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By:

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HEC_HMS modelling of the rainfall-discharge relationship for the Oued Mekerra (Algerian NW)

Defended on, 06/29/2024 , before the jury composed of:

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Appreciation

I thank God for giving me the courage and the will and conscience to write this modest work that I hope it will be estimable and successful.

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Dedication

To my mother, whose unwavering support, endless patience, and boundless love have been my guiding light. Your strength and resilience inspire me every day, and your belief in me has been my greatest source of motivation.

To my sisters, Rym Chahrazed and Amira, who have been my pillars of strength. Your encouragement, laughter, and constant companionship have made this journey more meaningful and joyous. You are my best friends and my greatest allies.

To my little brother, Mohamed El-Amine, whose innocence, and enthusiasm remind me of the pure joys in life. Your curiosity and zest for learning are a constant reminder of why I embarked on this academic journey.

To my best friends, thank you for your unwavering support and for always being there for me. Your friendship means the world to me.

Thank you all for your unwavering support and love. This achievement is as much yours as it is mine.

Dedication

This thesis is dedicated to the loving memory of my father. Though you are no longer with us, your spirit, wisdom, and guidance continue to inspire me every day. You taught me the value of hard work, perseverance, and integrity. Your dreams for me have been a constant source of motivation.

Eight years ago, I made a promise to you that I would study hard and succeed. Today, I am proud to fulfill that promise. I wish you were here to see this accomplishment, but I know you are watching over me with pride. This work is a testament to your love, sacrifices, and the lessons you imparted. You remain my hero, and I strive every day to honor your legacy.

Thank you, Dad, for everything. This is for you.

Abstract

This study presents a flood estimation model for upper Mekerra sub_basin in Mekerra watershed, North West of Algeria. To ensure the overall consistency of simulated results, it is necessary to develop a validation process, particularly in regions where data are scarce or limited and unreliable. To this we must calibrate and validate the model over the hydrograph as measured at the output. Calibration and validation processes were carried out using different sets of parameters (CN, lag time, initial abstraction) for the event of 23-26 october2000. Evaluation on the performance of the developed flood model derived using HEC-HMS (hydrologic modelling system) yield a correlation coefficient R2 close to 1 and the Nash–Sutcliffe efficiency.

The results of the measuring approved the results of the model and showed that the model performs well in the subbasin5 with R2 value is 0.80 and Nash–Sutcliffe efficiency is0.83 were higher than Nash values and R^2 value of the others sub-basins but generally we can say that The present study concludes that the model can be utilized for the upper Mekerra watershed.

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Keywords: Rainfall-runoff modelling, Mekerra, HEC-HMS.

Résumé :

Cette étude présente un modèle d'estimation des crues pour le sous-bassin supérieur de la Mekerra dans le bassin versant de la Mekerra, au nord-ouest de l'Algérie. Pour garantir la cohérence globale des résultats simulés, il est nécessaire de développer un processus de validation, en particulier dans les régions où les données sont rares ou limitées et peu fiables. Pour cela il faut calibrer et valider le modèle sur l'hydrogramme tel que mesuré en sortie. Les processus de calibrage et de validation ont été réalisés à l'aide de différents ensembles de paramètres (CN, lag time, prélèvement initial) pour l'événement du 23 au 26 octobre 2000. L'évaluation des performances du modèle d'inondation développé dérivé à l'aide de HEC-HMS (système de modélisation hydrologique) donne un coefficient de corrélation R2 proche de 1 et l'efficacité de Nash – Sutcliffe.

Les résultats de la mesure ont approuvé les résultats du modèle et ont montré que le modèle fonctionne bien dans le sous-bassin5 avec une valeur R2 de 0,80 et une efficacité de Nash-Sutcliffe de 0,83, qui étaient supérieures aux valeurs de Nash et à la valeur R2 des autres sous-bassins, mais de manière générale, nous pouvons dire que la présente étude conclut que le modèle peut être utilisé pour le bassin versant haute Mekerra.

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Mots-clés : Modélisation pluie-débit, Mekerra, HEC-HMS.

LIST OF FIGURES:

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Abbreviations list:

HEC-HMS: Hydrology Modeling System

IDF: Intensity-Duration Frequency

HDF: Height-Duration-Frequency

CN: curve number

DEM: digital terrain model

S.C.S : Soil Conservation Service

CONTENTS:

GENERAL INTRODUCTION

GENERAL INTRODUCTION

HEC_HMS modelling of the rainfall-discharge relationship for the Oued Mekerra (Algerian NW).

The watershed concept is familiar to hydrologists, yet mastering or fully understanding it remains challenging. For instance, defining the slope of a watershed is complex due to the different types of slopes involved (such as those of the sides, tributaries, and main channel). Additionally, factors like soil composition, vegetation cover, land use, and the hydrographic network add to this complexity. As a result, mastering the watershed concept has become a significant focus for hydrologists.

Given these challenges, it is evident that developing management and decision-support tools is essential for gaining a better understanding of the functioning of natural hydrosystems and the behavior of water within its environment. These tools help users obtain a clearer picture of the spatial and temporal distribution of water flows, as well as the materials and compounds transported within the watershed.

In hydrology, it is crucial to have a simplified mathematical representation of all or part of the processes within the hydrological cycle. Hydrological concepts are therefore expressed mathematically to replicate observed natural behaviors. The utility of a model lies in its ability to provide a "satisfactory" answer to questions about the modeled subject. The development of rainfall-runoff models began in the 1960s (Nascimento, 1995).

For hydrologists, understanding and having detailed knowledge of a watershed is vital, especially in predicting its response to rainfall events. Development projects are always based on estimates and forecasts. Hydrological modeling allows for a deeper understanding of the watershed by representing it as a system with two key parameters: input (rainfall) and output (runoff). The study of the relationships between precipitation and the resulting runoff is essential, as these are core components of the hydrological cycle. Rainfall-runoff modeling aims to provide engineers and hydrologists with a straightforward tool to estimate or predict runoff for any given development project.

Despite the variety of models available today—whether global or local, physical or empirical—choosing and evaluating the appropriate model is crucial. The HEC-HMS model, widely used hydrological modeling software developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center, has demonstrated its effectiveness in the watersheds where it has been applied.

The work is divided into four chapters:

- **Chapter 1:** Understanding Hydrological Modeling.

In this chapter, we delve into the world of hydrological modeling. We begin by defining what hydrological modeling is and what it aims to achieve. Then, we take a closer look at various hydrological models currently in use, classifying them based on their features and purposes.

- **Chapter 2:** Presentation and Description of the Study Area (upper Mekerra) basin.

This chapter aims to introduce and provide a detailed description of the study area, focusing on the Oued Mekerra.

- **Chapter 3:** This chapter focuses on investigating the hydroclimatological parameters of the watershed, utilizing precipitation, discharge, and temperature data. Additionally, it includes a statistical analysis aimed at determining the fitting law for the distribution of precipitation and discharge.

- **Chapter 4:** Application of the HEC-HMS Hydrological Models in Our Study Area (Oued Mekerra), where we will aim to provide an overview of this software and the results of its application.

In this section, we will apply the HEC-HMS hydrological models to our study area, focusing on the Oued Mekerra. Our goal is to give an understanding of this software and present the results obtained from its application.

Chapter I:
State of the art of modeling

CHAPTER I: STATE OF THE ART OF MODELING.

I.1 INTRODUCTION

Hydrology is the science that helps predict resource recharge, manage water systems, and plan structures by using models. This field requires both hydrological and computational skills to understand how rainfall turns into runoff as part of the hydrological cycle.

Before diving into popular hydrological models and software, it's important to give a brief overview of the hydrological cycle, which forms the basis for all hydrological modeling work.

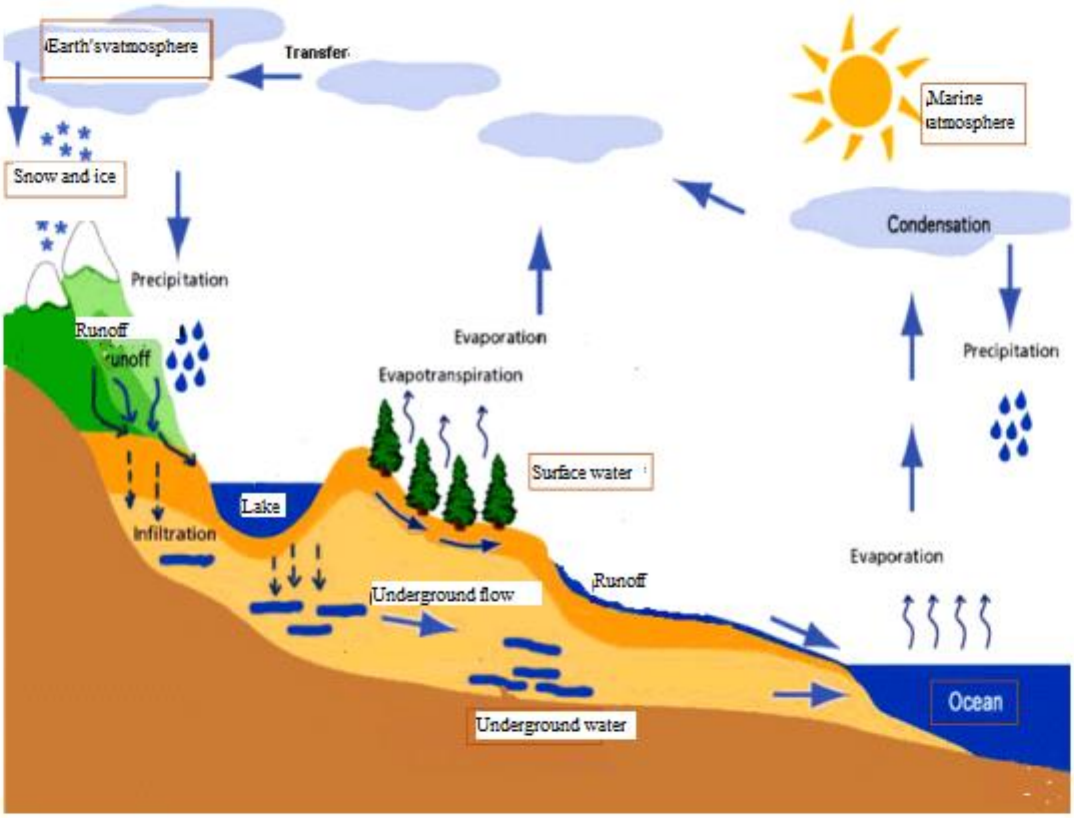
According to the Environmental Dictionary, a model is "a simplified, relatively abstract representation of a process or system, designed to describe, explain, or predict it." Hydrological modeling, therefore, is a representation, either partial or complete, of the water cycle.

In this work, we focus specifically on rainfall-runoff models, which depict the transformation of rainfall into runoff over land surfaces. These models have numerous applications, including simulating the impact of human activities on a watershed's hydrology (such as dam construction or urbanization), managing flood alerts for watersheds, and reconstructing flow records in areas where only rainfall data is available.

I.2 Hydrological cycle:

The hydrological cycle is a marvelously intricate system, orchestrating a symphony of processes including precipitation, evaporation, transpiration (from plants), interception, runoff, infiltration, percolation, storage, and underground flow. At its heart is the sun, the driving force behind this vital dance of water. To tackle water resource management projects effectively, hydrologists must skillfully quantify or estimate each of these elements:

- Encompassing flood management.
- Providing essential irrigation and drinking water during droughts.
- Assessing the impact of reservoirs and flood control structures on watercourses.
- Evaluating urban development's influence on drainage system capacity.
- Pinpointing flood-prone areas in anticipation of potential inundations.



With: ***P***: Precipitation; ***A***: Surface runoff; ***F***: Infiltration.

G: Underground flow; ***E***: Evaporation; ***T***: Sweating.

Figure 1: *The hydrological cycle.*

I.3 Hydrological modeling and rainfall-runoff model:

I.3.1 Modeling:

Hydrological modeling serves as a depiction, whether partial or comprehensive, of the hydrological cycle. It entails translating the complexities of the water cycle into the language of mathematics, as explained by Chaponnière (2005). This transformation is accomplished through a series of mathematical equations designed to replicate the system's dynamics.

I.3.2 Modeling objectives:

Three primary applications of hydrological modeling can be identified:

- **Modeling as Research Tools**: In this capacity, hydrological models serve as invaluable tools for interpreting measured data. They enable the exploration of various operational scenarios within watersheds, facilitating a deeper understanding of hydrological processes and their implications.

- **Modeling as Forecasting Tools:** Hydrological models are extensively employed as forecasting tools to anticipate future developments in water throughput. This represents one of the most prevalent and practical applications of hydrological modeling, aiding in the proactive management of water resources and the mitigation of potential risks.
- **Modeling as Extrapolation Tools:** Another significant application involves using hydrological models as extrapolation tools. These models facilitate the reconstruction of plausible flow rates, providing valuable insights into past or hypothetical hydrological scenarios.

I.3.3 The rainfall-flow relationship:

Today, there's a pressing need to measure extreme events like major floods, but it's equally crucial to understand more common water flows, especially concerning everyday water demands. Every spot along a river or stream defines a watershed, where flow rates are directly linked to the amount of rainfall in the area. By measuring rainfall, we can predict how water will flow through the watershed using hydrological modeling.

However, turning rainfall data into flow predictions is a complex task. To simplify this process, we use conceptual modeling, which aims to accurately mimic basin behavior based on historical rainfall data while using a limited set of parameters. The factors influencing how water moves through a watershed vary greatly over time and space, so we need mathematical models to represent these complex phenomena.

Global modeling techniques have evolved to include parameters that address local differences, such as variations in soil type. This allows us to forecast water resources at the scale of entire river basins with more accuracy. The goal of this research approach is to develop methods that can be applied across different watersheds, which requires aligning model parameters with the physical characteristics of each environment.

Furthermore, dealing with variations within a watershed often involves breaking down the study area into smaller sections through distributed modeling. This ensures that the physical parameters used in the models are consistent across different parts of the watershed. However, a key challenge is finding the right balance between detailed, distributed modeling and simpler, global modeling approaches. One way to address this challenge is by integrating soil data into rainfall-runoff algorithms, providing more detailed information at smaller scales.

I.3.4 The different modeling approaches:

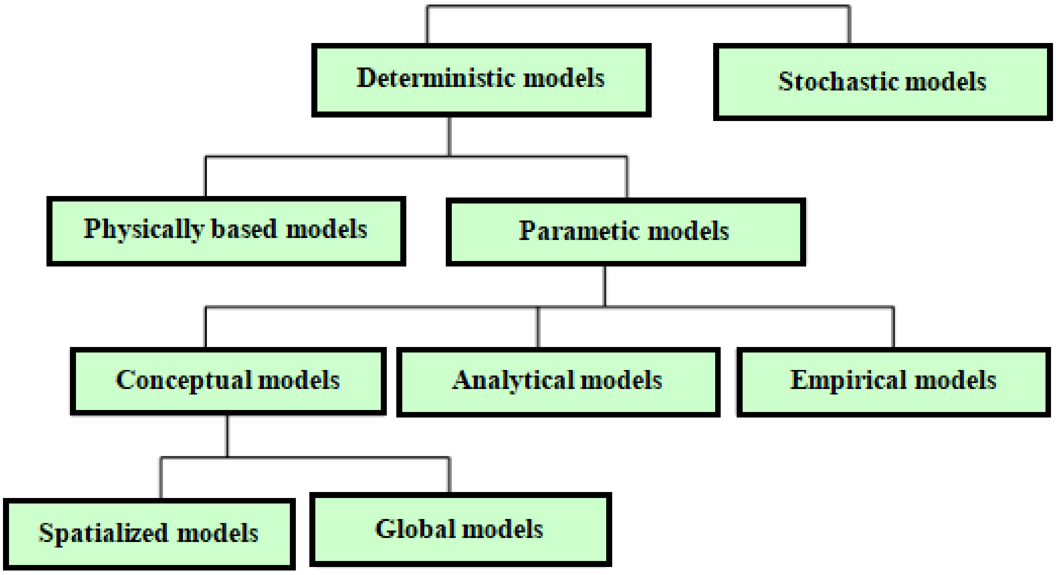


Figure 2: *Types of models used in hydrology.*

a) Deterministic models:

Deterministic models are like blueprints based on well-understood laws and controlled experiments. However, complex phenomena such as friction and turbulence can make it tricky to apply these models universally. Despite this, deterministic models excel in predictability, with every model variable having a clear value at each moment and location. This means that given the same input data, deterministic models always produce the same output, making them reliable tools for understanding and predicting water behavior.

b) Stochastic models:

Stochastic modeling steps in when there are uncertainties in either the data or the processes involved. These models use random variables to capture the inherent uncertainty, producing different outcomes even when the external conditions remain the same.

c) Physical models:

Before digital modeling took over, physical scale models were used to study how rivers behave. These models include solid transport and moving water, but they're challenging to balance because they must replicate the flow characteristics while also making sure materials move in the same way they would in nature. While hydrology doesn't have strictly physics-based models, some, like the SHE model, try to come close. However, the complexity of watersheds makes them difficult to use.

d) Parametric models:

Parametric models use parameters that need to be estimated through calibration. These models simplify the representation of physical processes by using parameters that aren't directly linked to measurable variables.

e) Conceptual models:

Conceptual models simplify complex watershed systems by likening them to networks of interconnected reservoirs. They're useful when the system's structure and rules are hard to pin down, distilling complex factors into a simpler model. These models create structures based on input variables like rainfall and evapotranspiration to predict outputs like flow and concentration.

f) Empirical models:

Empirical models look for relationships between variables, with predetermined functions linking them together. Calibration involves finding the combination of functions that best matches the measured data.

g) Spatial models:

Spatial models deal with inputs and outputs distributed across a watershed's attributes. They come in three main types:

i. Spatialized or semi-spatialized:

Conceptual models break down watersheds into spatial units, treating them as interconnected from upstream to downstream.

ii. Spatial physical models:

Describe the mechanics of a watershed using fundamental principles of physics and mechanics, simulating various hydrological processes.

iii. Semi-distributed models:

Strike a balance between detailed distributed models and simpler global models. An example is the HEC-HMS model, known for its computational efficiency and quality results.

h) Global models:

Global models focus on relationships between inputs and outputs at a watershed level, often using transfer functions. They're simple to use and require minimal data but lack the ability to validate parameters. While they're good for flood forecasting, they may not capture all the complexities of hydrological processes. The Gardenia model is a prime example of this approach.

I.4 Presentation of the models used:

I.4.1 The HEC-HMS Model:

The HEC-HMS (Hydrology Modeling System) is a software package that simulates the hydrological behavior of a watershed following predefined rainfall events, developed by the Hydrology Engineering Center (HEC) of the U.S. Army Corps of Engineers.

HEC-HMS is a distributed model that allows a watershed to be subdivided watershed into several sub-basins, each of which is considered to have each with homogeneous characteristics,

This software can be used to calculate flood hydrographs for several purposes: urban drainage studies, flood forecasting and impact, reservoir design and flood mitigation.

