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Modelling the impact of land use changes on hydrology using HBV-light

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Declaration

I hereby declare that this thesis, submitted only to the Pan-African University; Institute of Water and Energy Sciences (Including climate change) PAUWES, entitled "Modelling the impact of land use changes on hydrology using HBV-Light" has been prepared by me under the guidance and supervision of Pr. Lars. Ribbe, director of The Institute for Technology and Resources Management in the Tropics and Subtropics (ITT) at TH KOLN and Co-supervision of Pr. S. M. Chabane Sari national coordinator at PAUWES.

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DEDICATION

To my dear father Abdallah

To my dear mother Zohra

To my brothers Lazhar & Noureddine&

Mohamed Baraa

To my sisters

And all my friends.

I dedicate this work with all

The love and respect I have for them.

NABIL.Khorchani

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Abstract

During the last years, problems of flows risks have become a very interesting issue in Tunisia due to many factors such as changes in the land use. Deforestation together with agriculture expansion, due to the anthropogenic activities, has an effect on the land use/cover change influencing the hydrology of a sub-basin by changing the magnitude of stream flow. In this work, the likely land use/cover change impacts on hydrology of the Mellegue river sub-basin in the Upper Medjerda River Basin have been evaluated using the semi-distributed HBV-Light hydrological model and remote sensing for two different periods. ArcGIS was used to generate the land use-cover maps from Landsat TM (1984-1997) for the year 1988 and second land use/ land cover map on 2003 was taken from the Regional Commissariat of Agricultural Development (CRDA) of Kef region. The land use-cover map of 1988 were generated using the Maximum Likelihood Algorithm of Supervised Classification. The accuracy of the classified maps was assessed using contingency matrix, it gives an overall accuracy of 89.6%. The result of this analysis showed that the forest area has decreased by 5.16% from 1988 to 2003 due to anthropic activities, as well, there is an expansion of irrigated land by 4% due to the converting toward more advanced agriculture technologies and the encouragement of the government by making more projects focusing in agriculture enhancing production. The model calibration was processed using observed hydro-meteorological data (precipitation, temperature, potential evapotranspiration, discharge) for the period ranging from 1980 to 1986. The validation of the model was run for a period between 1995 to 1999 using the same data input as calibration. The efficiency of the model was obtained directly from HBV model using the Reff method. The result was acceptable for the both calibration and validation. An efficiency of 0.38 for calibration and 0.1 for validation for the land use/cover of 1988. An efficiency of 0.33 for calibration and 0.1 for validation for the land use of 2003. By comparing the outputs of the two calibration and validation, the hydrograph shows a variation of the streamflow along the years by either increasing or decreasing, this therefore could be interpreted due to the occurrence of changes in land use/cover (deforestation and expansion of irrigated land).

Key words: Land use/cover, deforestation, irrigation, HBV-Light, remote sensing.

RÉSUMÉ

Au cours des dernières années, les problèmes de risques de flux sont devenus une question très intéressante en Tunisie en raison de nombreux facteurs tels que les changements dans l'utilisation des terres. La déforestation et l'expansion de terre agricole, en raison des activités humaines, a un effet sur le changement d'utilisation des terres influençant l'hydrologie d'un sous bassin en changeant l'ampleur de l'écoulement des cours d'eau. Dans ce travail, le probable impact de changement d'utilisation des terres sur l'hydrologie du sous-bassin de la rivière Mellegue dans le bassin de Haute Medjerda ont été évalués en utilisant le modèle hydrologique semi-distribué HBV-Light et la télédétection pour deux périodes différentes. ArcGIS a été utilisé pour générer les cartes d'occupation du sol en se basant sur des images Landsat TM (1984-1997) pour l'année 1988 et d'autre pour l'année 2003 qui été tirée du Commissariat Régional du Développement Agricole (CRDA) de la région du Kef. La carte d'utilisation des terres de 1988 a été générés en utilisant l'algorithme du maximum de vraisemblance de classification supervisée. La précision des cartes classées a été évaluée en utilisant la matrice de contingence, il donne une précision globale de 89,6%. Le résultat de cette analyse a montré que la superficie forestière a diminué de 5,16% entre 1988 et 2003 en raison des activités anthropiques, ainsi, il y a une expansion des terres irriguées de 4% en raison de la conversion vers des technologies agricoles plus avancées et l'encouragement de gouvernement en faisant plus de projets axés sur l'agriculture et l'amélioration de la production. Le calage du modèle a été traité en utilisant les données observées hydrométéorologiques (précipitations, température, évapotranspiration potentielle, débit) pour la période allant de 1980 à 1986. La validation du modèle a été exécuté pour une période comprise entre 1995-1999 en utilisant les mêmes données d'entrée et le paramètres que celle du calage. L'efficacité du modèle a été obtenu directement à partir du modèle du HBV en utilisant la méthode Reff. Le résultat était acceptable pour calage à la fois et de validation. Une efficacité de 0,38 pour le calage et 0,1 pour la validation de l'utilisation des terres de 1988. Une performance de 0,33 pour le calage et 0,1 pour la validation de l'utilisation des terres de 2003. En comparant les sorties des deux calages et de validations, l'hydrographe montre qu'il y a une variation de l'écoulement le long des années, soit avec augmentation ou bien par diminution de débit, ce pourrait donc être interprété en raison de l'impact de changements dans l'utilisation des terres (déforestation et de l'expansion des terres irriguées).

Mot clés : Utilisation de terres, déforestation, irrigation, HBV-Light, télédétection

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CHAPTER ONE

Introduction

1. 1 Background

Water is an essential factor for the development of agriculture, industry, tourism and for the supply of drinking water. Quantifying current and future water hydrological pattern variation is a critical aspect of a proper basin management practices. Located at the extreme North of Africa, Tunisia has mainly a temperate climate in the northern part of its territory but is still in a semi-arid to arid climate zone for the Centre and South. Thus, in the northern part of the country concentrates 78% of surface water over a quarter of the national territory, indicating a significant regional imbalance regarding the distribution of surface water resources. (Ribeiro et al., 2002). The Northwest (Medjerda upstream basin) is considered the water tower of Tunisia, with its potential for rainy water, this is where the average annual rainfall exceeds 400 mm / year (Ben Boubaker, 2010). The global advances in economy, agricultural developments and modern standards of living style have resulted in a growing dependency on natural resources.

The search for virgin lands for agriculture, economic development and increasing human population are major causes of land use cover change in most developing economies (Ndulue et al., 2015). The rapid Population growth always results into an increase of water need and land for agriculture, while as economic development brings about clearing of forests, burning down trees for energy and creating space for settlement. In addition to climate change, land use change is one of the important human interventions altering the quality and quantity of both surface and ground water (Dwarakish et al., 2015). The land use cover change has adverse implications on the natural hydrologic system in terms of variation in the runoff regime, evapotranspiration (ET), subsurface flow and infiltration (McColl et al., 2007).

Surface runoff is essentially estimated in most of the water resource applications to assess the water yield potential of a watershed, extent of soil erosion, flood hazard in the basin, decision making for water resource management, conservation etc., (Patil et al., 2008). The land use/cover changes usually have an impact on forests and national reserves caused by the anthropogenic activities which lead to an over exploitation and expansion in arable land as well cattle ranching that encroach on forest land (Kundu et al. 2008; Mutua and Klik. 2007; Onyando et al. 2005). These practices have had diverse influences on the storm runoff which has significant effect on both the quality and quantity of the river flow (Dwarakish et al., 2015).

The land use cover change influences the river basin hydrology in two ways, Land cover under little vegetation is subjected to high surface runoff and low water retention whereas, the high vegetation covers (agricultural area as example) increase evapotranspiration and decrease the mean annual river flow (Legesse et al., 2003). The Land use-cover plays a fundamental role in driving hydrological processes within a sub basin (Gwate et al., 2015). These include changes in water demands such as irrigation, changes in water supply from altered hydrological processes of infiltration, groundwater recharge, and runoff, and changes in water quality from agricultural drainage.

In Tunisia, Medjerda river together with its tributaries (Mellegue, Tessa, and Kassab river), is one of the largest river system in the Maghreb countries. The Medjerda basin covers an area of 23,700 km² of which 7,300 km² are located in Algeria (Ben Hamza, 1994).

The watershed of Mellegue river, a tributary of Medjerda basin, has an area cover 10,400 km². It is divided into several sub watersheds, the total length of this river to the junction with Mejerda river, is 252 km with about 205 km located in Tunisia. The main influent sources of Mellegue river located in the Tunisian part are Sarrath river, Ksob river, Wadi Khol and Wadi R'Mel (right bank) and Wadi Melah (left bank).

Nebeur dam constructed on Mellegue river in March 1954, controls more or less a wide watershed of the river. It has an influence on the flood regime control (Colombani et al, 1981). The watershed of the Mellegue river was affected by several floods in the years 1969, 1973, 1984 and 2003, some of which have had notable consequences. Both 1973 and 2003 floods were characterized by a peak flow greater than 400 m^3/s (Ben Mammou, 1998; Oueslati, 2005). Due to the lack of data concerning its management in terms of storage, release and distribution, a small sub-basin chosen based on the discharge station k13 located upstream of the dam for the hydrological modelling part in this study.

As evidenced from various studies, changing in land use cover has a direct effect on the runoff, which impacts directly on hydrological processes. An understanding of the impacts of land use cover change on the current and future hydrology in Mellegue river basin is of great importance.

The main objective of this study is to assess quantitatively the impact of land use changes (including shifting in the geographic extent) to the runoff processes and hydrologic response due to precipitation in Mellegue river sub-basin using the conceptual rainfall-runoff hydrological HBV-Light model, remote sensing and Geographic Information Systems GIS.

1.2 Problem Statement

A number of studies have been carried out in the Medjerda River Basin focusing mainly on the assessment of flooding risks (Djebbi. M et al. 2006, Zahar. Y, et al. 2008). However, none or little emphasis has been put on the cause of the variations of streamflow resulting from land use changes. Land use has a finite impact on water catchment and storage which on large scale influences the water balance within a catchment. Deforestation and increase of irrigated land are the most common factors affecting changes in land use in this study area. In order to have a profound analysis of the effect of deforestation and agriculture expansion, a HBV-Light model was used to generate the streamflow variations resulting from variations of land use.

1.3 Objectives

The main objective of this study is to evaluate and spatialize the impact of land use change in Mellegue river sub-basin through Remote Sensing, GIS, and modelling. This is further subdivided into the following objectives, which are:

i. To assess quantitatively the impact of land use changes to the runoff processes and hydrologic response due to precipitation.
ii. To utilize remote sensing to provide extensive, adequate and reliable geospatial land use data for the hydrologic model (HBV).
iii. To use HBV to convert the excess rainfall to overflow (runoff).
iv. To simulate the runoff process impact due to change in land use in the watershed.

1.4 Justification

The driving forces that make us choose this topic was, first of all, the lack of research interesting on the effect of land use changes in Mellegue river basin which is affected by the phenomenon of flooding since long time ago due to the increase of streamflow, which was also affected the cities downstream of Mellegue river basin like Bousalem and Medjez el Bab. Secondly, some projects are going to be implemented on the rehabilitation of upper Medjerda basin in order to look at the efficient management of water resources by storing it for future use (a deficit of surface water reserve of 34 % during the last year due to the decrease of annual precipitations according to the minister of agriculture) and reducing the flooding risk of the downstream cities. Therefore, this work will help to know if land use changes is one of factor that really have an impact on increasing or decreasing the quantity of streamflow.

CHAPTER TWO

Literature Review

2.1 Introduction

In order to have a general idea on the effect of land use changes on hydrology and its modelling that was done in several areas around the world, a literature review was done on this objective.

2.2 Effect of land use/land cover change on streamflow

Land cover as defined in the literatures, refers to the natural cover such as vegetation, water bodies, bare soil. As well, it could be the created land use by human activities, which is defined as the human use or management of land cover type, this may include among others, land conversion from forest to urban area, modification of rain fed agriculture into irrigated area and use of water body as hydroelectric reservoir (Cihlar and Jansen, 2001).

According to Lambin et al (2006) land use can be considered the root source of factors causing land cover changes. Those factors are mainly brought by the human activity such as expansion or reduction of urban setting, agriculture, grassland area, etc. However, it can be as well nature whose affects bring up land cover changes.

Land use changes can have many implications on hydrology causing floods, landslides and affecting the annual and seasonal flow, water quality and soil erosion within the catchment due to some modification on the cover (afforestation, deforestation) (Calder.I.R, 1993). Water balance of a catchment are influenced generally by the infiltration rate, precipitation and the evapotranspiration. Urban area expansion leads to a reduction in the infiltration rate which results in higher peak discharges and runoff. Different vegetation cover gives different runoff generation area because of the difference in the evapotranspiration rate, each crop has its own leaf area index, root depth and albedo (Ward and Robinson, 1990)

Modelling the impact of land use changes within watersheds has been studied since long time ago by several researchers (e.g., Onstad and Jamieson, 1970; Hillman and Verschuren, 1988; Bultot et al., 1990, Miller et al., 2002). Onstad and Jamieson (1970) represents one the first essay to predict the effects of land use changes in response to runoff using hydrological model. It was an initiation to the use of computer simulation for such predictions, but unfortunately they could not validate the model due to the lack of data (Lorup et al., 1998).

Nie. W et al (2011) indicates in his paper "Assessing impacts of Land use and Land cover changes on hydrology for the upper San Pedro watershed" that urbanization (increased by 0.44 to 2.24% from1973-1997) was the major contributor to the increased surface runoff and water yield for the studied watershed. At the same time, the replacement of desert scrub or grassland by mesquite from 1973 to 1997 was identified as the second major predictor for the declines of baseflow, percolation and for the increase of ET in the upper San Pedro watershed.

Im. S et al (2008) used the model MIKE SHE to describe the impact of forest-to-urban land use conversion on watershed hydrology. The results from the changes in land use was a runoff increases in the whole watershed and overland flow due to the expansion in urban area that encroach on forest land. Urbanization helps runoff flowing by decreasing the infiltration rate and evapotranspiration.

In Tunisia, over-exploitation of land is the main factor that leads to the phenomenon of erosion by runoff affecting seriously the potentiality of water and soil of the country. About 325,000 ha of soil is mainly affected by erosion during the intense precipitation due to change in land use (Laajili Ghezal et al. 1998). This erosion enhances the desertification in many parts of country.

2.2.1 Hydrological response to the land use-cover change

Deforestation is where there is a decrease of forest land by destroying it. Forest cover acts as a filter and determines in large part the precipitation perspective. Thus, by destroying forest cover the different components of the hydrological cycle are affected.

The decrease in volume of the canopy environment affect more particularly the hydrological cycle. The decline in the volume of the canopy is due to the effect of reducing the interception and the evaporation, therefore increasing surface runoff. The decrease in soil infiltration capacity has the direct effect of increasing the surface runoff, reducing the response time in case of heavy rain event and the amount of water stored in the soil.

Expansion of irrigated land could be a cause of an increase in surface runoff by the phenomenon of seepage loss or drainage.

2.2.2 Agriculture in Tunisia

Between 1960 and 1980, the agricultural sector was neglected by government policies that promoted export-oriented industries. Most farmers practice traditional subsistence farming in the country, food production has stagnated while the population increases. Thus, food dependence on importation from abroad has escalated. From 1960 to 1980, the proportion of imported food increased from 30% to 70%. In the early 1980s, Tunisia started to prepare its entry into the international market and adjust domestic prices to world prices. In this context, the government implemented in 1986 a structural adjustment program that provides for the restoration of the food balance and improving agricultural production, it was a move phase out subsidies and embrace the exact prices (Bachta M. S, Ben Mimoun A, 2003). In 1990, the agricultural sector generally enhanced, however, large gaps of success in products still existed. Tunisian agriculture remains confronted by climatic, agricultural and food deficit. Meanwhile, technological advances (use of inputs, increase irrigated area) have increased yields.

2.2.3 Agriculture production

In 2005, agriculture employed 22 % of the workforce and accounted for bulk Monetary 9 % of exports. A third of the land area, 5 million hectares is cultivated in the country, the rest consists of steppes and rangelands mainly for sheep population. About 45 % of cultivated areas are reserved for field crops (cereals, fodder legume), 52 % goes to arboriculture (olives, figs) and the rest (3 %) is used for market gardening (National Institute of Statistics, 2005). In 2004, these areas have respectively produced 1.7 Mt of cereals, 2.2 Mt of vegetable products and 0.9 Mt of fruit from the orchards. Figure (2.1) shows the evolution of these productions since 1961.

