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Abstract

This thesis examines the impact of climate change on the Safsaf watershed, integrating land-use analysis, land-suitability assessment through the Analytical Hierarchy Process (AHP), and climate-environment relationships based on satellite indices.

The study aims to understand how climate variability affects water availability, agricultural potential, and the functioning of irrigation systems.

An integrated methodological framework was developed to capture spatial and temporal variability. AHP was used to evaluate land suitability for agriculture, considering factors such as slope, aspect, and elevation.

The analysis of land use was conducted through Sentinel World Dynamic imagery, enabling a comprehensive assessment of agricultural and urban distributions.

Data from geological maps and satellite imagery (including NDVI and NDWI) assessed land use, vegetation health, and water availability. Correlation analysis explored relationships among temperature, vegetation, and moisture.

And the surface area of Zerdaza Dam was estimated via NDWI and Modified NDWI (MNDWI) from Landsat 8, underscoring the intricate effects of climate change and land variables on irrigation systems.

Key findings indicate that only a limited portion of the watershed is suitable for sustainable irrigation, with many areas constrained by environmental factors.

Land use changes, driven by urban expansion and degradation processes, reveal increasing stress conditions characterized by temperature variability and low surface moisture. Correlation analysis shows that temperature influences water availability more significantly than precipitation.

The analysis of the Zerdaza Dam highlights water scarcity and prioritization during dry periods.

Ultimately, the findings suggest that irrigation systems are highly vulnerable due to reliance on limited and contested water resources, necessitating a shift from traditional practices to integrated and adaptive water resource management strategies.

الملخص:

تبحث هذه الأطروحة في تأثير تغير المناخ على حوض سافساف، من خلال دمج تحليل استعمالات الأراضي، وتقييم ملائمة ، ودراسة العلاقات بين المناخ والبيئة اعتمادًا على المؤشرات المستخرجة (AHP) الأراضي باستخدام أسلوب التحليل الهرمي من صور الأقمار الصناعية

يهدف هذا البحث إلى فهم كيفية تأثير التغيرات المناخية على توفر المياه، والإمكانات الزراعية، وكفاءة أنظمة الري

لتقييم ملائمة الأراضي AHP تم تطوير إطار منهجي متكامل لالتقاط التغيرات المكانية والزمانية. وقد تم استخدام أسلوب للزراعة، مع الأخذ بعين الاعتبار عوامل مثل الانحدار، والتوجه، والارتفاع

، مما أتاح تقييمًا شاملاً للتوزيع الزراعي Sentinel World Dynamic تم تحليل استعمالات الأراضي باستخدام صور والعمراني

لتقييم استعمالات (NDWI و NDVI بما في ذلك) كما تم الاعتماد على بيانات الخرائط الجيولوجية وصور الأقمار الصناعية الأراضي، وصحة الغطاء النباتي، وتوفر المياه. كما تم إجراء تحليل الارتباط لدراسة العلاقات بين درجة الحرارة، والغطاء النباتي، والرطوبة

، مما Landsat 8 المستخرجين من MNDWI و NDWI كما تم تقدير المساحة السطحية لسد زردازة باستخدام مؤشري. يبرز التأثيرات المعقدة لتغير المناخ والعوامل الأرضية على أنظمة الري

تشير النتائج الرئيسية إلى أن جزءًا محدودًا فقط من الحوض صالح للري المستدام، حيث تُقَدَّر العديد من المناطق بعوامل بيئية مختلفة

تُظهر تغيرات استعمالات الأراضي، الناتجة عن التوسع العمراني وتدهور الأراضي، زيادة في الضغوط البيئية المتمثلة في تذبذب درجات الحرارة وانخفاض رطوبة السطح. كما يبين تحليل الارتباط أن درجة الحرارة تؤثر على توفر المياه بشكل أكبر من تأثير التساقطات

ويُظهر تحليل سد زردازة وجود ندرة مائية وألوية في توزيع المياه خلال الفترات الجافة

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List of abbreviations

AOT: Administrative organization of the territory

AWC: Algerian Water Company

CC: Climate Change

CCD: Climate Change Directorate

DWS: Drinking Water Supply.

FAO: Food and Agriculture Organization

GDF: General Direction of Forests

GDE: General Direction of Environment

GHG: Greenhouse Gases

IPCC: Intergovernmental Panel on Climate Change

LST: Land Surface Temperature

LULC: Land Use Land Cover

MARDF: Ministry of Agriculture, Rural Development, and Fisheries

MERE: Ministry of the Environment and Renewable Energies

MWR: Ministry of Water Resources

NADT: National Agency of Dams and Transportation

NCCA: National Climate Change Agency

NDVI: Normalized Difference Vegetation Index

NDWI: Normalized Difference Water Index

MNDWI: Modified Normalized Difference Water Index

NIDO: The National Irrigation and Drainage Office

NOAA: National Oceanic and Atmospheric Administration

PNC: National Climate Plan

UNFCCC: United Nations Framework Convention on Climate Change

WBG: World Bank Global

WMO: World Meteorological Organization

USEPA: United States Environmental Protection Agency

General Introduction

In the context of global challenges, climate change emerges as one of the most pressing issues of the 21st century, with far-reaching implications for ecosystems and human societies alike. The phenomenon of rising global temperatures, a principal contributor to global warming, has been rigorously documented by the Intergovernmental Panel on Climate Change (IPCC). This warming trend can be attributed to a myriad of factors stemming from human activities, including urbanization, widespread deforestation, and various industrial processes. These activities have led to a marked increase in greenhouse gas emissions, as well as air and water pollution, resulting in cascading environmental consequences (Yuanmao et al, 2021).

Moreover, the rapid concentration of the global population in recent decades, as reported by the United Nations (2022), has instigated significant changes in land use practices, water resource allocation, and environmental integrity. This burgeoning population has precipitated an unprecedented demand for housing and infrastructure, driving the expansive growth of urban areas. Simultaneously, agricultural demands are soaring, necessitating additional land for farming to achieve food security and sufficiency, as highlighted by the Food and Agriculture Organization (FAO). These transformations in land cover, marked by the shift from natural landscapes to artificial environments, are among the principal factors propelling global environmental changes (M.W. Naikoo et al. 2020).

The ramifications of these shifts are profound: green spaces are dwindling, and the surging population exacerbates air and water pollution levels (Li, C. et al, 2023). Elevated greenhouse gas emissions, coupled with the clearing of forests and grasslands for agricultural purposes, further aggravate issues such as deforestation, soil degradation, and loss of biodiversity. Ultimately, these factors are intertwined with the escalating threat of global warming and climate change, as evidenced by extensive research from the IPCC.

The ecosystem, comprising vital resources such as land, water, and vegetation, plays a crucial role in maintaining the delicate balance of urban and natural environments. Land and water are indispensable resources that significantly influence the life cycles of numerous organisms (K.N. Moharir et al. 2024). However, the adverse effects of climate change have disrupted ecological balances, particularly in terms of vegetation cover. Vegetation is instrumental in environmental stabilization, functioning as a natural carbon sink that absorbs considerable amounts of greenhouse gases, thus helping to mitigate the pace of climate

change. The interactions between climate change and vegetation, as well as water bodies, display a complex dynamic influenced by spatial and temporal variations across different geographical regions **(Zhisong et al. 2023)**.

In the agricultural sector, climate change has had significant impacts, particularly through changes in rainfall patterns, which are becoming more erratic. Some regions experience increased rainfall, while others suffer from prolonged droughts, leading to uncertainty in water supply. Rising global temperatures contribute to higher rates of evaporation, exacerbating water scarcity during crucial growing periods. Additionally, shifts in the soil water balance affect crop health and yield, as soil moisture levels can fluctuate dramatically due to changing weather patterns. **(Boundi, A. 2021)**.

The demand for irrigation water is increasing due to population growth and the need for food security. However, agriculture faces the pressing challenges of diminishing water availability from natural sources and the degradation of water quality caused by pollution and runoff. Many traditional irrigation practices are inefficient and lead to substantial water losses through evaporation and deep percolation.

To address these issues, it is essential to implement advanced irrigation techniques such as drip irrigation, which delivers water directly to the plant's root zone, enhancing water use efficiency. Other technologies like soil moisture sensors and automated irrigation systems can help monitor crop needs in real time, reducing water waste.

Furthermore, integrating rainwater harvesting and wastewater recycling can also supplement the water supply, ensuring a more sustainable approach to irrigation. Effective irrigation systems are not just a means of providing water; they play a crucial role in maintaining agricultural productivity, adapting to climate change, and securing food resources for future generations.

This study is specifically focused on evaluating the impacts of climate change on irrigation systems' operation, vegetation health, and surface water resources within the Safsaf irrigation perimeter. To comprehensively assess these factors in the Safsaf basin, a structured work plan has been devised, encompassing five detailed chapters:

The first chapter offers a comprehensive overview of the geographical context, geomorphological features, and various anthropogenic activities occurring in the study region, alongside an examination of the morphological characteristics of the Safsaf basin.

The second chapter delves into the geological framework of the Safsaf region, outlining significant geological features, identifying various tectonic faults, and analyzing the geological structure that influences land use and resource management.

In the third chapter, an in-depth analysis of hydro-climatological characteristics is presented, providing a rigorous study of climatological factors and establishing a comprehensive water balance to enhance understanding of rainwater distribution within the region.

Chapter four discusses the operational framework of the Safsaf irrigation perimeter, detailing the diverse types of crop rotation practices and employing the Analytic Hierarchy Process (AHP) to discern optimal agricultural land sites.

The concluding chapter evaluates the various land use and land cover classifications within the Safsaf watershed, scrutinizing temporal changes in these categories and assessing the impact of climate change on vegetation and water resources through satellite imagery analysis.

The transition towards sustainable agriculture that maximizes the efficient use of water resources and enhances agricultural yields necessitates the improvement of irrigation systems and the implementation of immediate, targeted measures to combat the effects of climate change within the study area. This comprehensive approach is vital for fostering resilient agricultural systems amid the challenges posed by a changing climate.

Chapter 1
Presentation of the Study
Sites

1. Geographical Location of the Study Area

The Saf-Saf wadi watershed is located in northeastern Algeria, between latitudes 36° – 37° North and longitudes $6^{\circ}30'$ – 7° east. As part of the Constantine coastal basins, it extends over an area of approximately 1167.9 km². It is bounded to the north by the Mediterranean Sea, to the south by the El-Khantour pass and Jebel Bou-Abed, to the east by the Bissy pass, and to the west by the Staiha pass (Fig. 01). Administratively, the Saf-Saf basin lies entirely within the wilaya of Skikda.

The Saf-Saf basin occupies the central part of the wilaya, encompassing six districts (daïras) : Skikda, El Hadaeïk, Ramdane Djamel, El Harrouch, and parts of Sidi Mezghiche and Azzaba.

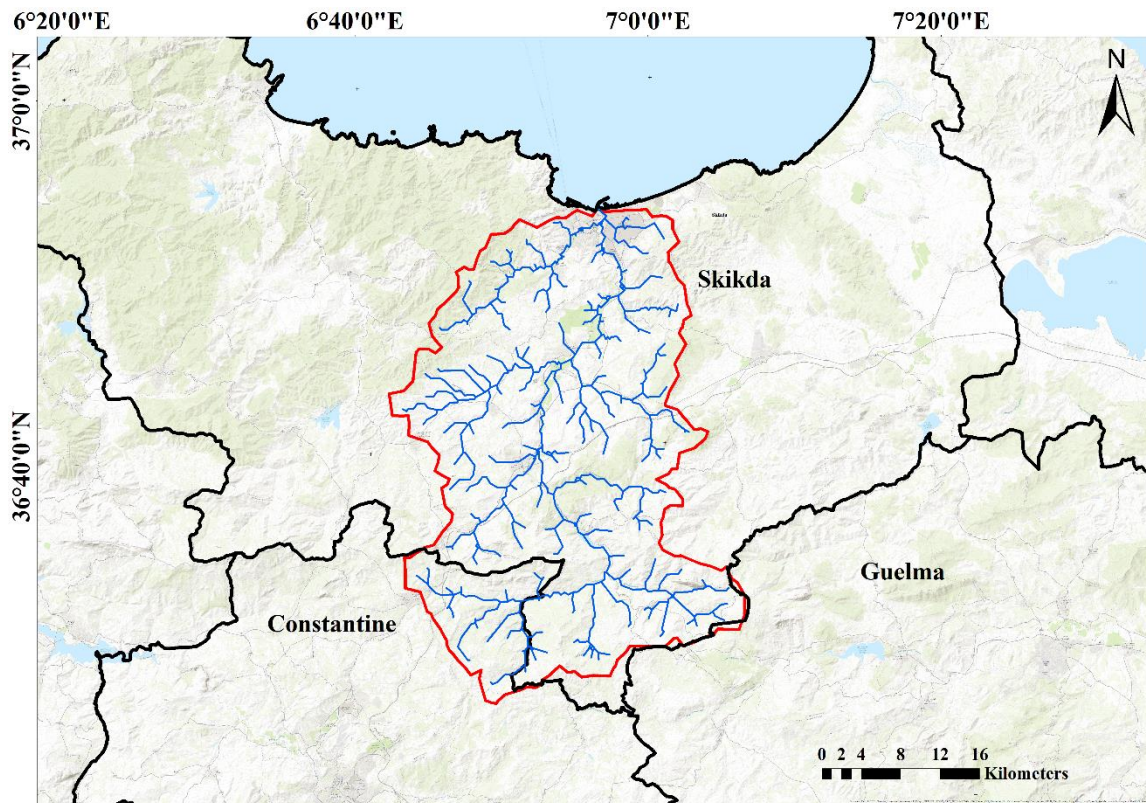


Figure 1: Geographical location of the Saf-Saf basin

2. Population

As of 2020, the population of the wilaya was estimated at 1,115,380 inhabitants, representing an annual natural growth rate of 1.17% compared to the 2008 census (*Monograph of the wilaya of SKIKDA*), with an age distribution primarily between 15 and 59 years.

Currently, the wilaya of Skikda comprises 38 municipalities (communes), of which 15 are located within the Saf-Saf watershed (Fig. 03).

It should be noted that the population in the Saf-Saf basin increased by 91,300 inhabitants between 2010 and 2020.

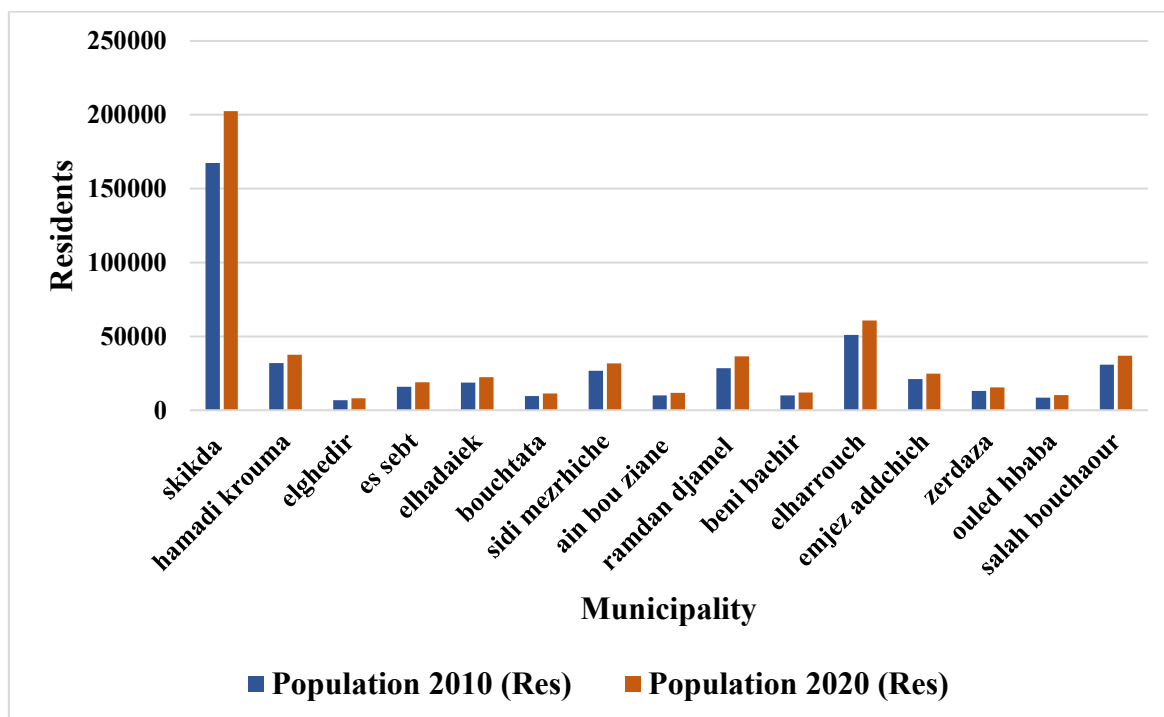


Figure 2 : Population variation in the municipalities of the Saf-Saf basin

3. Socio-economic overview

3.1. Industrial and mining activities

Aside from hydrocarbon development, the wilaya's industrial fabric is made up of processing units for useful materials and substances (wood, cork), agri-food, textiles, and iron and steel. The main characteristics of the industrial production units are listed below by branch of activity:

- Industrial zones:

The wilaya of Skikda has five (05) industrial zones: the petrochemical zone, the small industrial zone, and the three (03) zones of Hamadi Krouma.

- Petrochemicals:

In the energy sector, nine production units operate in the Skikda industrial zone, employing 7,723 people.

- **Mining and quarrying:**

In the mining and quarrying sector, a total of 30 sites are exploited by 23 operators.

- **Dry port:**

The wilaya has a 7-hectare dry port, commissioned in 2007, which can accommodate up to 3,800 TEUs (20-foot equivalent units) in the form of 20- or 40-foot containers used to store a variety of goods.

3.2. Vegetation and Agricultural Activities

The climatic conditions favor the development of typical vegetation in the region. With a total agricultural area (SAT) of 193,023 hectares and a useful agricultural area (SAU) of 131,829 hectares—including 30,989 hectares under irrigation—agriculture remains, alongside industry, one of the main economic sectors in the wilaya.

- **Cereal crops:** Dedicated area of 36,034 hectares, with a production of 777,000 quintals (qx).

- **Forage crops:** Dedicated area of 11,184 hectares, with a production of 476,544 quintals (qx).

- **Market gardening (vegetable crops):** Dedicated area of 21,993 hectares, with a production of 5,500,300 quintals (qx). (**Ministry of the Interior, Algeria**)

The Saf-Saf basin is mainly agricultural. Agriculture is found throughout the basin, with a wide variety of crops, mainly including fruit trees, alfalfa (lucerne), market gardening, and grain maize.

For the other types of vegetation in the Safsaf watershed, we have the shrubs and grassland with 50% of the area of the watershed, around 20% sparse vegetation, and 1% dense vegetation.



Figure 3: The different types of vegetation in the Saf-Saf watershed

3.3. Relief and Morphology

The eastern Algerian coastline is known for its mountainous landscapes, with only a few small coastal plains. Mountain peaks range between 500 and 600 meters in elevation. This mountainous terrain forms a significant natural and physical barrier (including Kef Sidi-Driss, Kef-Toumiet, Djendel El-Ali, the Collo massif, and Jebel-Edough).

There are three main valleys oriented south–north, following the courses of the Saf-Saf wadi, the Guebli wadi, and the El-Kebir wadi.

Plains are limited to the sub-regions of Collo, Skikda, Ain Charchar, and Ben-Azzouz. These are small coastal or inland plains located at the outlets of the main wadis.

3.4. Physiographic characteristics of the Saf-Saf watershed

3.4.1. Geometrical parameters

3.4.1.1. Area (A) and perimeter (P)

The surface area is the portion of the plane bounded by the crest line, or basin contour, and is expressed in Km². The perimeter is the length, expressed in km, of the basin contour line.

The geometric characteristics of the Saf-Saf basin have been calculated with the "ArcGIS 10.8" software. The results are shown in the table below:

Table 1: area and perimeter of the Saf-Saf watershed

Watershed	Area (Km ²)	Perimetre (Km)
Saf-Saf	1167.9	178.84

3.4.2. Shape parameters

3.4.2.1. Gravelius Compactness Index (Kc)

This is the ratio of the perimeter "P" to the perimeter of a circle with the same area, and gives important information about the concentration of flow at the outlet and the shape of the basin.

$$KC = \frac{0.28P}{\sqrt{A}}$$

If :

$Kc < 1 \Rightarrow$ circular watershed.

$Kc = 1.12 \Rightarrow$ square-shaped watershed.

$Kc > 1.12 \Rightarrow$ elongated watershed.

3.4.2.2. The Equivalent Rectangle :

To appreciate the shape and subsequently the dimensions of a watershed, we assimilate it to a rectangle with the same surface area, perimeter, and compactness. This rectangle, known as the equivalent rectangle, is characterized by its length (L) and width (l) in km, which can be calculated using the formulas below:

$$L = \sqrt{A} \frac{Kc}{1.12} \left[1 + \sqrt{1 - \left(\frac{1.12}{Kc} \right)^2} \right] \quad I = \sqrt{A} \frac{Kc}{1.12} \left[1 - \sqrt{1 - \left(\frac{1.12}{Kc} \right)^2} \right]$$

With:

KC: Compactness index. A: Watershed area in km².

3.4.3. Relief parameters

3.4.3.1. Hypsometric curve

It represents the distribution of the watershed's surface area according to its altitude. It expresses the surface area of the basin or the percentage of surface area above a certain altitude:

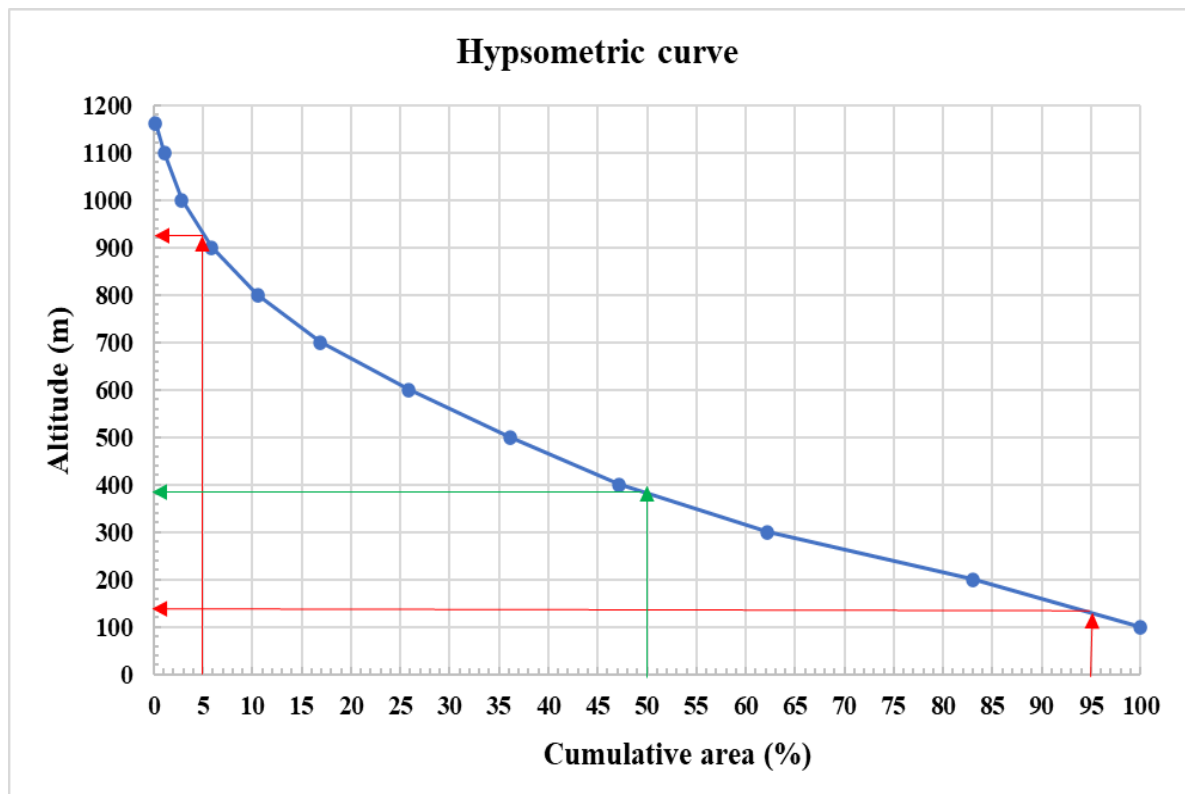


Figure 4: Hypsometric curve for the safsaf subcatchment

- Characteristic Altitudes :

- **Maximum altitude:** represents the highest point in the basin.
- **Minimum altitude:** represents the lowest point, generally located at the basin outlet.
- **Mean altitude:** this is the average altitude of the basin. $H_{mean} = \frac{\sum(H_i \cdot A_i)}{\sum A_i}$

- **Characteristic altitude H5%:** altitude representing 5% of the catchment area above this altitude.
- **Characteristic altitude H50%:** median altitude that divides the surface area into 50% above and 50% below this altitude.
- **Characteristic altitude H95%:** altitude representing 95% of the catchment area above this altitude.

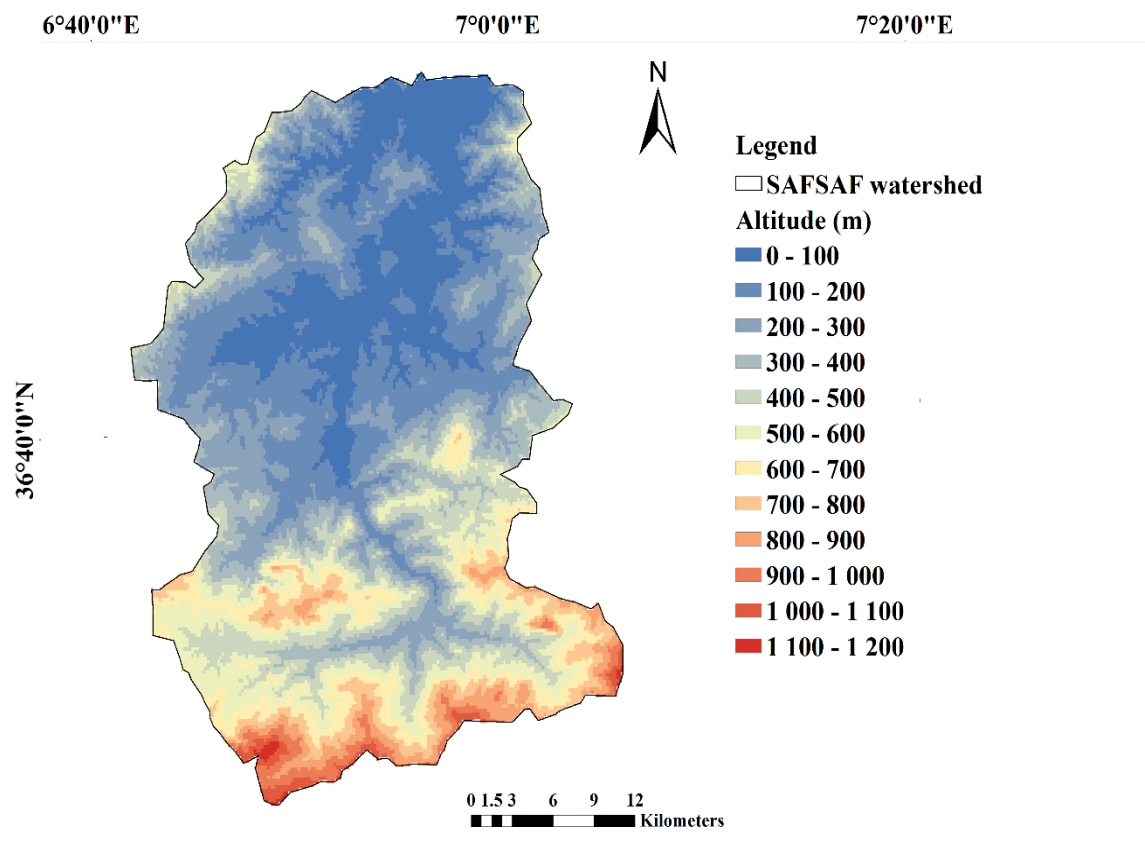


Figure 5: Altitude map of the Saf-Saf watershed

Table 2: Area distribution by altitude band

Altitude (m)	Area (km ²)	Area (%)	Cumulative area (%)	Hi (mean)	Ai*Hi
0-100	197.4	16.9	100	50	9870
100-200	243.2	20.8	83.0	150	36476
200-300	175.1	15.0	62.2	250	43785
300-400	129.6	11.1	47.2	350	45353
400-500	119.9	10.3	36.1	450	53951
500-600	104.6	9.0	25.8	550	57534
600-700	73.9	6.3	16.9	650	48035

700-800	54.5	4.7	10.6	750	40882
800-900	35.6	3.1	5.9	850	30293
900-1000	20.4	1.7	2.8	950	19380
1000-1100	10.6	0.9	1.1	1050	11100
1100-1200	2.1	0.2	0.2	1150	2419
	1167	100.0			399078

- **Elevation Difference (D) :**

On the hypsometric curve, we take the vertical distance in (m), which separates the altitudes having 5% and 95% of the surface of the sub-catchment, the simple difference in level is thus equal to :

$$D = H_{5\%} - H_{95\%}$$

3.4.3.2. Slope Indices

The slope map of the Saf-Saf watershed was processed and produced using a digital terrain model (DTM) under a geographic information system (ArcGIS). We then adopted the following classification (Fig. 07).

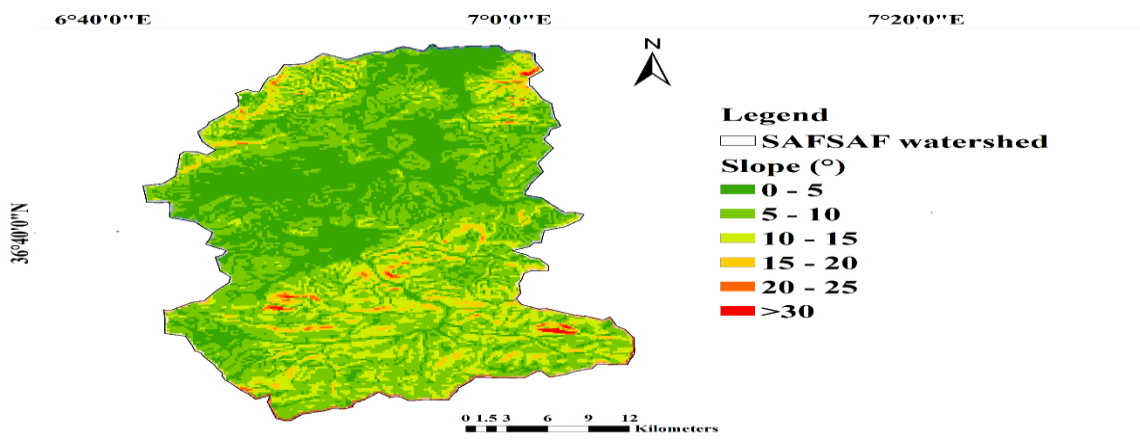


Figure 6: Slope map of the Saf-Saf watershed

- **Global Slope Index (Ig) :**

This is the ratio between the difference $H_{5\%} - H_{95\%}$ and the length L of the equivalent rectangle, expressed in meters of vertical drop per Km of length.

$$Ig = D/L$$

Relief is classified according to the value of (Ig):

- $Ig > 35$ (m/km), fairly strong relief.

- $20 < I_g < 35$ (m/km) strong relief.
- $I_g < 20$ (m/km) moderate relief.

- Mean Slope Index (Im) :

This is the ratio between the difference $H_{\max} - H_{\min}$ and the length L of the equivalent rectangle, expressed in meters of vertical drop per Km of length.

$$I_m = H/L$$

- Rock Slope Index (Ip) :

The rock slope index is calculated by:

$$I_p = \sqrt{I_g/0.8}$$

- Specific Relief (Ds) :

The specific relief makes it possible to compare the values of different basins, as it is one of the indices used to classify the relief of a watershed. Expressed in m, it is obtained from the overall slope index and the surface area by the relationship:

$$D_s = I_g \cdot \sqrt{A}$$

Table 3: Classification of landforms according to specific relief.

Relief class	Ds (m)	Relief Type
1	$D_s < 10$	Very low
2	$10 < D_s < 25$	low
3	$25 < D_s < 50$	Fairly low
4	$50 < D_s < 100$	Moderate
5	$100 < D_s < 250$	Fairly strong
6	$250 < D_s < 500$	strong
7	$D_s > 500$	Very strong

3.4.3.3. The hydrographic network

The hydrographic network is the set of watercourses and permanent or temporary tributaries where all runoff flows and converges towards a single discharge point (the outlet) of the watershed.

- Stream order :

Later course classification is facilitated by a numbering system for watercourse sections.

The length of the main watercourse L is the curvilinear distance from the outlet to the watershed divide, always following the highest order segment when there is a branch, and by extension from the last to the topographic watershed boundary. We obtained the length and number of the watercourse using ArcGIS.