The HEC-HMS software can process or simulate the following data at the same time data:

- **Precipitation:** These data can correspond to actual rainfall records actual rainfall records from ordinary or exceptional rainfall events, as well as theoretical rainfall events based on a statistical study.
- **Losses** (through infiltration, retention, or evapotranspiration): which enable us to assess runoff based on rainfall and watershed characteristics.
- **Direct runoff**: which takes into account surface runoff, storage and storage and head losses.

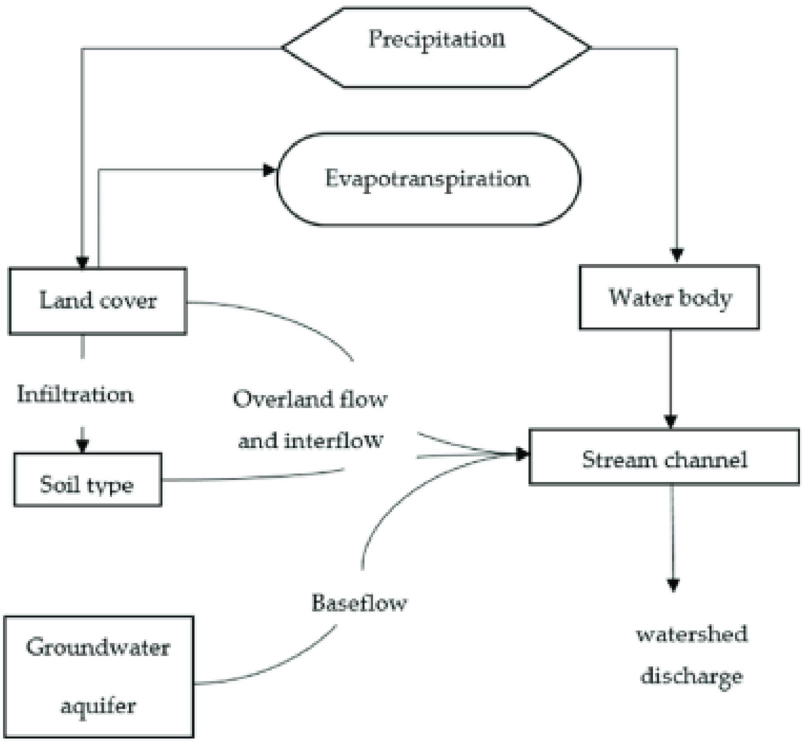


Figure 3: *Flow chart of the steps of building on HEC-HMS model.*

I.5 Rainfall-flow modelling using the HEC-HMS model:

The modelling of the response of a watershed to a rainfall event using the HEC HMS software is divided into two parts.

1) Watershed modeling.
2) Rainfall modeling.

Catchment modeling consists, firstly, in dividing the catchment into several sub-catchments. Into a number of elementary sub-catchments, then specifying the methods used to calculate losses (production function) and runoff (transfer function).

The watershed model diagram is the representation of the hydrological model of the basin and its elements (reaches, junctions, sub-basins....) and their connectivity.

I.5.1 Representation of the rainfall model:

Various forms of precipitation data are available. The HEC-HMS model accommodates this diversity in presenting precipitation data. To this end, it offers seven types of rainfall events, most of which are tailored to American rainfall measurement networks. Using HEC-HMS, users can generate hypothetical rainfall events, simulating rainfall patterns based on data that may not necessarily originate from actual rainfall measurements, but are essential for engineering design purposes. Among the three standard types of rainfall events are:

- Hypothetical rainfall based on frequency,
- Standard project rainfall: a method employing parameters specific to the U.S. territory as defined by certain organizations,
- Hypothetical rainfall with user-defined distribution.

For frequency-based project rainfall, the input data includes rainfall heights and amounts for different rain durations with a 50-year return period, typically derived from Intensity-Duration-Frequency (IDF) curves.

I.5.2 The production function: use of SCS – CN:

The production function is a key element of a hydrological model because it allows us to reproduce the evolution of soil infiltration capacity. Using a function production therefore makes it possible to convert raw rain into effective running rain.

The SCS Curve Number (CN) model estimates excess precipitation as a function cumulative precipitation, cover and initial soil moisture from main equation of the SCS model to estimate runoff is given:

$$Q = \frac{(p-I_a)^2}{(p-I_a)} - S \qquad \text{(I-1)}$$

With:

- Q: Cumulative runoff or net rain (in millimeters).
- P: Cumulative precipitation or raw rain (in millimeters)
- Ia: Initial loss (in millimeters).
- S: Maximum potential loss (in millimeters).

Ia: Represents losses before runoff begins. They include, retention by ground depressions, interception by vegetation, evaporation and infiltration. The value of Ia is very variable, but is generally linked to the type of floor and type of floor covering; following numerous studies experimental, the SCS proposed the following empirical relationship: Ia = 0.2S

The maximum potential retention S is linked to the soil cover conditions (coating for impermeable floors, and plant cover and practice for permeable soils), the latter being represented by the CN.

The relationship between S and CN is given in metric system:

$$CN = \frac{25400}{S} + 254 \qquad \text{(I-2)}$$

Where CN = Curve Number (unitless). The latter varies between 0 and 100.

I.5.3 Hypothetical rain based on frequency:

The objective of this method is to define an event for which the height and the duration of precipitation are determined for an exceedance probability given. To define this event with HEC-HMS the user must specify the precipitation height in each time step for a probability of chosen overrun. Precipitation amounts can be inferred from HDF (Height-Duration-Frequency) curves. HEC-HMS applies a coefficient surface correction to the heights given by the HDF curves. Generally, the distribution of precipitation intensity is non-uniform over the basin slope, the average height on the surface of the basin is less than the height given by the HDF curves. To remedy this problem, the U.S. Weather Bureau, defined factors that make it possible to adjust the heights given by the curves HDF at medium height. These factors, expressed as a percentage, are a function of the basin surface and the duration of the rain (figure 4.).

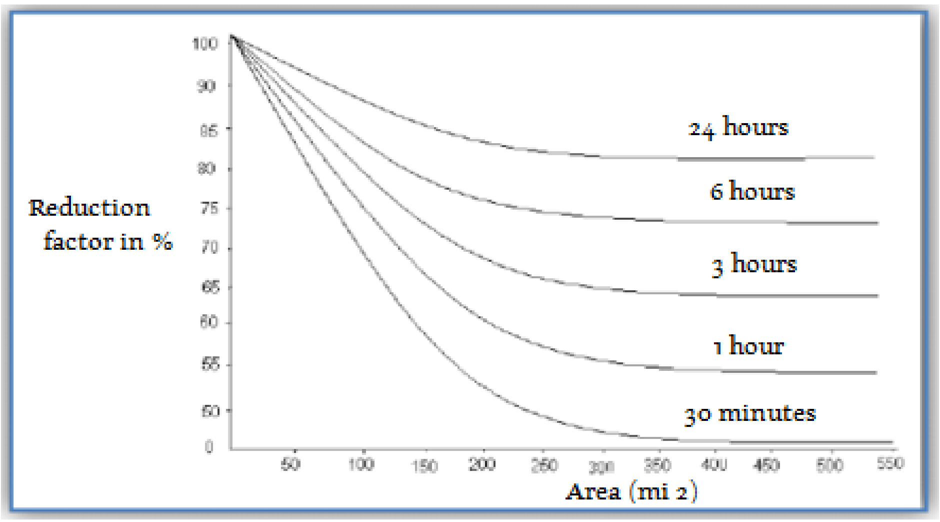


Figure 4: *Height reduction factors deduced from HDF curves.*

I.5.4 The basic flow module:

This is one of the two additional modules of the model, failing which the HEC-HMS can rotate, but its presence improves the understanding of mechanisms that control runoff in the study basin. The flow basis is the contribution of the underground reservoir to the flow, its knowledge is important for modeling the recession of the hydrograph before and after the peak flow and to better estimate the flood volume. Three formalisms are proposed by the model:

• “Constant Monthly”: Monthly constant. He considers the flow underground as fixed for periods of one month. This basic flow monthly is therefore added to the direct runoff from precipitation sharp. This method is very simple, but not adapted to the semiarid context where the variation in the saturation conditions of the watersheds occurs.in less than a month.

• “Linear Reservoir”: Linear reservoir. It simulates underground storage at a reservoir, so it is always associated with the SMA type production function.

• “Recession”: uses an exponential base flow recession. She is used for basins where flood volumes are influenced by rainy events.

I.5.5 The routing module:

This is the second of the two additional modules, it allows you to calculate a hydrograph downstream of the watershed, knowing the upstream hydrograph. All these formalisms use the equations of continuity and momentum for simulation (USACE, 1994).

«The G ";

“Muskingum”;

“Modified Pulls”;

“Kinematic-wave”;

“Muskingum Cunge”.

I.5.6 The objective function:

It measures the quality of the adjustment of the simulated hydrograph to the hydrograph observed whether in terms of flow, volume or time. The HEC-HMS in has 7 objective functions, namely:

- “Peak weighted RMS error”: modification of the objective function widely used which is the error on the root mean of the squares of flow. This method gives more weight to flow rates above average and less weight at flows below.
- “Sum of squared residuals”: the sum of squared residuals attributes more weight for large errors and less for small errors.
- “Sum of Absolute Residuals”: the sum of absolute residues, which does not does not differentiate between wide and narrow errors.
- “Percent Error in Peak Flow”: the percentage of error on the peak flow peak, which focuses on adjusting peak flow rates.
- “Percent Error in Volume”: the percentage error on the volume, which is focuses on adjusting runoff volumes.
- “RMS Log Error”: uses the error on the average of the square root of log flow rates to phase low and high flow rates.
- “Time weighted”: gives weight to errors close to the end of the event and less to the errors at the beginning.

The choice of this or that function is dictated by the problem studied and/or the modeling objectives. For example, if we have to make a delimitation flood zones, the objective function on the volume is appreciated, if by against the objective being to determine the project flow of any work, the recommended objective function is that affecting the peak flow. On the other side if we are in the presence of continuous modeling to understand the hydrological functioning of a basin, it will be preferable to opt for example for the first function which will focus more on large flow peaks. Thus, we choose the function that will help us solve our problem and achieve our objectives.

I.5.7 The automatic optimization function:

It is used to search, without user intervention, the optimal set of parameters giving the objective function its best possible value. To carry out this task, the HEC-HMS offers 2 methods:

“Univariate Gradient”: the univariate gradient adjusts a single parameter at a time while keeping the others constant.

“Nelder and Mead”: uses an approach that consists of optimizing all parameters simultaneously.

In conclusion, we can say that the diversity of formalisms available to HECHMS places it at the top of the most robust models in the simulation of runoff within the basin, the most complete in the integration of different flow components and the least demanding from a point of view input data. In addition, its diversity in terms of modular combinations possible, leaves it to its user the ability to adapt it to its data, its objectives, and its needs but above all to its experience.

I.5.8 Justification for the choice of model:

The choice of the model was dictated by several constraints of means and factors of privilege which make this model a good choice. Among those most important:

- The data required by the model are more or less simple, accessible and available, therefore, the model can run without worries.
- Possibility of integrating the major factors affecting the transformation rainfall-flow (watershed morphometry, land use, types of soils and previous humidity), and therefore the results will be more realistic.

The SCS-CN has been validated in several watersheds around the world, and its Results are reliable and similar to complex models (Motevalli et al. 2012).

I.6 Conclusion:

After thorough examination of the various hydrological models, our preference gravitates towards one model specifically tailored for managing flows in arid and semi-arid regions: the HEC-HMS hydrological model. Our decision to adopt HEC-HMS for simulating watershed behavior is well-founded for the following reasons:

HEC-HMS is a comprehensive model, making it theoretically adaptable to any climatic conditions, particularly those of arid zones. Its versatility enables the simulation of losses, surface flow, groundwater flow, and river flow.

The proven reliability of HEC-HMS results in American watersheds instills confidence in its application to Mediterranean watersheds.

One of the model's key strengths lies in its capability to consider the geographical intricacies of watersheds, achieved through integration with a Remote Sensing-GIS-Hydrological system. This integrated approach enhances the accuracy and efficiency of watershed analysis.

Chapter II:

Presentation of the study area

CHAPTER II: Presentation of the study area:

II. Presentation of the study area

II.1 the Macta watershed:

The Mekerra wadi watershed is part of the large Macta basin, which extends in North-West Algeria. The Mekerra wadi basin has its source in the highlands area plateaus of the Ras El Ma region, from Djebel Rharbal (1189 m), Djebel El Kamiti (1265 m) and Djebel Marhoum (1250 m) to the south, up to the town of Sidi Bel Abbes.

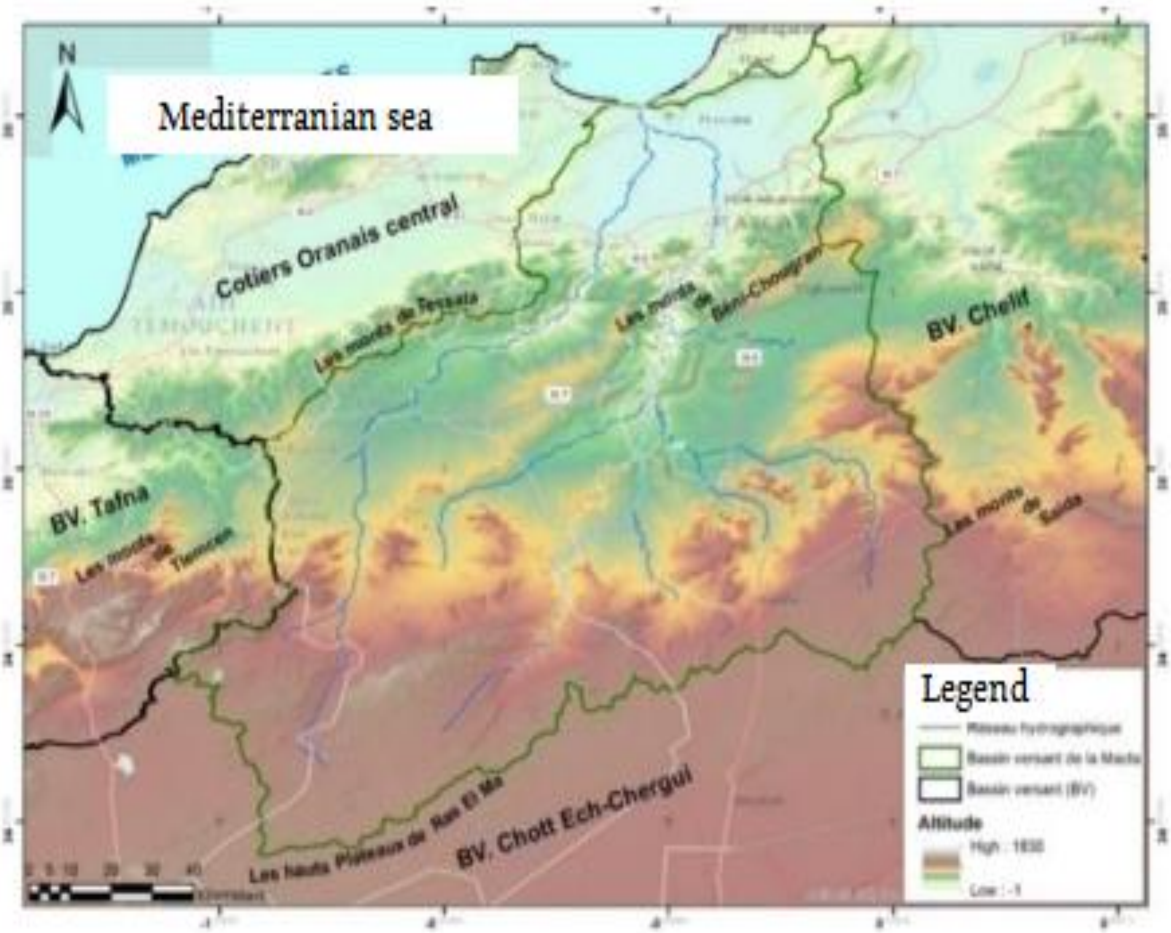


Figure 5: *Geographical location of the Macta watershed.*

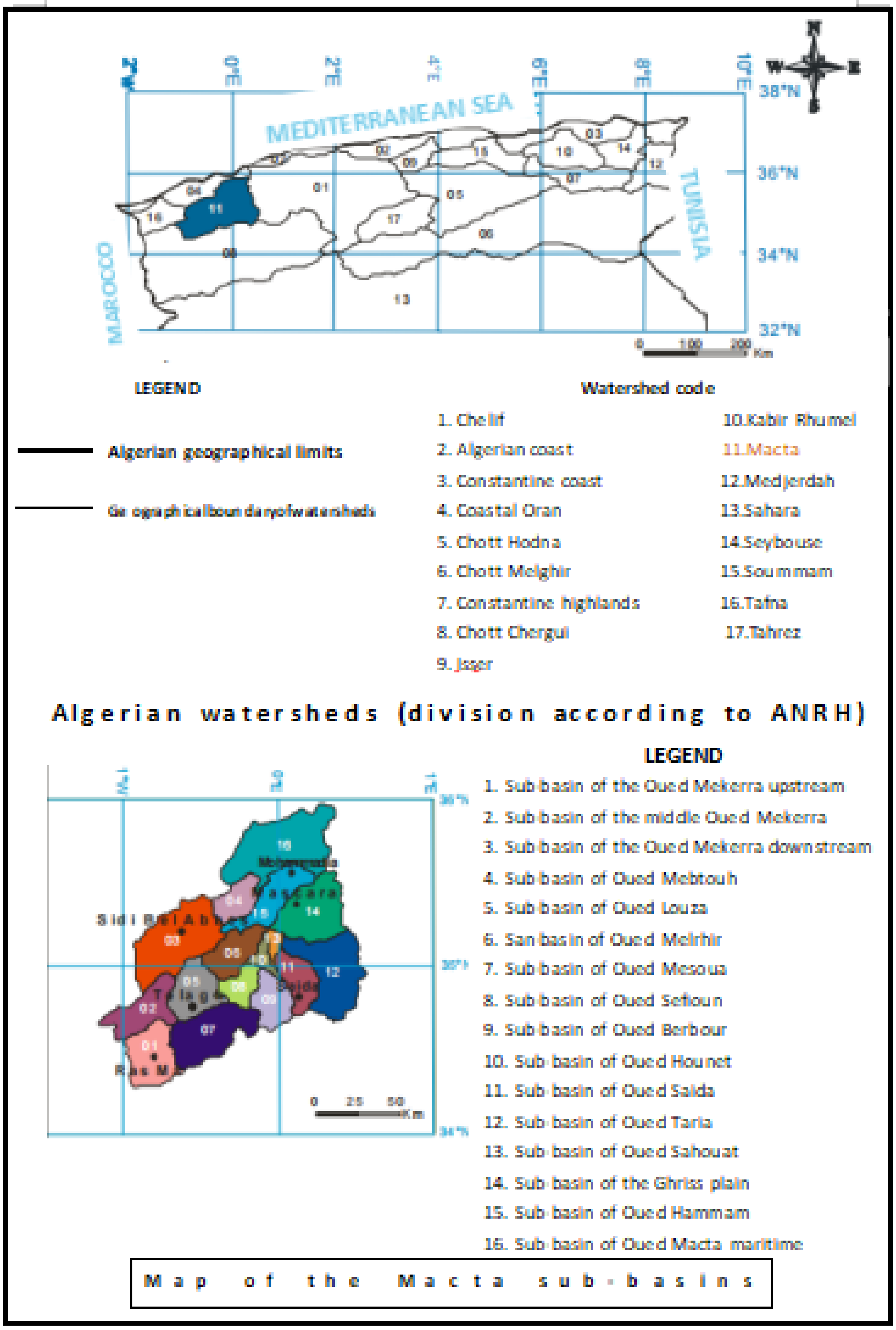


Figure 6: *Situation of the Macta sub-basin.*

II.2 Presentation of the Oued Mekerra watershed:

