarios. The high Spring run-off potential can be justified by a saturated soil after Winter precipitation. The same conclusion was obtained by Ho *et al*., (2013). They have demonstrated that run-off and erosion in Spring are higher than in Winter.

Effect of climate change on soil moisture of second layer:

Under both scenarios, soil moisture of second layer showed a decrease pattern for the period 2013-2050 in all seasons. Under RCP2.6 scenario, it decreased by a maximum of 8.6% during Spring season and a minimum of 4.5% during Winter season. Under RCP 8.5 scenario, it decreased by a maximum of 17.4% during Spring season and a minimum of 8.5% during Winter season. The simulated soil moisture of second layer depending on climate change showed a decreasing trend in all seasons under both RCP scenarios. The results showed that the soil moisture of second layer is expected to decrease more under RCP8.5 than under RCP2.6. the similar pattern of decrease that affects soil moisture under both scenarios can be explained by the predicted decrease of precipitation and the predicted rise of temperature. After comparing the current soil moisture of layer 2 with the values of soil moisture of second layer under RCP2.6 and RCP8.5 scenarios, the results show that no significant difference is registered under RCP2.6: the decrease percentage of soil moisture recorded in all seasons is less than 10% while a significant decrease of soil moisture of second layer is recorded in all seasons except winter (a decrease of 8.5%) under RCP8.5 scenario. In our case study, a decrease of 10% in precipitation and an increase of 2 °C in the mean temperature do not affect significantly the soil moisture of second layer. It is only under RCP8.5 scenario, after decreases in precipitation of 20% and a rise in temperature of 5 °C, when significant decreases of soil moisture of layer 2 are recorded. This study has shown that the influence of land use change (previous chapter results) on soil moisture of second layer is much more significant when compared to climate variability and climate change. The results show that climate and land use each exerts a control on soil moisture (Amir *et al.*, 2016). Their effects vary depending on the land use change and on the level of projected climate change. A 20% precipitation reduction accompanied with 5°C of temperature increase is projected to decrease the soil moisture of second layer in a significant way.

5.2. References

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Chapter 6. General Conclusions

6.1. General Conclusions

This research has achieved the general objectives listed in the introduction and the specific objectives of each chapter.

The Land capability map of El-Hermel District produced during the first step shows that the zoning map proposed for this region doesn't respect the land capability classification which will result in increasing the stress applied on the soil and therefore increases the risk of desertification. This map will certainly help decision makers to control urban expansion and follow the implementation of rules for the construction on relevant land capability classes. They have now the ability to propose fine tuning of the land use planning developed centrally based on large scale maps because the land capability map of 2005 and the one published in this study used basically the same methodology, but the results were different. The small scale used in 2005 classification does not show well the variability of soil characteristics as the large scale of the current study does. It should be noted that the validity of the analysis is related to the scale of the input maps. For more detail planning, more detailed input maps are required. Since now, we got the chance to have the land capability map of El-Hermel District (1:20,000).

First suggested restoration activity is to produce a master urban plan for this region that will help the decision makers and the planners to control land use options and urban expansion to prevent desertification and land degradation by chaotic urban sprawl, support suitable land use, and raise awareness to hasten local governance for the protection and sustainable use of natural resources in the area. For its effective use, it is needed to increase policy maker's awareness about the capability of soils and provide land use planners with information on the land's best use. A strong communication between soil experts and decision makers is likely to increase sustainable use of lands and to help in environmental protection if earlier interventions are made.

But to propose more restoration activities and to combat land degradation and desertification in this area, the land capability map is not enough. It is necessary to evaluate additional factors containing detailed climatic, geomorphic and hydrological parameters that have impact on desertification and environmental sustainability. This research should be followed by a land suitability study and other detailed studies to suggest correct land use for each parcel of this region. Such kind of work enables governors and planners to develop crop managements able to increase the land productivity and to decrease the risk of desertification.

In the second part of work, we have compared land use change between 2005 and 2013 in El Asi – Orontes watershed. The results show that major decline with respect to area coverage in El Asi–Orontes watershed was observed in the dense forests class. During 2005 – 2013 period, the area covered by dense forests decreased by 93.2%. Also, a decrease of bare areas by 12.3% was noticed, in favor of the increase of agricultural areas (5.8%), fruit trees areas (34.8%) and urban areas (38.5%). The main reason for the decreasing trend of forest areas is the frequency and intensity of the forest fires, that form a real threat of the sustainability of the forest ecosystems in semi-arid regions of Lebanon. In addition to forest fires, this region is one of the areas that are mainly affected by dry land degradation and desertification, and there is also the absence of effective protection and the pressure of overgrazing.