Table 4: Classification of the hydrographic network

Ordre	Numbre (Nx)	Length (lx) Km
1	172	272.72
2	77	118.95
3	51	75.09
4	39	50.22
Total	339	516.98

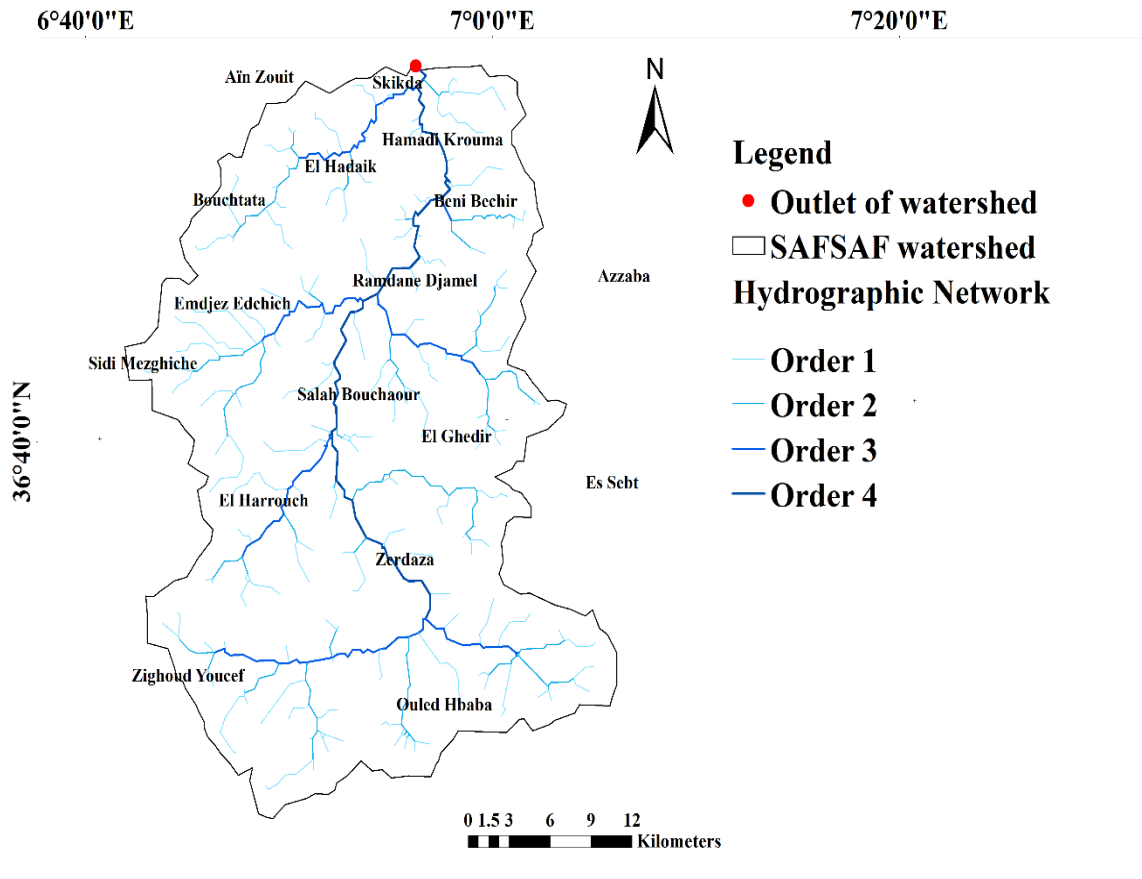


Figure 7: map of the hydrographic network

3.4.3.3.1. Sub-watershed of the Safsaf

The Safsaf basin has 5 sub-watersheds as follows:

- Oued Saf-Saf upstream sub-basin:

Upstream of the basin, the Oued Saf-Saf results from the confluence of the courses of the Oueds Khemakhem and Bouhadjeb, which drain the south-eastern and south-western parts of the basin, respectively (AMEL, M. 2011). It is the main feeder to the Zardézas dam. Elongated in shape, it covers an area of 324.9 km² and is characterized by relatively steep slopes (average gradient of around 40 m/km). It is controlled upstream of the dam by the Khémakhem gauging station.

- Oued Nessa sub-basin:

Oued Nessa (at El-Harrouch) drains a highly compartmentalized, predominantly marl basin of 93.2 km². The basin is triangular in shape and more or less narrow, at an altitude of 80m. It is bounded by a relief line culminating at 300m to the north and over 800m to the south (El Kentour pass and Kef Toumiettes). (Amel et al. 2025)

- Oued Ammeur sub-basin:

The Oued Ghbel, 17.5 km long, originates in the Mdjez-Edchich region and empties on its right bank, under the name Oued Ammeur, into the Oued Saf-Saf three kilometers south of Ramdane Djamel. It drains a fairly extensive, gently sloping basin (planimetric surface area of around 144.4 km²). Like the Oued Zerga sub-catchment at Ramdane Djamel, it is characterized by quaternary formations with little or no permeability and contains marshy areas. (Maou. 2011).

- Oued Haddarat sub-basin:

The Oued Hadarat, which originates in the Jebel Rhédir, flows from south-east to north over a length of 15 km and a surface area of 132.5km². (Amel et al. 2025) It drains a more or less 10 km wide area with relatively gentle to moderate slopes. The summits of the koudiats are covered with Numidian sandstone. Oued Ksob to the south-west and Oued Deb to the east drain the eastern flank of El Fedj and the south-western flank of Fedj-Moussa, respectively.

- Oued Zeramna sub-basin:

Oued Zeramna, which rises in the Bouchtata mountains at Jebel Staiha, drains an elongated basin of 132.7 km². With a length of 15.5 km². It cuts into the metamorphic bedrock of Little Kabylia along National Highway 43. The alluvial fill, which is very small along the wadi, becomes more significant from El-Hadaik onwards, where the low terrace is very pronounced. The eastern and western flanks are characterized by steep slopes, favouring flooding during high-water periods. Slopes become much gentler to the north of El-Hadaik at the level of the 35 plain, and as it approaches its confluence with the Saf-Saf, a few dozen metres to the east of Route Nationale 44 (at Merdj Edib). (Maou. 2011).

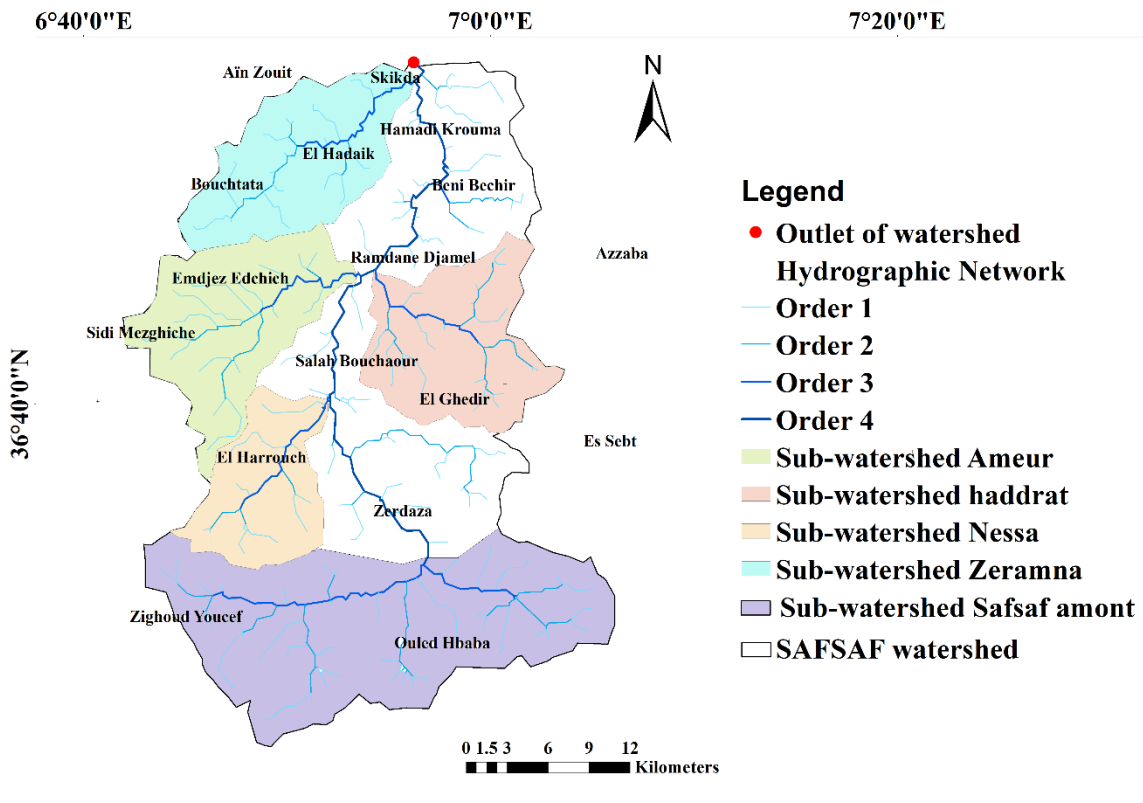


Figure 8: Sub-basin of the Saf-Saf watershed

- Drainage density (Dd) :

Drainage density is closely linked to two main factors: lithology and rainfall abundance, and allows us to assess the density of the drainage network in the catchment area.

It is expressed in km/km², by the ratio of the total length (Lx) of watercourses to the total surface area of the watershed (A).

$$Dd = \sum Lx / A$$

- Torrentiality coefficient (C_T) :

This coefficient reflects the torrential nature of downpours in the basin. It is strongly related to the drainage density and the frequency of drains by the relationship:

$$C_T = F_1 * Dd \longrightarrow F_1 = N_1/A$$

- Concentratison time (T_c) :

This is the time taken for the first drop of rain falling on the furthest point of the basin to reach the outlet. It is expressed in hours. We'll use Giandotti's formula to express it.

$$T_c = \frac{4\sqrt{A} + 1.5L_p}{0.8\sqrt{H_{moy} - H_{min}}}$$

L_p : length of main watercourse (km)

- Runoff Velocity (V_c) :

It is calculated using the following expression :

$$V_c = L_p / T_c$$

L_p : length of main watercourse (km)

T_c : concentration time

The table below summarizes the values of the various morphometric parameters discussed above.

Table 5: The values of the various morphometric parameters of the saf-saf watershed

	Morphometric characteristics of the Safsaf sub-catchment	Values
1	Area (A) in km ²	1167.9 km ²
2	Perimeter (P) in km	178.84 km
3	The compactness index Kc	1.47
4	Watershed shape	elongated watershed
5	Length of equivalent rectangle L in km	73.92 km
6	Width of equivalent rectangle l in km	15.79 km
7	Maximum altitude in m	1162 m

8	Minimum altitude in m	2 m
9	Average altitude in m	342m
10	Characteristic altitude H5% in m	920 m
11	Characteristic altitude H50% in m	380 m
12	Characteristic altitude H95% in m	140 m
13	Elevation Difference (D) in m	780 m
14	Global Slope Index (Ig) in m/km	10.55 m/km
15	Type of relief according to Ig	Moderate relief
16	Mean Slope Index (Im) en m/km	15.69 m/km
17	Rocks slope index (Ip)	3.63
18	Specific Relief (Ds) in m	360.49
19	Relief class	Strong relief
20	Drainage density (Dd) in (km/km ²)	0.443 km/km ²
21	Torrentiality coefficient	0.66
22	Concentration time (Tc) in h	14.37 h
23	Flow velocity (Vc) in km/h	3.5 km/h

Conclusion

The saf-saf sub-catchment is characterized by high relief, with a maximum altitude of 1162 m and a minimum altitude of 2 m. The sub-catchment has an average drainage density of 0.44 km/km². The median altitude obtained on the hypsometric curve is very close to the mean altitude value read on the same curve, 380 m. Moreover, the shape of this curve reflects a relief that has been clearly eroded. The time of concentration, calculated using Giandotti's formula, equals 14.37 h.

Chapter 2

Geology

Introduction

The analysis of the geological environment is fundamental to the study of agricultural lands and agricultural areas. Geology helps identify the materials and structures of formations that can conduct precipitation water both deep underground and on the surface. It also allows for the determination of the lithology of the study area. The geology of the terrain influences water flow; knowledge of the structural and lithological characteristics of the studied terrain helps explain certain chemical elements found in the soils.

1. Local Geology

The study area is part of the northern zone of the North African coastal orogen and belongs to Petite Kabylie, which lies entirely within the geological framework of the Tellian Atlas. The constantinois neritic block bordering the southern part of the watershed (Kef Toumiette, Kef Hahouner) is represented by the Kabylia ridge (the limestone range), oriented east-west. The western and northeastern flanks of the basin exhibit ancient metamorphic terrains (the Kabylia basement), and between these two units lies the Kabylia flysch nappe. This zone, characterized by its lithological and structural complexity, can be defined by the superposition of several structural units. The region has been the subject of numerous studies, notably by **Raoult (1974)**, **Durand Delga (1996)**, **Bouillin (1977)**, and **Vila (1981)**. These units are briefly described below (Fig. 10):

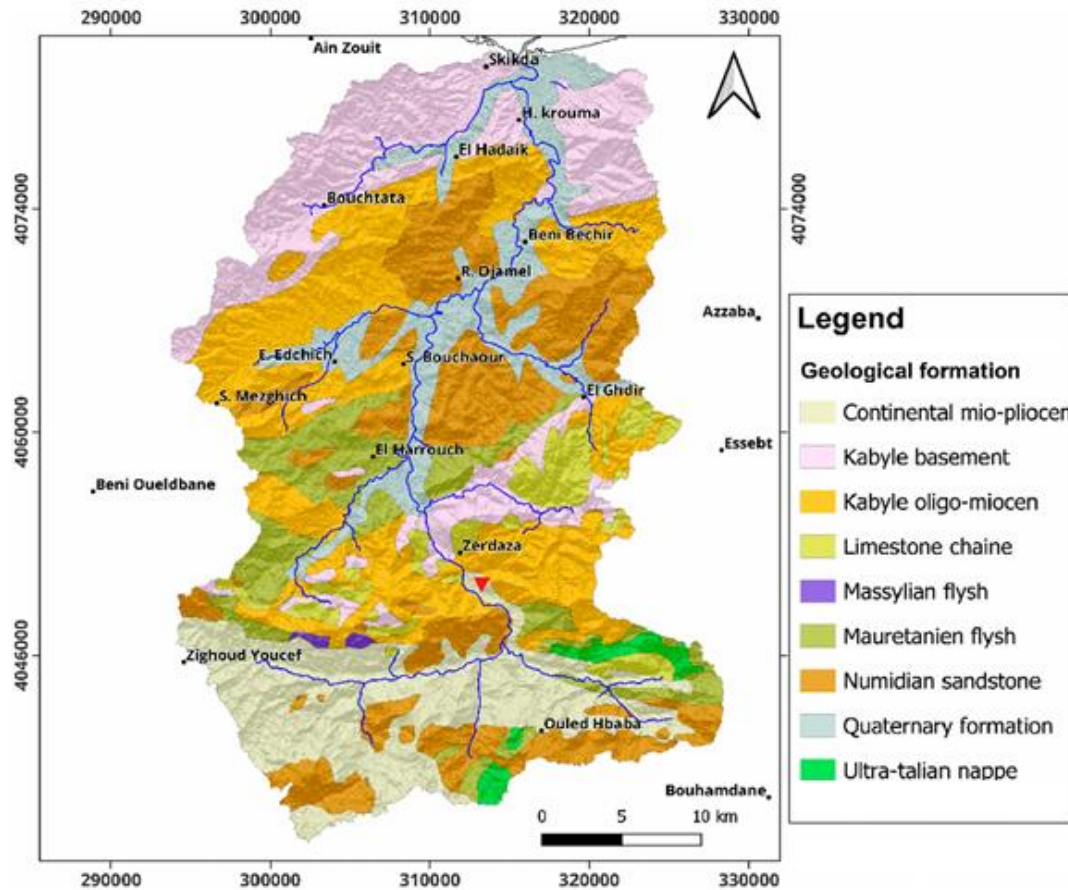


Figure 9: Geology of the study area (Vila, 1981, modified)

1.1. The Kabylia Basement

This is a set of metamorphic formations (gneiss, schists, and phyllades) exposed to the north of the ridge. All Paleozoic formations that serve or have served as substratum for the limestone chain are included. The southern part of Skikda marks its lower limit (**J.F. Raoult, 1974**).

It is essentially composed of three superimposed units: two metamorphic and one predominantly sedimentary. The lower metamorphic unit consists of biotite and muscovite gneisses with intercalations of marbles and amphibolites. The second metamorphic unit consists of phyllades or satin schists (200–300 m thick). The third, predominantly sedimentary unit of Paleozoic age, is mainly visible within the study region (**D. Delga, 1967**).

Ancient metamorphic massifs occupy a large part of the Saf-Saf basin. To the west, they extend from Stora to the Col de Staïha. They also outcrop south of El-Harrouch and

northeast of Aïn-Bouziane. They consist of phyllades, micaschists, and porphyroids. In the northeastern part of the basin (Dj. Filfila), they are dominated by schists and marbles.

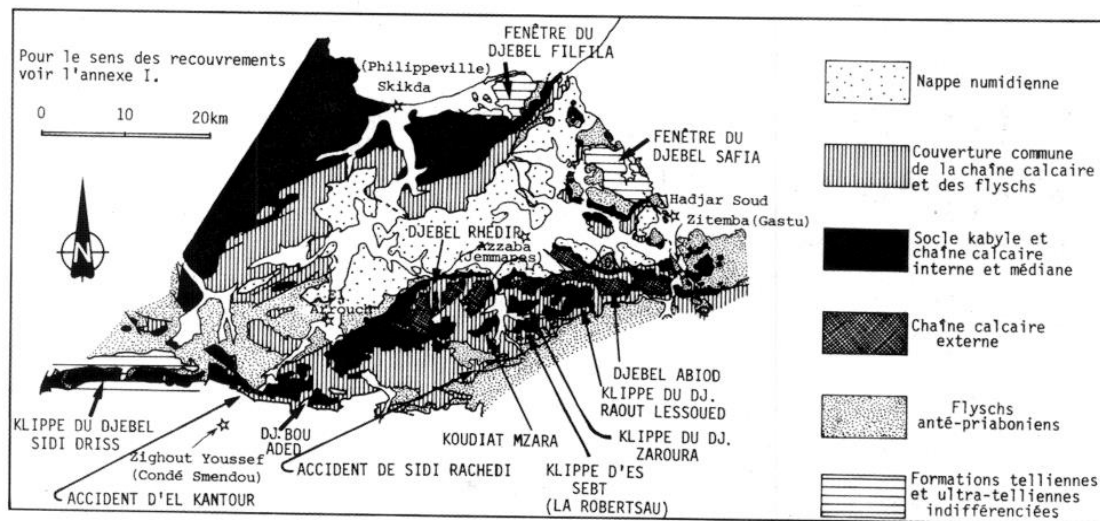


Figure 10: Main structural elements of the study area (Raoult, J. F. 1975)

1.2. The Kabylia Ridge

This is the Permo-Triassic cover over a Paleozoic series, itself attached to a metamorphic basement composed of phyllades. The stratigraphy consists of four main formations: over the Permo-Triassic layers of red conglomerates, sandstones, and pelites, the upper Lias is deposited, composed of laminated dolomites, dolomitized limestones, and massive limestone. Above these two formations lie the Domerian and upper Lias, composed of yellowish marly limestones with dark flint. The entire sequence is covered by recent allochthonous flyschs (Vila 1981). (Boucenna, N. 2007).

1.2.1. Internal Limestone Range

Visible at the southern boundary of the area, where the deposition of massive limestones was interrupted by the upper Lutetian tectonic phase, forming the plateaus of Kef Sebergoud and Kef Toumiete, where a small karst system has developed. (Raoult, J. F. 1975). The layers include:

Permo-Triassic: Red clays and sandstones, very reduced and often absent.

Lower Lias: Sandy dolomites, followed by massive white limestones, gravelly with algae and small benthic foraminifera.

Neocomian-Barrémian: Condensed and discontinuous series of laminated limestones with more or less abundant flint, sometimes red, sometimes glauconitic, dated by brachiopods and numerous ammonites from Carixian to Bajocian, microfauna, and rare ammonites from Malm.

Lutetian: Nummulitic I, with basal layers of sandy dolomites or Paleocene-Eocene conglomerates, followed by thick massive limestones containing nummulites, orthophragmines, alveolines, and meleobesiids.

1.2.2. Median Limestone Range

Found at the southern boundary of the area. The formations of the median limestone range, rich in pelagic microfauna, do not favor the development of prominent karst forms, unlike the internal limestone range. (Raoult, J. F. 1975). Three series are identified :

- Bou Aded Series :

Permo-Triassic: Conglomerates, sandstones, and purple-red clays, followed by sandy or vermiculated limestones of Muschelkalk ;

Lower Lias: Dolomitic limestones, then massive white limestones, gravelly with algae and benthic foraminifera ;

Upper Lias: Laminated limestones with flint (ammonites of Domerian), red limestones with filaments ;

Neocomian-Barrémian: Limestones with flint (possibly at the top), rare lenses of light red sandstone

Upper Albian: Light marly limestones, with rare flint, containing pelagic foraminifera ;

Paleocene to Lutetian: Gray marly limestones with small flint, globigerines, and crowned globorotalia, capped by a bioclastic limestone layer with nummulites and orthophragmines of upper Lutetian (Series 5 and 6 are highly discontinuous and condensed).

- Rhedir Series:

Permo-Triassic: Conglomerates, sandstones, and purple-red clays;

Lower Lias: Laminated dolomitic limestones, then massive white gravelly limestones;

Sinemurian and Domerian: Limestone breccias and red laminated limestones with flint, containing *Arnioceras* and *Rhynchonellines* from Sinemurian, overlain by limestones and marls with ammonites from Domerian;

Paleocene: Unconformably overlying coarse conglomerates, then thin sandy marls with *Microcodium*-bearing limestone plates.

- Tengout Series:

Discontinuous and condensed series of laminated limestones from Dogger to Neocomian-Barrémian, followed by a horizon of microbrecciated and oolitic limestones with silicifications, from upper Albian-Cenomanian; Unconformably overlying coarse Campanian conglomerates, then microbrecciated and sandy limestones in metric dark gray beds, from upper Campanian-Maastrichtian (*Globotruncana*, *Orbitoides*, *Siderolites*, *Navarella*); Nummulitic I, similar to that of Taïeb but thicker.

1.2.3. External Limestone Range

Found at Jebel El Ghédir as a plateau oriented NNW-SSE, forming a cored anticline (**Raoult, J. F. 1975**). , composed of:

Permo-Triassic: Clays, pelites, and sandstone beds showing red hues;

Upper Triassic and base of Lias: Poorly laminated brecciated dolomites and thick beds of gravelly, often oolitic, dolomitic limestones;

Lower Lias: A thick layer (100–400 m) of whitish massive limestones;

Middle Lias: Laminated limestones with dark gray flint showing yellowish patina and gray to gray-blue fracture, with marl layers;

Paleocene: At the base, massive or irregular coarse conglomerates; at the top, yellow to reddish sandy marls.

- Sidi Dris Series:

Permo-Triassic: Conglomerates, sandstones, and purple-red clays, followed by sandy or vermiculated limestones of Muschelkalk;

Lower Lias: Laminated dolomitic limestones, then massive white gravelly limestones;

Turonian-Coniacian: A few meters of fine limestones, with conglomeratic horizons, containing Globotruncanids.

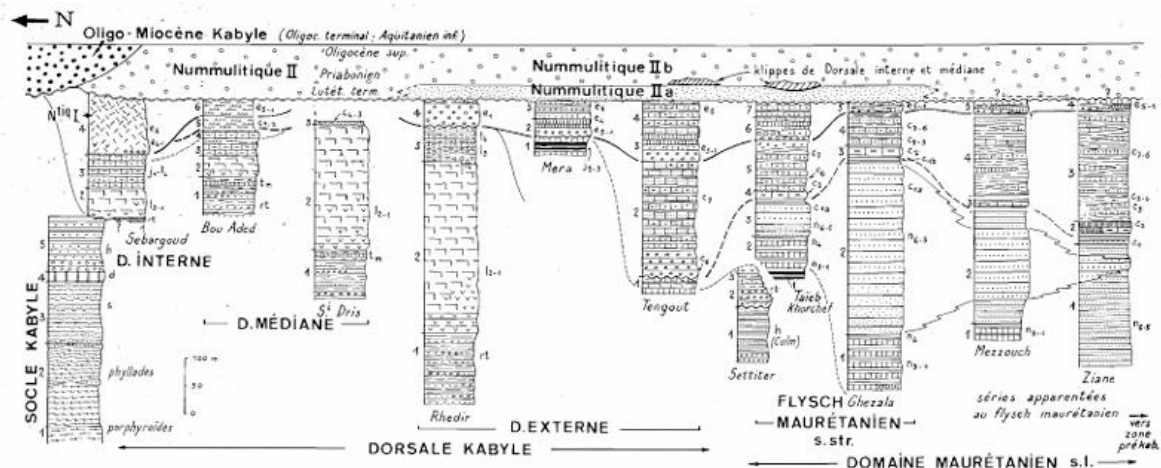


Figure 11: Stratigraphic columns of the Kabyle Ridge and the Mauritanian domain (Raoult, J. F. 1975).

1.3. The Kabylian flysch series

The flysch is characterized by abyssal formations emplaced by turbidity currents. These formations are divided into three:

1.3.1. Mauritanian Flysch

Dating from Neocomian to Lutetian, it exists continuously with the external limestone range. So far, it has been difficult to establish a clear separation between the two. It is observable on the northern slope of Jebel Sidi Driss, rich in Albo-Aptian sandstones, which decrease in thickness and give way to the Sidi Mezghich basin, carved mainly in softer rocks, directly affecting the landscape. The Mauritanian flysch, being the most widespread, is dominated by microbrecciated limestones containing sandstone beds and clay layers. It outcrops north of Ain Bouziane and north of Kef Hahouner. (J.F. Raoult, 1974).

1.3.2. Massylian Flysch

A highly varied flysch series located south of the SAF-SAF valley. From bottom to top, it consists of Albo-Aptian argillaceous-quartzitic flyschs, phthanite breccias, and Senonian microbrecciated flyschs. It outcrops over small areas southwest of Kef Toumiette, south of the Zardézas dam, on the northern slope of Jebel Sidi Driss, and at the El Kantour pass. It consists of thin hard layers (sandstones and limestones) that do not resist erosion, leading to various forms of landslides and gully erosion. The Massylian flysch represents a transition zone between the flysch domain and the external Tellian series (J.F. Raoult, 1974).

1.3.3. Numidian Flysch (Middle Oligocene - Burdigalian)

The Numidian nappe occupies the summits of the three domains mentioned, outcropping at Zerdézas and forming all the hills at the foot of Kef Toumiette, those between the Col des Oliviers and Jebel Bougrina, from Kef Toumiette to Jebel Bouabed, eastward around Jebel Tasselment and Tengout, and at most koudiats in the center of the basin, characterized by sandy series and sub-Numidian clays, often referred to as molassic series. In the Numidian chain, in the region of El Harrouch (Jebel Boussatour and Jebel Bougrina) and at Sidi Mezghich, where landsliding and gully erosion are spectacular, alternations of hard and soft rocks are observed (J.F. Raoult, 1974) (Allouche, M. 2015).

1.4. Post-Lutetian stratigraphic units

1.4.1. Ultra-Tellian Series

Characterized by predominantly marly facies with some limestone beds, resulting in generally soft topography where landslide forms are common. The position of these limestone beds overlying softer formations creates escarpments pushed by erosion. The alternation of soft and hard rocks appears at Kef Sidi Driss and Jebel Safia.

1.4.2. Nummulitic II Formations

Nummulitic II, IIa, and IIb: These formations are syn- and post-Lutetian nappe events and are not included in the definitions of the Dorsal and Mauritanian flysch series affected by this phase.

Nummulitic II: Molassic assemblage of conglomerates and micaceous sandstones with limestone pebbles from the Dorsal and numerous debris from the Kabylia basement; dated

from upper or terminal Lutetian at the base to upper Oligocene (Lepidocyclines) at the top. On certain cross-sections, subdivided into Nummulitic IIa and IIb.

Nummulitic IIa: Terminal Lutetian to lower Priabonian at the base, reddish pelites and argillaceous or microbrecciated limestones; above, thin layers of fine micaceous sandstones, tobacco-brown in color, approximately 200 m thick south of Jebels Tengout and Tasselemt; thinner (10–50 m) and generally reddish in the Bou Taïeb and Ghezala hamlets south of these mountains. **(Raoult, J. F. 1975).**

Nummulitic IIb: Lower Priabonian to upper Oligocene; average thickness 200–500 m; yellowish series with often marked flysch characteristics, including marls, bioclastic limestones, sandy and micaceous microbrecciated limestones, conglomerates with basement debris, and abundant micaceous sandstones (especially toward the top).

1.4.3. Kabylia Oligo-Miocene

Forms a discordant and transgressive sedimentary cover over the Kabylia basement. This formation outcrops in the El Harrouch region and consists of a molassic series 20 to 300 m thick of conglomerates and micaceous sandstones with basement debris, dated from terminal Oligocene at the base to lower Aquitanian at the top. Silicites are present, and olistostromes with blocks and klippen (olistoliths) derived from Cretaceous-Nummulitic flyschs (mostly Mauritanian and related) are developed at many points, having slid over the top of the Kabylia Oligo-Miocene. **(Raoult, J. F. 1975).**

2. Tectonics

The most significant tectonic phases (Raoult, 1974) are

2.1. Early tectonic movements (Cretaceous-Paleocene)

The Kabylia ridge (Dj. RHEDIR) was affected by numerous small faults during the Jurassic and Neocomian–Barrémian. These movements also affected the median ridge (Dj. BOUABED, Upper Cretaceous), and Dj. BOUGRINA, surrounded by the Mauritanian flysch, exhibits two major faults—one extensive NE-SW fault and another less significant NW-SE fault.

2.2. Late Lutetian Phase (upper Lutetian – upper Priabonian)

Occurred at the northeastern edge of the external ridge (Dj. TENGOUT and Dj. RHEDIR). This phase is characterized by tangential tectonics, post-Paleogene in age.

2.3. Late Oligocene and Miocene Phase (terminal Oligocene – Aquitanian)

Characterized by numerous folds and faults, this phase is responsible for the El-KANTOUR fault and the structural position of the FILFILA series. This major tectonic activity resulted in numerous faults, giving rise to several springs and watercourses that drain the Saf-Saf watershed.

3. Lithology and Superficial Formations

The Saf-Saf basin is characterized by great diversity in its rock composition. The following formations are distinguished :

3.1. Quaternary Formations

These are recent formations (alluvium and sands) developed along the Oued, with limited spatial extent on very gentle slopes (0–3%). They may constitute a wide aquifer.

3.2. Hard Rocks

Composed of micaschists and Numidian sandstones, characterizing the most prominent reliefs with steep slopes, represented by Jebel Messioune, Kef El Mezzaoudj, and the koudiets outcropping in the west and southeast of the sub-basin. These facies cover 34.46% and 11.34% respectively of the total rock outcrop surface. Also composed of metamorphic rocks such as gneiss and phyllade, and sedimentary rocks such as limestone and dolomite. The Kabylia basement is flanked in the western and northwestern parts, primarily represented by gneisses. Limestones and dolomites are mainly located south of Elharrouch, on Kef N'souna and Sebergou at the foot of Jebel Darrah. (Boucenna, N. 2007).

3.4. Soft Rocks

Represented by moderately and weakly erosion-resistant formations, including flysch, schist, marls in the Tellian and ultra-Tellian series, and sub-Numidian clays. Schist is the predominant rock component in the watershed, widely distributed in Mount Sapiou, across the plain, and further south on the mountains of Kef Djedj and Kef Mourguet.

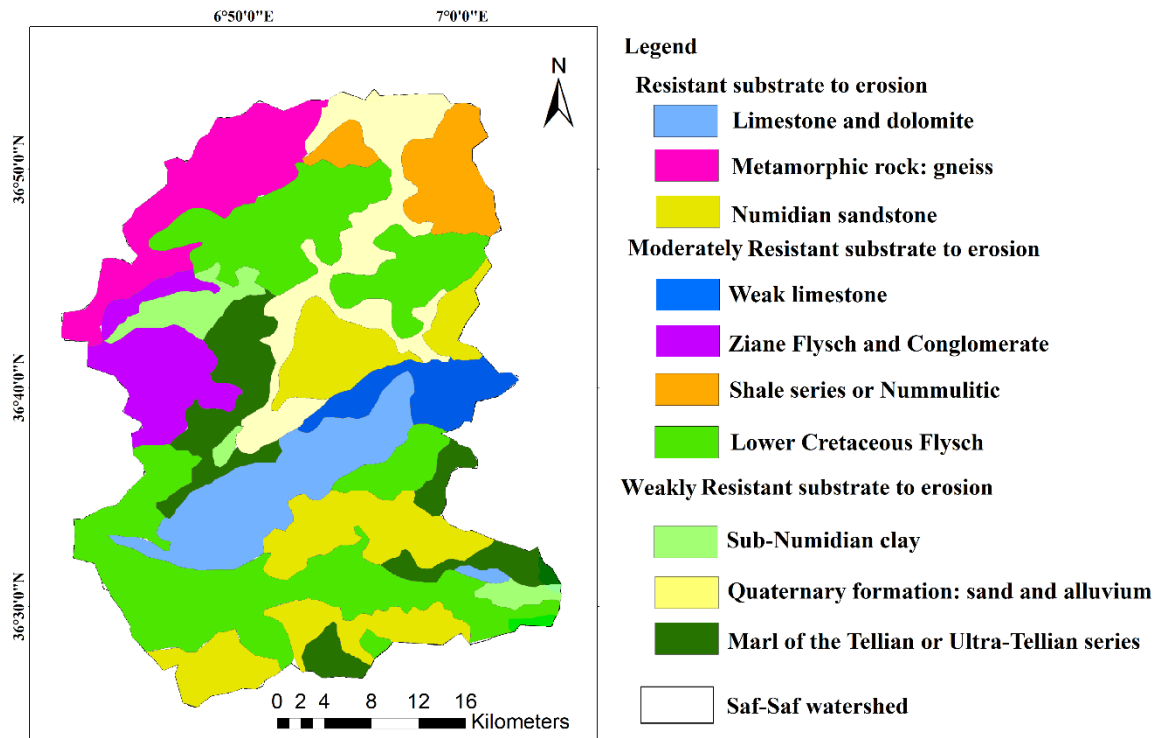


Figure 12: Lithology of the study area

Conclusion

The Saf-Saf zone showcases a complex geological landscape marked by various tectonic units, each representing distinct geological formations. The Kabylean basement mountains are primarily composed of Paleozoic metamorphic rocks, while the Kabylean ridge features Permo-Triassic formations. Nestled between these two significant units are the Mauritanian and Massylian flysch series, alongside the Numidian nappe.