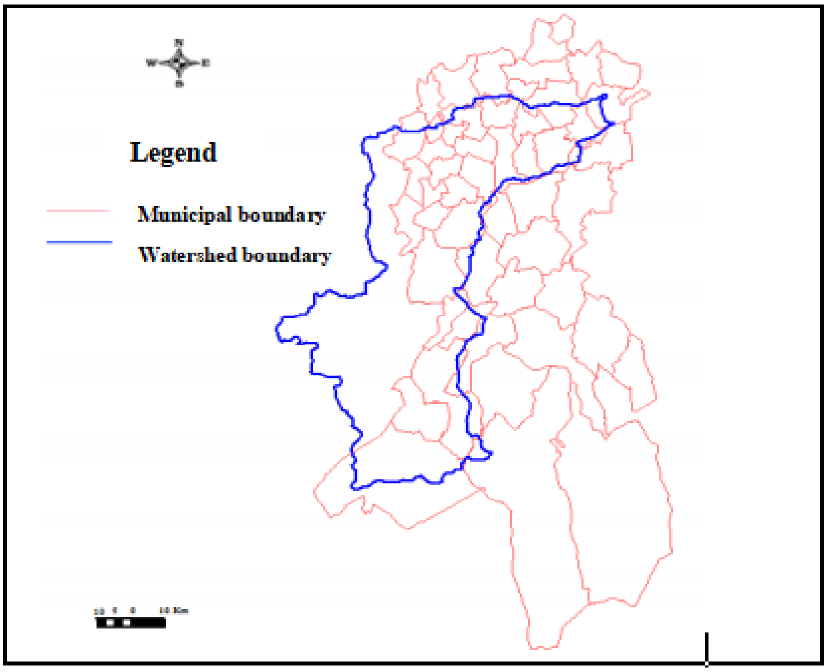


Figure 7: *Situation of the Mekerra wadi basin in relation to the wilaya of Sidi Bel Abbes.*

From a geomorphological point of view, the watershed of Wadi Mekerra can be subdivided into three parts:

- The upper Mekerra: It extends from the source of this river to the south of Ras El Ma to Sidi Ali Benyoub.
- The average Mekerra: Occupies the area between Sidi Ali Benyoub and Sidi Bel Abbes.
- The lower Mekerra: It corresponds to the entire part of the watershed located downstream of the town of Sidi Bel Abbes.

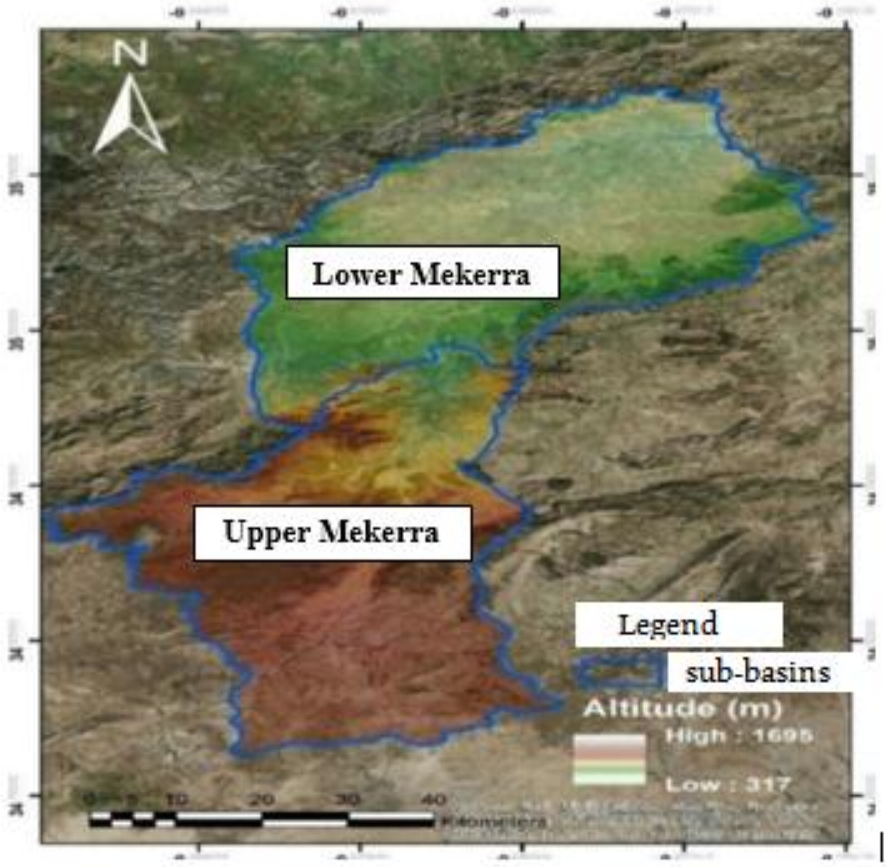


Figure 8: *Subdivision of the Mekerra watershed after 2010.*

The watershed of Oued Mekerra is part of the large watershed of the Macta which is located in the northwest of Algeria. It is between the latitude 34°31 and 35°21 and longitude 1°16 and 0°58. It takes the name of its main wadi and covers an area exceeding 3000 km².

Oued Mekerra crisscrosses the plain of Sidi Bel Abbes from South to North over a distance of approximately 119 km, with an embryonic hydrographic network and whose bed main course was dug in a vast Pliocene lacustrine deposit.

From upstream to downstream, Oued Mekerra is crossed by the following towns: Ras El Ma, Sidi Ali Ben Youb, Tabia, Boukhanifis, Sidi Khaled and Sidi Bel Abbes.

II.3 Study of the up Mekerra watershed:

II.3.1 Morphometric characteristics:

a) Basin surface:

The area encompassed by a watershed is a crucial hydrological parameter, as the volume of water drained is directly proportional to the size of the basin. A larger basin captures a greater amount of precipitation.

The up Mekerra watershed spans an area of **1871, 85km²**.

b) Perimeter of the basin:

Perimeter is the most used characteristic of length; it can be measured directly on the topographic map by curvimetry or indirectly using the length of the equivalent rectangle.

The perimeter of the watershed is obtained directly using MapInfo 7.0.

The perimeter of the Mekerra basin is P= 254, 93 km.

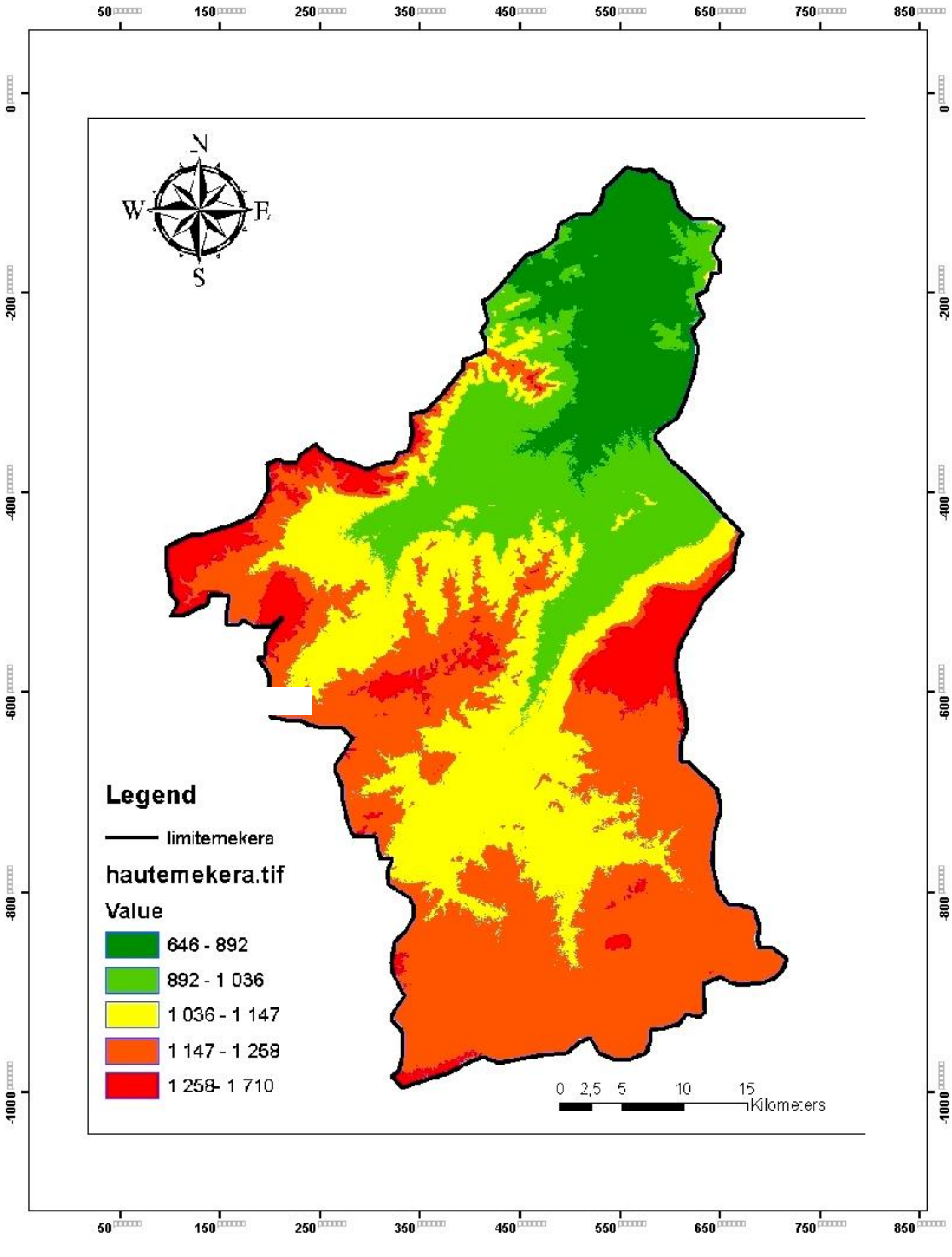


Figure9*: Geomorphological map of the upper Mekerra watershed. (Allouach.2024)*

II.3.2 Shape characteristic:

The shape of a watershed influences the shape of the hydrograph at the outlet of the basin slope. For example, an elongated shape favors, for the same rainfall, low flow rates of peak of the flood, due to longer transport times for water to the outlet. This phenomenon is linked to the notion of concentration time.

On the other hand, fan-shaped pools, which have a shorter concentration time, will have the highest peak flow rates.

There are different morphological indices making it possible to characterize the environment, but also to compare watersheds with each other. Let us cite as an example, the compactness index of Gravelius (1914) KC, defined as the ratio of the perimeter of the basin to the perimeter of the circle having the same surface:

Gravelius compactness index (Kc):

$$k_c = 0.282 \frac{P}{\sqrt{s}} \qquad \text{(II-1)}$$

P: the perimeter of the watershed (Km).

S: the surface area of the watershed (Km2).

If Kc is close to 1, we say that the basin is circular in shape and the more Kc is greater at 1, the more elongated the pelv is.

Table 1: *Shape coefficient.*

Hydrological unit	A(Km2)	P(m)	Kc	Form
Upper Mekerra	1871,85	254,93	1,65	Elongated

Equivalent rectangle:

The notion of equivalent rectangle introduced by Roche (1964) not only allows the comparison of basins with each other from the point of view of the influence of shape on flow, but also to facilitate the calculation of the average slope of the basin and the slopes partial sections of the different parts of the basin included between the contour lines.

The equivalent rectangle has the same area and the same perimeter as the pool considered and therefore the same compactness index. The outlet is represented by the widths of the rectangle and the contour lines by the parallels.

The equivalent rectangle is characterized by the length “L” and the width “1” defined respectively by the following formulas:

- The length of the equivalent rectangle:

$$L = \frac{k_c}{1.128} * \sqrt{s}[1 + \sqrt[2]{1 - (\frac{1.128}{k_c})^2} \qquad \text{(II-2)}$$

- The width of the equivalent rectangle:

$$l = \frac{k_c}{1.128} * \sqrt{s}[1 - \sqrt[2]{1 - (\frac{1.128}{k_c})^2} \qquad \text{(II-3)}$$

Table 2: *Calculation of the equivalent rectangle.*

Under SB	A(Km2)	kc	L(Km)	L(Km)
Upper Mekerra	1871,85	1,65	109,460	17,100

II.3.3 Relief characteristics

The relief has a direct influence on climatic factors and a indirect influence on the formation of surface flows. It determines in largely the ability of land to runoff, infiltration and evaporation.
It is a crucial element in the hydraulic behavior of a basin.

a) Hypsometric curve

In general, we are not interested in the average altitude but rather in the dispersion of altitudes. The statistical study makes it possible to trace the "hypsometric curve". This curve gives the surface A (in km² or % of the total surface) where the altitudes are greater than a given dimension h. This curve is established by planning for different altitudes.

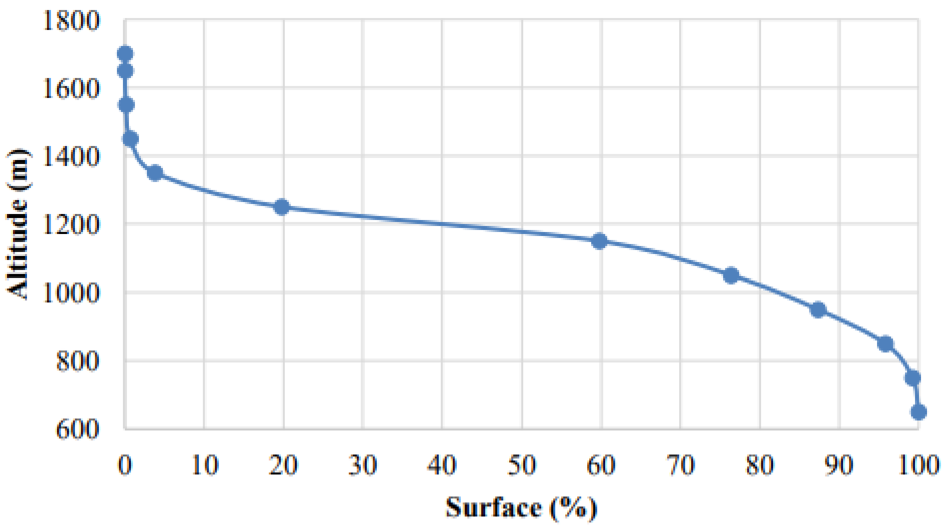


Figure 10: *Hypsometric map of the upper Mekerra watershed.*

II.3.4 Characteristic altitudes:

- Average altitude of the watershed:

It is deduced directly from the hypsometric curve. We can define it as following:

$$H_{moy} = \frac{1}{A}\sum H_i A_i \qquad \text{(II-4)}$$

With:

Hi: Average altitude between two contour lines (m).

Ai: Partial surface between two contour curves (Km²).

A: Total surface area of the watershed (Km²).

Then **Hmoy** = 977.47m

a) Median altitude:

The median altitude corresponds to the altitude read at the abscissa point 50% of the total surface of the basin, on the hypsometric curve, this quantity is close to the average altitude in the case where the hypsometric curve of the basin concerned presents a regular slope.

b) Minimum altitude:

The minimum altitude corresponds to a cumulative surface area of 95% on the curve hypsometric.

c) Maximum altitude:

The maximum altitude corresponds to a cumulative area of 5% on the curve hypsometric.

Table 3: *The characteristic heights of the sub-basins of the Mekerra wadi.*

	Symbol	Upper Mekerra
Characteristic heights	H max.	**1710**
	H med.	**1156,49**
	H min.	**646**
	H med.	**1190,00**

- Slope index:

a) Overall Slope Index Ig:

From the hypsometric curve, we reduce the frequency altitudes 5% and 95% of the watershed surface.

$$Ig = \frac{H_5\% - H_{95}\%}{L} = \frac{D}{L} = \frac{1400-650}{233.065} \qquad \text{(II-5)}$$

With:

L: length of the equivalent rectangle.

D: H5% - H95% vertical drop, defined on the hypsometric curve or even directly on the topographic map.

b) ROCHE slope index (Ip):

It is the average of the square root of the slopes measured on the equivalent rectangle, and weighted by the areas, given by the following formula:

$$Ip = \frac{1}{\sqrt{L}} \sum_{i=1}^{n} \sqrt{\beta i(Hi(Hi - 1))} \qquad \text{(II-6)}$$

ßi : Fraction de la surface totale du bassin comprise entre les cotes **Hi** et **Hi −1**, fonction donnée par le tableau hypsométrique,

L : longueur du rectangle équivalent (m),

(Hi − Hi − 1) : Dénivelée entre deux courbes de niveau voisines (m).

c) Average slope index (Ipm):

The average slope index is the ratio between the height difference and the rectangle length equivalent

$$Ipm = \frac{H_{max} - H_{min}}{L} \qquad \text{(II-7)}$$

Table 4: *The different slope indices.*

Watershed	Slope Index Overall (m/Km)	Average Slope Index (%)	Slope Index Of Rock
Upper Mekerra	**3,59**	**0,63**	**3,78**

II.4.3. Height difference:

Very often, we define the "**height difference D**" as being the difference in height between **H5%** and **H95%**:

$$D = H5\% - H95\% = 750m \qquad \text{(II-8)}$$

Specific height difference Ds:

As the surface area of a basin expands, the **Ig** index decreases, complicating comparisons between basins of different sizes. Yet, the specific height difference, **Ds**, addresses this issue.

Calculated from the overall slope Ig, it compensates for the surface area influence by being inversely related to the square root of the area ($\sqrt{A}$).

$$Ds = Ig\sqrt{A} = \frac{D}{L}\sqrt{A} = D\sqrt{\frac{1}{L}} \quad \text{(II-9)}$$

Ds= 178m

Therefore, the specific height difference solely depends on the hypsometry (**D = H5% - H95%**) and the shape of the basin (l/L). This results in a secondary classification by **O.R.S.T.O.M.**, which is independent of basin sizes.

Table 5: *Classification of relief using specific height difference according to O.R.S.T.O.M.*

Classification	State of the relief	The interval of Ds
R1	Very low relief	Ds < 10 m
R2	Low relief	10 m < Ds < 20 m
R3	Fairly low relief	25 m < Ds < 50 m
R4	Moderate relief	50 m < Ds < 100 m
R5	Fairly strong relief	100 m < Ds < 250 m
R6	High relief	250 m < Ds < 500 m
R7	Very strong relief	Ds > 500 m

The Oued Mekerra basin falls into class R5 (Moderately Strong Relief). Therefore, according to the two classifications by **O.R.S.T.O.M**, it can be said that the Mekerra watershed is characterized by weak to moderately strong relief.