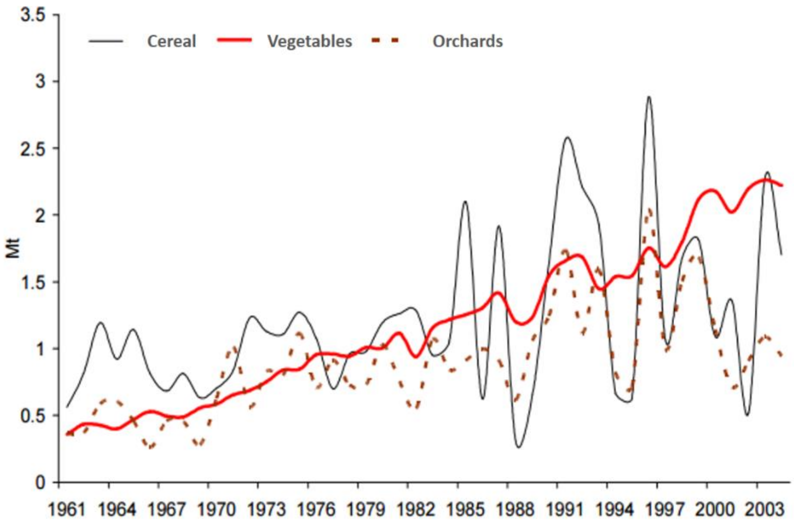

Figure 2. 1: Variability of principal Tunisian agriculture productions (FAO, 2004)

In dry years, losses are considerable and often reduce yields by more than half. In 1988 and 1995, particularly dry years, grain production accounted for only 15 % of volumes normally produced in wet years. Vegetable production using irrigation is much less sensitive to variations in rainfall.

Most varieties are irrigated (Almond, apricot, apple, pear, peach, orange trees, date palms). The olive trees represent nearly 50 % of the plantations (56 million trees). The olive groves are mostly not irrigated. 57 % of farms practice olive growing and 99 % of the olive groves are for the production of oil (Ministry of Agriculture and Republic of Tunisia, 1996).

Over the last decade, olive production represented on average of 13 % of the tonnage of the total agricultural production of the country and 4 % of world oil production. 13 % of Tunisian olive oil production is exported, contributing 41 % of foreign exchange inflows from exports of agricultural products. Regarding livestock, Tunisia produced respectively 7 and 1.4 million head of sheep and goats in 2004. Cattle are a minority with 760,000 heads (FAO, 2004).

2.2.4 Importance of irrigation

Over the five million hectares, 360,000 (7.2 %) are irrigated. They represent over 20 % of national agricultural production. The introduction of irrigation is the main factor of change in rural areas. It is accompanied by a group operating change in private and individual appropriation of land with an orientation towards the farm irrigated fruit trees (cultivated area increased from 1 to 2 million hectares from 1960 and 2005). This development leads to critical variations in the use of farm labour causing a sharp decline in small farmers (Picouet et al., 2006).

2.3 Hydrological response to high streamflow

2.3.1 Flood definition

A flood can be any high flow, overflow, or inundation by water that causes or threatens damage (NWS, 2012). Its effects vary according to the nature of the terrain and the degree of human occupation. Some floods happen due to long rainfall (slowly event) and others comes in a few minutes (very fast event). Floods can cover small areas like neighbourhoods or village and others cover large areas like cities. It can be caused by natural phenomenon like rainfall and glacier melt, and others are caused by engineering defects like dam or levee failure (Bingwa. F, 2013).

As shown in the figure (2.2) Flood is the most recorded disaster in the world especially the last years, it reaches 550 flood in the year between 2004 and 2006 comparing to other disasters, this could be due to many factors (climate change, land use change, etc.). Figure (2.3) shows the recorded flood number by continent, Africa considered the second continent after Asia within the last years that is affected by a high number of flood disasters (Adikari.Y and Yoshitani. J, 2009).

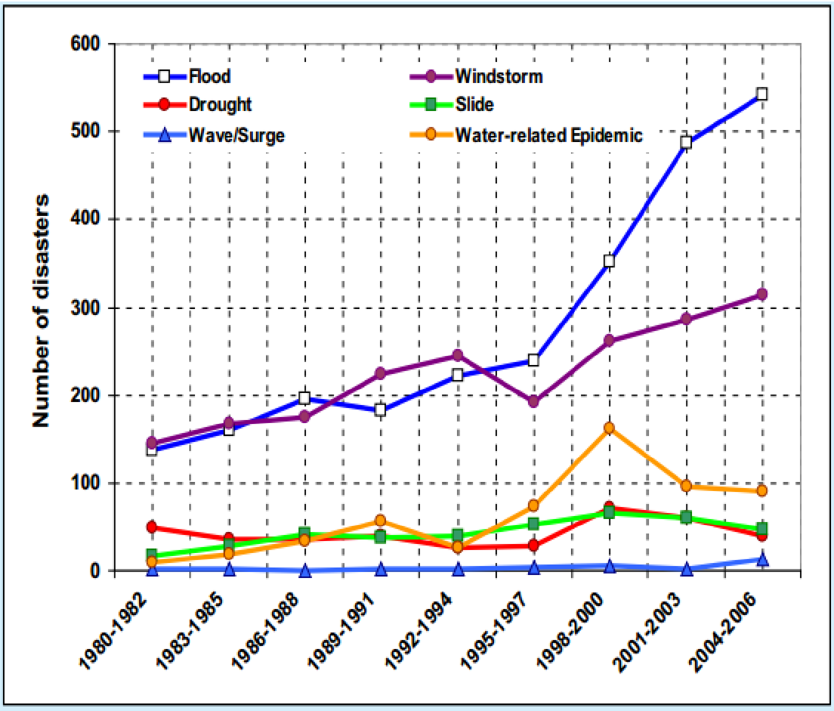

Figure 2. 2. Water-related disaster events recorded globally (Adikari.Y and Yoshitani. J, 2009)

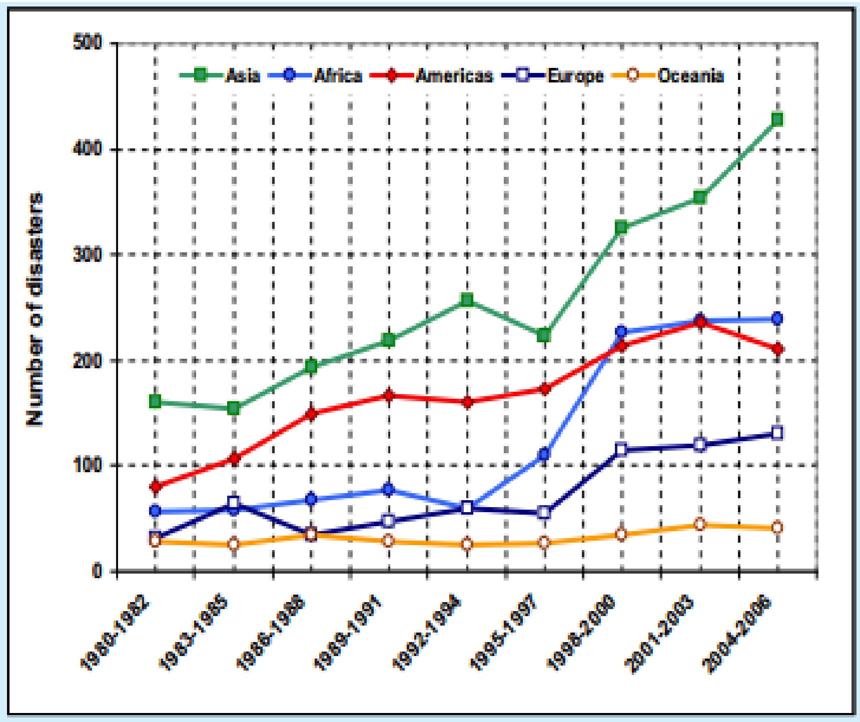

Figure 2. 3. Recorded water-related disasters by continent, (Adikari.Y and Yoshitani. J, 2009)

The volume of a flood can be divided into three main parts: surface runoff, interflow and base flow. The importance of each of these variables depends on the study area, the initial conditions for the flow, and the characteristics of the rainy event (spatiotemporal distribution, intensity and volume). The surface runoff is affected mainly by the change in land cover/ land use and soil type.

The first major theory regarding runoff assessment appeared early last century with the study of Horton (1933). This theory is based on the concept of soil infiltration capacity and the notion of overflow capacity. The logic of the concept is simple, as long as the maximum capacity soil infiltration within the study area is not exceeded, the total amount of rainfall occurs in the ground by infiltration, and once the rainfall intensities exceed this maximum threshold, the exceeding intake water reaches the surface and accumulate a certain volume of runoff and it’s the runoff that is responsible for the creation of floods. The infiltrated water in this case is located in the lower soil layers and contributes very slowly to groundwater recharge and supports base flow. This process is controlled by soil surface cover and textures.

2.3.2 Flood records for Tunisia

In general, the number of floods increased between 1980 and 2006 in every world’s region. Floods increased more than four-fold in Africa in the 1990s (NWS, 2012).

Tunisia is characterized by irregular and torrential rains which may create a violent and episodic flooding. One of the major characteristics of the rainfall regime in Tunisia is the amount of rain that is received in a region in a few days, a day or even hours may exceed the average monthly value and sometimes even the annual average of this region (Oueslati, 1999).

2.3.2.1 Floods of December 1973

In the Medjerda basin, the flood of 24 to 28 March 1973 caused catastrophic inundations in the middle and lower valley of the Medjerdah. Mediterranean intakes were estimated at 1 billion m^3, which is equivalent to the annual contribution of Medjerdah, the main river of Tunisia. According to Kallel and Colombani (1973), runoff coefficients extended from 0.60 upstream the watershed (Medjerdah to Jendouba 2410 km^2) to 0.35 for the entire watershed (Medjerdah to Slouguia 20,990 km^2). According to Frigui (2002), the return period of the flood was higher than the centennial.

2.3.2.2 Floods of September 1986

Ghorbel et al. (1986) studied the exceptional floods of 29-30 September 1986 which concerned a part of the Greater-Tunis and some of Northern East part. The amount of rainfall that fell represent about 104.5 mm in 24 hours in Tunis-Manoubia and 240.6 mm in 2 days in Grombalia region. For the damage caused by this event, it was noted that 7 houses collapsed in Tunis, damaged about 174 houses and 7 families left homeless; in Ben Arous, 4 people were killed and seven collapsed. Ghorbel et al. (1986) estimated that at the Tunis Manoubia station, the return period of 104.5 mm recorded in 24 hours is quinquennial. As regards to the intensity of 145 mm / h within 5 min observed at the same station, it estimates an occurrence of centennial return period.

2.3.2.3 Floods of 2003

An extreme flood occurred in the Medjerda basin in 2003. Exceptional rainfall on the entire watershed area and the intensity of the rain was important. The rains had different maximum intensity, this event was explained by major conditions according to Bouzaiane and Frigui , (2003):

- Waterlogged soils no longer play their role of retention;

- Flow rates exceeded the drainage system capacity

- An aggravating condition for large agglomerations of Tunis: the occupation of the natural expansion areas and flood waters over the obstruction caused by uncontrolled construction in the wadi beds. All this abandonment contributes to impede the flow during floods and contributes to flooding (DG / ACTA 2004). A huge amount of water which was stored in the dams of the Northern West part flowed into the Mediterranean Sea. (Bouzaiane and Frigui, 2003).

The figure (2.4) shows the recorded flow rate discharge for the days between 12/12/2003 and 15/12/2003 of Mellegue K13 station located on Mellegue river. This measurement was recorded during the flood of 2003.

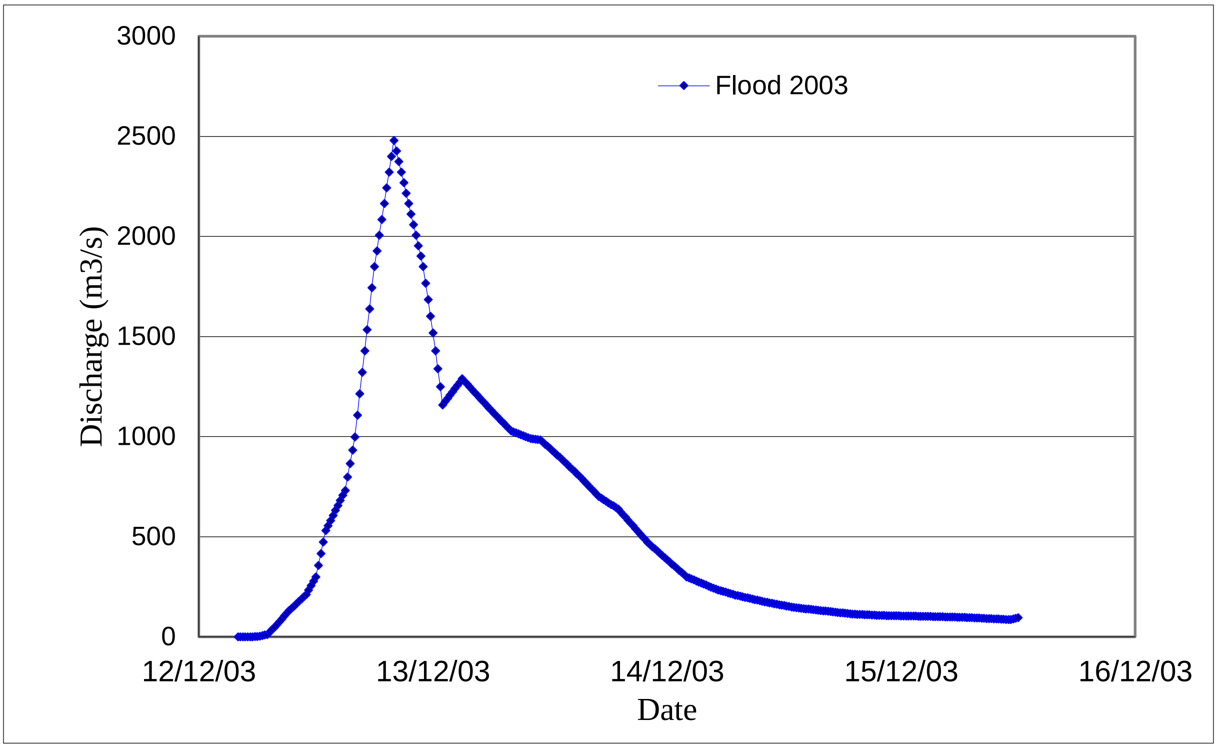

Figure 2. 4. Recorded flood of 2003 in Mellegue K13 station (MARH, 2004)

Figure 2. 5. Flood of 2003 observed downstream of Mellegue river basin (Fehri. N, 2014)

2.3.2.4 Flood of 2007

More recent flood occurred in October 2007, particularly on 13th October a flood causing materials and humans damages occurred on small watershed at the area of Sabbelet Ben Ammar in northern Tunisia. Frigui and Ben Mansour (2007) conducted a study of hydrology and precipitation for this rainfall event. They compared the observed rainfall over the middle of October estimating that they represent 160 % of the area of their study. They concluded that the return period of daily annual maximum is estimated at 52 years.

2.4 Factors controlling flooding

The flow measured at the outlet of a watershed is the result of a series of simultaneous processes with the consideration of the spatio-temporal variability. Activation of hydrological processes governing the phenomenon of flow is largely dependent on the physical properties of the watershed, meteorological parameters, land use and initial water conditions.

2.4.1 Topography

Chaplot and Walter (2003) indicate that the topography and sometimes the geology of deep soil layer play an important role in the control of hydrological processes at the watersheds and the topography is a determining factor that affect directly the behaviour of the fluid in the soil. These studies are very useful in the field of hydrology. Knowing the basin's topography and geomorphology is essential to understand the flow using more realistic modelling. Nowadays, this topographic variability is often taken into account for example in model inputs such as DEM (Digital Elevation Model).

2.4.2 Land use

Land use is one of the major factors that can enhance or mitigate the flooding risk. In urban areas with impermeable soils or cultivation areas with compacted soil, flows are concentrated on the surface. In contrast, for forest areas, where the soil porosity is much important, there is a preponderance (balance) of the subsurface flow compared to other types of flow. Forest areas play an important role in controlling the process of the water cycle, it becomes a point of agreement of the community hydrologists to ascertain the influence of the forest on the water cycle or the functioning and contribution of vegetation in the conditioning climate data of the basin.

2.4.3 Meteorological conditions

The meteorological factors also play a role in the phenomenon of flood generation. The intensity and volume of rainfall influence strongly the hydrological response. The solar radiation and the temperature within the basin helps to have a good estimation of the evapotranspiration. Spatial variability of data is an important factor in the process of infiltration and surface runoff (Ambroise. B, 1991).

2.5 Water balance

Water Balance in this guidance is defined as the numerical calculation accounting for the inputs to outputs and for the changes in volume of water in various components (e.g. reservoir, river, aquifer) of the hydrological cycle within a specified hydrological unit (e.g., river catchment or river basin) and during a specified time unit (e.g. during a month or a year), occurring both naturally and as a result of the human induced water abstractions and returns (EU, 2015).

According to the Dublin Statement on Water and Sustainable Development (UN, 1992)

"Measurement of components of the water cycle, in quantity and quality, and of other characteristics of the environment affecting water are an essential basis for undertaking effective water management. Research and analysis techniques applied on an interdisciplinary basis, permit the understanding of these data and their application to many uses", understanding the hydrologic impact of land use change should be based on the component of water balance equation which is:

$$P = R + E + \Delta S$$

where

P is precipitation

E is evapotranspiration

R is streamflow

ΔS is the change in storage (in soil or the bedrock / groundwater)

Runoff model is the base of most of the hydrological models means that river flow computed according to the meteorological data for a given basin. Water balance equation used in this case to model the runoff by calculating the amount of precipitations focusing on the quantities directed as runoff R which also depending on other factors (ET, T, etc.). water balance equation determining the runoff is:

$$R = P - E - \Delta S$$

2.6 Hydrological modelling structure

A hydrological model depends on both the authenticity of conceptions and assumptions on which it is based and the purpose for which it was designed.

