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Department of Earth and Universal Sciences

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Theme:

The use of GIS in geotechnical studies and the design of large hydraulic structures: Case study of the upper basin of Saf Saf Wadi in the El Malabiod region (Northeast Algeria)

Presented by :
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Dedication

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Boukraa Boutheyna

Abstract

The El Malabiod plain is located in the northeast of Algeria in the province of Tebessa. It occupies part of the Chott Melghir basin and features a semi-arid climate. The El Malabiod basin includes three sub-basins (Al Goussa, Malassoued, and E'Zned), all of which drain into the El Malabiod wadi. This study aims to calculate the morphometric parameters of these sub-basins and estimate the liquid flows by integrating GIS tools. Additionally, it seeks to draw a flood susceptibility map for the El Malabiod basin, with the goal of reducing flood risk and better managing excess surface water for potential storage works (dams, reservoirs, etc.).

Keywords: Tebessa, El Malabiod, Flood, Morphometric Parameters, GIS

Résumé

La plaine d'El Malabiod est située au nord-est de l'Algérie dans la province de Tebessa. Elle occupe une partie du bassin du Chott Melghir et présente un climat semi-aride. Le bassin d'El Malabiod comprend trois sous-bassins (Al Goussa, Malassoued et E'Zned) qui se jettent tous dans l'oued El Malabiod. Cette étude vise à calculer les paramètres morphométriques de ces sous-bassins et à estimer les débits liquides en intégrant les outils SIG. En outre, elle vise à dresser une carte de susceptibilité aux inondations pour le bassin d'El Malabiod, dans le but de réduire les risques d'inondation et de mieux gérer les eaux de surface excédentaires pour d'éventuels ouvrages de stockage (barrages, réservoirs, etc.).

Mots-clés : Tebessa, El Malabiod, inondation, Les paramètres morphométriques, SIG

الملخص

يقع سهل الماء الأبيض في الشمال الشرقي للجزائر في ولاية تبسة. ويحتل جزءاً من حوض شط ملغيغ ويتميز بمناخ شبه جاف. يضم حوض الماء الأبيض ثلاثة أحواض فرعية (القوسة، الماء الأسود، والزناد)، تصب جميعها في وادي الماء الأبيض. تهدف هذه الدراسة إلى حساب المؤشرات المورفومترية لهذه الأحواض الفرعية وتقدير التدفقات السائلة من خلال دمج أدوات نظم المعلومات الجغرافية. بالإضافة إلى ذلك، تسعى الدراسة إلى رسم خريطة قابلية الفيضانات لحوض الماء الأبيض بهدف الحد من مخاطر الفيضانات وإدارة المياه السطحية الزائدة بشكل أفضل لأعمال التخزين المحتملة (السدود والخزانات وغيرها)

الكلمات المفتاحية : تبسة، الماء الأبيض، فيضان، المؤشرات المورفومترية، نظم المعلومات الجغرافية .

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General Introduction

General Introduction:

Watersheds are fundamental geomorphic units for hydrological management and sustainable development of natural resources. Geological and morphological setting, topography, and climate are important physical factors that control the geometry of the river system, drainage systems, and density [1]. Detailed morphometric analysis of watersheds, helps to explore the geomorphic history, evolution and characteristics of landforms, and development of drainage networks [2]. The delineation of drainage networks within a watershed or subwatershed has traditionally been based on field observations, topographic maps, and aerial photographs. Recently, geospatial analysis techniques (GIS and remote sensing) have been developed and used as powerful tools for calculation, quantitative description and evaluation of morphometric parameters, thematic mapping of morphometric variables, and application of morphometric analysis in various research fields such as: hydrology and environmental hazard assessment [3]-[6]. As floods witch consider one of the most catastrophic types of natural events around the globe, after excessive rainfall, persistent rainfall and snowmelt combined with unfavorable conditions. Floods are influenced by several factors, including climate, human activities, and physical situations. Determining flood-prone areas with high accuracy is critical to accurately predict this complex phenomenon [7] and is considered the first step in flood prevention and management [8]. Identifying places prone to flooding can be accomplished via flood susceptibility modeling in conjunction with a geographic information system (GIS) and remote sensing. Geospatial tools have dramatically reduced the time and cost of analysis and can be easily applied in mountainous, complex terrain / rugged topography as well as in accessible areas [9]-[13]. This work describes the results of the morphometric analysis of three sub-basins in the region of El Malabiod (Wilaya of Tebessa), located in the east of Algeria, in order to understand the behavior of the basins with respect to flash floods using Geographic Information Systems (GIS). The study aims to illustrate the procedure of assessment of morphometric parameters, drainage network and hydrographie using geoprocessing tools provided by ArcGIS software. The potential of DEM data and GIS in watershed morphometry has been verified in comparison with conventional methods. The use of DEM and GIS also provides fast, accurate, and inexpensive tools to extract and analyze morphometric data for flash flood assessment and other applications such as hydrology, watershed prioritization for soil and water conservation [9]-[13].

Chapter 1:

Study Area Overview

Study Area Overview:

1. Introduction:

The area we're trying to study is part of Chott Melghir watershed. The plain of El Malabiod has not been the subject of a detailed geological study, but it is part of a little-known geological complex. However, drilling and geophysical surveys have been carried out since the 1970s in search of water and oil.

The northern border of the El Malabiod plain is formed by the Doukkane, Anoual and Bouroumane mountains. These reliefs form an important ridge in the local geography as they are part of the Mediterranean-Saharan watershed. To the north of the study area is the Oued Ksob watershed, which drains water to the sea.

The eastern edge of the plain nears Tunisian territory in the Koudiat Sidi Salah area. To the west lies the Cheria plain. A little further south, we come across the Telidjen plain, characterized by a weak hydrographic network.

The relief is contrasted, consisting mainly of limestone, stretching along a SW-NE axis, separated by a depression (El Malabiod cultivated plain) of mid-quaternary age. This structure is the result of two tectonic phases that have affected the region.

The sedimentary fill of the El Malabiod sub-basin consists of:

- Epicontinental deposits with variations in facies and thickness in a SW-NE direction (Aptian to Maastrichtian).
- Miocene sandstones and variegated clays.
- Germanic Triassic in diapiric form.

These two tectonic phases, whose interaction affected the region, are at the origin of the structure it has adopted [14].

2. Geographical location and natural environment:

2.1 Characteristics of the study area:

The plain of El Malabiod is located 260 km from the Mediterranean Sea and about twenty kilometers from the province of Tebessa. It is one of the constituencies of the province. The municipality covers an area of 316 km². Its altitude decreases from north to south from Mount Doukane (1712 m) to the town of El Malabiod (1019 m).(Figure1)

According to the administrative division, this region is delimited as follows

- The Daira of Oum Ali, in the south.
- The Algerian-Tunisian border, to the east.
- The city of Tebessa, to the north.
- The Daira of Cheria, to the west.

The plain of El Malabiod belongs entirely to the Saharan watershed and is an integral part of the high plateaus, which form a dense network of medium to high mountains more or less separated by depressions.

- The northern border of the El Ma El Malabiod plain is formed by Doukkane, Anoual and Bouroumane mountains. These reliefs form an important ridge in the local geography as they are part of the Mediterranean-Saharan watershed.
- The eastern border of the plain approaches Tunisian territory in the Koudiat Sidi Salah region.
- To the west is the Cheria plain, the highest of the southeastern Constantine regions.
- The southern boundary is formed by the Mio-Quaternary Bir Sbeikia syncline.

The peculiarity of the El Malabiod plain, compared to other high plateau depressions, is the absence of closed basins such as those found in Tebessa, Cheria, Ain El Beida, etc... Each depression has its own outflow into a watercourse, where surface drainage takes place down to the shallows of the eastern Sahara (Chott), below sea level (-40m) in the case of the Chott Melghir [14].

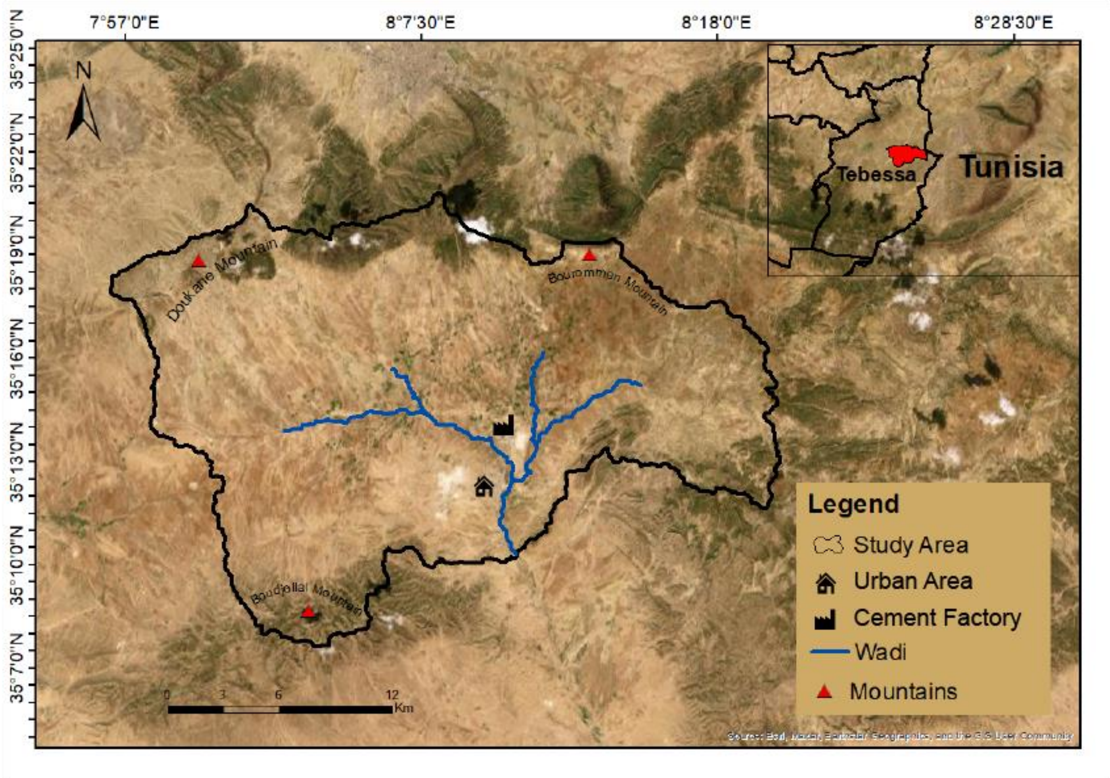


Figure 1. Geographical location of El Malabiod basin

2.2 Topography:

The El Malabiod region has the appearance of a basin. Its altitude varies between 1050m (in the center of the basin) and 1500m in the north of the region studied (the highest peak in the region is Doukkane mountain in the north, with an altitude of 1712m). The central part of the region consists of a plain that is bordered by steep mountains to the north and south. It should be noted that in the axis parallel to the national road, south of the headwaters of wadi El-Goussa, there are some slopes with a relative height between 10 and 20 meters above the basin (Figure2). This is probably due to the rise of the impermeable layers [14].

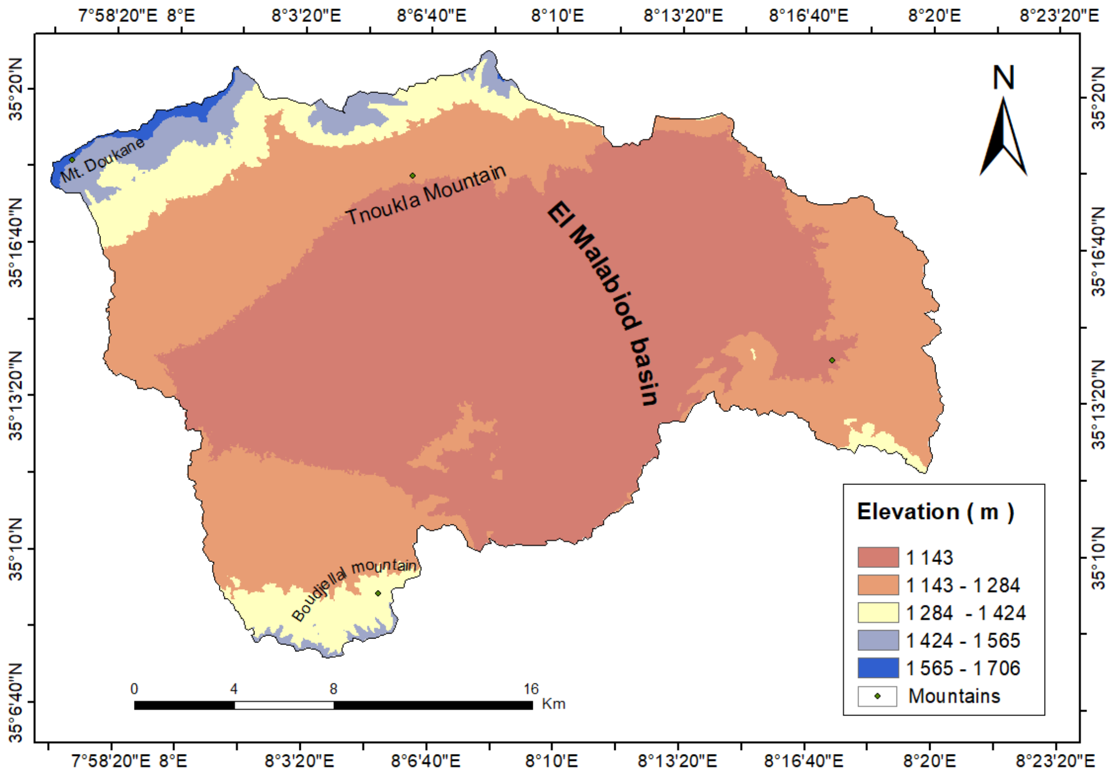


Figure 2. Elevation map of the El Malbiod Basin

2.3 Vegetation cover:

The vegetation cover has a significant influence on the geological aspects of a region. In addition to the protective role it plays against all forms of erosion that threaten our heritage, it undoubtedly has an irrefutable influence on rainfall. In fact, the speed, duration and consequences of a flood or runoff are inversely proportional to the degree of development, abundance and land use.

Not to be overlooked, of course, is its influence on the recovery of runoff or partially infiltrated water, through a natural action commonly known as transpiration, which, combined with the physical action of evaporation, is a constant source of concern even to specialists, given the water losses it causes [14].

The plain of El Malabiod belongs to a sub-Saharan domain, which benefits from a semi-arid climate with low rainfall and consequently the development of vegetation cover is limited. The mountains bordering the plain of El Malabiod are characterized by Aleppo pine forests. The natural vegetation, based on Aleppo pine, is developed in the north of the study area and becomes increasingly rare towards the south until it disappears at the southern limit at Boudjelal Mountain. We can also mention the thick juniper trees of Labiod Mountain. Everywhere else, Alfa dominates, growing in the steppes and among the rocks [15].

2.4 Climatology:

Tebessa's climate is transitional Mediterranean, with some continental features, and semi-arid. Winters are fairly mild, but it gets cold at night, and the city is subject to cold snaps and snowfalls (though not like the cities of the northern High Plains). Despite the altitude, the summer is very hot, hotter than on the coast, but not as hot as in the desert areas of Algeria. Temperatures can sometimes reach or exceed 40°C [16].

2.4.1 Temperature:

The year 2013 is considered the hottest year in the last two decades, as the average temperature during this year reached 18.22°C, while temperatures decreased in 2014 and 2019 to reach their minimum values (15.92 and 15.88°C, respectively).(Figure 3).

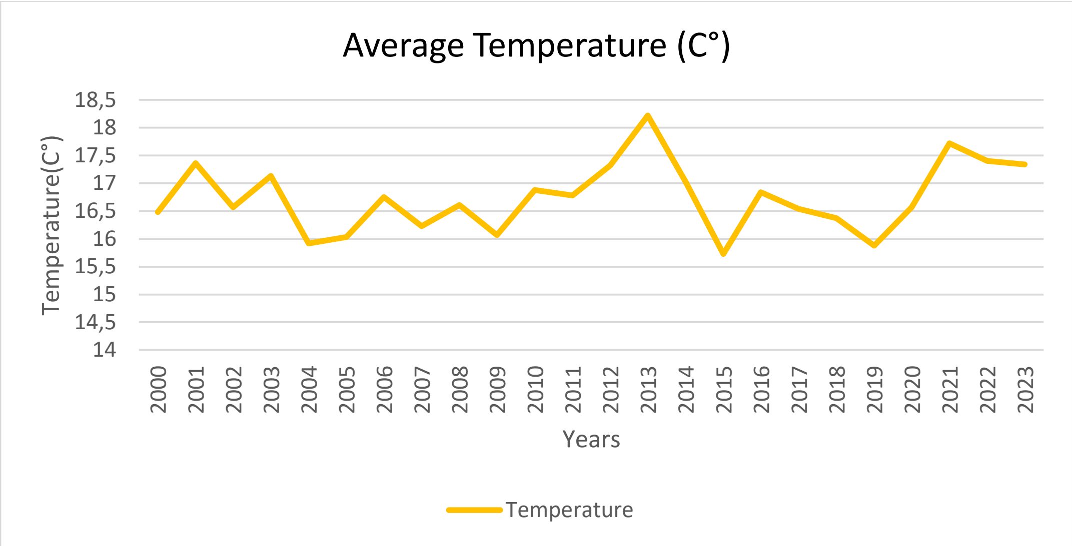


Figure 3. Annual average temperatures from 2000 to 2023

2.4.2 Rainfall:

The average rainfall in the province of Tebessa is around 200 mm per year. The wettest year in the last two decades was 2004 with 490 mm of rainfall. 2011 and 2019 were also notable for their high rainfall, with 480.3 and 480 mm, respectively, and the driest year was 2021 with an average annual precipitation of only 180 mm (Figure 4).

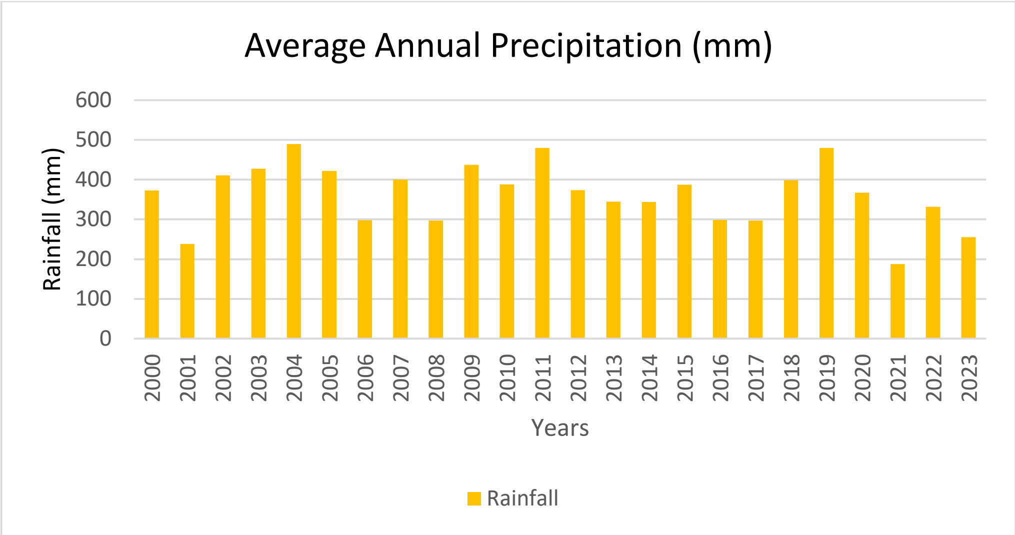


Figure 4. Annual rainfall from 2000 to 2023

2.5 Hydrographic Network:

In terms of surface watercourses, the number of incised rivers is so limited that no permanent rivers are known. Drainage is therefore provided by the three secondary wadis that join upstream of the town of El Malabiod to form the El Malabiod wadi, which flows intermittently from north to south.

- El Malassoued wadi:

El Malassoued wadi considered as a collector of surface runoff from the north and northeast of the area, coming from Mount Taga after a 12-kilometer journey to flow into the eastern part of the plain (Figure 5).

- E’Zned wadi :

Originating in the north, it receives the Wadi of Tnoukla (from Kef Tnoukla) and flows, towards the south.

- El Goussa wadi:

With a length of 28.2 km, it is considered a collector of tributaries such as the Kriz and Es-Sagui wadis and drains from west to east.

- El Malabiod wadi:

It is the main valley in which all the above-mentioned secondary valleys converge. Further south, Berzguene and Saf Saf wadis originate (Figure 5). These in turn receive the Gh'routa, Guelb Es'sfa and El Ouesra wadis, which is the origin of the course that drains the waters to the south towards Chott Melghir. The intertwined system flows from north to south, a typical feature of Saharan atlas streams, although not always continuous. Floods are not associated with a specific (wet) season, but result from the specific impact of storms that occur in late spring and early fall [14].

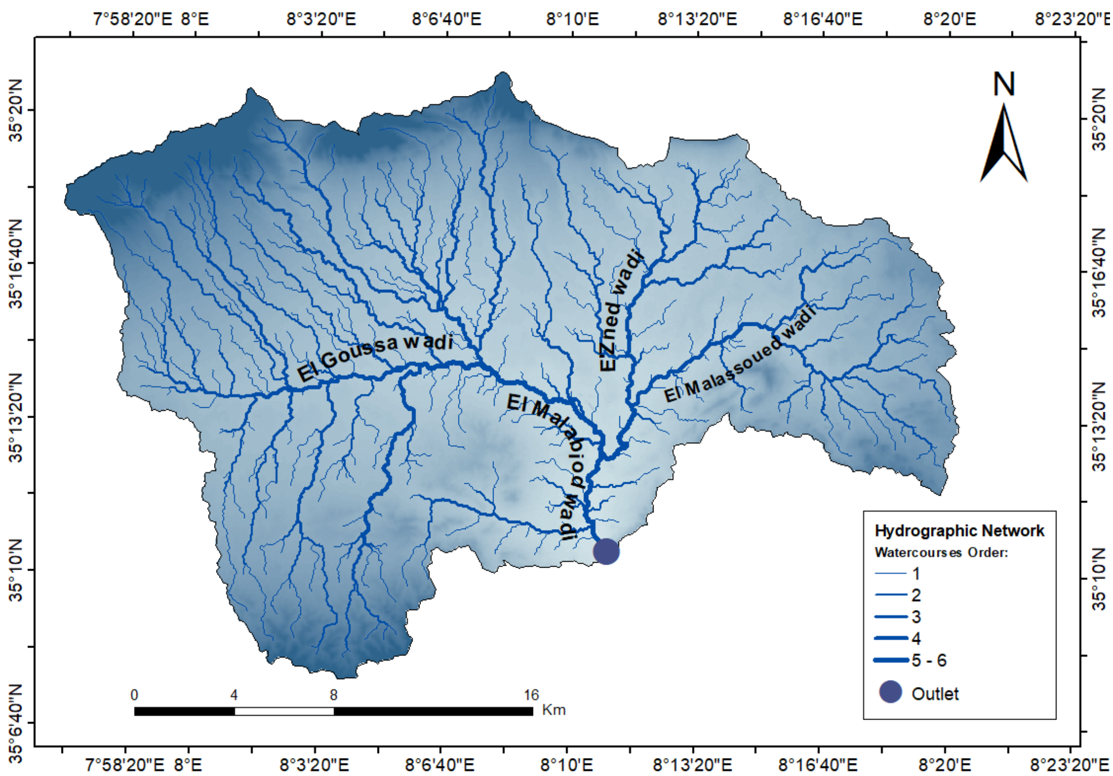


Figure 5. Hydrographic network of the El Malabiod Basin.

2.6 Geomorphological overview:

Morphological evolution in this area has led to the shaping of the relief, resulting in various morphological forms typical of sedimentary terrain in the El Malabiod basin, different micro and macro geomorphological forms can be observed:

2.6.1 The basin – watershed:

The watershed is mainly composed of Cretaceous formations (marl, marl-limestone), which form the underlying ancient base on which the Miocene formations were deposited. It has also been observed that the Cretaceous formations forming the watershed are strongly tectonically faulted and folded. The limestones can sometimes be strongly karstified, which is particularly important from a hydrogeological point of view.

2.6.2 Miocene depression:

The Miocene fill consists mainly of red sandstones, sands and clays, covered by colluvium and alluvium along the rivers. Known for their high permeability, they form a water table of increasing interest.

2.6.3 The Miocene basin:

The Miocene infill deposits are composed of red clay, sand and sandstone, overlain by colluvium and alluvium that line the rivers. From a hydrogeological point of view, these formations are highly permeable and form a significant water table.