Table 6: *The height difference and the specific height difference and their loss.*

Watershed	Elevation	Specific Elevation	Class
Upper Mekerra	**206**	**109,09**	**Fairly strong relief**

II.4.4 Hydrographic characteristics of the upper Mekerra watershed:

Similar to surface area, shape, and height differential, the hydrographic network of a watershed profoundly influences water flow. The hydrographic network encompasses the natural drainage channels through which runoff water flows or groundwater is discharged, either as springs or continuous seepage along riverbeds. Characteristics such as the order of watercourses, drainage density, and river profile are utilized to describe the network.

The hydrographic network can be delineated by three primary elements: its hierarchy, development (number and length of water courses), and long profile

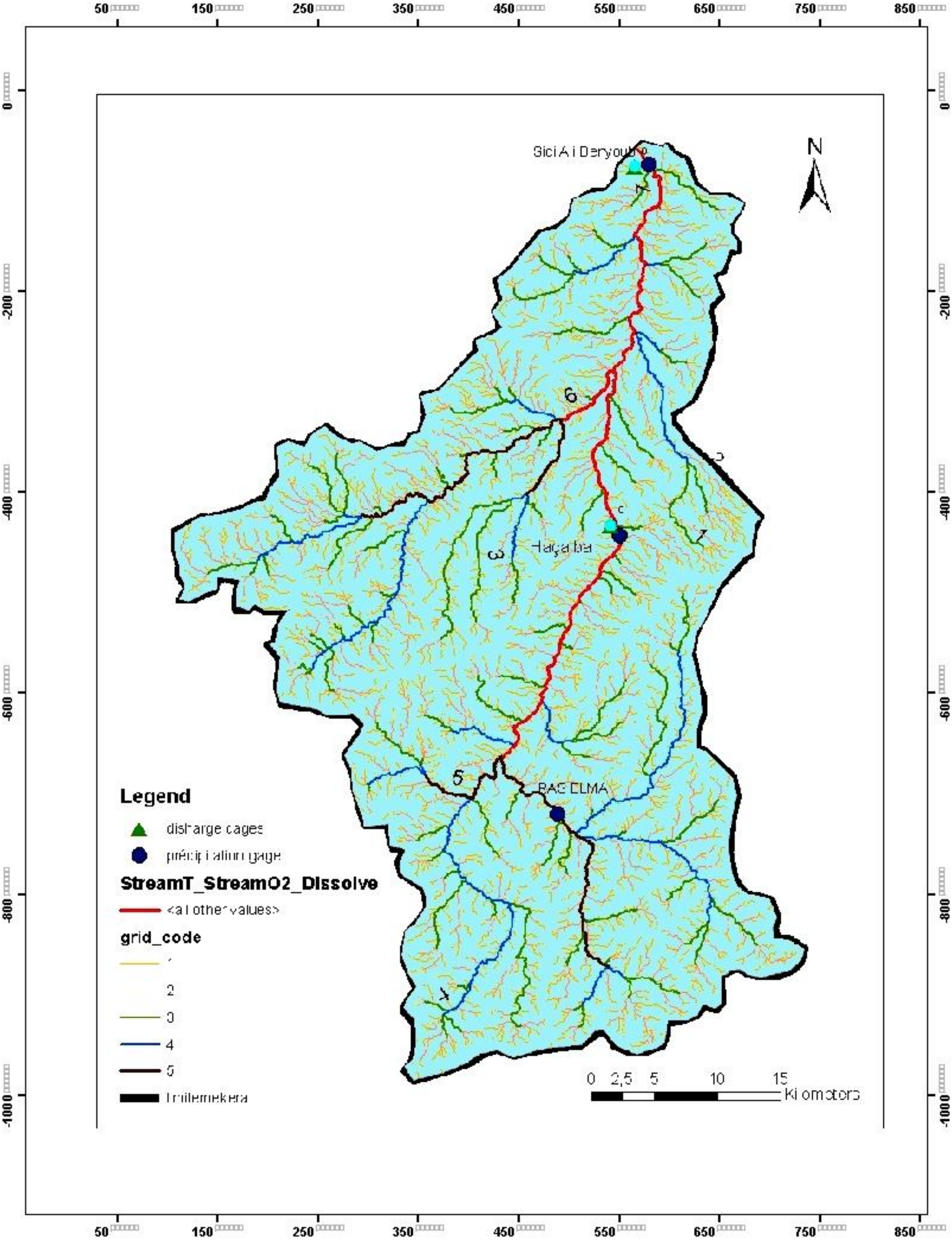


Figure 11: *Hydrographic network of the upper Mekerra watershed (Allouache.2024).*

Table 7: *Hydrographic network classification.*

Order (n)	Number (N)	Length (Km)	Average Length (Km)
1	56	217.5	7.77
2	13	135	9.03
3	3	37.25	29.37
4	1	21.76	21.76
Sum	90	411.51	67.93

- Long profile of the wadi's axis:

The Mekerra wadi has a fairly regular longitudinal profile. This profile is derived from a topographic map at a 1/200,000 scale, taking into account the altitude and length of the watercourse at the outlet. The profile is shown in Figure (I-14).

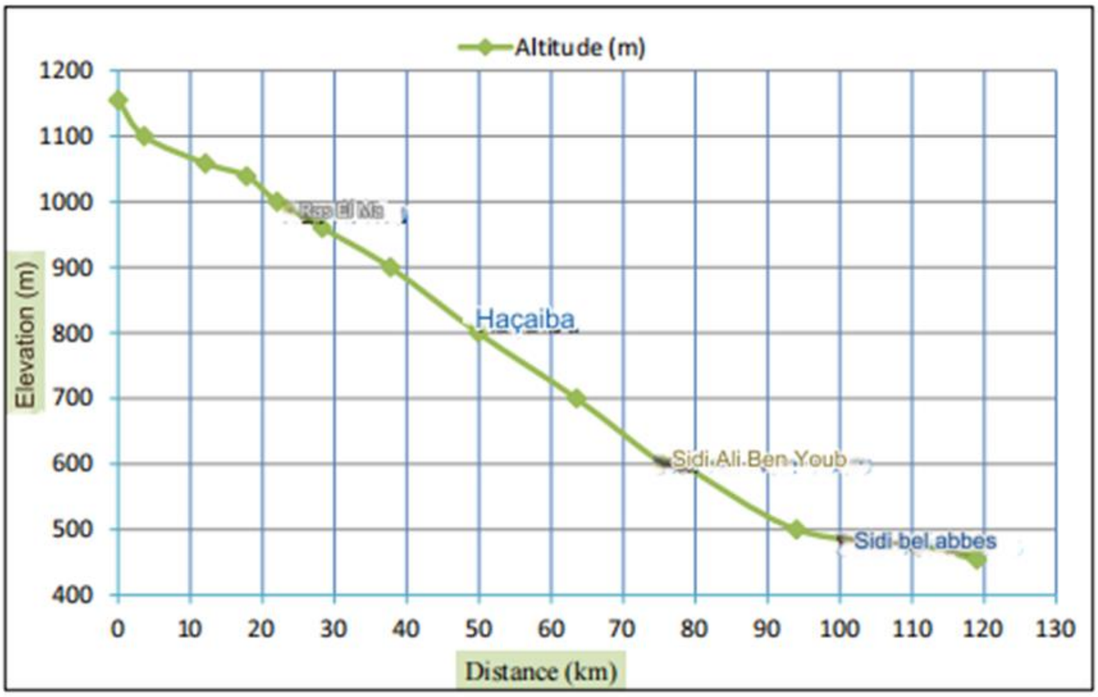


Figure 12: *Long profile of wadi Mekerra.*

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II.4.5 STUDY OF THE HYDRORAPHIC NETWORK:

Several parameters are used to characterize the hydrographic network, with some of the most significant being drainage density (**Dd**), confluence ratio (**Rc**), length ratio (**Rl**), and time of concentration (**Tc**).

- Drainage density:

It is defined by the ratio of the total length of watercourses to the surface area of the watershed:

$$D_d = \frac{\sum L}{A} (km^{-1}) \qquad \text{(II-10)}$$

∑L: sum of the lengths of all watercourses of order i in (km).

A: surface area of the watershed (Km2).

Drainage density is affected by the geological and topographic characteristics of the watershed, and to some extent by climatic conditions. A high stream order, along with high drainage density, indicates a dense hydrographic network, which likely enables rapid drainage of the basin.

Table 8: *Drainage density calculations.*

	Stream Length (Km)	A (Km)	D_d
Upper Mekerra	**411,51**	**1871,85**	**0,22**

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- Confluence ratio:

It is given by the following relation:

$$R_c = \frac{N_n}{N_{n+1}} \qquad \text{(II-11)}$$

With:

RC: river confluence ratio;

n: order of a watercourse u varies between 1 and w (w is the order of the main watercourse, classification according to Strehler);

Nn: number of watercourses of order u;

Nn+1: number of rivers of the following order.

Table 9: *Confluence ratio.*

Order	1/2	2/3	3/4	moy
Upper Mekerra	4.07	4.33	3	4.96

- Length ratio (Rl):

It represents the quotient of the length of thalwegs of order "n" by the length of the thalwegs of higher order "n+1", given by the relation:

$$R_L = \frac{L_{n+1}}{L_n} \qquad \text{(II-12)}$$

With Rl: length ratio.

Ln: Average length of thalwegs of order n.

Ln+1: Average length of thalwegs of order n+ 1.

Table 10: *Length ratio.*

Order	1/2	2/3	3/4	sum
Upper Mekerra	0.62	0.27	0.58	0.49

- Concentration time:

This is the time it takes for a particle of water coming from the hydraulically most point away from the basin to reach the outlet.

For its calculation, we use the following formulas:

1) **Giandotti formula (Southern Italy, 1937):**

It was developed in Italy in 1937 by Professor Mario Giandotti on the database of several watersheds.

$$t_c = \frac{4\sqrt{A}+1.5L}{0.8\sqrt{H_{avg}-H_{min}}} = 20{,}70\ hours \qquad \text{(II-13)}$$

With

tc: concentration time (hour).

A: area of the basin (km2).

L: length of the main thalweg (km).

Havg: average altitude (m).

Hmin: minimum altitude (m).

We will use Giandotti's formula for determining the time of concentration, because it gives results more adapted to the pool.

Table 11: *Concentration time (Giandotti)*

	A(Km²)	L(Km)	Havg(m)	Hmin(m)	Tc(H)
Upper Mekerra	**1744,81**	**67,93**	**586,19**	**317**	**20,70**

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II.5 Land use:

Vegetation cover also influences runoff, in addition to the geological and soil characteristics of the land. Forests, in particular, significantly limit surface runoff, which is more pronounced on deforested land compared to forested areas. Conversely, impermeable surfaces increase the volume of flowing water and reduce the retention time within the watershed.

Analysis of the land use map (fig. II.13 and fig. II.14) reveals that the basin's cover is dominated by steppe, scrub, and forest in the upstream areas from south to north, while agriculture predominates downstream in the Sidi Bel Abbes plain, with over 50% of the area dedicated to crops.

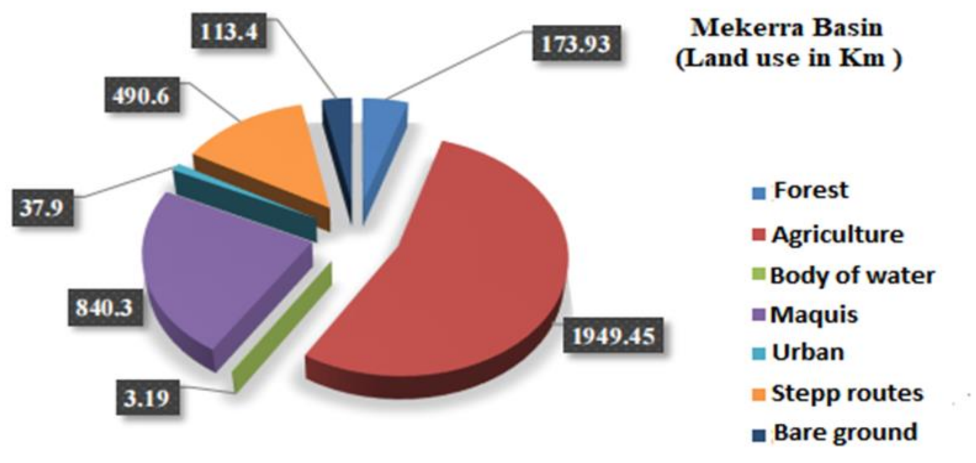

Figure 13: *Land use of Mekerra basin.*

II.5.1 Geological framework (taken from the synthesis produced by Otmane 2019):

The Mekerra basin, illustrated from north to south in fig. II.15, includes:

- Ain El Berd Depression: Primarily occupied by blue marls, which can reach a thickness of several meters to the WSW of Sig, gradually thinning along the axis of the depression until they disappear along the Boujebaa fault.
- Oued Mebtouh Bulge: Comprised of allochthonous Oligo-Miocene lands, with the NE boundary defined by the Cheurfas fault (Fenet and Magne, 1973).
- Folded Tessala Range: This represents the northern limit of the plain, extending in a NE-SW direction. It consists of a succession of Triassic, allochthonous Jurassic, and Cretaceous formations, all covered by tertiary sediments mainly affected by mild tectonic activity (Benyahia et al., 2001).

These reliefs, with their complex structures, are remnants of the ancient Mediterranean furrow, divided into two primary groups:

- Middle and Upper Cretaceous: A marl-clay ensemble with a salt-bearing Triassic sole and gypsum, in anomalous contact with the pre-Miocene substrate.
- Oligo-Miocene: Consisting of blue clay formations and organogenic limestones, which include fragments of the Middle and Upper Eocene, lying in anomalous contact with the Middle and Upper Cretaceous.

To the east, these formations give way to a continental series from the Pliocene era.

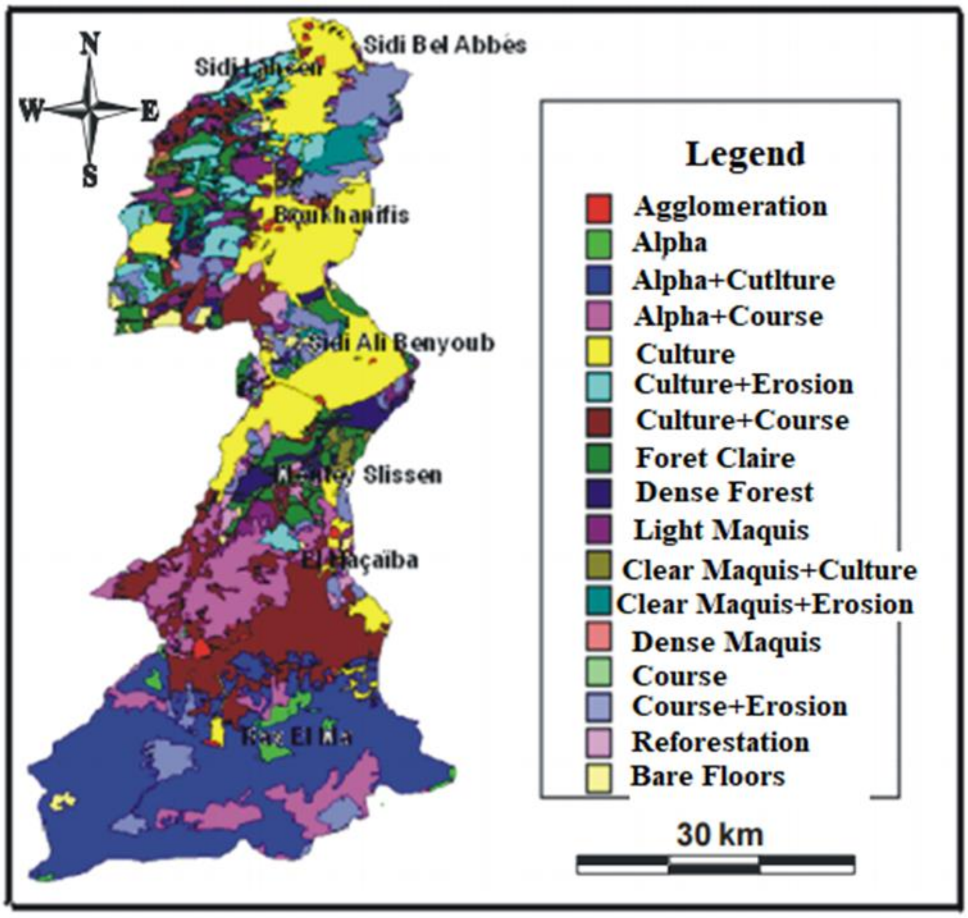

Figure 14: *Lithology of the wadi Mekerra watershed.*

II.6 Hydrogeology:

Our work will focus on determining the main hydrogeological characteristics and will particularly investigate the surface water-groundwater interactions through the study of Oued-aquifer relationships.

The plain of Sidi Bel Abbes is situated between the Tell Atlas to the north and the Tlemcen-Saida tabular massif (the northern edge of the high plateaus) to the south. It extends westward to the Hennaya-Isser plain and eastward towards the Mascara plain, bounded by the Sfisef strait.

This plain corresponds to the Mekerra watershed downstream, between the Sidi Ali Ben Youb lock and the Rock Threshold downstream of Sidi Bel Abbes. The study region can be subdivided into four distinct hydrogeological entities (fig. 18):

- Plio-Quaternary alluvial layer.
- Pliocene sandstone aquifer of the Tenira forest.
- Eocene limestone aquifer of Sidi Ali Boussidi (aquifer of carried soils).
- Jurassic-Cretaceous limestone and dolomite aquifer of Sidi Ali Ben Youb.

II.7 Conclusion:

The morphometric study of the Oued Mekerra watershed made it possible to provide information on the following characteristics:

Table 12: *Wadi Mekerra characteristics.*

Parameters	Upper Mekerra
Area (Km2)	1871.85
Perimeter (Km)	200
Gravelius coefficient	1.65
Equivalent length (Km)	109.46
Equivalent width (Km)	17.1
Average altitude (m)	848.5
Overall slope (%)	0.44
Roche slope index (%)	0.0936
Average slope (%)	0.57
Drainage density (km/ Km2)	0.222
Concentration time (h)	20.7

With low to fairly high relief and an elongated shape, the Mekerra basin resembles an oak leaf. It features low drainage density and a poorly developed, poorly hierarchical hydrographic network, predominantly occupied by agricultural land. Over 57% of the soil is brown limestone type.

Chapter III:

Rainfall analysis.

CHAPTER III: Rainfall analysis.

III.1. Introduction:

The aim of the climate study is to provide an overview of the variation of different factors. Climatic conditions in the watershed. Either on a temporary scale over a long period observation (several decades), or on a spatial scale (the variation from one region to the other). Among these factors we distinguish, precipitation, especially rainfall, temperature and evapotranspiration. Through which, we can define the type of climate of the watershed.

This chapter includes a study of climatic factors such as precipitation: the rainfall, temperature, and other factors which play a particular role in the hydrological behavior of watercourses and solid transport.