HBV-light is a dynamic mass-balance model, which is run with a daily time-step, including other parameters within the catchment coupled to the water balance. The recent version of HBV-light model was used in this study to investigate the water balance for Mellegue river sub-basin.

2.5.1 Model selection

In order to select the appropriate model, there is a need to adapt with some objectives.

- The model must simulate the hydrological processes in the watershed to reach at the end the simulation of water balance.
- There must be a continuity to simulate the impacts of different processes in the short and long term of the watershed.
- The model must allow any development or modification of information as needed.
- The model must be applied successfully in different environments.
- The model type should address the objectives and available information of the study area.

2.5.2 Modelling Steps

The considered stages of development and implementation models for the relationship "rainfall-runoff" are (Haan et al., 1982):

- Definition of the objectives of the model;
- Analysis of the structure of the system to be modelled;
- Construction of the model;
- Calibration or parameter identification;
- Verification or sensitivity analysis;
- Validation of the model.

2.5.3 Types of hydrological models

2.5.3.1 Lumped conceptual models

Lumped conceptual models are very sophisticated with good description of the hydrological processes. In this case the hydrology is studied through series of interrelated processes and storages or “boxes”, each box corresponds to water store, for example, ground water or soil moisture and the connections between the boxes correspond to flow processes such as base flow and surface flow (Donald et al.1995). It describes the process mathematically in a lumped conceptual way. The advantages of the lumped conceptual models are the simplicity and limited requirements of input data.

2.5.3.2 Distributed models

This type is more complex and takes into account the spatial variability of both physical characteristics and meteorological conditions. Distributed models are partitioned into hydrological units and each process is computed independently in each of the units (Donald et al. 1995). Implementing these models is time consuming and the requirements of data and parameters are large. Distributed models are therefore restricted to use in certain areas.

Comparing to the distributed model, semi-distributed models attempt to calculate flow contributions from separate areas or sub-basins that are treated as homogeneous within themselves.

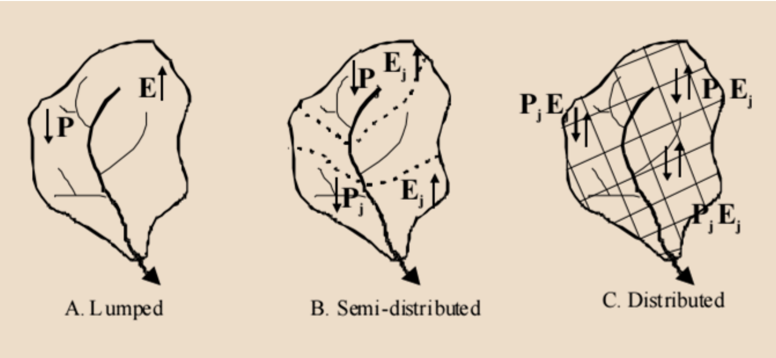

Figure 2. 6. Model types

2.5.4 Model construction

It consists of the selection, establishment and synthesis of mathematical or numerical relationships that represent each physical component of the hydrological processes and the dynamic behaviour of the system (Mahjoub. M. R, 1999).

2.5.4.1 Calibration

Once the model structure is chosen, the algorithms are verified and parameterization is defined in terms of the watershed, certain parameters are often difficult to measure or assess. This incomplete identification of the model requires to estimate the missing parameters with a calibration (adjustment).

The principle of calibration is to look for which values of these parameters gives better simulation of a series of observed data without changing the parameters already identified. This ability to adjust the parameters from experimental data called identification.

There are two ways of calibration, one is manual which is based on the assessment of parameter using a number of simulation runs. It can consume a lot of time to calibrate. The second one called Automatic calibration, the parameters here are adjusted automatically, it involves use of a numerical algorithm. The calibration criteria measure the goodness of fit of the simulation model. This method is fast and less subjective (Madsen.H and Jacobsen.T, 2001). The successful use of a hydrological model depends on its quality calibration.

The calibration objectives in this study that characterize the hydrological behaviour of the watershed is the change in land use and the streamflow hydrograph.

2.5.4.2 Sensibility analysis

According to Neitsch *et al* (2002), the sensitivity analysis identified the effect of changing the calibration parameters on streamflow. Identification of the key parameters and the parameter precision required for calibration it is mandatory (Arnauld et al 2012 and Ma et al., 2000). Sensitivity analysis can most likely complete the calibration step varying, successively or simultaneously, the parameters around optimal values (measured or calibrated), clarifies the "domain of indifference "of each parameter within the quality of the simulation which is not significantly impaired (Sorooshian and Gupta, 1985). This allows to detect the parameters to which the model is insensitive and simplify the calibration step.

2.5.4.3 Model validation

This is the most critical step, starting by checking if the calibrated model simulates correctly the series of data (spatial and temporal) which is not used during calibration.

The validation can be done either in a purely intuitive way as the visual comparison of results made using graphs or tables, or analytically as the statistical comparison of results made with appropriate testing or using experimental criteria such as the criterion of Nash-Sutcliffe.

According to Klemes (1986), validation should at least include the following iterative steps:

- Calibration within certain period of time and within a reference basin, if possible, for several variables of interest.

- Validation within other periods for the same basin and several streams and internal variables of the basin without modifying the estimated or calibrated parameters.

- Transposition to other similar basins and for special periods, with respecting the previous parameters without new calibration.

The validation step can indeed limit the parameterization or the model structure in case of an unsatisfactory simulation of the goal.

In conclusion, the comparison of the validated hydrograph with the observed hydrograph for the validation period can assess if the fit is acceptable therefore the model prediction is valid.

2.7 HBV model

2.7.1 Generality

Hydrologiska Byrans Vattenbalansavdelning, (HBV) developed on 1976 by Bergström, proposed by the Swedish Hydrological Service (SMHI), which is a semi distributed conceptual model (Bergström, 2006), has had a wide application in hydrologic modelling and has been applied in more than 30 countries worldwide (Bergström, 1992).

HBV like other hydrological models represent a simplified mathematical descriptions of processes controlling the water cycle in a watershed (Payraudeau, 2002). This is a transformation that, by having precipitation record and possibly other climate variables such as potential evapotranspiration and temperature, can reproduce the response of a watershed in terms of discharge and actual evapotranspiration.

This semi-distributed model is able to simulate a catchment by dividing it into different sub-basin each one has separate vegetation and elevation zones (Seibert & Vis, 2012). It uses lumped applications to describe the water balance of catchments. The model can be applied in forecasting of hydrological phenomena and understanding the water balance.

One of the main limitations of modelling is the lack of sufficient *in-situ* data which largely affects the accuracy of model simulations. Bergström, (2006) insists of importance of a simple model with a small number of model parameters and at the same time performs well in areas where there is scarcity of data.

In different model versions, HBV has been applied in more than 40 countries all over the world. It has been applied to countries with such different climatic conditions, for example; Sweden, Zimbabwe, India, Colombia and Tunisia as well.

2.7.2 Structure

The general structure and equations of HBV can be summarized as shown in Figure (5). The reservoirs are connected to each other by means of exchange fluxes which define the amount of water between the different zones. The general water balance equation is shown in equation [1]. HBV has four routines which include the snow, soil moisture, response function and routing routines. HBV-light uses the Microsoft windows platform and was re-written by Marc Vis at the University of Zurich using Visual basic (Seibert & Vis, 2012).

$\Delta S/\Delta t = Input - output$ Where: ΔS = Change in storage

Δt = Change over time

$$P - E - Q = \frac{d}{dt}\left[SP + SM + TZ + UZ + LZ + lakes\right]$$

Where

P	is precipitation
E	is evapotranspiration
Q	is runoff
SP	is snow pack
SM	is soil moisture
TZ	is storage in soil top zone (introduced in HBV-light)
UZ	is upper groundwater zone
LZ	is lower groundwater zone
Lakes	is lake volume

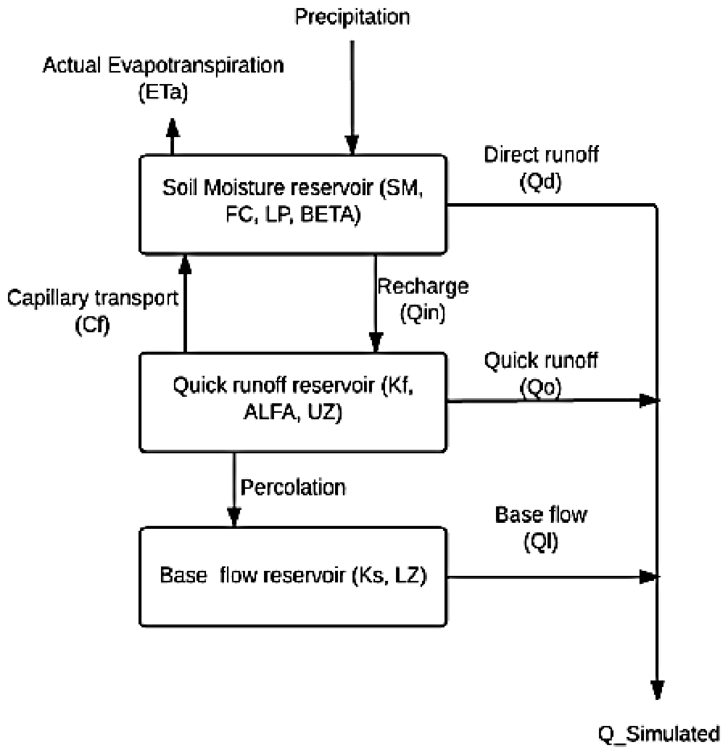

Figure 2. 7 HBV-Light structure

The HBV model is a simple multi-tank-type model for simulating runoff.

$Qd=Max\ (P+SM+FC,0)$

$Qin=(SMFC)^{\mathrm{BETA}}\times(P-Qd)$

$Cf=CFLUX\times[FC-SM/FC]$

$Qo=Kf\times UZ^{(1+ALFA)}$

$Q\mathrm{l}=Ks\times LZ$

The HBV-Light model is based on three boxes or routines explained below.

2.7.3 Precipitation and snow routine

Precipitation that falls in vegetated areas can be intercepted by vegetation or lost by evaporation, transpiration, process where water is released as vapour from the stomata of vegetation, is another way of water loss by returning to the atmosphere. Those two processes; evaporation from soil surface and transpiration from plant are called evapotranspiration. The remaining amount of precipitation after evapotranspiration continues as surface runoff or begins to infiltrate into the ground. Surface runoff occurs if there is an intense rainfall period, a powerful snow melt period or whenever the water rate exceeds the infiltration rate.

The snow melt rate and snow accumulation are calculated in the snow routine. Both the temperature and precipitation differences due to elevation, and differences for snow melt in forest and open land due to vegetation types are considered in this routine. It is based on a simple degree-day factor (a melting factor) and a threshold temperature (Bergström, S., 1992).

$$Snowmelt = CFMAX * (T - TT) \qquad \text{(mm/day)}$$

Where

$CFMAX$ is the degree-day factor (mm/day °C).

T is the actual temperature in the elevation zone.

TT is the threshold temperature (normally close to 0 °C).

TT determines if the precipitation falls as snow or rain. The snow melt starts at temperatures above the threshold temperature.

The use of the snow routine of HBV requires data for simulation and is only applicable to areas that experience snow. The study area for this research is located in a semi-arid zone where there is no that much snow component, therefore, this routine was negligible.

2.7.4 Soil moisture routine

Soil moisture routine is the main part of the runoff formation. This routine takes into account elevation and vegetation in the same manner as the snow routine. The soil moisture routine is based on two functions and three parameters (FC, LP and BETA) must be calibrated in this routine.

The actual evapotranspiration (Ea) increases as the soil becomes wetter (SM). The Ea is highest when the Ea/potential evapotranspiration (ETP = 1). This is called limit for potential evapotranspiration (LP) and Ea is almost constant when the soil moisture reaches this level. Ea remains constant until the maximum soil moisture storage is reached field capacity (FC) (Bergström, S., 1992).

The contribution to runoff from snow melt and rain will be large when the soil is wet (high soil moisture values) and small at dry conditions (low soil moisture values). All precipitation contributes to runoff when the field capacity (FC) is reached.

The soil moisture routine utilizes the potential evapotranspiration data and in this case the mean standard values are good enough. This routine uses interception and soil moisture storage which determines the wetness index of the basin. These datasets can be retrieved using the Penman formula.

2.7.6 Response routine

This routine transforms excess water from the soil moisture routine to runoff. This part of the model generates the runoff over time during a flow transport through storage in groundwater, aquifers and lakes.

This routine is divided into two reservoirs, one upper and one lower zone. The lower zone represents the drainage from the base flow with a slow recession. The upper zone, represents a drainage through more superficial channel with faster recession. As long as the upper reservoir contains water it will percolate down to the lower reservoir. Water will begin to flow out from the upper reservoir when the lower reservoir is filled (Bergström, S., 1992).

2.8 Application of GIS in hydrological modelling

Firstly, hydrology focused on the understanding of all the phenomena that link the rainfall occurring on a watershed and flow rates measured at its outlet, as well, to the development of models simulation of the behaviour of the watershed in order to establish the forecasts of the likely effects of extreme weather events.

The attempt to answer the question of how spatial analysis with the aid of geographical information systems (GIS) contributes to more flexible use, more efficient models for simulation, to the eventual design of new, more efficient models requires knowledge of hydrology approach methods, the implementation evidence of the components of information using spatial dimension and finally a reflection on the contribution of integration of GIS in the methodology of the hydrologist.

Geographic Information Systems (GIS) has become a very useful and indispensable tool in hydrology, especially in hydrologic modelling processes where nowadays is widespread along the world. GIS can be used in hydrological modelling, for example, to extract the spatial and temporal distribution of inputs and parameters controlling surface runoff. DEM as well used to extract several components (topography, basin and sub-basin, flow direction, flow accumulation, streams, etc.) describing the study area, as well as other maps such as, land use/cover, soil map, meteorological distribution. Those parameters are most of the time the inputs in the simulation of hydrologic processes (Vieux, 2001).

For the conceptual model, knowing the spatial distribution becomes more mandatory. A GIS then appears as a powerful tool to access the data for pre-process and extract the parameters required by the models.

A GIS is very useful in modelling for a visual identification of the analysis area, interface to access to the database established for the watershed. It becomes essential to the procedure of identification of hydrological objects and determination of their characteristics. Spatial analysis thus becomes one of the most sensitive links in the simulation approach.

It induces the choice of models and the grouping of operations cumulated effects basin items. Specifically, the following can be mentioned:

- The catchment subdivision objects: sub-basins, piping, reservoirs.

- Extracting information to characterize the objects determined in the previous stage: geographical and geometric characteristics of the objects (Location, shape, dimension)

-Physical characteristics to describe the hydrological behaviour (section of the pipeline roughness coefficient. type of land cover, etc.)

- Calculation of synthetic parameters required by the model, such as runoff coefficient from land use, calculating the limits of a sub-basin.

Land use understanding is of interest for hydrological modelling since it provides an indication of the roughness of the surface. It has a considerable influence on the runoff and surface water. Therefore, GIS and remote sensing are potentially rich sources of information in hydrology. It is relatively easy to distinguish the areas with different covers and occupations, as well as express the vegetation cover density using the NDVI (Normalized Difference Vegetation Index). The potential of remote sensing images is not only related to the automated production of such a numerical and spatial information about the roughness, but more about the frequency acquisition.

CHAPTER THREE

Study Area

3.1 Introduction

Mellegue River is the main tributary of Medjerda basin located on its right bank. This river has a wide catchment distributed between the two neighbouring countries Tunisia and Algeria. Its source comes from Algeria. The southern boundary of the basin follows the long mountain range of Tunisian Atlas separating the north and centre of the country, it reaches the Eastern-North part of Algeria extends along the mountains of Tebessa. Mellegue was a group of tributaries and has since long time become a convergence point with the main Medjerda river due to the phenomena of erosion.

The Mellegue river rises in Algeria and its watershed covers an area of 10,200 km^2. The average annual rainfall is 400 mm and the average annual contribution is 150 million m^3. This basin divided into several sub-basins. On this basin, hydrological station K13 was the focal point of this research. Mellegue K13 station controls an area of 9,000 km^2, only small sub-basin will have our interest within this paper.

3.2 Topography and location

In the modelling part, emphasis was put on one small sub-catchment with an area of around 1,100 km^2 and 163.1 km of perimeter located on the western-south of Mellegue basin in the limit with Algeria.