Additionally, several smaller units contribute to the diversity of the region, including the Ultra-Tellian Series, Nummulitic II Formations, and the Kabylean Oligo-Miocene, each belonging to different geological ages and formations.

Tectonically, the study area has been influenced by three significant phases of movement over time: the early tectonic movements during the Cretaceous-Paleocene, the Late Lutetian Phase (spanning the upper Lutetian to the upper Priabonian), and the Late Oligocene to Miocene Phase (covering the terminal Oligocene to the Aquitanian).

In terms of lithology, the watershed comprises a variety of rock types, including resistant, moderately resistant, and weakly resistant rocks, as represented in the Quaternary formations found throughout the study area.

Chapter 3
Hydro-climatology,
Hydrology, and
Hydrogeology

Introduction

Hydro-climatology is the study of climatic characteristics based on precipitation and temperature data. These data provide an overview of their distribution in space and time.

The hydroclimatic study is necessary to better understand the exchange and circulation mechanisms of surface water used for irrigation and drinking water supply, and to identify water balance terms such as precipitation, temperature, evapotranspiration, runoff, and infiltration.

1. Measuring stations

The data used for rainfall are those from the zerdaza dam (1975-2024), Skikda port (1975-2014), Ramdan Djamel (1975-2014), and Elharrouch (1975-2014) stations, and those from the Skikda port climate station (T°) (1975-2014). The coordinates of these stations are given in the table below.

To complete the series of observations for Skikda Port, Ramdan Djamel, and Elharrouch, we used the Google Earth Engine to download precipitation data from CHIRPS (Climate Hazards Group Infrared Precipitation with station data) and temperature data from ERA5 (European center for Medium-Range Weather Forecasts) from 2015 to 2024.

Table 6: coordinates of the pluviometric stations

Station	X(m)	Y(m)	Altitude (m)	Observation period
Skikda port	874500	406400	5	1975/76 to 2023/24
Zerdaza Dam	875623	373573	199	1975/76 to 2023/24
Ramdan Djamel	874950	389850	45	1975/76 to 2023/24
El harrouch	869700	379700	137	1975/76 to 2023/24

2. Climate Parameters

2.1. Precipitation

Precipitation represents all the meteoric water that falls on the Earth's surface in liquid or solid form. We will use a data series covering 49 years (1975/76-2023/24).

2.1.1. Monthly precipitation

The series of average monthly precipitation observed for the period 1976-2024 at the four stations used in this study:

Table 7: Average monthly precipitation (1975-2024)

month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
P (mm)	skikda port	47.6	69.7	106.6	128.1	106.2	88.7	78.3	56.6	36.6	15.9	2.5	10.7	747.4
	zerdaza dam	35.2	53.0	81.4	98.5	92.4	85.1	75.4	57.7	40.1	15.3	6.5	8.6	649.2
	ramdan djamel	34.1	58.0	85.7	101.2	90.5	73.4	70.1	50.0	34.0	11.3	3.1	7.6	619.2
	Elharro uch	36.8	52.0	78.1	93.5	83.6	71.2	69.5	50.8	38.1	13.4	2.8	7.8	597.6

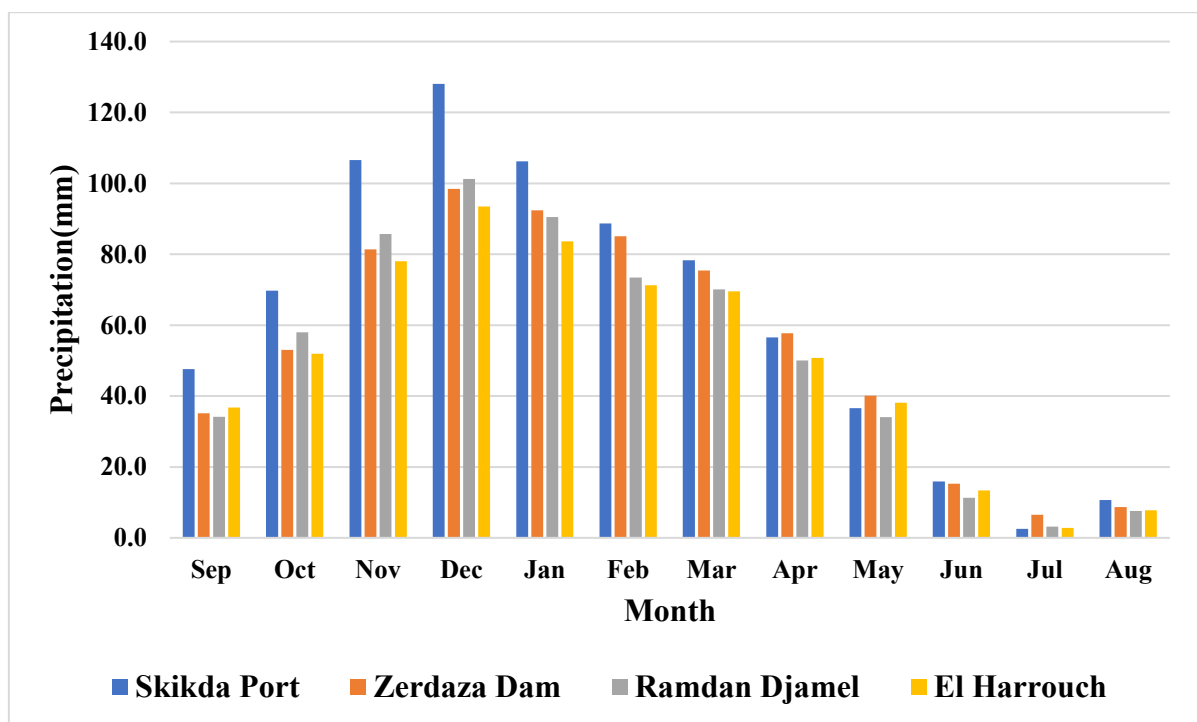


Figure 13: Variation in monthly precipitation (1975/76-2023/24)

From the data processed, we can observe that:

The wettest month at all stations is December, with a monthly mean precipitation of 128.1 mm at Skikda Port Station. 98.5 mm at the barrage de zerdaza station. 101.2 mm at the Ramdan Djamel station. 93.5 mm at El Harrouch station.

July was also the driest month in all stations, with a monthly average rainfall of

2.5 mm at Skikda Port Station. 6.5 mm at the barrage de zerdaza station. 3.1 mm at Ramadan Djamel station. 2.8 mm at El Harrouch station.

2.1.2. Annual precipitation

For annual precipitation, we have 4 series from 1976 to 2024 from the following stations: Zerdaza Dam, Skikda Port Station, Ramdan Djamel, and Elharrouch.

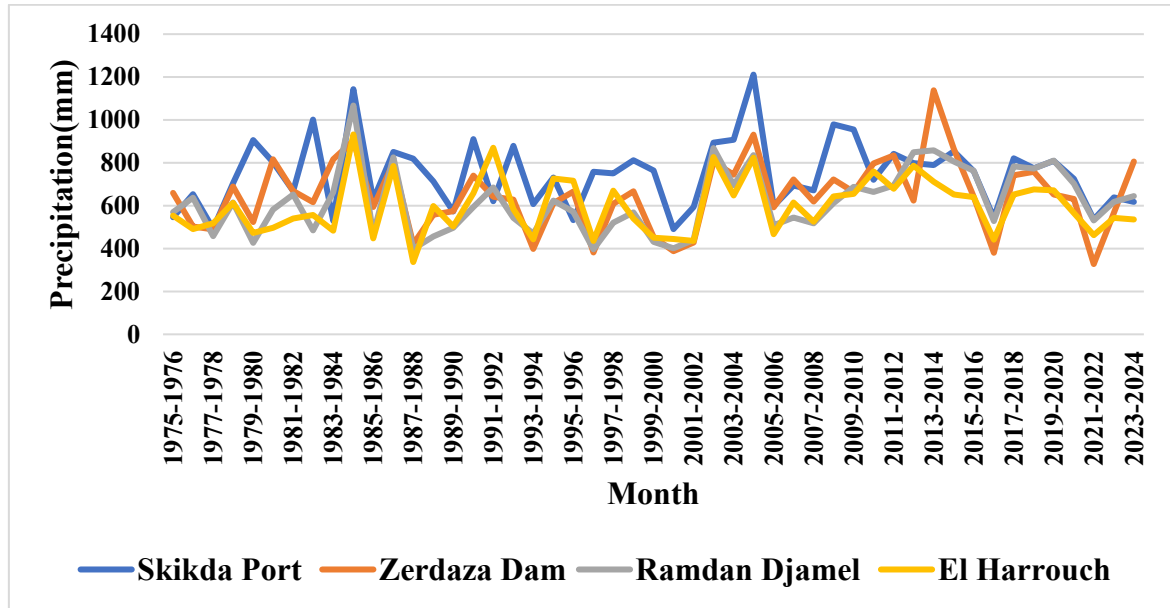


Figure 14: Variation in inter-annual precipitation (mm). Period: (1975/76-2023/24)

Analysis of these graphs over 49 years shows that:

For the zerdaza dam station, the driest year is 2021-2022, with precipitation of 327.7 mm; the wettest year was 2013-2014, with precipitation of 1138.08 mm, and the average annual rainfall is 649.2 mm.

For the Skikda Port Station, the driest year was 2000-2001, with precipitation of 490.1 mm, the wettest year was 2004-2005, with rainfall of 1211.3 mm, and the average annual rainfall is 747.4 mm.

For Ramdan Djamel Station, the driest year was 1996-1997, with precipitation of 396.6 mm, the wettest year was 1984-1985, with rainfall of 1067.2 mm, and the average annual rainfall is 619.2mm.

For Elharrouch station, the driest year was 1987-1988, with 337.1 mm of precipitation, the wettest year was 1984-1985, with rainfall of 932.2 mm, and the annual average is 597.6 mm

2.1.2.1. Rainfall coefficient

The interannual variability of precipitation is expressed by the rainfall coefficient (RC). This parameter is very important in determining surplus and deficit years.

and deficit years. It is obtained by dividing one year's rainfall by the average rainfall of a series at a given station:

$$RC = P / \bar{P}$$

With :

RC: rainfall coefficient. P: annual rainfall (mm). $\bar{P}$: average annual rainfall (mm).

We have two cases:

If $RC > 1$: surplus year. If $RC < 1$: deficit year

Table 8: Annual precipitation (mm) and rainfall coefficients for study stations

Years	Skikda Port Station			Zerdazas Dam station			Ramdan Djamel Station			El Harrouch Station		
	P (mm)	RC	year type	P (mm)	RC	year type	P (mm)	RC	year type	P (mm)	RC	year type
1975-1976	545.7	0.7	deficit year	660.12	1.0	surplus year	569.3	0.9	deficit year	553	0.9	deficit year
1976-1977	654.1	0.9	deficit year	503	0.8	deficit year	637.2	1.0	surplus year	491.5	0.8	deficit year
1977-1978	492	0.7	deficit year	489.6	0.8	deficit year	458	0.7	deficit year	517	0.9	deficit year
1978-1979	705	0.9	deficit year	689.6	1.1	surplus year	615.2	1.0	surplus year	613.5	1.0	surplus year
1979-1980	906	1.2	surplus year	524.2	0.8	deficit year	427.2	0.7	deficit year	473.5	0.8	deficit year
1980-1981	802.7	1.1	surplus year	816.6	1.3	surplus year	581.5	0.9	deficit year	496.5	0.8	deficit year
1981-1982	669	0.9	deficit year	668.5	1.0	surplus year	652	1.1	surplus year	539.8	0.9	deficit year
1982-1983	1001	1.3	surplus year	616.9	1.0	surplus year	484.6	0.8	deficit year	556.6	0.9	deficit year
1983-1984	530.2	0.7	deficit year	816.5	1.3	surplus year	663.2	1.1	surplus year	483.3	0.8	deficit year
1984-1985	1143.9	1.5	surplus year	903.1	1.4	surplus year	1067.2	1.7	surplus year	932.2	1.6	surplus year
1985-1986	626.2	0.8	deficit year	594.6	0.9	deficit year	466.8	0.8	deficit year	447.1	0.7	deficit year
1986-1987	850	1.1	surplus year	799.9	1.2	surplus year	825.9	1.3	surplus year	785.5	1.3	surplus year
1987-1988	819	1.1	surplus year	420.9	0.6	deficit year	397.7	0.6	deficit year	337.1	0.6	deficit year
1988-1989	714	1.0	surplus year	558.01	0.9	deficit year	456.8	0.7	deficit year	598.8	1.0	surplus year
1989-1990	573	0.8	deficit year	574.5	0.9	deficit year	496.9	0.8	deficit year	502.4	0.8	deficit year

1990-1991	911	1.2	surplus year	740.3	1.1	surplus year	593.3	1.0	surplus year	658.3	1.1	surplus year
1991-1992	621	0.8	deficit year	641.9	1.0	surplus year	684.7	1.1	surplus year	870.4	1.5	surplus year
1992-1993	879	1.2	surplus year	627.5	1.0	surplus year	542.6	0.9	deficit year	583.1	1.0	surplus year
1993-1994	607	0.8	deficit year	398	0.6	deficit year	470.5	0.8	deficit year	443.5	0.7	deficit year
1994-1995	731	1.0	surplus year	611.1	0.9	deficit year	624.2	1.0	surplus year	726.6	1.2	surplus year
1995-1996	533	0.7	deficit year	665.1	1.0	surplus year	571.4	0.9	deficit year	716.1	1.2	surplus year
1996-1997	757.7	1.0	surplus year	381.4	0.6	deficit year	396.6	0.6	deficit year	435.5	0.7	deficit year
1997-1998	750.7	1.0	surplus year	608.1	0.9	deficit year	520.4	0.8	deficit year	670.6	1.1	surplus year
1998-1999	811.8	1.1	surplus year	667.3	1.0	surplus year	569.2	0.9	deficit year	540.8	0.9	deficit year
1999-2000	763.7	1.0	surplus year	452.8	0.7	deficit year	431.5	0.7	deficit year	451.1	0.8	deficit year
2000-2001	490.7	0.7	deficit year	388.3	0.6	deficit year	400.7	0.6	deficit year	445.3	0.7	deficit year
2001-2002	594	0.8	deficit year	427.7	0.7	deficit year	440.7	0.7	deficit year	435	0.7	deficit year
2002-2003	893.3	1.2	surplus year	804.7	1.2	surplus year	868.8	1.4	surplus year	826.1	1.4	surplus year
2003-2004	907	1.2	surplus year	744.5	1.1	surplus year	695.3	1.1	surplus year	647.2	1.1	surplus year
2004-2005	1211.3	1.6	surplus year	931.8	1.4	surplus year	835.4	1.3	surplus year	823.9	1.4	surplus year
2005-2006	599.1	0.8	deficit year	592.1	0.9	deficit year	508.8	0.8	deficit year	466.8	0.8	deficit year
2006-2007	694.4	0.9	deficit year	721.9	1.1	surplus year	545.3	0.9	deficit year	615.4	1.0	surplus year
2007-2008	671.2	0.9	deficit year	618.7	1.0	surplus year	518.4	0.8	deficit year	525.2	0.9	deficit year
2008-2009	978.9	1.3	surplus year	722	1.1	surplus year	612	1.0	surplus year	642.5	1.1	surplus year
2009-2010	955.6	1.3	surplus year	664.8	1.0	surplus year	688.5	1.1	surplus year	655.2	1.1	surplus year
2010-2011	721.4	1.0	surplus year	797	1.2	surplus year	664.3	1.1	surplus year	759.2	1.3	surplus year
2011-2012	841.5	1.1	surplus year	834.54	1.3	surplus year	693.6	1.1	surplus year	679.3	1.1	surplus year
2012-2013	798.2	1.1	surplus year	623.8	1.0	surplus year	849.7	1.4	surplus year	786.7	1.3	surplus year
2013-2014	789.4	1.1	surplus year	1138.08	1.8	surplus year	858.0	1.4	surplus year	711.5	1.2	surplus year
2014-2015	854.1	1.1	surplus year	864.28	1.3	surplus year	805.6	1.3	surplus year	652.0	1.1	surplus year
2015-2016	760.7	1.0	surplus year	641.68	1.0	surplus year	762.2	1.2	surplus year	639.9	1.1	surplus year
2016-2017	543.5	0.7	deficit year	380.1	0.6	deficit year	527.7	0.9	deficit year	441.0	0.7	deficit year
2017-2018	820.7	1.1	surplus year	741.5	1.1	surplus year	784.1	1.3	surplus year	652.7	1.1	surplus year
2018-2019	774.2	1.0	surplus year	758.3	1.2	surplus year	772.4	1.2	surplus year	676.3	1.1	surplus year

2019-2020	809.4	1.1	surplus year	652.5	1.0	surplus year	810.2	1.3	surplus year	670.8	1.1	surplus year
2020-2021	725.4	1.0	surplus year	631.1	1.0	surplus year	703.1	1.1	surplus year	566.0	0.9	deficit year
2021-2022	536.2	0.7	deficit year	327.7	0.5	deficit year	530.6	0.9	deficit year	462.1	0.8	deficit year
2022-2023	639.0	0.9	deficit year	566.7	0.9	deficit year	617.5	1.0	surplus year	542.5	0.9	deficit year
2023-2024	618.0	0.8	deficit year	805.468	1.2	surplus year	645.1	1.0	surplus year	535.2	0.9	deficit year

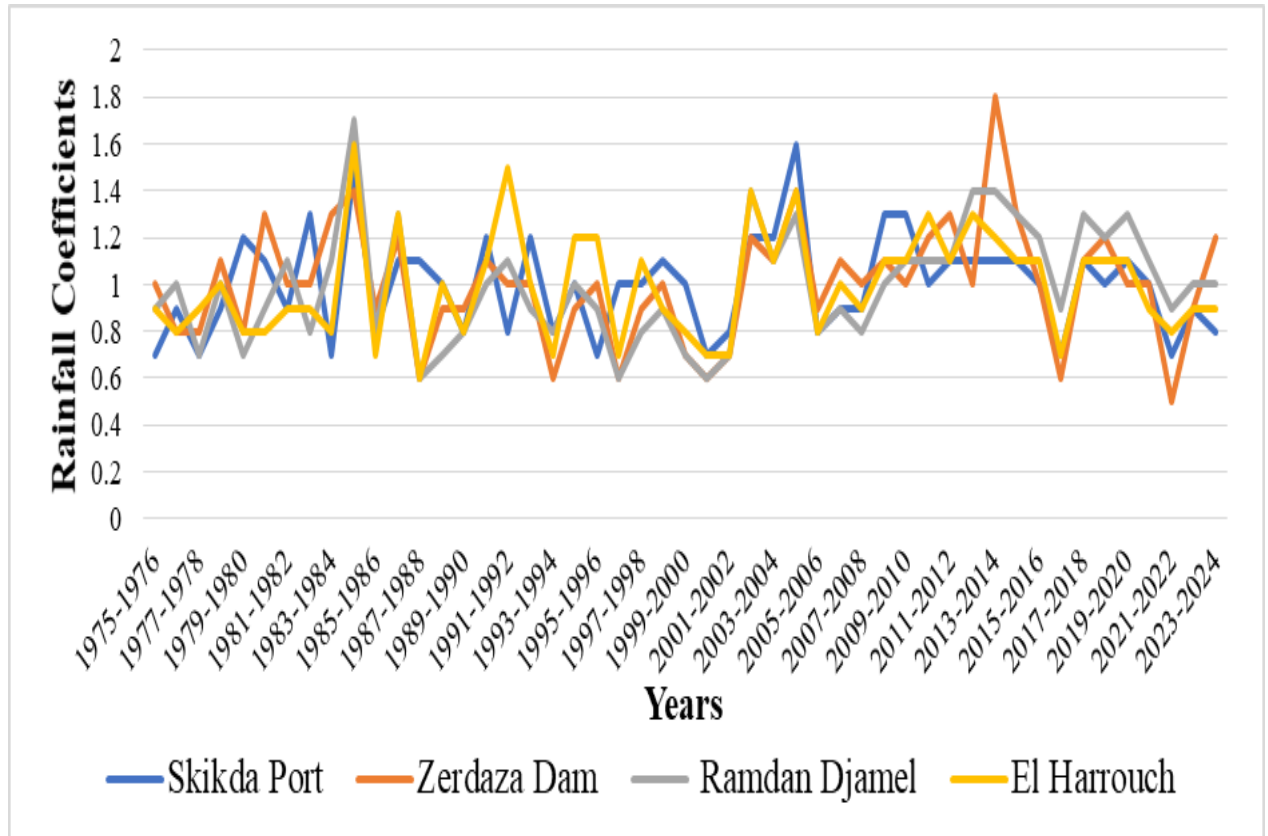


Figure 15: The variation of the rainfall coefficients of the stations of the study (1975/76-2023/24)

2.1.3. Seasonal precipitation

Table 9: Average seasonal precipitation at study stations (1975/76-2023/24)

seasons		Autumn	Winter	spring	summer	total
P (mm)	skikda port	223.9	323.0	171.5	29.1	747.4
	zerdaza dam	169.6	275.9	173.2	30.5	649.2
	ramdan djamel	177.9	265.1	154.2	22.0	619.2
	elharrouch	166.8	248.3	158.4	24.0	597.6

P (%)	skikda port	29.9	43.3	23.0	3.9	100%
	zerdaza dam	26.1	42.5	26.7	4.7	
	ramdan djamel	28.7	42.8	24.9	3.6	
	elharrouch	27.9	41.6	26.5	4.0	

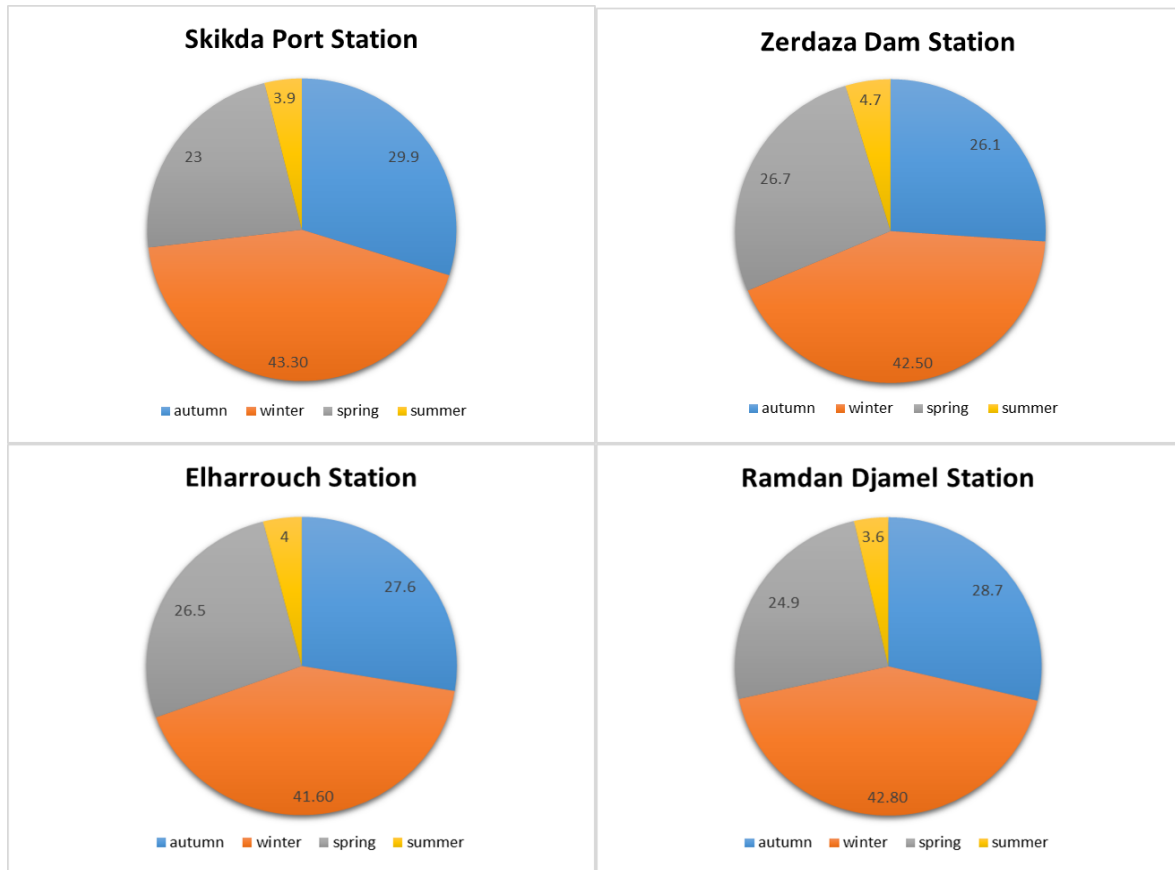


Figure 16: Variation in seasonal precipitation at study stations (1975/76-2023/24)

At all stations, winter is the wettest season in the Safsaf watershed, with between 41% and 43.3% precipitation, and autumn and spring receive almost the same amount of rainfall, with the driest season being summer, with between 3.6% and 4.7% precipitation.

2.2. Temperature

Temperature is a very important factor, conditioning phenomena and water balance parameters in particular. We will use a data series from the Skikda port station covering 49 years (1976-2024).

2.2.1. Monthly temperature

Table 10: monthly temperature at Skikda Port Station (1975/76-2023/24)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Mean
T(°c)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4

Analysis of these values shows a steady increase in temperatures from January to August, followed by a decrease until December.

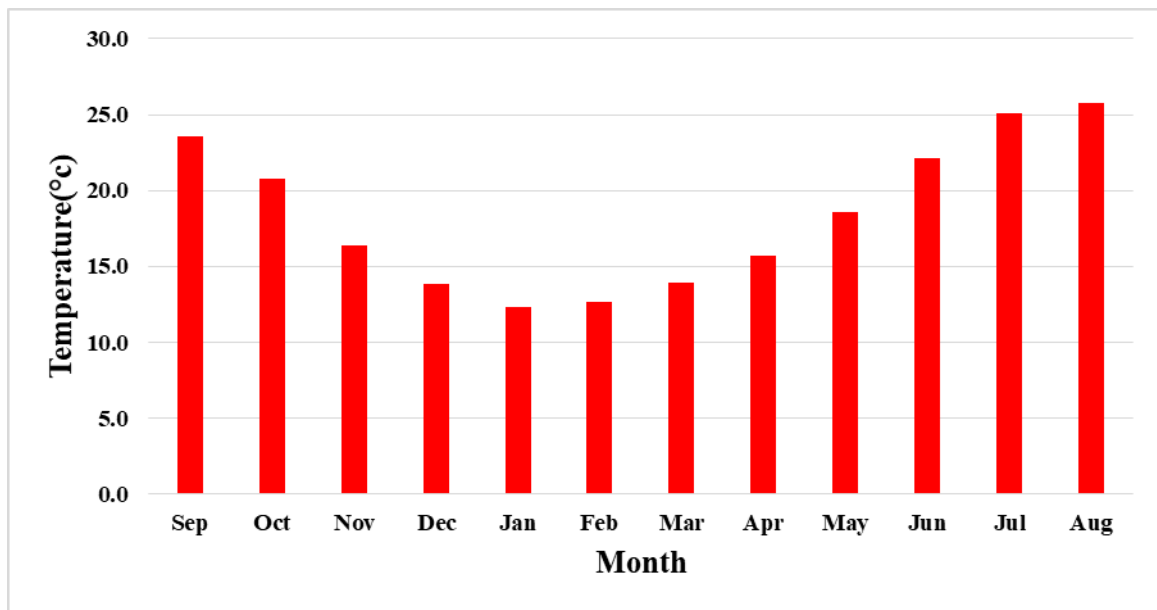


Figure 17: Variation in mean monthly temperature at Skikda Port Station (1975/76-2023/24)

The average minimum temperature in January is around 12.3°C, while the average maximum temperature in August is around 25.7°C. The average monthly temperature is 18.4°C.

2.3. Gaussen Ombro-thermal diagram

The Gaussen diagram can be used to determine the beginning and end of a dry or wet period. This relationship makes it possible to draw up rainfall-temperature diagrams on which temperatures are plotted on a scale twice that of rainfall.

Table 11: average monthly precipitation/temperature (1975/76-2023/24)

Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Mean /Total
Skikda Port Station	P (mm)	47.6	69.7	106.6	128.1	106.2	88.7	78.3	56.6	36.6	15.9	2.5	10.7	747.4
	T (°C)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4

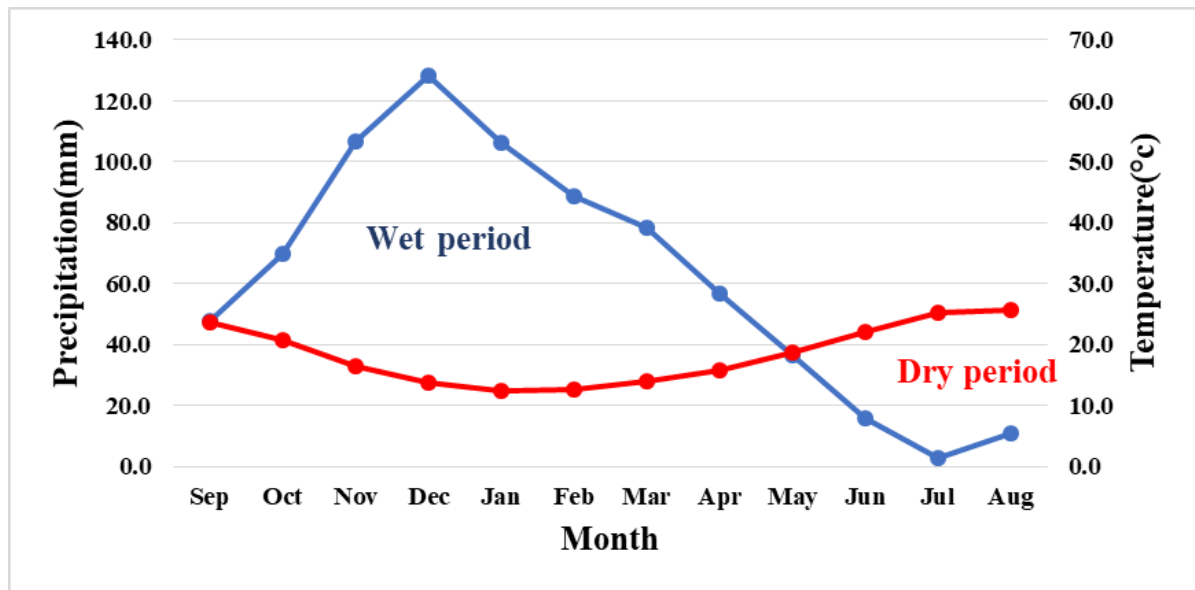


Figure 18: Gaussen ombro-thermal diagram (period: 1975/76-2023/24)

The ombro-thermal diagram shows two different periods:

- The dry period runs from June to September with 76.7 mm of precipitation.
- The wet period runs from October to May, with 670.8 mm of precipitation

2.4. Determining the type of climate

2.4.1. Martonne aridity index

This index, proposed by De Martonne in 1923, is a climatic index that defines aridity I by the rainfall and thermal regime. It is calculated by the following formula:

$$I = P / (T + 10)$$

with :

I: De Martonne annual aridity index

P: mean annual precipitation (mm)

T: mean annual temperature (°C)

Table 12: Climate classification by aridity index

aridity index ranking	climate type
$I < 5$	Hyperarid climate
$5 < I < 7.5$	Desert climate
$7.5 < I < 10$	Steppe climate
$10 < I < 20$	Semi-arid climate
$20 < I < 30$	Temperate climate
$I > 30$	Humid climate

Table 13: De Martonne aridity index

Station	P (mm)	T (°C)	I	Climate type
Skikda port	747.5	18.4	26.32	Temperate climate
Zerdaza dam	650.3	18.4	22.9	Temperate climate
Ramdan djamel	620.6	18.4	21.85	Temperate climate
Elharrouch	597.9	18.4	21.05	Temperate climate

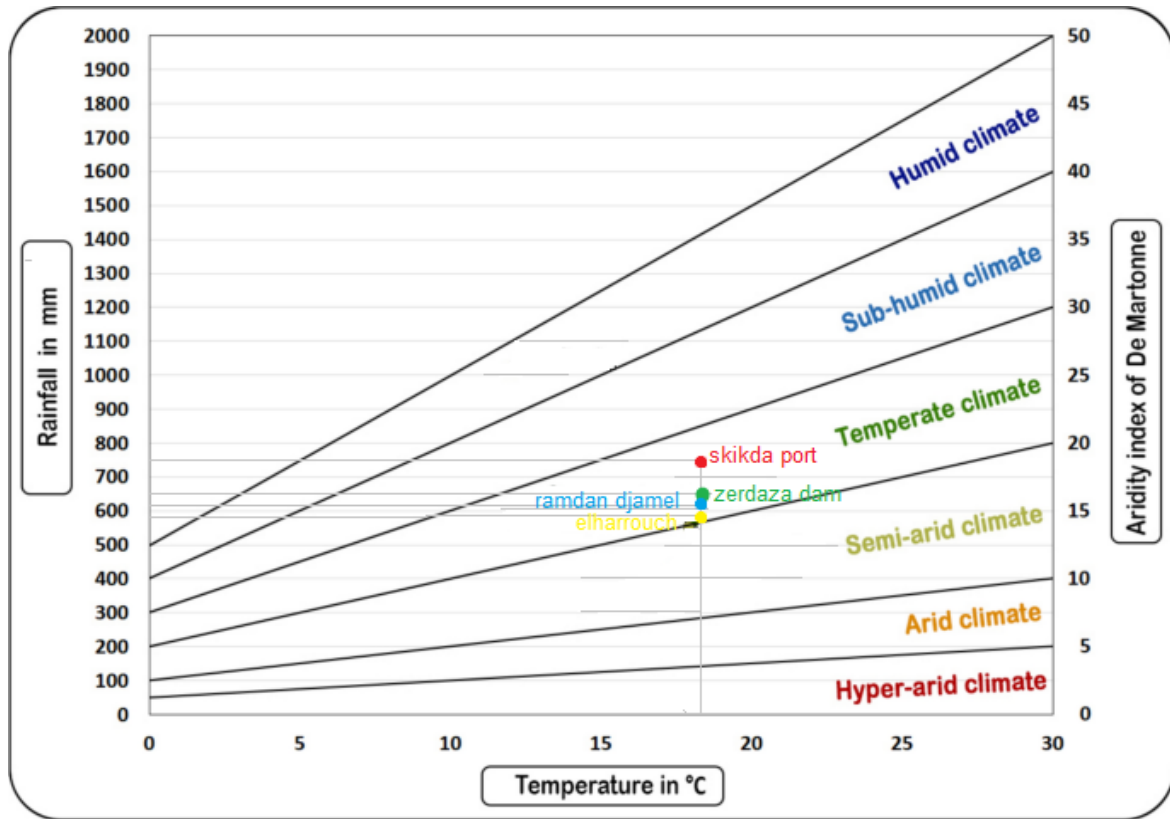


Figure 19: De Martonne aridity index chart

The Safsaf catchment area is characterized by a temperate climate according to De Martonne's aridity index.