2.6.4 Hills:

These are geomorphic forms, horsts or remnants of the watershed that underwent very intense tectonics. They appear as "islands" between Miocene formations.

2.6.5 The watershed - Miocene basin boundary:

The boundary between the Miocene and Cretaceous formations is characterized by scree, a collection of loose rocks that are abundant in the northern part of the study area.

2.6.6 Wadi beds:

Wadi beds are formed by the process of erosion. Within these dry channels, one can identify the terrace and upper Miocene formations.

2.6.7 Quaternary alluvium:

In this region, it is not possible to distinguish between high, middle, and low terraces because the thickness of these alluvial formations is small and not of great hydro geologic interest [15].

2.6.8 Springs:

They are mainly located at the contact between the Cretaceous and Miocene fill formations. They are currently dry [14].

2.6.9 The rocky barriers:

The northern barrier extends for almost 60 km without interruption and consists of a series of imposing mountain massifs in a northeast-southwest direction, including the Arrour, Doukkane Mountains (culminating at 1,712 m), Tella, Anoual and Bouroumane Mountains. Southern barrier; similar to the previous one in terms of orientation and hydrological behavior (watershed), it is cordoned off to the south by the Fouwa, Botna and Saf Saf mountain ranges. The Boudjellal, El Outed and Ed'Dalaa mountain ranges divide the area, culminating at 1,496m. To the south lies the Boudjellal plain, while to the north is the El Malabiod plain [14].

3. Geological overview

3.1 Stratigraphy

From a structural point of view, studies have shown that the region is a subsurface basin, framed to the north by limestone massifs (Anoual, Tnoukla and El Khorza, mountains...), with a significant relief, elongated in a general west-east direction [15].

Two main groups can be distinguished:

- The first group consists of Cretaceous outcrops on the edge of the plain.
- The second group is made up of Miocene and Quaternary formations that occupy the entire surface of the plain.

These two sets constitute an incomplete stratigraphic series (absence of Eocene formations) whose lithology and distribution are as follows:

3.1.1 Triassic:

Triassic is qualified as the oldest formation in the region, outcrops in the southern part of the plain at Dalaa and Er-Rouail mountains, in diapiric form. It is represented as follows:

- Gray and pink gypsum, limestone. In the northeast and at Djebissa Mountain, the Triassic appears in diapiric peaks.
- Red clay with gypsum.
- Black limestone and dolomitic limestone in the form of platelets.

3.1.2 Cretaceous:

A. Middle and Lower Aptian:

At the northern end of the study area, on the eastern flank of Bouroumane Mountain, a combination of limestone and dolomite outcrops. The lower part is almost entirely dolomitic. A few rudists are found in the intercalations of rocky limestones. But Orbitolina are abundant. The average thickness is 400 meters. To the south of the El Malabiod plain, at Koudiat Adeila, the Boudjellal-2 [BDJ2] oil well has intersected the Middle and Lower Aptian at 2531m and 2786m respectively.

- The Middle Aptian is a hard, compact, bioclastic and slightly dolomitic light gray to brownish gray limestone with thin beds of slightly carbonated green and gray clay. Its thickness is about 225 m.
- The Lower Aptian is characterized by alternating dark gray compact marls and dark gray compact cryptocrystalline limestones. The average thickness is 107 meters.

B. Upper Aptian:

The outcrops from this period, in the northern part of Bouroumane Mountain, are massive gray or reddish limestones with intercalations of a few meters of marl and marl-limestone. The average thickness towards the south is 70 meters. The oil well BDJ2 encountered the Upper Aptian at a depth of 2316m, consisting of light-grey to dark-grey limestones, bioclastic, sometimes cryptocrystalline. Thickness is 215m.

C. Lower Albian :

This stage occurs in the Bouroumane Mountain in the form of thick, very hard, brown limestone blocks with Ostrea Latissima and beds of rudist limestone. South of the study area, the BDJ2 well shows the following sequence from bottom to top:

- Light gray, whitish, brownish, compact oolitic limestones, often bioclastic, chalky or gravelly, with traces of foraminifers and gray clay intercalations: 85m thick.
- Alternating light gray, whitish, often bioclastic and rarely gravelly clayey limestones and gray to dark gray, blackish laminated clays: 87 m thick.
- Compact microcrystalline white to brownish gray dolomites: 40m thick.

D. Upper Albian:

The Upper Albian is present in small outcrops at the Triassic contact of Draa M'taa El Malabiod (Dalaa Er Rouail Mountain). It consists of limestones and marly limestones in plates. At Adeila, where the BDJ2 well was drilled, the sequence from bottom to top is as follows:

- Alternating light gray, beige, clayey limestones and gray to dark gray, more or less dolomitic, laminated clay: 116 m thick.
- Alternating gray, dark gray, clayey limestones and blackish gray marls, compact, hard, silty: 129 m thick.

To the north, on Bouroumane Mountain, this stage forms the lower slopes. They consist of limestones and marly limestones in plates and small benches. Numerous ammonite and belemnite footprints are present and the thickness of this formation is 150 m.

E. Cenomanian:

It is quite widespread in the southeastern part, in tectonic contact with the Triassic. It is a series of yellow marls, sometimes gray, and lumachellic limestone beds. The fauna is very rich (Ostrea, Exogyra, Cardita). The thickness reaches 560m. In Adeila, according to the oil well BDJ2, where the Cenomanian series is the most complete, we can see from bottom to top:

Gray to dark gray carbonate clay: 238m thick.

- Alternating light gray limestone and gray to greenish, scaly clay: 130m.
- Gray to light gray cryptocrystalline limestone with interbeds of gray to greenish-gray clay: 76m.
- Alternating dark gray clays and dark gray to light gray lumachellic limestone: 73m thick.
- Gray, greenish-gray clay with interlayers of white chalky limestone: 209.5m
- Alternating lithographic white limestone and gray to greenish-gray laminated clays: 204m thick.
- White to cream-colored, sometimes gray, cryptocrystalline to chalky limestone: 39m thick.
- Fossiliferous, greenish-grey calcareous clay, becoming marly in the last 16 m, with thin layers of whitish-grey limestone: 72 m thick.

F. Turonian:

It is widely exposed to the north (Bouroumane, El-Koreiz Mountains). At its base, there is a constant series of small banks of gray marly limestone. The thickness does not exceed 60 to 70 meters. Below it is a massive layer of beige limestone and dolomite or dolomitic limestone. In the upper part there are flints. Near Tnoukla, the Upper Turonian, 150 m thick, gives the following sequence from top to bottom:

- Black gypsiferous marl.
- Gray marl limestone in platelets.
- Black marls, often lumachellic and laminated.
- Limestones, marls and limestone banks are found in the south, on Mount Ed Dalaa.

G. Lower Campanian – Emscherian:

These are marls interbedded with lumachellic limestone. These facies outcrop extensively on Mount Doukkane to the northwest and on Mount Ed-Dalaa. Small outcrops can be found near Tnoukla, M'Taguinaro and Adeila, southwest of the town of El Malabiod. After the BDJ2 oil well, where the series is most complete, we note from bottom to top:

- Reddish-brown clay and greenish-gray marl: 47m thick.
- Gray clay with some light gray limestone beds: 83m thick.
- Gray clay with some fossiliferous light gray limestone beds: 242m.
- Indurated gray marl, slightly dolomitic, intercalated with brown-red limestone, often marly: 88 m thick.

H. Upper Campanian – Maastrichtian:

It is located to the northwest of Koreiz mountain and in the center of the plain (M'Taguinaro), as well as around the town of El Malabiod. It is characterized by white limestone and marly limestone with inoceramus. It outcrops extensively at Adeila in the form of white marl. The BDJ2 well encountered the following facies:

- Compact white limestone, clayey biomicrite with pelagic fauna: over a thickness of 67 meters.

3.1.3 Tertiary:

A. Miocene:

The Miocene is extensively exposed in the eastern part of the El Malabiod plain, while in the center of the plain it is covered by the Quaternary (according to the report of G. DUROZOY dated 18/04/1949 and the data sheets of the hydrogeological boreholes drilled in the region). The series begins with extremely hard siliceous conglomerates with large, more or less rounded flinty conglomerates and small, very rounded, generally white siliceous pebbles. To the south and east of M'Taguinaro, these conglomerates contain very large flints; in the center of the Oglat Chaachaa plain, the siliceous elements of the rock are smaller. Above, is a layer of sandstones with beds of quartz pebbles, followed by a layer of ferruginous sandstone (Figure 6).

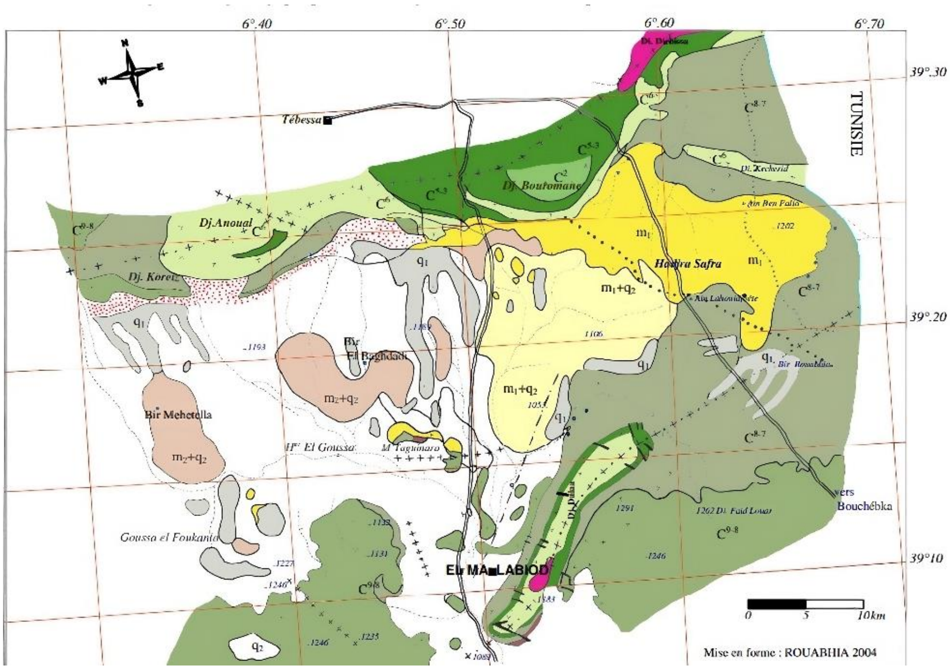


Figure 6. Geological sketch of the study area (modified by Rouabhia, A.

Legend (Edited):

a b **:** Quaternary [a - alluvium b- scree].

q_1 : Early Quaternary (structural surface and limestone crust).

m_2+q_2 : Vindobonien (Clay under low alluvial cover, red clays, variegated clays).

m_1+q_2 m_1 : Burdigalian (Sandstone under low alluvial cover, siliceous poudingue, white sandstone, ferruginous brown).

c^{9-8} : Maastrichtian and Upper Campanian (limestone and marl- limestone).

c^{8-7} : Lower Campanian. Emscherian (Marls and intercalated limestone beds).

c^6 : Uronian and Cenomanian (to the north), Turonian (limestone and marl) to the south.

c^{5-3} : Cenomanian (marl and limestone beds).

c^2 : Upper Albian (schistose limestone at the Draa M'ta El Malabiod Triassic contact)

t : Triassic (gypsum clay, limestone).

Table 1. Doukane mountain permit, Oil drilling Boudjellal -2 [BDJ-2]

value	section	Lithological description	Stage
138		▪ White, compact limestone. ▪ Clay biomicrite with pelagic fauna.	**Maastrichtian, Upper Campanian**
576		▪ Greenish-gray marl and reddish-brown clay. ▪ Dark grey, calcareous clay with rare light grey limestone banks. ▪ Grey clay with some fossiliferous light grey limestone beds. ▪ Compact gray marly limestone with foraminifera. ▪ Indurated gray marl, slightly dolomitic, intercalated with reddish-brown limestone, often marly.	**Lower Campanian, Emscherian**
917		▪ Light gray clayey limestone, gravelly, partly lumpy, compact limestone with calcite-filled fractures, intercalated with marly clay, dark gray, traces of calcite and pyrite. ▪ Brown, multicolored, medium-hard, calcareous, slightly dolomitic limestone, partly lumachelic, bituminous, trace of white calcite, translucent, with greenish clay bands.	**Turonian**
1010		▪ Greenish-gray, calcareous, pyritic, fossiliferous clay becoming marly from 873m with thin layers of whitish-gray, lumellic limestone. ▪ White to cream-colored limestone, sometimes gray, cryptocrystalline to chalky, pyritic. ▪ Alternating lithographic white limestone, cryptocrystalline, speckled chalk, lumachellic gray to greenish-gray clay, flaky marl. ▪ Gray, greenish gray, lamellar, calcareous clay, finely pyritic, sometimes slightly glauconitic and lumellic with intercalations of white limestone, lithographic gray, cryptocrystalline, chalky with traces of calcite. ▪ Alternating dark gray, flaky, slightly silty marly clay and gray to light gray, microcrystalline lumellic limestone Gray to light gray, indurated cryptocrystalline limestone. ▪ Cryptocrystalline gray to light gray indurated limestone, sometimes whitish chalky with fossil debris, intercalated with gray clay.	**Cenomanian**
2050		▪ Alternating gray, dark gray, sometimes blackish clayey limestone. Alternating light gray, beige, chalky crystalline limestone.	**Upper Albian**
1093		▪ White to brownish gray, microcrystalline, bituminous, compact dolomite. ▪ Alternate limestone, light whitish gray, often bioclastic. ▪ Light gray, whitish, brownish limestone, compact, often calcareous, rarely bioclastic or gravelly, oolitic, traces of foraminifera. ▪ Light gray to dark gray limestone, oolitic, bioclastic, sometimes cryptocrystalline. ▪ Light gray limestone, slightly dolomitic, with fine green clay layers. ▪ Alternating compact dark gray marl, gray to dark gray clay, laminated, carbonated.	**Albo-Aptian**
2058		▪ White to gray sandstone, fine to very fine, well consolidated, quartzite, glauconitic silico-dolomitic cement with gray to blackish gray clay layers, compact, silty, carbonate. ▪ Intercalations of quartzite sandstone, siltstone, dolomitic clay and dolomite.	**Barremian**
3560		▪ Dolomites, gray, brown and beige, cryptocrystalline to microcrystalline, fine gray and gray-blackish clays. ▪ Alternating oolitic dolomites, dolomitic limestones, quartzite sandstones and silty dolomitic clays at 3760 m.	**Neocomian**

Geographical coordinates: X = 8°07’35’’E; Y = 35°13’12’

3.1.4 Quaternary:

The Quaternary formation covers most of the plain (Figure 7). It is very thin, not more than ten meters thick. The Quaternary is generally composed of ancient facies (conglomerates, limestone crust) and recent facies (silty gravel).

A. Conglomerate:

They are formed by a mixture of clays, pebbles, gravel and limestone pebbles. The hydrogeological borehole, located north of the village of El Malabiod, traversed a twenty-meter thick series of alternating limestone gravels, coarse pebbles at the base, or coarse sands and limestone pebbles. This conglomerate is absent to the east. The thickness of the series varies but remains small.

B. Limestone Crust:

This whitish-colored formation, found mainly in the north of the plain, is composed of thin elements of varying thickness. In the ravine west of Oglat Chaachaa, this 30-meter-thick crust lies directly on Miocene sand and contains well-preserved snail shells and flint fragments.

C. Spring deposits:

These are the travertines, resulting from the precipitation of lime carbonates, found at the Tnoukla spring (currently dry).

D. Pebble layer :

It covers a large area, especially west of the Tebessa, El Malabiod road; these thick materials never form notable accumulations, and are small in size except near the hillsides.

E. Recent deposits

The most recent deposits consist of silty layers that occupy most of the basin floor. This formation is becoming increasingly saline, as evidenced by small temporary marshes at Oglat Chaachaa, where the salt rises to the surface and forms crystals during the warm season.

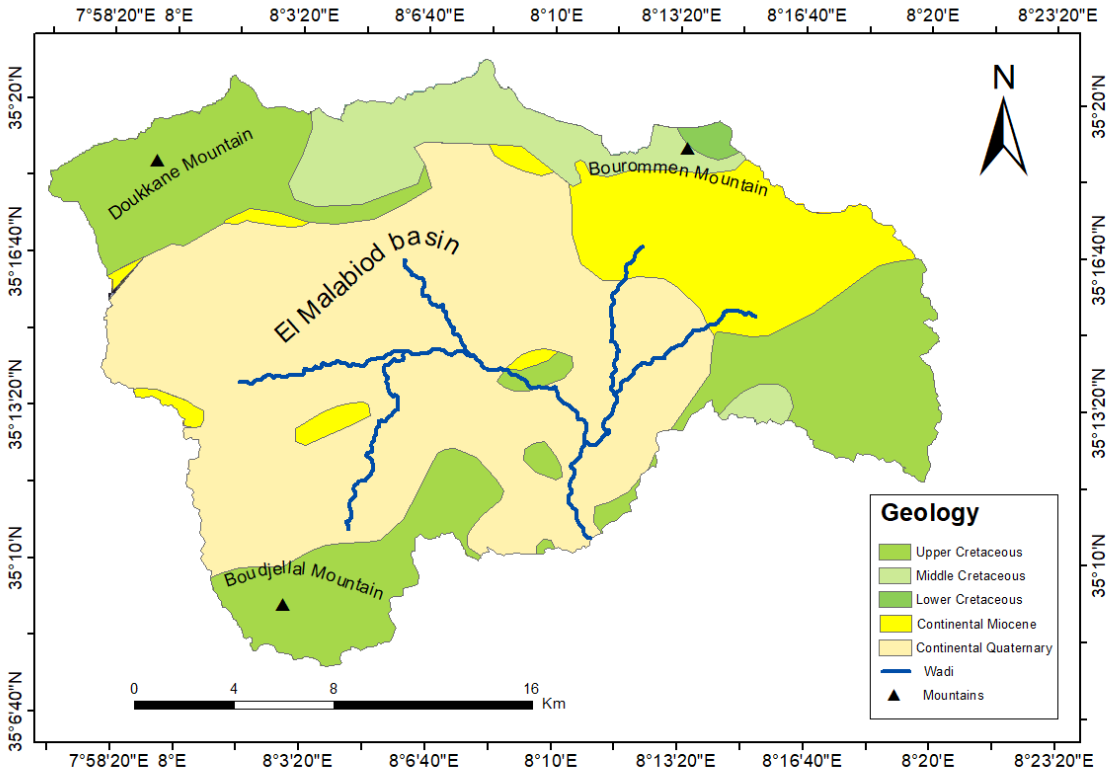


Figure 7. A skech of geologic formations in the study basin

3.2 Tectonics:

The tectonic structure of the study area must have developed as a result of two orogenic phases [17].

3.2.1 First phase:

This phase begins at the end of the Upper and Lower Cretaceous. It culminates between the Upper Lutetian and the Lower Miocene. This is the Atlasic phase, which is the most important folding phase in the study area. it is the main orogenic phase in the Saharan Atlas. During this phase the SW-NE-trending cover folds were formed, giving rise to the major anticlinal axes (Bouroumane Mountain).

The Tnoukla fault and the NW-SE faults orthogonal to these folds date from this period, and the Triassic diapirism must have started during this tectonic phase [18].

3.2.2 Second phase:

This phase follows the previous folding, after the movements of this phase, the large basins bounded by the anticlinal mountain ranges were certainly subjected to subsidence movements, creating the El Malabiod plain in its present form [19].

3.3 Tectonic style:

In the study area, two dominant structural directions can be recognized in the tectonic faults: folds, flexures, basin elongations and fractures. They are reflected in the topographic morphology and partly in the hydrography. The two directions are SW-NE and E-W.

The folds are typical of those generally found in the Saharan atlas. They are originating from the middle structural level. They are often tight, set in vertical planes, reflecting a strong shortening of the sedimentary cover [14].

3.3.1 Recent movements:

The recent tectonics responsible for the formation of the El Malabiod trough does not disturb the organization of the older folds. This tectonics is characteristic of the native formations of eastern Algeria and Tunisia [20, 21].
There is a difference in the intensity of folding and brittle tectonics affecting the Cretaceous formations (fractures breaking the Turonian cliff of Tnoukla) and the dislocation of the Cenomanian-Turonian anticline of Draa M'Ta Abiod on the one hand, and the Miocene (folding of the Miocene sandstone of the Tnoukla pass) on the other. This phase is considered to be the Atlasic phase responsible for the folded structures. It is a compressive phase with principal stress oriented NN - SE.

These structures are the result of large slides that affected the basement during the Plio-Quaternary. The opening of the gullies is the result of fractures caused by expansion fractures in the cover, partly driven by the Mediterranean movement in the area of El Malabiod. This movement is characterized by numerous NE-SW fractures of variable length, up to 30 km. It is represented by three faults running from south to north [22]:

- Fault 1: located east of the town of El Malabiod, 6 km long.
- Fault 2: With a very large break, it crosses the middle of the plain. It trends NE-SW, then changes direction and becomes EW further east, near the village of Houidjbate, about 30 km of fault zone.
- Fault 3: marks the northern part of the NE-SW trending plain, the fault zone is significant, on the order of 22 km (Figure 8).

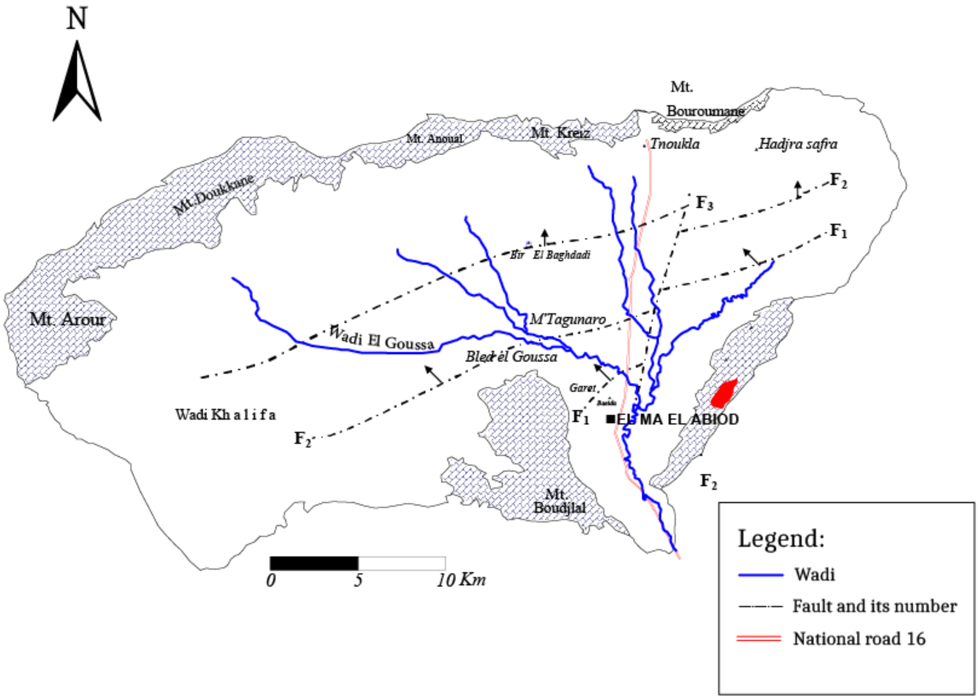


Figure 8. Fault system map (UGF-BRNO 1971) (Edited)

Conclusion:

The catchment area covered by this study is part of the Melghir watershed and thus of the eastern high plains of the Saharan Atlas. Comprising one daira and two communes, it covers an area of 648 km² and is not overpopulated (27 inhabitants/km²). Known for its agricultural vocation, with a UAA of about 27,400 ha, other activities are beginning to flourish.

Forestry accounts for 23.7% of the area, with alfa and plant associations (Aleppo pine, oak, and juniper) for 23.59% and pastureland for 7.86%. The topography of the basin is varied, with a plain at an average altitude of between 1,020 and 1,200 m, surrounded by a series of mountains reaching 1,400 and even 1,600 m in altitude.

Geologically, the region is part of the Saharan Atlas. It is bounded by folds running NE-SW to the north and south, and is a high plateau where two main groups can be distinguished: - Cretaceous outcrops; - Miocene and Quaternary formations that occupy the entire plain. The plain has the shape of a basin, with a calcareous, marly Cretaceous basement separated from the Miocene by highly permeable scree [14].