The influx of Syrian refugees in large numbers wills definitely result in an increase of agricultural areas. Potato and vegetable growers in the Bekaa Valley have increased their planted surface area in order to cover the increasing local demand for food commodities. There is a significant increase in olive cultivation in the area. The interest in olives comes from a study that has evaluated the quality of olive oil in the whole country. This study emphasizes that the olive oil produced in El- Hermel District has the best quality compared to oils of other regions. Based on these results, an augmentation of area covered by urban sprawl and sites was clear at the expense of green areas. The study area also presents an increase in the uncontrolled urban development like linear expansion along the main axes, urban sprawl and creation of urban continuum, scattered sprawl on wood lands and the encroachment of construction projects into wooded areas.

In addition to soil erosion and degradation the partial disengagement of the state in El-Hermel District pushed the local farmers to adopt independent agricultural and livestock farming strategies to raise their incomes and meet their needs, which may be the reason for the significant increase in Grasslands and Fruit trees areas. Aldo the augmentation of area covered by urban sprawl and sites was clear at the expense of green areas.

This study found that the land use change from 2005 to 2013 has a negative effect on the hydrological characteristics of this watershed decreasing the infiltration capacity and the soil moisture of second layer in this area. Based on the results of the simulations, it can be concluded that in term of runoff low differences was registered in all seasons between 2005 and 2013. The lack of proper management and land use planning is a limiting factor responsible for further loss in forest areas in the future. Hence proper management of this region is required or else these resources will soon be lost and no longer be able to play their role in the development of the area.

Therefore, the results of this study can contribute to define adequate policies and strategies for territorial management and planning, in terms of land use. Adequate spatial planning aimed at productive and sustainable development in this region of Lebanon should consider the influence that possible changes in land use could have on available water resources.

After studying the effects of land use change on hydrological behavior of El Asi –Orontes watershed, an attempt has been made to compare the current hydrological variables of the study area (infiltration, run-off, soil moisture of second layer) to the simulated variables in 2050 under 2 RCP scenarios, RCP2.6 and RCP8.5, assuming that the future land use is the same as the current land use (2013 land use/land cover map). Based on this study, the following important points are highlighted. Under same land use conditions, a rise of temperature accompanied with a decrease of precipitation will result in a decrease of infiltration, soil moisture of second layer in all seasons, and run-off of second layer during spring and winter. All the hydrological variables within the study area are expected to have further decreases under RCP8.5 compared to RCP2.6 for all seasons. However, the influence of land use change on soil moisture of second layer is much more significant when compared to climate variability and climate change.

These direct influences of the climate change on hydrological variables could cause unfavorable consequences in the study region. for groundwater replenishment, we depend largely on recharge (water moving from the surface to the groundwater) from infiltration of the precipitation. In other hand, the decrease of surface run-off consequently decreases water erosion hazard but increases the risk of wind erosion for dry surfaces. The projected decrease of soil moisture of second layer may affect the water supply of plants, influences the biological activity and plant nutrient status of the soil, it will also decrease the drought sensitivity and the cracking and erosion risk.

Being aware of these facts offers possibilities for the elaboration of efficient measures for adaptation to the predicted climate change scenarios preventing, or at least moderating their unfavorable consequences. As noted above, the hydrological variables within the Lebanese part of El-Asi-Orontes watershed is expected to have higher variations due to climate change. Therefore, the results of this study are necessary to predict the spatiotemporal variability of hydrological parameters in order to determine policies for sustainable water resource development.

The results of this research present an essential tool to evaluate the state of El Asi-Orontes watershed, a semi-arid area in Lebanon. Producing land capability map, studying the effects of land use change and climate change on hydrological variables are necessary actions to combat desertification, manage the basin water resources and prevent the urban flooding. As mentioned before, this work was helpful to assess the stress on the land and hydrological states of the study region under different climatic scenarios, but to suggest restoration activities and to reduce the negative effects of land use change and climate change, more detailed studies are needed to suggest the correct land use type and to find a way to mitigate the effects of climate change in El Asi-Orontes watershed specifically and semi-arid areas generally.