2.4.2. Paul Moral Index

This index is calculated from annual rainfall (mm) and average annual temperatures (°C).

The value of the index indicates:

- If $MI < 1$, we have a sec climate
- If $IMI > 1$, we have a humid climate.

$$MI = P / (T^2 - 10T + 200)$$

With:

MI: Moral index

P(mm): annual precipitation T(°C): average annual temperatura

Table 14: Paul Moral index results

Station	P (mm)	T (°C)	MI	Climate type
Skikda Port	747.4	18.4	2.11	Humid climate
Zerdazas Dam	649.2	18.4	1.83	Humid climate
Ramdan Djamel	619.2	18.4	1.75	Humid climate
El Harrouch	597.6	18.4	1.69	Humid climate

The Safsaf catchment area is characterized by a Humid climate according to the Paul Moral index.

2.5. Evapotranspiration

Evapotranspiration is the sum of all losses from the soil, vegetation, open water tables, lakes, etc., through the transformation of water into vapor.

2.5.1. Real evapotranspiration (RET)

Real evapotranspiration is the amount of water actually evaporated by the soil, plants, and open water surfaces. There are several formulas for calculating RET:

2.5.1.1. Turc Formula (1960)

This expression is used to estimate the annual RET of a catchment from the annual rainfall and mean annual temperature.

$$RET = \frac{P}{\sqrt{0.9 + \left(\frac{P}{L}\right)^2}}$$

With:

RET: real evapotranspiration (mm)

P: mean annual precipitation (mm)

L: evaporative capacity of the atmosphere. Where: $L = 300 + 25T + 0.05T^3$

T: mean annual temperature (°C)

2.5.1.2. Coutagne Formula (1939)

The Coutagne formula is used to calculate AET as a function of mean annual temperature (°C) and annual rainfall measured in mm. AET is expressed by the following formula:

$$RET = P - \lambda * P^2$$

With :

RET: Real evapotranspiration (mm);

P: mean annual precipitation

λ : factor dependent on mean annual temperature. $\lambda = 1/(0.8 + 0.14T)$

Table 15: Real evapotranspiration values obtained by different methods

Station		Skikda Port	Zeradza Dam	Ramdan djamel	El Harrouch
RET	Turc	634.78	577.43	558.34	543.24
	Coutagne	582.1	525.1	506.51	550

2.5.2. Potential Evapotranspiration (PET) using the Thornthwaite Method

This is the evapotranspiration of a surface with a sufficient water supply to evaporate the maximum quantity of water permitted by the given climatic conditions.

This formula was established by Thornthwaite in 1948 and is expressed as follows :

$$PET = 16 * ((10 * T) / I)^a$$

With :

ETP: Monthly potential evapotranspiration (mm)

T: Average monthly temperature (°C)

I: Annual thermal index where

$$I = \sum i \text{ Avec : } i = (T/5)^{1.514} \quad i: \text{ monthly thermal index}$$

a: climatic exponent given by L. Serra in 1954. $a = (1.6/100) * I + 0.5$

The corrected monthly potential evapotranspiration is obtained from the following formula:

$$\text{PET corrected} = \text{PET} * K$$

Where k: correction factor

2.5.2.1. Hydrological Balance

The water balance aims to determine the distribution of precipitation received by a surface from the values of monthly precipitation and potential evapotranspiration PET.

The balance is calculated as follows:

If $\text{PET} > \text{P}$, a deficit occurs; all or part of the EUR will be solicited until PET is compensated, and evapotranspiration acts on the soil. No infiltration towards the water table

If $\text{PET} = \text{P}$, there is real evapotranspiration (RET), the EUR is not influenced, and no infiltration occurs from the water table.

If $\text{PET} < \text{P}$, RET equals PET, and a surplus occurs, leading to infiltration into the water table if the RFU is at its maximum.

According to G.Kastany, when the quantities of water from rainfall exceed those lost through evapotranspiration, the surplus is stored and constitutes what is known as the easily usable reserve (EUR).

At all the stations in this study, rainfall exceeds evapotranspiration. For this reason, we take the EUR to be equal to 100 mm.

Table 16: Thornthwaite water balance (Skikda Port Station (1975/76-2023/24))

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	mean/ Total
T(°C)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4
i	10.5	8.7	6	4.7	3.9	4.1	4.7	5.7	7.3	9.5	11.5	11.9	
k	1.05	0.91	0.75	0.7	0.73	0.78	1.02	1.05	1.32	1.33	1.33	1.24	
PETc	110.1	74.9	39.2	26.3	22	25	38.8	50.4	87.7	123	156.9	153	907.3
P(mm)	47.6	69.7	106.6	128.1	106.2	88.7	78.3	56.6	36.6	15.9	2.5	10.7	747.4
EUR	0	0	67.4	100	100	100	100	100	48.9	0	0	0	
RET	47.6	69.7	39.2	26.3	22	25	38.8	50.4	87.7	64.8	2.5	10.7	484.7
Ad	62.5	5.2	0	0	0	0	0	0	0	58.2	154.4	142.3	422.6
Sp	0	0	0	69.3	84.2	63.7	39.5	6.2	0	0	0	0	262.9

Table 17: Thornthwaite water balance (Zerdaza Dam Station (1975/76-2023/24))

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	mean/ Total
T(°C)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4
i	10.5	8.7	6	4.7	3.9	4.1	4.7	5.7	7.3	9.5	11.5	11.9	
k	1.05	0.91	0.75	0.7	0.73	0.78	1.02	1.05	1.32	1.33	1.33	1.24	
PETc	110.1	74.9	39.2	26.3	22	25	38.8	50.4	87.7	123	156.9	153	907.3
P(mm)	35.2	53.0	81.4	98.5	92.4	85.1	75.4	57.7	40.1	15.3	6.5	8.6	649.2
EUR	0	0	42.2	100	100	100	100	100	52.4	0	0	0	
RET	35.2	53	39.2	26.3	22	25	38.8	50.4	87.7	67.7	6.5	8.6	460.4
Ad	74.9	21.9	0	0	0	0	0	0	0	55.3	150.4	144.4	446.9
Sp	0	0	0	14.5	70.4	60.1	36.6	7.3	0	0	0	0	188.9

Table 18: Thornthwaite water balance (Ramdan Djamel Station (1975/76-2023/24))

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	mean/ Total
T(°C)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4
i	10.5	8.7	6	4.7	3.9	4.1	4.7	5.7	7.3	9.5	11.5	11.9	
k	1.05	0.91	0.75	0.7	0.73	0.78	1.02	1.05	1.32	1.33	1.33	1.24	
PETc	110.1	74.9	39.2	26.3	22	25	38.8	50.4	87.7	123	156.9	153	907.3
P(mm)	34.1	58.0	85.7	101.2	90.5	73.4	70.1	50.0	34.0	11.3	3.1	7.6	619.2
EUR	0	0	46.5	100	100	100	100	99.6	45.8	0	0	0	
RET	34.1	58	39.2	26.3	22	25	38.8	50.4	87.7	57.1	3.1	7.6	449.3
Ad	76	16.9	0	0	0	0	0	0	0	65.8	153.8	145.4	457.9
Sp	0	0	0	21.5	68.5	48.4	31.3	0	0	0	0	0	169.7

Table 19: Thornthwaite water balance (El Harrouch Station (1975/76-2023/24))

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Mean /Total
T(°C)	23.6	20.8	16.4	13.8	12.3	12.7	13.9	15.7	18.6	22.1	25.1	25.7	18.4
i	10.5	8.7	6	4.7	3.9	4.1	4.7	5.7	7.3	9.5	11.5	11.9	
k	1.05	0.91	0.75	0.7	0.73	0.78	1.02	1.05	1.32	1.33	1.33	1.24	
PETc	110.1	74.9	39.2	26.3	22	25	38.8	50.4	87.7	123	156.9	153	907.3

P(mm)	36.8	52.0	78.1	93.5	83.6	71.2	69.5	50.8	38.1	13.4	2.8	7.8	597.6
EUR	0	0	38.9	100	100	100	100	100	50.4	0	0	0	
RET	36.8	52	39.2	26.3	22	25	38.8	50.4	87.7	63.8	2.8	7.8	452.6
Ad	73.3	22.9	0	0	0	0	0	0	0	59.2	154.1	145.2	454.7
Sp	0	0	0	6.2	61.6	46.2	30.7	0.4	0	0	0	0	145.1

Table 20: Results of the Thornthwaite water balance for the stations of the study

Station	Skikda port	Zerdaza dam	Ramdan djamel	Elharrouch
Precipitation (mm)	747.5	650.3	620.6	597.9
PET (mm)	890	890	890	890
RET(mm)	505	481	468	472
Agricultural deficit (mm)	385	409	422	418
Surplus (mm)	242	168	151	127
Deficit months	June to October	June to October	June to October	June to October
surplus months	December to April	December to April	December to April	December to April
Start of reconstruction of the reserve (DRR)	November	November	November	November
Full reserve	December	December	December	January
Beginning of exhaustion of reserve (BER)	May	May	May	May
Dry reserve	June	June	June	June

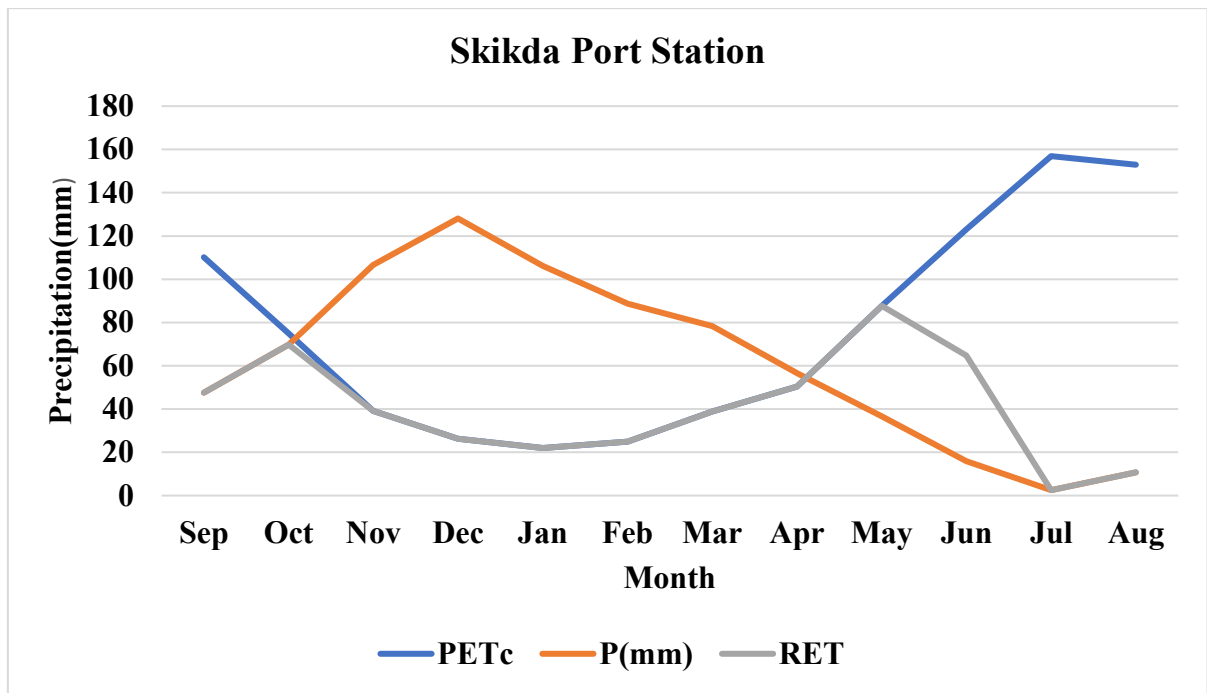


Figure 20: variation in P, PET, and RET (Skikda port station)

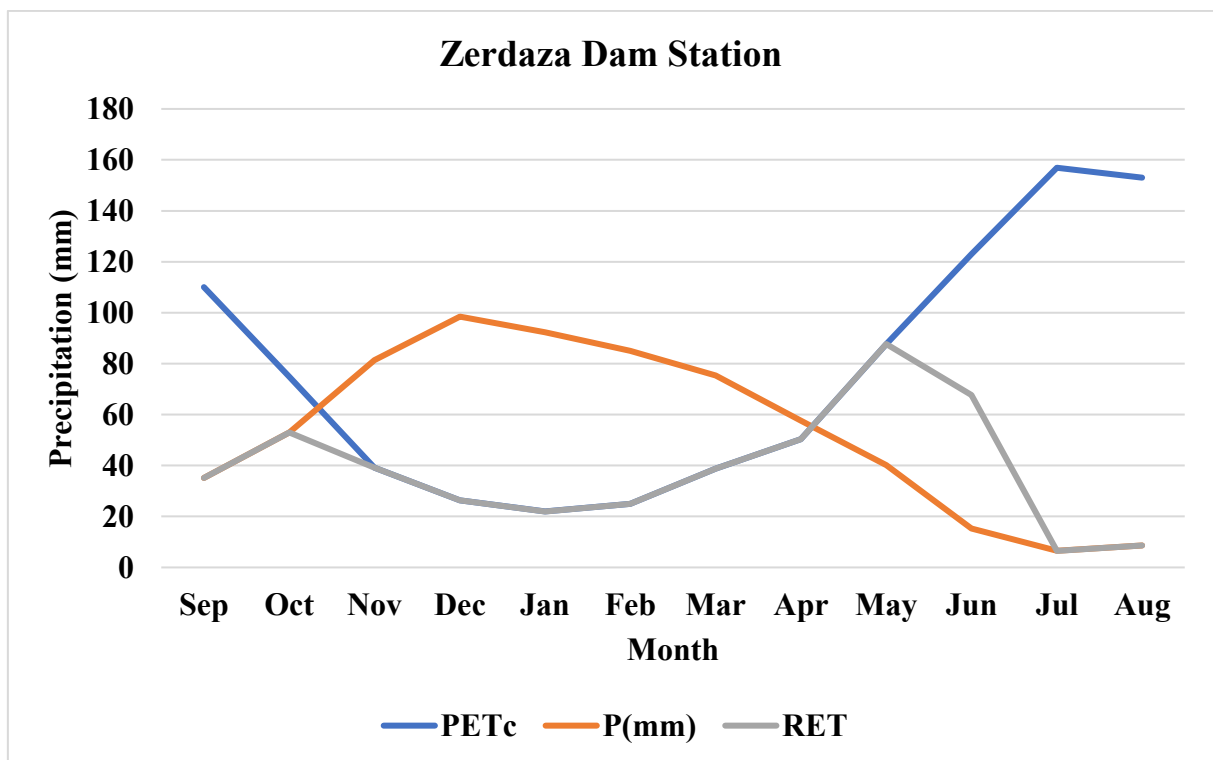


Figure 21: variation in P, PET, and RET (Zerdaza Dam Station)

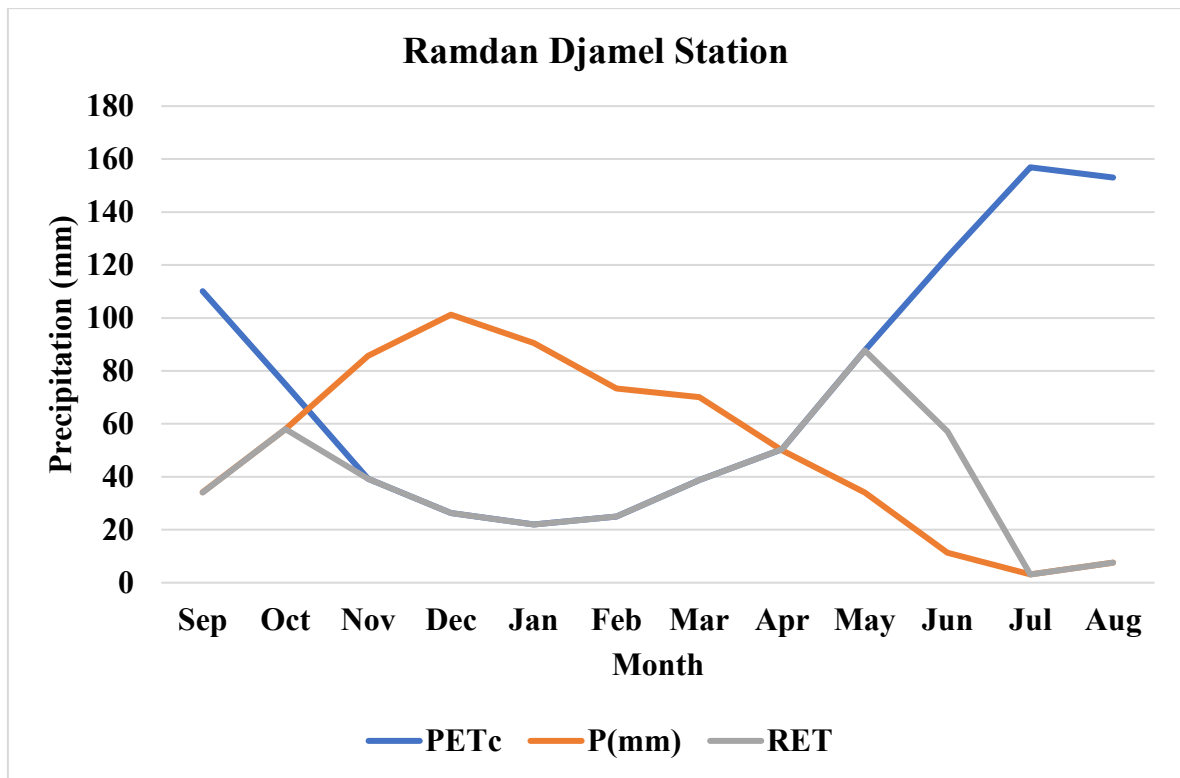


Figure 22: variation in P, PET, and RET (Ramdan Djamel Station)

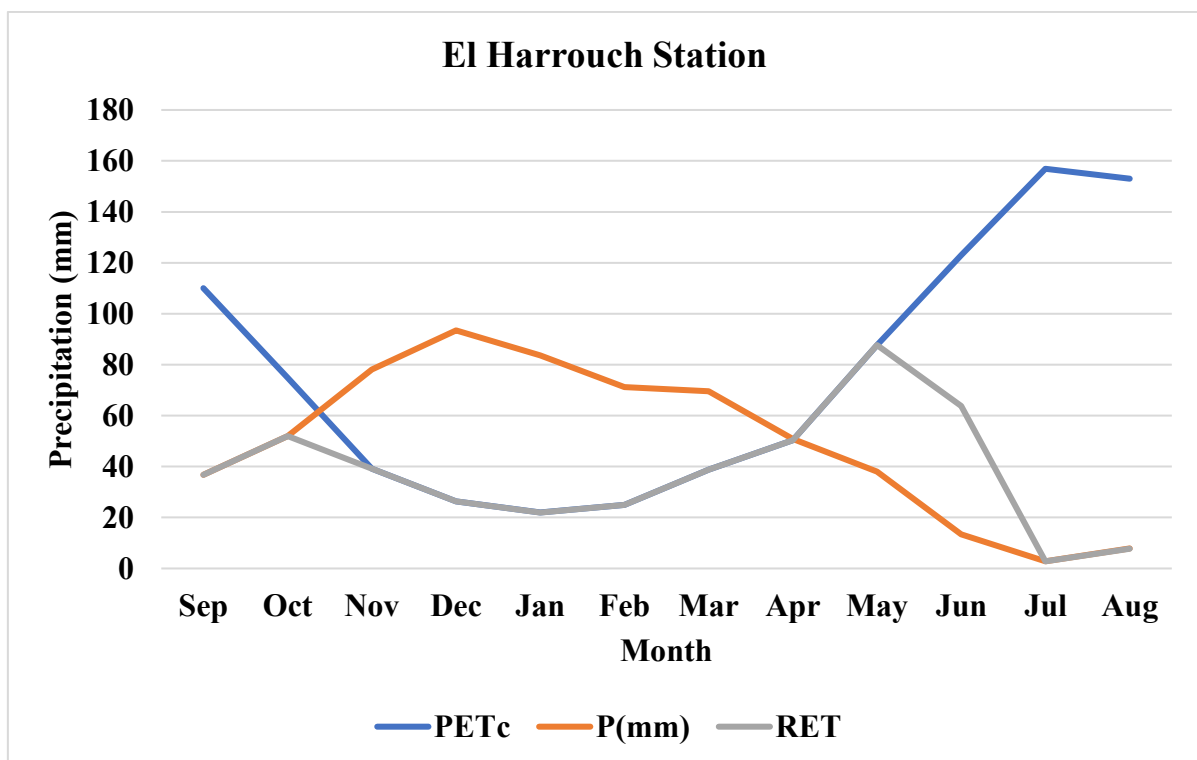


Figure 23 : variation in P, PET, and RET (El Harrouch Station)

The graphical representation of the Thornthwaite water balance for the study stations shows that maximum evapotranspiration was observed in July, with a value of 156.9mm, resulting in an agricultural deficit of between 422.6mm and 457.9mm, necessitating irrigation for the cultivated areas. However, during the months of November through to March, the water table is recharged. When the water table exceeds the EUR, the surplus water is channelled into surface runoff

2.6. Runoff calculation (R)

Runoff is calculated using the Tixeront-Berkaloff formula (1961), which applies to arid and semi-arid zones:

$$R = P^3 / 3(PET)^2$$

Where :

R: runoff (mm)

P: mean annual precipitation (mm)

PET: annual potential evapotranspiration (mm)

Table 21: runoff calculation results

Station	P (mm)	PET (mm)	Runoff (mm)	Runoff(%)
Skikda Port	747.4	907.3	169.06	22.62
Zerdaza Dam	649.2	907.3	110.8	17.1
Ramdan Djamel	619.2	907.3	96.13	15.53
El Harrouch	597.6	907.3	86.42	14.5

2.7. Infiltration calculation (I)

Infiltration is the quantity of water that penetrates the subsoil. This parameter can be estimated using the water balance formula given by the following relationship:

$$P = RET + R + I \longrightarrow I = P - (RET + R)$$

With :

P: Mean annual precipitation (mm)

RET: real evapotranspiration (mm)

R: Annual runoff (mm)

I: Mean annual effective infiltration (mm)

The calculation results are summarized in the table below:

Table 22: infiltration calculation results

Station	P (mm)	RET+R (mm)	Infiltration (mm)	Infiltration (%)
Skikda Port	747.4	680.76	66.61	8.91
Zerdaza Dam	649.2	571.2	78	12.02
Ramdan Djamel	619.2	545.43	73.77	11.914
El Harrouch	597.6	539.02	58.58	9.803

3. Hydrology

The Saf-Saf basin is primarily traversed by the Khémakhem, Bou Adjeb, and Saf-Saf wadis and their tributaries. These wadis contribute significantly to the recharge of groundwater. Unfortunately, this basin is poorly equipped with hydrometric stations; it has only one station, at Khémakhem, monitoring the Zardézas sub-basin, which covers an area of 322 km² (the upstream portion of the Saf-Saf basin). For the remainder (70% of the total watershed), there is in fact no station monitoring the basin's outlet. The hydrometric network is therefore considered very limited, necessitating the use of empirical formulas in the study of the basin's surface runoff. To quantify these inflows, we attempted to analyze the variations in water volumes gauged at the Khémakhem station over 39 years (1973/74–2011/12).

3.1. Annuelle variation

Interannual variations in average annual discharge recorded at the Khémakhem station (1973/74–2011/12). A clear interannual irregularity in absolute average discharge is observed (CV = 83.17%). The interannual modulus is approximately 1.07 m³/s, a value exceeded only 10 times during the entire period. The year 1984/85 set a record with an average annual flow of 4.10 m³/s, as did the year 1986/87 with 2.08 m³/s. Furthermore, this modulus exceeded the annual values 19 times, including the 1996/97 year, which had the lowest average flow (0.04 m³/s).

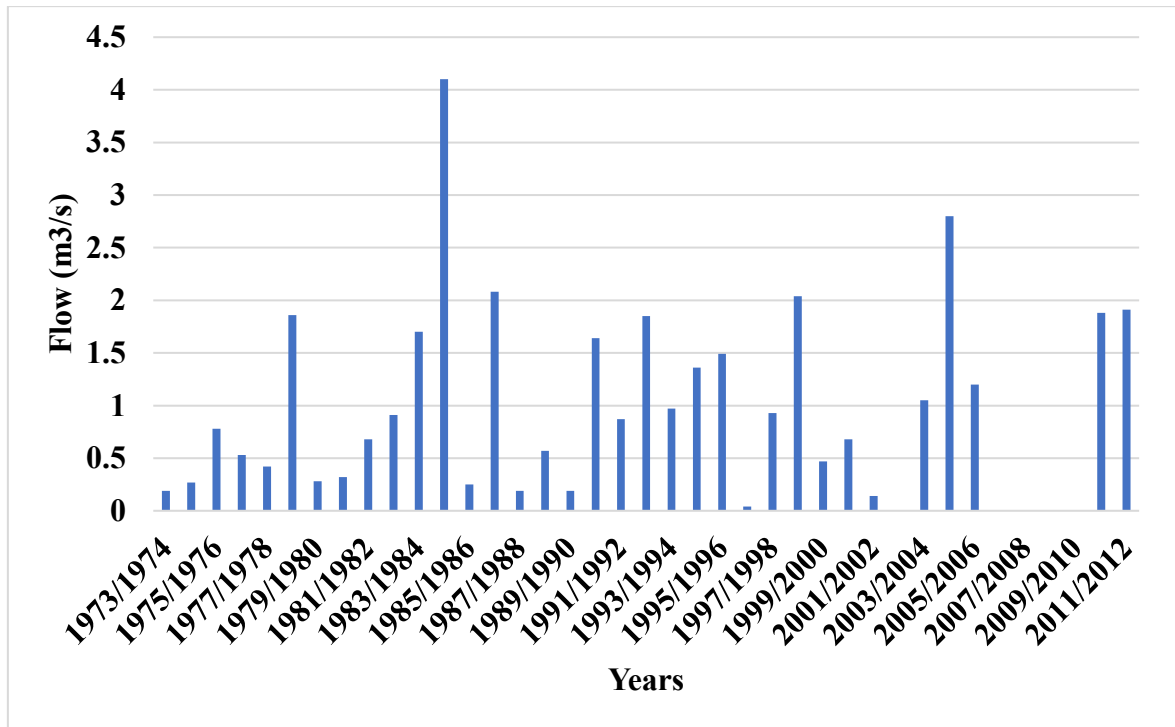


Figure 24 : The annual variation of flow at Khemekhem station (1973/74-20011/12)

3.2. Monthly variation

An analysis of monthly flow rates helps to highlight water flow patterns and their interannual and inter-seasonal variations. To understand average flow patterns, we will attempt to identify the months with the highest surface runoff and their average values.

Indeed, the wet season (winter and spring), running from December to April, has the highest average flow. The average flow regime of the Saf-Saf basin, which is primarily rain-fed, peaks in February ($3.73 \text{ m}^3/\text{s}$), followed by a low in March ($2.11 \text{ m}^3/\text{s}$). However, average flows do not necessarily correspond to maximum flows, where peak flows are concentrated in two peak months: December first ($29.33 \text{ m}^3/\text{s}$) with an interannual maximum of $404.0 \text{ m}^3/\text{s}$ observed in December 1984, followed by February ($24.78 \text{ m}^3/\text{s}$), whose maximum was in 1983–84 ($283.2 \text{ m}^3/\text{s}$), which is, however, the month with the highest average flow.

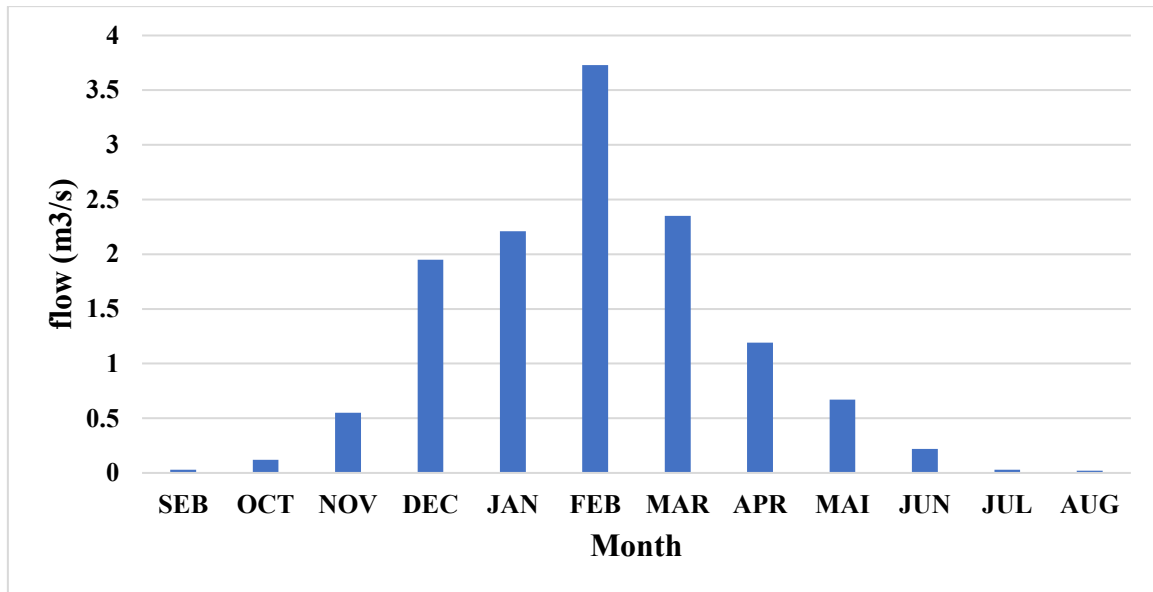


Figure 25: The monthly variation of the flow at the Khemekhem station (1973/74-20011/12)

4. Hydrogeology

The hydrogeological study serves to supplement and confirm the findings previously established by the geological survey.

Therefore, this study is necessary to gain a thorough understanding of the aquifer zones and their hydrodynamic characteristics.