Chapter 2:

General Information about Geographic Information Systems

1. Introduction :

Geographic information is growing in both volume and availability. It is at the heart of geography, spatial planning, the environment and urban development, but also extends too many other fields and economic activities. The production of geographic data has been largely democratized, thanks in particular to mobile devices equipped with geolocation systems. As a result, the spatial dimension has become an integral part of the description and analysis of many phenomena, be they environmental, territorial, economic, social, historical or other. It is embodied in cartographic representations, as evidenced by the numerous productions on the Web. The purpose of maps is now widely recognized. However, cartographic production requires prior modeling, acquisition, transformation, combination, statistical processing and analysis of geographic information, all of which can be more or less complex depending on the objectives set. Since the 1960s, Geographic Information Systems have been developed to facilitate all these steps and, more generally, to help manage territories. Geographic Information Systems commonly referred to as GIS, have revolutionized the way we perceive and interact with spatial data. In an increasingly interconnected world, where location plays a pivotal role in decision-making across various fields, GIS serves as the backbone for organizing, analyzing, and visualizing geographical information. At its core, GIS harnesses the power of technology to integrate, manipulate, and display layers of geographic data, providing invaluable insights into the complex relationships between people, places, and phenomena.

From a functional point of view, GIS make it possible to acquire, store, retrieve, process, analyze and visualize geographic data... And from a hydrogeological point of view, GIS provide hydrologists with a powerful arsenal for capturing, analyzing, and visualizing spatial data related to water resources. By integrating geographic information with hydrologic models and analytical techniques, GIS facilitate a comprehensive understanding of watershed dynamics and water quality [23].

2. Definition of Geographic Information System (GIS):

A Geographic Information System (GIS) is a computer system designed to collect, store, review, and display data related to locations on the Earth's surface. It collects and stores information about geographic features such as roads, buildings, vegetation, rivers, and more. GIS can use various representations of location, including latitude and longitude, addresses, or postal codes. The system enables spatial analysis and relationships by connecting seemingly unrelated data, helping individuals and organizations understand patterns and connections. It allows comparisons between different types of information to reveal insights. Applications consist of both hardware and software systems, and cartographic data (already in map form) can be input directly into GIS. Photographic interpretation plays an important role, involving the analysis of aerial photographs to assess features.

GIS is a general term for a number of technologies, processes and methods. These are closely related to land use planning, infrastructure and network management, insurance, telecommunications, engineering, planning, education and research, and so on. As a result, GIS is at the root of many geo-location services based on data analysis and visualization [24].

3. History:

The birth of geographic information systems can be traced back to 1854 during a cholera outbreak in London, England. At the time, the prevailing belief was that the disease was airborne. However, an English physician named Dr. John Snow decided to map the outbreak. When he did, a startling pattern emerged: the disease was not airborne, but waterborne [25].

Since then, GIS has evolved from a rudimentary tool to a powerful platform for understanding and planning our world, thanks to several pivotal moments; let's review these significant moments in the following table [26] [27].

Table 2. Major periods in the development of GIS

Periods	Evolution of GIS
Early Concepts and Research (1960s)	▪ The field of GIS emerged in the 1960s with the advent of computers and early concepts of quantitative and computational geography. ▪ Academic research played a critical role during this period, with the National Center for Geographic Information and Analysis (NCGIA) formalizing research on topics such as spatial analysis and visualization.
The first computerized GIS (1963)	▪ In 1963, Roger Tomlinson pioneered the first computerized GIS while working on the Canada Geographic Information System. ▪ He envisioned using computers to merge natural resource data, leading to the creation of a design for automated computing. ▪ This system enabled Canada to initiate its national land-use management program, and Tomlinson also coined the term "GIS".
Harvard Computer Graphics Laboratory (1965)	▪ While at Northwestern University, Howard Fisher developed one of the earliest computer mapping software programs called SYMAP. ▪ In 1965, he founded the Harvard Laboratory for Computer Graphics, where concepts for GIS and spatial analysis were conceived. ▪ A talented group of geographers, planners, and computer scientists contributed to the Lab's research.
Esri's Founding (1969)	▪ In 1969, Jack Dangermond, a member of the Harvard Lab, founded the Environmental Systems Research Institute, Inc. (Esri). ▪ Esri applied computer mapping and spatial analysis to assist land use planners and resource managers. ▪ Their early work demonstrated the value of GIS for problem solving. ▪ Esri went on to develop many of the GIS mapping and spatial analysis methods used today.
Commercialization of GIS (1981)	▪ Esri's work was recognized by the academic community as a new way of doing spatial analysis and planning. ▪ In 1981, Esri released ARC/INFO, the first commercial GIS product, which further revolutionized the field.

4. GIS components:

A GIS consists of five main components, as shown in the diagram below [27, 28].

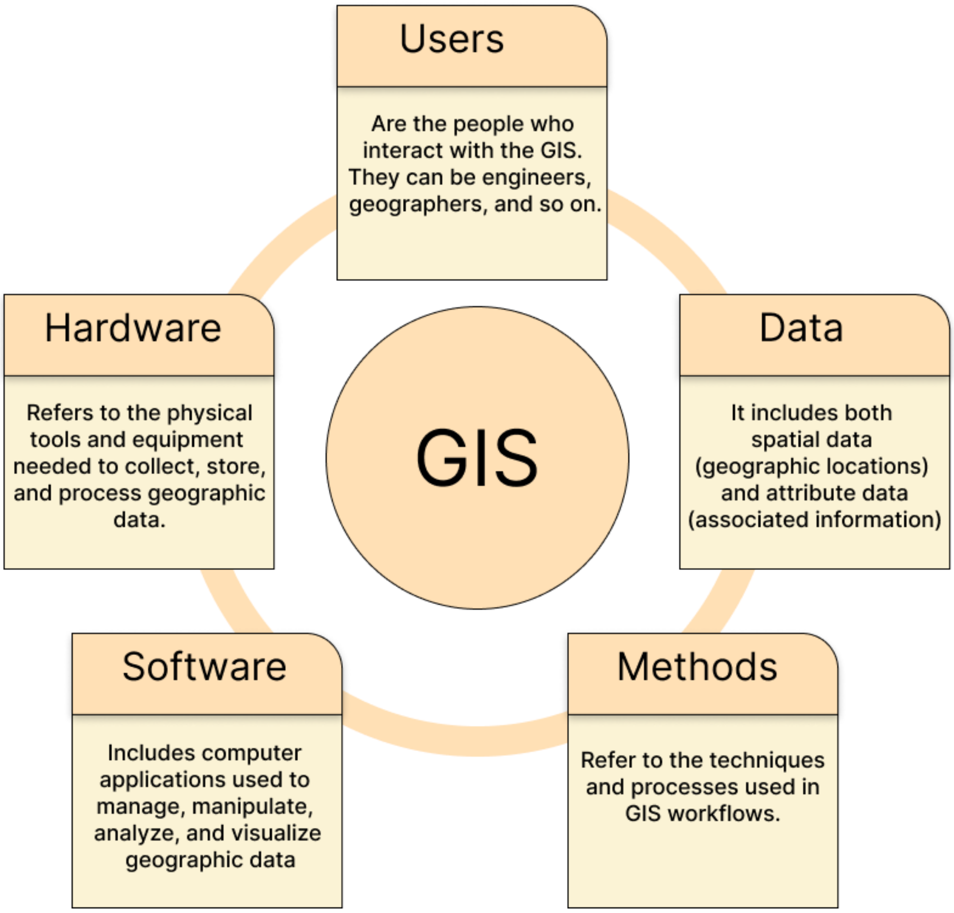


Figure 9. The five components of a GIS(This figure has been reproduced based on the information provided in the explanation).

4.1. Hardware:

The hardware components of a GIS play a critical role in enabling efficient data management and analysis. It refers to the physical tools and equipment needed to collect, store, and process geographic data. Some of these include:

- **GPS Devices:** These are critical hardware components for collecting geospatial data with high accuracy. Global Positioning System (GPS) devices determine the precise location of objects or points in space, making them essential for mapping and geolocation applications.
- **Scanners:** Scanners convert paper maps, drawings, and other hard-copy materials into digital formats that can be stored and analyzed in GIS software. They play a critical role in converting legacy data into a digital format.

- **Computer Systems:** Robust computer systems are necessary for the effective operation of GIS software. These systems include processors, memory, hard drives, and graphics cards. They should be able to handle large datasets and run complex GIS software applications without lag.

4.2. Software:

GIS software includes computer applications used to manage, manipulate, analyze, and visualize geographic data, and they are diverse and fall into three categories:

- Open source software: These are free and often allow contributions to the development.
- Proprietary and commercial software: These are generally not free.
- Free proprietary software: Some proprietary software can be used for free.

Here is a non-exhaustive list of major GIS software packages:

- **QGIS:** Free and powerful software.
- **ArcGIS:** A popular proprietary solution.
- **Spring:** Proprietary, but sometimes free.
- **GRASS GIS:** Free spatial analysis software.
- **MapInfo:** Commercial mapping and analysis solution.
- **PostGIS:** Geospatial extension for PostgreSQL.
- **GeoServer:** Geospatial data server.
- **Google Earth Pro:** Geospatial visualization application.
- **ENVI:** For processing satellite imagery.
- **Global Mapper:** Versatile mapping and analysis software.

4.3. Users:

Users are the people who interact with the GIS. They can be geographers, urban planners, engineers, policy makers, and so on. Each user has specific needs for geospatial information.

4.4. Methods:

Methods cover a wide range of techniques and processes. These methods are essential for data manipulation, analysis, and visualization. Key methods include geocoding (converting textual descriptions into coordinates), spatial analysis (buffering, overlay, interpolation), remote sensing (image classification, change detection), spatial modeling (land suitability models, hydrological models), and network analysis (routing, service area analysis) [27, 28].

4.5. Data:

GIS data represent phenomena that exist in the real world. These phenomena can be anything from natural features such as rivers and forests to man-made structures such as roads and buildings. The most common types of phenomena represented in GIS data fall into two conceptual categories [29].

4.5.1. Spatial data:

Spatial data refers to information that describes the absolute and relative location of geographic features on the Earth's surface. Spatial data can be maintained as vector data (using points, lines, and polygons) or raster data (organized in a matrix of cells or pixels). **It allows us to** visualize and analyze the spatial relationships between different features on maps [30].

A. Vector data:

Vector data is defined by vertices and paths, creating points, lines and polygons. This structure makes it possible to accurately represent geographic features such as city locations, rivers and national boundaries [31, 32].

- **Points:** Represent specific locations on the map, defined by a single coordinate pair (latitude and longitude). As the simplest object, it can represent trees, hydrants, garbage collectors, on a large scale. But at smaller scales, such as a 1/1000000 road map, it can represent a regional capital.(Figure 10)
- **Lines:** a line is a spatial feature represented by a series of connected points, called vertices, which form a continuous path. The line represents communication, energy, water and sewage networks. It can be fictitious, representing the axis of a road, or virtual, modeling the flow of information or money. Lines are defined by their length and direction and, unlike polygons, do not enclose an area. Each vertex in a line feature has an X and Y coordinate (and sometimes a Z coordinate for elevation), and the line itself may have associated attributes such as name, type or traffic volume (Figure 10).

- **Polygons:** A polygon is a two-dimensional shape formed by connecting a series of points (vertices) to form a closed loop. Each polygon is defined by a list of coordinates that delineate its shape, and often includes additional data attributes related to the area it represents. It can represent an abstract entity such as the area of a municipality, or entities with a geographical existence such as a forest, a lake, a built-up area, etc [31, 32].

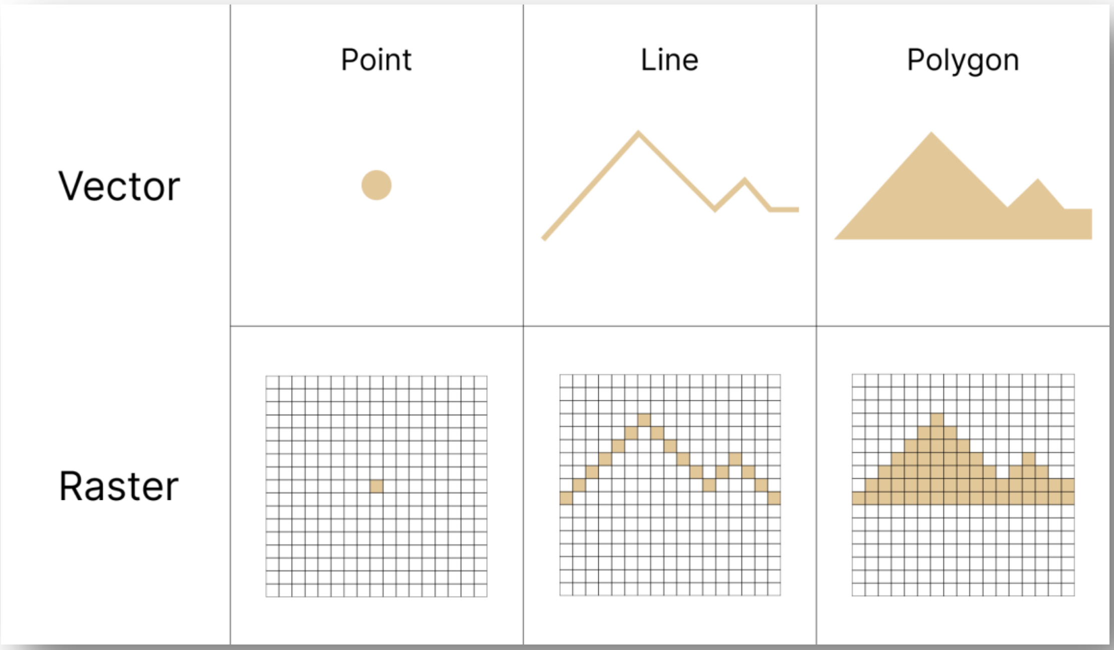


Figure 10. The difference between raster and vector mode

B. Raster data:

Raster data is represented as an image, a grid of cells, also known as a matrix, made up of pixels organized in rows and columns, where each pixel contains a value representing a particular attribute, such as elevation, temperature, land cover, or spectral data. It is taken by a camera or aerial camera (drone, airplane...), it can also be scanned, digitized or orthorectified (corrected for scale distortions) [31, 32].

- **Scanned map:**

A scanned map is a paper map that is scanned to a digital format. Archives of hard-copy maps are a rich source of geographic data. However, as geographic science migrates to digital formats, these maps often sit in drawers unused. By scanning these maps and managing them using mosaic datasets, they can be used, analyzed, and shared digitally. Using a mosaic dataset configured to manage scanned maps makes it straightforward to visualize, query, and analyze large collections of scanned maps. You can render the data seamlessly and without collars (or reveal the collar for reference if needed), query the collection, view the maps as time-enabled (if available), and add more feature data. Often the same area is covered by multiple maps with different dates or versions [33].

- **Satellite images:**

Satellite images are obtained by sensors on satellites that orbit the Earth, gathering data in a range of spectral bands. This data is relayed to terrestrial ground stations, where it is subjected to radiometric corrections to rectify any sensor or atmospheric distortions, and geometric corrections to ensure accurate map alignment. Once enhanced for clarity, the imagery is analyzed to derive insights, including land cover types or temporal changes. These refined images are then incorporated into Geographic Information Systems to facilitate extensive spatial analysis, and it is one of the most common data methods used by GIS.

- **Image satellite radar:**

Satellite radar imagery, particularly from Synthetic Aperture Radar (SAR) systems, is a powerful tool for Earth observation. Unlike optical sensors, SAR systems are "active", meaning that they emit their own electromagnetic waves to illuminate the Earth's surface. The strength of the signal reflected back, known as 'backscatter', varies with surface properties such as roughness, material type and moisture content. SAR imagery can penetrate vegetation and is sensitive to surface roughness, making it invaluable for applications such as environmental monitoring, urban planning and disaster management. In GIS, these images are processed to correct for geometric and radiometric distortions, ensuring accurate spatial representation. The integration of SAR data with GIS technology enables sophisticated analysis and decision making in areas ranging from agriculture to urban development.

4.5.2. Attribute data:

Both vector and raster data usually come with associated attribute data. This is additional information that describes the characteristics of the spatial features. For example, a polygon representing a field in vector data can have its own attribute data, such as area and plant species [30].

5. How a GIS works:

Geographic information system stores information about the world in the form of thematic layers that can be linked geographically. This simple yet powerful concept has been proven to solve many practical problems.

The concept of thematic layers in a geographic information system (GIS) is essential for understanding and analyzing the many facets of the physical and human world. Each thematic layer contains data specific to a particular topic, such as hydrography, vegetation, infrastructure, or urban areas. These layers can be overlaid and linked together because of their common geographic reference, allowing for multidimensional spatial analysis. This method of overlaying data is simple because it mimics the way transparent maps can be stacked (Figure11). However, it is powerful because it reveals relationships and dynamics that would not otherwise be apparent. For example, by overlaying a layer of rainfall data with another layer of land use data, we can study the impact of rainfall on agriculture [34].

6. The main functions:

6.1. Input:

Before paper data can be used in a geographic information system, it must be converted into a computer format. This essential step from paper to computer is called digitization. Modern GIS systems are able to fully automate these tasks for large projects using scanner technology. Other, smaller projects may only require a manual digitizing phase (digitizing table). Today, a wide range of geographic data is available in standard GIS-readable formats. This data is available from data producers and can be integrated directly into a GIS.

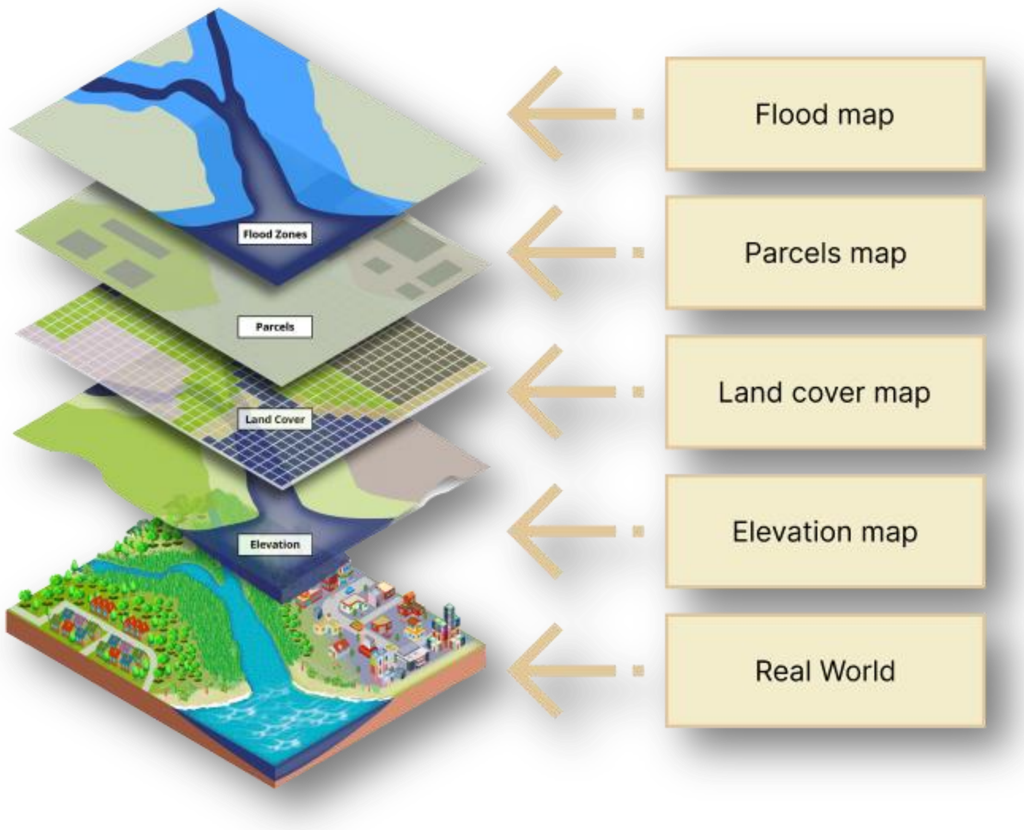


Figure 11. Different layers in GIS [35]

6.2. Handling:

While it may be possible to store geographic information as simple files for small projects, this is not the case as the volume of data grows and the number of users of the same information becomes significant. In such cases, it is essential to use a DBMS (Database Management System) to facilitate data storage, organization, and management. A DBMS is simply a database management tool. There are many different types of DBMS, but the most commonly used in Geographic Information Systems is the RDBMS (Relational Database Management System). Here, data is represented in the form of tables, with specific fields used as links. While this approach may seem simplistic, it offers unparalleled flexibility, allowing GIS to adapt to any situation.

6.3. Spatial analysis:

Integrating data across multiple layers of information enables rigorous spatial analysis. While this analysis can be done visually (by overlaying layers), it often requires cross-referencing with alphanumeric information. Cross-referencing soil type, slope, and vegetation with property owners and taxes paid is an example of the sophisticated analysis that is possible with a GIS.

6.4. Visualization

For many geographic operations, the ultimate goal is to visualize maps and graphs. The map is a powerful tool for synthesizing and presenting information. GIS brings new forms of expression to modern cartography and greatly enhances its educational role. Maps created with GIS can now easily integrate reports, 3D views, photographic images and all kinds of multimedia elements. And to realize this vision, a GIS must provide several components for displaying and manipulating geographic information [36]:

A. The Geospatial Component:

A GIS is a spatial database containing datasets that represent geographic information according to a generic GIS data model (entities, rasters, attributes, topologies, networks, etc.).

B. The Geovisualization Component:

A GIS is a set of intelligent maps and views that represent entities and their relationships on the earth's surface. Different cartographic views of the underlying geographic information can be created and used as "windows on the geographic database" for querying, analyzing, and modifying geographic information. Each GIS integrates a number of two-dimensional (2D) and three-dimensional (3D) cartographic applications and provides a full range of tools for processing geographic information using these components.

C. The geoprocessing component:

A GIS contains information transformation tools that create information from existing data sets. Geoprocessing functions take the information contained in existing datasets, apply analytical functions, and write the results to new datasets. Geoprocessing means you can plan your work and automate workflows by creating an ordered sequence of operations [36].

7. Fields of application:

- **Agriculture:** GIS helps determine the best agricultural practices by using data about farms, weather, and water resources. Researchers can help farmers find suitable weather conditions for specific crops and locate nearby water sources for irrigation.
- **Environment:** GIS monitors air quality in specific areas, helping assess how clean the air is It aids in environmental impact assessments, habitat mapping, and conservation efforts.
- **Urban Planning & Transportation:** Urban planners use GIS to analyze land use patterns, infrastructure, and transportation networks. It helps optimize city layouts, plan efficient transportation routes, and manage urban growth.
- **Disaster Management:** GIS plays a critical role in disaster preparedness, response, and recovery. It helps identify vulnerable areas, assess risks, and plan evacuation routes during natural disasters.
- **Health & Human Services:** GIS aids in disease tracking, health facility location planning, and epidemiological studies. It helps visualize health data, analyze patterns, and allocate resources effectively.
- **Tourism:** GIS assists in creating interactive maps for tourists that highlight attractions, trails, and points of interest. It enhances travel planning and navigation.
- **Oil & Gas:** GIS is used for exploration, pipeline management, and environmental impact assessment in the energy sector.
- **Astronomy:** Astronomers use GIS to map celestial objects, study cosmic phenomena, and plan observations.
- **Banking:** Banks use GIS for risk assessment, branch location analysis, and fraud detection.
- **Education:** GIS is integrated into educational curricula for teaching geography, spatial analysis, and map interpretation [36] [37].

8. Geographic Information System (GIS) and Hydrology:

Geographic information System combines spatial and attribute data to provide insight into water-related processes and phenomena. It's a powerful tool for hydrologists to study, manage, and protect our water resources. GIS is used in many hydrologic applications, including:

8.1. Collection and Management of Geospatial Data:

Geographic data systems store information and records about water resources. The information collected about water resources is stored on servers in different parts of the world. A part of the data is usually because of the handling done on the information gathered by GIS. Huge measures of information identified with water assets would thus be able to be put away for imparted access with the assistance of GIS. Huge remotely propelled geospatial satellites that are constantly on movement and turning close to the world's environment are coordinated with GIS and subsequently used to help in between mainland information and data dissemination. The satellite gives remote information access to any base station that demands the geospatial information. Most geographic information frameworks additionally offer cloud-based stages. This implies that a geospatial focus on any part of the world can approach information put away in any of the GIS servers. This ubiquity and flexibility of data and information access is part of the applications or uses of GIS.