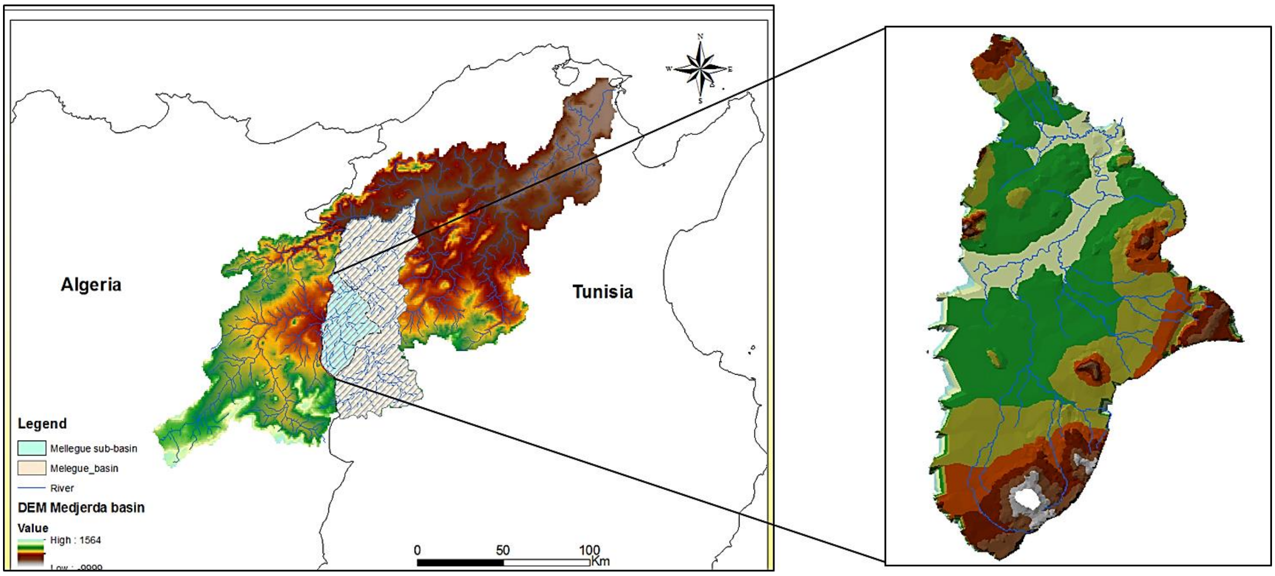

Figure 3. 1. Topography of Mellegue river basin and sub-basin

3.3 Physical characteristics of the Mellegue basin

The longitudinal profile of the river extends from 1,700 m upstream to 140m downstream within a total length of 317 km of main drain with an overall average slope of about 5 m/km. The topographic profile shows clear variations in slope along the river.

The morphological characteristics of Mellegue watershed at the K13 station are summarized in table (3.1). All indexes calculated (Gravelius compactness coefficient Kc, Length, width equivalent rectangle) shows that the catchment area of the Mellegue river at K13 station is with elongated shape where the landscape is dominated by high relief (Ds = 288).

The study of the natural environment of the catchment area of the Mellegue river allows to better know the behaviour of the water flow of the basin during rainy periods with different return periods and its contribution to the runoff erosion phenomena.

K_G Gravelius's shape index

$$K_G = \frac{P}{2\cdot\sqrt{\pi\cdot A}} \approx 0.28\frac{P}{\sqrt{A}}$$

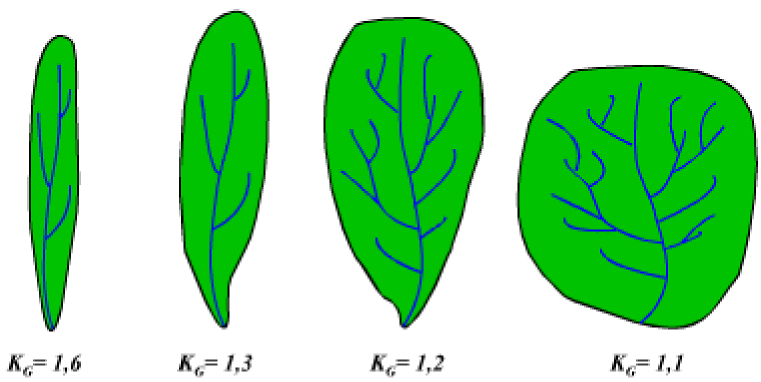

Figure 3. 2. K_G values for different watershed shapes (Musy, 2001)

3.3.1 Overall Slope index (Ig)

This index is calculated from the equivalent rectangle. It is equal to the sum of the square roots of the average slopes of each of the weighted elements by the given surface;

$$I_g = \frac{A_{5\%} - A_{95\%}}{L_{eq}}$$

Where;

Ig: overall slope index (m/km);

$A_{5\%}$; the altitude at 5% of the total area of the watershed (m);

$A_{95\%}$: the altitude at 95% of the total area of the watershed (m);

Leq: length of the equivalent rectangle (km)

3.3.2 Specific height

The specific height difference is given by the following formula:

$$\mathbf{D_s = I_g * \sqrt{S}}$$

D_s : Specific height (m) ;

I_g : Overall slope index (m/km) ;

S : Surface of the watershed (km²).

Table 3. 1. Physical characterises of Mellegue river basin (Colombani et al, 1981)

Designation	**Unit**	**K 13 station**
Area (S)	Km 2	9000
Perimeter of watershed (P)	Km	508
Gravelius index (Kc)	-	1.51
Length of the equivalent rectangle (L)	km	212
Width of the equivalent rectangle (L)	km	42
Minimum altitude (H min.)	m	327
Maximum altitude (H max.)	m	810
Average altitude (H mid.)	m	1712
Altitude at 5 % (H 5 %)	m	1130
Altitude at 95 % (H 95 %)	m	485
Height (D)	m	645
Overall Slope index (Ig)	-	3.038
Specific height (Ds)	m	288
Roche slope index (Ip)	-	0.074

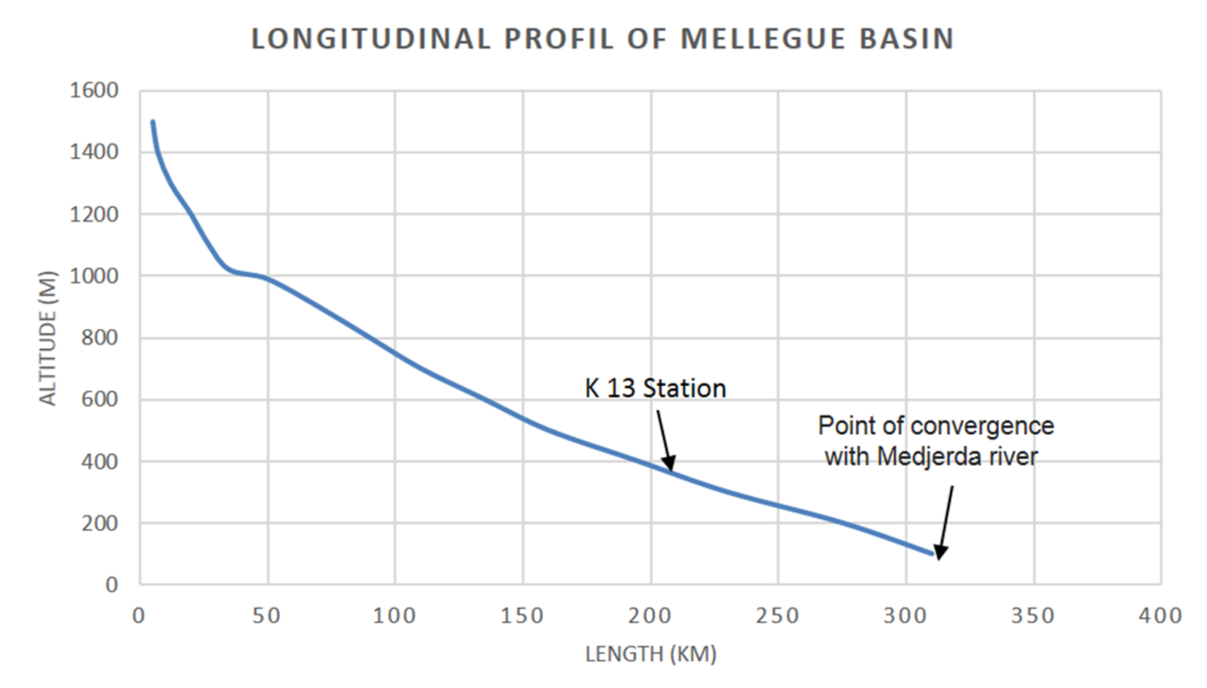

Figure 3. 3. Longitudinal profile of Mellegue basin (Colombani et al,. 1981., edited)

About 60 to 70 % of the catchment area can be assimilated to a line between 600 m and 1,000 m altitudes. The slope of the equivalent rectangle is regularly between these two elevations, and it is estimated to 4.8 m/km (4.8 %).

The watershed of Mellegue at K13 station covers about 84 % of the total area of the basin. The slope over 1,000 m is estimated at 4.3 m/km and at 5 m/km below 600 m (Monograph of Medjerda). The watershed of Mellegue can be subdivided into several watersheds each representing a few hundred km².

With the constraint of lack of data on the natural environment and hydrological stations of the Algerian side, it was not possible to maintain this area integrated into the overall study of the watershed of Mellegue basin.

3.4 Climate

Similar to many Mediterranean countries, Tunisia's climate is characterized by annual and inter-annual variability, with a yearly deficit rainfall, normal or exceptionally rainy. Precipitation starts mainly from October to April. The duration of the rainfall ranges from minutes to hours and exceptionally few days.

The upper stream zone of Medjerda basin is the region that corresponds to the humid Mediterranean area. This is a high area and sunny to rainy, with daily maximum between 50 and 90 mm, but that is limited in size.

According to (Colombani et al,. 1981) there are three kind of disturbances that affect Medjerda basin, those are the polar front, the Mediterranean front and the Saharan disruptions. Mediterranean front disruptions resulting from confrontation between cold air European masses and hot Saharan air. They are likely to cause heavy rains. Saharan disturbances are infrequent.

Based on the climatic map of Mellegue river basin (fig.3.4), three kinds of climatic class are observed, the humid and sub humid climate located on the North-Western part where the most highlands (<900 m) are situated. Semi-arid climate, with a cold winters and hot summers, is distributed all over the remaining part of the basin. This climate has an impact on the types of land cover within the basin.

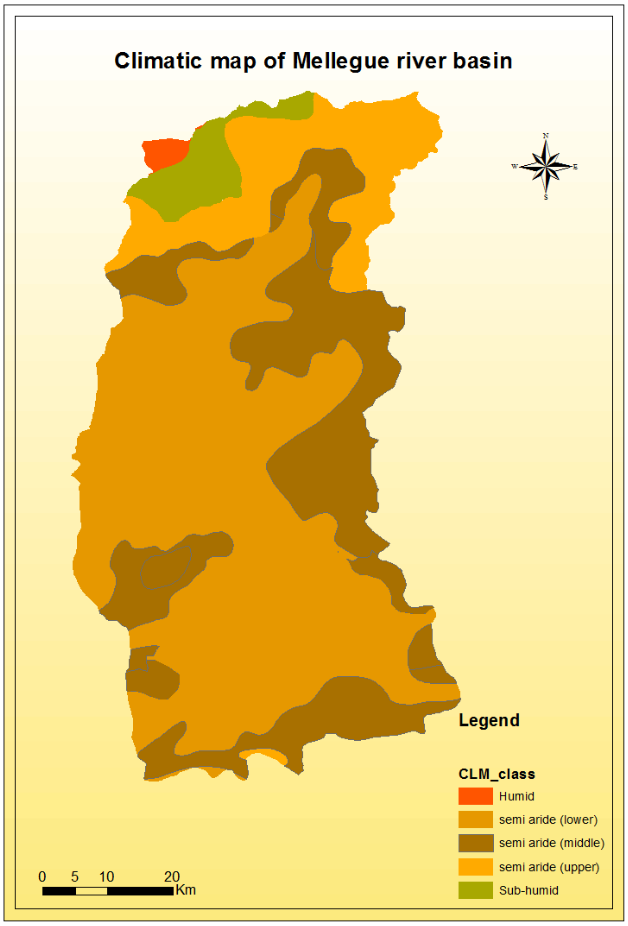

Figure 3. 4. Climate map of Mellegue river basin

3.5 Precipitation

Average annual rainfall over the Mellegue river basin are relatively important compared to the other regions of the country. In the centre and southwestern part of the basin, rainfall varies from 320 to 380 mm/year. The Thala station, located at 1,020 m altitude, receives more than 590 mm of annual rainfall. During dry seasons, precipitation may go to 200 mm. On the other hand, in the wettest areas in north and the city of Kef, rainfall can reach 520 mm/year.

3.5.1 Monthly precipitation

The measurement of annual precipitation for 32 years between 1974 to 2006 for the two stations (kef and Jendouba, Fig. 7 and 8) shows that dry season starts from June to August with a minimum rainfall during the month of July, the wettest season starts from November to March as shown in the figures below.

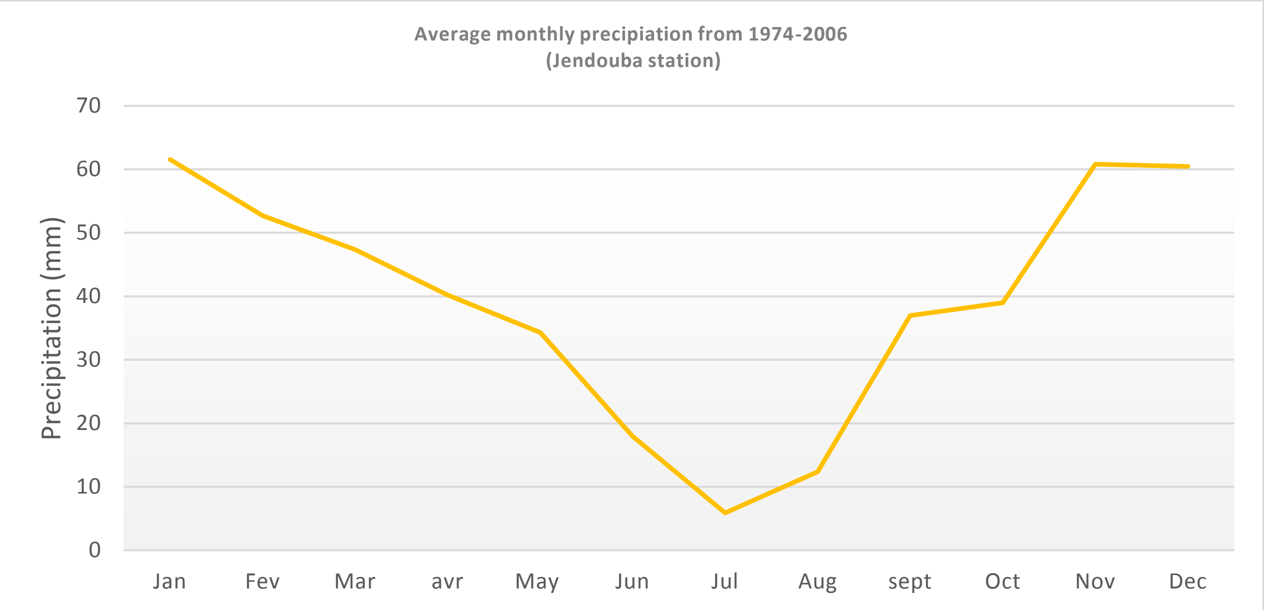

Figure 3. 5..Average monthly precipitation from 1974-2006 (Jendouba station)

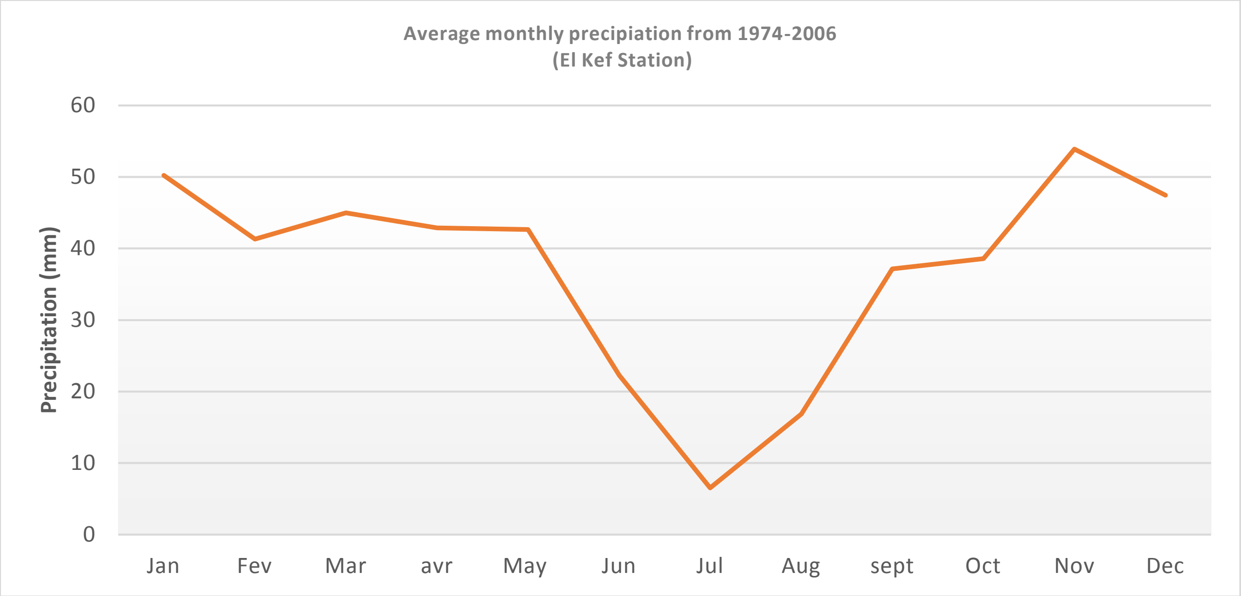

Figure 3. 6. Average monthly precipitation from 1974-2006 (Kef station)

3.5.2 Rainfall fraction

The rainfall fraction compares the meteorological stations and determine the precipitation regime (regular or irregular) (Gilli et al, 2004).

$$Fm = \left({}^{Pm}/_{Pa}\right) \times 100$$

Fm is Monthly rainfall fraction

Pm is Average monthly precipitation

Pa is Average yearly precipitation

- If the rainfall fraction is constant within the period (1974-2006), the rainfall fraction regime is regular.
- If the rainfall fraction is variable, the regime is irregular.