III.2. Precipitation study:

To better understand the study of rainfall, we used rainfall series monthly averages for rainfall stations in the Mekerra basin. These stations are distributed in this basin as shown in figure (III-1) Geographical characteristics (Lambert coordinates) with their observation periods are given in the table.

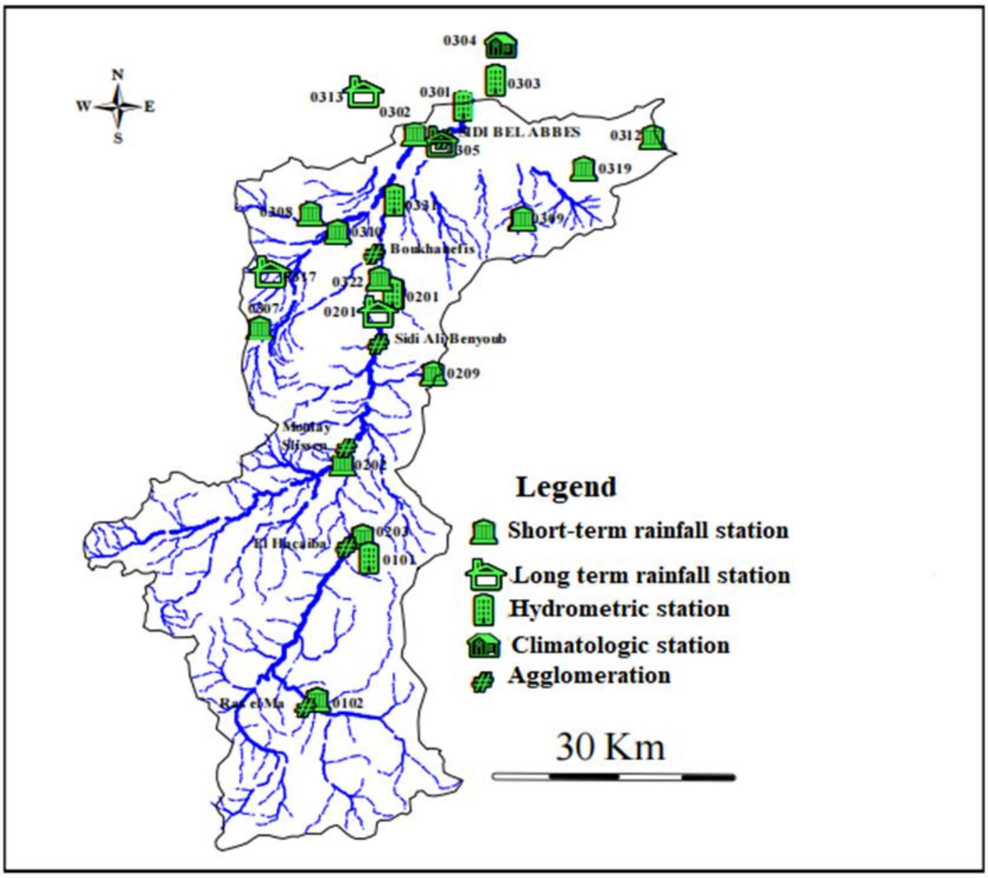

Figure 15: *Location of pluviometric, hydrometric and climatological stations in the wadi Mekerra basin.*

Table 13: *Characteristics of the rainfall stations in the Mekerra basin.*

Station Name	Code	Contact details Lambert			Period
		Z (m)	X (m)	Y (m)	
S.B.A (city)	110305	485	194250	215600	1990-2005
Sidi Ali Ben Youb	110201	635	186500	192200	1990-2005
Haçaiba	110203	950	183300	161600	1990-2005
Ras EL Ma	110102	1097	177700	138800	1990-2005

The table above (21) shows that all watershed stations have a long observation period which extends from 1990 to 2005 and does not contain any gaps annual.

The double accumulation method is used to verify the homogeneity of the annual totals of the series of the rain gauge station at the SIDI BEL ABBES station, figures (16), (17), (18), confirms this homogeneity.

The results of correlation analysis for the rainfall records of the different stations, are given in table (14).

In general, we observe that the alignment of observation points is acceptable, except that of (S.B.A -Ras El Ma). This is linked by the distance between these two stations (80 km). But overall, the correlation between the data from these stations with those from S.B.A is satisfactory, because the correlation coefficient is very high (0.9942).

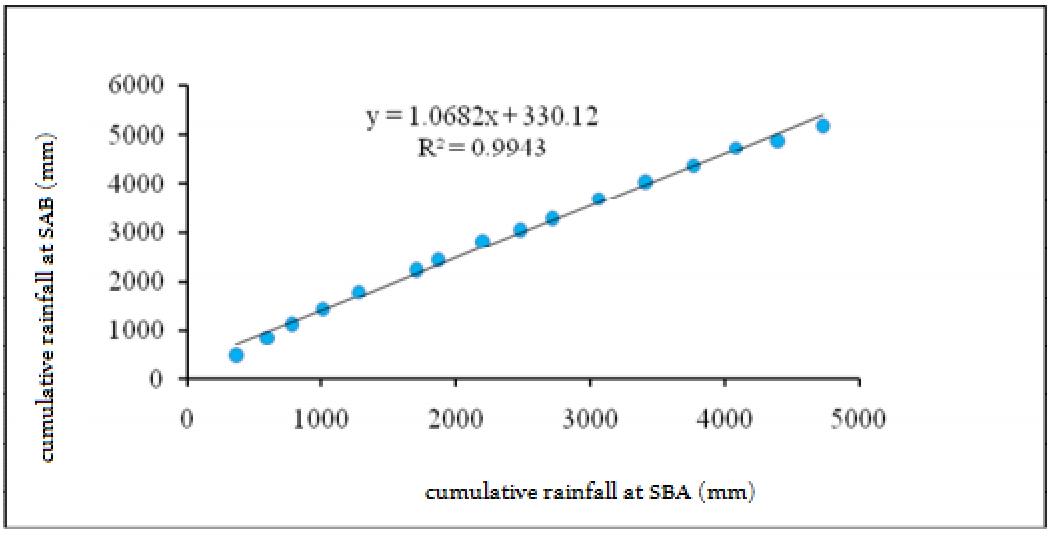

Figure 16: *Woolen regression between annual rainfall at SAB and S.B.A stations.*

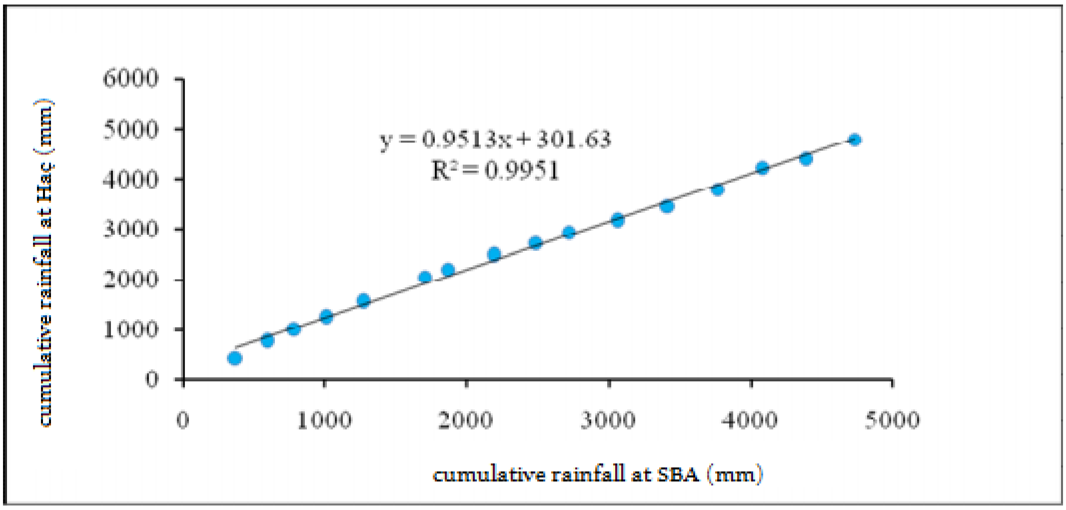

Figure 17: *Woolen regression between annual rainfall at HAC and S.B.A stations.*

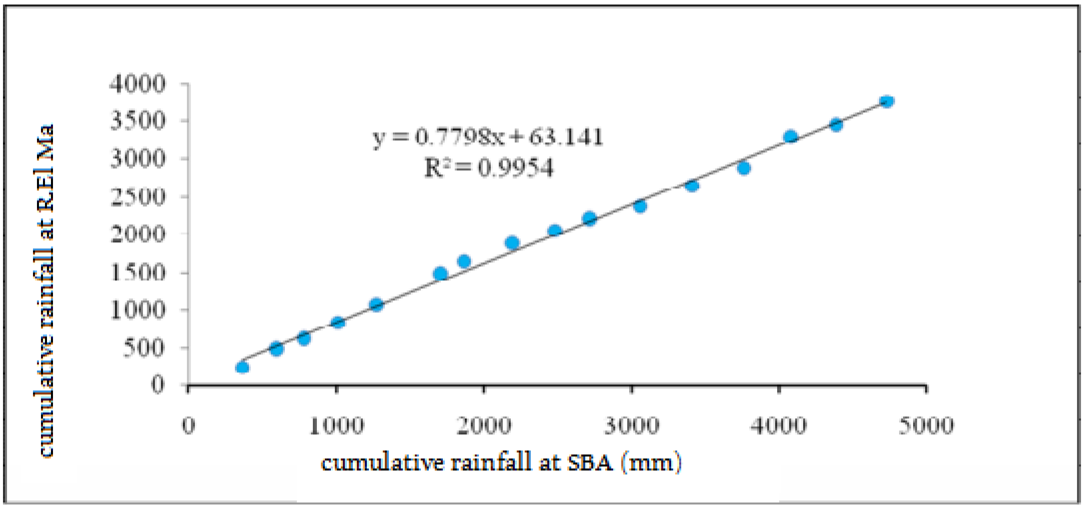

Figure 18: *Woolen regression between the annual rainfall of the RAS EL MA and S.B.A stations*

Table 14: *Correlation and regression table.*

Stations	correlation coefficient (R^2)	regression line
SAB/SBA	0.9943	y = 1.0682x + 330.12
SBA/HAÇ	0.9951	y = 0.9513x + 301.63
SBA/R.El Ma	0.9954	y = 0.7798x + 63.141

III.2.1Adjustment of daily maximum rainfall:

The adjustment was carried out using the “HYFRAN” software.

Among the five most used laws or statistical models, the series was adjusted maximum daily rainfall to Gumbel's law (double exponential).

Table 15: *Statistical parameters of maximum daily rainfall.*

Basic statistics	S.HAÇAIBA	S.SIDI ALI BENYOUB	S.SIDI BEL ABBES
Minimum	13,4	16	15,8
Maximum	63,5	77,2	73
Average	31,8	37,97	35,54
Standard deviation	10,3	15,78	13,42
Median	31,1	35,95	32,05
Coefficient. variation (Cv)	0,323	0,416	0,378
Asymmetry coefficient (Ac)	0,868	0,755	1,09
Coefficient. flattening (Cf)	4,33	2,5	3,63

III.2.1.1. Short-term rains:

Short-term rain is used for flood estimation. Calculating rainfall short durations for different frequencies was carried out using the Body relation expressed by:

$$P_t = Pj_{max} x \left(\frac{t}{24}\right)^b \qquad \text{(III-1)}$$

Pt: short-term rains with frequency given in (mm)

Pjmax: daily rainfall with frequency given in (mm)

t: time in hours.

b: climatic exponent is calculated by the formula (III.2).

The results are given in table (16)

$$b = 1 + \frac{ln\left(\frac{Pjmax}{24}\right) - \ln(25)}{\ln(24) - \ln(0.5)} \qquad \text{(III-2)}$$

The rainfall intensity is given by the following formula:

$$I_t = \frac{P_t}{t} \qquad \text{(III-3)}$$

Table 16: *Values of the climatic exponent for the three rainfall stations of wadi Mekerra.*

Station	Pj Max (mm)	Climatic exponent
HAÇAIBA	31.76	0.24
SIDI ALI BENYOUB	37.97	0.29
SIDI BEL ABBES	35.54	0.27
Pelvis (average)	35.09	0.27

The intensity and short-term rain corresponding to a variable time step, are represented for the three stations and of different frequencies, in table 17:

Table 17: *Different frequencies for the three stations.*

		10		20		50		100	
Station	t (h)	pt (mm)	It (mm/h)	pt (mm)	It (mm/h)	pt (mm)	It (mm/h)	pt (mm)	It (mm/h)
Haçaiba	0.5	18.50	37.00	21.02	42.03	24.32	48.65	26.76	53.53
	1	21.86	21.86	24.84	24.84	28.74	28.74	31.63	31.63
	2	25.83	12.92	29.35	14.67	33.97	16.98	37.37	18.69
	3	28.48	9.49	32.36	10.79	37.45	12.48	41.21	13.74
	4	30.53	7.63	34.68	8.67	40.14	10.03	44.16	11.04
	6	33.66	5.61	38.24	6.37	44.26	7.38	48.70	8.12
	12.41	**40.10**	**3.23**	**45.56**	**3.67**	**52.72**	**4.25**	**58.01**	**4.67**
	18	43.85	2.44	49.82	2.77	57.66	3.20	63.45	3.52
	24	47.00	1.96	53.40	2.23	61.80	2.58	68.00	2.83
Sidi Ali Benyoub	0.5	19.19	38.39	22.12	44.25	25.91	51.82	28.74	57.48
	1	23.42	23.42	26.99	26.99	31.61	31.61	35.07	35.07
	2	28.57	14.29	32.93	16.47	38.57	19.28	42.78	21.39
	3	32.10	10.70	37.00	12.33	43.33	14.44	48.06	16.02
	4	34.86	8.72	40.18	10.05	47.06	11.76	52.20	13.05
	6	39.16	6.53	45.14	7.52	52.87	8.81	58.64	9.77
	9.78	**45.06**	**4.61**	**51.94**	**5.31**	**60.82**	**6.22**	**67.47**	**6.90**
	12	47.78	3.98	55.08	4.59	64.50	5.38	71.55	5.96
	18	53.68	2.98	61.87	3.44	72.46	4.03	80.38	4.47
	24	58.30	2.43	67.20	2.80	78.70	3.28	87.30	3.64
Sidi Bel Abbes	0.5	17.38	34.76	19.82	39.64	23.01	46.02	25.38	50.76
	1	21.21	21.21	24.18	24.18	28.08	28.08	30.97	30.97
	2	25.88	12.94	29.50	14.75	34.26	17.13	37.79	18.89
	3	29.07	9.69	33.14	11.05	38.48	12.83	42.45	14.15
	4	31.57	7.89	36.00	9.00	41.80	10.45	46.10	11.53
	6	35.47	5.91	40.44	6.74	46.95	7.83	51.79	8.63
	12	43.27	3.61	49.34	4.11	57.29	4.77	63.19	5.27
	14.62	**46.19**	**3.16**	**52.66**	**3.60**	**61.15**	**4.18**	**67.44**	**4.61**
	18	48.62	2.70	55.43	3.08	64.36	3.58	70.99	3.94
	24	52.80	2.20	60.20	2.51	69.90	2.91	77.10	3.21

The graphs representing the short-term rainfall curves and the Intensity-Duration Frequency curves for the three stations and at different frequencies are given in figures (19, 20, 21, 22, 23 and 24).