8.2. Hydrologic Management:

Studies of water have shown that in most cases water is moving or changing its state and pressure over time. GIS plays a major role in keeping track of these water conditions. Several types of water studies can be performed using a sophisticated GIS. Hydrogeology, for example, is a discipline that studies groundwater along with its storage, occurrence, and movement characteristics. The nature and characteristics of water stored underground or on the surface, either stagnant or in motion, can be entered as data into GIS, stored, and retrieved for future processing by the geographic information system.

8.3. Demonstrating of Groundwater:

Groundwater displaying involves hydrologists trying to understand groundwater behavior and attributes. Considering the scarcity of water, such a lot of study should be possible to ensure water catchment areas. GIS can also help in the creation of models and structures to help use groundwater wisely. Soil properties and other geographical highlights are normal to explore using GIS corresponding to groundwater. For example, advanced images of groundwater could then be madeb.

8.4. Classification Study of Water:

Not all water in the world is safe for consumption by humans or any other living creatures. Collecting unsuitable water can lead to unfavorable health circumstances. Through GIS, inspections on a slope, sewage features and land utility design can be utilized to divine whether the water in a providing location is safe to take or not. Due to the ability of GIS to sort huge amounts of data, sample data can be handled, stored as well as details generated. These details can be used by the relevant authority or even public administration to make further studies and regulations on water and to understand whether the water is safe to drink or not.

8.5. Morphomitric paramaters:

The study of natural hazards in a watershed requires a good understanding of hydrology, geology, geomorphology, ecology and climate to determine the factors that influence the occurrence of natural hazards (slope, land use and hydrographic network). These indices are needed to determine the prioritization of watersheds and thus plan a program to combat natural hazards. The proper management of a watershed, as well as the study of the prioritization of sub-watersheds, requires the use of Geographic Information System (GIS) techniques and Digital Terrain Models (DTM) of SRTM type for a better assessment of the study area in terms of slope, drainage system, topography, geomorphology and lithology based on geological maps. These data were used to analyze the morphometric parameters of the watershed and sub-watersheds, allowing the prioritization of watersheds for possible protection against flood and landslide risks [39].

8.6. Flood Disaster Management:

Considering all factors, during floods and storms, water tends to accumulate in areas where people live. This can demonstrate trying for the rescue group to go into recusing tasks with little data about the overflowed regions. GIS helps to save and manage natural disasters safely and professionally. Subsequently, in such cases of flood debacles and unforgiving climate conditions, GIS can be utilized to give insights on influenced regions, empower the government to design clearing too as can be integrated with climate forecasting systems to provide accurate predictions. Aerial views and simulations of floods can also be created using specialized components and tools that rely on Geographic Information Systems [39].

9. Conclusion:

Geographic Information Systems (GIS) have become an indispensable tool in a wide range of scientific and practical fields, fundamentally changing the way spatial data is collected, analyzed, and used. In the context of hydrology and geomorphology, GIS plays a critical role, particularly in the calculation of morphometric parameters and flood mapping, thereby significantly improving our understanding and management of natural landscapes and water resources. GIS facilitates the calculation of essential morphometric parameters such as basin area, perimeter, drainage networks, slope, aspect, and relief by providing accurate spatial data and analysis tools. This quantitative assessment informs water resource management, soil conservation, and environmental protection efforts. In addition, GIS is revolutionizing flood mapping by integrating multiple data sources, such as topographic, land use, hydrologic, and meteorological data, and using digital elevation models (DEMs) to produce accurate flood risk assessments. With these capabilities, GIS not only supports detailed geomorphologic analysis, but also plays a critical role in disaster management and urban planning, and that's what we'll look at in the next chapter.

Chapter 3:

GIS-based analysis of morphometric parameters for three sub-basins in the El Malabiod region (northeastern Algeria):

1. Introduction:

A common definition of a watershed is the area that drains into a large body of water, such as a lake, ocean, or river that is much larger than others. The process of identifying the boundaries of a watershed, also known as a catchment area, drainage basin, or river basin, is called watershed delineation. Users are able to identify surface water characteristics within a watershed and understand downstream impacts when a watershed is delineated, which assists in the planning and implementation of water quality and quantity protection and mitigation activities. Morphometric analysis quantifies and mathematically quantifies landforms. This is critical to infer the flow patterns of the topographic feature and, in turn, the geohydrologic characteristics of the watershed. Watersheds are fundamental geomorphic units for hydrologic management and sustainable natural resource development. Geological and morphological setting, topography, and climate are important physical factors that control the geometry of the river system, drainage systems, and density. Variations in physical conditions have occasionally resulted in variations in the morphometric characteristics of drainage basins and associated fluvial systems. The delineation of drainage networks within a watershed or subwatershed has traditionally been based on field observations, topographic maps, and aerial photographs.

Geographic Information Systems (GIS) have proven to be an effective tool for determining the physical characteristics of watersheds, providing a comprehensive and accurate method for hydrologic analysis. GIS facilitates the extraction and analysis of critical watershed characteristics such as shape, size, drainage density, and stream length and size from Digital Elevation Models (DEMs) and hydrographic data. Using GIS tools, hydrologists can delineate watershed boundaries, calculate watershed areas, and efficiently quantify stream networks. Metrics such as circularity and aspect ratio describe watershed shape, while drainage density and stream length measurements help understand hydrologic behavior and potential water flow within the watershed. These spatial analysis capabilities make GIS an indispensable tool for watershed management and environmental planning; in this chapter, we will calculate the morphometric parameters of the three sub-basins of the El Malabiod region using GIS and a digital elevation model (DEM).

2. Watershed physical study:

2.1. Shape features:

2.1.1. Surface and perimeter:

In order to characterize the shape, the first step was to delineate the three sub-basins from the digital elevation model, downloaded from USGS earth explorer at 30-meter resolution, and then calculate the area and perimeter of each subwatershed from the extracted shapefile models [14].

2.1.2. The Shape of the Watershed:

This characteristic can be expressed by determining a parameter commonly known as the Gravlius compactness index (Kc). It is well known that the shape of the catchment has a definite influence on the overall surface runoff, and above all on the shape of the hydrograph for any given rainfall event. The closer this index is to unity, the more circular the watershed, and consequently the shorter the time of concentration (Tc) of runoff water. Conversely, an elongated basin will not react in the same way. This parameter is defined as the perimeter of the basin in relation to that of a circle with the same surface area, and can be easily calculated using the following expression [14]:

$$\mathrm{Kc} = 0.28\ \frac{\mathrm{P}}{\sqrt{\mathrm{A}}}$$

With:

K_c: The Gravelius compactness index.
A: Basin area (Km^2), P: Perimeter (Km).

If:

$K_c < 1$: Circular watershed.

$K_c = 1, 12$: Square-shaped watershed.

$K_c > 1, 12$: Elongated watershed.

The area and perimeter of the large basin as well as the sub-basins were calculated digitally using the ArcGIS program by following the following steps:

- Open ArcGIS Pro and load the shapefile into the map.

- Open the attribute table for the shapefile by right-clicking on the layer in the Contents pane and selecting "Attribute Table."
- In the attribute table, add new fields to store the calculated values. Right-click on the table header and select "Add Field." Choose the appropriate field type (e.g., double for area or length).
- Select the features' area and perimeter. You can do this by selecting rows in the attribute table.
- Input Features: Choose the feature layer with the selected features:
- Geometry Attributes: Select the fields where you want to store the calculated values (e.g., "Area" and "Length").
- Choose the Unit: Specify the desired units (e.g., meters, feet, square kilometers, etc.).
- Click Run to calculate the geometry attributes (Figure 12).

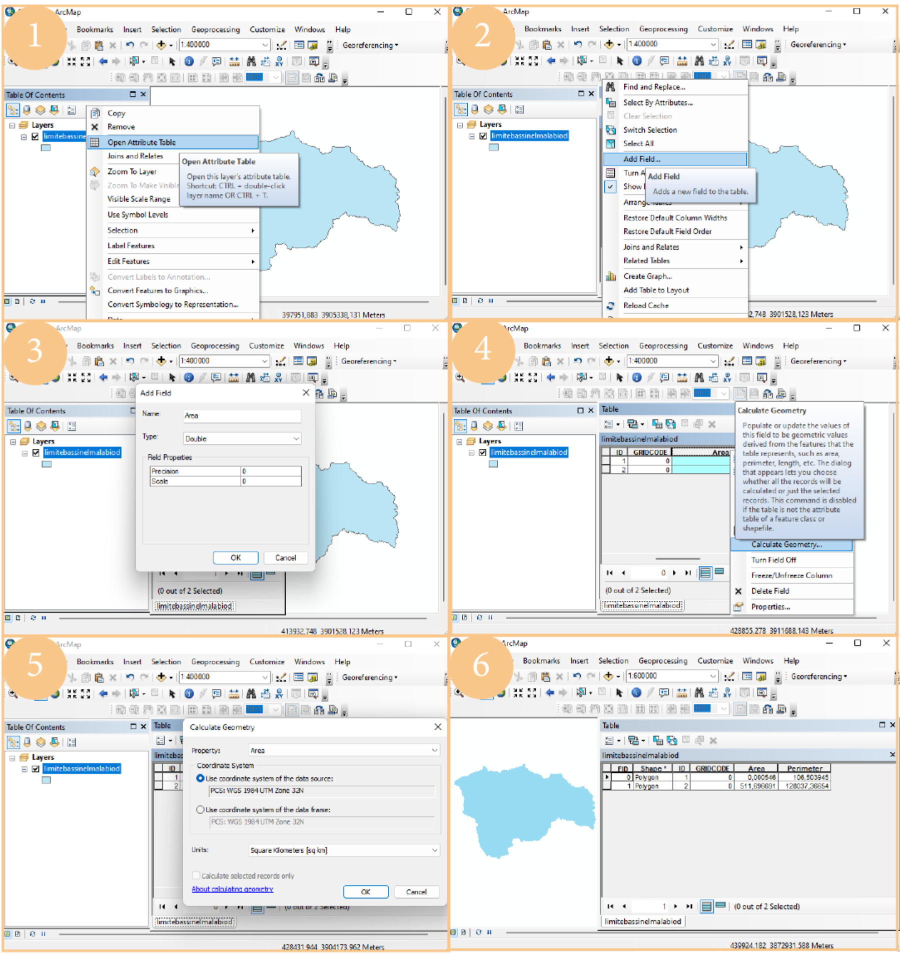


Figure 12. calculate area and perimeter in ArcGIS

Table 3. Areas and perimeters and Kc of each watershed

Watershed	Area (Km^2)	Perimeter (Km)	Gravelius Compactness Index (Kc)	Watershed shape
El Goussa	297,11	95,75	1,56	Elongated
El Malassoued	85,01	61,51	1,87	Elongated
E'Zned	73,78	61,90	2,02	Elongated

- **Validation**

The three sub-basins have an elongated shape because the Gravlius coefficient of the three sub-basins is greater than 1.12. The E'Zned basin is the most elongated of the three sub-basins, followed by the El Malassoued basin and then the El Goussa basin with less elongated shapes (Table 3).

2.1.3. **Dimensions of the equivalent rectangle:**

The equivalent or Gravelius rectangle, a concept introduced by L. Roche (1963), enables easy comparison between watersheds, especially in terms of the influence of their characteristics on flow. By means of a geometric transformation, the real watershed becomes rectangular. In the latter case, the perimeter and surface remain unchanged (and therefore the same compactness index), and consequently the same hypsometric distribution [14].

Let L and l respectively be the length and width of the equivalent rectangle; its perimeter and area are respectively expressed by the relationships:

$$P = 2.(L + l) \ \ and \ A = L.l \ \ so: \ l = \frac{A}{L}$$

$$And \ we \ have \ the \ previous \ equation: Kc = 0.28 \ \frac{\mathrm{P}}{\sqrt{A}}$$

$$We \ get: \ \mathrm{L} = \frac{\mathrm{Kc}\sqrt{\mathrm{A}}}{1{,}12}\left[1 + \sqrt{1 - \left[\frac{1{,}12}{\mathrm{Kc}}\right]^2}\ \right] \quad \text{if Kc} \geq 1.12$$

Table 4. Dimensions of the equivalent rectangle of the three watersheds

Watershed	**Equivalent rectangle Length L (Km)**	**Equivalent rectangle width l (Km)**
El Goussa	40,72	7,30
El Malassoued	27,72	3,07
E'Zned	28,38	2,60

2.2. Relief:

It's easy to imagine the impact of relief on runoff, since many hydrometeorological parameters (precipitation, temperature, etc.) vary with altitude and basin morphology. Flow velocity is also influenced by slope. Relief is often depicted on topographic maps in the form of contour lines, and is also determined by the following characteristics:

2.2.1. The hypsometric curve:

It provides an overview of the slope of the basin, i.e. its relief. It's a graphical representation of the distribution of the surface area (or percentage of surface area, on the x-axis) of the said basin as a function of its altitude (on the y-axis). This type of analysis highlights the typical profile and slopes of the basin, which is the determining factor in its flow. Hypsometric curves are a practical tool for comparing watersheds with each other or with different sections of the same watershed. They provide an indication of the hydrological and hydraulic behavior of the basin and its drainage system [14].

2.2.1.1. Hypsometric curves of the three sub-basins:

Hypsometric curves were created from the elevation ranges of each sub-basin, and this was done through ArcGIS software to produce the following curves (Figures 2, 3, and 4).

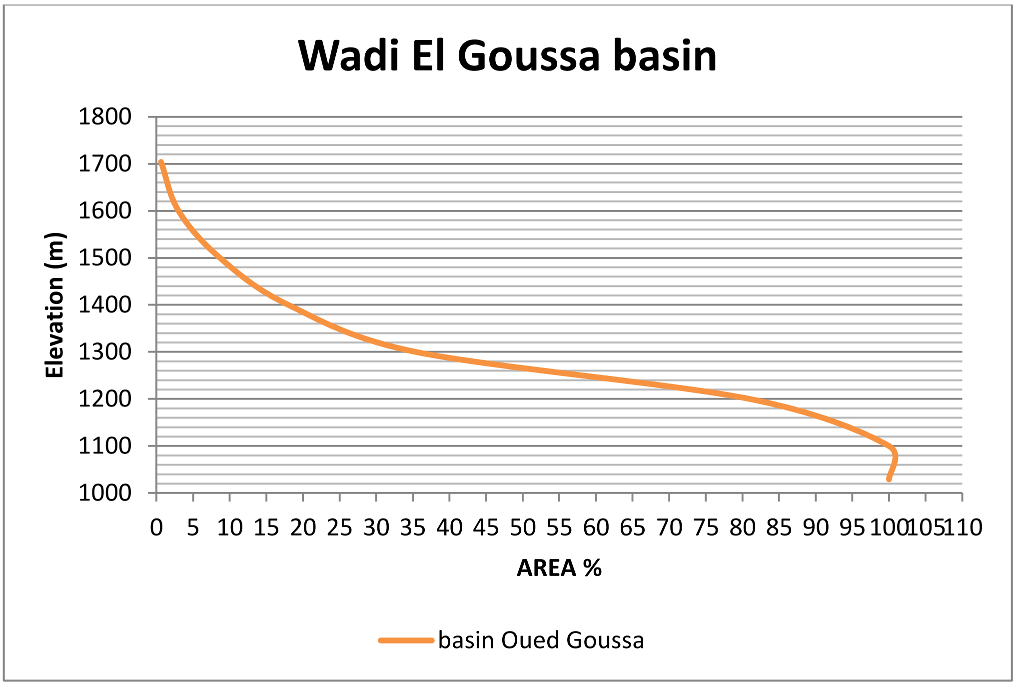


Figure 13. El Goussa basin Hypsometric curve

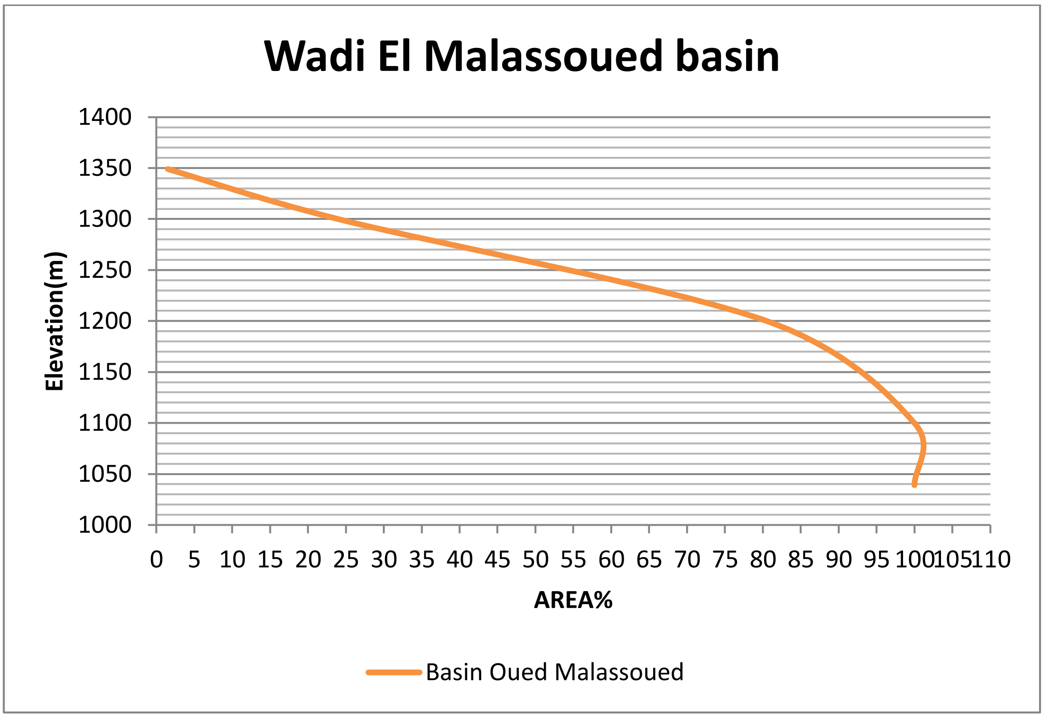


Figure 14. El Malassoued basin Hypsometric curve

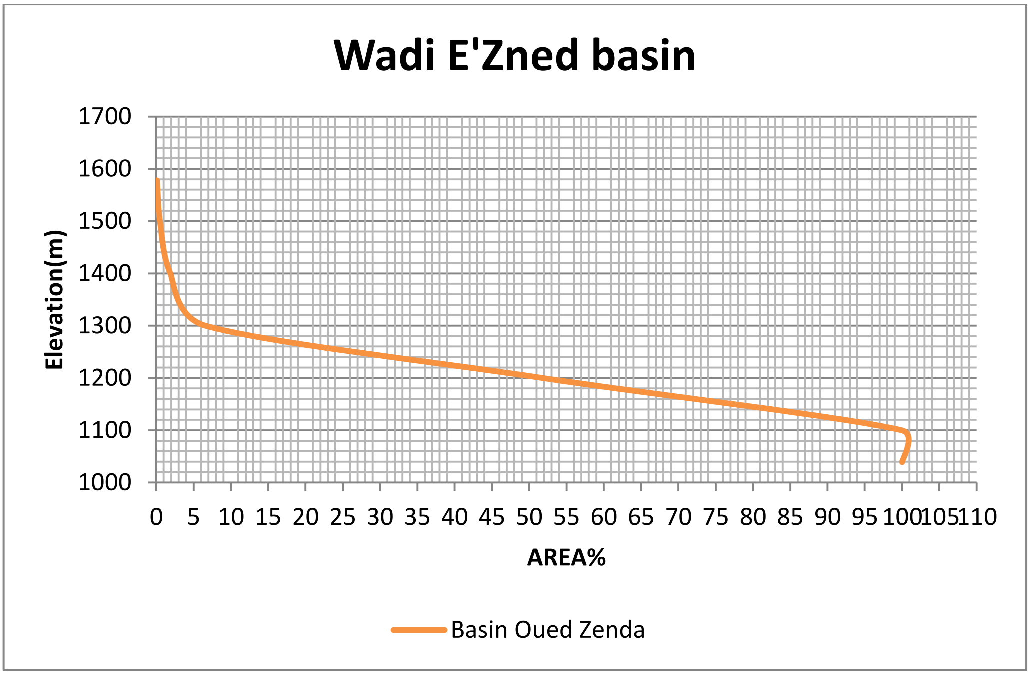


Figure 15. E'Zned basin Hypsometric curve

2.2.2. Characteristic altitudes:

2.2.2.1. Maximum and minimum Elevation and mean:

The maximum elevation represents the highest point in the basin, while the minimum elevation considers the lowest point, generally at the outlet (Rouabhia. 2006). We can calculate these values in ArcGIS, as well as the mean elevation, using the following method:

- Open ArcGIS.
- Search for Zonal Statistics Tool in the search bar
- Configure the following parameters:
- Input raster or feature zone data: Choose a polygonal layer or a raster that defines your study areas (such as watersheds).
- Zone field: Select the field that defines each zone.
- Input value raster: This is the raster containing the altitude values.
- The tool calculates statistics (including max, min and average altitude) for each zone and creates a table output with the results (Figure 16).

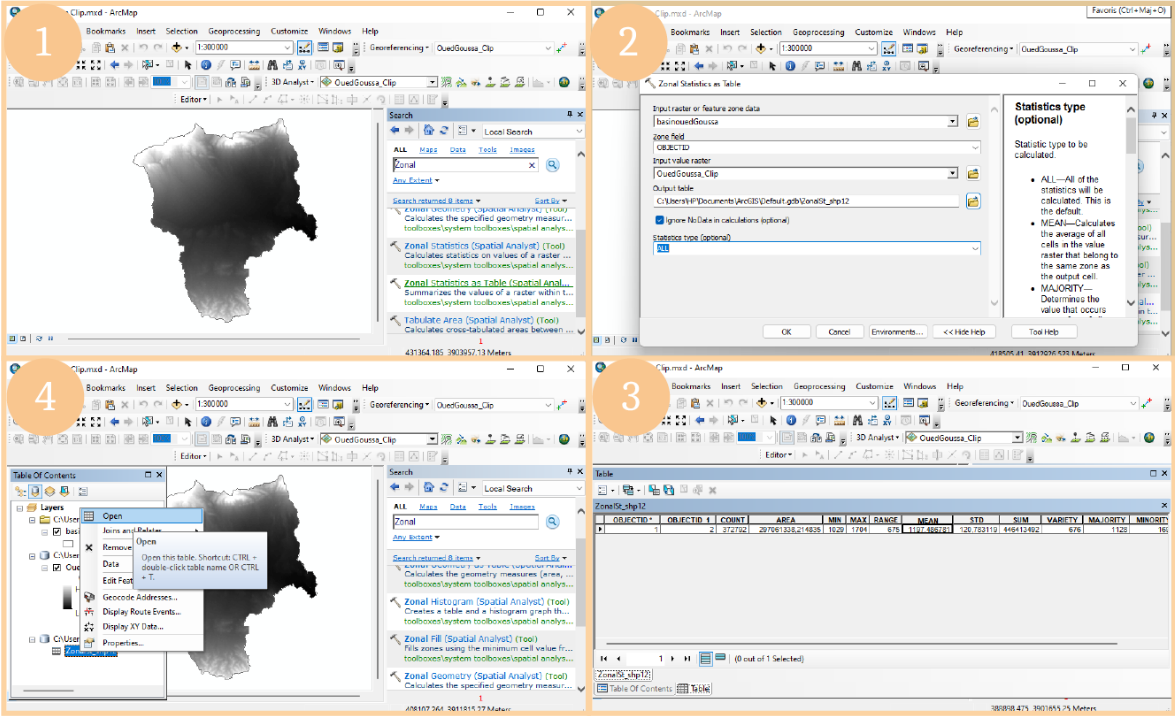


Figure 16. Calculating Elevations in ArcGIS

Table 5. Maximum, minimum and average heights

Watershed	Maximum Altitude H_{max} (m)	Mean Altitude H_{moy} (m)	Minimum Altitudes H_{min} (m)
El Goussa	1704	1197,49	1029
El Malassoued	1349	1158,16	1039
E'Zned	1578	1113,83	1039

2.2.3. **Slope:**

From a hydrological point of view, the role of relief is irrefutable, since one of the determining elements of topography is slope, which also provides information on runoff. Relief can be characterized by at least two indices [14].