This study is based on data from pumping tests and measurements of the piezometric level in boreholes, provided by the DHW in Skikda and the ANRH in Constantine.

4.1. Aquifer horizons

The geological and geophysical survey conducted in the study area identified three distinct aquifers: a porous aquifer (from the Quaternary and Tertiary periods), a karst aquifer, and a dual-system aquifer. The superimposition of these three horizons results in several groundwater bodies that represent the different types of aquifers found in the region.

4.1.1. Porous aquifer

It is characterized by unconsolidated loose rock (gravel, sand, sandstone, conglomerate, etc.). These formations allow water to pass through. In our case, there are two porous aquifers, the Quaternary and the Tertiary, each of which can form a significant aquifer by using the metamorphic rocks or black clays of the Numidian as a substrate. The thickness of the alluvium varies from one sub-basin to another; in the El Harrouch sub-basin, the alluvium is 5 to 10 m thick (based on a geophysical survey of the area); the same thickness

is observed at Salah Bouchaour. In Ramdane Djamel, it ranges from 15 to 30 m; in contrast, in the Zeramna (El Hadaeïk) sub-basin, the thickness varies from 5 to 15 m. In the Skikda plain (Hamadi Krouma), the gravel layers are very thin. **(F. Khelfaoui, 2014)**

4.1.2. Karst Aquifer

It consists of compact rocks, such as carbonate rocks (limestone, dolomitic limestone, dolomite, etc.). This aquifer may be fissured and fractured due to tectonic activity affecting the region. The karst aquifers in the study area are located in Kef M'Souna, Djebel Tasselment, and Djebel El Ghédir. The karst aquifer may be unconfined in the absence of Tertiary formations. Otherwise, it is confined; Kef M'Souna is a confined karst aquifer due to the presence of black clays forming its cap. **(F. Khelfaoui, 2014)**

4.1.3. Binary aquifer system

It consists of porous rocks (permeable formations: sandstone) overlying compact rocks (limestone: karst formations), with interconnection between the two reservoirs. This interconnection constitutes what is known as a binary system. In our case, the binary system consists of a porous aquifer and a karstic aquifer; the former is composed of sandstone, puddingstone, and conglomerates, with a thickness of 200 m. The second, meanwhile, consists of carbonate formations (nummulite limestone and Lias limestones), with a thickness of approximately 200 m.

The binary (deep) aquifer is almost entirely overburdened, resting on metamorphic formations, and is composed of black clays. In some places, the clays disappear, and the porous shallow aquifer comes into direct contact with the deep aquifer. **(F. Khelfaoui, 2014)**

4.2. Hydrogeological profiles

To better understand the hydrogeological system and to determine the extent of the aquifer formations in the Saf-Saf alluvial plain, hydrogeological and lithological profiles of the boreholes. Parmieux, specifically the one oriented NW-SE in the lower Skikda plain. It reveals the existence of three superimposed aquifers: the first, a shallow aquifer composed mainly of sand, with a thickness varying from 11 to 20 m from north to south. The underlying strata consist, generally speaking, of gravelly marl, with a thickness varying from 35 to 45 m. The flow direction is from north to south, facilitated by a slight slope of the underlying strata. Also note the presence of a 10-meter-thick gravel lens within the underlying strata (SD7).

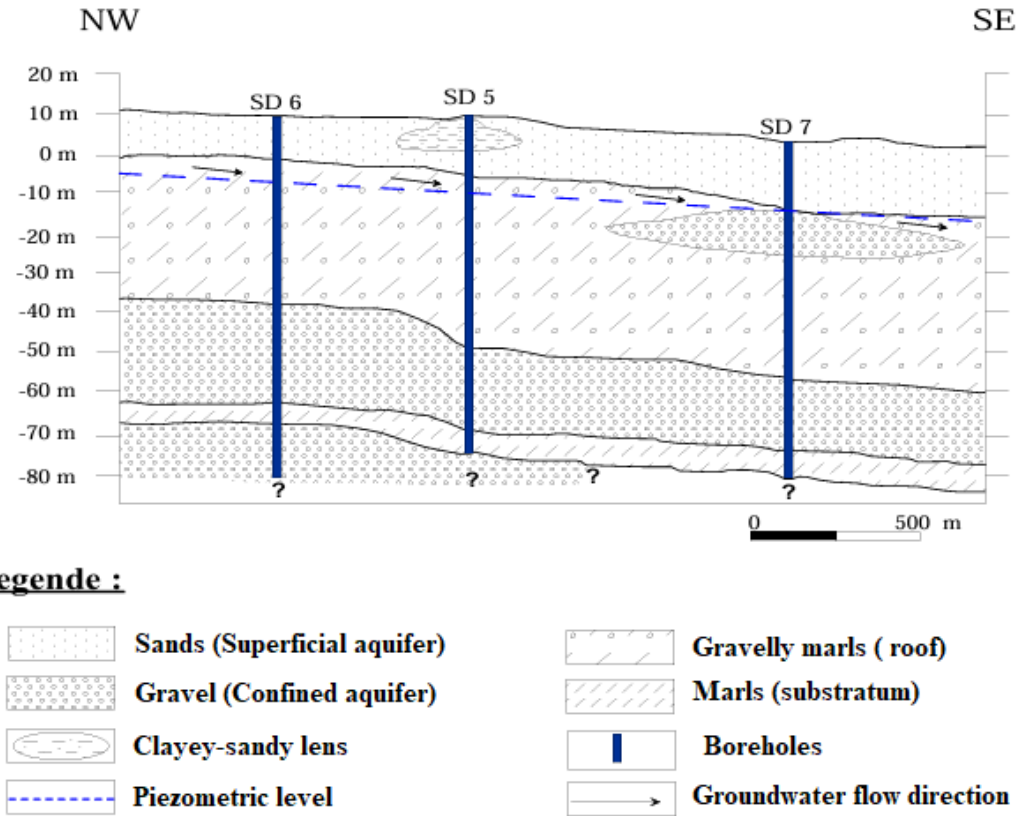


Figure 25: Hydrogeological profile of the aquifer-oriented NW-SE in the lower Skikda plain . (F. Khelfaoui, 2014)

The second aquifer is confined to semi-confined, consisting mainly of gravel, with a thickness ranging from 20 to 30 m from south to north. Its underlying strata (which form the roof of the third aquifer) are thinner than the roof (5 to 10 m) and consist of gray marl. Its extent is visible throughout the cross-section; the dip always follows the trend of the substrate with a slope that decreases from northwest to southeast. The third aquifer is clearly visible in the northwestern part of the plain (the two boreholes SD6 and SD5); the approximate thickness visible in the cross-section is 15 m. In terms of thickness, the most significant aquifer is the second one (gravel layer), followed by the sand aquifer, and finally the third, with a thickness of approximately 5 to 15 m. Regarding hydrodynamic parameters (1), transmissivity ranges from 3×10^{-4} to $1 \times 10^{-2} \text{ m}^2/\text{s}$ with a permeability of approximately 10^{-5} m/s . The total flow rate calculated for the wells and boreholes covering more or less the Saf-Saf basin is 676 l/s. (F. Khelfaoui, 2014)

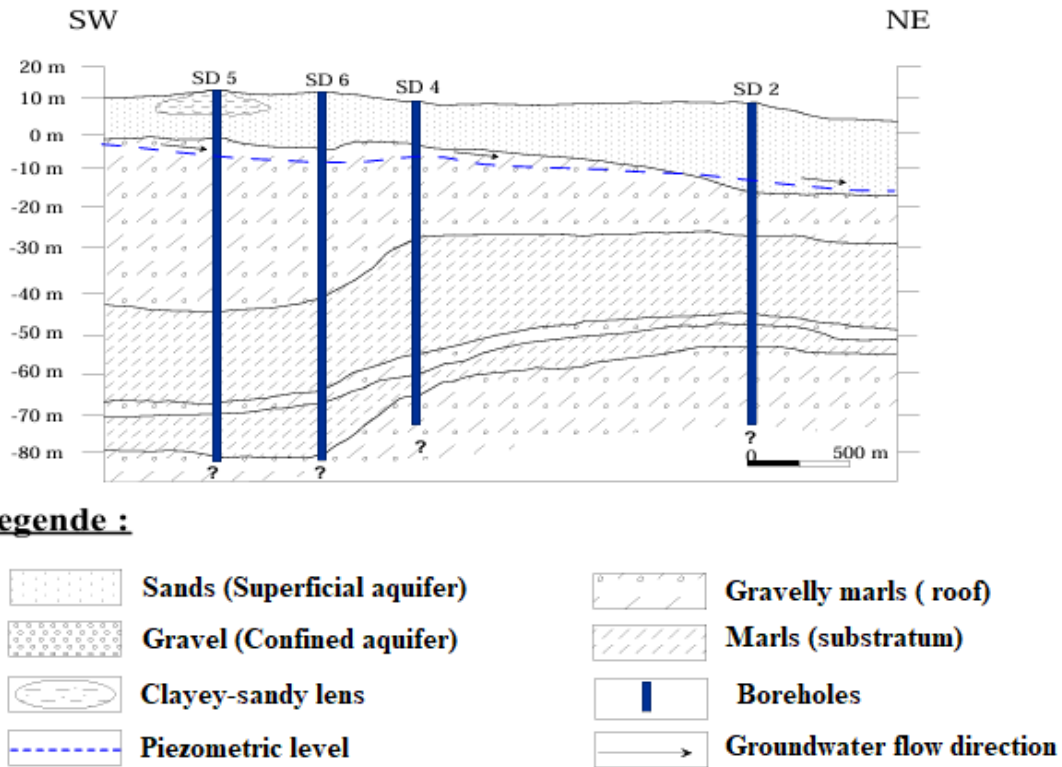


Figure 26: Hydrogeological profile of the aquifer-oriented SW-NE in the lower Skikda plain . (F. Khelfaoui, 2014)

Conclusion

And from a climatic point of view, the study area is characterized by a temperate climate with very cold winters and very hot summers,

-The average annual precipitation ranges from 747.5 mm to 597 mm, depending on the rainfall station used in the study.

- With an average annual temperature of around 18.4 °C.

Calculation of the water balance for the Safsaf basin, using Thornthwaite's method, enabled us to assess the respective share of each of the main terms in the balance (precipitation, runoff, and runoff deficit), leading to the following conclusions:

- The overall balance is in surplus, but there is a deficit from June to October.

-Real evapotranspiration at the 4 stations is between 484.7 mm/year and 449.3 mm/year, giving an average of 360 mm/year of precipitation.

Chapter 3 _____ Hydroclimatology, Hydrology, and Hydrogeology

- The agricultural deficit is high, between 422 mm and 458 mm, while interannual recharge is relatively low, necessitating drainage irrigation.
- Runoff is between 169 mm and 86.42 mm, an average of 17.44% of precipitation.
- Infiltration is between 58 mm/year and 78 mm/year.

Chapter 4
Irrigation perimeter
presentation

Introduction

In Algeria, where climatic conditions are characterised by low rainfall and poor regional distribution, irrigation is essential to ensure regular agricultural production in sufficient quantity.

An irrigation perimeter is an agricultural area specifically designed to manage and control water distribution effectively. The Safsaf perimeter, located in the wilaya of Skikda, is characterized by its reliance on the Zerdazas dam and the Oued de Safsaf as key irrigation water resources.

To determine suitable agricultural land within the Safsaf catchment area, the AHP (Analytic Hierarchy Process) method can be employed. This decision-support approach involves evaluating multiple criteria, such as altitude, slope, soil type, humidity, and proximity to water sources, by assigning them relative importance. The collected spatial data can be processed using a Geographic Information System (GIS) like ArcMap, ultimately creating an agricultural land suitability map that indicates the most favorable areas for agricultural development.

1. Presentation of the Safsaf-Skikda perimeter

The Safsaf perimeter is located in the wilaya of Skikda, spread over the communes of Skikda, Hammadi Krouma, Ramdan Djamel, Salah Bouchaour, Emdjez edchiche, and El-harrouche, covering a total area of 5654 ha.

The Emdjez edchiche IV sector was commissioned in 1991, the Elharrouch III sector in 1996, and the Salah Bouchaour II sector in 2004. Sector I of Skikda had a water supply problem from the Zerdaza dam, which was recommissioned in 2009. **(NIDO,2023)**

The Safsaf perimeter is divided into 4 sectors with a total surface area of 5,654 ha, equipped according to the following table:

Table 23: the various sectors of the Safsaf irrigation perimeter (2023)

Sector	Area (ha)		Location
	Equipped	Irrigable	
Sector I	1720	1600	Ramdan Djamel
sector II	1591	1428	Salah Bouchaour

sector III	1023	832	El Harrouche
sector IV	1320	1240	Emgjez Edchiche
Total	5654	5100	/

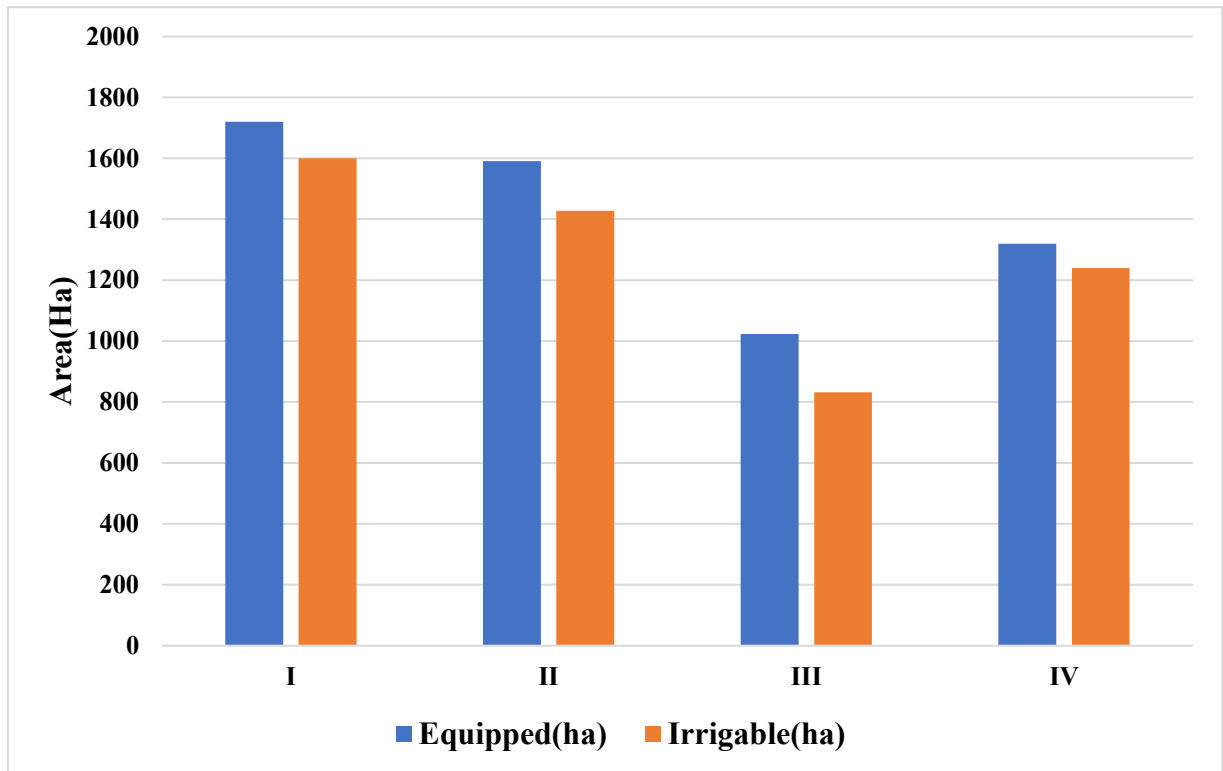


Figure 27: Changes in the surface area of the different sectors of the Safsaf perimeter

1.1. Water resources and requirements

The supply of irrigation water to the perimeter sectors is ensured from the Guenitra and zerdaza dam. The volume that can be regulated from Guenitra is 47 hm³, and that from Zerdaza is 18 hm³.

These regulable volumes are intended for irrigation of the perimeters and for supplying drinking water to the city of Skikda and the industrial zone. (NIDO,2023)

The water needs of the perimeter and the AEP of Skikda from the 2 dams are given in the following table:

Table 24: Water needs of irrigation and the drinking water supply in the Safsaf watershed

Dam	Drink water(hm ³)	Irrigation water (hm ³)				Total (hm ³)
		Sec 1	Sec 2	Sec 3	Sec 4	
Guenitra	31.35	/	7.5	/	8.15	47
Zerdaza	/	10.5	2.1	5.4	/	18

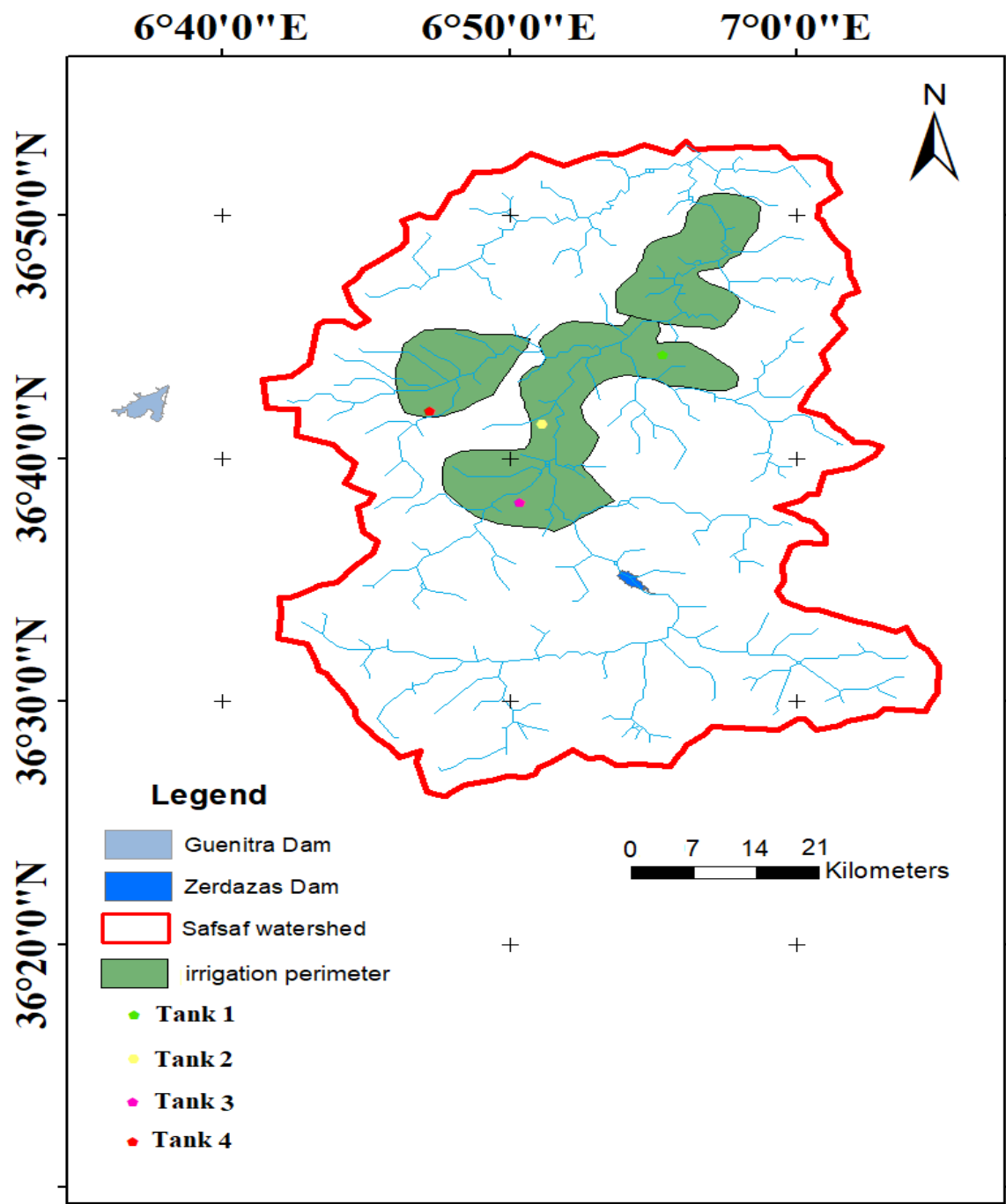


Figure 28: The situation of the Saf-Saf perimeter of irrigation sectors

in the sectors of Elharrouche (22,000 m³) and Skikda (30,000 m³) will be supplied by gravity from the Zerdaza dam. (NIDO,2023)

Table 27: Channelling and equipping the safsaf perimeter

	Linear pipe(ml)				Hydromechanical equipment			
	Cement	Cast iron	Concrete	Steel	Terminals	Suction Cup	Valve	Drain
SEC 1	15907	9451	2940	5225	87	52	22	55
SEC 2	20330	10259	6472	5008	111	56	24	52
SEC 3	11385	8861	7339	1256	58	66	22	43
SEC 4	15166	11449	922	294	101	60	24	60
water supply Guenitra	/	/	18765	7445	/	41	8	10
water supply Zerdaza	/	/	2180	6545	/	19	3	19
Total	62788	40020	38618	25773	357	294	103	239

1.3. Practical crop rotation within the perimeter

According to the agro-pedological study carried out by the Spanish consultancy INTECS in 1976, A, B, C, and F crop rotations were established for each sector:

Table 28: Practical crop in the Safsaf perimeter

	Crop rotation				Total area(ha)
	A	B	C	F	
Sector I	467	180	349	724	1720
Sector II	635	190	60	706	1591
Sector III	691	129	105	98	1023
Sector IV	792	/	385	143	1320

Crop rotation A: Vegetables, beetroot, cotton, and oat vetch

Crop rotation B: Vegetable crops, alfalfa

Crop rotation C: Grain maize, Market gardening, Alfalfa

Crop rotation F: Fruit trees

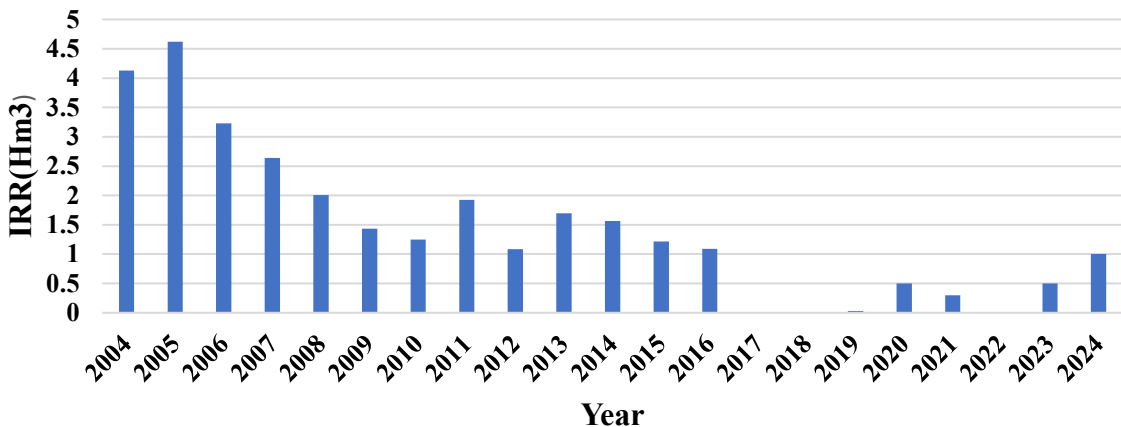


Figure 30: status of irrigation water volumes from the Zerdazas dam (2004/2024)

1.6. Suitability for irrigation

The Saf-Saf Wadi is the main watercourse in the basin; the quality of its water varies spatially from upstream to downstream and temporally with the seasons (high and low water). To fully understand the evolution of water quality in the Saf-Saf Wadi, we considered the results of chemical analyses conducted in 2009 by the National Agency for Water Resources (NAWR) in Constantine, as well as those conducted in 2012 by the Laboratory of Marine Studies (LEM Algiers).

The dam's water is used for irrigation; for this reason, we are required to classify this water using the Wilcox diagram.

On the Wilcox diagram, the water quality classes for the 14 years under study can be distinguished. For the years 2000 through 2003 and 2005 through 2013, electrical conductivity ranges between 250 and 750 $\mu\text{S}/\text{cm}$. This explains why the water is classified as good quality. Unlike in 2004, when conductivity exceeded 750 $\mu\text{S}/\text{cm}$ (950 $\mu\text{S}/\text{cm}$), the water is therefore of acceptable quality. **(F. Khelfaoui, 2014)**

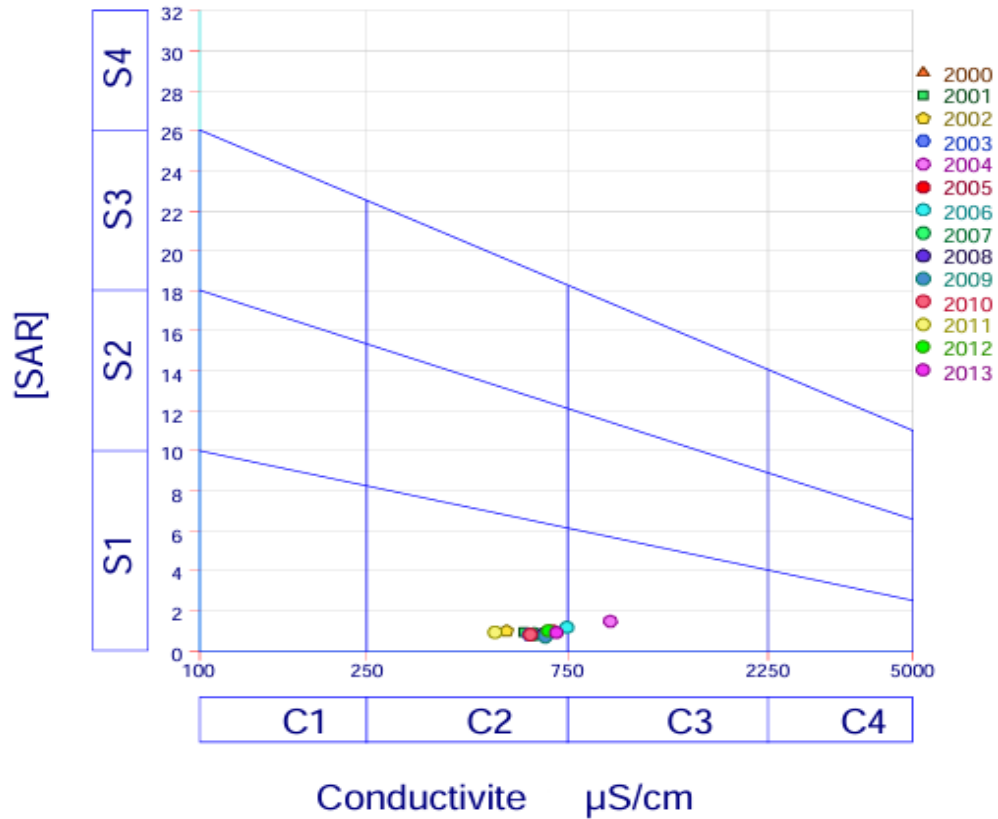


Figure 31: Wilcox diagram, the water quality classes for the Zeradaza dam

1.7. Evolution of Modes of Irrigation

Adequate water supply is essential for crop growth and development. When rainfall is insufficient, irrigation may be necessary to cover crop water requirements. There are currently several irrigation methods for supplying water to crops. Each method has its advantages and disadvantages, which need to be taken into account when selecting the method best suited to local conditions. **(Brouwer, C.1990)**

The following fig present a design of an irrigation network with :

(a) is supply pump, (b) is a pressure regulator and pressure relive valve, (c) is air release valve, (d) is water meter, (e) is one way valve or a non-return valve, (f) is an injection tank, (g) pressure guage, (h) is a filtration unit, (i) is a manifold and electric valves, (j) is an irrigation controller, (IZ1, IZ2) are irrigation zone 1 and 2 irrigation crops with different water needs

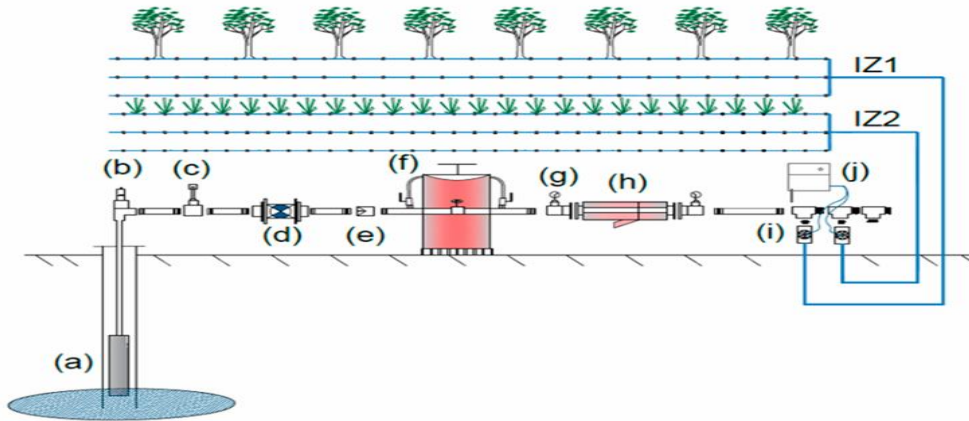


Figure 32: Irrigation distribution network design (Nikolaou, G et al. 2020)

Irrigating large areas, or irrigation perimeters, requires more sophisticated irrigation methods. The three techniques used in the Safsaf perimeter are :

1.7.1. Gravity irrigation

Surface irrigation covers all irrigation techniques where the water available at the head of the plot is distributed over the land to be irrigated by a surface gravity flow requiring only appropriate soil management. The various surface irrigation techniques are generally classified into three main groups: submersion irrigation (flooding), trickle irrigation (spilling), and infiltration gutter irrigation.



Figure 33: image of flooding irrigation

1.7.2. Sprinkler irrigation

Sprinkler irrigation involves supplying the water needed by crops in a form similar to natural rainfall. The water is put under pressure, generally by pumping, and then distributed

through a network of pipes. The water is distributed by means of spray bars fitted with sprinklers. The water emerges in the form of a jet and is distributed in droplets that fall to the ground. The choice of pumping system, sprinklers, and water management must ensure that the irrigation water is distributed evenly.



Figure 34: image of sprinkler irrigation

1.7.3. Drip irrigation

Drip irrigation, also known as micro-irrigation, involves delivering water in drops to the surface of the soil at a low dose (2-20 litres per hour). The water is channelled through plastic pipes fitted with holes called drippers. The water is delivered to the immediate vicinity of the plant so that wetting is limited to the root zone of the soil. This is a more efficient use of water than with surface or sprinkler irrigation, where the entire subsoil of the plant is wetted. With drip irrigation, the frequency of watering is greater than with other methods (usually every 1 to 3 days), which maintains a high level of soil moisture, favourable to crop growth.

According to the table, gravity-fed irrigation was used to irrigate 146.5 ha in 2020, 167.28 ha in 2021, and 241.65 ha in 2022, while aspersion irrigation was used to irrigate 147 ha, 141.41 ha, and 395 ha. 07 ha for 2020, 2021, and 2022, respectively. Finally, there is the drip irrigation method, which started to be used in the perimeter from 2021. An area of 15.25 ha was irrigated, and in 2021, an area of 84.39 ha was irrigated.