Average yearly precipitation (1974-2006):

Jendouba = 39.12 mm

El kef = 37.06 mm

Table 3. 2. Rainfall fraction of Jandouba and Kef station

Sation	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean (P) Jendouba	61.54	52.67	47.35	40.19	34.29	17.97	5.88	12.37	36.96	38.95	60.80	60.44
Mean (P) El kef	50.24	41.30	44.99	42.86	42.64	22.26	6.53	16.87	37.14	38.59	53.90	47.46
rainfall fraction (Jendouba)	1.57	1.34	1.21	1.02	0.87	0.45	0.15	0.31	0.94	0.99	1.55	1.54
rainfall fraction (El kef)	1.35	1.11	1.21	1.15	1.15	0.60	0.17	0.45	1.00	1.04	1.45	1.28

This table shows that the rainfall fraction varies during the period 1974-2006, it is therefore an irregular rainfall regime.

3.6 Temperature

Monthly fluctuations on average, maximum and minimum temperature are illustrated in Figure (3.7). The interpretation of the different curves identifies two temperature variation periods: first range that extends from May to September with a temperature starting from 18.3 ° C to 26.5 ° C with the average temperature reaching 34.8 °C during the month of August. The second period starts from October to April with the average temperature ranges from 7.8 ° C to 17.6 °C (CDCGE, 2006)

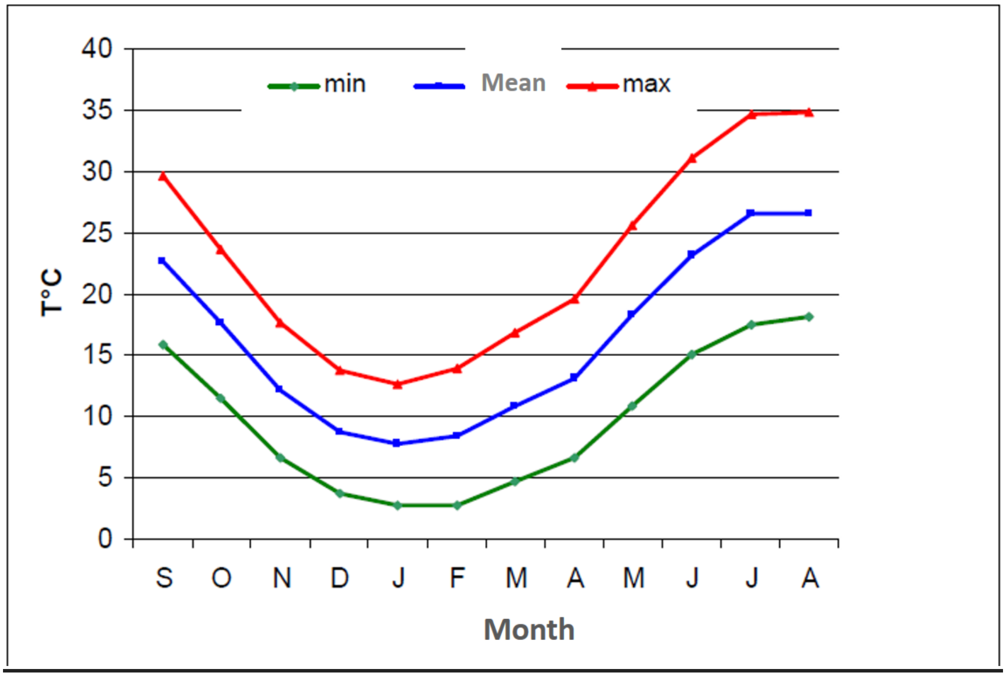

Figure 3. 7. Average monthly temperature of Kef station (CDCGE, 2006)

3.7 Wind

Winds with a North or Northwest direction are the most dominant. Those in the North West are frequent during the period of October to April. Both directions are the wettest. Winds with South-East and South -West direction frequently blow from the month of May to September over twenty days/year.

In general, the wind speed greater than 4 m/s are at 70% of West - North - West direction.

Meteorological data (T ° C, wind speed) recorded in the Kef station situated at an altitude of 518 m and coordinates 36°4 'latitude and 8°27' longitude (National Institute of Meteorology INM) are summarized in the table (CDCGE, 2006).

Table 3. 3. Temperature and wind speed of Kef station (1951-2005) (CDCGE, 2006)

Month	Period		S	O	N	D	J	F	M	A	M	J	J	A	Mean
T° C	(1951-2005)	Min.	15,8	11,5	6,6	3,8	2,8	2,8	4,7	6,6	10,9	15,1	17,5	18,1	9,7
		M	22,7	17,6	12,1	8,7	7,8	8,4	10,8	13,1	18,3	23,1	26.5	26,5	16,3
		Max.	29,7	23,7	17,6	13,7	12,7	14,0	16,9	19,6	25,6	31,1	34,7	34,8	22,8
Wind speed m/s	(1951-2005)	M	2,5	2,4	2,5	2,6	2,5	2,8	2,7	2,9	2,7	2,7	2,6	2,5	2,6
		Max.	10,9	9,8	9,4	9,1	8,7	9,8	9,8	10,9	10,7	11,4	10,7	10,6	10,2

3.8 Evapotranspiration

Evaporation is the process in which the water is transformed into steam.

The phenomena of evaporation and transpiration process is known as evapotranspiration (ET). It represents one of the fundamental components of the hydrological cycle. The precision in which it is estimated is essential for calculating the water balance, calculation of irrigation, water resources management and also for the dimension of hydraulic management. The concept of evapotranspiration was introduced as a climatic parameter, for the first time by Thornthwaite (1948).

3.8.1 Potential Evapotranspiration (ETP)

The potential evapotranspiration (PET) represents the amount of water could be evaporated and transpired if the water supply is sufficient to meet all the needs of the plant cover. It depends on the climatic conditions and in particular the temperature. (Allen et al. 1998)

In Tunisia, the potential evapotranspiration (PET) within in the north western part (Precipitation-PET) is positive, and it is negative everywhere, ranging from -800 mm/year to-1,200mm/year from North to South.

The monthly values of evaporation vary widely, they vary between 42.6 mm for the month of January of 1989 and 315.1 for the month of August of 2004. The average monthly evaporation varies 103.13 mm between the months of February and 211.23 mm in July.

Potential evapotranspiration is calculated by different formulas; in the region of Kef (Tunisia) PET has an average about 1,700 mm/year.

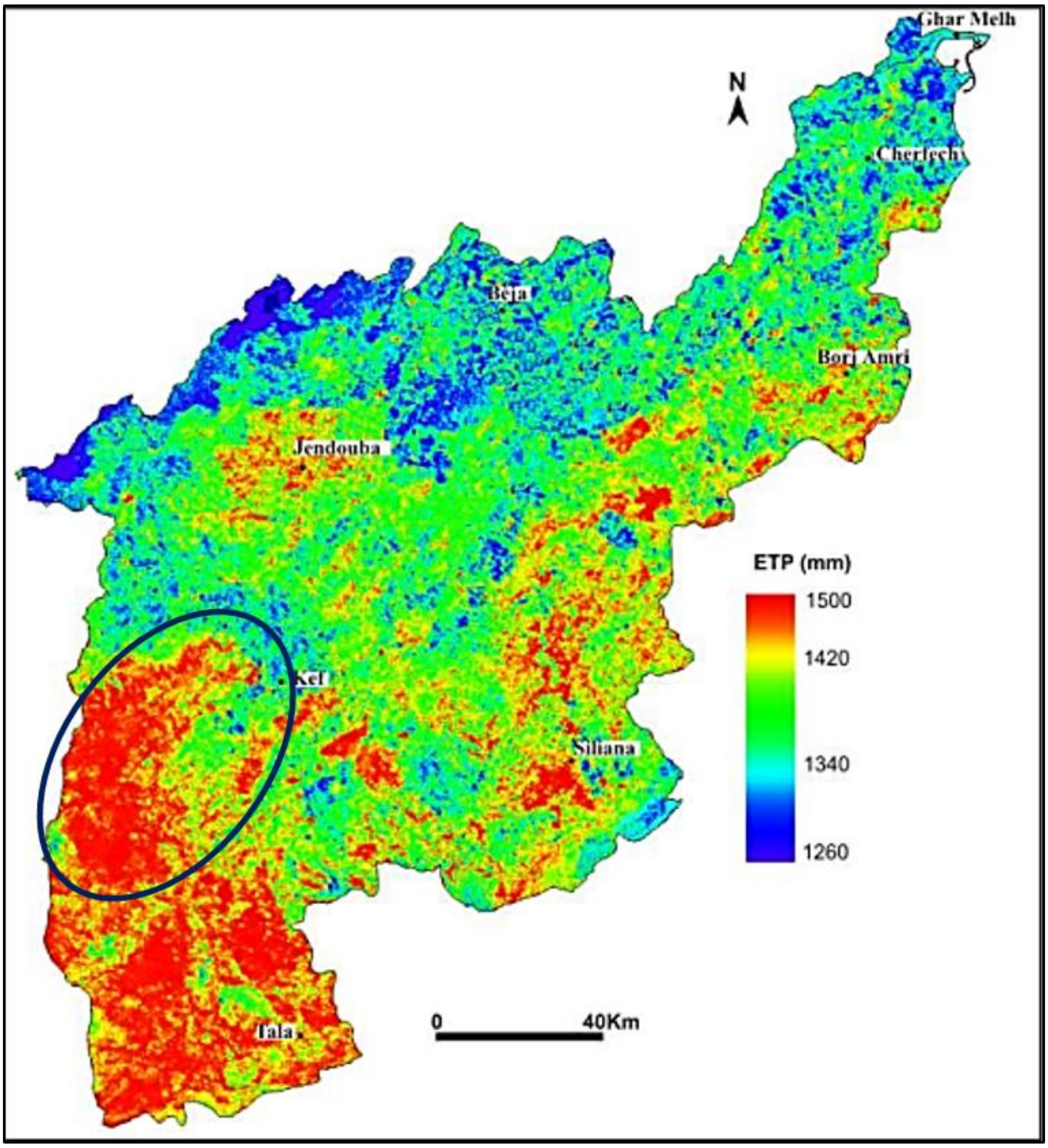

Figure 3. 8. Average Potential Evapotranspiration ETP (mm) for the Medjerda basin (Mjejra.M, 2015)

3.8.2 Actual evapotranspiration

It refers to the amount of water actually lost as water vapour through the canopy when the water supply is not ensured optimally. The actual evapotranspiration ETa of vegetation is considered the determining factor in agricultural production. It reflects all interactions: soil, plant type, climate. Thus, the limiting factor of ETa may be due to pedology (rapid depletion of readily usable water storage in the soil) or physiology (vegetation cover unable to ensure adequate water flow from the roots to the leaves) or climatic (insufficient rainfall for example). The ETR is most often used by hydrologists in the rainfall-runoff models, they can determine a water deficit (DE) by the difference between the ETP and Eta.

$$DE = ETP - ETa$$

It is used by agronomists to assess agricultural water deficit and climatologists to determine the evaporation deficit when land use is taken into consideration.

Eta can be measured using a Lysimeter (device that can measure the Eta released by plants by recording the amount of precipitation that an area receives and the amount lost through the soil).

3.9 Soil

Mellegue river drains a watershed consisting of mountains and highlands easily erodible. Land present in the watershed are formed mainly by the following rocks: marl, alluvium, limestone, evaporates.

The soil landscape of Mellegue watershed contains different types of soils including the following ones according to the classification of FAO:

- The erosion soil and vertic soil on the limestone rocks are associated with shreds of calcimorphic soil and they are most prevalent in the watershed.

- The erosion soil formed on calcareous hard rocks or Triassic complexes rocks associated with either rendzimorphes soil or red Mediterranean soil

- The humus calcimorphic soil related to natural vegetation on soft and hard rocks are visible in the upstream basin of Sarrath river.

- The calcimorphic crusted soils associated with soils isohumic mainly visible in the Algerian part. This type of soil is widespread in the basin of the Mellegue river.

- The gypsum crusted soils are very localized and are differentiated and distributed between Algeria and Tunisia, where they run along the Mellegue river.

-The alluvial soils are recent deposits of valleys they occupy the floodplain. These soils are mainly visible along the main tributaries of the Mellegue river.

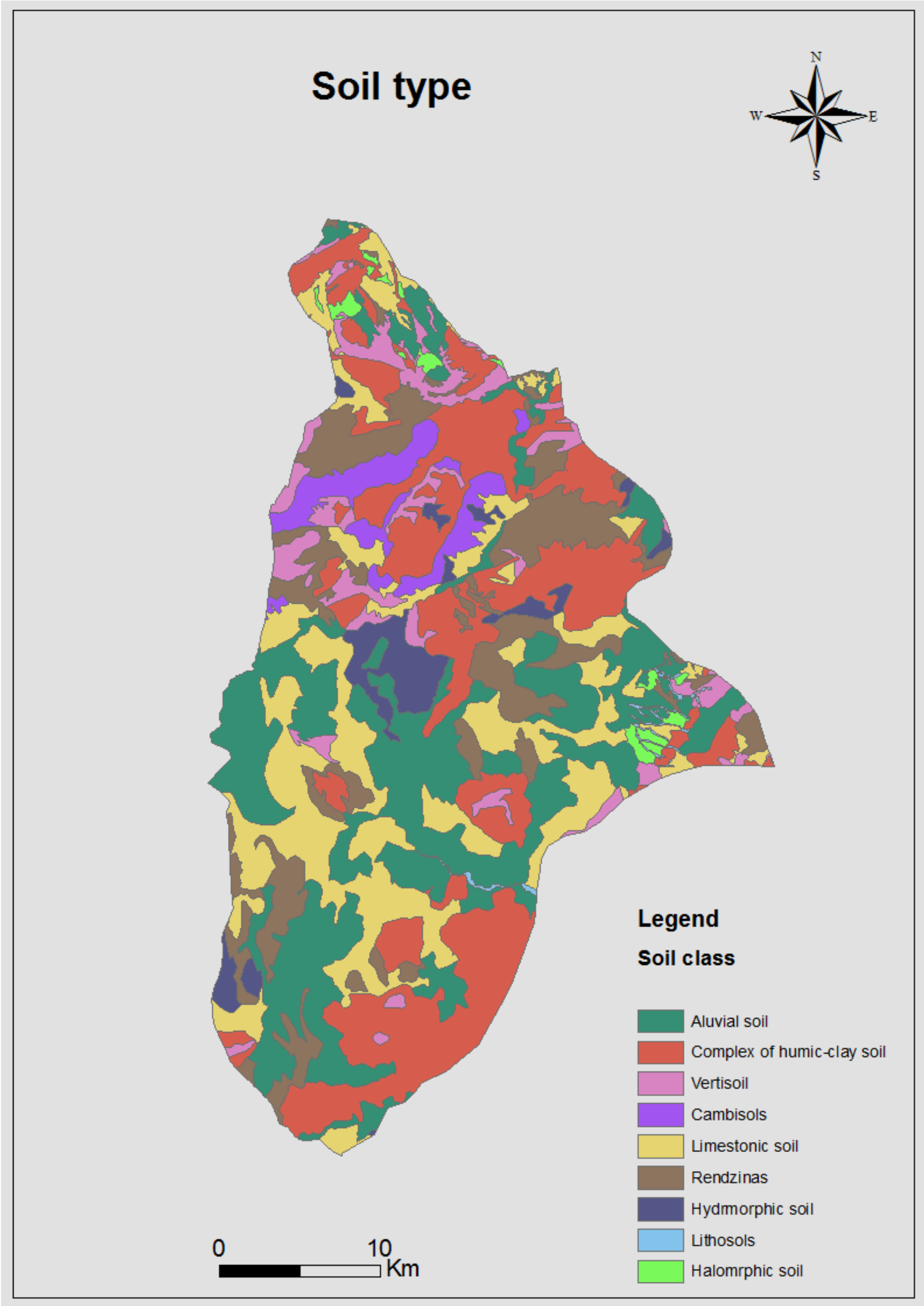

Figure 3. 9. Distribution of soil classes along the Medjerda river sub-basin.

CHAPTER FOUR

Methodology

4.1 Introduction

This chapter describes the input data and their sources used to model the effect of land use/ land cover changes in the Mellegue river sub-basin. The land use/cover maps used was described in terms of its methodologies (remote sensing, GIS) to analyse the most visible changes and scenario detected between the two maps using statistical analysis. After the description of data collected and their sources there was a need to apply the scenarios into hydrological modelling. The hydrological modelling is based on the calibration and validation steps in order to assess the outputs which is the variation in streamflow due to the change on land use/cover.