2.2.3.1. The average slope:

Considered as an independent variable, it gives a good indication of the travel time of the direct runoff and, therefore, of the time of concentration (Tc), and has a direct influence on the peak discharge during a downpour. By calculating the weighted average of the slopes (Carlier and Leclerc. 1964) of all the elementary surfaces delimited between two given heights. The following relationship gives an approximate value for the characteristic [14]:

$$Im = \frac{DL}{St} \ \equiv \%$$

With:

I_m: Average slope (m / Km), L: Total length of the contour lines (Km).
D: Equidistance between two level curves (m), St: surface of the watershed (Km^2)

The development of this formula gives:

$$Im = \frac{DL}{St} \quad hence, \quad Im = \frac{DL}{Ll} \quad so: \ Im = \frac{D}{l}$$

With:

D = $H_{5\%}$- $H_{95\%}$: from the hypsometric curve of each basin.
l = Width of equivalent rectangle.

Table 6. Height difference and the average slope

Watershed	**Height difference D**	**The average slope I_m (%)**
El Goussa	400	54,79
El Malassoued	200	65,15
E'Zned	190	73,08

- **Validation**:

We observe that the E'Zne basin has the highest slope values of 73.08%, while the El Goussa basin has the lowest slope values of 54.79%, while in the Malassoued basin it takes an average value of 65.15 %.(Table 6)

2.2.3.2. Slope indices:

A. Global slope index (I_g):

The points taken on the hypsometric curve are such that the area above or below is equal to 5% of the total surface. From this we deduce the altitudes $H_{5\%}$ and $H_{95\%}$, between which 90% of the surface of the basin lies, and the height difference (D).
It is then defined by the expression, the height difference in level (D) referred to the length of the equivalent rectangle (L), and whose relationship is written [14]:

$$Ig = \frac{D}{L} \ \equiv m/Km$$

With:

L: Length of equivalent rectangle (Km), Ds: Specific height difference.

Table 7. Global slope index

Watershed	Global slope index Ig (m/Km)	Global slope index Ig (%)
El Goussa	9,82	0,98
El Malassoued	7,22	0,72
E'Zned	6,69	0,66

B. Specific height difference (D_s):

It has the advantage of being derived from the expression of (the global slope index) or the global slope (Ig); admittedly inversely proportional to the square root of the surface, corrected of course for the effect of the latter [14].

$$Ds = Ig\sqrt{A} \quad hence: \quad Ds = \frac{D}{L\sqrt{Ll}} \quad we\ get: \quad Ds = D\sqrt{\frac{l}{L}} \quad \equiv \quad m$$

Table 8. Specific Height Difference

Watershed	Specific Height Difference (D_s)
El Goussa	118,55
El Malassoued	26,62
E'Zned	30,27

2.3. Hydrography:

2.3.1. Hydrographic network:

This is a group of natural (or artificial), perennial (or ephemeral) watercourses that drain runoff or groundwater restitution, in the form of springs or along wadi beds.

They are differentiated according to four main factors: geology (susceptibility to erosion, presence of structures that determine the direction of flow, etc.), climate (dense network in mountainous and humid regions, etc.), slope (network in erosive or sedimentary phase, etc.), and human presence (modification of the original course of the network by drainage, damming, construction of reservoirs, etc.) [14], Here we focus on three of them (El Goussa wadi, El Malassoued wadi, E'Zned wadi) .(Figure 17).

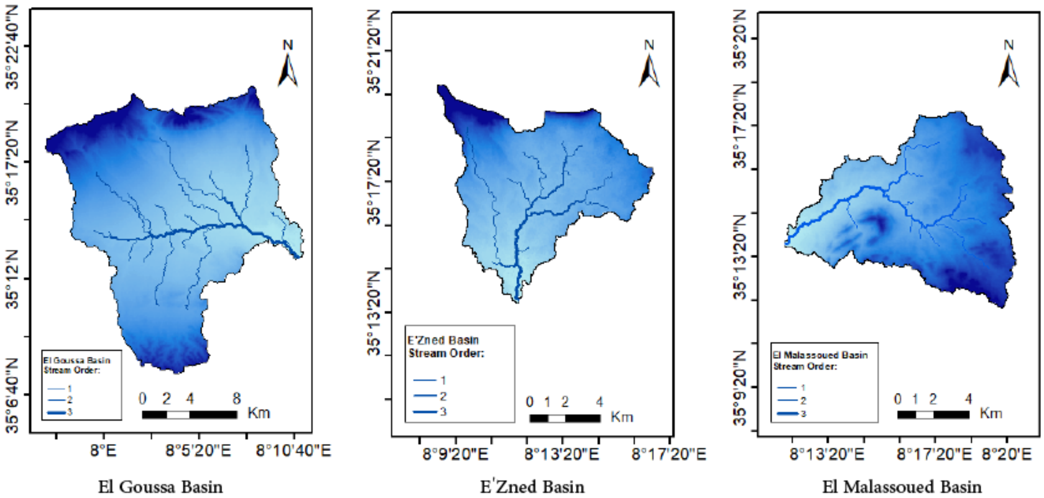


Figure 17. Hydrographic network and watercources order of the three subwatersheds

2.3.2. Degree of network development:

2.3.2.1. Drainage density:

It depends on the geology (structure and lithology), the topographical characteristics of the watershed and, to a lesser extent, climatic and anthropogenic conditions. Physically, it represents the surface area of the basin required to maintain stable hydrological conditions in a unitary hydrographic vector (network section). It can be expressed by its inverse expression: C = 1/Dd (according to Schumm), known as the stream stability constant. Drainage density, introduced by Horton, is defined by the total length of the watercourses in relation to the surface area of the basin. It is a parameter that provides information on the degree of density or looseness of the hydrographic network (Table 9).

The following expression helps to give it a value:

$$Dd = \frac{\sum L_i}{A} \equiv \mathrm{Km/Km^2}$$

With:

Dd: Drainage density, Li: Stream length (Km), A: Basin area (Km^2)

Table 9. Drainage density

Watershed	Drainage density D_d (Km/km²)
El Goussa	0,11
El Malassoued	0,22
E'Zned	0,18

2.3.3. Concentration time:

This is the time it takes for water (or a drop of water) to reach an outlet from the furthest hydrological point upstream in the watershed. It is controlled by many factors, including rainfall intensity, slope, lithology, and vegetation cover, which can act together, or separately to impede or promote runoff [14]. This parameter can be estimated by several formulas, including Giandotti's, whose expression is as follows:

$$Tc = \frac{4\sqrt{A + 1{,}5.L_p}}{0{,}8\sqrt{H_{moy} - H_{min}}} \quad \equiv \text{h}$$

With:

Tc: Concentration time (hours), A: watershed area (Km²), H_{moy}: Mean altitude (m)
L or LP: Length of main thalweg (Km), H_{min}: Minimum altitude (m).

Table 10. Concentration time

Watershed	Concentration time
El Goussa	12h 28 min
El Malassoued	7h 19 min
E'Zned	9h 1min

Table 11. Summary of morphometric parameters of the three subasins

Parameters			Results		
Parameter (symbol)	**Unit**	**Formula/means of determination**	**El Goussa**	**El Malassoued**	**E'Zned**
Area (A)	Km²	Calculated from ArcGIS	297,11	85,01	73,78
Perimeter (P)	Km	Calculated from ArcGIS	95,75	61,51	61,90
Gravelius Compactness Index (Kc)	/	$Kc = 0.28\,\frac{\mathrm{P}}{\sqrt{A}}$	1,56	1,87	2,02
Equivalent rectangle Length(L)	Km	$L = \frac{\mathrm{Kc}\sqrt{A}}{1,12}\left[1 + \sqrt{1 - \left[\frac{1,12}{Kc}\right]^2}\right]$	40,72	27,72	28,38
Equivalent rectangle width (l)	Km	$l = \frac{A}{L}$	7,30	3,07	2,60
Maximum Altitude (H_{max})	m	Calculated from ArcGIS	1704	1349	1578
Mean Altitude (H_{moy})	m	Calculated from ArcGIS	1197,49	1158,16	1113,83
Minimum Altitudes (H_{min})	m	Calculated from ArcGIS	1029	1039	1039
Height difference (D)	/	Obtained from the hypsometric curve	400	200	190
The average slope (I_m)	%	$Im = \frac{D}{l}$	54,79	65,15	73,08
Global slope index I_g	%	$Ig = \frac{D}{L}$	0,98	0,72	0,66
Specific Height Difference (D_s)	m	$Ds = D\sqrt{\frac{l}{L}}$	118,55	26,62	30,27
Drainage density (D_d)	Km/km²	$Dd = \frac{\sum L_i}{\mathrm{A}}$	0,11	0,22	0,18
Concentration time (t_c)	Hours	$tc = \frac{4\sqrt{A + 1,5.L_p}}{0,8\sqrt{H_{moy} - H_{min}}}$	12h 28 min	7h 19 min	9h 1min

3. Flood predetermination

3.1. Flood definition:

Flooding corresponds to an increase in the amount of water flowing down the river (discharge) and can affect the entire main bed of the river. The extent of flooding depends on three parameters: the height of the water, the speed of the flow, and the duration of the flood. These parameters are conditioned by rainfall, the state of the watershed and the characteristics of the watercourse (depth, valley width, etc.). These natural characteristics can be exacerbated by the presence of human activities [40].

3.2. Flood origins:

3.2.1. Hydro-meteorological event

A. **Rainfall:** the intensity and duration of rainfall over a given catchment area generates runoff, thus increasing the flow of a watercourse. The extent of this phenomenon also depends to a large extent on the permeability and water saturation of the soil in the catchment area.

B. **Snowmelt:** in spring, the transformation of snow into liquid water is a relatively slow phenomenon. The quantities of water stored in the form of snow or ice can be considerable, and in the event of rapid, intense softening accompanied by rain. Melting snow can cause flooding.

C. **Ice jam or breakup:** are caused by the spring thaw in regions where rivers freeze during the winter, a situation typical of cold regions such as Siberia and Canada. The thaw sets blocks of ice in motion, which can accumulate at an obstruction. The resulting damming can cause water levels to rise upstream, resulting in overtopping and possibly flash flooding.

3.2.2. Other causes:

Natural or Artificial Dam Failure: Overtopping of a dam due to insufficient spillway capacity or sudden filling of the reservoir with floating debris or rocks, often resulting in downstream flooding known as "breaking waves".

Flooding is often associated with other phenomena that are just as important, but which are the subject of specific studies and analyses:

- Debris flows (transport of solid materials by water).
- Landslides (near or along the river during flood events).
- Torrential erosion (in and around the riverbed).

3.3. The flooding process:

To understand this process, we need to analyze the various factors that contribute to the formation and temporary increase in the flow of a river. To simplify, we distinguish between:

- **Mobilizable water:** made up of water received by the watershed.
- **Runoff:** is the fraction of water that cannot be filtered through the soil. It depends on the type of soil, its surface cover, and the intensity of the rainfall event.
- **Concentration time:** defined as the time it takes a drop of water to travel from the furthest point of the outlet to the watershed;
- **Flood wave propagation:** Depends on the structure of the bed and alluvial valley, particularly the slope and floodplain characteristics [40].

3.4. Types of floods:

3.4.1. Fluvial floods (river floods):

A fluvial, or river flood, occurs when the water level in a river, lake or stream rises and overflows onto the neighboring land. Rise of the river could be due to excessive rain or snowmelt.

The severity of a river flood is determined by the terrain profile and the duration and intensity (volume) of rainfall in the river's catchment area. Other factors include soil water saturation and climate change effects on rainfall duration and intensity. In flat areas, floodwater tends to rise more slowly and be shallower, but it can often remain for days. In hilly or mountainous areas, floods can occur within minutes after a heavy rain, drain very quickly and cause damage due to debris flow [41] (Figure 18).

Figure 18. Illustration of fluvial floods [41]

3.4.2. Pluvial floods (flash floods and surface water):

A pluvial flood occurs when an extreme rainfall event creates a flood independent of an overflowing water body. A common misconception about flood is that you must be located near a body of water to be at risk. Yet pluvial flooding can happen in any location, urban or rural, even in areas with no nearby bodies of water (Figure 19)

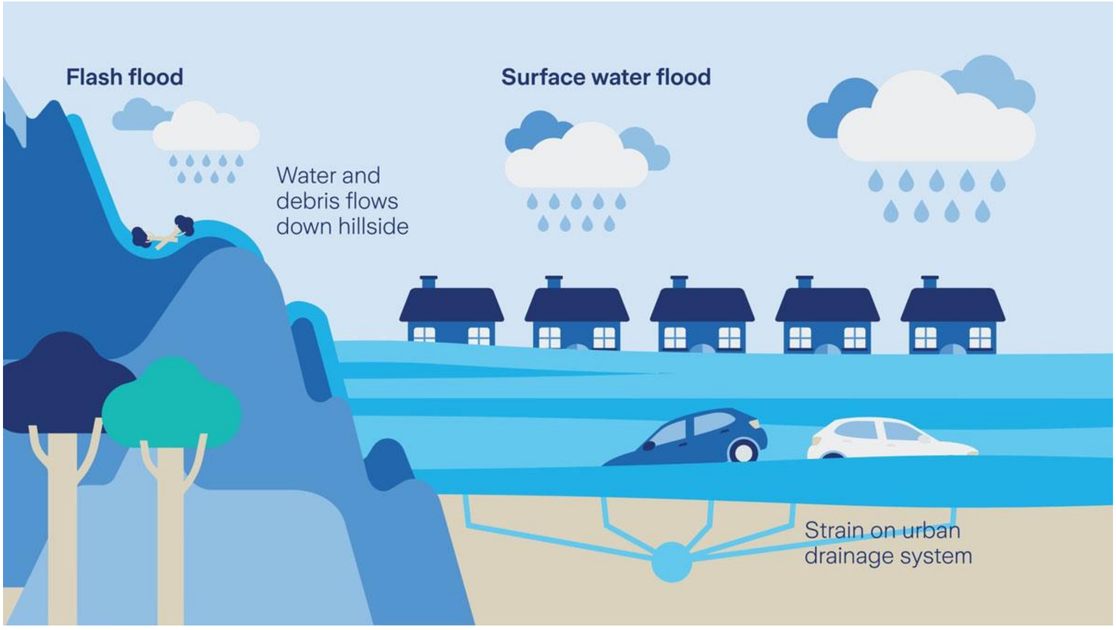


Figure 19. Illustration of pluvial floods [41]

There are two common types of pluvial flooding:

- **Surface water flooding** occurs when an urban drainage system is overwhelmed, causing water to overflow into streets and nearby buildings. It occurs gradually, giving people time to move to safer locations, and the water level is usually shallow (rarely more than 1 meter deep). It does not pose an immediate threat to life, but can cause significant economic damage.
- **Flash floods** are characterized by an intense, high-speed flow of water. They are caused by torrential rains falling within a short period of time in the vicinity or on nearby elevated terrain or by the sudden release of water from an upstream dam or levee. They can be very dangerous and destructive, not only because of the force of the water, but also because of the flying debris that is often swept up in the flow.

3.4.3. Coastal flood (storm surge):

Coastal flooding occurs when seawater inundates land along the coast. It is usually caused by intense storms - especially when they coincide with high tide - that creates a storm surge. Coastal flooding can also be caused by tsunamis.(Figure 20).

Figure 20. Illustration of coastal flood [41]

Storm surge occurs when strong winds from a storm push water onshore and is often the greatest threat associated with a hurricane or typhoon. The impact depends on the tide. Storms that occur during high tide can result in storm surge flooding that overwhelms low-lying areas and causes devastating loss of life and property.

The severity of a coastal flood is determined by several other factors, including the strength, size, speed, and direction of the storm. Onshore and offshore topography also play an important role. To determine the probability and magnitude of a storm surge, coastal flood models consider this information in addition to data from historical storms that have affected the area [41].

3.5. Flood characteristics:

3.5.1. Flood height:

Theoretically, it's the most important property because it's what determines the overflow. Hydrologically, however, it is not the most appropriate for flood assessment because it varies from point to point and thus characterizes a given cross section, but not the flood wave moving along the course.

In addition, elevation is not always the best indicator of flood severity. For example, a flood caused by a summer thunderstorm may be very high, but often of short duration and relatively small volume. As a result, the flood may not cause much damage because of the small volume of water involved and the short time that the land is under water.

3.5.2. Peak flood flow:

Peak flood flow is the maximum instantaneous value of flow during a flood. It is a very convenient hydrologic characteristic because it refers to the flood wave rather than a specific cross section. However, it does not remain constant as the flood moves downstream. Also, flood discharge doesn't depend on local bed variations (erosion, sedimentation) like flood elevation does: so it is a more representative characteristic not only of the flood itself, but also of any given cross-section.

3.5.3. Flood volume:

Flood volume refers to the total amount of water that accumulates and flows during a flood event. It is a critical measure in hydrology and flood management because it quantifies the magnitude of flooding and helps in the design of flood control and mitigation strategies.

3.5.4. Duration of a single flood event:

The notion of duration is essential in describing flood regimes. For this reason, hydrologists have defined numerous durations. The characteristic times defined below are all relative to a flood event. They are orders of magnitude rather than precisely calculable values. In fact, their definition refers to a highly simplified representation of the rainflow transformation (in particular, streamflow is assumed to be predominantly runoff).
The following definitions are taken from Roche (1963):

- **Response Time:** Response time is the time interval between the center of gravity of the effective rainfall and the peak of the hydrograph.
- **Rise Time:** This is the time elapsed between the start of the runoff arrival at the outlet and the maximum of the hydrograph.
- **Base Time:** The base time is the abscissa length of the base of the runoff hydrograph.
- **Concentration time:** concentration time is the time it takes for a water particle from the part of the watershed furthest from the outlet to reach the outlet. It can be estimated by measuring the time between the end of effective rainfall and the end of runoff.

3.5.5. Flood frequency and the notion of return time:

When we study quantities such as flood flows from a statistical point of view, we generally try to determine the probability that a given flow will not be exceeded. This probability is called the frequency of non-exceedance. Its unit complement is called probability of exceedance, frequency of exceedance or frequency of occurrence. The return time T of an event is then defined as the inverse of the frequency of occurrence of the event.

3.5.6. Flood return period:

The concept of flood is often associated with the concept of return period (decadal, centennial, millennial, etc.). The longer the return period, the more intensive the flood will be. We characterize these periods in the following ascending order:

- Frequent floods: with a return period between one and two years.
- Moderate floods: with a return period between ten and twenty years.
- Exceptional floods: with a return period of about one hundred years.
- The maximum probable flood: Occupies the entire major river bed.

3.6. Descriptive elements of a flood:

- **Time of Concentration:** The time required for the drop of water falling at the furthest point in the basin to reach the outlet.
- **Flood peak:** the power of the flood and the duration of the critical period.
- **Drying curve:** Represents the return of the river to its pre-flood level.
- **Recurrence Frequency:** A 100-year flood has a one in a hundred (1/100) chance of occurring.

3.7. Estimating maximum flood flow:

The choice of the maximum flood flow can be either the result of a consequence study or it can be fixed and not to be exceeded, depending on the user. Several methods are used; the choice is very wide and very difficult, where some countries have even standardized the estimation method. These methods can be divided into three groups:

3.7.1. Methods based on flood history:

This very old method is based on the idea that we'll never see anything worse than what we've already seen in a sufficiently widespread past. It is still used when observations of the maximum flow recorded during an exceptional flood are not available and when there is a current tendency to forget this.

The information derived from historical floods is invaluable and constitutes a very important database. It can be defined as the study of ancient floods before their direct measurement by modern techniques, with the aim of defining floods of historical periods in order to complete the existing data, to compare them with other methods and to improve the degree of precision of the values resulting from the application of statistical extrapolation methods [40].

3.7.2. Probabilistic methods:

We can categorize probabilistic methods into:

- Fixed-sample methods such as the annual maximum method, which is simple and widely used around the world, but still very inadequate for sample sizes less than 30.
- Hydrometeorological methods such as Gradex, valid for limited (S < 20000 Km) and homogeneous catchments.
- Stochastic methods are widely used to simulate complex variables by statistically modeling the process on a daily and monthly scale. However, they have very poor control over uncertainties (Masson, 1991).
- Renewal-type methods: This is based on probabilistic methods [40].

3.7.3. The empirical methods used:

3.7.3.1. Mallet-Gauthier formula:

$$Qmax = \frac{2.\mathrm{K}.\log\left(1+\mathrm{A.Pmoy}\right).S.\sqrt{1+4\log T\_\log S}}{\sqrt{L}}$$

With:

Q_{max}: Maximum flood flow for a given frequency (m³/s).

P_{moy}: Mean annual rainfall; We take P_{moy}=0.20 m.

S: Watershed area (Km²).

L: Length of main talweg [Km].

K: coefficient depending on catchment characteristics, varying between 2 and 4;

We will take [K = 2].

A: constant relative to the basin, varying between 20 and 30, a value generally used in Algeria by the A.N.R.H.; A=20

T: return period [year].

Table 12. Maximum Flood Flow using Mallet-Gauthier formula

	Maximum Flood Flow (Q_{max}) (m^3/s)		
Return Time(Years)	**El Goussa**	**El Malassoued**	**E'Zned**
5	43,64	31,2	28,83
10	60,32	40,14	36,75
20	73,30	47,36	45,31
50	87,55	55,48	50,56
100	96,95	60,91	55,45
200	105,5	65,89	59,95
1000	123,12	76,22	69,28
2000	129,97	80,26	72,93
10000	144,64	88,93	80,78

- **Graphical representation of the results :**

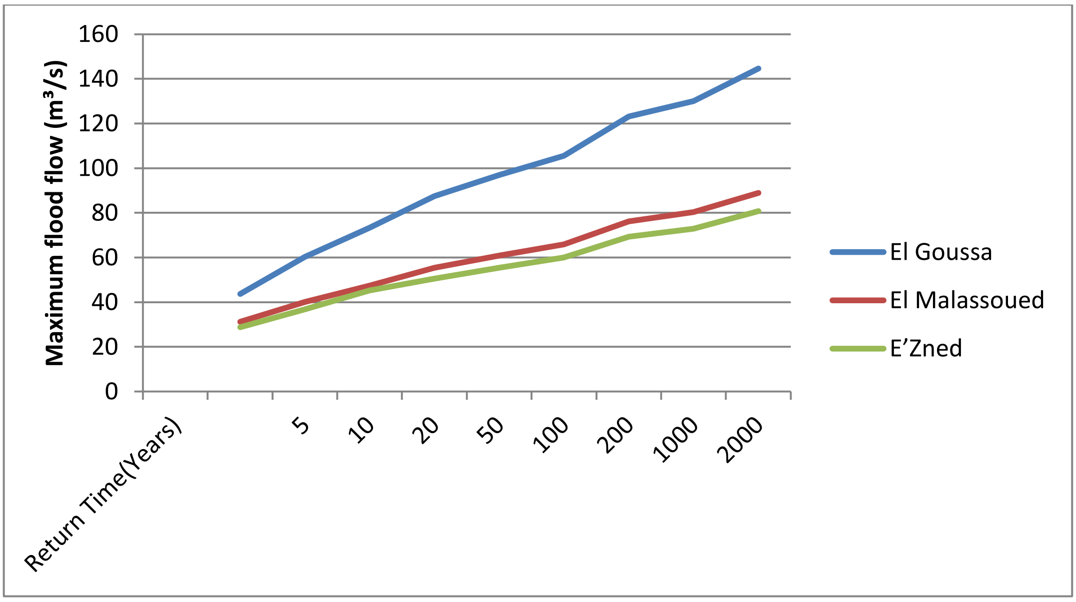


Figure 21. Maximum flood flow

- **Validation:**

From the data, it is clear that the flood flow increases over time, which makes sense. The El Goussa basin has the highest flood flow, the El Malassoued basin has an average flow, while the E'Zned basin has a lower flow compared to the previous two basins (Figure 21).

3.7.3.2. Giandotti formula:

In their study of water problems in Algeria, they established a formula expressing the maximum flood flow in Giandotti's method is inspired by runoff laws based on the morphometric characteristics of the catchment area. This formula gives satisfactory results, particularly for typically mountainous basins.

$$Q_{max} = \frac{C.S.Ptc.\sqrt{H_{moy} - H_{min}}}{4\sqrt{S} + 1{,}5L}$$

With:

Q_{max}: Maximum flood flow in m³/s

S: Watershed area in km²

P_{tc}: Short-duration rainfall corresponding to time of concentration in m

L: Length of main thalweg in Km

H_{moy} and H_{min}: Average and minimum watershed elevations (m)

C: topographical coefficient varying between 100 and 166.