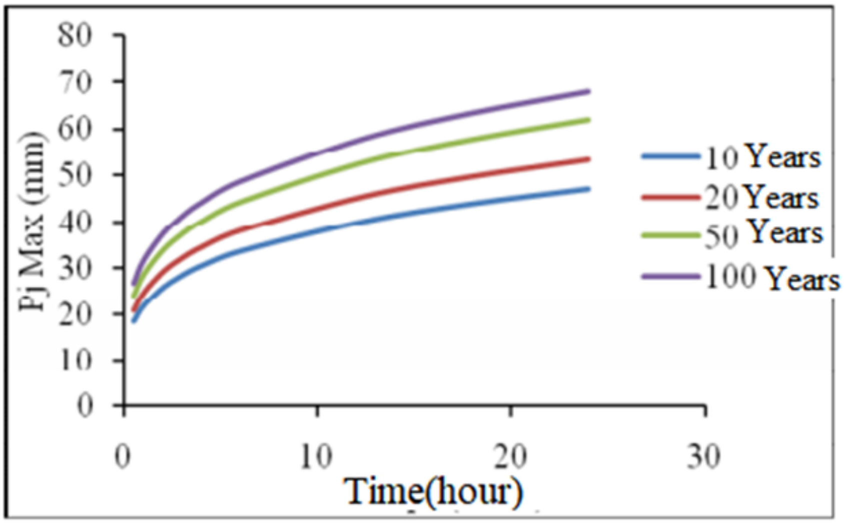

Figure 19: *Short-term rainfall curve in Haçaiba.*

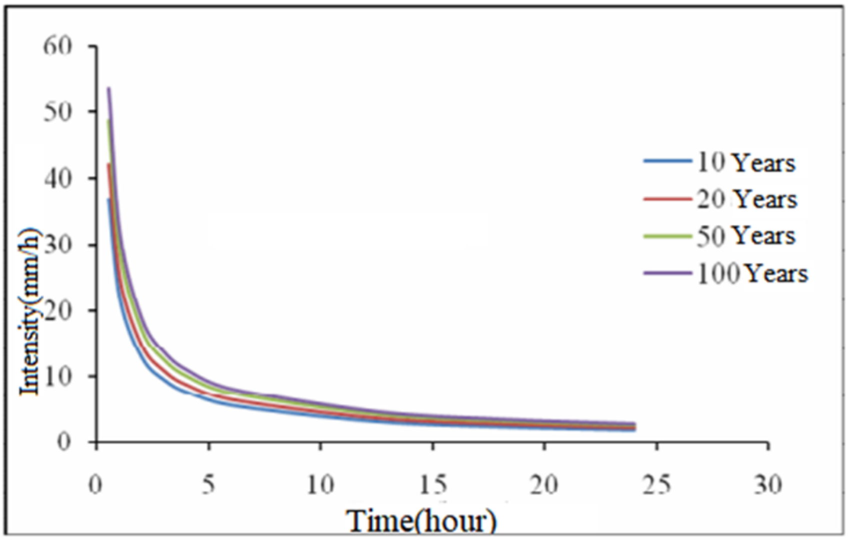

Figure 20: *Intensity-Duration-Frequency curve in Haçaiba.*

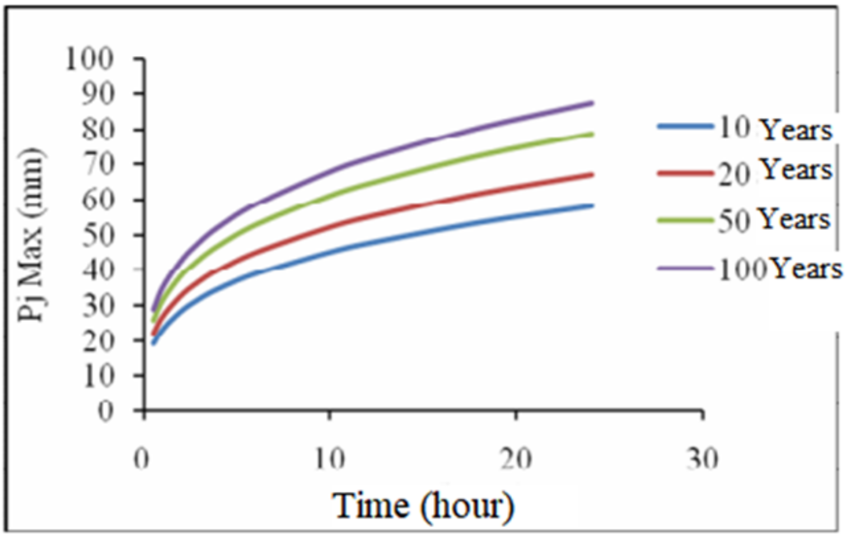

Figure 21: *Short-term rainfall curve in Sidi Ali Benyoub.*

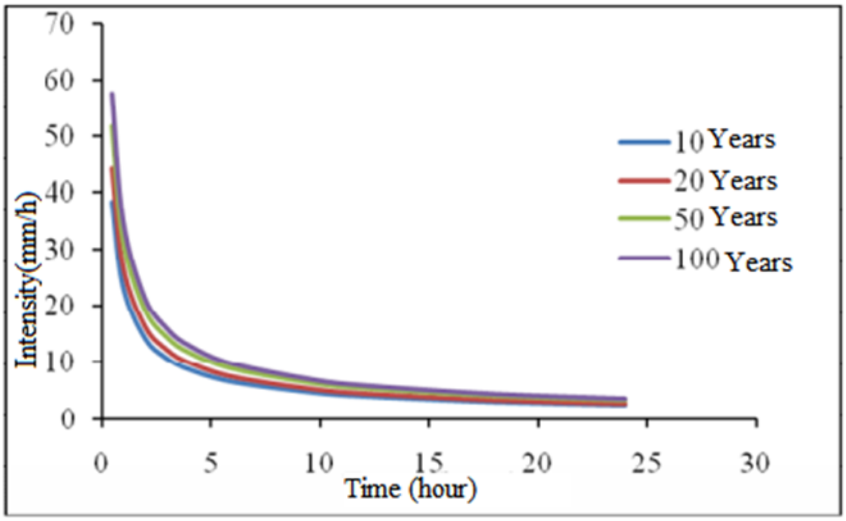

Figure 22: *Intensity-Duration-Frequency curve in Sidi Ali Benyoub.*

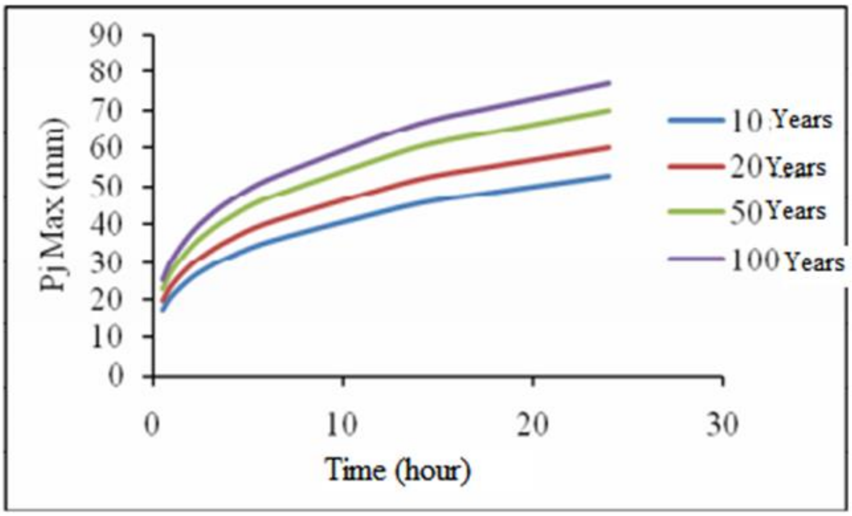

Figure 23: *Short-term rainfall curve in Sidi Bel Abbes.*

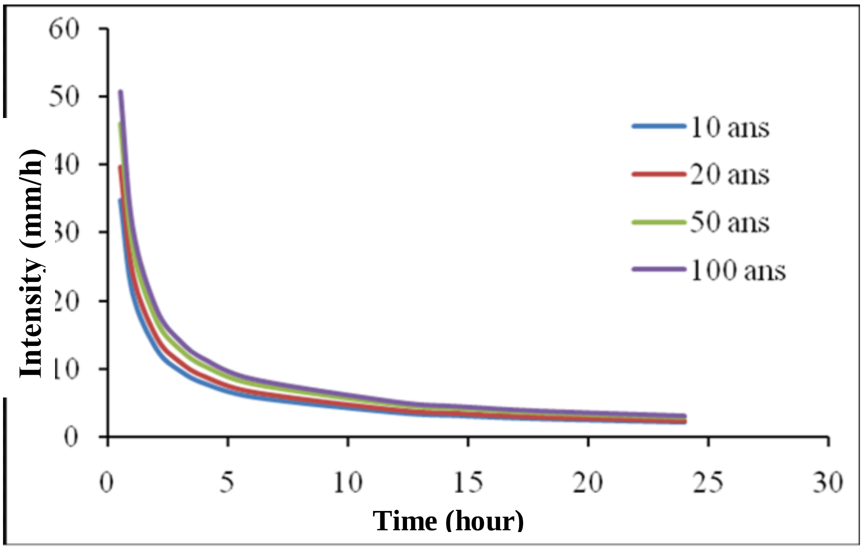

Figure 24: *Intensity-Duration-Frequency curve in Sidi Bel Abbes.*

Among the three laws of adjustment, the GUMBEL line gives, in our case, the best law for adjusting daily maximum precipitation:

At the Haçaiba station, the maximum daily rainfall (figure 19) corresponding to concentration time 12.41 h and for a recurrence period of 100 years, is 58.01 mm, and the maximum intensity (figure 20) is (I1 2 .4 1 h, 1 0 0 %=4.67 mm/h).

At the Sidi Ali Ben Youb station, the maximum daily rainfall (figure 21) corresponding to the concentration time 9.78 h and for a recurrence period of 100 years, is 67.47 mm, and the maximum intensity (figure 22) is (I9.7 8 h, 1 0 0 %= 6.90 mm/h).

At the Sidi Bel Abbes station, the corresponding maximum daily rainfall (figure 23) at concentration time 14.62 h and for a recurrence period of 100 years, is 67.44 mm, and the maximum intensity (figure 24) is (I14.62 h, 100% = 4.61 mm/h)

FLOOD STUDY:

III.2.2 Adjustment of max flow rates by Gumbel:

The purpose of flood forecasting is to identify the most significant frequent floods to ensure maximum safety for structures. These floods can be determined using the Gumbel distribution, which is best suited for extreme flows and inputs. In this case, we have a series of hydrometric measurements spanning 23 years of daily maximum flows. These measurements are fitted to a statistical distribution using the Hydrognomon model to estimate the most probable flood flows for different return periods. The Gumbel distribution function for exceedance frequencies is as follows:

$$F(X) = e^{-e^{-\frac{x-a}{b}}} \qquad \text{(III-4)}$$

Reduced Gumbel variable:

$$g = -[ln(F(X))] \qquad \text{(III-5)}$$

III.2.2.1 Frequency study of maximum observed floods:

Haçaiba Station:

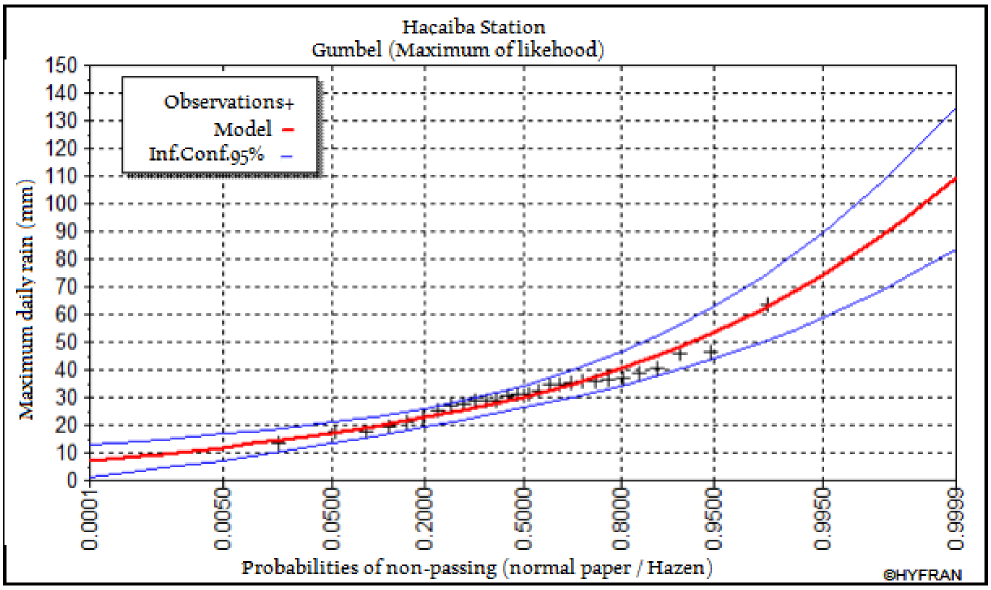

Figure 25: *Adjustment to Gumbel's law of Haçaiba station.*

Table 18: *Maximum frequency throughput of Haçaiba station.*

Year	**10**	**20**	**50**	**100**
Frequency	0.9	0.95	0.98	0.99
Qmax	184	259	380	491
Standard deviation	47	75.4	127	180
Int. Conf.	91.8-276	111-407	130-630	138-843

Sidi Ali Benyoub station:

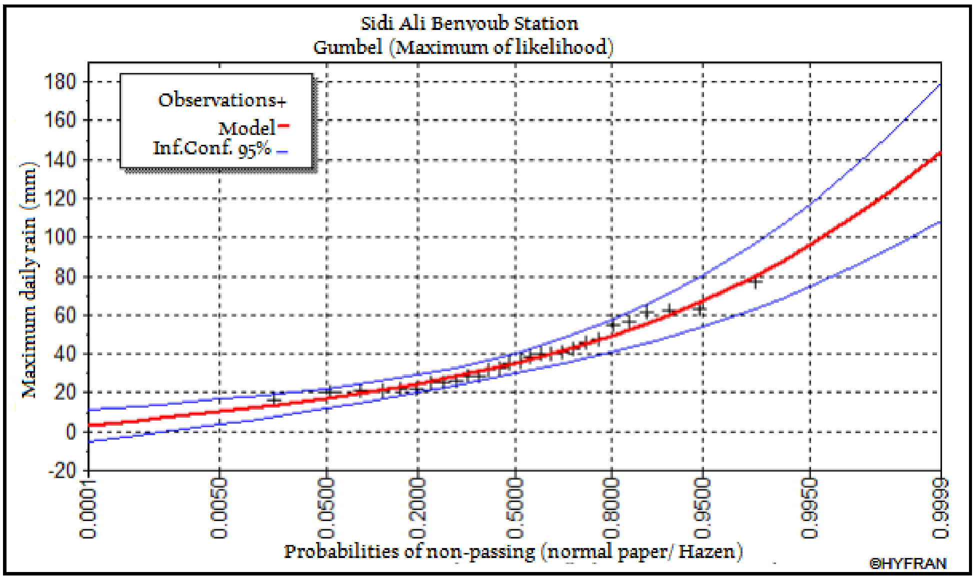

Figure 26: *Adjustment to Gumbel's law of the Sidi Ali Benyoub station.*

Table 19: *Maximum frequency flow pf the Sidi Ali Benyoub.*

Year	10	20	50	100
Frequency	0.9	0.95	0.98	0.99
Qmax	519	800	1300	1800
Standard deviation	162	284	533	805
Int. Conf.	201-836	242-1360	257-2350	-

Sidi Bel Abbes station:

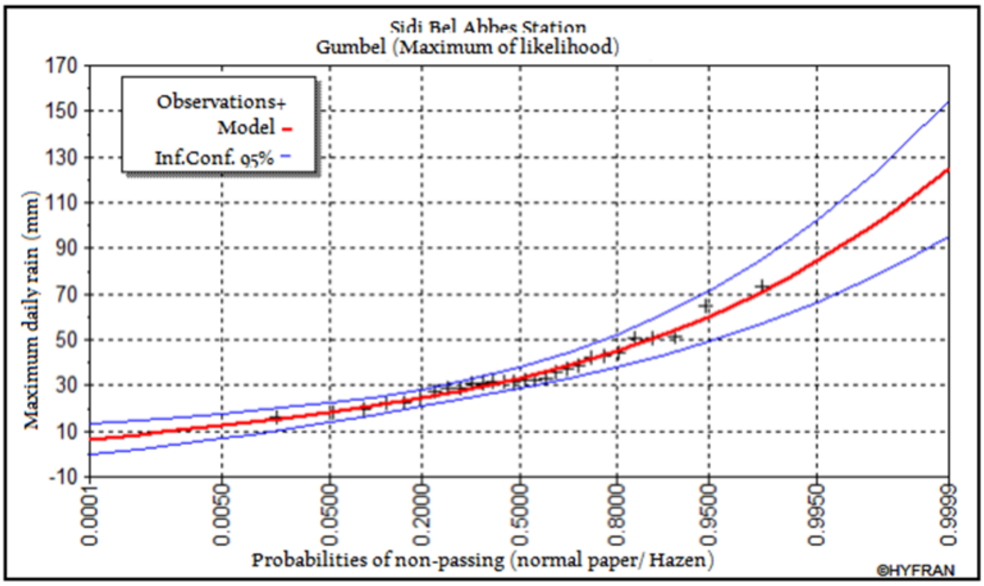

Figure 27: *Adjustment to the normal log law of the Sidi Bel Abbes station.*

Table 20: *Maximum frequency throughput of Sidi Bel Abbes station.*

Year	10	20	50	100
Frequency	0.9	0.95	0.98	0.99
Qmax	225	337	533	723
Standard deviation	65.8	113	205	304
Int. Conf.	95.6-354	117-558	131-934	-

III.4 Conclusion:

The application of the Gumbel distribution in our rainfall analysis study of the Upper Mekerra watershed has proven to be an effective method for understanding and predicting extreme hydrological events. By utilizing the Gumbel distribution, we have been able to accurately model the frequency and magnitude of extreme rainfall events, which are critical for flood risk assessment and water resource management.

The analysis revealed that the Gumbel distribution effectively captures the variability and extremity of rainfall patterns in the Upper Mekerra region. This statistical approach has allowed us to estimate the return periods of significant rainfall events, providing valuable insights into the potential for future flooding. The characteristics of the Gumbel distribution, particularly its suitability for extreme value analysis, make it an indispensable tool for hydrological studies in this region.

Key findings from our study include:

- Accurate predictions of extreme rainfall events and their return periods, essential for designing flood mitigation infrastructure.
- Identification of critical thresholds for rainfall that can trigger significant flooding, aiding in the development of early warning systems.
- Enhanced understanding of the hydrological behavior of the Upper Mekerra watershed, supporting sustainable water resource management and planning.

In conclusion, the use of the Gumbel distribution has greatly enhanced our ability to analyze and predict extreme rainfall events in the Upper Mekerra watershed. This approach provides a robust statistical foundation for managing flood risks and developing strategies to mitigate the impact of extreme hydrological events. By leveraging the insights gained from this study, we can improve our preparedness and resilience against future flooding, ensuring the safety and well-being of the communities in the Upper Mekerra region.

Chapter IV:
Application of the HEC-HMS model.

CHAPTER IV: APPLICATION OF THE HEC-HMS MODEL

IV.1 Introduction:

HEC-HMS operates on the principle of distinct tasks, which allows it to simulate a watershed as a uniform system composed of multiple components. Each component represents a specific aspect of the rainfall-runoff process and acts in succession to produce the flow hydrograph. The flexibility of HEC-HMS lies in its modular design, which allows users to select and configure modules according to their specific needs and data availability. By altering the formalisms within a module, HEC-HMS can transition between different types of models, such as from event-based to continuous, from lumped to distributed, and from empirical to conceptual models.

IV.2 The operating process:

As we just mentioned in the previous chapter, the HEC-HMS assigns to each module a step of the rainfall-runoff transformation, and it is the combination of the results of the modules with each other which gives the final hydrograph.

IV.2.1 FEATURES:

Input data can be designed for watershed elements such as sub-basins and stream sections or simultaneously for groups of similar elements. The tables and forms for entering the necessary data are accessible {from a visual diagram of the watershed. To carry out a first simulation, it is necessary to create a database to characterize the watershed and determine the rainfall which will be used as input data to the model.

The main stages of the simulation are:

- Starting a new project.
- Definition of the watershed model.
- Data from the weather station(s).
- Definition of the precipitation model.
- Definition of simulation control parameters.
- Creation and execution of a simulation.
- Visualization of results.

IV.2.2 Data Requirements for HEC-HMS Simulation:

Applying the HEC-HMS model requires a comprehensive dataset related to the watershed or study sites to ensure accurate simulation. The essential data for our case includes:

a) Morphometric Characteristics of the Basins:

- Sub-basin Areas: The surface area of each sub-basin.
- Soil Type: Classification and properties of the soil.
- Vegetative Cover: Types and extent of vegetation cover.

b) Meteorological Characteristics:

- Precipitation: Detailed rainfall data.
- Evapotranspiration: Data on the evaporation and transpiration rates.
- Control Specifications Data: Parameters required for simulation control.
- Initial Date: Starting date for the simulation period.
- Final Date: Ending date for the simulation period.
- Calculation Time Interval: The time step for the simulation calculations.

IV.3 Watershed Schematic with HEC-HMS

The initial step in using HEC-HMS involves schematizing the studied watershed into fundamental interconnected elements, resembling a branched tree. HEC-HMS allows for the representation of all natural and artificial entities within a watershed that influence the rainfall-runoff transformation process. These entities include sub-basins, outlets, river channels, water diversion channels, reservoirs, and dam impoundments.

The key elements and their roles in representing the watershed state are:

1. **Sub-basin Element**: Represents the entire basin in a global model or individual sub-basins in a semi-distributed model. Basic attributes include the area, associated production function, and transfer function.
2. **Reach Element:** Typically represents the river, connecting various elements within the model. The primary associated information is the routing function.
3. **Reservoir Element:** Describes reservoirs and dam impoundments, with characteristics that define storage and release conditions.

In our case, this schematization step will be fully and automatically conducted using **ARC GIS** and **WMS** software during the physical characterization phase. These tools help in accurately identifying and representing different entities and their interactions within the watershed, ensuring precise and effective hydrological modeling with HEC-HMS.

Subsequent processing of the digital terrain model (DEM) by HEC-HMS produced seven sub-basins, seven routing reaches, six junctions and the main physiographic features of the watershed, as illustrated in Figure (28).