4.2 Data input and sources

The impact of land use changes on hydrology derived by the runoff process generation, this process is spatially distributed which depends on several factors like the land use/cover type and rainfall distribution along the catchment.

The conceptual rainfall runoff HBV-light model is data driven. This hydrological model requires four data input which has series of daily rainfall, daily discharge, daily temperature (optional), average monthly potential evapotranspiration and average monthly temperature. Arc-GIS 10.2 and other statistical tools were utilized first to analyse land use/cover map derived from Landsat image, to extract components from the DEM and finally to spatialize the rainfall variation with the watershed. Soil map was used to understand the types of soil and its criteria of resistance against runoff. Those data are collected from different sources as mention below.

In this study, data was accessed from different sources, starting from online data source to *in situ* data from the Ministry of agriculture and many other sources as shown in table below.

Table 4. 1. Data input and sources

Data requirements	Sources	Notes
Land use map 1988	http://earthexplorer.usgs.gov/	Landsat Legacy TM (1984-1997)
Land use map 2003	Regional Commissariat of Agricultural Development (CRDA)	Digital data
Hydrological data	Ministry of Agriculture, Water resources (MARH).	Rainfall, discharge, Temperature
Digital elevation model	https://asterweb.jpl.nasa.gov/gdem.asp	30 m resolution
Soil type map	Regional Commissariat of Agricultural Development (CRDA)	Digital data
Climate map	Regional Commissariat of Agricultural Development (CRDA)	Digital data

4.2.1 Digital elevation model

Digital Elevation Model (DEM) is a raster file (grid cell) used in ArcGIS to construct and delineate the watershed used for this study, gives the different elevation within the catchment and defines the location of streams network, those the data required for analysing the effect of land use changes for the HBV model. A spatial resolution of 30 m by 30m downloaded from ASTER Global Digital Elevation Model obtained from the NASA website. This DEM projected to Transverse Mercator (UTM) on spheroid of Zone 32 N. This projection was used for all the GIS files especially the land use map to fit for overlaying with this DEM in order to get the percentage of land use type within a given elevation.

4.2.2 Potential evapotranspiration (PET)

The calculation of PET can be done using several methods such as FAO-56 Penman-Monteith (Monteith, 1965), Turc (1962) and Thornthwaite (1948). In this study, calculation of ETP parameter was done using the formula G.W.Thornthwaite.

The American Agronomist G. W. Thornthwaite proposed in 1948 an expression to estimate the potential evapotranspiration (ETP) taking into account only the monthly temperature. The development of this expression gives the following formula:

$$ETP = 16\left(10.T/_I\right)^a$$

ETP = potential evapotranspiration in (mm)

T = monthly mean temperature (°C)

$$I = \sum i \quad and\ i = \left(t/_5\right)^{1.514}$$

According to Serra L. (1954):

$$a = \left(1.6 \cdot I/_{100}\right) + 0.5$$

Table (4.2) shows an example of calculated data using Thornthwaite equation.

Table 4. 2. Measured ETP of the year 1980

Months	**T mean (1980) kef**	**i=Heat Index**	**I=sum i**	**a**	**ETP (1980)**
Jan	7.3	1.773	64.874	1.538	19.18
Feb	8.7	2.313	64.874	1.538	25.13
Mar	10.5	3.075	64.874	1.538	33.55
Apr	11	3.299	64.874	1.538	36.04
May	15.2	5.384	64.874	1.538	59.27
June	12.9	4.199	64.874	1.538	46.05
Jul	24.5	11.091	64.874	1.538	123.50
Aug	26	12.135	64.874	1.538	135.32
Sep	22.7	9.881	64.874	1.538	109.83
Oct	16.1	5.873	64.874	1.538	64.75
Nov	12.8	4.150	64.874	1.538	45.50
Dec	7.1	1.700	64.874	1.538	18.38
		64.874			

1.2.3 Mean areal precipitation

In order to estimate the average cover of rainfall within a basin using the multi-station there are many methods that can do it such as the arithmetical method, Thiessen method and isoheytal method. Each method is more accurate than other depending on the characteristics of the basin itself. In this study we have chosen Thiessen method because there is a good distribution of meteorological station over the catchment.

To evaluate the total daily amount of rainfall in the basin, we have to measure the height of rain (mm). Rainfall data collected from the General Administration of Water Resources (DGRE) for 7 stations spread over, outside and very close to the limit of the basin. For this evaluation, we have selected one calculation method called method of Thiessen polygon.

Thiessen polygon is a statistical methods used to give different weight to each point of measurements. This method can evaluate the average rainfall on a basin according to the weighted average of recording data in several stations. The station weighting factor is the area of the polygon formed by the union of segments mediating between this resort and surrounding stations. This method takes into account the spatial distribution within the stations (ROCHE, 1963). The average rainfall inter-annual in the Mellegue sub-basin is given by:

$$P_{mean} = \frac{\sum_{i=1}^{N} P_i \cdot A_i}{\sum_{i=1}^{N} A_i}$$

In this formula, Pi and Ai represent respectively the inter-annual average rainfall of station (i) and the surface of the polygon representative of this station. The calculation was performed using the measured data.

Table 4. 3. Rainfall stations used to calculate Thiessen polygon

Code	NAME STATION	COORD_X	COORD_Y	Altitude
1.49E+09	El Felta	437427.1	3970693.5	525
1.49E+09	Kalâat Snan Délégation	440398.6	3958289.8	623
1.49E+09	Tajerouine Ferme d'état	455778.82	3970950.8	511
1.49E+09	Tajerouine Ain Zouagha	460846.74	3980258.4	750
1.49E+09	Sidi Mtir	454440.1	3989806.7	507
1.49E+09	Mellegue K13	454308.87	3996384.1	324
1.49E+09	Djérissa Délégation	466819.09	3966310.4	633

Figure 4. 1. Discharge station Mellegue k13 located on Mellegue river

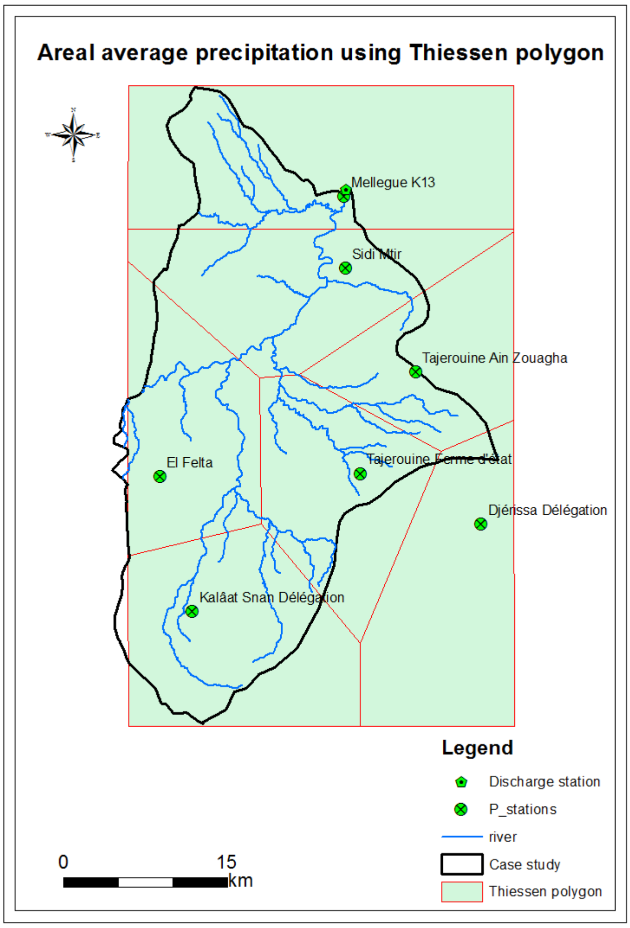

Figure 4. 2. Thiessen polygon of Mellegue river sub-basin

Thiessen method gives us an idea about the daily mean rainfall with the sub-catchment of Mellegue basin used as one of the input in the HBV model inside the file ptq.txt for the calibration and validation period.

4.2.4 Temperature

The HBV model needs a daily temperature data and long term mean monthly temperature measurement but this file is optional. Temperature data is needed in catchments with snow and is calculated as a weighted mean of stations in and around the catchment. When different elevation zones are used temperature will be corrected for elevation above sea level with usually -0.6 °C per 100 m (parameter TCALT of HBV).

4.2.5 Land use/ land cover maps

The land use/land cover map gives the spatial variation and types of different land use/land cover classes in the study area. Land use/cover data were treated and classified to quantify the coverage of different land use classes and the changes that happened between the two periods 1988 and 2003. Each of these land use/ land cover maps are processed with different methods.

4.2.5.1 Land use/ land cover map 1988

This land use/cover map obtained from Landsat TM (Thematic Mapper) (1984-1977) was classified into six class using GIS tool. First of all, the land use/cover map of 27 January 1988 downloaded in Geo TIFF format with the WRS-2 path/row (192/35) from the USGS website with its 8 bands including the Panchromatic one added to the Arc-GIS 10.2 to start the image processing in order to identify the land use/cover change in the Mellegue river basin comparing to the recent map of 2003.

Table 4. 4. Landsat TM (1984-1997) characteristics

Bands	**Description**	**Spatial resolution (m)**	**Spectral resolution (µm)**	**Temporal resolution (days)**
1	Blue	30	0.45-0.515	16
2	Green	30	0.525-0.605	16
3	Red	30	0.63-0.69	16
4	Near Infrared	30	0.75-0.90	16
5	Short-wave Infrared	30	1.55-1.75	16
6	Thermal Infrared	120	10.40-12.5	16

7	Short-wave Infrared	30	2.09-2.35	16
8	Panchromatic	15	0.52-0.90	16

A supervised classification method within the arc toolbox of GIS software was used to analyse the land use/cover changes. In general, to perform a supervised classification, define training sample in a polygon vector layer to classify the grid cells as land use/ land cover type according to a reference zone, in this case, Google Earth image was used as reference tool. Then, this shapefile was converted to a signature file (according to ArcGIS help "A signature is a subset of cells that are representative of a class or cluster. The statistics of signatures are stored in a signature file that will be used to classify all cells in the raster"). Supervised classification uses the maximum likelihood classifier (MLC) tool to generate and classified land use/cover map based on the signature file produced previously and the raster bands and to have meaningful information classes.

4.2.5.2 Land use/ land cover map 2003

Land use/cover data in this case was obtained from Regional Commissariat of Agricultural Development (CRDA) of Kef region where is located the study area. This map was classified using field data collected by a consultancy office and aerial photographic images for the whole region.

According to this land use/land cover map, within the Mellegue river basin there are different types of land use/cover ranging from cultivated area, forest, irrigated land, rangeland, bare land to urban infrastructure.

According to the results of the First National Forest Inventory in Tunisia (DGF, 1995), it is realized that forest species covering over 75% of the land are poorly represented in the regions of Kef and Kasserine, while the species with low covering (10-25%) occupy large areas. Thus, the soil is highly exposed to the effects of runoff and erosion.

4.3 Modelling the impact of land use/land cover changes

In order to model the impact of changes in land use/ land cover within the Mellegue river basin, a calibration and validation step should be performed. The calibration and validation of the model was preceded by the model setup, efficiency criteria used to look at the model goodness and performance and finally parameter sensitivity analysis.

4.4 Accuracy Assessment

The accuracy assessment is very important when doing image classification process, this was done in order to estimate the accuracy of the Landsat image TM (1988) of the land use by comparing the classified map with a reference map (Caetano *et al*, 2005), in this study, Google Earth map 2016 was used as a reference map. Error matrix is the most useful classification accuracy; it is based on the collection of referenced data for each class type and to compare them with the classified image. Overall accuracy is accuracy of the whole classification which was computed by dividing the total of correctly classified pixels (obtained by summing the diagonal of error matrix) with the total number of pixels in the error matrix. (Foody, 2002)

4.5 Model set up

Data input for the HBV-Light model was described previously, it contains several parameters most of them are mentioned according to Seibert. J (2000):

- ptq.txt: file contains time series of daily precipitation [mm/day], temperature [ºC] and discharge [mm/day].
- evap.txt: file of the mean potential-evapotranspiration, it contains 12 values (long-term monthly mean values)
- t_mean.txt: file of The mean temperature that contains long-term mean values for the temperature [°C].

In this research the period used for HBV-light model calibration ranged from 1980 to 1986 with all data input. The basin outlet was defined at the Mellegue K13 discharge gauge station.

To start the model there was a need to identify the first period as ‘warming-up’-period which could be the first one year from data input, in this study warming up period starts from Jan 1980 to Dec 1980, according to Seibert. J, (2005) “The ‘warming-up’-period is needed to get appropriate initial values of the different state variables for the start of the simulation period, the simulations during the ‘warming-up’-period are neither stored nor used for any further analysis”.

Within the catchment settings, one catchment was used and divided into four elevation zones (ranging from 400m, 600m, 800m to 1000 m) each zone represents the mean elevation and three vegetation zones. Precipitation calculations are made separately for each elevation/vegetation zone within the catchment.

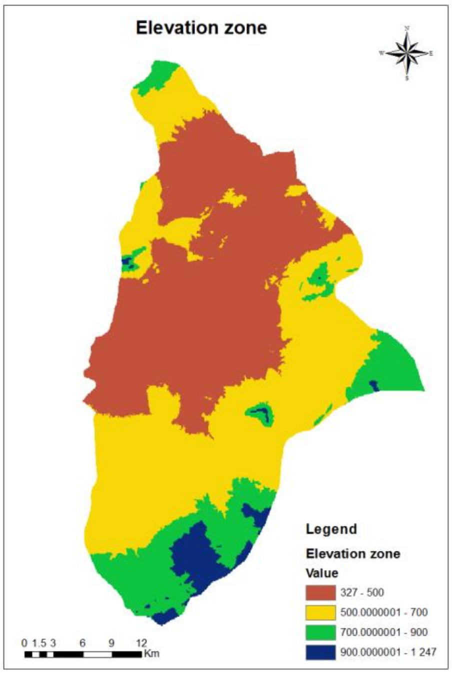

Figure 4.3. Elevation zone

4.5.1 Model Efficiency

Hydrological modelling has the ability to quantitatively estimate and forecast the watershed behaviour. Model performance assessment involves using a few algorithms to establish the differences in observed and simulated values. There are a number of error checking techniques which can be used to evaluated model performance. One example of model performance assessment tools is the use of objective functions. An objective function is a mathematical expression which allows a contrast analysis of observed and simulated state variables. Some of the algorithms used for objective function include the Nash-Sutcliffe efficiency analysis, Root-mean Square error and Relative Volume Error.

In HBV-Light, the model performance assessment is summarized by goodness of fit values. The outputs include the model efficiency, efficiency for log (R), flow weighted efficiency and mean difference between the simulated and observed values which are calculated at the outlet of the catchment. A summary of these assessments shows the model performed well since the obtained values were within the acceptable ranges.

During the calibration and validation step it is necessary to look at the its efficiency. To do this, statistical method was used to evaluate the model output with the observed. In this study, the Nash-Sutcliffe efficiency criteria was used to well evaluate the model performance.

4.5.2 Nash-Sutcliffe efficiency R eff

The *E* criterion for runoff presented by Nash and Sutcliffe (1970) is one of the very useful criteria to express the efficiency of the hydrological modelling on predicting the observed data. Its value ranges from -∞ to 1 (perfect result when R^2= 0). A value between zero and one means that the simulated runoff is performing well with those parameters in the model. A value over one means that the model under predict the simulated runoff response, in other hand, negative values indicate that the model is not at all well performing and predicting the observed data.

Nash-Sutcliffe efficiency (NSE)

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$$

Where;

Q_o is the mean of observed discharges

Q_m is modeled discharge

Q_o^t is observed discharge at time t

4.6 Model sensitivity

The sensitivity analysis for HBV-Light was done to calibration parameters in order to determine which ones influence the model performance more than the other. These were done for soil moisture routine and for the response and routing routines.

The most sensitive parameters in HBV model are FC, LP, Beta, Perc, UZL, K0, K1, K2 and MAXBAS values, an analysis was focused on them. The analysis was done by reducing and increasing the final calibration values by 10% The analysis used. The sensitivity analysis show that there are calibration parameters which are more sensitive to the performance of the model more than others. K0 (Recession coefficient for the upper storage) is the most sensitive of all the calibration parameters. It is a coefficient of storage and a slight change of this value shows a great variation in the model performance. LP (threshold for reduction of evaporation) and BETA (shape coefficient) are also sensitive in that order. FC (maximum of SSOIL (storage in the soil)) is the fourth in sensitivity. Other parameters such as UZL (threshold for the K0), K1 (recession coefficient for upper storage) and K2 (recession coefficient for lower storage) show very low sensitivity to the model performance.

4.7 Calibration

Calibration is the process where we look at parameters that closely simulate the behaviour of the basin (Madsen et al, 2002). It consists of adjusting numerical values assigned to the model parameters to reproduce the best observed response. This process can be used manually by trial and error method, or automatically by an optimization process in looking at the optimum value of a given criterion to enhance consistency between the observed and simulated discharge response of the basin for a certain period of time (Madsen et al, 2000).