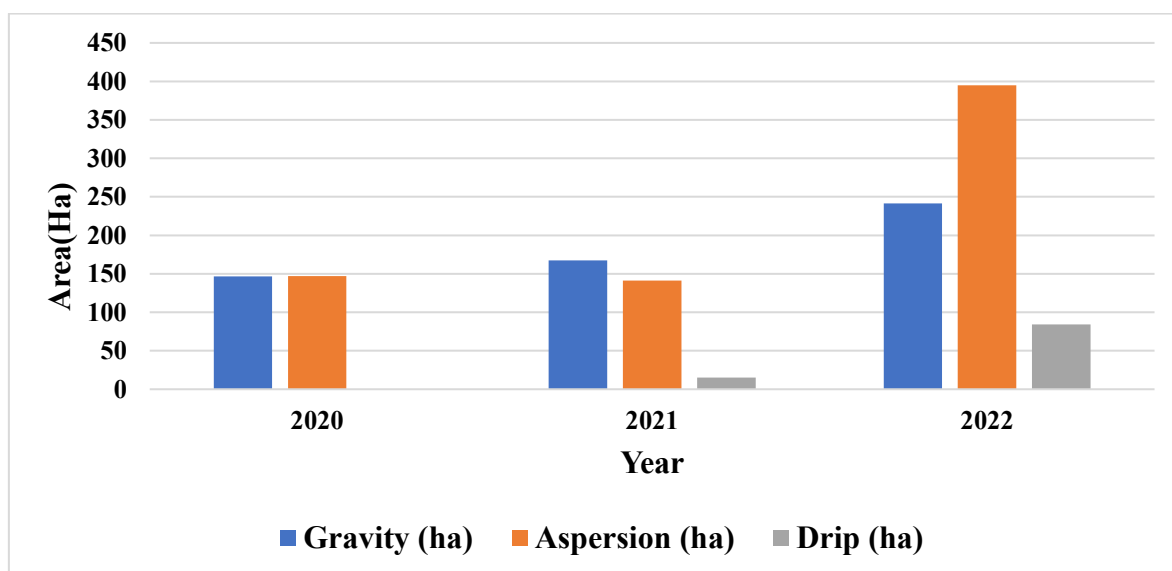


Figure 36: variation in irrigated area by irrigation method

1.8. Area irrigated by irrigation method and crop

The following table shows the areas irrigated within the Safsaf perimeter in the years 2020, 2021, and 2022, along with the irrigation method used and the type of crop in each area. (NIDO,2023)

Table 32 shows the areas irrigated in the safsaf perimeter with the type of crop

Perimeter	Year	Irrigation method	Irrigated areas (ha)										Total
			Tree crops		Fodder		Vegetable crops		Industrial crops		Cereals		
			Area (ha)	Rate %	Area (ha)	Rate %	Area (ha)	Rate %	Area (ha)	Rate %	Area (ha)	Rate %	
Saf Saf	2020	Gravity	146.5	0%	0	0	0	0%	0	0%	0	0	146.5
		Aspersion	0	0	0	0	147	100%	0	0	0	0	147
		Drip	0	0%	0	0	0	0%	0	0%	0	0	0
	S/ Total		146.5	50%	0	0	147	50%	0	0%	0	0%	293.5
	2021	Gravity	167.28	100%	0	0%	0	0%	0	0%	0	0%	167.28

1.10. Impact of climate change on the irrigation systems

Over the past century, the repercussions of climate change have been manifested across various aspects of human existence, critically influencing agricultural productivity. Investment in collective pressurized irrigation infrastructure has markedly augmented agricultural production, yielding beneficial effects on both the rural economy and the sustainability of local livelihoods. Nevertheless, the observed climatic trends and intensified agricultural practices present substantial threats to the sustainability of irrigated agriculture. Projections indicate that by 2025, one in four people globally may confront extreme water scarcity. **(Daccache, A., & Lamaddalena, N. 2010)**

The implementation of pressurized irrigation systems, in conjunction with well-designed irrigation schedules, has the potential to substantially enhance water productivity—defined as the yield of agricultural products relative to the volume of water utilized—while concurrently minimizing water losses due to evaporation and inefficiencies inherent in traditional surface irrigation methodologies. In regions characterized by scarce water resources, the complexity of irrigation management is frequently aggravated. Innovative practices such as deficit irrigation and the utilization of alternative water sources, including treated wastewater and brackish groundwater, have emerged as vital strategies in mitigating the impacts of climate change and addressing the challenges of water poverty. (Nikolaou, G et al. 2020)

The efficacy of irrigation networks represents a pivotal determinant of crop yield and the advancement of sustainable agricultural practices. As these systems are typically engineered according to regional climatic conditions and prevailing crop patterns, they exhibit vulnerability to the alterations induced by climate change. Efficiency, in a broad sense, is defined as the ratio of materials recovered to those introduced within a specified domain. In the context of irrigation efficiency (EI), this is specifically quantified by dividing the volume of water beneficially used for crop production by the initial volume of water supplied to the agricultural field. Assessing the efficiency of different irrigation techniques facilitates improved water management practices (Hsiao et al., 2007). To evaluate water consumption for a specific crop, this efficiency metric is further correlated with agronomic productivity, expressed as the ratio of the harvested yield to the volume of water effectively utilized (Van Halsema and Vincent, 2012).

Implementing advanced irrigation practices that demonstrate resilience to climate change will be instrumental in ensuring adequate food and water supplies, enhancing livelihoods, fostering economic growth, generating employment, reducing greenhouse gas emissions, and bolstering resilience against climate-driven disruptions. In light of the challenges presented by climate change and drought, exemplified by alarmingly low surface water levels in reservoirs and valleys, it is increasingly critical to adopt more efficient irrigation methodologies. (Dehghan, Z et al. 2019).

Moreover, the upward trend in population density intensifies the demand for agricultural products, as evidenced by data presented in prior analyses. Given these circumstances, drip irrigation emerges as an optimal approach for conserving water while concurrently achieving significant agricultural yields. This approach minimizes water wastage by delivering water directly to plant roots in controlled quantities, thereby not only enhancing water utilization efficiency but also promoting healthier crop growth.

In comparison to alternative irrigation strategies, drip irrigation offers numerous advantages, including reduced evaporation losses, diminished weed proliferation, and the capacity to apply fertilizers directly to the root zone, thus maximizing overall productivity. The implementation of drip irrigation systems within the Safsaf perimeter could substantially alleviate the ramifications of water scarcity, bolster sustainable agricultural practices, and fulfill the increasingly pressing food demands of a growing population

2. Geographical suitability of agricultural land modelling using the AHP method

Multi-criteria site suitability modelling was developed to identify suitable and potential locations for agricultural development, based on a range of constraints and criteria. Nine different constraints and criteria were selected based on their importance to agriculture. The identification of these criteria was based on the maximum limitation method that influences agricultural yield, including geology, soil type, altitude, slope, aspect, distance from roads, etc.

2.1. Criteria of the study

2.1.1. Geology

Geology is an important parameter that plays a role in determining whether a piece of land is suitable for agriculture, as it influences several fundamental characteristics of the soil and terrain.

The rocks that underlie the land influence the chemical composition of the soil that forms there and also determine the depth of useful soil. For example, in areas where the rocks outcrop or are close to the surface, the depth of cultivable soil is reduced, especially for the roots of deep crops.

The Geology map was derived using the digitalisation of the geological map of Villa (carte structurale au 1/500000 de la chaîne alpine d'Algérie orientale et des confins algéro-tunisiens)

As shown in the figure, the study area is characterised by variations in geological formations, including metamorphic rocks (gneiss, schist), sandstone and conglomerate with marl and clay (flysch), limestone and dolomite in the limestone chain, and quaternary formations of sand and alluvium in the centre of the basin.

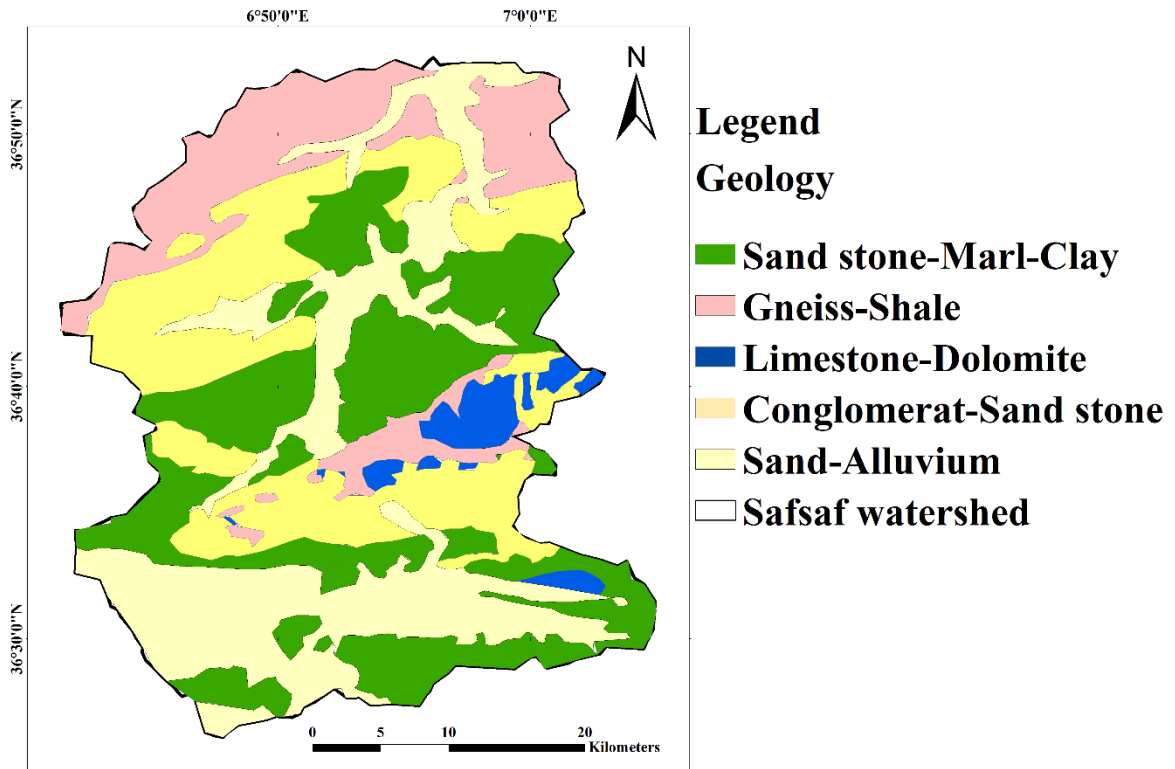


Figure 37: Geology map of the study area

2.1.2. Soil type

Soil type has its own specific criteria that are essential for assessing. Whether a soil is suitable for agriculture or not, for example

Texture depends on the proportions of Leman sand and clay, which influences water retention because clayey soils retain a lot of water, and sandy soils lose water quickly. Alteration of roots and ease of working the soil, as well as the depth of the soil, allow good root development, or limit crops and productivity.

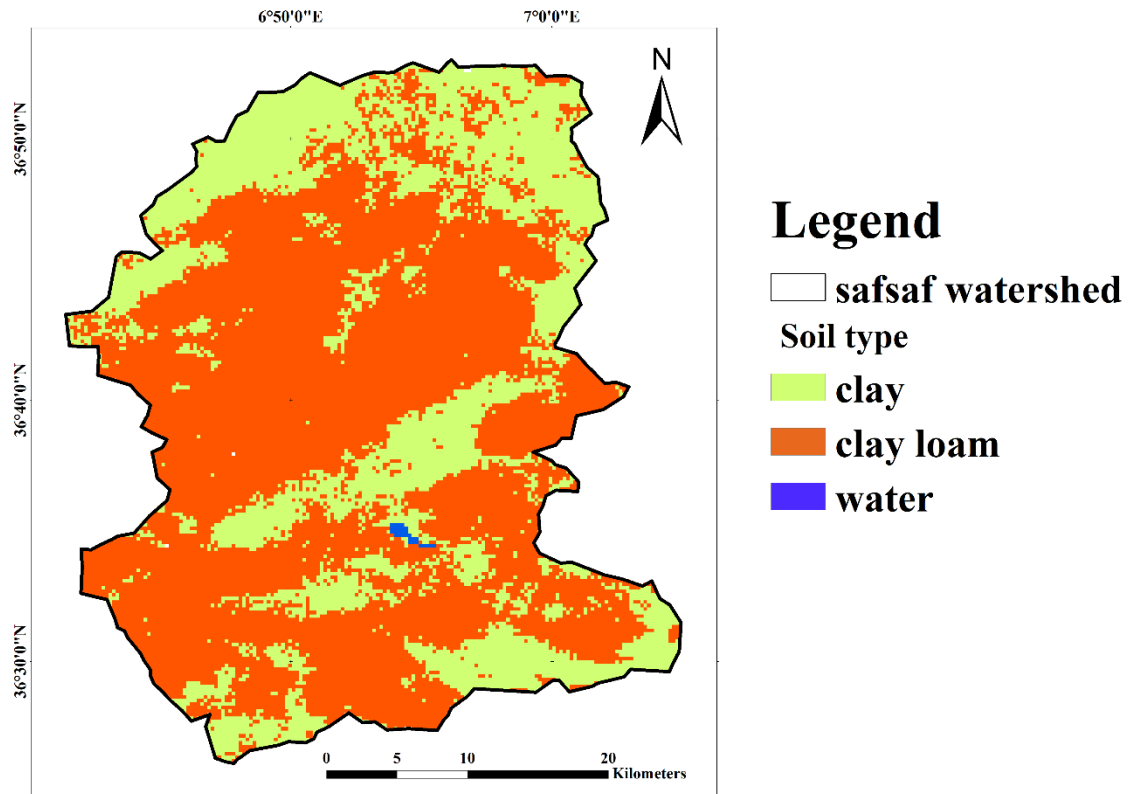


Figure 38: Soil map of the study area

2.1.3. LULC

Land cover is what physically covers the surface of the land (forest, body of water, etc.), and land use is how humans use this land (agriculture, housing, industry, etc.).

It is important for agricultural suitability because some classes are already favourable for agriculture, while others are less favourable (urban areas, forests, etc.). This automatically excludes non-cultivable areas.

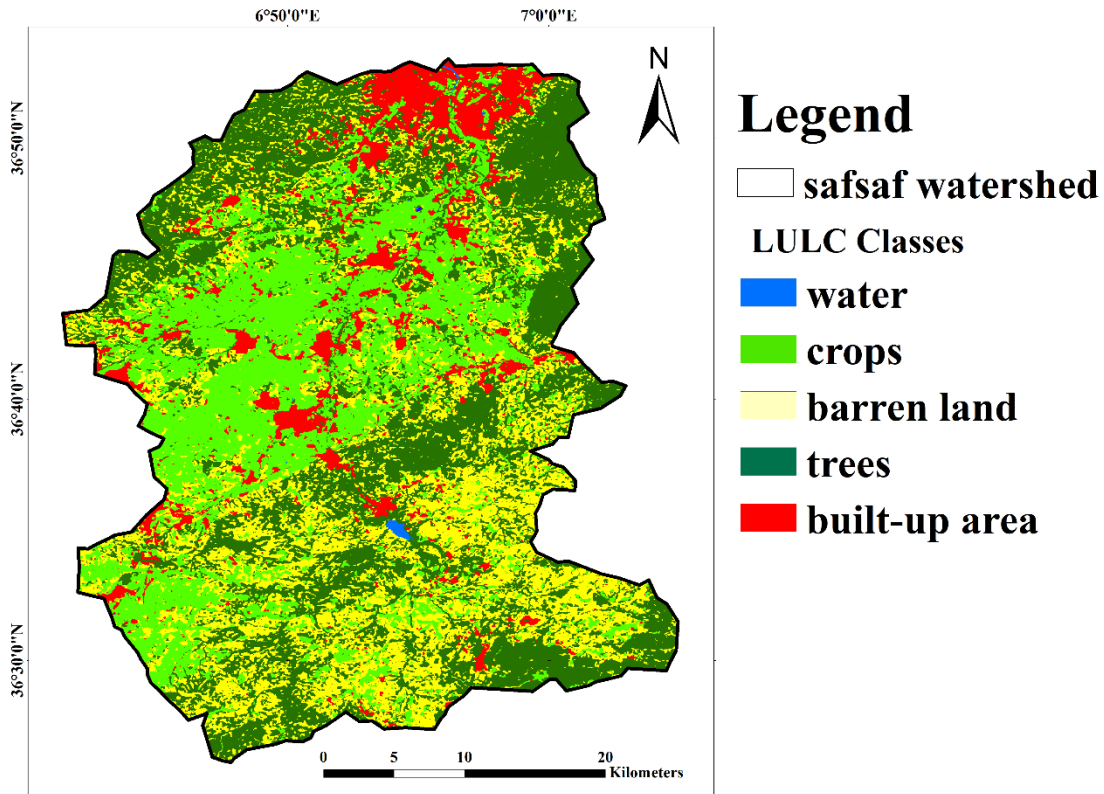


Figure 39: LULC map of the study area

The soil type and LULC maps were extracted using the GEE code editor, the soil map from the open land map soil texture class (USDA system), and the land use land cover map from the Dynamic World Sentinel 2 satellite.

In terms of soil type, the basin is characterised by 2 types: clays in the northern part, a soft clay in the south, and silty clays in the central part of the basin.

The basin is also characterised by 5 different classes: water surface, agriculture, forest, building, and bare land.

2.1.4. Elevation

Altitude influences climatic parameters such as temperature and precipitation because the higher you go, the lower the temperature, and altitude can also increase precipitation. Too much rain on bridges poses a problem of soil erosion because the soil at higher altitudes is generally deeper and more fertile, easier to irrigate, and higher altitudes are less accessible to roads and more difficult to establish farming.

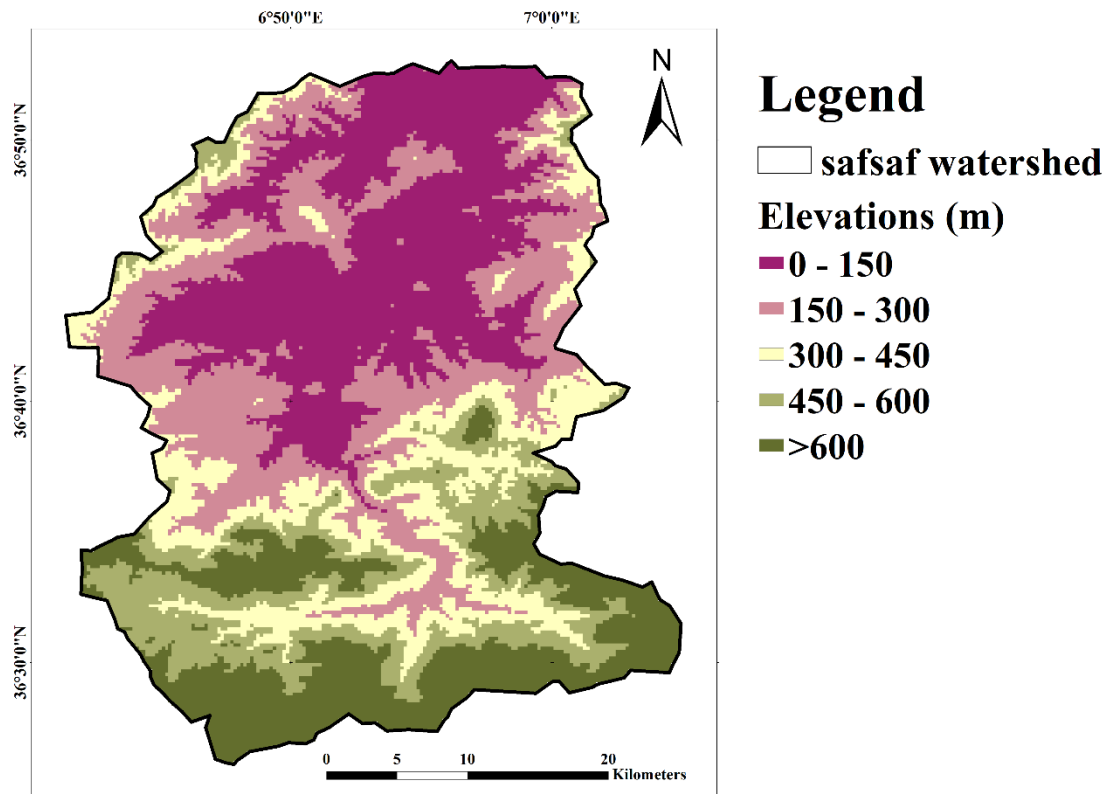


Figure 40: Elevation map of the study area

2.1.5. Slope

The slope is another criterion for assessing the agricultural suitability of a plot of land.

-Erosion: the steeper the slope, the greater the risk of erosion

-Water retention: on steep slopes, rainwater runs off quickly and does not infiltrate; water is lost, and the soil dries out quickly, and the opposite is true for flat land.



☐ **safsaf watershed**

Slope in degree

0 - 5

■ 5 - 10

10 - 15

15 - 20

■ >20

2.1.6. Aspect

80



Elevation, slope, and aspect maps were generated using Shuttle Radar Topography Mission (SRTM) data of 30 m resolution obtained from the United States Geological Survey (USGS), extracted using GEE

2.1.7. Soil moisture

Soil moisture is a parameter used to assess whether a plot of land is suitable for agriculture, as water in the soil is essential for plant growth.

A soil moisture map was prepared using Sentinel 1 satellite images of 10 m spatial resolution.

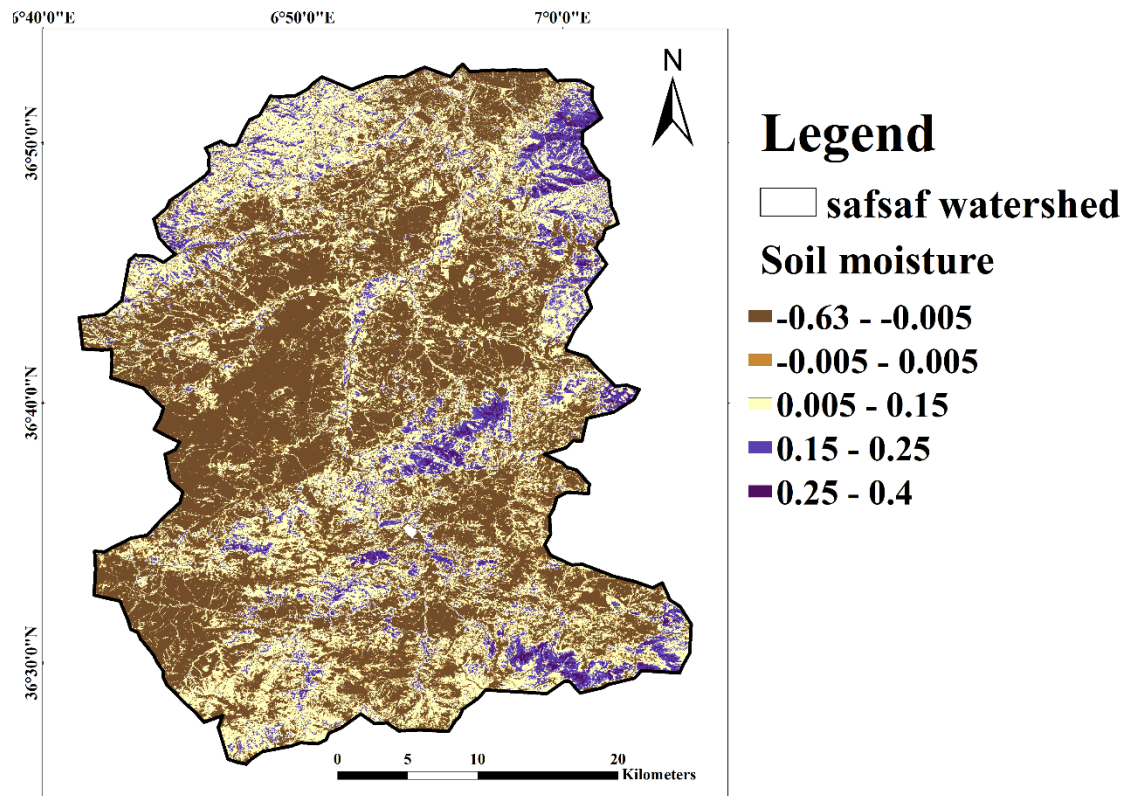


Figure 43: Soil moisture map of the study area

2.1.8. Distance from rivers

Proximity to rivers is important to facilitate the irrigation process and ease of access to water, and also less need for complex infrastructure (pumping and canals), but there is also the risk of flooding and soils being too wet or unstable.

The rivers map was extracted from Shuttle Radar Topography Mission (SRTM) data of 30 m resolution obtained from the United States Geological Survey (USGS)

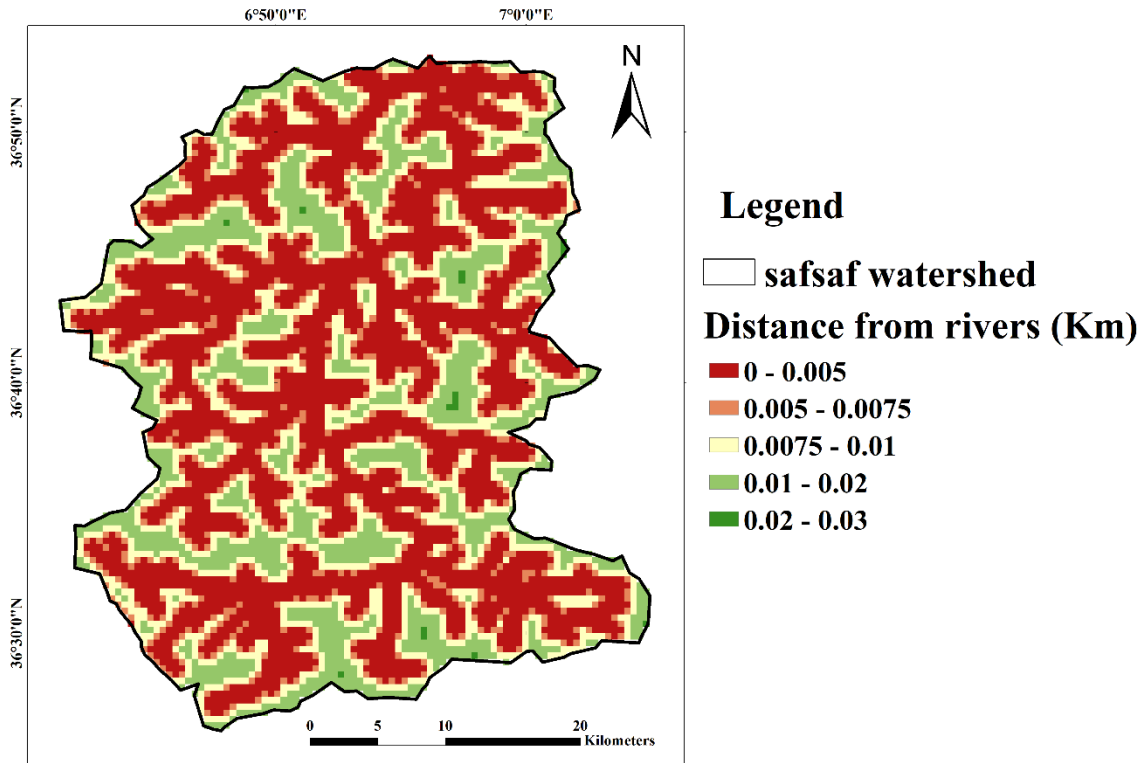


Figure 44: Distance from rivers map of the study area

2.1.9. Distance from roads

The distance to the road is a social and economic criterion in this analysis, especially when aiming for a profitable and accessible farm.

The advantages of land close to a road include reduced transport costs, rapid access to the market, agricultural services, easier labour, and mechanisation. The disadvantages include the problem of pollution, the risk of theft, and the risk of accidents. The road system map was derived using an open street map (BBBike.org).

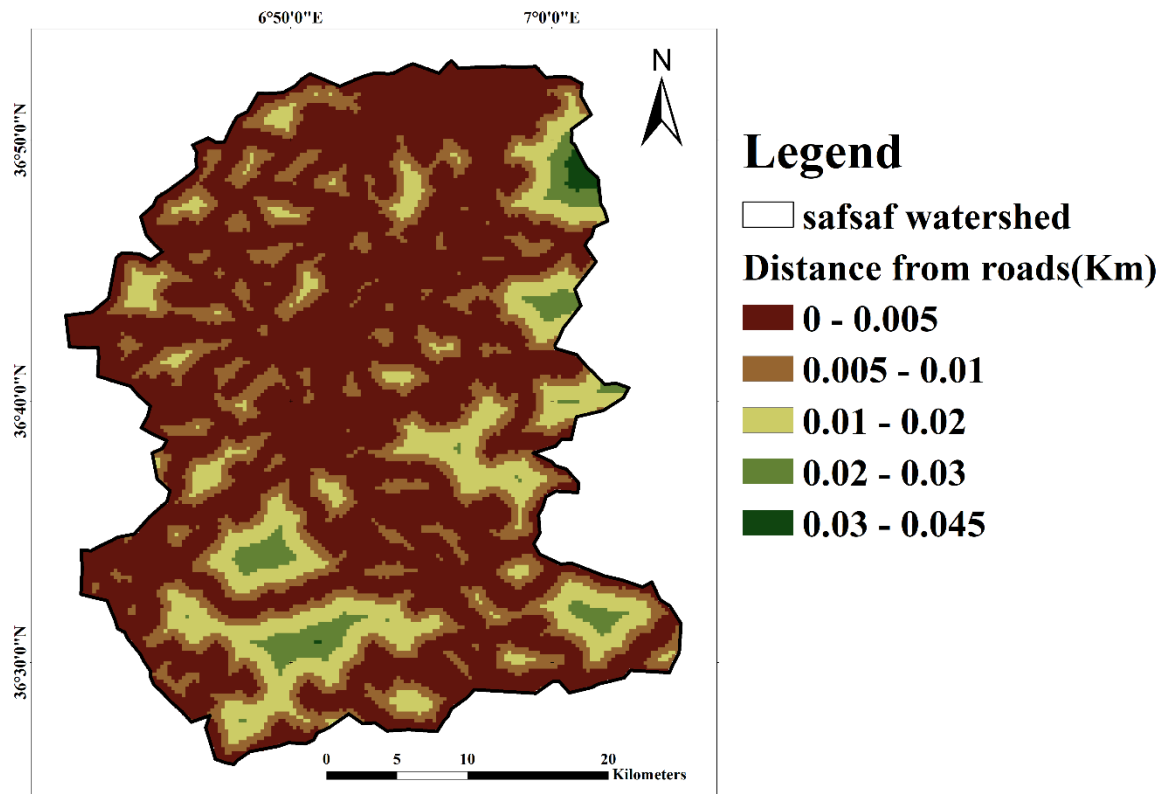


Figure 45: Distance from roads map of the study area

All of the selected criteria are in different units, so to execute the Weighted Overlay Method, they need to be converted to the same units and hence require standardization. Standardization techniques convert the measurement to uniform units, and the resulting scores lose their dimension along with their measurement unit for all criteria (**Effat and Hassan 2013**).

The vector layer of all criteria maps was converted into a raster layer. Subsequently, all raster layers were reclassified and used as input data for the weighted overlay method, which ultimately produces the suitability map for agriculture. The reclassification method, available in the Spatial Analyst toolbox of ArcMap software, standardizes the values of all selected criteria for comparative analysis.

Agriculture depends on good geology and soil types with proper drainage, which are essential for irrigation and transportation. Elevation, slope, and aspect are also crucial factors in determining suitable land for agricultural development. During the analysis of potential agricultural zones, all these parameters were considered. Each parameter was reclassified into five categories. The sub-criteria were ranked on a scale from 1 to 9, with 1 indicating the least significance and 9 indicating the highest significance.

Table 33: criteria and sub-criteria used in the study

Criteria	Sub-Criteria	Criteria	Sub-Criteria	Criteria	Sub-Criteria
Slop (degree)	0_5	Distance from rivers(km)	0_0.005	LULC	Agricultural land
	5_10		0.005_0.0075		water
	10_15		0.0075_0.01		barren land
	15_20		0.01_0.02		built-up area
	>20		0.02_0.04		trees
Elevation (m)	0_150	aspect	Flat_N	Soil moisture	-0.5_-0.005
	150_300		NE_E		-0.005_0.005
	300_450		SE_S		0.005_0.15
	450_600		SW_W		0.15_0.25
	>600		NW_N		0.25_0.4
Geology	Gneiss_Shale	Distance from roads(km)	0_0.005	Soil type	Clay
	Conglomerat_Sandstone		0.005_0.01		Clay loam
	limestone_Dolomite		0.01_0.02		water
	Marl_Clay		0.02_0.03		/
	Sand_Alluvium		0.03_0.045		/

2.2. Calculation of weight for each criterion

The analytic hierarchy process is one of the most significant multicriteria decision-making techniques. The process is applied to a set of criteria or sub-criteria to establish a hierarchical structure by giving the weight of each criterion incomplete decision-making process, the weight value analyzes the relative significance of individual criteria and hence is chosen deliberately. The analytic hierarchy process gives a structural ground for quantifying the strong comparison of design criteria and elements in a pairwise technique and thus decreases the complexity of the decision-making process (Saaty 1977). The process determines the weight values by the pairwise comparison technique by relative significance of the criterion, taken two at a time (Miller et al. 1998)

Using the analytic hierarchy process explained above, the pairwise comparison matrix was calculated using the scale of 1–9, where 9 indicates extreme significance and 1 indicates equal significance between criteria of the matrix shown in Table (Feizizadeh et al. 2014)

Table 34: The fundamental scale for the pairwise comparison matrix (Saaty, 1980)

Importance rank	Definition	Explanation
1	Equal importance	Two criteria enrich equally to the objective criteria
3	Low importance of one over another	Judgments and experience slightly favor one criteria over another
5	Strong or essential importance	Judgments and experience strongly favor
7	Established importance	A criteria is strongly favored and its dominance established in practice
9	Absolute or high importance	The evidence favoring one criteria over another is of the highest probable order of affirmation
2,4,6,8	Intermediate values between the two adjacent importance or judgements	When adjustment is needed

The comparison matrix mainly has the criteria of reciprocity, which is mathematically expressed as $n(n-1)/2$ for n number of components in a pairwise comparison matrix (Saaty 1980).

After the computation of the pairwise matrix, relative weights/eigenvectors are calculated using Saaty's method.

Moreover, the analytic hierarchy process also identifies and calculates the inconsistencies of decision makers, which is one of the significant characteristics (Feizizadeh et al. 2014).

The efficiency criteria of the analytic hierarchy process are estimated by the consistency relationship (CR), which is measured by

$$CR = CI/RI$$

Equation 2 represents the CR, where CI indicates the consistency index, and RI indicates the random index.

Consistency relationship facilitates the determination of possible events and measures logical inconsistencies of the decision maker/judgments.

It represents the likelihood that the matrix judgments were formed randomly. The CR mainly depends on the Consistency Index and Random Index. (Park et al. 2011)

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

This equation indicates the Consistency Index (CI) when $\lambda_{\max}$ is the principal or highest eigenvalue of the computed matrix and n denotes the order of the matrix.