Table 13. Maximum Flood Flow using Giandotti formula

Watershed	**El Goussa**	**El Malassoued**	**E'Zned**
Q_{max} (m³/s)	97,92	93,57	69,99

3.7.3.3. Possenti formula:

$$Qmax = \frac{\mu.P_{max}\,j.S}{L}$$

With:

P_{max}: Maximum daily rainfall corresponding to each return period in m

μ: Coefficient between 700 and 800; we take (μ=700)

L: Length of the main river in Km.

S: Watershed area in Km².

Table 14. Maximum Flood Flow using Possenti formula

Watershed	**El Goussa**	**El Malassoued**	**E'Zned**
Q_{max} (m^3/s)	86,8	110,56	104,68

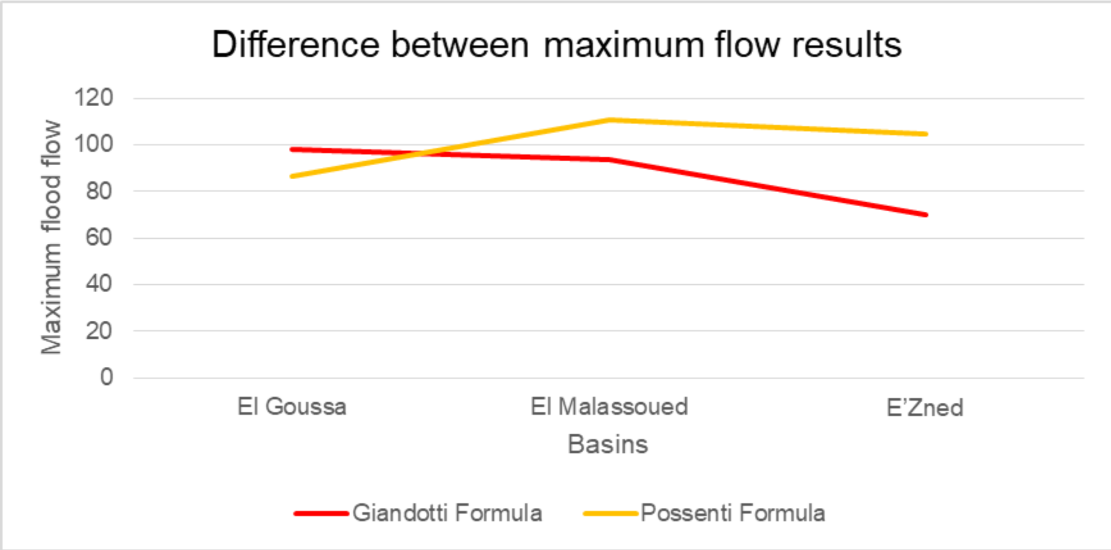


Figure 22. The difference between using different formulas to calculate the maximum flow

Validation:

From the graph, it is clear that the maximum flow is almost identical in the results in the three basins, but the results of the Possenti formula gave higher values in the maximum flow compared to Giandotti (Figure 21).

Conclusion:

After meticulously calculating the morphometric parameters for three sub-basins within the El Mlabiod region, a comprehensive understanding of the hydrological characteristics of these areas emerges. These morphometric parameters, including area, perimeter, drainage density and concentration time, provide crucial insights into the geomorphological and hydrological characteristics of the study area.

First, the calculated areas of the sub-basins shed light on their respective sizes, indicating variations in their spatial extent. This variation in area may indicate differences in potential water yield and runoff generation within each sub-basin, influenced by factors such as topography, land cover, and geological characteristics. The perimeters of sub-basins reflect the length of their boundaries, which play an important role in influencing the flow path and connectivity of water within the drainage network. Subwatersheds with longer perimeters may have greater opportunities for surface water interactions, potentially affecting overall hydrologic processes and water quality dynamics. Drainage density, a fundamental morphometric parameter, provides valuable insight into the density and distribution of the drainage network within each sub-basin. Higher drainage density indicates a more dissected landscape with numerous channels and tributaries, facilitating efficient runoff and groundwater recharge processes. Conversely, a lower drainage density may indicate a less dissected landscape, affecting the hydrologic response and flow characteristics of the subwatershed.

Overall, the calculated morphometric parameters offer valuable insights into the hydrological behavior and geomorphological attributes of the three sub-basins in the El Mlabiod region of, Understanding these parameters is essential for effective watershed management, flood risk assessment, and sustainable water resource planning in the region. Further analysis and integration of these findings with other environmental variables can enhance our understanding of the complex interactions shaping the hydrological dynamics of the study area, ultimately contributing to informed decision-making and resource management practices.

Chapter 4 :
GIS-based MCDM - AHP Modeling for Flood susceptibility Mapping of Arid Areas, El Malabiod region (Northeastern Algeria)

4. Itroduction :

Flooding is a natural part of the water cycle. However, it has the potential to cause death, displacement, and environmental damage, all of which can jeopardize economic progress. Flooding is one of the most common natural disasters, often with catastrophic consequences, affecting 170 million people worldwide each year [42]. In addition, climate change projections, changes in land use patterns, and population growth are expected to increase the frequency and intensity of floods by 2050, which could result in significant losses [43]- [47]. Flood hazard mapping provides easy-to-read charts and maps that allow planners to identify risk areas and prioritize mitigation activities [48] - [51].Flood risk is a measure of vulnerability to damage and loss from flooding that is commonly estimated by taking into account physio-climatic, hydrodynamic, economic, social, and ecological factors [52].Flood hazard has been efficiently assessed using remote sensing and Geographic Information System (GIS) approaches. In hazard and vulnerability analysis, GIS overlay analysis [53], multi-criteria decision analysis, fuzzy method [54], and other methods have been used. Multi-criteria decision analysis (MCDA) with a geographic information system (GIS) is a collection of approaches for analyzing and combining geographic data and user expectations to improve decision making. The MCDA method is often used to spatially reflect flood vulnerability assessments because of its adaptability in assessing diverse and overlapping characteristics [54], and that's what we'll use for this part of the study.

1. Literature Review:

1.1. Flood Mapping:

Regional flood mapping is essential to reduce flood risk or to take adaptation and mitigation measures against the devastating effects of floods [55].With the use of satellite imagery, flood susceptibility maps can be generated in near real time. The interpreted flood boundary can then be used to later measure flood water levels.

Flood hazard mapping and analysis, which identifies the most vulnerable areas based on physical characteristics that indicate a propensity to flood, is one of the most important parts of early warning systems or methods for preventing and mitigating future flood situations. Flood hazard mapping is a critical component of flood-prone land use planning and mitigation strategies [56]. Flood hazard mapping provides easy-to-read charts and maps that allow planners to identify risk areas and prioritize mitigation measures [41] [44].

A flood hazard map is an important tool for determining the level of risk in a given location. The hazard map is required for centralized planning of development activities and can be used as a decision support system (DSS). As a result, it should be easy to understand, with the goal of creating a hazard map that both technical and non-technical people can read and understand [57].

1.2. Flood Mapping using GIS:

GIS has become an attractive and effective tool for managing flood hazards and determining risk zones based on specific geographic areas [58]. As a result, its significant capabilities made it possible to create a flood risk map by outlining the actual flood prone zones. In a GIS, geographic information is stored in a database, queried, and displayed graphically for analysis. By overlapping or intersecting different geographic layers, flood risk zones can be identified and used explicitly for mitigation or more stringent floodplain management measures.

The combination of multi-criteria decision making (MCDM) with geographic information systems (GIS) proposed in this study allows the integration of the three components of risk assessment (hazard, exposure and vulnerability). The result of this methodology is a flood risk map showing the spatial distribution of flood risk along with its intensity level, ranging from very high to very low risk. In MCDM, there are several methods to evaluate the weights of the criteria: entropy, ranking, rating, trade-off analysis, and pairwise comparison, among others

[9].The Analytic Hierarchy Process (AHP) proposed by Saaty is one of the most common MCDM methods, and it has been widely used to solve decision problems related to water resources. The purpose of AHP is to provide decision makers with the decision that best suits their goal among different alternatives and criteria. This method compares two criteria at a time through a pairwise comparison matrix in which values of relative importance of one criterion to another criterion are assigned. It provides a measure of a level of consistent judgment supported by a theoretical background. The scale of relative importance ranges from one to nine, with one representing equal importance and nine representing extreme importance [59].

1.3. **Analytic Hierarchy Process (AHP):**

The technique involves the comparison of the criteria, which as well allows one to compare the importance of two criteria at a time. This very technique, which was proposed and developed by Saaty in 1980 within the framework of a decision making process known as Analytical Hierarchy Process (AHP) is capable of converting subjective assessments of relative importance into a linear set of weights. The criterion pair-wise comparison matrix takes the pair-wise comparisons as an input and produces the relative weights as output. Further the AHP provides a mathematical method of translating this matrix into a vector of relative weights for the criteria. By quantifying its metrics and alternative solutions and linking these parts to the overarching goal, AHP provides a coherent basis for a necessary decision [60]. AHP is a multi-criteria decision making (MCDM) model commonly used to rank factors. It can be used to solve decision-making problems that require the simultaneous consideration of both quantifiable and non-quantifiable measures. It is widely accepted because of its simplicity, ease of use, and versatility [60].

The first step in the analysis is to select the influencing factors, and then a pairwise comparison matrix is created based on the relative importance of each pair of criteria [60]. Next, the criteria at each level are sorted and checked for consistency. The maximum eigenvalue of the matrix is then calculated, and the consistency index (CI), consistency ratio (CR), normalized values for each criterion. If ($CR < 0.1$), the consistency of the judgment matrix is acceptable; otherwise, the judgment matrix must be revised to meet the consistency requirement. Finally, the overall priority of the alternatives is determined. The overall weight of each criterion/alternative relative to the final goal is calculated according to the weights obtained at all levels, which are relative to their respective upper levels.

1.4. GIS-Based Multi-Criteria Approach:

The combination of multi-criteria decision making (MCDM) with geographic information systems (GIS) proposed in this study allows the integration of the three components of risk assessment (hazard, exposure and vulnerability). The result of this methodology is a flood risk map showing the spatial distribution of flood risk along with its intensity level, ranging from very high to very low risk. In MCDM, there are several methods to evaluate the weights of the criteria: entropy, ranking, rating, trade-off analysis, and pairwise comparison, among others. The Analytic Hierarchy Process (AHP) proposed by Saaty is one of the most common MCDM methods, and it has been widely used to solve decision problems related to water resources. The purpose of AHP is to provide decision makers with the decision that best suits their goal among different alternatives and criteria. This method compares two criteria at a time through a pairwise comparison matrix in which values of relative importance of one criterion to another criterion are assigned. It provides a measure of a level of consistent judgment supported by a theoretical background. The scale of relative importance ranges from one to nine, with one representing equal importance and nine representing extreme importance.

This GIS-based multi-criteria approach has been increasingly used for flood risk assessment due to its several advantages. Some more complex alternative methods involve hydraulic and hydrological models for flood hazard assessment, and require information on the monetary value of exposed assets for vulnerability assessment. In contrast, the proposed approach requires only the spatial layers of the parameters contributing to the flood hazard and land use information to evaluate the vulnerability. Therefore, the main advantage of this methodology is the possibility to obtain a reliable flood hazard map with a relatively low financial and time investment to help stakeholders to evaluate only the areas that need further detailed assessment. In addition, it is easy to update, uses readily available open source input data, and is flexible in terms of which criteria are included [61].

2. Materials and Methods:

2.1. Flood condition factors Database:

To determine flooding in the study area, it is necessary to define the causal factors and the location of flooding, and we have collected relevant data from various sources (Table 15). Several factors such as land use and soil texture affect the occurrence of flooding because they either increase or decrease water runoff, but slope, drainage density, and elevation remain the most important factors affecting flooding. It should be noted that there is no map of rainfall distribution because the area is small, with an average rainfall of about 200 mm per year. The flood susceptibility factors were then categorized into very low, low, moderate, high, and very high susceptibility based on the relevance of the criteria (Table 15). The numerous components and their ranks in the flood susceptibility mapping are listed in the table.

Table 15. Data Sources

Primary Data	Format	Year	Source	Extracted Data
DEM	Raster	2020	Earth Explorer https://earthexplorer.usgs.gov/	Slope, Elevation, drainage Density
Land use Data	Raster	2019	Copernicus Land Monitoring Service (CLMS) https://land.copernicus.eu/en/map-viewer?product=333e4100b79045daa0ff16466ac83b7f	Land use and Land Cover
Soil Texture Data	Raster	2015	ISRIC World Soil Information https://data.isric.org/geonetwork/srv/fre/catalog.search#/metadata/2a7d2fb8-e0db-4a4b-9661-4809865aaccf	Soil Texture

Table 16. Causative Factors Classes and Ratings

Flood causative criterion	Unit	Class	Susceptibility class ranges and rating	Susceptibility class ratings
Elevation	m	1143	Very High	5
		1143_1284	High	4
		1284_1424	Moderate	3
		1424_1565	Low	2
		1565_1706	Very low	1
Slope	%	0_1	Very High	5
		1_2	High	4
		2_4	Moderate	3
		4_6	Low	2
		6_19	Very low	1
Drainage density	Km/Km²	0 - 0,24	Very low	1
		0,24 - 0,66	Low	2
		0,66 - 1,09	Moderate	3
		1,09 - 1,58	High	4
		1,58 - 2,7	Very High	5
Soil type	/	Clay Loam	Very High	5
		Sandy Clay Loam	High	4
		Loam	Moderate	3
		Sandy Loam	Low	2
LULC	/	Shrubland	Low	2
		Herbaceous land	Moderate	3
		Cropland	Very High	4
		Bare land	High	4
		Forests	Very low	1

3. Result and discussion:

3.1. Factors influencing flooding in the El Malabiod basin:

3.1.1. Drainage Density:

One of the key variables leading to flooding is drainage density; the runoff rate is critical when it is high [62]. As a result, there is a greater chance of flooding [63]. The drainage density map of the study area was prepared from stream network data using the "Line Density" tool in ArcGIS 10.8. Line density is calculated by dividing the total length of all streams and rivers in a catchment by the total area of the catchment (Figure 23).

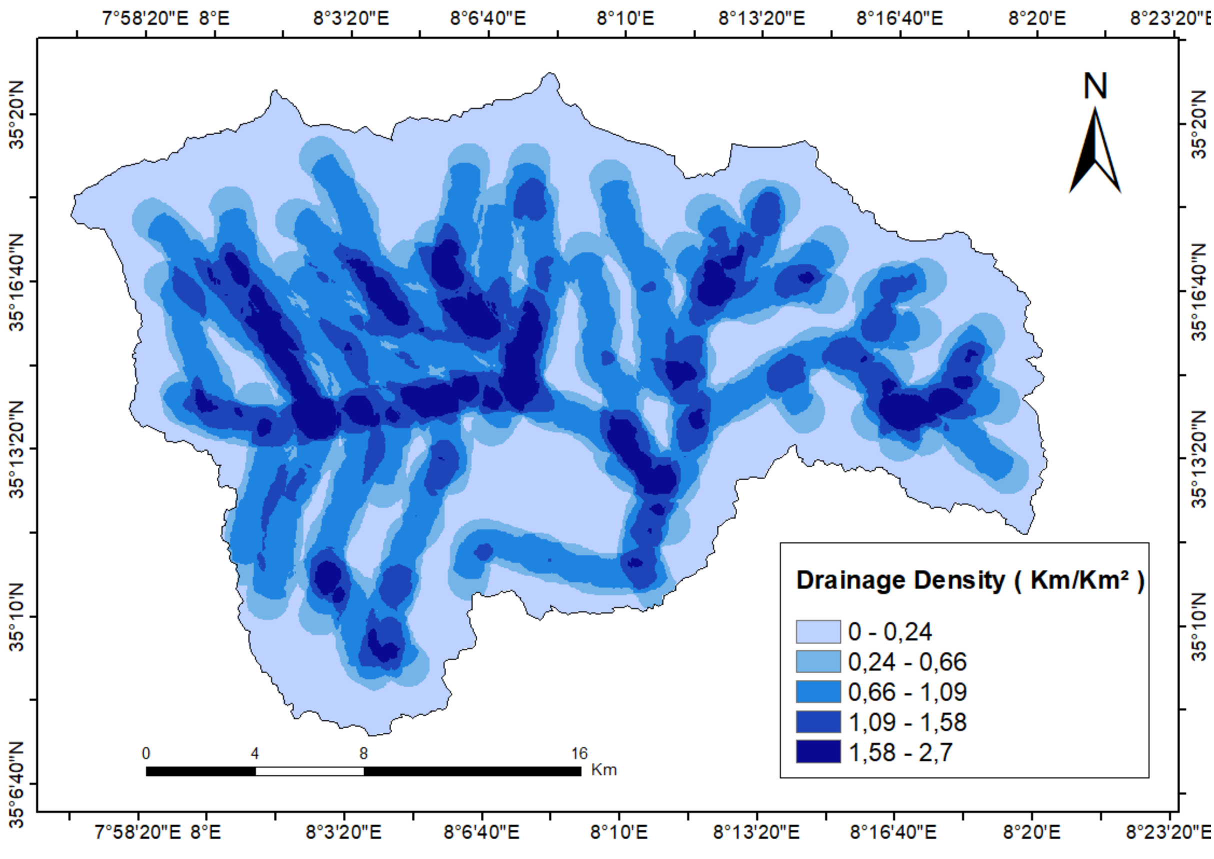


Figure 23. Drainage Density Map

3.1.2. Slope:

The slope is also considered another important flood-triggering parameter [64]. It has a direct impact on drainage and runoff accessibility and affects the volume and velocity of surface runoff, as well as groundwater infiltration [62]. The slope map was created from the Digital Elevation Model (DEM) using the surface analysis tool in ArcGIS 10.8. In the study area, slopes less than 6%, which are considered the most vulnerable, are concentrated in low-lying areas and river beds. On the other hand, areas with slopes greater than 16%, which generally represent mountainous regions, are less prone to flooding (Figure 24).

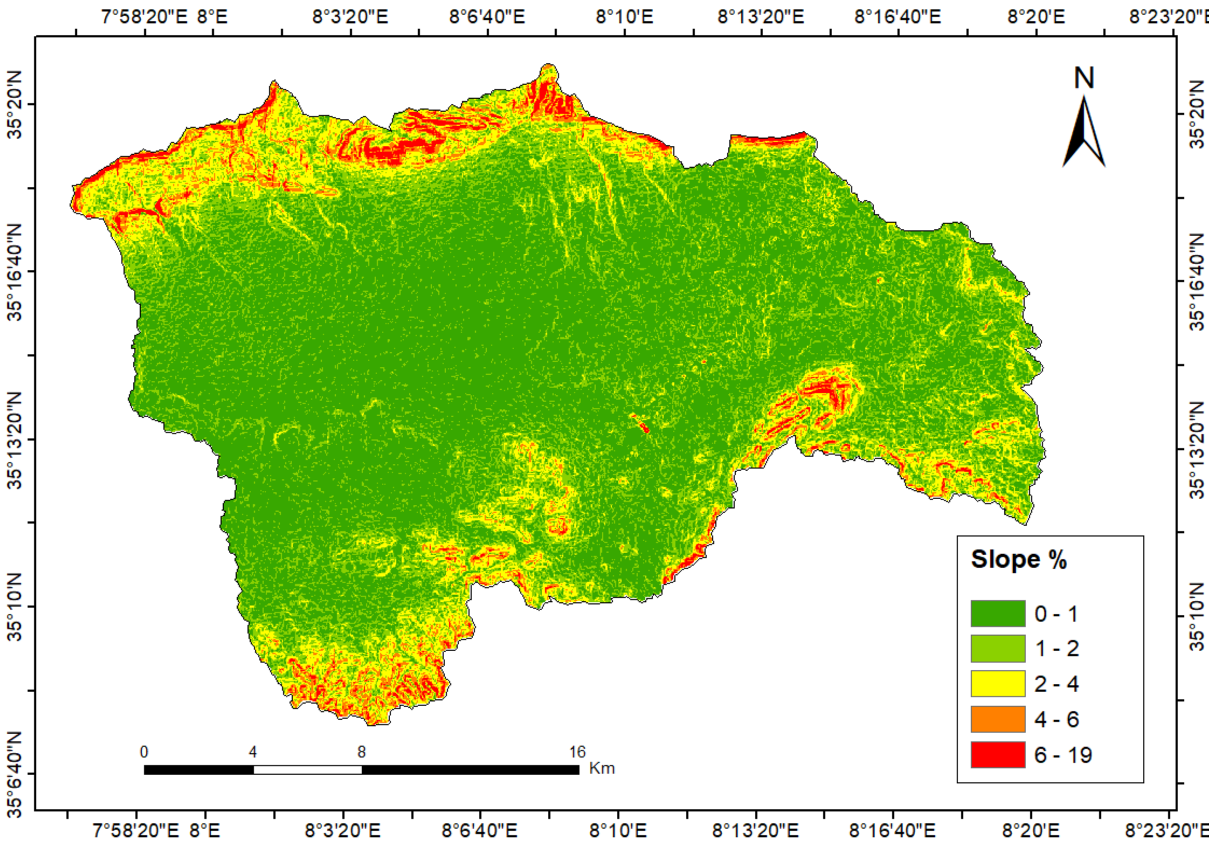


Figure 24. Slope map

3.1.3. Elevation:

Lowland areas are more susceptible to flooding as water moves from higher to lower altitudes [65]. The elevation map of the study area was created by reclassifying a 30-meter resolution digital elevation model downloaded from the USGS Earth Explorer (Figure 25). The topography of the El Malabiod watershed ranges from 1003 to 1706 meters, with the highest points in the Doukane and Boudjellal Mountains, while the lowest points are in the El Malabiod basin area. Due to the high altitude and steep slope upstream, there is considerable runoff after heavy rains, causing high flows downstream.

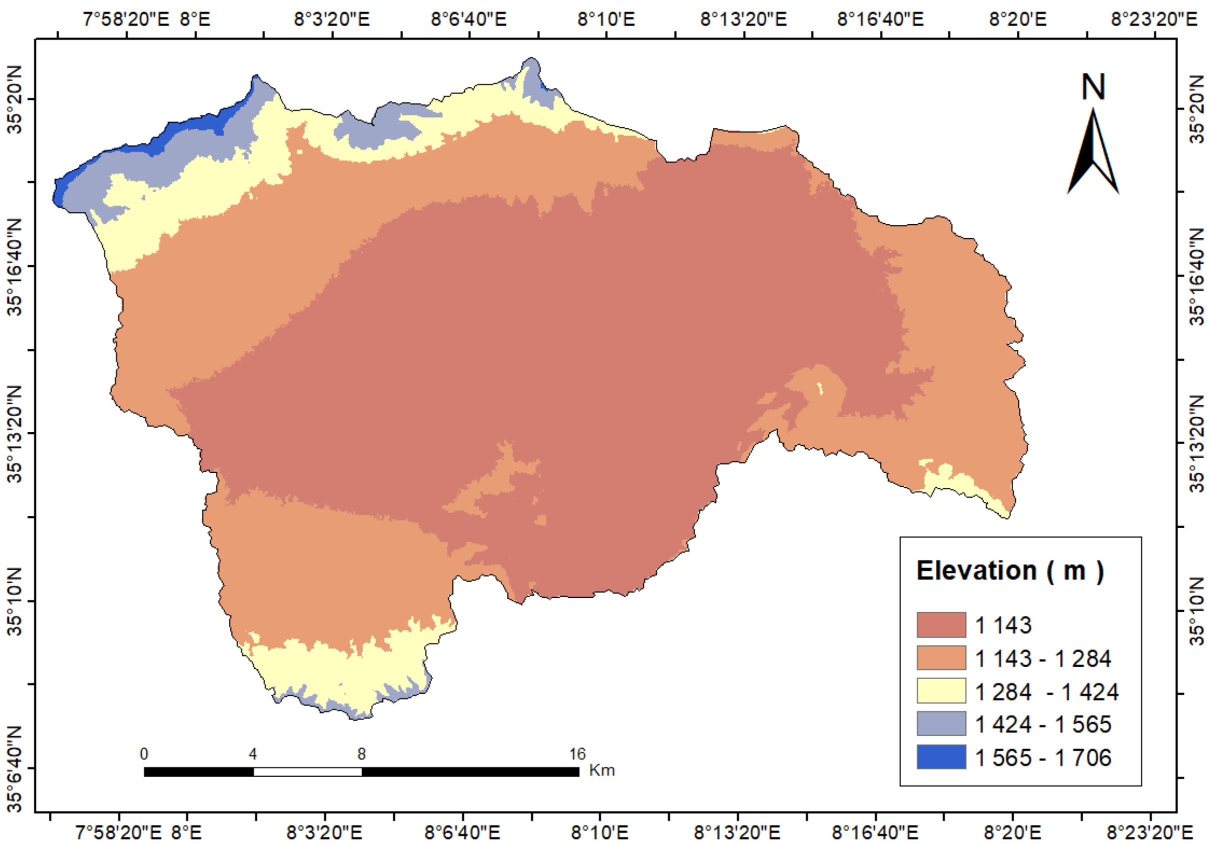


Figure 25. Elevation map

3.1.4. Soil Texture:

Soil texture is another factor that strongly controls hydrology and directly affects infiltration rates, depending on porosity and permeability. The infiltration phase would be accelerated by lithological units with increased permeability, while the impermeable layer would increase surface runoff, possibly causing flooding. Rainwater infiltration is facilitated by porous formations (coarse sand, conglomerates, etc.), which reduces the risk of flooding. On the other hand, impermeable deposits (marl, clay, gypsum, etc.) increase runoff rates, thereby increasing the risk of flooding [64]. The soil map was obtained from ISRIC - World Soil Information and the soil data was uploaded at a depth of 100-200 cm derived from sand, silt and clay contents predicted using the Africa Profiles Database (Figure 26).