In this research, HBV model calibration was done with a daily time step for observed data of precipitation, temperature and discharge for the period between January 1980 until December 1986 for only one catchment (conceptual model). This process was carried out to estimate the change in land use/ land cover by establishing the percentages of the different classes of land use falling within different elevations. To get the estimated change in land use/cover there is a need to make a calibration for each land use/land cover because some parameters going to be modify from one land use to another for different period. Land use of 1988 was set first with its own parameters for calibration and validation then the land use map of 2003 was calibrated also and validated.

The calibration process was repeated iteratively until the best fit between observed and simulated streamflow was achieved. An automatic calibration based on the genetic algorithm GAP optimisation offered by HBV-light model was used to get the best fit.

4.7.1 Automatic calibration using GAP optimization

Automatic calibration can be done using the GAP simulation technique. GAP optimization was based on the Darwin theory by involving automatic calibration using parameter sets within a given range and generating new parameter set from different selected population, a parameter sets with best fit will have a higher probability to be selected as best simulation. GAP calibration is described in more detail by Seibert (2000). This is found in the tools tab of HBV-Light.

Most of the parameters of GAP simulation ranges for reproduction settings and vegetation zone was used according to Seibert (2000) who evaluate the lower and upper ranges. The parameters of the snow and soil routines can be identified by increasing it or decreasing with vegetation zone, have the same value for all vegetation zones or select a random value for each vegetation zone. The GAP calibration method used in this research was started by a 100000 number of model runs, 1200 number of local optimization (Powel) with four population and 20 calibrations to give the best fit and goodness.

4.8 Validation

Once the hydrological model implemented on a given watershed, then the question of what is the model's ability to simulate the present or the future is answered by the validation step. Validation step based on setting the same simulation's parameters of calibration in order to look at the new hydrologic response of that simulation during future period mostly used for future forecasting.

In this study the parameters of HBV model generated from calibration set up were used for validation during different period which runs from 1995 to 1999 by keeping all data input used for the calibration, the simulated hydrograph produced was compared to the observed. The model efficiency was assessed using the same criteria of performance (NSE).

CHAPTER FIVE

Results and Discussion

5.0 Introduction

In this Chapter the results of this study are presented and discussed. In the first section, the result from classified land use map of 1988 and processed map of 2003 was discussed to extract the land use/cover changes scenarios. In the second section, calibration and validation results was assessed by comparing the four simulated hydrographs to see how the streamflow varied along the time.

5.1 Land use/cover map of 1988

The supervised classification was done as explained previously for the land use/ land cover map of 1988 (Landsat TM). This method was used to generate a land use/ land cover from the Landsat TM image for January 1988. Six land use/cover types were defined by supervised classification ranging from cultivation, forest, irrigated land, rangeland, bare land to urban areas as shown below (fig. 16).

Cultivation fields and Forest are the largest cover along the basin. The western part has covered by some irrigated land.

Table 5. 1. Land use/ cover 1988 areas distribution

Land use/cover	Area (km^2)	% Area
Forest	259589284	23.50
Cultivation	746872763	67.60
Range	46156551	4.18
Bare land	34561823	3.13
Irrigated land	16016166	1.45
Urban area	1617138	0.15

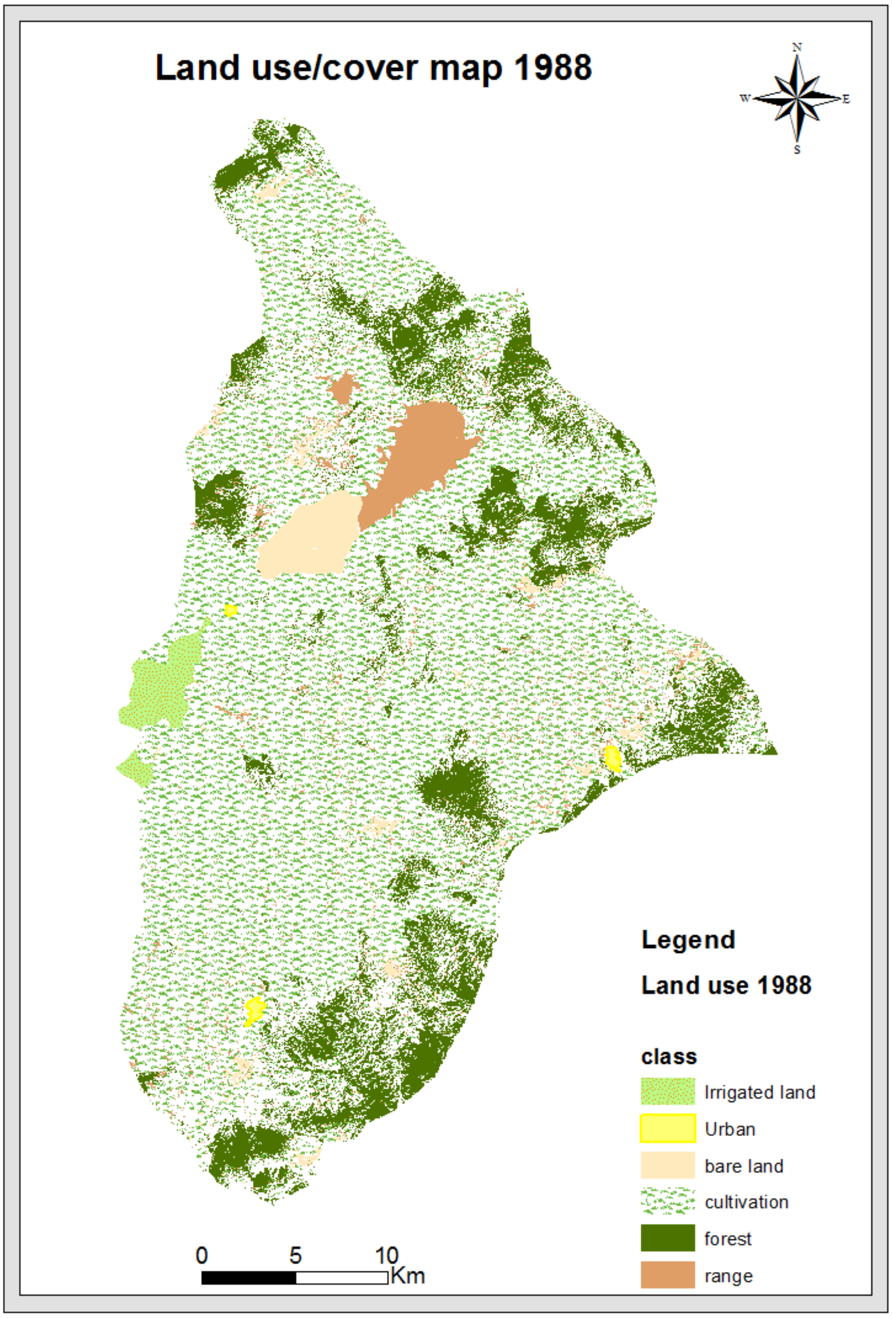

Figure 5. 1 Land use/ land cover map 1988 of Mellegue river basin

5.2 Land use/cover map of 2003

The land use map of 2003 taken from CRDA, was processed in Arc-GIS, the result in figure (17) shows that cultivated areas are mainly based on cereal and olive plantation, it covers the major area within the whole watershed. Cereals and olives are the main products of the region and contribute about 31 % of regional production. Those products depend on the precipitation falls mostly in winter and autumn, cereal cultivation harvested in the hot summer season.

Irrigated area consists of vegetable plantations using water from underground. The use of advanced techniques in agriculture and the encouragement of the government by introducing a lot projects in order to enhance the productivity and provide food security for the population located in this basin.

Rangeland mainly located on the hills, on the mountains and rocky soils; they constitute a transition zone between forest and bare land, the alfa steppes, are scattered and less representative in the basin. This coverage plant protects the soil against erosion by affecting the infiltration rate. Rangeland located in Mellegue river basin used mostly for grazing livestock and/or as wildlife reserves.

The land covered are: forested mountains of Aleppo pine or dense scrub and cork oak forests (19%), cultivation characterised mainly by land occupied by cereal crops and olives plants (68%), irrigated land (5%), rangeland (5%), bare land (2%) and some urban area (0.3%).

Table 5. 2. Land use/cover 2003 areas distribution

Land use/cover	Area (km^2)	% Area
Cultivation	747.92	67.93
Forest	204.09	18.54
Irrigated land	59.21	5.38
Range	64.55	5.86
Bare land	21.97	2.00
Urban area	3.33	0.30

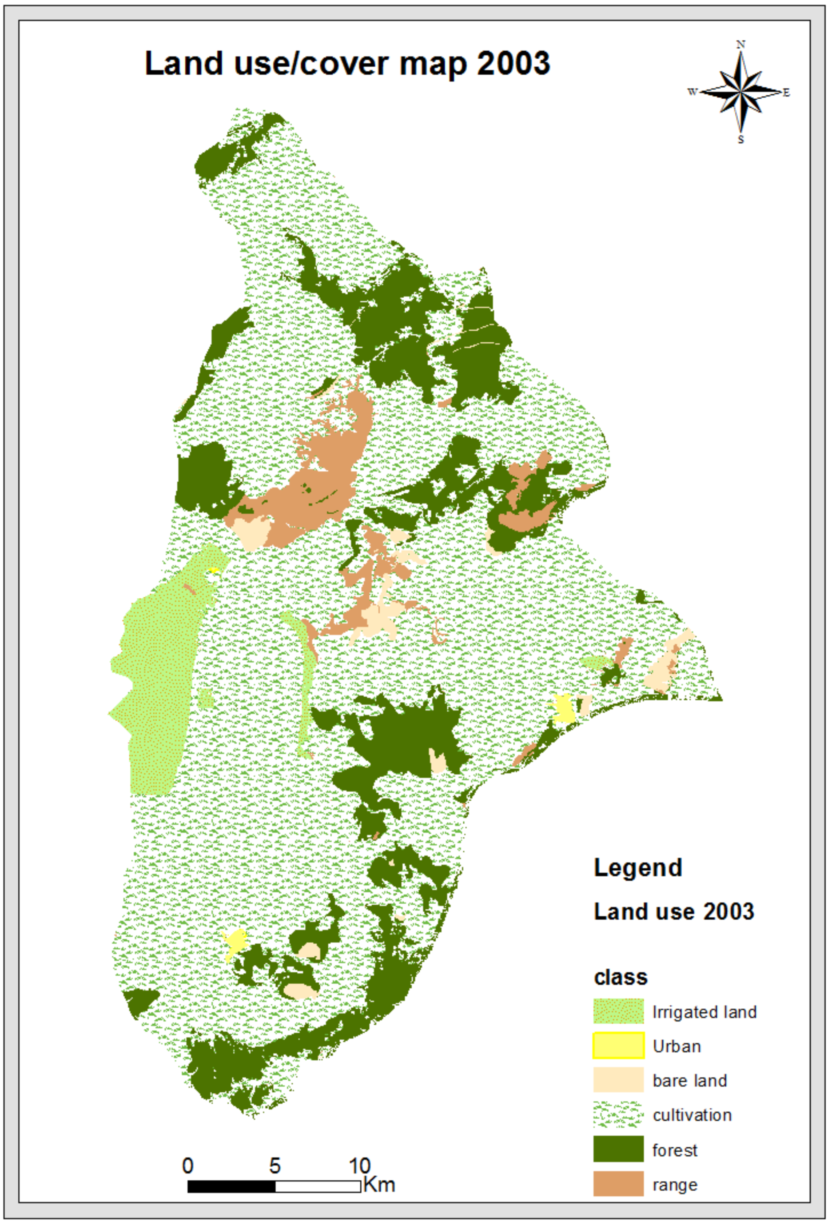

Figure 5. 2. Land use/ land cover map 2003 of Mellegue river basin

5.3 Land use/ land cover analysis and scenarios

The two land use/land cover maps of different periods (1988-2003) show that cultivation is the major land use/cover type in both. Concerning the second major cover which is forest land, the land use/cover map for the period 2003 comparing to the map of 1988 it indicates a clear decrease of forest cover. This deforestation caused by anthropic activities which were not regulated by the government, as well, the expansion of ranges that replace forested area. Forest cover has decreased by 5.16 %, this area was converted mostly into rangeland and some cultivation.

A second major variability was detected from those land use/cover maps is the agricultural expansion from 1988 to 2003, the cultivated zone was converted into irrigated land with an increase by 4 % due to the use of advanced technologies and the encouragement of the government towards the irrigation sector, many projects was done there since 1995 to enhance agriculture production.

Therefore, the major scenario or driver for land use change were identified form both land use/ land cover maps, one was deforestation and agriculture expansion (irrigated land)
The two histogram gives more details about the drivers of changing in land use/cover for the two periods (1988-2003) in Mellegue river basin.

Based on the previous scenario, HBV model will give the hydrologic response which seems increasing of streamflow due to this converting in land use.

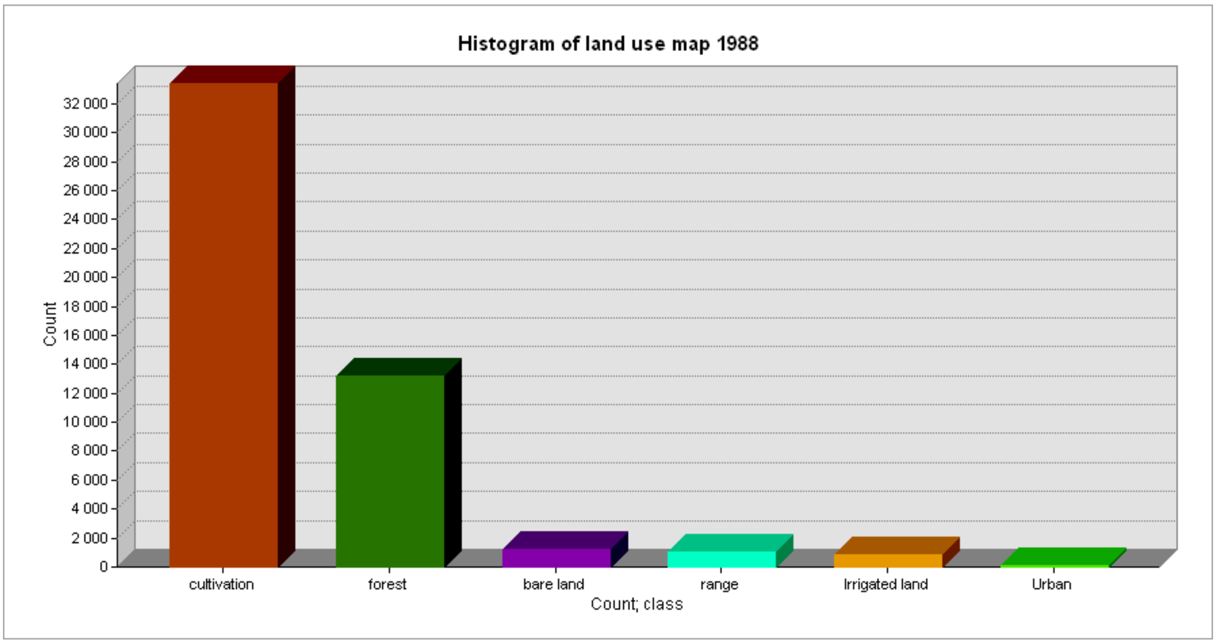

Figure 5. 3. Histogram of land use 1988

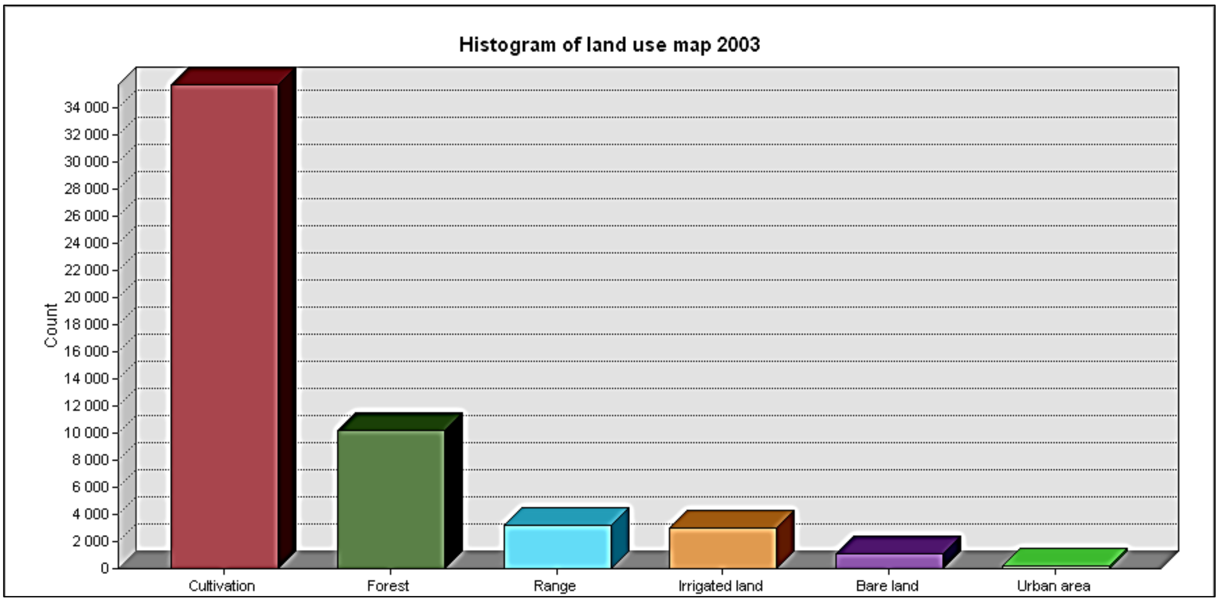

Figure 5. 4. Histogram of land use map 2003

5.4 Accuracy assessment

The statistical calculation of the accuracy of the classified land use image (1988) was done by Excel, the results are shown in the table (10).