Random Index (RI) is the mean value of the consistency index depending on the computed matrix order given by Saaty (1977), as shown in Table 7. If the value of $CR > 0.10$, then the

weight values of the matrix indicate inconsistencies and the method (AHP) may not give meaningful results (Saaty 1980).

Table 35: The pairwise comparison matrix

Criteria	Slop	Elevation	Geology	LULC	Soil type	Soil moisture	Distance from rivers	Aspect	Distance from roads
Slop	1	2	2	3	3	5	5	8	9
Elevation	0.50	1	3	4	5	6	7	8	9
Geology	0.50	0.33	1	1	2	3	5	7	8
LULC	0.33	0.25	0.33	1	3	5	7	8	7
Soil type	0.33	0.20	0.50	0.33	1	2	3	5	7
Soil moisture	0.20	0.17	0.33	0.20	0.50	1	2	4	5
Distance from rivers	0.20	0.14	0.20	0.14	0.33	0.50	1	4	5
Aspect	0.13	0.13	0.14	0.13	0.20	0.25	0.25	1	0.11
Distance from roads	0.20	0.11	0.13	0.14	0.14	0.20	0.20	0.20	1
Sum	3.39	4.33	7.63	9.94	15.18	22.95	30.45	45.20	51.11

Table 36: The synthesized matrix for multi-criterion decision making

Criteria	Slop	Elevation	Geology	LULC	Soil type	Soil moisture	D from rivers	Aspect	D from roads	Weighted
Slop	0.29	0.46	0.26	0.30	0.20	0.22	0.16	0.18	0.17	0.250
Elevation	0.15	0.23	0.39	0.40	0.33	0.26	0.23	0.18	0.17	0.261
Geology	0.15	0.08	0.13	0.10	0.13	0.13	0.16	0.15	0.15	0.132
LULC	0.10	0.06	0.04	0.10	0.20	0.22	0.23	0.18	0.13	0.140
Soil type	0.10	0.05	0.07	0.03	0.07	0.09	0.10	0.11	0.13	0.082
Soil moisture	0.06	0.04	0.04	0.02	0.03	0.04	0.07	0.09	0.10	0.054
D from rivers	0.06	0.03	0.03	0.01	0.02	0.02	0.03	0.09	0.10	0.044
aspect	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.00	0.017
D from roads	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0.004	0.02	0.018

Table 37: Random inconsistency indices (RI) for n =9

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46

-Maximum eigen value: ($\lambda_{\max}$) = 10.16 - n=9

-Consistency index: $(CI) = (\lambda_{\max} - n)/(n-1) = 0.145$

- Random index: $(RI) = 1.46$

-Consistency ratio : $(CR) = (CI/RI) = 0.0993$

In the present study, the calculated CR was 0.0993, which is under acceptable limits, and the computed weight values are valid. Further, the computed weight values are converted into percentages for weighted overlay analysis (WOA) in GIS, that shown in the Table.

Table 38: Weights of the criteria and scores of the sub-criteria

Criteria	Weighted	influence(%)	Sub-Criteria	score
Slop (degree)	0.250	25.0	0-5	9
			5_10	7
			10_15	5
			15_20	3
			>20	1
Elevation (m)	0.261	26.1	0_150	9
			150_300	7
			300_450	5
			450_600	3
			>600	1
Geology	0.132	13.2	Gneiss_Shale	1
			Conglomerat_Sandstone	2
			limestone_Dolomite	5
			Marl_Clay	7
			Sand_Alluvium	9
LULC	0.140	14.0	Agricultural land	9
			water	1
			barren land	1
			built-up area	1
			trees	1
Soil type	0.082	8.2	Clay loam	9
			Clay	7
			water	1
Soil moisture	0.054	5.4	-0.5_-0.005	1
			-0.005_0.005	3
			0.005_0.15	5
			0.15_0.25	7
			0.25_0.4	9
D from rivers(km)	0.044	4.4	0_0.005	9
			0.005_0.0075	7
			0.075_0.01	5
			0.02_0.02	3
			0.02_0.03	1

5. Permanently Not Suitable for Agricultural Production: This designation applies to land designated for non-agricultural uses or natural vegetation, including forests, wildlife habitats, water bodies, rocky terrain, and conservation areas.

Table 39: The appropriate agricultural area with the suitability level

Suitability level	Suitable area (km ²)	Percentage (%)
Highly suitable agricultural land	362.20	32.04
Moderately suitable agricultural land	221.8	19.62
Marginally suitable agricultural land	267.3	23.65
Currently not suitable for agriculture	218	19.28
Permanently not suitable for agricultural use	61.13	5.41
Total	1130.43	100

According to the generated land suitability map for agriculture, it was determined that 32.04 % (362.20 km²) of the study area be highly suitable for agricultural production, 19.62 % (221.8 km²) is moderately suitable, 23.65 % (267.3 km²) is marginally suitable land, 19.28 % (218 km²) is currently not suitable land for agricultural production, and 5.41 % (61.13 km²) is permanently unsuitable.

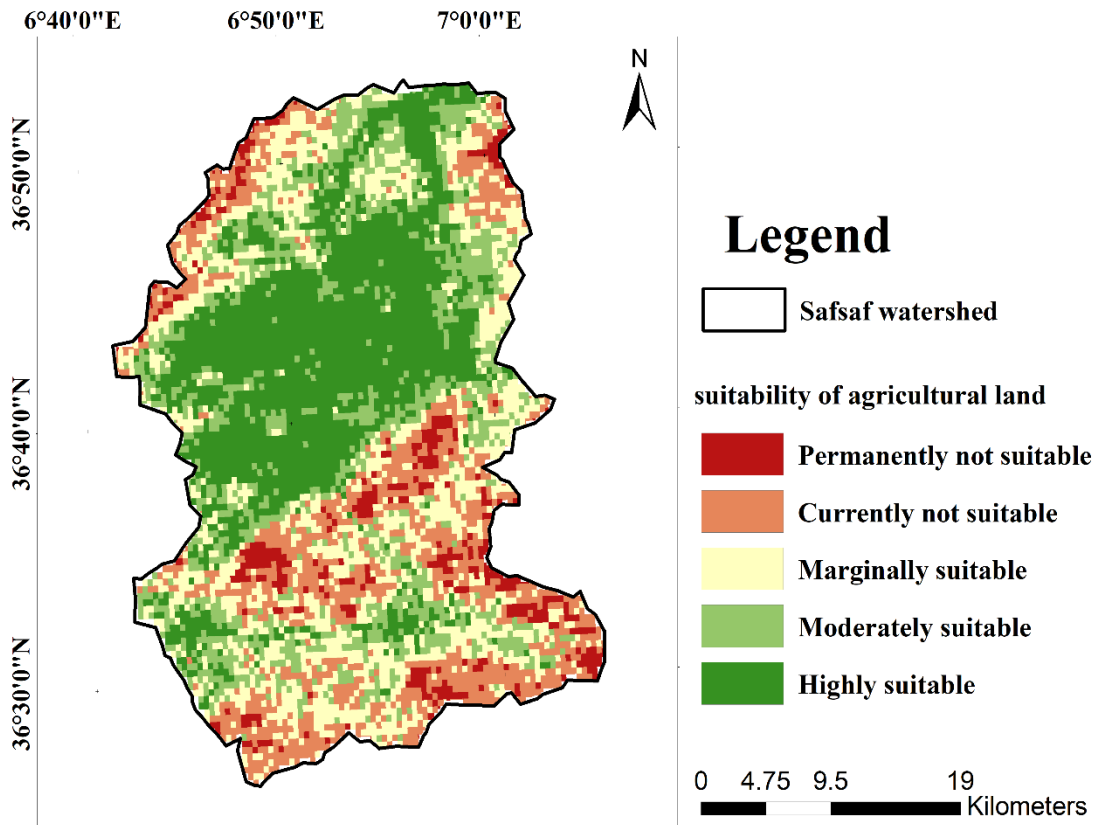


Figure 46: Suitability of agricultural land in the study area

AHP model validation:

The AHP-based land suitability model was validated by comparing its suitability classes with the location of existing agricultural land, assessing how well the model reflects real land use patterns.

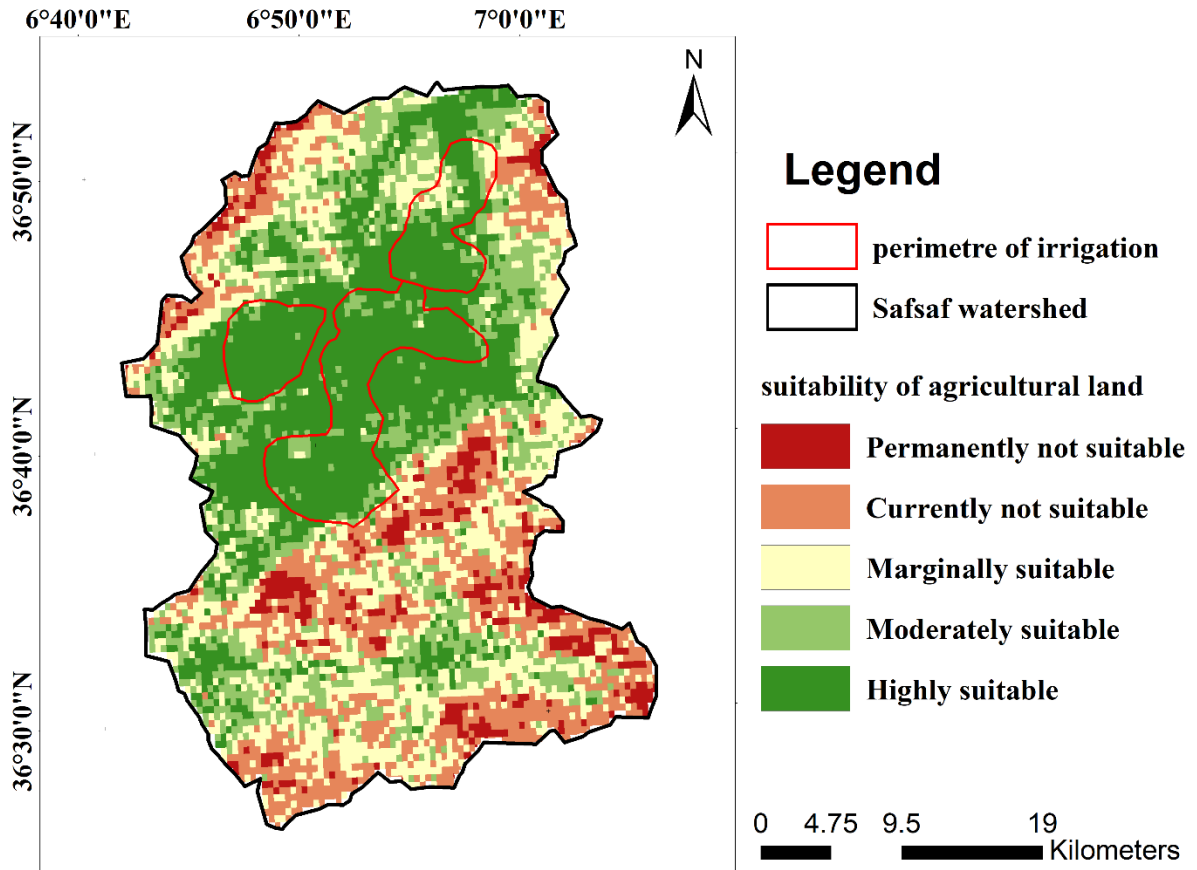


Figure 47: AHP model validation

The validation results show that the majority of existing agricultural land is located within highly and moderately suitable classes, indicating a strong spatial agreement between the model output and real land use

3. Irrigation system for each suitability level

According to the FAO, each irrigation system has selection criteria and parameters for implementation. Below are the main parameters to consider when selecting a system. Other parameters and factors are also taken into consideration, such as ease of access, location in a protected area, integration into an organized farm, labor availability, operation and maintenance facilities, etc.

Table 40: Criteria and parameters of irrigation systems

Criteria/ Irrigation systems	Drip irrigation	Sprinkler irrigation
Crop Types	Field crops, all row crops, watermelons, and Deciduous trees	Wheat, barley, chickpeas, lentils, potatoes, industrial crops of soybeans, corn, sunflowers, leafy vegetables, watermelons, clover, perennial crops, etc.
Area, and Size	The area to be irrigated can be any farm planted with row crops of any length between 40 and 150 m Plot sizes can vary from 0.2 to 1 ha.	The area to be irrigated must be a normal agricultural field of at least 1.8 hectares.
Shape	The shape must be standard, rectangular, or square.	shape standard
Topography	in the mountains or on the plains	Can work on uneven ground; However, horizontal ground or a uniform, gentle slope of less than 1 percent is recommended.
Soils	The soil can be of any texture, but preferably medium and/or fine, with infiltration rates less than 20 mm/h	The soil should be of medium texture with a high infiltration rate (> 15 mm/h), good internal drainage, and good moisture retention capacity.
Water Availability	The water source can be a borehole, a river, or a small water reservoir. If a re-pressurization pump is required, it must be installed upstream of the system.	The water source can be a borehole, a river, or a small water reservoir. The system can be supplied by hydrants placed at various points along the edges of the agricultural plot. The water source should be located as close as possible to the field to be irrigated.
Suitable agricultural land	Highly to marginally suitable	Highly to moderately suitable

Conclusion

The Safsaf irrigation perimeter spans approximately 5,654 hectares and is divided into four sectors: Sector I, Sector II, Sector III, and Sector IV. Water resources for irrigation are sourced from two dams, Guenitra and Zerdazas. The perimeter is characterized by four types of crop rotations:

- Crop rotation A: Vegetables, beetroot, cotton, and oat vetch
- Crop rotation B: Vegetable crops and alfalfa
- Crop rotation C: Grain maize, market gardening, and alfalfa
- Crop rotation F: Fruit trees

The Safsaf perimeter employs three methods of irrigation: gravity irrigation, sprinkler irrigation, and drip irrigation. Based on the land suitability map, we conclude that out of the study area of 362.2 km² in the Safsaf watershed, a portion is highly suitable for agricultural production, particularly the lands near rivers. Specifically, 221.8 km² is moderately suitable, while 267.3 km² is deemed marginally suitable. Additionally, 218 km² of land is currently classified as not suitable for agricultural production, with 61.13 km² considered permanently unsuitable.

Chapter 5
***The impact of climate
change on vegetation and
water resources***

Introduction

Climate change is a major new challenge for Algeria. A large part of Algeria belongs to the Mediterranean basin, which is a "hot spot" for climate change and must therefore be protected. In April 1993, Algeria ratified the United Nations Framework Convention on Climate Change (UNFCCC), fully endorsing its commitments to stabilize greenhouse gas emissions in order to prevent any anthropogenic disruption of the climate system.

Algeria joined the United Nations Framework Convention on Climate Change (UNFCCC) in 1993, the Kyoto Protocol in 2004, and the Paris Agreement in 2016. To demonstrate its commitment, Algeria set up a Climate Change Directorate (CCD) within the Ministry of the Environment in 2016 and a National Climate Change Agency (NCCA) in 2005, to deal with this issue. Algeria has demonstrated its determination to participate in the international effort to combat climate change and its potential impact on water resources, natural ecosystems, and the sustainability of economic development.

1. Climate change

1.1. Definition

Climate change, as used by the IPCC, refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change in climate that is attributed directly or indirectly to human activity altering the composition of the global atmosphere, and that is in addition to natural climate variability observed over comparable periods. (Richardson et al., 2009)

1.2. Causes and drivers

Climate change refers to long-term variations in temperature and weather conditions. These changes can be natural, due to changes in solar activity or major volcanic eruptions or even during ocean circulation changes because it can disrupt the movement of warm and cold currents. But since the 19th century, human activities have been the main driver of climate change, mainly due to the burning of fossil fuels such as coal, oil, and gas according to the United Nations (UN, 2023)

1.2.1. Anthropogenic causes

1.2.1.1. Greenhouse effect

The greenhouse effect is a natural phenomenon caused by the exchange of energy between the sun and the Earth. The infrared radiation emitted by the sun is absorbed by the atmosphere and in particular by the greenhouse gases present in it: water vapour, carbon dioxide, methane and others. This heat reserve helps maintain temperatures that are conducive to life on Earth.

1.2.1.2. Greenhouse gases

The greenhouse gases and their sources are as follows:

Water vapour H₂O: It is the most common greenhouse gas, but others are very important too. Some occur naturally, and some come from human activity.

Carbon dioxide or CO₂: It is the most significant greenhouse gas released by human activities, mostly through the burning of fossil fuels. It is the main contributor to climate change. (O. Adeje et al., 2014)

Methane CH₄: is produced when vegetation is burned, digested or rotted with no oxygen present. Garbage dumps, rice paddies, and grazing cows and other livestock release lots of methane (USEPA)

Nitrous oxide N₂O: can be found naturally in the environment but human activities are increasing the amounts.

Nitrous oxide is released when chemical fertilizers. Nitrous oxide is released when chemical fertilizers and manure are used in agriculture.

Halocarbons: are a family of chemicals that include CFCs (which also damage the ozone layer), and other human-made chemicals that contain chlorine and fluorine. (WMO)

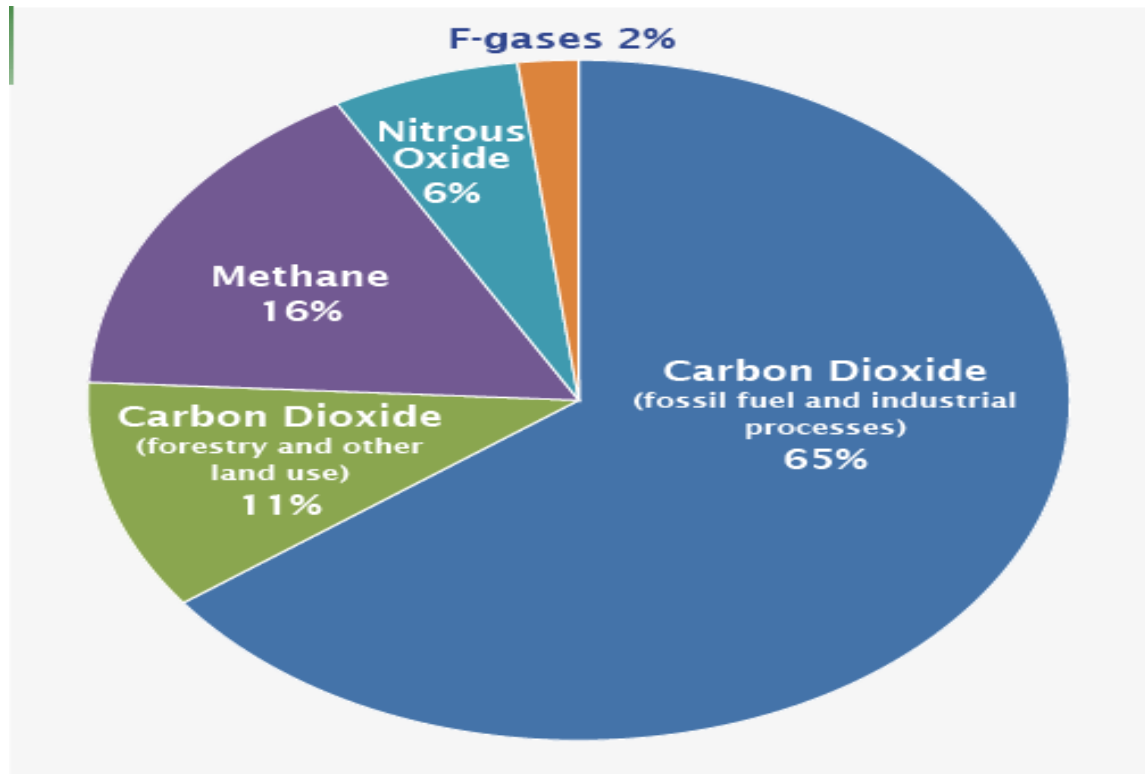


Figure 48: global percentage greenhouse gas emission (IPPC, 2014)

2. Climate change in Algeria

From north to south, Algeria's climate changes dramatically. It changes from a humid Mediterranean tone to a dry desert environment, passing through a semi-arid climate. This climate is the result of the dual influence of mid-latitude atmospheric circulation and tropical and Saharan circulation. The Mediterranean is a transition zone between these climatic components.

Since climate change was a global problem, Algeria had its share of it, An analysis of recent climate trends shows that the effects of climate change are now perceptible in the Mediterranean region, and that they are increasingly leading to the recurrence of climatic anomalies and extreme phenomena. **(MERE. 2019)**

As studies confirmed the average annual temperature rise in the Mediterranean region is about 1.5°C specifically Algeria, are higher than the world average.

Moreover, the precipitation decrease ranges between 10 and 20%. Thus, Rainfall in Algeria has decreased by 40% in the west, 30% in the center, and 20% in the east.

2.1. National GHG emissions

2.1.1. National GHG emissions

The greenhouse gases covered by this third GHG emissions inventory are : Carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulfur hexafluoride (SF₆), nitrogen trifluoride (NF₃), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). (MERE, 2023)

The following figures show the temporal evolution of total national gross (Fig. 47) and net (Fig. 48) GHG emissions for the period 1990-2020.

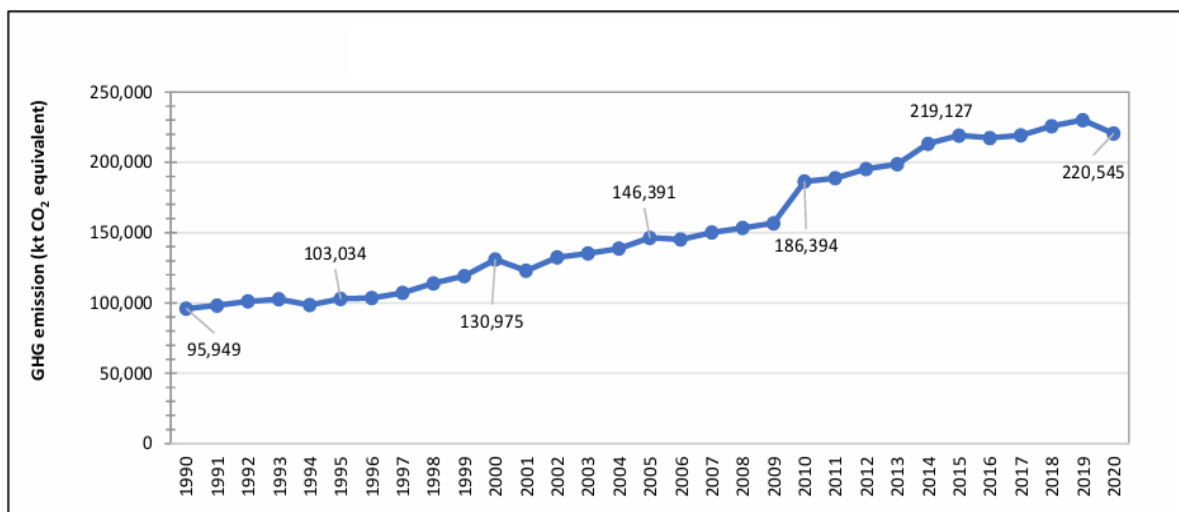


Figure 49: temporal evolution of total national gross GHG emissions for the period 1990-2020. (MERE, 2023)

Total gross GHG emissions for 2020 have been estimated at 220544.85 kt CO₂eq. They are 129.9% higher than in 1990 (95948.77 kt CO₂eq) and 50.7% higher than in 2005 (146390.81 kt CO₂eq).

Total net GHG emissions for 2020 were 211611.44 kt CO₂eq. They are 211521.1 ktCO₂eq higher than in 1990, 90.394 ktCO₂eq

Mainly due to the significant increase in activity in the energy, manufacturing and construction industries, as well as in the transportation sector. Between 2019 and 2020, GHG emissions fell by 4.1% due to the global pandemic of COVID-19 and the accompanying restrictive measures taken by the country's public authorities (230,093.50 kt CO₂eq in 2019).

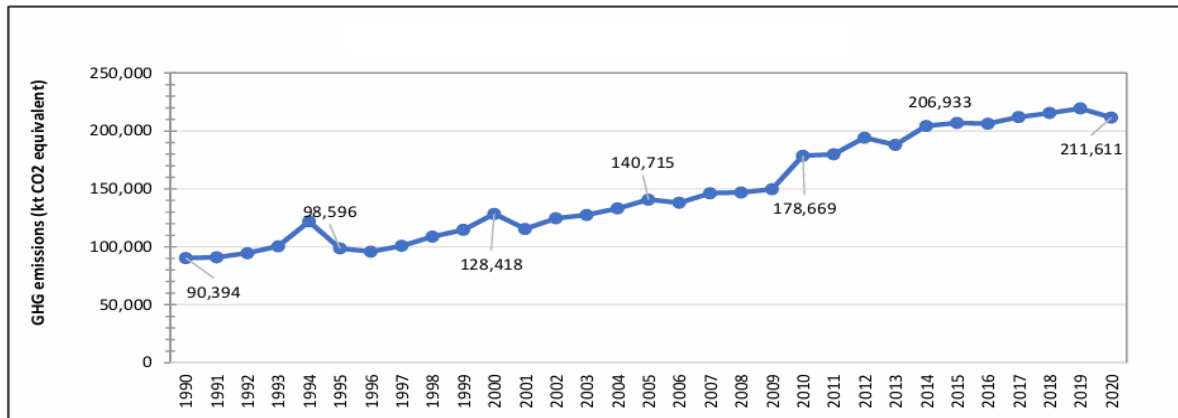


Figure 50: temporal evolution of total national net GHG emissions for the period 1990-2020. (MERE, 2023)

2.2. Climate scenarios and projections for Algeria

2.2.1. Climate scenarios

Climate scenarios are hypothetical descriptions of future climate evolution according to different possible trajectories of greenhouse gas emissions and other climate forcings. They serve as a basis for climate models to simulate future conditions. The types of scenarios used in climate studies are:

- RCP (Representative Concentration Pathways):

RCPs are greenhouse gas concentration and radiative forcing trajectories used in climate simulations. They describe different possible paths for the evolution of greenhouse gas emissions and their impact on climate. Four main RCPs are used in IPCC climate projections:

RCP2.6: Low-emissions scenario where emissions peak early and decline rapidly.

RCP4.5: Intermediate stabilization scenario where emissions peak around 2040 and then decline.

RCP6.0: Higher stabilization scenario where emissions peak around 2080 and then decline.

RCP8.5: High-emissions scenario where emissions continue to rise throughout the century.

- SSP (Shared Socioeconomic Pathways):

SSPs are socio-economic scenarios that describe possible future trajectories in terms of economic, demographic, technological and social development. They are often combined with PCRs to explore how different socio-economic contexts might influence greenhouse gas emissions and climate change. Five main SSPs are used:

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SSP1: Sustainability (green path) - a world with strong international cooperation and sustainable development.

SSP2: Middle of the road - an intermediate world following historical trends.

SSP3: Regionality (fragmentation) - a fragmented world with conflicts and uneven development.

SSP4: Inequality - a world with great social and economic disparities.

SSP5: Fossil fuel-led development - a world with strong economic growth based on fossil fuels.

2.2.2. Climate projection in Algeria

2.2.2.1. Temperature projection

- RCP scenarios:

Figure 13 shows average temperatures for the period 1981-2010 and their evolution in the future: 2031-2060 and 2069-2098.

The first series of maps shows the results of RCP 4.5, an optimistic scenario assuming a reduction in atmospheric GHGs. (MERE, 2023). The second series presents the RCP 8.5 scenario, the most catastrophic scenario assuming no reduction in GHG emissions, which would accentuate CC and tend towards an increase in average maximum temperatures in Algeria.

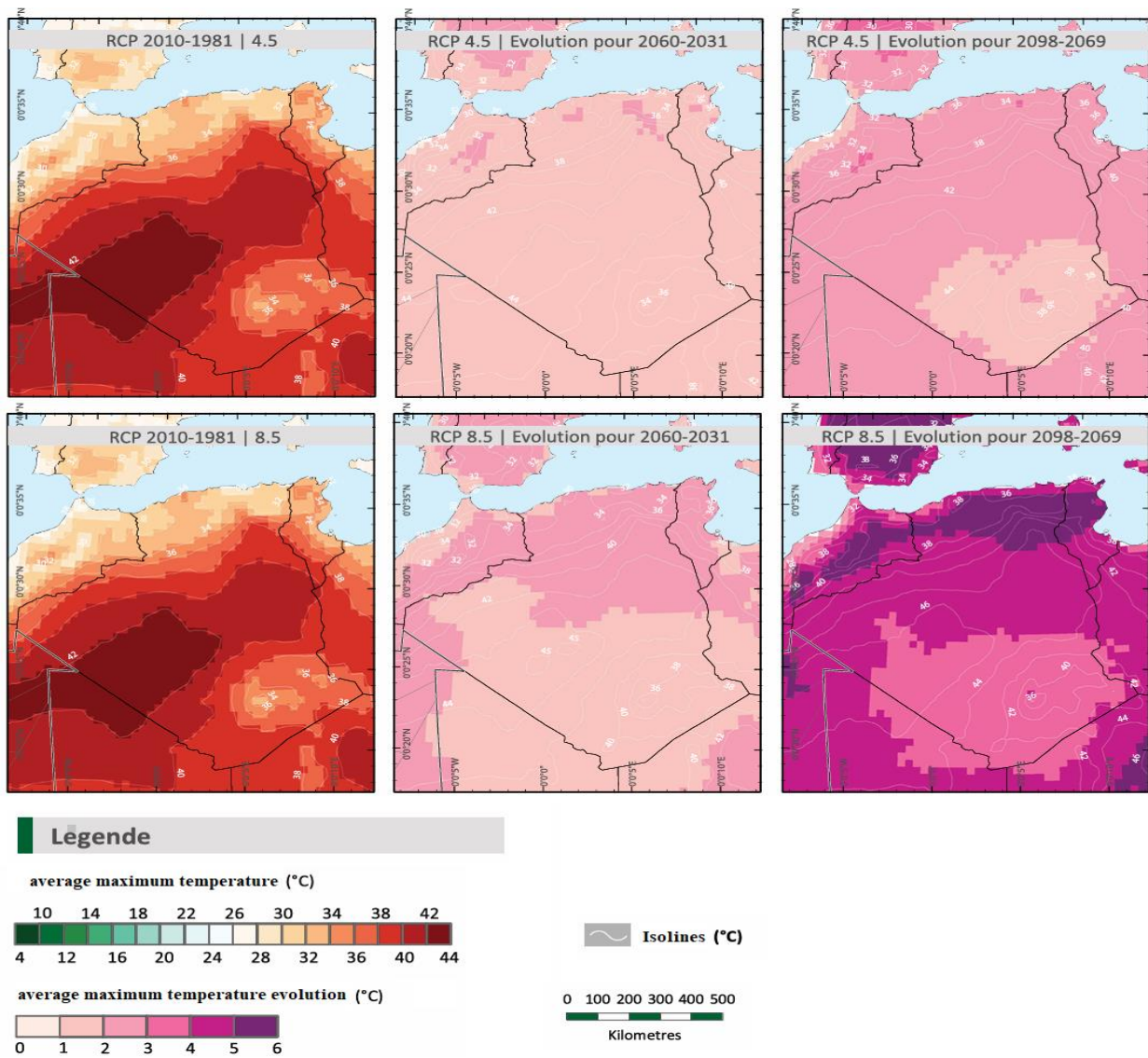


Figure 51: projection of average maximum temperature between September and May (MERE & GIZ, 2017)

- SSP scenarios:

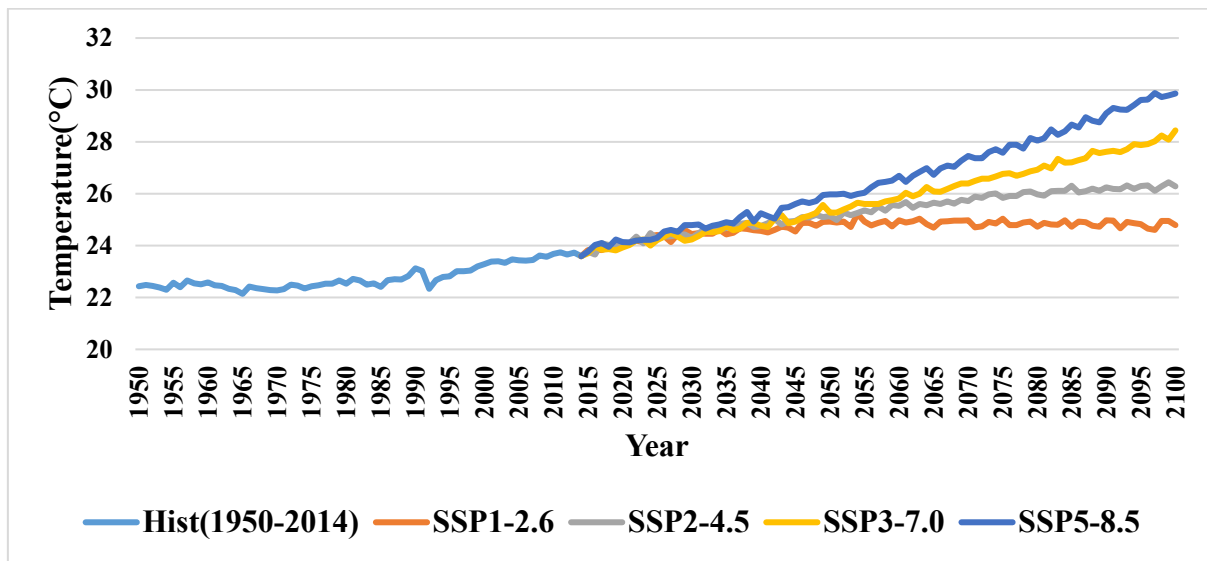


Figure 52: projection of the average temperature of Algeria by the Multi-Model Ensemble and Ref. Period: 1995-2014 (WBG, 2024)

2.2.2.2. Precipitation projection

- RCP scenarios:

Figure 14 illustrates average annual precipitation for the wet period (with the presence of notable rainy episodes between September and May) between 1981-2010 and the evolution of this average in the future: 2031-2060 and 2069-2098. (MERE, 2023)

The two map series are based on the two IPCC scenarios: top: RCP 4.5; bottom: RCP 8.5.