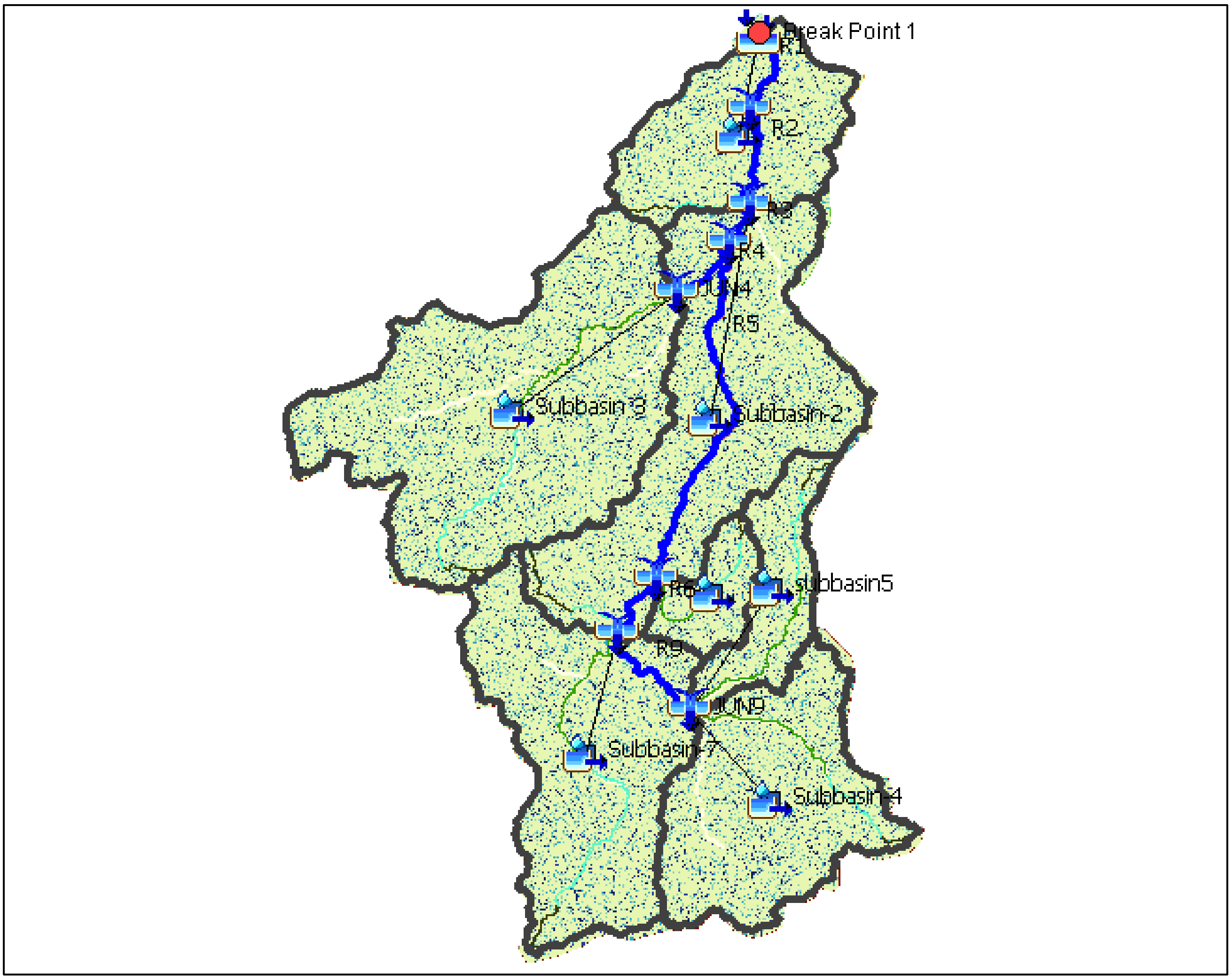

Figure 28: *The study area under HEC-HMS (Allouache.2024)*

IV.3.1 Computation of sub watershed curve number:

Runoff curve number is the main watershed parameter for the estimation of runoff. The curve number was generated by combining soil and land cover of the watershed. The final curve number grid map is shown in Figure 35. The CN value varies from 30 for urban area to 98 for water body. Figure 29 indicates the range of curve number in different colors. The minimum curve number 75 represented by red color, which is for urban area, and the maximum curve number 88 is represented by green color, which represents semi-arid region. Subsequently, the weighted average value of CN for each sub-watershed computed using the parameter estimation tool of the HEC-HMS.

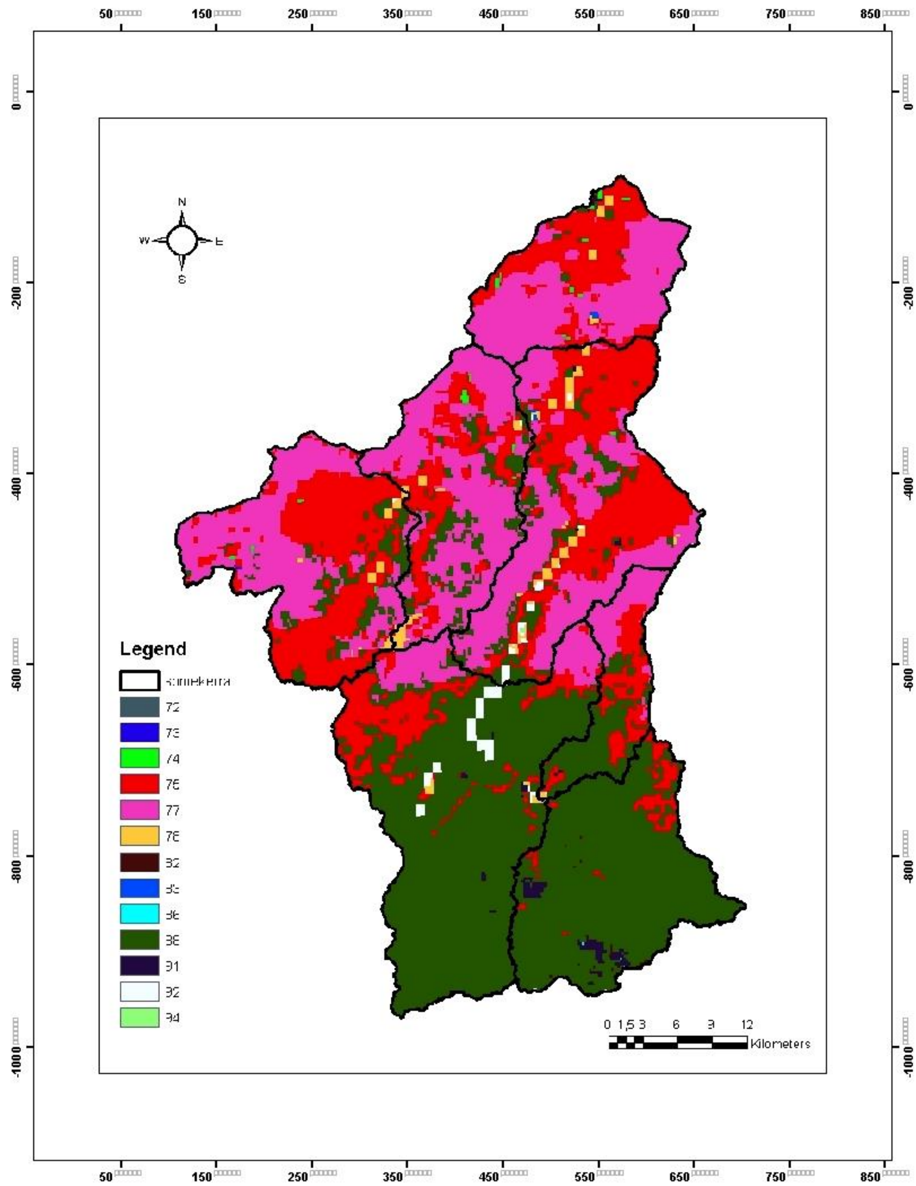

Figure 29: *Curve number grid map of the upper Mekerra watershed (Allouache.2024).*

IV.3.1 Computation of lag time:

The lag time (tlag) is one of the input parameters for the SCS unit hydrograph of the transform method. For this study, HEC-HMS tool was used to compute the lag time for each sub-watershed using Concentration time;

Lag time = concentration time * 0, 6

The concentration time is calculated by S.C.S formula

S.C.S (Soil Conservation Service) formula:

$$T_c = \left(\frac{0.87 Lp^3}{H}\right) 0.385 \qquad \textbf{(IV-1)}$$

Tc: Concentration time (h).

Lp: Length of the main thalweg (Km).

H: Difference between the extreme points of the thalweg

IV.3.3 Computation of Initial abstraction Ia:

Initial Abstraction is a parameter that accounts for all losses prior to runoff and consists mainly of interception, infiltration, evaporation, and surface depression storage. In theory all Rainfall minus Initial Abstraction will generate the runoff from a specified Catchment.

The formula for Initial Abstraction is utilized in the SCS method. The formula is:

$$I_a = 0.2 * S \qquad \textbf{(IV-2)}$$

With

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad \textbf{(IV-3)}$$

S = Potential maximum retention (mm) after runoff

the generated weighted CN value ,lag time and Initial Abstraction Ia for each sub-watershed is shown in Table 21.

Table 21: *Characteristics of the sub-basins.*

Sub basin	Area (km^2)	Curve number CN	Lag time mn	basin slope	Initia abstrac-tion IA
Sb1	190,70	76	30,2	0,17626	0,63
Sb2	391,0	76	64,82	0,14097	0,63
Sb3	506,16	77	47,92	0,16513	0,35
Sb4	264,42	87	51,17	0,09432	0,27

Sb5	95,018	80	61,68	0,08882	0,44
Sb6	57,462	79	34,36	0,10136	0,60
Sb7	332,02	85	66,61	0,10127	0,63

IV.4 Simulation results of the study area by HEC-HMS:

This chapter represents the simulation results of the Mekerra wadi watershed by HEC-HMS. The data necessary to obtain the results under HEC-HMS are the rainfall depth taken from the IDF curves of the rainfall stations of Sidi Ali Benyoub and Heçaiba for the period 1999-2018

IV.4.1 Sub-basin simulation results:

Project: hautemekera1 Simulation Run: Run 1

Start of Run: 23oct.2000, 06:00 Basin Model: Basin 1
End of Run: 25oct.2000, 06:00 Meteorologic Model: Met 1
Compute Time:DATA CHANGED, RECOMPUTE Control Specifications:Control 1

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Alphabetic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
R6	691,0	1096,0	23 October 2000,...	36,00
R9	359,0	892,0	23 October 2000,...	42,00
Sink-1	1837,0	1695,0	24 October 2000,...	44,00
Subbasin 3	506,0	2701,0	23 October 2000,...	56,00
Subbasin-1	190,0	901,0	23 October 2000,...	44,00
Subbasin-2	391,0	1350,0	23 October 2000,...	44,00
Subbasin-4	264,0	1204,0	23 October 2000,...	44,00
Subbasin-7	332,0	865,0	23 October 2000,...	30,00
subbasin5	95,0	308,0	23 October 2000,...	37,00
subbasin6	57,0	219,0	23 October 2000,...	31,00

Figure 30: *Sub-basin simulation results.*

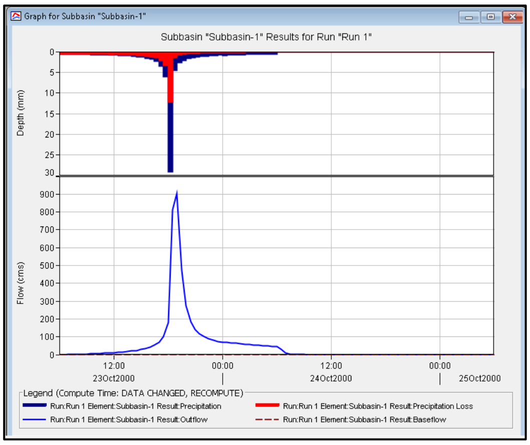

Figure 31: *Flood hydrograph of sub-basin 1.*

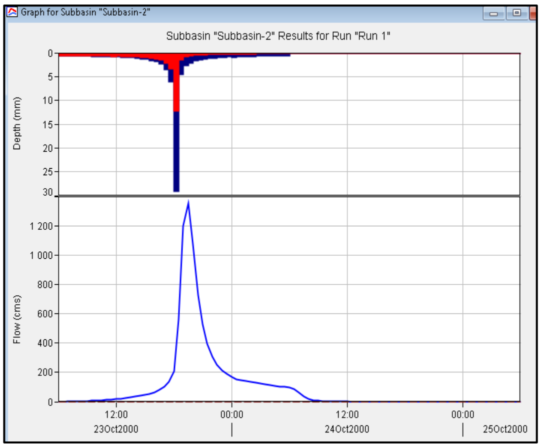

Figure 32: *Flood hydrograph of sub-basin 2.*

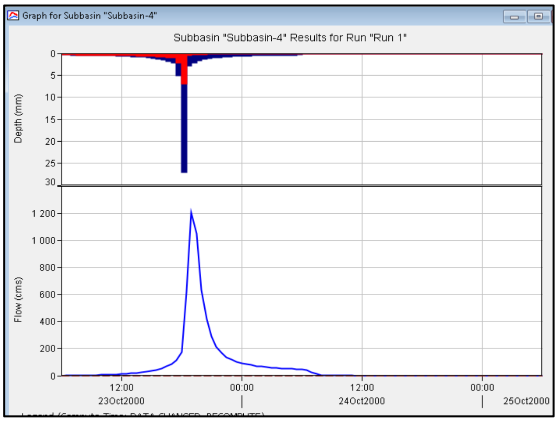

Figure 33: *Flood hydrograph of sub-basin 3.*

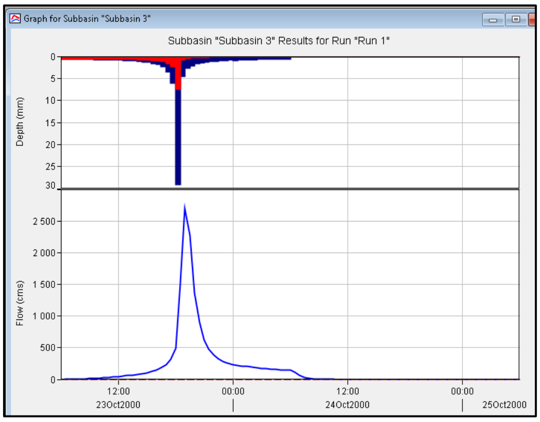

Figure 34: *Flood hydrograph of sub-basin 4.*

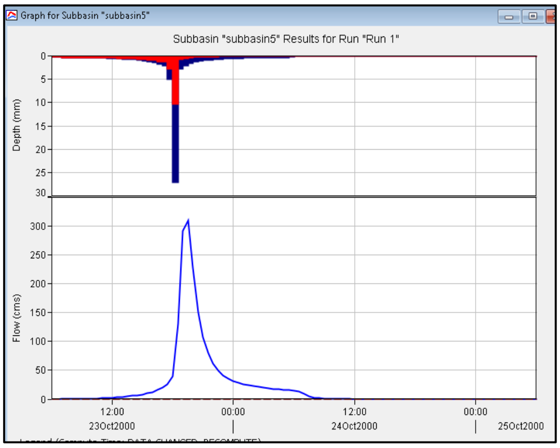

Figure 35: *Flood hydrograph of sub-basin 5.*

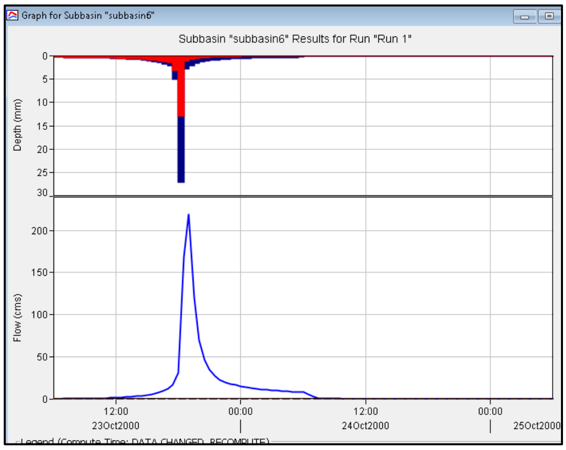

Figure 36: *Flood hydrograph of sub-basin 6.*

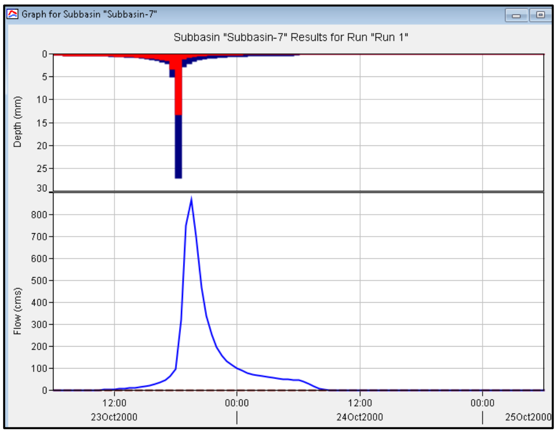

Figure 37: *Flood hydrograph of sub-basin 7.*

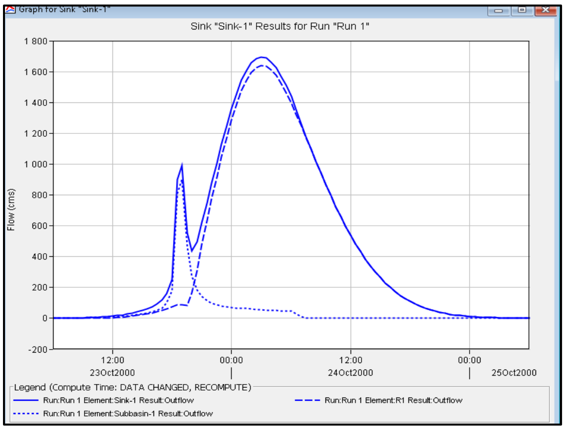

Figure 38: *Flood hydrograph of outlek (sink).*

Table 22: *Simulation results of the sub-basins.*

Sub basin	Precipitation volume(MM)	Loss volume(MM)	Excess volume(MM)	Peak Flow (m3/s)
Subbasin1	86	**41**	44	**901.1**
Subbasin2	86	**41**	44	**1350**
Subbasin3	86	**29**	56	**2701**
Subbasin4	68	**23**	44	**1204**
Subbasin5	68	**30**	44	**308**
Subbasin6	68	**36**	31	**219**
Subbasin7	68	**37**	30	**865**
sink	/	/	44	**1695**

IV.4.2 Characteristics of the sub-basins:

Sub-basin 1:

The losses by infiltration of sub-basin 1 are 41 mm (table 22), the soil of sub-basin 1 has an average infiltration capacity because of its agricultural nature where CN is 76. Figure (31) illustrates the flood hydrograph of sub-basin 1. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 901.0 m3/s with a peak time of 20:00, and this basin has an area of 190.70 km2.

Sub-basin 2:

The losses by infiltration of sub-basin 2 are 41 mm (table 22), the soil of sub-basin 2 has an average infiltration capacity because of its agricultural nature where CN is 76. Figure (32) illustrates the flood hydrograph of sub-basin 2. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 1350.01 m3/s with a peak time of 21:00, and this basin has an area of 334.46 km2.