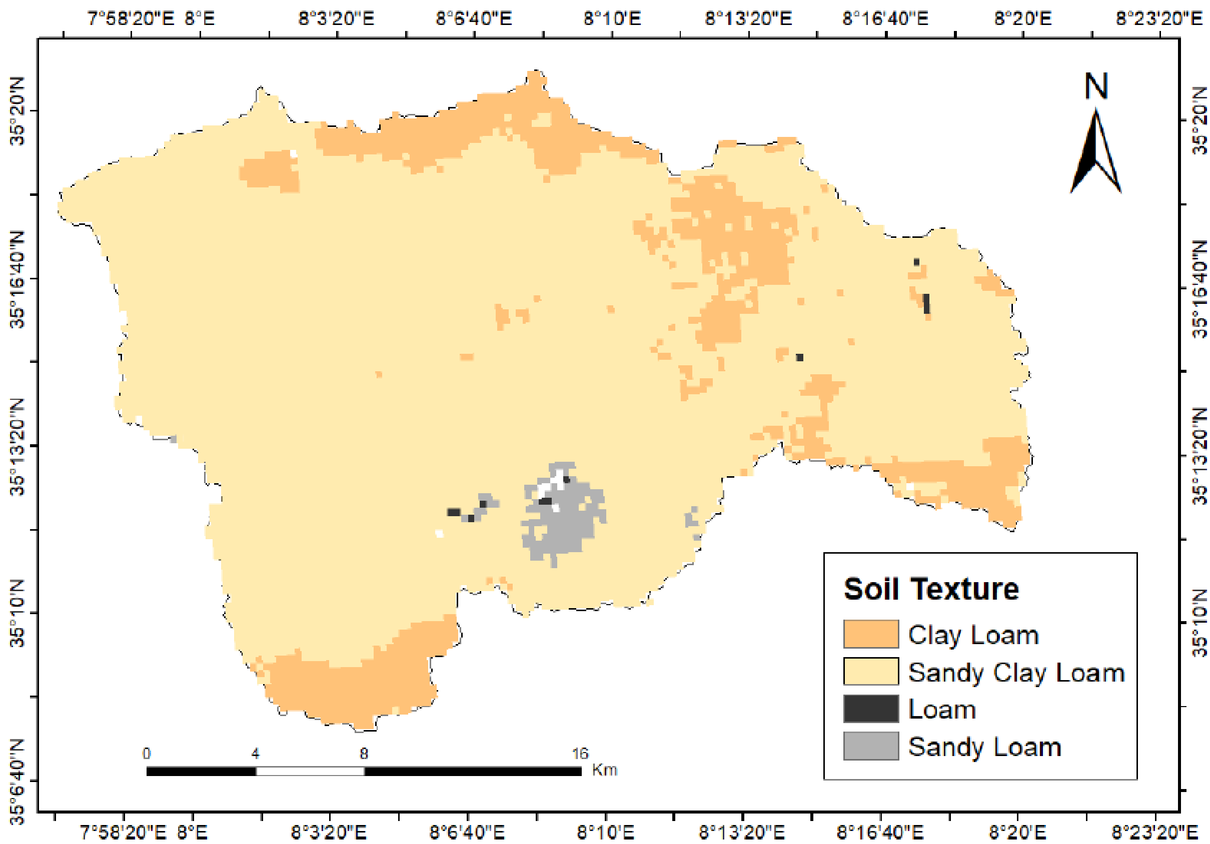


Figure 26. Soil texture map

3.1.5. Land use land cover:

Land use plays an important role in regulating the movement of water through various processes such as runoff, infiltration, evaporation, and evapotranspiration. As a result, it directly influences the likelihood of flood events. Land use categories include a number of factors such as soil deposits, distribution of buildings, watercourses, vegetation cover, and bare land. The occurrence of floods is influenced by specific land use patterns and their evolution over time [65]. Land use data for the study area were downloaded from the Scihub Copernicus website with a resolution of 100 m. Most of the data related to the area were covered, including cropland, scrubland, and also built-up areas (Figure 27).

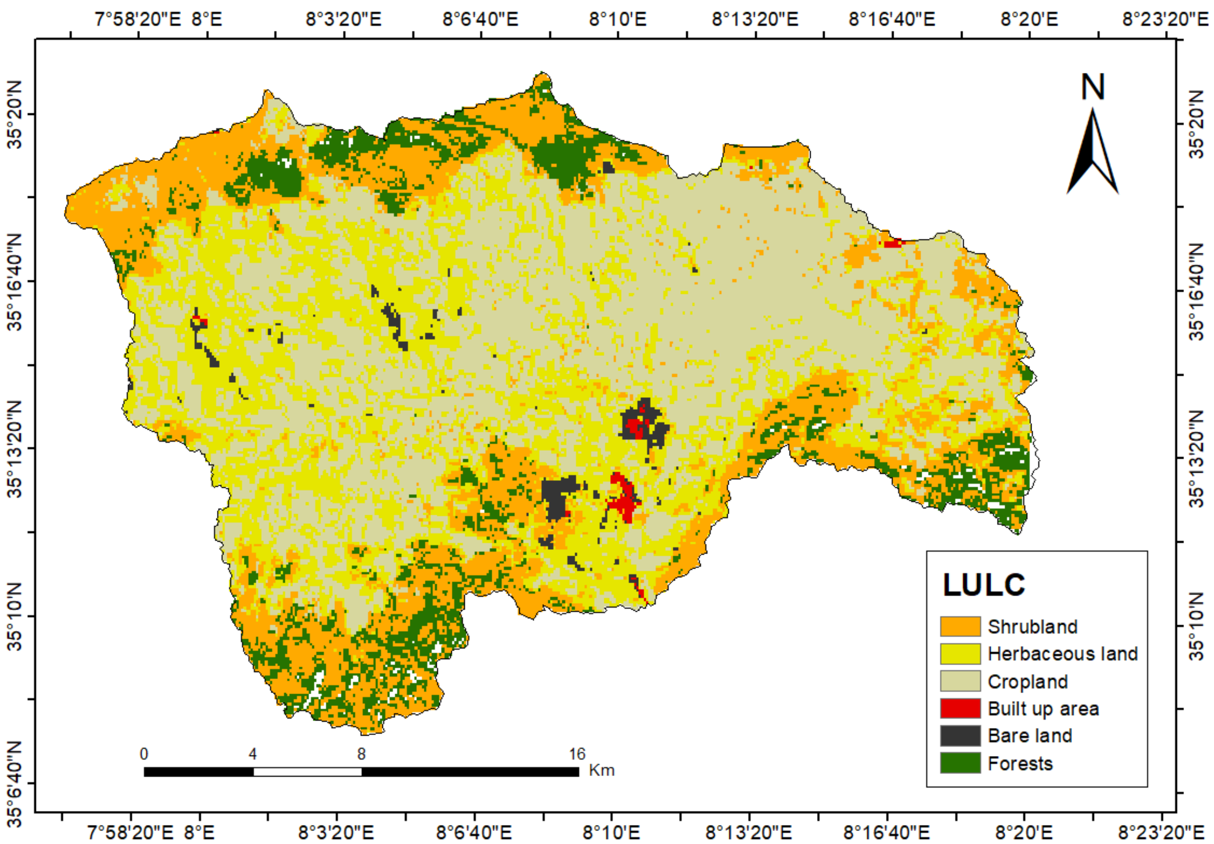


Figure 27. Land use/Land cover map

3.2. Analytic Hierarchy Process (AHP) :

3.2.1. Pairwise comparison matrix

Based on the chosen flood contributing criteria, a pairwise comparison matrix table was created. Following that, based on the Expert's assessment, each aspect was given a specific weight. The scale relative importance was used to assign relative relevance or value. The comparison matrix table was used to determine factor weight, class weight, and the CR value. The following expression is used to calculate the CR value.

Table 17. Pairwise comparioson matrix

Criteria	LULC	Elevation	Soil Texture	Drainage density	Slope
LULC	1	1/3	3	1/5	1/7
Elevation	3	1	5	1/3	1/5
Soil Texture	1/3	1/5	1	1/7	1/9
Drainage density	5	3	7	1	1/3
Slope	7	5	9	3	1

3.2.2. Normalized Pairwise Comparison Matrix:

First, we sum each column, and then we divide each element by its column sum to normalize the matrix:

Table 18. Normalized Pairwise Comparison Matrix

Criteria	LULC	Elevation	Soil Texture	Drainage density	Slope
LULC	0.061	0.035	0.120	0.043	0.032
Elevation	0.184	0.105	0.200	0.071	0.037
Soil Texture	0.020	0.021	0.040	0.015	0.012
Drainage density	0.306	0.315	0.280	0.214	0.123
Slope	0.429	0.524	0.360	0.643	0.368

3.2.3. Priority Vector:

The priority vector is derived by averaging the rows of the normalized matrix. This gives a vector of relative weights representing the priorities of the elements.

Table 19. Priority Vector

Criteria	Priority Vector
LULC	0.058
Elevation	0.119
Soil Texture	0.021
Drainage density	0.248
Slope	0.416

3.2.4. Consistency Check :

The rule of transitivity is widely used to check for consistency in outcomes. The following expression is used to calculate the value of λ_{max}:

$$\lambda_{\max} = 0.28\ \frac{(16.33 \times 0.058) + (9.53 \times 0.119) + (25 \times 0.021) + (4.67 \times 0.248) + (2.71 \times 0.416)}{5}$$

$$\lambda_{\max} \approx\ 5.269$$

The Consistency Index (CI) is then calculated as:

$$CI = \frac{\lambda_{\max\,\_}\,n}{\mathrm{n\_1}}$$

Where n is the number of criteria is 5:

$$CI = \frac{5.269 - 5}{5\_1}\ \approx\ 0.067$$

The Consistency Ratio (CR) is calculated using the Random Consistency Index (RI). For n=5, RI=1.12:

$$CR = 0.28\ \frac{\mathrm{CI}}{\mathrm{RI}}\ \approx\ \frac{0{,}067}{1{,}12}\ \approx 0{,}06$$

Since CR < 0.1, the consistency is acceptable.

3.3. Weighting factors in the flood susceptibility:

Weighting strategies are used to rank the relative value of each factor in relation to another. In a weighted overlay, the higher the weight, the more important the component is compared to the other factors. The final flood hazard map was created by overlapping the above maps of flood susceptibility factors for the El Malabiod region. The flood vulnerability map was created by the weights calculated for each criterion (Table 17).The resulting vulnerability map derived from the AHP analysis is shown in (Figure 28) The map was categorized into five different classes (very low, low, medium, high, and very high).

Table 20. Results of weights for each factor

Citerions	Weight (%)
Elevation	20
Slope	25
Drainage density	23
Soil Texture	14
LULC	18

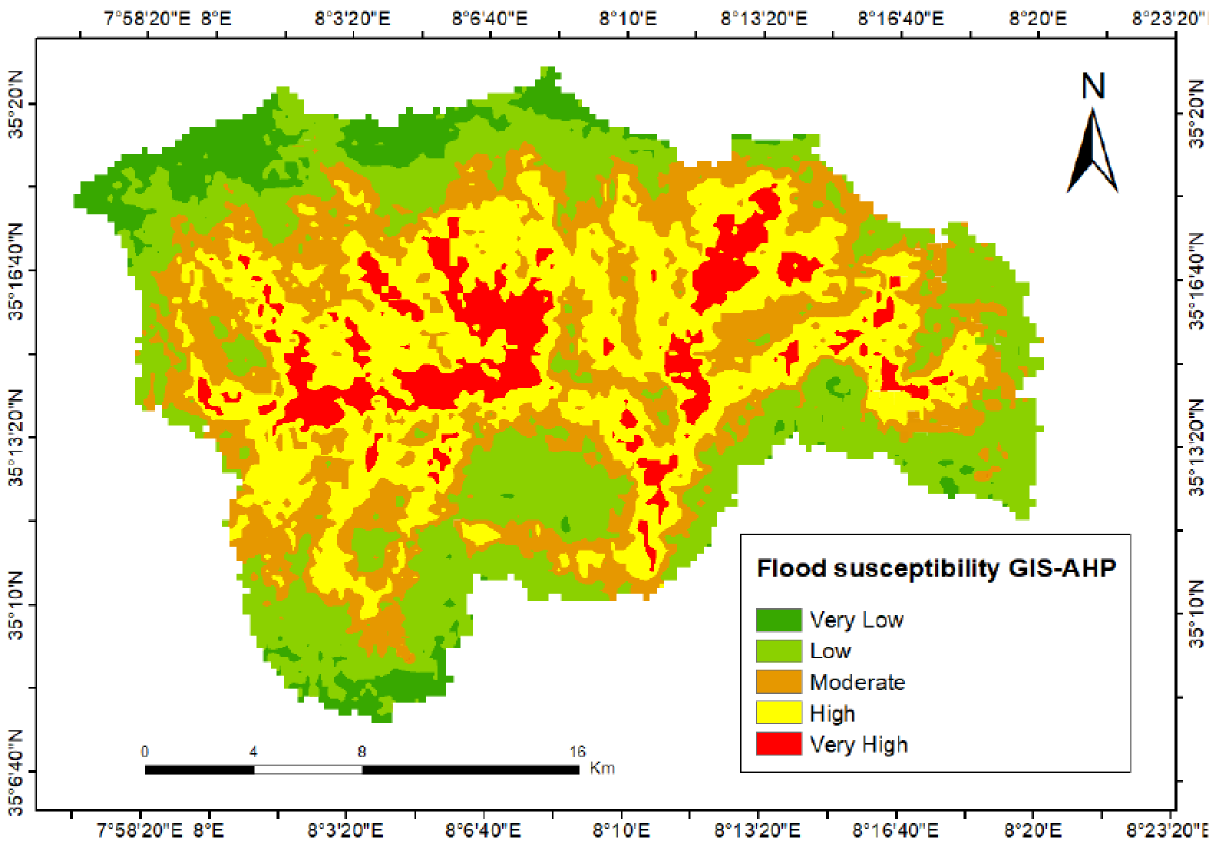


Figure 28. Flood Susceptibility Map Using the AHP Analysis

3.3.1 Flood susceptibility mapping:

The results of the AHP analyses indicate that the areas prone to very high and moderate flooding are the basin areas, which are low-lying compared to the surrounding mountainous terrain. These areas are mainly impermeable to water, leading to reduced infiltration and increased runoff (Figure 28).

The AHP analysis technique showed that slope has the maximum contribution to the occurrence of floods with a weight of 25%, followed by drainage density with a weight of 23%. Elevation has a moderate impact on the occurrence of floods with a weight of 20%, while land use and soil texture are the least important factors with weights of 18% and 14%, respectively.

4. Conclusion:

In fact, the identification of flood-prone areas is essential for the identification of risk areas that are likely to be flooded and for floodplain development control measures. The final results, which will be in the form of maps showing the susceptible/risk areas, will also serve as valuable tools for planners, insurers, and emergency services in assessing flood risk.

The present study is an attempt to prepare a flood hazard susceptibility map of the El Malabiod region using the 'Multi-Criteria Decision Making - Analytical Hierarchy Process' model in a geographic information system environment. What we found is that the basin area is at risk of flooding, and areas close to the river and with a low slope are the most vulnerable.

Flood susceptibility mapping plays a critical role in watershed management by identifying areas at high risk of flooding, thereby informing strategic planning for excess surface water management and potential storage solutions such as dams and reservoirs. By accurately delineating flood-prone areas, these maps enable planners and engineers to more effectively design and locate flood control infrastructure and ensure that excess water is directed to designated storage facilities or areas suitable for artificial recharge. This process is particularly important for the implementation of capping dams, which are designed to capture and store floodwaters to enhance groundwater recharge and reduce the risk of downstream flooding. The knowledge gained from flood hazard mapping facilitates proactive decision making that optimizes the use of natural and engineered systems to mitigate flood impacts, improve water availability, and support sustainable watershed managemen.

General Conclusion

In summary, geographic information systems (GIS) greatly enhances the analysis of watershed morphometric parameters by providing precise spatial data and advanced analytical tools. It facilitates the extraction of key parameters such as drainage density, stream frequency, and bifurcation ratio from digital elevation models, ensuring accurate and detailed topographic assessments. The ability to efficiently handle large datasets and create rich visualizations helps communicate findings effectively [66] [67].

In addition, this study used the Analytical Hierarchy Process (AHP) technique, a robust multi-criteria decision making tool, to systematically evaluate and weigh the relative importance of several factors contributing to flooding, including slope, land use, soil type, drainage density and elevation. The AHP framework facilitated the rational aggregation of these diverse factors, resulting in a flood hazard map that categorises the catchment into different hazard zones. This map highlights areas of high, medium and low flood risk, providing a critical spatial representation that is essential for effective flood risk management, planning and resource allocation [59] [68].

GIS can also be used to simulate and analyse different catchment management scenarios. For example, it can model the impact of different land use practices, conservation measures and infrastructure developments on hydrological processes and flood risks. These scenario analyses help to identify the most effective strategies for reducing flood risks and increasing the resilience of the watershed [69].

Incorporating GIS into watershed management also improves the ability to monitor and evaluate the effectiveness of implemented management practices. By regularly updating GIS data and conducting periodic assessments, managers can track changes in watershed conditions and assess the success of their interventions. This continuous feedback loop supports adaptive management, ensuring that strategies are adjusted as necessary to achieve desired outcomes [70].

Bibliography and websites:

[1] : Chorley, R. (1971) The Drainage Basin as the Fundamental Geomorphic Unit. In: Chorley, R., Ed., Introduction to Fluvial Processes, Methuen and Co. Ltd., London, 30-32.

[2] : Strahler, A.N. (1952) Dynamic Basis of Geomorphology. Geological Society of America Bulletin, 63, 923-938. http://dx.doi.org/10.1130/0016-7606(1952)63[923:DBOG]2.0.CO;2

[3] : Arnous, M., Aboulela, H. and Green, D. (2011) Geo-Environmental Hazard Assessment of the North Western Gulf of Suez, Egypt. Journal of Coastal Conservation, 15, 37-50. http://dx.doi.org/10.1007/s11852-010-0118-z

[4] : Angillieri, M.Y.E. (2008) Morphometric Analysis of Colanguil River Basin and Flash Flood Hazard, San Juan, Argentina. Environmental Geology, 55, 107-111. http://dx.doi.org/10.1007/s00254-007-0969-2

[5] : Patel, D., Dholakia, M., Naresh, N. and Srivastava, P. (2012) Water Harvesting Structure Positioning by Using GeoVisualization Concept and Prioritization of Mini Watersheds through Morphometric Analysis in the Lower Tapi Basin. Journal of the Indian Society of Remote Sensing, 40, 299-312. http://dx.doi.org/10.1007/s12524-011-0147-6

[6] : Abdul Rahman, S.S., Abdul Ajeez, S.A. and Jegankumar, R. (2015) Prioritization of Sub Watershed Based on Morphometric Characteristics Using Fuzzy Analytical Hierarchy Process and Geographical Information System—A Study of Kalla Watershed, Tamil Nadu. Aquatic Procedia, 4, 1322-1330. http://dx.doi.org/10.1016/j.aqpro.2015.02.172

[7] : Castany, G. (1954). Les grands traits structuraux de la Tunisie. Bulletin de la Société géologique de France, 6(1-3), 151-173.

[8] : Darriet, P., Pons, M., Lamy, S., & Dubourdieu, D. (2000). Identification and quantification of geosmin, an earthy odorant contaminating wines. Journal of Agricultural and Food Chemistry, 48(10), 4835-4838.

[9] : Javed, A., Khanday, M.Y. and Ahmad, R. (2009) Prioritization of Sub-Watersheds Based on Morphometric and Land Use Analysis in Guna District (MP): A Remote Sensing and GIS Based Approach. Journal of the Indian Society of Remote Sensing, 37, 261-274. http://dx.doi.org/10.1007/s12524-009-0016-8

[10] : Javed, A., Khanday, M.Y. and Rais, S. (2011) Watershed Prioritization Using Morphometric and Land Use/Land Cover Parameters: A Remote Sensing and GIS Based Approach. Journal of the Geological Society of India, 78, 63-75. http://dx.doi.org/10.1007/s12594-011-0068-6

[11] : Farhan, Y. and Anaba, O. (2016) A Remote Sensing and GIS Approach for Prioritization of Wadi Shueib Mini-Watersheds(Central Jordan) Based on Morphometric and Soil Erosion Susceptibility Analysis. Journal of Geographic Information System, 8, 1-19. http://dx.doi.org/10.4236/jgis.2016.81001

[12] : Sreedevi, P.D., Sreekanth, P.D., Khan, H.H and Ahmad, S. (2013) Drainage Morphometry and Its Influence on Hydrology in an Semi Arid Region: Using SRTM Data and GIS. Environmental Earth Sciences, 70, 839-848. http://dx.doi.org/10.1007/s12665-012-2172-3

[13] : Prasad, R.K., Mondal, N.C., Banerjee, P., Nandakumar, M.V. and Singh, V.S. (2008) Deciphering Potential Groundwater Zone in Hard Rock through the Application of GIS. Environmental Geology, 55, 467-475. http://dx.doi.org/10.1007/s00254-007-0992-3

[14] : Djebari, H. (2011). RESSOURCES ET ESSAI DE GESTION INTÉGRÉES DES EAUX DU BASSIN D'EL MALABIOD, W. DE TÉBESSA, NORD-EST ALGERIEN.

[15] : Rouabhia, A. (2006). Vulnerabilite et risques de pollution des eaux souterraines de la nappe des sables miocenes de la plaine d'el ma el abiod nord-est algerien (Doctoral dissertation, Annaba).

[16] : Climates et voyages.com : https://www.climatsetvoyages.com/climat/algerie/t%C3%A9bessa

[17] : Avogadro, A., & Villa, M. (1977). Nuclear magnetic resonance in a two-dimensional system. The Journal of Chemical Physics, 66(6), 2359-2367.

[18] : Faurel, L., & Laffite, R. (1949). Facteurs de répartition des cédraies dans les massifs de l'Aurès et du Bélezma. Bull Soc Hist Nat Afr N, 40, 178-186.

[19] : Wróblewski, F., Ruegsegger, P., & LaDue, J. S. (1956). Serum lactic dehydrogenase activity in acute transmural myocardial infarction. Science, 123(3208), 1122-1123.

[20] : Castany, G. (1954). Les grands traits structuraux de la Tunisie. Bulletin de la Société géologique de France, 6(1-3), 151-173.

[21] : Darriet, P., Pons, M., Lamy, S., & Dubourdieu, D. (2000). Identification and quantification of geosmin, an earthy odorant contaminating wines. Journal of Agricultural and Food Chemistry, 48(10), 4835-4838.

[22] : Caire, A. (1957). Étude géologique de la région des Biban (Algérie) (Doctoral dissertation, Toulouse).