Table 5. 3.. Error matrix of the classified map derived from Landsat Thematic Mapper data of the Mellegue river basin.

	Referenced data						
Classified image	Cultivation	Forest	Irrigated land	Rangeland	Bare land	Urban	Total
Cultivation	**58**	4	3	5	1	0	71
forest	2	**52**	1	2	4	0	61
Irrigated land	0	0	**61**	0	0	0	61
Rangeland	3	1	2	**44**	2	0	52
Bare land	0	0	0	3	**32**	0	35
Urban area	0	0	0	0	0	**38**	38
Total	63	57	67	54	39	38	**285**

Overall accuracy calculated by dividing the sum of the diagonal correctly classified pixels which equal to 285 over the total number of reference which is 318. Therefore, overall accuracy of the Landsat TM 1988 equal to 89.62%, this seems good accuracy.

5.5 Calibration and validation of HBV model

Calibration and validation was done in HBV-model for different periods, each land use was processed by a calibration and validation because of the parameter changes in the vegetation zone for each one. The results of simulation discussed in this section.

5.5.1 Calibration

Calibration was done for land use 1988 and land use 2003. The results of calibration using daily input values of streamflow are presented in the figure (5.5 and 5.6).

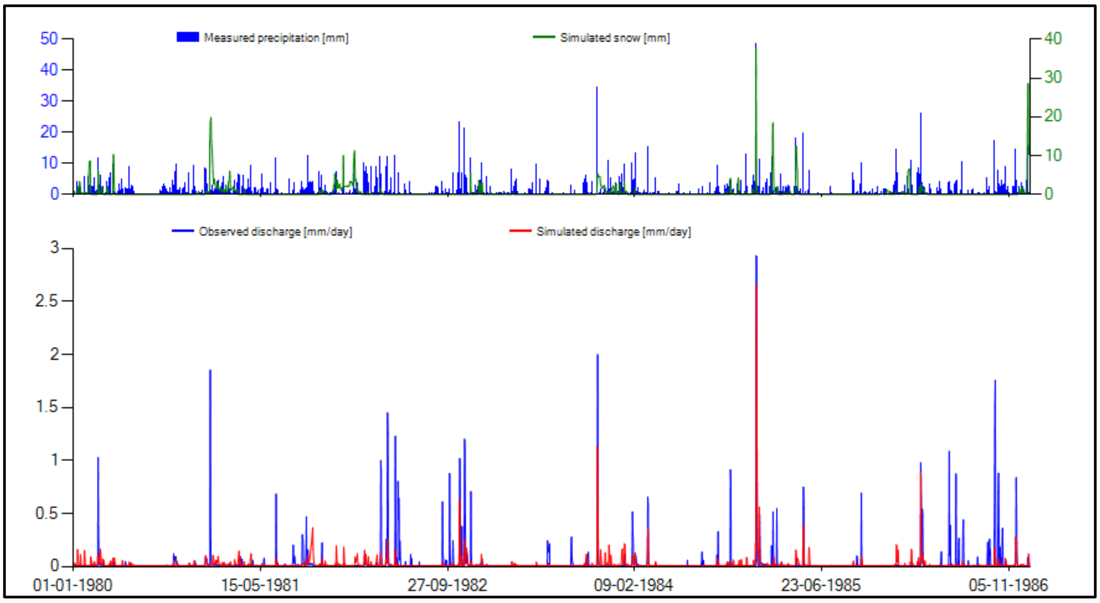

Figure 5. 5. Calibration of Land use 1988

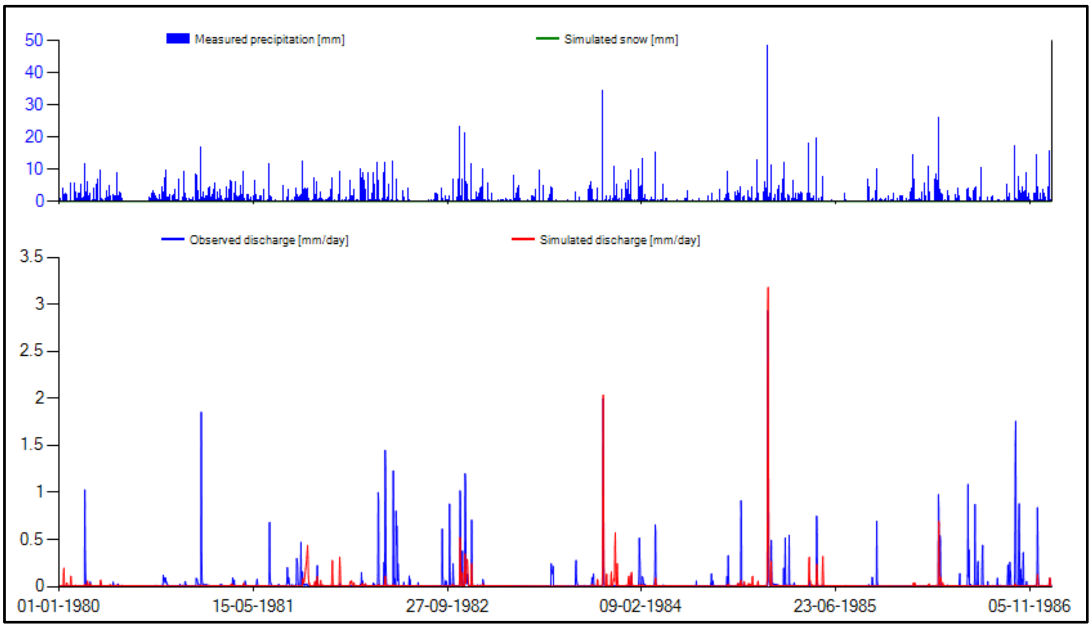

Figure 5. 6. Calibration of Land use 2003

Within the first calibration and validation there was a very low efficiency which could be due to the occurrence of some observed high peak flow that it not expressed by the precipitation graph above which at the same time cannot be appear in the simulations. Therefore, there was a need to treat and correct the observed data for daily discharge by making a relation between the observed precipitation and the observed discharge. The results are shown in the figures above.

By analysing the automatic calibration GAP optimization results, it gives somehow an acceptable model efficiency value of 0.33 for land use 1988 and 0.38 for land use 2003. By comparing both simulation, an increase of simulated discharge in the land use 2003 comparing to the land use 1988 due to the impact of deforestation which lead to more runoff by decreasing the infiltration, as agricultural expansion could be as well one of the factors that increase simulated discharge. In the fourth and fifth year there is a significant change from 1988 to 2003 of the highest peak flow. The others peak flow are underestimated. The underestimation of high flow could be the reason of data quality within the Mellegue K 13 discharge station or may be the ability of HBV model to characterize the intensive streamflow discharge due to the amount of precipitation. The overestimated low flow could be explained by the water drainage from the agricultural area which has expanded from 1988 to 2003.

A summary table (5.4) indicate the important outcomes from the HBV-light calibration, it shows an increase in runoff by 2 mm/year from 1988 to 2003.

Table 5. 4. Summary of the calibration results of Land use 1988

Calibration	Land use 1988	Land use 2003
Water Balance [mm/year]:		
Sum Qsim	7	9
Sum Qobs	12	12
Sum Precipitation	331	331
Sum AET	465	470
Sum PET	4110	7638
Contribution of QSUZ	0.183	0.182
Contribution of QSLZ	0.290	0.274
Goodness of fit:		
Coefficient of determination	0.3607	0.3886
Model efficiency	0.3326	0.3822
Efficiency for log(Q)	0.3211	0.3509
Flow weighted efficiency	0.6149	0.6036
Mean difference	5	4

5..5.2 Validation

The model efficiency during the validation step was slightly decreased comparing to the result of calibration for both periods, a validation efficiency of land use 1988 and land use 2003 was 0.1 and 0.1 respectively. The validation was done the period between 1995 and 1999, figure (23) shows a hydrograph with observed versus simulated discharge for Mellegue river sub-basin. A similar pattern was resulted from the validation step as from the calibration (underestimation of high flow and overestimation of low flow). An increase of direct runoff is clearly visible in the land use 2003 comparing the runoff in land 1988.

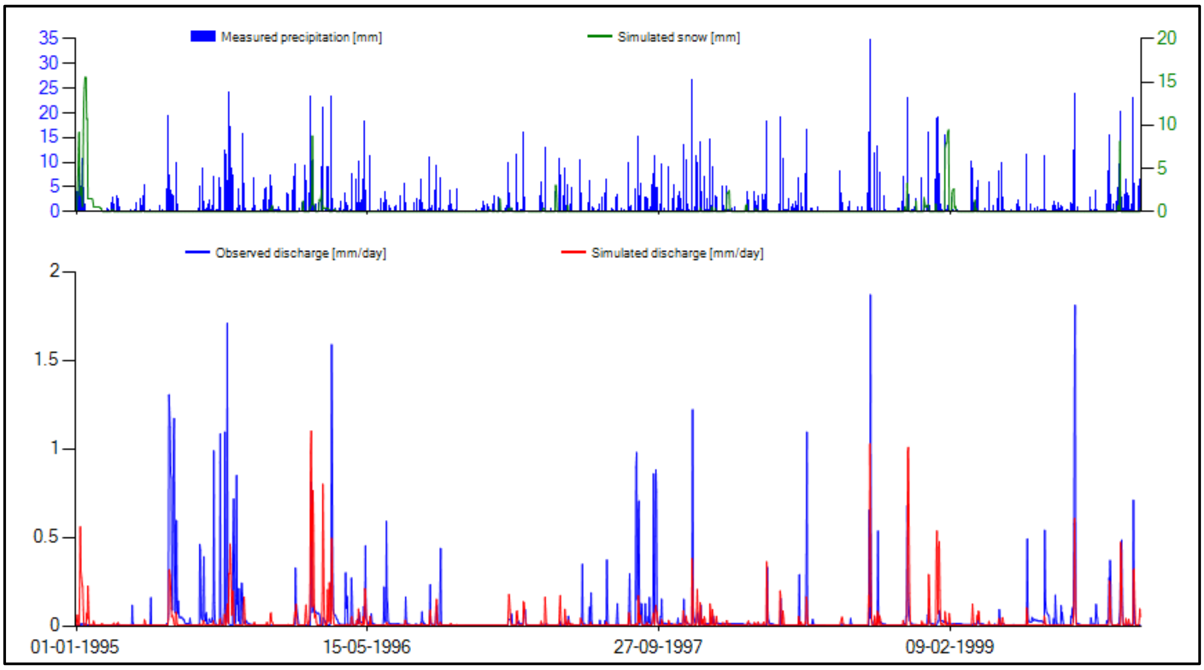

Figure 5. 7. Validation of Land use 1988

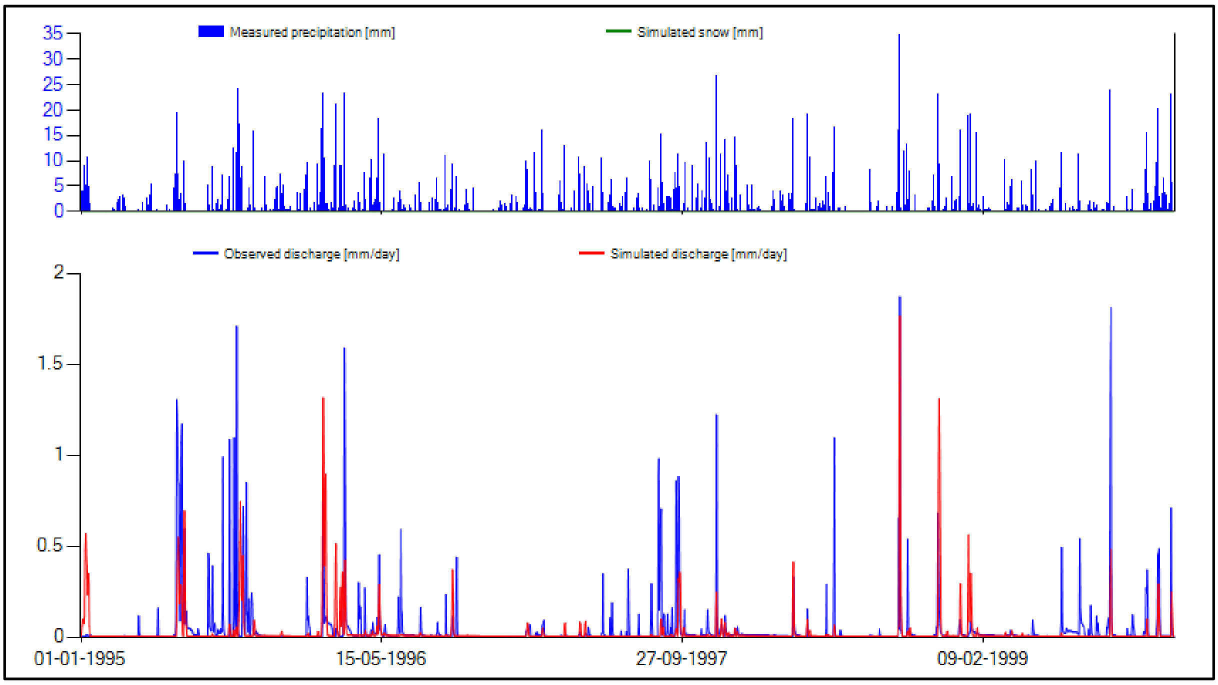

Figure 5. 8. Validation of Land use 2003

A summary in HBV model of the simulated and observed discharges at the outlet of the catchment shows that there is a slightly increase in runoff by 1 mm/year during the period between 1988 and 2003. The values of evapotranspiration (outflow) is very high comparing to the inflow (precipitation). This could be explained by the climate and the impact of land use/cover type in the basin.

Table 5. 5. Summary of validation results

Validation	Land use 1988	Land use 2003
Water Balance [mm/year]:		
Sum Qsim	8.988	10
Sum Qobs	15	15
Sum Precipitation	435	435
Sum AET	661	669
Sum PET	8059	4226
Contribution of QSUZ	0.221	0.203
Contribution of QSLZ	0.116	0.210
Goodness of fit:		
Coefficient of determination	0.1536	0.1839
Model efficiency	0.1149	0.1115
Efficiency for log(Q)	0.105	0.2061
Flow weighted efficiency	0.2973	0.3493
Mean difference	6	5

CHAPTER SIX

Conclusion and recommendation

1.1 Conclusion

The main objective this study was to assess quantitatively the impact of the land use change on streamflow, this was done by several methodologies. Remote sensing and GIS was used to classify the land use map of 1988 form Landsat TM images. An accuracy assessment was calculated by statistical method indicate a good overall accuracy of 89 %. GIS was used as well to process the land use 2003. The output from the two land use was the extraction of areas and percentages of each land use type. The result shows that there is change by 5% and 4% of forest and irrigated land respectively. The percentages were not very high so normally this will not show very high variation within the streamflow. The HBV hydrological model was used as means to express how change in forest and irrigated area will reflect the change in discharge of the Mellegue river in the Mellegue K13 station. This section was done in two steps; calibration and validation. The calibration done by the GAP optimization run for Land use 1988 gives a model with an efficiency of 0.38 and 0.33 for land use 2003. The validation was slightly decreased comparing to the calibration step with 0.1 for 1988 land use and 0.1 for 2003 land use. The efficiency was not really very high; this could be due to the data quality. By analysing the output data from calibration and validation we can conclude that HBV simulate more low flow than high flow, this will be confirmed if it is used with higher efficiency. As well, the deforestation has actually the first influenced factor for the increasing of runoff from 1988 to 2003, loss by drainage from agricultural land can help also this change in streamflow. Several studies confirm that the deforestation has a great impact in hydrology by helping some disaster like flood to occur. That’s could be one of the influenced factors that enhanced the several recorded flooding in the northern part of Tunisia.

5.2 Recommendation

- The Changes in land use and cover have caused an impact on hydrology by increasing the incidences and intensities of flooding to some extent in Mellegue river basin. There necessitate some control mechanisms such as reducing the rate of deforestation which was evidently the high contributing factor and proper land use management practices especially in the cultivated areas through agroforestry, deep tillage and banding to minimize run off and facilitate infiltration and ground water recharge.

- HBV model used in this research was very helpful because of the limitation with data since it did not require many inputs. However, within a semi-arid area it may not be sufficient enough to judge the results by using only one model. Therefore, there is a need to look at other hydrological models in order to have more accuracy of the outputs and give better investigation of the effects of land use changes on the hydrology of the sub basin.

- From the results obtained, the increase in runoff due to changes in land use cannot solely explain the occurrence of recorded flood hazard during the several past years, there might have been other factors that increased the streamflow such as climate change. Therefore, there is a need to investigate and assess the impact of climate change in Mellegue river basin.

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