Sub-basin 3:

The losses by infiltration of sub-basin 3 are 29 mm (table 22), the soil of sub-basin 3 has an average infiltration capacity because of its agricultural nature where CN is 77. Figure (33) illustrates the flood hydrograph of sub-basin 3. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 2701.01 m3/s with a peak time of 19:00, and this basin has an area of 231.15 km2.

Sub-basin 4:

The losses by infiltration of sub-basin 4 are 23 mm (table 22), the soil of sub-basin 4 has an average infiltration capacity because of its agricultural nature where CN is 76. Figure (34) illustrates the flood hydrograph of sub-basin 4. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 2701.01 m3/s with a peak time of 18:30, and this basin has an area of 275.00 km2.

Sub-basin 5:

The losses by infiltration of sub-basin are 30 mm (table 22), the soil of sub-basin 5 has an average infiltration capacity because of its agricultural nature where CN is 85. Figure (35) illustrates the flood hydrograph of sub-basin 5. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 308.0 m3/s with a peak time of 20:30, and this basin has an area of 95.0 km2.

Sub-basin 6:

The losses by infiltration of sub-basin 6 are 36 mm (table 22), the soil of sub-basin 6 has an average infiltration capacity because of its agricultural nature where CN is 82. Figure (36) illustrates the flood hydrograph of sub-basin 6. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 219.0 m3/s with a peak time of 19:30, and this basin has an area of 57 km2.

Sub-basin 7:

The losses by infiltration of sub-basin 7 are 37 mm (table 22), the soil of sub-basin 7 has an average infiltration capacity because of its agricultural nature where CN is 88. Figure (37) illustrates the flood hydrograph of sub-basin 7. The appearance of the ascent curve is flat for 12 hours, after a rapid ascent of the curve which signifies soil saturation, the peak reaches a flow rate of 865.0 m3/s with a peak time of 19:30, and this basin has an area of 264.06 km2.

Outlet (sink):

The Figure (38) illustrates the flood hydrograph at the outlet. The simulated flow rate is of the order of 1700 m3/s with a very significant peak time of 23 hours which indicates the large surface area of up Mekerra basin which is 1871,85 km^2.

IV.4.3 HEC-HMS model performance evaluation criteria:

Different statistical tests of error functions have different objectives. Therefore, it is preferred to check the model performance using more than one and widely accepted error functions. In this study, Nash and Sutcliffe efficiency (NSE), coefficient of determination (R2), were selected for model performance evaluation. It is important to use multiple evaluation criteria to minimize bias during model evaluation [KUMARASAMY, BELMONT 2018]

Several previous studies proved the widely applicability of this statistics for evaluation of different hydrological model.

Nash–Sutcliffe efficiencies:

Is a measure of efficiency that relates the goodness-of- -fit of the model to the variance of measured data. NSE can range from – ∞ to one and an efficiency of one indicates perfect equivalent between the observed and simulated discharge [ZOU et al. 2003]. Mathematically, it is expressed as:

$$NSE = 1 - \frac{\sum_{t=1}^{T}\left(Q_m^t - Q_o^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \bar{Q}_o\right)^2} \qquad \text{(IV-4)}$$

Qo: observed discharge,

Qm: average observed discharge,

Qs: simulated discharge;

All Q variables have the unit runoff volume per time step (e.g. m3/s).

- Nash–Sutcliffe efficiencies can range from – ∞ to 1. An efficiency of 1 (NS = 1) corresponds to a perfect match between the modelled and observed time series, whereas an efficiency of 0 (NS = 0) indicates that the model predictions are as accurate as the mean of the observed data. If the efficiency is less than 0 (NS < 0), the observed mean is a better predictor than the model.
- The optimization was applied to the subbasin5, subbasin6, subbasin4 and subasin7 which are equipped with a gauging station el Haçaiba, from this station we were able to construct the flood hydrograph observed during the period of 23 October to 26 October 2000.
- The objective of the model optimization is to match observed simulated runoff volumes, runoff peaks and timing of hydrographs with the observed ones. In the present study, a combination of manual and automated calibration techniques was used. Automated calibration, known as “trial optimization” in HEC-HMS, was used to obtain optimum parameter values that give the best fit between observed and simulated flow volume values [RUELLAND et al. 2008].
- The hydrological model results showed a reasonable fit between simulated and observation hydrograph shape. Figures 45 and 46 a time-series comparison of simulate and observed streams flow

for the subbasin5, 6, 7 and 4 for the calibration periods 23–26 october2000 (we limit ourselves to modeling flood of short duration for which the process of evapotranspiration is negligible).

➢ After optimization of the model, we notice a greatly decreasing of peak discharge compared before optimization for the subbasin5, 7 and 4. Optimized values of the HEC-HMS parameters for a period23-26 october.2000 are presented in Table 23:

Table 23: *Optimized value of the model parameters (SCS lag and CN; Qs and Nash).*

Sub-basin ID	CN		lag time		Ia		Qs (m3/s)		Nash	
	initial	optimiz	initial	optimiz	initial	optimiz	initial	optimiz	initial	optimiz
Subbasin 5	80	62.02	61.68	35.19	0.44	0.24	308.8	230	0.78	0.83
Subbasin 6	79	78.49	36.36	33.22	0.60	0.58	219.7	233	0.40	0.58
Subbasin 4	88	35	51,17	30.6	0,27	0,001	1204	410	-7	0.53
Subbasin 7	76	35	66.61	28.7	0.63	0.001	865	516	-3	0.49

In this study, the performance of the HEC-HMS model was tested for continuous runoff simulation of up Mekerra watershed. The sensitivity analysis indicated that curve number and lag time were the most sensitive parameters whereas, the initial abstraction was moderately sensitive parameter.

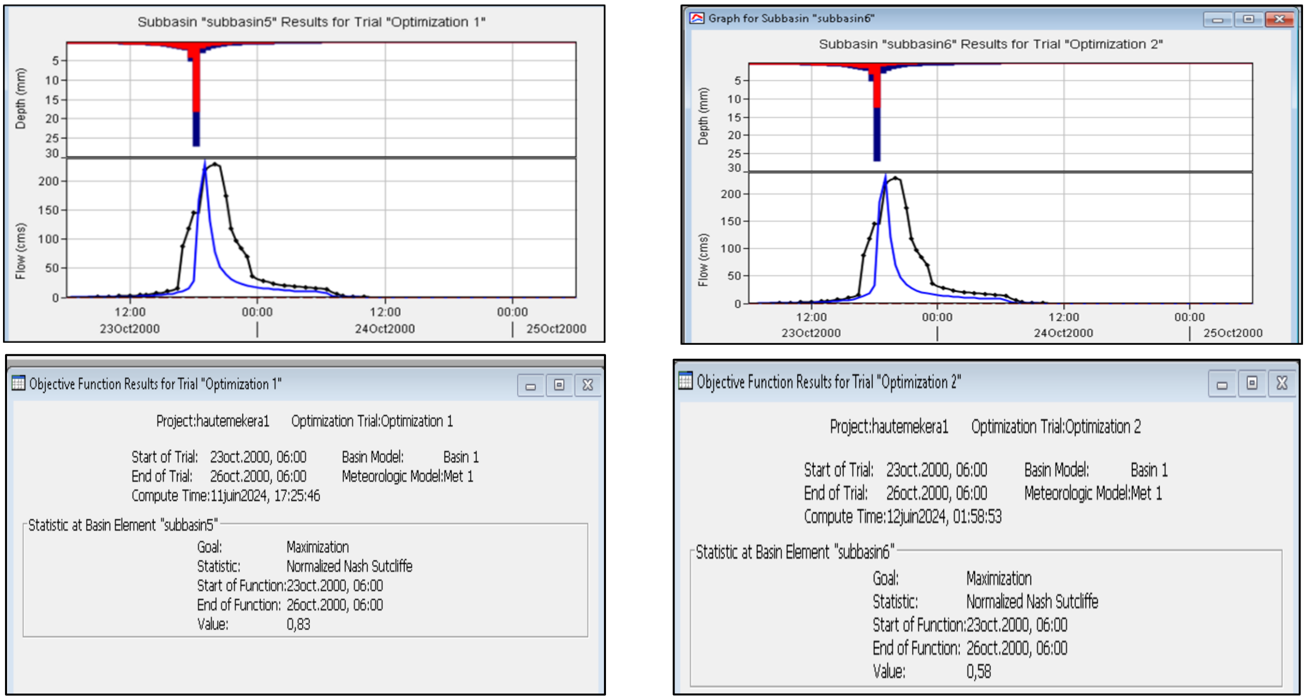

Figure 39: *Observed and simulated streamflow hydrographs after the validation (29-26 october*

2000) sub-basin 5/6

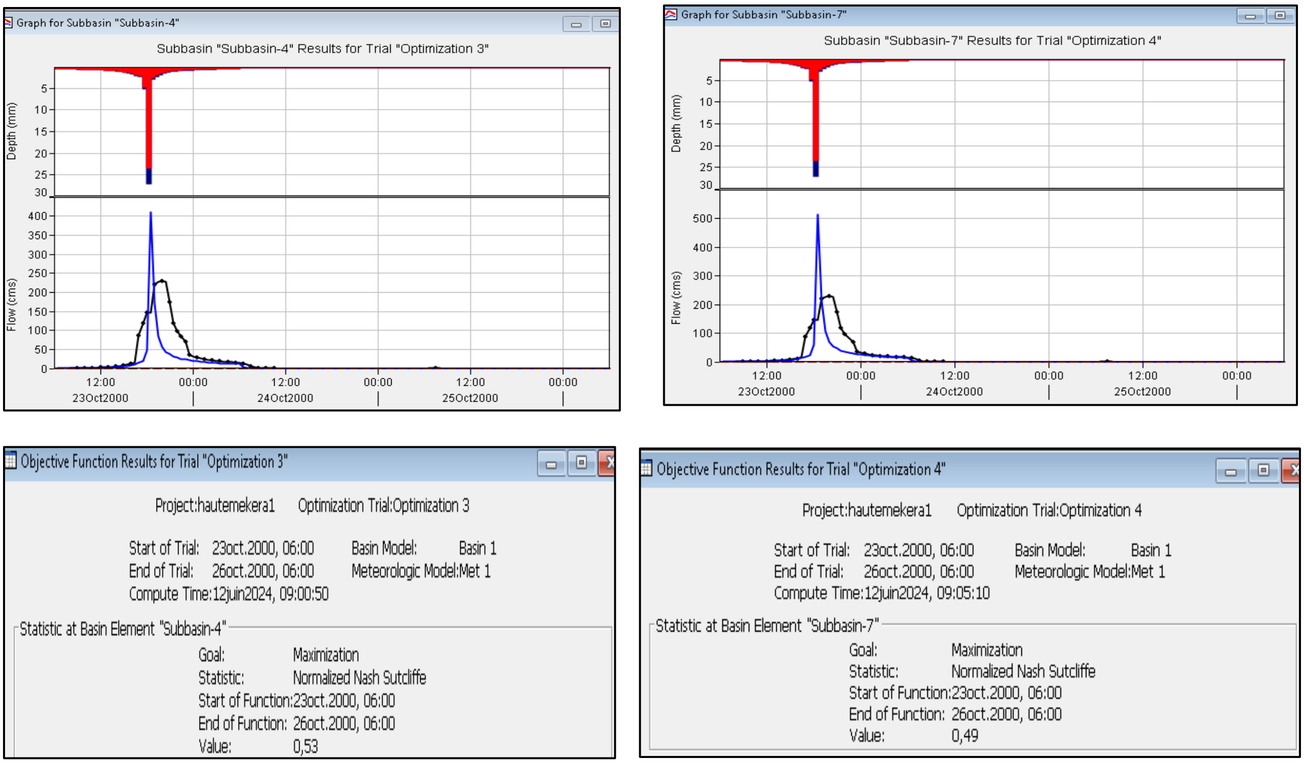

Figure 40: *Observed and simulated streamflow hydrographs after the validation (29-26 october2000) sub-basin 4/7 (own study).*

Graph of simulated versus observed flows before and after the validation (23–26octoberb 2000) period are shown in Figures 41

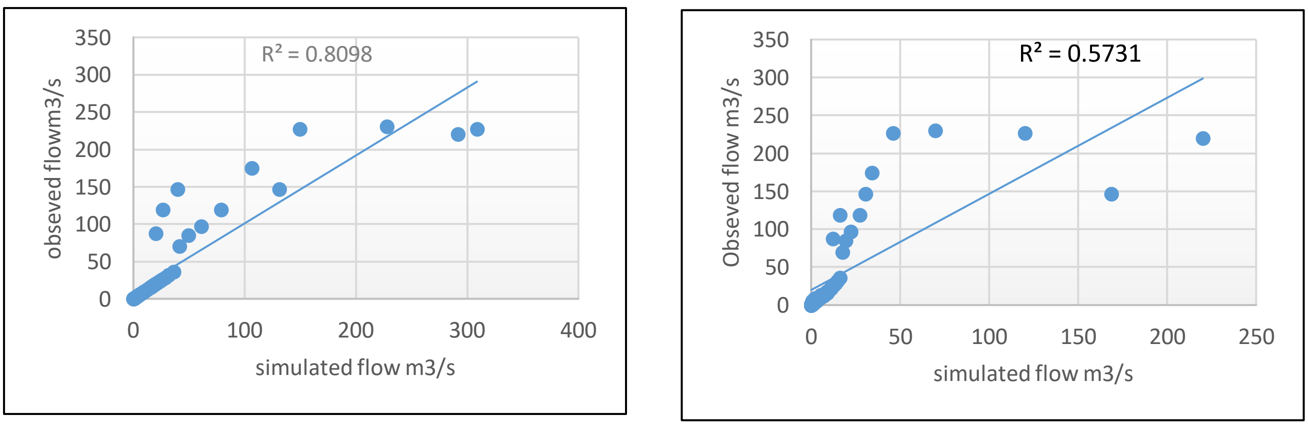

Figure 41: *Graph of simulated versus observed flows before and after the validation (23-26 october2000) period.*

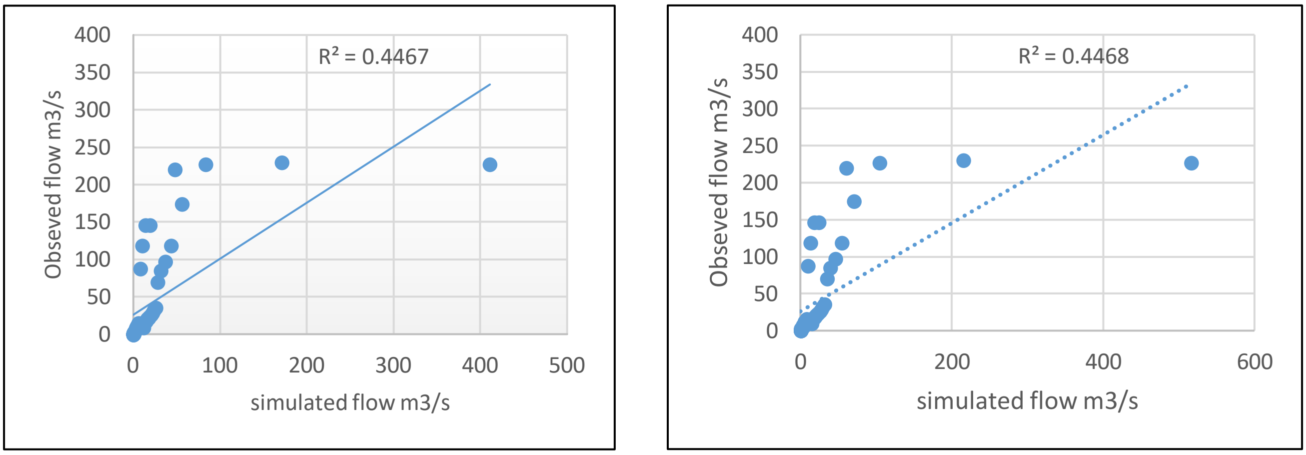

Figure 42: *Graph of simulated versus observed flows after optimization (23-26 october2000) period for sub-basin 4/7 (own study).*

Model performance is assessed using two performance indicators, namely the NS and R^2, who have the values 0.83and 0.80 respectively for subbasin5 which represent the highest values compared to values of other sub-basins whose values range between (0,58 and 0,49) for Nash and between (0,57 and 0,44) for The correlation coefficient R^2 .

The result showed that the model performs well in the subbasin 5 of the validation period (23-26 october2000). Where the peak values of measured flow match well with the peak values of the simulated flow, however For the other sub-basins, the results obtained are acceptable; this can be explained by the irregularity of precipitation and especially the state of the soil and geological conditions (saturation and occupation) in semi-arid zones at the south of upper Mekerra watershed.

General conclusion

GENERAL CONCLUSION:

This dissertation presents a comprehensive study on modeling the rainfall-discharge relationship for the up Mekerra watershed using HEC-HMS. The up Mekerra basin, located in northwestern Algeria, spans approximately 1744, 81 square kilometers and includes diverse topography and land uses. The basin's Mediterranean climate, characterized by wet and dry seasons, significantly influences its hydrological behavior. Understanding these characteristics is crucial for effective hydrological modeling.

A thorough review of current hydrological modeling techniques highlighted the advancements and limitations in predicting rainfall-runoff relationships. Modern models, like HEC-HMS, integrate various hydrological processes, making them suitable for complex basins such as upper Mekerra. The literature emphasized the importance of calibration and validation for reliable simulations.

Historical rainfall data from multiple meteorological stations were analyzed to identify patterns, variability, and extreme events. The analysis revealed significant seasonal and annual variability in rainfall, which directly affects runoff generation. This information provided essential inputs for the HEC-HMS model, ensuring accurate representation of rainfall events for model calibration and validation.

The HEC-HMS model was applied to simulate the rainfall-discharge relationship. Key parameters, including Curve Number (CN), lag time, and initial abstraction were optimized using Percentage Error per Deviation (PEPD).

Runoff estimation is mandatory to sustain the water resources but in this region the monitored data are limited. The present research tries to study the efficiency of HEC-HMS model in upper Mekerra basin. A sensitivity analysis was carried out by adjusting different parameter values in the HEC-HMS for watershed. After running the models repeatedly, the simulated streamflow results were compared with monitored values in sub-basins 5, 6, 4 and 7 (where the discharge station (El Haçaiba is located) at each change of parameters. In this regard, the Curve Number, SCS Lag and initial abstraction parameters are optimized for the event of 23-26 october2000.

The results of the measuring approved the results of the model and showed that the model performs well in the subbasin5 with R2 value is 0.80 and Nash–Sutcliffe efficiency is0.83 were higher than Nash values and R^2 value of the others sub-basins but generally we can say that The present study concludes that the model can be utilized for the upper Mekerra watershed. For applying advanced hydrological models in similar basins. Future work could involve integrating other models and climate change scenarios to further improve predictive capabilities and support sustainable water resource management. This dissertation sets a solid foundation for ongoing and future hydrological studies in the upper Mekerra watershed.

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