[23] : esri.com: https://www.esri.com/en-us/what-is-gis/overview

[24] : esri.com : https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/something-in-the-water-the-mythology-of-snows-map-of-cholera/

[25] : : esri.com**:** https://www.esri.com/en-us/what-is-gis/history-of-gis

[26] : Spatialpost.com: https://www.spatialpost.com/history-of-gis/

[27] : spatialpost.com: https://www.spatialpost.com/components-of-gis/

[28] : landgate.com: https://www.landgate.com/news/the-power-of-gis-software

[29] : Mangomap: https://mangomap.com/gis-data

[30] : atlan :https://atlan.com/spatial-data/

[31] : Gisgeography : https://gisgeography.com/spatial-data-types-vector-raster/

[32] : geographyrealm.com: https://www.geographyrealm.com/geodatabases-explored-vector-and-raster-

[33] : arcgis.com: https://doc.arcgis.com/en/imagery/workflows/resources/managing-scanned-maps.htm

[34] : Resources.arcgis.com : https://resources.arcgis.com/fr/help/getting-started/articles/026n00000006000000.htm

[35] : gisgeography.com: https://gisgeography.com/what-is-gis/

[36] : esrifrance.fr: https://www.esrifrance.fr/produits/sig4.aspx

[37] : sgligis :https://www.sgligis.com/applications-of-gis/

[38] :]: ibm.com : https://www.ibm.com/blog/geographic-information-system-use-cases/

[39] : Brahim, B., Larbi, B., Abdallah, D., & Driss, S. (2016). Utilisation du sig dans l'analyse morphometrique et la prioritisation des sous-bassins versants de oued ınaouene (Nord-Est du maroc). European Scientific Journal, 12(6), 283-306.

[40] : Kusumandari, A., & Suprayitno, N. (2018). A study of flood causal priority in Arui watershed, Manokwari Regency, Indonesia.

[41] : zurich.com : https://www.zurich.com/en/knowledge/topics/flood-and-water-damage/three-common-types-of-flood

[42] : Gezahegn, M. A., & Suryabhagavan, K. (2018). Developing flood hazard forecasting and early warning system in Dire Dawa, Ethiopia. Int. J. Adv. Multidiscip. Res, 5(9), 11-27.

[43] :]: Balezentiene, L., Streimikiene, D., & Balezentis, T. (2013). Fuzzy decision support methodology for sustainable energy crop selection. Renewable and Sustainable Energy Reviews, 17, 83-93.

[44] : Lim, T. T., Rahardjo, H., Chang, M. F., & Fredlund, D. G. (1996). Effect of rainfall on matric suctions in a residual soil slope. Canadian Geotechnical Journal, 33(4), 618-628.

[45] : Das, K., Samanta, S., & Pal, M. (2018). Study on centrality measures in social networks: a survey. Social network analysis and mining, 8, 1-11.

[46] : Tehrany, M. S., Jones, S., & Shabani, F. (2019). Identifying the essential flood conditioning factors for flood prone area mapping using machine learning techniques. Catena, 175, 174-192.

[47] : Liu, T. Y., Yan, T. H., Scheuerlein, R., Chen, Y., Lee, J. K., Balakrishnan, G., ... & Fasoli, L. (2013). A 130.7-$\hbox {mm}^{2} $2-Layer 32-Gb ReRAM Memory Device in 24-nm Technology. IEEE Journal of Solid-State Circuits, 49(1), 140-153.

[48] : Forkuo, E. K. (2011). Flood hazard mapping using Aster image data with GIS. International journal of Geomatics and Geosciences, 1(4), 932-950.

[49] : Han, B. F., He, G. Q., Wang, X. C., & Guo, Z. J. (2011). Late Carboniferous collision between the Tarim and Kazakhstan–Yili terranes in the western segment of the South Tian Shan Orogen, Central Asia, and implications for the Northern Xinjiang, western China. Earth-Science Reviews, 109(3-4), 74-93.

[50] : Hagos, Y. G., Andualem, T. G., Yibeltal, M., & Mengie, M. A. (2022). Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash River basin, Ethiopia. Applied Water Science, 12(7), 148.

[51] : Rincón, D., Khan, U. T., & Armenakis, C. (2018). Flood risk mapping using GIS and multi-criteria analysis: A greater Toronto area case study. Geosciences, 8(8), 275.

[52] : Argaz, A., Ouahman, B., Darkaoui, A., Bikhtar, H., Ayouch, E., & Lazaar, R. (2019). Flood hazard mapping using remote sensing and GIS Tools: a case study of souss watershed. J. Mater. Environ. Sci, 10(2), 170-181.

[53] : Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. Int J Geogr Inf Sci 20(7):703–726.

[54] : Mohamed AE (2013) Managing shared basins in the Horn of Africa–Ethiopian projects on the Juba and Shabelle rivers and downstream effects in Somalia. Nat Resour Conserv 1(2):35–49.

[55] : Khadraoui, M., Khiari, R., Bergaoui, L., & Mauret, E. (2022). Production of lignin-containing cellulose nanofibrils by the combination of different mechanical processes. Industrial Crops and Products, 183, 114991.

[56] : Bhatt, D. L., Kandzari, D. E., O'Neill, W. W., D'Agostino, R., Flack, J. M., Katzen, B. T., ... & Bakris, G. L. (2014). A controlled trial of renal denervation for resistant hypertension. New England Journal of Medicine, 370(15), 1393-1401.

[57] : Zakaria, S. F., Zin, R. M., Mohamad, I., Balubaid, S., Mydin, S. H., & MDR, E. (2017, November). The development of flood map in Malaysia. In AIP Conference Proceedings (Vol. 1903, No. 1). AIP Publishing.

[58] : Lawal, D. U., & Khalifa, A. E. (2014). Theoretical and statistical models for predicting flux in direct contact membrane distillation. IJERA, 4(8), 124-135.

[59] : Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). Journal of systems science and systems engineering, 13, 1-35.

[60] : Hauru, L. K., Hummel, M., Michud, A., & Sixta, H. (2014). Dry jet-wet spinning of strong cellulose filaments from ionic liquid solution. Cellulose, 21, 4471-4481.

1. **[61] :** García-Soriano, D.; Quesada-Román, A.; Zamorano-Orozco, J.J. Geomorphological Hazards Susceptibility in High-Density Urban Areas: A Case Study of Mexico City. J. S. Am. Earth Sci. **2020**, 102, 102667.

[62] : Lim, T. T., Rahardjo, H., Chang, M. F., & Fredlund, D. G. (1996). Effect of rainfall on matric suctions in a residual soil slope. Canadian Geotechnical Journal, 33(4), 618-628.

[63] : Das, K., Samanta, S., & Pal, M. (2018). Study on centrality measures in social networks: a survey. Social network analysis and mining, 8, 1-11.

[64] : Balezentiene, L., Streimikiene, D., & Balezentis, T. (2013). Fuzzy decision support methodology for sustainable energy crop selection. Renewable and Sustainable Energy Reviews, 17, 83-93.

[65] : Balezentiene, L., Streimikiene, D., & Balezentis, T. (2013). Fuzzy decision support methodology for sustainable energy crop selection. Renewable and Sustainable Energy Reviews, 17, 83-93.

[66] : Maidment, D. R. (Ed.). (2002). Arc Hydro: GIS for water resources. ESRI, Inc..

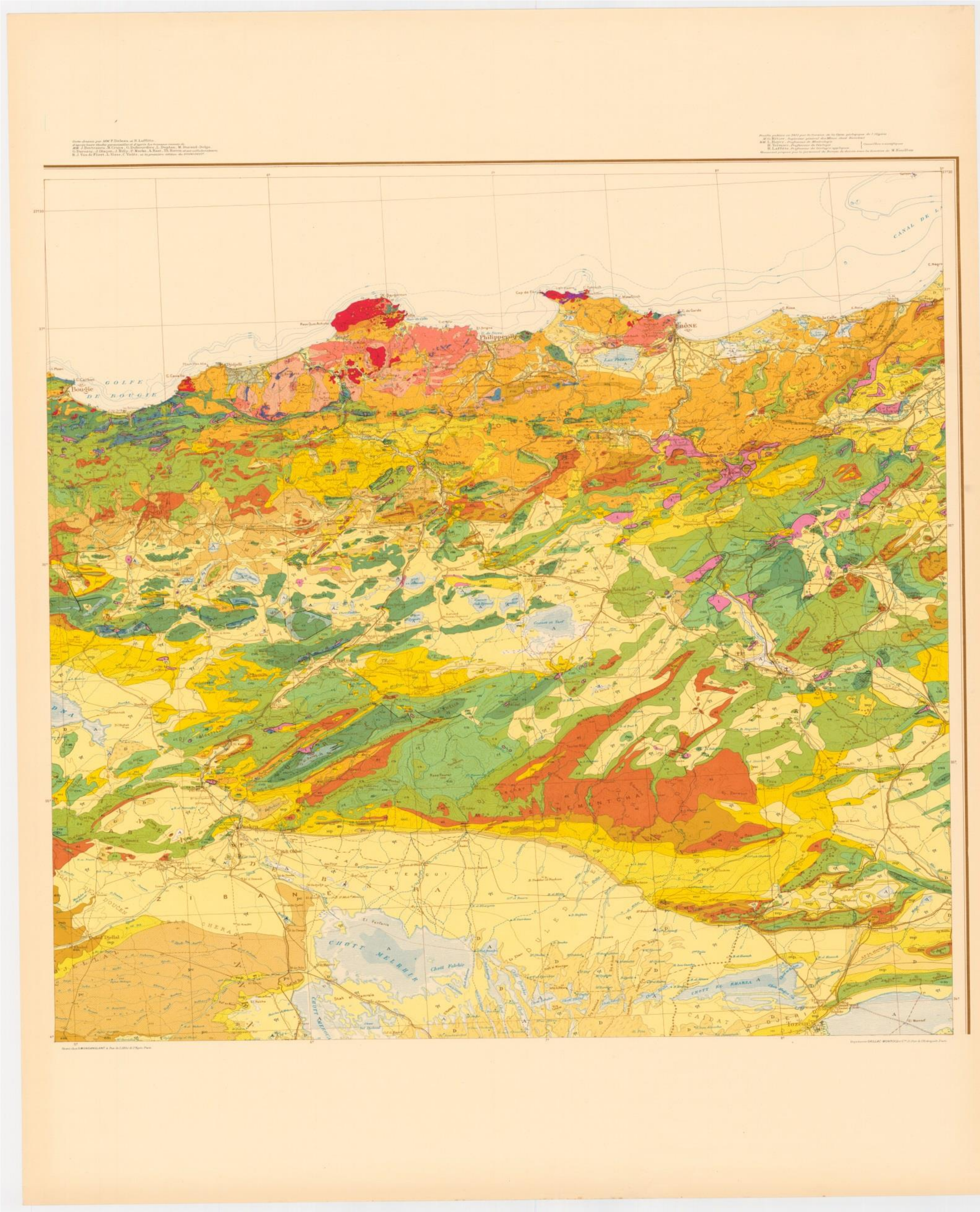
[67] : Einfalt, T., Arnbjerg-Nielsen, K., Golz, C., Jensen, N. E., Quirmbach, M., Vaes, G., & Vieux, B. (2004). Towards a roadmap for use of radar rainfall data in urban drainage. Journal of hydrology, 299(3-4), 186-202.

[68] : Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. European Journal of operational research, 169(1), 1-29.

[69] : Chang, H., & Franczyk, J. (2008). Climate change, land-use change, and floods: Toward an integrated assessment. Geography Compass, 2(5), 1549-1579.

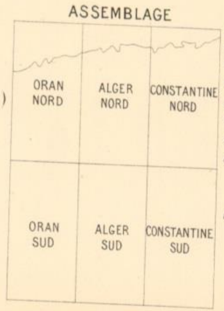
[70] : Sanyal, J., & Lu, X. X. (2004). Application of remote sensing in flood management with special reference to monsoon Asia: a review. Natural Hazards, 33, 283-301.

Appendices:



TERRAINS SÉDIMENTAIRES

- A — *Alluvions actuelles: lacs, marécages, dayas, chotts, sebkhas, limons et croûtes gypso-salines*
- D — *Dunes récentes*
- qt — Quaternaire continental: *alluvions, regs, terrasses*
- qm — Quaternaire marin: *plages anciennes et formations dunaires consolidées qui les accompagnent*
- qC — Calabrien: *grès marins et formations dunaires associées*
- qV — Villafranchien: *calcaires lacustres, argiles à lignite, couches rouges*
- pV — Pliocène continental et Villafranchien non séparés (pV)
- pc — Pliocène continental: *poudingues, calcaires lacustres*
- p — Pliocène marin | *conglomérats, marnes bleues, mollasses, grès et formations dunaires subordonnées*
- mp — Pontien *(localement équivalent du* mc)
- ms — Miocène terminal marin et lagunaire: *couches à Tripoli, marnes à gypse*
- mm — Miocène supérieur marin: *calcaires, grès, argiles*
- mc — mc Miocène continental antépontien
- mi — Miocène inférieur marin (Burdigalien)
- oa — Aquitanien continental *(pouvant inclure localement la base du* Burdigalien)
- oc — Oligocène continental *(pouvant inclure localement l'* Eocène sup.^r continental)
- o — Oligocène marin *incluant localement l'* Eocène supérieur)
- em — Eocène moyen marin
- ec — ec Eocène moyen et inférieur continental
- ei — Eocène inférieur marin
- cs, csc, csm — cs Crétacé supérieur marin; csc Crétacé supérieur continental; csm Crétacé supérieur marin non subdivisé
- cm, ct, cn — cm Crétacé moyen (marin ou lagunaire) *divisé éventuellement en* ct Turonien, cn Cénomanien
- c — c Crétacé marin non subdivisé
- ci, cir, cic — Crétacé inférieur (Vraconien à Berriasien) | ci *faciès marins normaux*; cir " *récifaux ou subrécifaux*; cic " *continentaux ou lagunaires*
- cj — Crétacé et Jurassique non séparés
- jc, jms, js, js_3, js_2, js_1 — jc Jurassique sup.^r et moyen; jms Jurassique sup.^r et moyen marins non séparés | js Jurassique supérieur non divisé | js_3 Portlandien et Kimmeridgien *(pouvant inclure localement le* Berriasien); js_2 Lusitanien; js_1 Oxfordien et Callovien
- jm — jm Jurassique moyen *(pouvant inclure localement l'* Aalénien supérieur)
- ji, ji_3, $ji_{3\text{-}2}$, ji_2, ji_1, $ji_{2\text{-}1}$ — ji Jurassique inf.^r marin | ji_3 Aalénien et Toarcien; ji_2 Domérien et Pliensbachien; ji_1 Lotharingien à Rhétien | $ji_{3\text{-}2}$ Aalénien à Domérien; $ji_{2\text{-}1}$ Pliensbachien à Rhétien
- t — Trias marin ou lagunaire
- rt — Permo-Trias: *grès rouges, conglomérats*
- hs — hs Westphalien D et Stéphanien
- hW, hWC, hWAB — hW Westphalien AB et C *éventuellement séparé en* Westphalien C (hWC), Westphalien AB (hWAB)
- hN — hN Namurien
- h — h Carbonifère non subdivisé
- hD, hV, hT — hD Dinantien | hV Viséen; hT Tournaisien
- d — Dévonien (sup.^r ds; moyen dm; inf.^r di)
- s, ss, si — s Silurien | ss Gothlandien; si Ordovicien



- ko — Cabro-Ordovicien
- ks — Adien
- ki — Gegien
- kx — *Coomérat de base du* Géorgien
- x — Prhaire non subdivisé
- x_{3a}, x_3 — Preambrien supérieur { *Schistes et grès* ; *Conglomérats*
- x_2 — Preambrien moyen: *schistes et séricitoschistes*

TERRAINS MÉTAMORPHIQUES

- *Métaorphisme faible de* cj *et* ci *(Région d'Oran)*
- *Métaorphisme de contact*
- ξ — *Micaistes, schistes satinés*
- ζ — *Gnei*
- γ — *Pegntites*
- C — *Calcees métamorphiques (calcschistes, cipolins)*
- ε — *Ampbolites, pyroxénites, grenatites, etc...*

ROCHES IGNÉES

- γ μγ — γ *Gnites, granodiorites*; μγ *crogranites, microgranodiorites*
- δ — *Diori, gabbros, dolérites*
- ρ — *Rhyos, dellénites, dacites et tufs associés*
- α — *Andées et tufs associés*
- β — *Basal et tufs associés*
- φ — *Phonoes*
- σ — *Serpeines*
- tω — *Rocheassociées au Trias (diorites, ophites, gabbros, etc...)*

Les lettres: q(uaternaire), t (Tertiaire), s (Secondaire), rt (Permo-Trias), h (Dévonien et arbonifère), $x_{1\text{-}2\text{-}3}$ (Précambrien), *ajoutées aux indices des roches éruptives précisent âge chaque fois qu'il a été possible de le faire.*

CARTE GÉOLOGIQUE DE L'ALGÉRIE

(2^ème édition)

Dressée d'aprla 1^ère édition et les travaux récents par MM. Cornet A., Dalloni M., Deleau P., Flandrin J., Gautier M., Gourinard Y., Gouskov N., Laffitte R., avec la collaboration de MM. Agé A., Bertraneu J., Caire A., Chadenson L., Cheylan G., Clair A., Cornet G., Cruys Drooger C., Dubourdieu G., Duplan L., Durand-Delga M., Durozoy G., Gevin P., Glaç J., Glangeaud L., Guillemot J., Hilly J., Karpoff R., Lucas G., Marks P., Mattau M., Moussu H., Muraour P., Rast A., Raven Th., Sadran G., Thiébaut J., Van de ert R. J., Visse L., Voûte C., du Service géologique de la Société Nationale de Recherche d'Exploitation des Pétroles en Algérie et des Services géologiques du Maroc et de la Tunisipour leurs Territoires respectifs.

Manuscrit mis point par les soins de M. Bouillon, Chef des Travaux graphiques.

Carte éditée en 11-1952, M. G. Bétier, Ingénieur Général des Mines, étant Directeur du Service de la Carte glogique, MM. R. Laffitte, L. Royer, H. Termier, Conseillers scientifiques.

Echelle: 500.000^e.

0 10 20 30 40 50 km.

Rainfull	January	February	March	April	May	June	July	August	September	October	November	December
2000	4	4	10	15	98,5	76	22	19	75,5	18	17	14
2001	27	16	15	3	49	2	8	1	55	34,1	20	8,3
2002	17	12	5	29	20	13	57	85	37	30	76	30
2003	19	7,5	39	49	27	51	37	63	28	27	30	50
2004	21	3	73	73	39	92	16	44	19	26	17	67
2005	29	34	24	20	1	30	1	47	33	94	32	77
2006	35	14	27	44	32	27	8	26	6	12	4	63
2007	5	11	61	59	38	39	30	54	50	15	9	29
2008	6	7	36	28	67	9	4	19	8	52	15	46
2009	77	12	27	112	66	0	23	13	97	2	2	6
2010	39	2	13	79	35	26	20	2	77	16	73	6
2011	27	67	61	43	47	28	54	10	3	86	12,3	42
2012	47	55	39	24	24	2	4	34	41	49	0	55
2013	15	22	25	33	9	0	40	27	47	39	60	28
2014	39	48	26	2	20	29	22	9	49	7	43	50
2015	30	43	42	1	23	66	38	72	14	42	16	0
2016	13	18	32	18	38	2	0	14	30	49	19	66
2017	23	9	11	47	33	18	14	10	41	49	33	9
2018	0	30	20	27	96	13	3	72	25	91	9	13
2019	21	22	91	69	35	0	5	55	90	30	26	36
2020	11	0	73	43	14	48	6	0	78	20	26	48
2021	4	12	15	22	20	5	1	49	2	43	5	10
2022	18	23	67	20	24	61	12	45	38	3	19	2
2023	4	1	1	18	126	40	3	11	0	0	24	27

Temperature	January	February	March	April	May	June	July	August	September	October	November	December
2000	4	7,8	11,7	16,1	21,2	22,4	27,5	26,8	22,1	15,9	12,8	9,4
2001	8,3	7,8	15,7	14	19,6	25	28,4	27,1	22,3	21,3	12	6,8
2002	6,3	9	12,5	15	19,4	25,1	26,6	24,9	21,2	17,8	12,2	8,8
2003	6,9	6	6,3	14,4	27,9	24,9	29	27,7	22,2	20,1	12,9	7,3
2004	6,9	9,6	11,2	11,2	15,9	22,4	26,2	27,9	20,8	20,6	10,2	8,1
2005	4,6	4,9	11,2	14,2	21,2	23,7	28,5	25,9	21,6	17,8	12,2	6,6
2006	4,9	7,2	11,9	17,1	21,4	24,8	26,6	25,9	21,4	19,7	12,1	8
2007	8,4	9,2	9,7	13,5	18,5	25,3	26,5	26,7	22	17,6	10,5	6,9
2008	7	8,3	11,5	15,6	19,3	23,4	28,7	27,2	25,1	16,9	10,5	5,8
2009	7,1	6,4	9,8	11,5	18	24,2	28,7	26,8	21	15,7	12,4	11,2
2010	8,3	10,2	13	15,9	17,4	24	27,2	27,1	21,7	17,5	11,4	8,8
2011	7,6	6,4	9,5	14,8	17,4	22,4	22,4	27,5	26,9	23,5	15,7	7,2
2012	6	4,5	10,5	14,4	14,4	27,1	28,9	28,8	22,4	19,3	23,1	8,4
2013	27,1	6,7	12,9	16,1	18,8	23,1	26,3	25,5	22,6	21,4	10,9	7,2
2014	7,9	9	8,8	15,2	19	23,6	27,3	28,3	24,6	19,1	14	7,5
2015	6,2	5,9	9,6	15,5	19,4	23	27,4	25,7	21,8	16,8	11,3	6,2
2016	8,6	8,6	10,7	17,3	19,6	23,2	27,2	25,7	21,1	19,2	12,1	8,8
2017	5,1	9,5	12	13,7	21,1	25,7	28,2	28,4	21,9	15,6	10,5	6,8
2018	8,7	7,2	12,1	15,9	17,8	23	30	23,7	22,8	15,9	11,4	7,9
2019	5,4	5,9	9,4	13,2	15,7	26,9	28,4	27,1	22	17,1	10,2	9,2
2020	6,6	9,5	10,4	15	21,1	23,6	26,6	28	21,3	16,1	12,6	8
2021	8,7	10,6	9,9	15,4	21,3	27,8	29,8	29,1	24,8	15,9	11,5	7,8
2022	5,6	8,2	10,4	14,1	19,8	28	28,6	26,8	24,1	18,9	13,1	11,2
2023	6,1	8,1	12,9	15,6	16,4	23,3	31,3	27	23,9	20,6	14	8,9

PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
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جامعة الشهيد الشيخ العربي التبسي
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FACULTY OF EXACT SCIENCES, NATURAL AND LIFE SCIENCES

Signature de l'étudiant (e)

Département de Sciences de la Terre et de l'Univers

Filière : Géologie

Spécialité : Géologie de l'Ingénieur et Géotechnique

Année universitaire 2023/2024

Formulaire de levée de réserves après soutenance d'un Mémoire de Master

Données d'identification du candidats (es) :

Nom et prénom du candidat : Boukraa Boutheyna

Intitulé du Sujet : L'utilisation des SIG dans les études géotechniques et dimensionnement de Grands aménagements hydrauliques dans le haut bassin de Oued Cafsaf. (NE Algérien)

Données d'identification du membre de jury :

Nom et prénom : Boubaya Djamel

Grade : Professeur

Lieu d'exercice : Université Echahid Cheikh Larbi Tebessi – Tébessa-

Vu le procès-verbal de soutenance de la thèse sus citée comportant les réserves suivantes :

Shutt ; Ksob Waddi

Mitcha

pagination

Et après constatation des modifications et corrections suivantes :

Chott ; Oued Kebir ; Whichare

Je déclare en ma qualité de président de jury de soutenance que le mémoire cité remplit toutes les conditions exigées et permet au candidat de déposer son mémoire en vue de l'obtention de l'attestation de succès.

Tébessa le : 09/06/2024

Président de jury de soutenance : (Nom/Prénom et signature)

Boubaya Djamel

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Département : des Sciences dela Terre et de l'Univers

Filière : Géologie

Spécialité : Géologie de l'ingénieur et géotechnique

Année universitaire 202 3/2024

Autorisation de Soutenance D'un Mémoire de Master

Je, soussigné, Pr. Fehdi Chemseddine, encadreur de l'étudiante Boukraa Boutheyna, ayant traité un sujet de Master qui a pour titre :

L'utilisation des SIG dans les études géotechniques et le dimensionnement de grands aménagements hydrauliques dans le haut bassin de l'oued Saf Saf, région El Malabiod (N.E Algérien)

Atteste que la concernée a mené à son terme le travail qui lui a été exigé. Le mémoire qu'il a rédigé a été lu et corrigé par mon soin.

Par conséquent, je l'autorise à déposer son mémoire en vue de soutenir son Master devant un jury que désignera le département.

0 4 جوان 2024

Tébessa le: 02/06/2024

Signature de l'encadreur

Fehdi CH

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