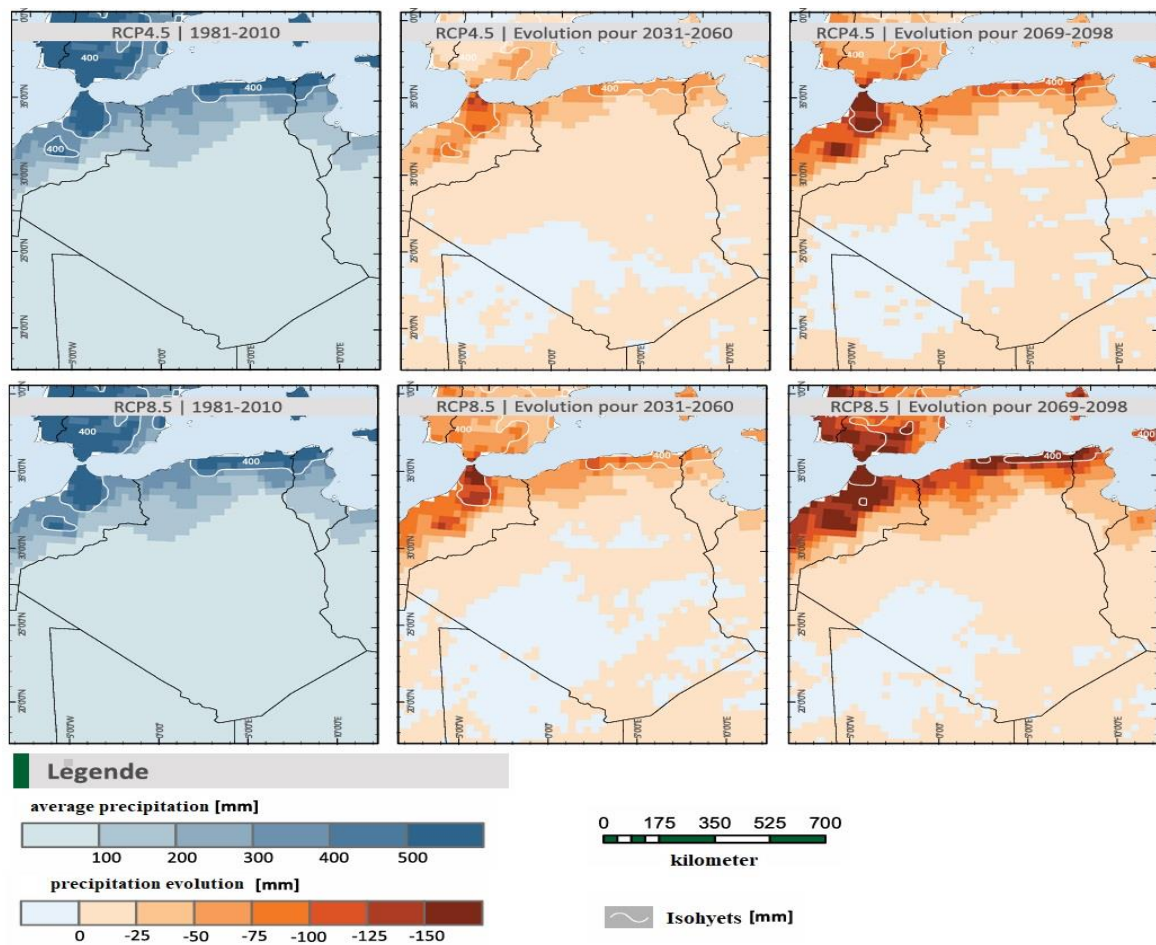


Figure 53: projected average precipitation between September and May (MEER & GIZ, 2017)

- SSP scenarios:

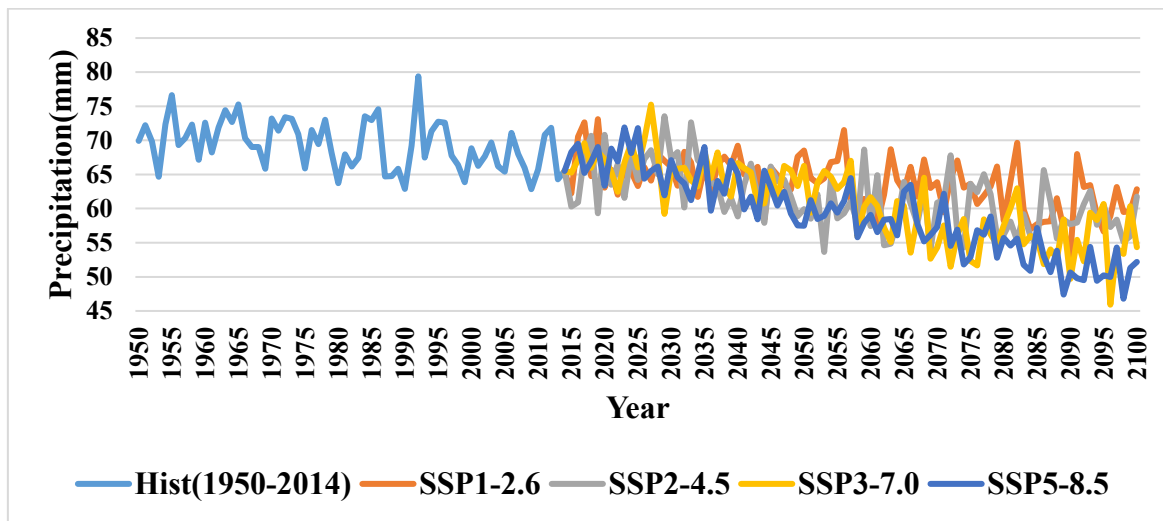


Figure 54: projection of average precipitation of Algeria, the Multi-Model Ensemble and Ref. Period: 1995-2014 (WBG, 2024)

2.3. Impact of climate change in Algeria

2.3.1. Impact of climate change on agriculture

The potential direct and indirect impacts of climate change on agricultural production, for both crops and livestock products, result from the combined effect of changes and greater variability in temperature and rainfall on crop yields (disruption of phenological cycles) and the destructive impacts of extreme weather events. It should be remembered that the agricultural sector consumes over 60% of mobilized water resources. It is envisaged that irrigated land will be extended to over 1,560,000 hectares by 2030. Although the extent of the impact of climate change remains uncertain, we can expect a sharp drop in crop production due to a reduction in yields and cultivable areas. **(Bakhtache et al., 2023)**

Cereal, root and tuber production, including potatoes and pulses, and livestock products will all suffer significant yield reductions, impacting employment and income in the agricultural sector. However, even if climate change is not explicitly taken into account, sectoral and cross-sectoral strategies for the period 2020-2030 incorporate this issue through the sustainable preservation of natural resources (water and soil), the restoration of forest and pastoral areas, the extension of irrigated land, the promotion of renewable energies and water-saving techniques and systems. Added to this are the fight against desertification, reforestation efforts, the development of organic farming (which emits fewer greenhouse

gases), the relaunch of the national gene bank and the labeling of local products (family farming with a low carbon footprint). (Lakhdari, H. 2009).

Today, Algeria has a national map of the risks associated with climate change, covering flooding, water stress, heat waves, coastal submersion, vector-borne and cryptogamic diseases, and land sensitivity to erosion.(MERE, 2023)

2.3.2. impact of climate change on water resources

The analysis of risk and vulnerability to climate change in the water sector only concerns ecosystems north of the Sahara (coastal, tellian, and steppe), given the existence of hydrometeorological and piezometric measurement networks. What's more, these areas are subject to fast-growing water use and competition between agriculture, industry, tourism and drinking water supply. The water stress they suffer is exacerbated by the effects of climate change, due to the reduction and greater variability of rainfall and the more frequent occurrence of extreme phenomena (drought and/or flooding). These areas are also home to almost all conventional water resource mobilization infrastructures (dams, boreholes, etc.) or non-conventional ones (wastewater treatment or desalination of salty or brackish water) and distribution networks via transfer pipelines. In terms of water availability, climate change will have an impact on the mobilization of conventional and non-conventional water resources, as well as on the degradation of their quality. (Mohammed et al., 2018)

2.4. Adaptation and national strategy

Algeria's National Climate Plan (PNC) is the main reference for the country's strategy to combat climate change. It translates the country's commitments in terms of both adaptation and mitigation of GHG emissions into guidelines and actions. The PNC contains 155 actions (63 adaptation actions, 76 mitigation actions and 16 cross-cutting actions).

2.4.1. Adaptation

Adaptation is a process of adjusting natural or human systems in response to current and anticipated climate stimuli or their effects, in order to mitigate adverse effects or exploit beneficial opportunities (IPCC, 2014).

In the NCP, adaptation actions specifically refer to priority initiatives and measures to reduce the adverse effects (or increase the positive effects) of CC. Adaptation needs vary widely depending on the location, population, and sector concerned.

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- The short-term action program (2020-2025):

Must respond to emergencies and contain actions that are achievable over the next few years. The human resources and skills needed to implement them are available. The main constraint is obtaining the necessary financial resources. The short-term program includes the CNP 2020-2025 action plan.

Tableau 41: The short-term action program (2020-2025)

Thematic.	Action(STA)	pilot
Water resources	STA 13: Impact of climate change on coastal aquifers in Algeria and combat marine intrusion.	MWR
	STA 14: The impact of future climate change on the capacity of reservoir dam regulations.	MWR
	STA 15: Optimization and rehabilitation of irrigation systems.	MWR
	STA 16: Development and extension of drip irrigation.	MWR+ MARDF
agriculture	STA 17: Valorization and duplication of the experience of the Wilaya of Oran on the production of organic compost as a natural fertilizer.	MERE
	STA 18: Geographic information system for effective management of agricultural droughts.	MARDF
Erosion, desertification, green dams, and soil protection.	STA 28: Rehabilitation of the courses by the defense. STA 29: Fight against sand encroachment and provide exposed areas with specific means to deal with it	MARDF MARDF

- The medium-term action plan (2025-2035):

Includes actions that will take longer to implement and will require strengthening the organizational framework as well as the human and material resources needed to execute them. Their implementation requires inter-sectoral coordination and preparatory analyses

Table 42: The medium-term action plan (2025-2035)

Thematic.	Action (MTA)	pilot
Water resources	MTA 10: Unconventional water reclamation in arid zones	MWR
	MTA 11: National study on the reuse of treated wastewater	MWR
	MTA 12: Reuse of demineralized drainage water in agriculture in the Oued Righ valley	MWR
	MTA 13: Pilot aquifer replenishment project from surface resources	MWR
		MWR

	MTA 14: Study of the vulnerability of groundwater resources to the effects of climate change	
agriculture	MTA 15: improvement of agricultural practices for the use of rainwater in semi-arid areas	MARDF
	MTA 16: introduction of new adapted spaces and their valorization, such as opuntia	MARDF
	MTA 17: selection and genetic improvement of cereal varieties Pulses, forages, market garden crops and arboriculture	MARDF
	MTA 18: develop direct seeding techniques in marginal and erosion-sensitive areas	MARDF
	MTA 19: Preservation of Bouhemama apple orchards against advanced drought and measures for sustainable irrigation	MARDF

2.4.2. Mitigation

An activity qualifies as a CC mitigation action if it helps achieve the goal of stabilizing GHG concentrations in the atmosphere, thereby preventing dangerous human-induced interference with the climate system (UNFCCC, Article 2). **(MERE, 2019)**

The activity is considered mitigative if it directly reduces emissions through one of these measures:

- Lowering or stabilizing GHG emissions across sectors like energy, transport, industry, and agriculture by adopting new or renewable energy sources, improving the energy efficiency of existing machinery and equipment, or implementing energy demand management tools.
- Reducing methane emissions via better waste management and wastewater treatment.
- Developing, transferring, and promoting technology and knowledge, along with capacity-building efforts to control, reduce, or prevent anthropogenic GHG emissions, especially in waste management, transport, energy, agriculture, and industry.
- Protecting and enhancing GHG sinks through sustainable forestry practices, planting, reforestation, and restoring areas impacted by drought and desertification.

In all, the NCP includes 76 mitigation actions in the fields of energy (19), industry (17), transport (15), buildings and housing (10), waste (7), local authorities (4), forestry (3) and tourism (1). These actions are at varying stages of completion or programming. **(Sahnoune et al. 2013)**

3. The impact of climate change on vegetation and water resources in the Saf-Saf watershed

3.1. Land use and land cover

Land cover is defined as the observed physical cover on the earth's surface, including vegetation (natural or planted) and human constructions. Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change, or maintain it. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment. FAO

The annual Land Use Land Cover (LULC) index is estimated from the Sentinel Dynamic World Satellite, a near-real-time (NRT) Land Use/Land Cover dataset. The results were exported in TIF format for the years of the study, and all images were processed in ArcMap 10.8 by reclassifying them. Subsequently, the attribute table containing the number of pixels for each class was extracted. From this data, we calculated the percentage (%) and area (km²) for each class over the different years of the study. Next, to calculate the changes in land use and land cover between the years, we used geoprocessing tools to dissolve and intersect the images, then detected the changes using the attribute table by extracting it and employing Excel to calculate the changes over time. cludes class probabilities and label information

Table 43: land use land cover classes

Class	definitions
Water	Areas where water is predominantly present throughout the year may not include places with sporadic or temporary water. These areas typically have little to no vegetation, no rock outcrops, and no constructed features like docks.
Trees	Any significant clustering of tall (approximately 15 meters or higher) dense vegetation, usually characterized by a closed or thick canopy.
Crops	Humans cultivate cereals, grasses, and crops that do not reach tree height.
Built Area	Human-made structures; major road and rail networks; large homogenous impervious surfaces, including parking structures, office buildings, and residential housing.
Bare ground	Areas of rock or soil with very sparse to no vegetation for the entire year; large areas of sand and deserts with no to little vegetation.

The classification results of land use and land cover based on LULC calculations from Sentinel Dynamic World images (Fig58) illustrate the spatial distribution of various classes from 2016 to 2024.

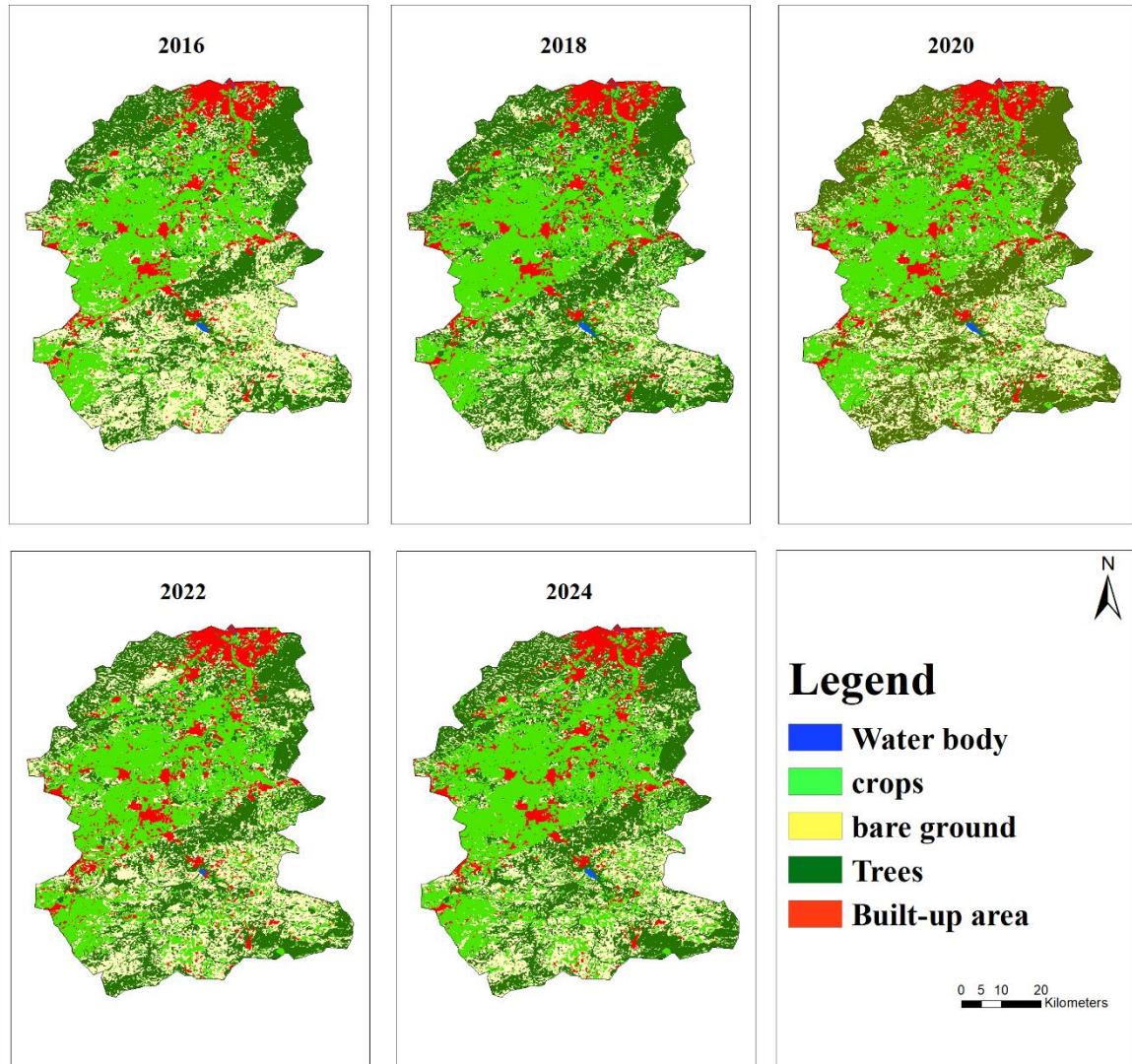


Figure 55: Land use land cover in Safsaf watershed from 2016 to 2024

According to the LULC maps and area estimations for each class (Table 44), changes in water surface area are significant throughout the study period.

In 2016, the water surface covered 1.44 km²; this increased to 1.88 km² in 2018, decreased to 1.76 km² in 2020, dropped to 0.83 km² in 2022, and then rose again to 1.54 km² in 2024.

Data regarding crop areas show fluctuations over the years: In 2016, it was 340.43 km²; in 2018, it increased to 374.05 km²; then it decreased to 342.58 km² in 2020, before rising again to 367.26 km² in 2022, and finally reaching 405.84 km² in 2024.

Chapter 5 _____ The impact of climate change on vegetation and water resources

For bare ground, the recorded areas were 365.85 km² in 2016, then dropping to 247.23 km² in 2018, rising to 279.05 km² in 2020, further increasing to 312.53 km² in 2022, and finally decreasing to 266.93 km² in 2024.

Tree areas showed slight changes over the years, with measurements of 360.74 km² in 2016, 450.22 km² in 2018, 443.09 km² in 2020, 374.26 km² in 2022, and 388.78 km² in 2024.

The built-up category recorded the following areas: 99.2 km² in 2016, 94.27 km² in 2018, 101.25 km² in 2020, 112.87 km² in 2022, and 104.67 km² in 2024

Table 44: area and percentage of land use and land cover classes of Safsaf watershed from 2016 to 2024

LULC range and classification	Water body		Crops		Bare Ground		Trees		Built-up area	
	Area (km ²)	Pourcent age(%)	Area (km ²)	Pourcent age(%)	Area (km ²)	Pourcent age(%)	Area (km ²)	Pourcent age(%)	Area (km ²)	Pourcent age(%)
2016	1.44	0.12	340.43	29.15	365.85	31.33	360.74	30.89	99.20	8.49
2018	1.88	0.16	374.05	32.03	247.23	21.17	450.22	38.55	94.27	8.07
2020	1.76	0.15	342.58	29.33	279.05	23.89	443.09	37.94	101.25	8.67
2022	0.83	0.07	367.26	31.45	312.53	26.76	374.26	32.05	112.87	9.67
2024	1.54	0.13	405.84	34.75	266.93	22.86	388.78	33.29	104.67	8.96

The flowing bar chart (Fig59) illustrates the distribution of various classes of land use land cover (LULC) from 2016 to 2024.

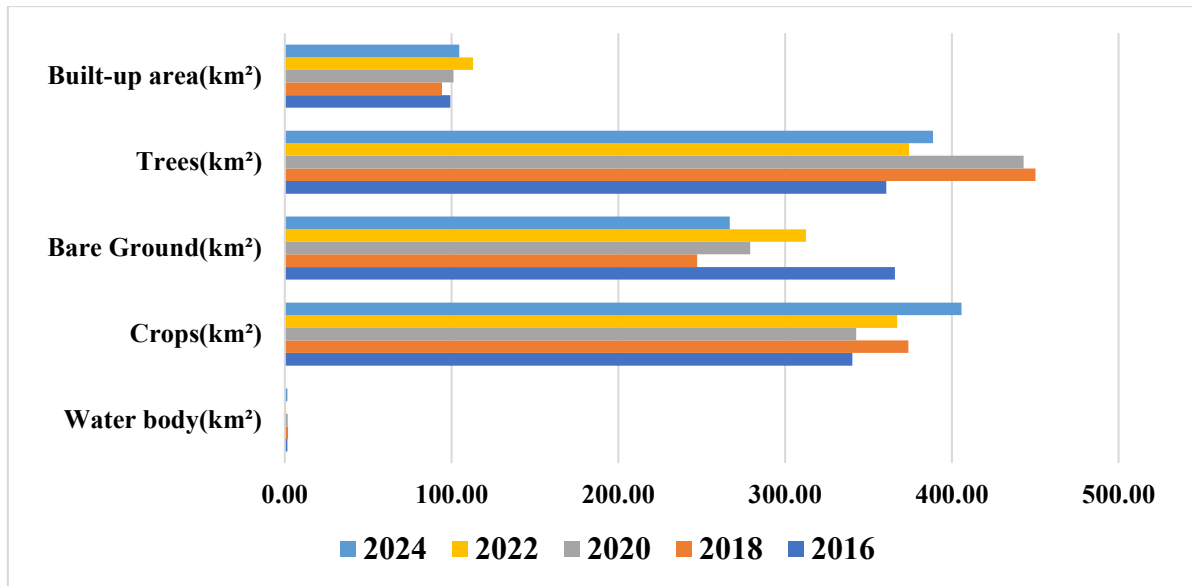


Figure 56: area of land use and land cover classes of Safsaf watershed from 2016 to 2024

3.1.1. LULC change

Land use involves activities and inputs within specific land cover types to produce, modify, or sustain land, linking human actions to the environment. It can include activities on one or multiple parcels, often coexisting, and helps analyze social, economic, and environmental aspects. Land cover change describes the transformation of natural or semi-natural areas, like forests, wetlands, and grasslands, into other types. Decreases in vegetated areas indicate pressure on biodiversity, while increases suggest opposite conversions, measured relative to initial amounts (FAO)

The results of land use and land cover changes throughout the study period are presented in Figure 60, demonstrating the detection of LULC changes every two years, with the final map depicting the changes between 2016 and 2024.

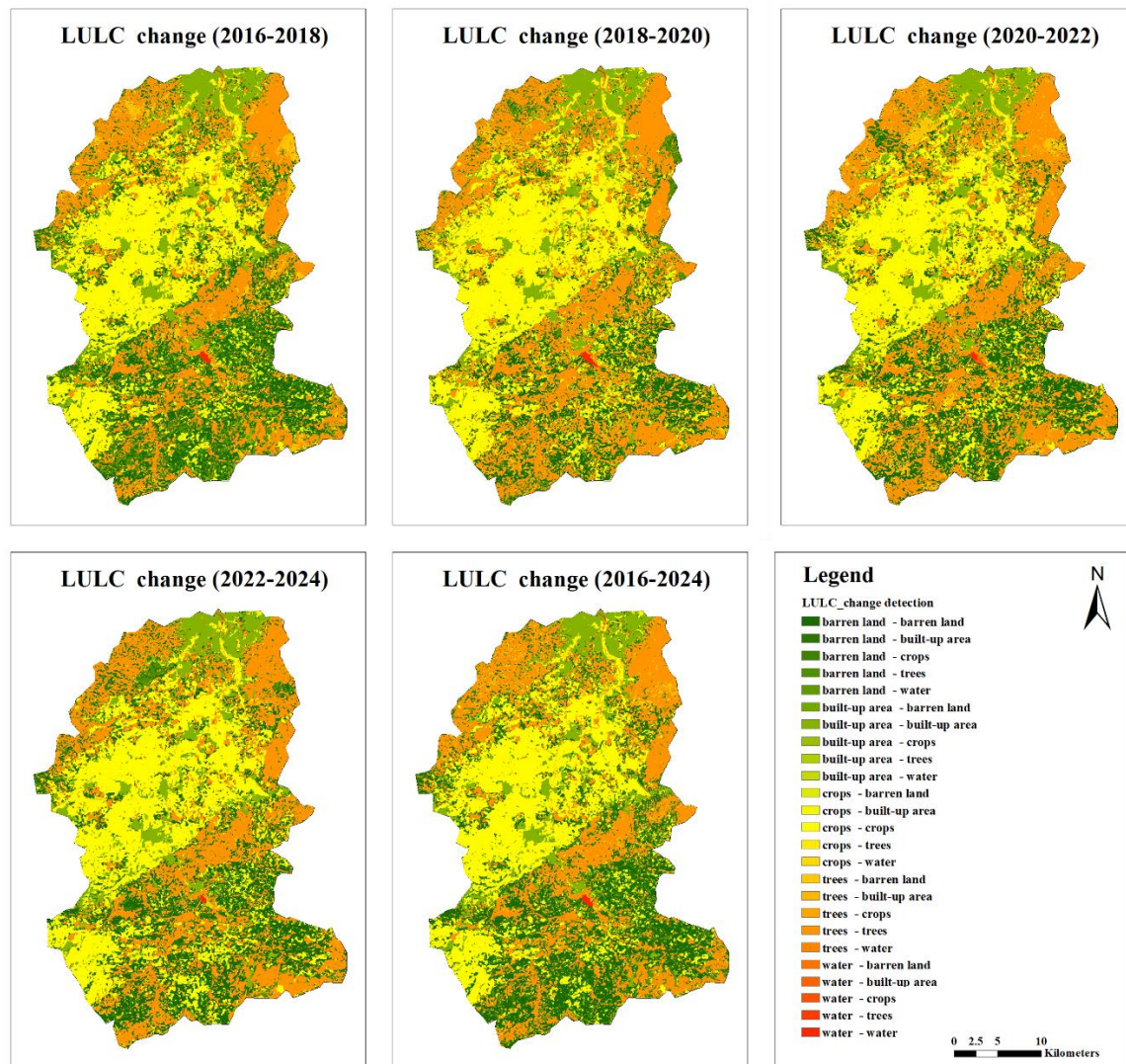


Figure 57: Land use land cover (LULC) change from 2016 to 2024

The analysis of land use and land cover (LULC) changes indicates that all classes have undergone significant transformations. Notably, the water body class experienced the highest changes from 2020 to 2022, with conversions to crops (0.32 km²), bare ground (0.09 km²), trees (0.15 km²), and built-up areas (0.42 km²) (table47). Conversely, the least change occurred between 2016-2018 and 2022-2024, where it converted to crops (0.01 km²) and trees (0 km²) in the latter period (table45 and 48).with minimal changes in 2016-2018 for bare ground (0.01 km²) and built-up areas (0.02 km²) (table45).

Crops showed significant changes, particularly transitioning to water bodies in the 2022-2024 period (0.23 km²) (table48) and to built-up areas (12.64 km²) in 2020-2022 (table47). In the 2018-2020 timeframe, crops changed to bare ground (39.37 km²) and trees (13.93 km²) (table46). The minor changes were observed in 2016-2018, where crops transitioned to built-up areas (3.82 km²) (table45) and to bare ground (15.18 km²) from 2016 to

2024(table49). From 2020 to 2022, crops also transitioned to water bodies (0.01 km²) and trees (3.40 km²) (Table 47).

The most significant changes occurred in 2016-2018 for bare ground, converting to water bodies (0.07 km²) and trees (113.55 km²)(Table 45). From 2016 to 2024, it transitioned to crops (73.52 km²) and built-up areas (10.53 km²) (Table 49). The min change occurred similarly in 2016-2018 and 2020-2022(Table 5), with no conversions to water and minimal changes to crops (17.44 km²) and built-up areas (3.2 km²) during 2018-2020(Table 46). Additionally, from 2020 to 2022, bare ground was converted to trees (18.16 km²) (Table 47).

Trees had the most substantial changes, primarily transitioning to water bodies in 2016-2018 (0.09 km²) and transforming into crops (18.88 km²), bare ground (69.26 km²) (Table 45), and built-up areas (3.3 km²) in the 2020-2022 period (Table 47). The minimum changes were noted between 2018-2020 and 2020-2022, with tiny conversions to water bodies (0.01 km²) (Table 46 and 47) and substantial bare-ground changes (23.03 km²) in 2022-2024 (Table 48). From 2016 to 2018, trees were converted to crops (6.84 km²) and built-up areas (1.14 km²) (Table 45).

The built-up area experienced its maximum change to water bodies in 2022-2024 (0.4 km²) (Table 48) and to crops (13.75 km²). From 2016 to 2024, it changed to bare ground (5.95 km²) (Table 49) and trees (3.43 km²) in 2016-2018(Table 45), while the least change occurred in 2020-2022 with negligible transitions to water bodies (0.02 km²) and trees (0.98 km²)(Table 47). During 2018-2020, it changed to crops (2.01 km²) and bare ground (2.91 km²) (Table 46).

Overall, this analysis highlights the dynamic nature of land cover changes and provides insight into the land use patterns over specific periods.

Table 45: Land use land cover (LULC) change between 2016 and 2018

LULC change 2016-2018		2018 km ²					total 2016
		water body	crops	bare ground	Trees	built-up area	
2016 km ²	water body	1.35	0.05	0.00	0.02	0.02	1.44
	crops	0.16	304.08	17.33	14.98	3.82	340.37
	bare ground	0.07	55.46	190.50	113.55	6.15	365.73
	Trees	0.09	6.84	34.41	318.12	1.14	360.60
	built-up area	0.16	7.57	4.91	3.43	83.12	99.18
total 2018		1.84	374.00	247.15	450.09	94.25	

Table 46: Land use land cover (LULC) change between 2018 and 2020

LULC change 2018-2020		2020 km ²					total 2018
		water body	crops	bare ground	Trees	built-up area	
2018 km ²	water body	1.64	0.05	0.03	0.13	0.02	1.87
	crops	0.06	312.88	39.37	13.93	7.76	374.01
	bare ground	0.00	17.44	179.61	46.89	3.20	247.14
	Trees	0.01	10.16	57.03	380.04	2.91	450.15
	built-up area	0.04	2.01	2.91	1.94	87.35	94.26
total 2020		1.76	342.54	278.96	442.93	101.24	

Table 47: Land use land cover (LULC) change between 2020 and 2022

LULC change 2020-2022		2022 km ²					total 2020
		water body	crops	bare ground	Trees	built-up area	
2020 km ²	water body	0.78	0.32	0.08	0.15	0.42	1.76
	crops	0.01	305.95	20.54	3.40	12.64	342.54
	bare ground	0.00	37.52	216.89	18.16	6.42	278.99
	Trees	0.01	18.88	69.26	351.51	3.30	442.97
	built-up area	0.02	4.51	5.66	0.98	90.06	101.24
total 2022		0.83	367.18	312.44	374.19	112.85	

Table 48: Land use land cover (LULC) change between 2022 and 2024

LULC change 2022-2024		2024 km ²					total 2022
		water body	crops	bare ground	Trees	built-up area	
2022 km ²	water body	0.77	0.01	0.01	0.01	0.03	0.83
	crops	0.23	339.13	18.26	5.40	4.20	367.22
	bare ground	0.06	43.74	220.80	41.64	6.22	312.45
	Trees	0.06	9.17	23.03	340.25	1.68	374.19
	built-up area	0.41	13.75	4.77	1.39	92.53	112.85
total 2024		1.54	405.79	266.87	388.68	104.66	

Table 49: Land use land cover (LULC) change between 2016 and 2024

LULC change 2016-2024		2024 km ²					total 2016
		water body	crops	bare ground	Trees	built-up area	
2016 km ²	water body	1.32	0.08	0.01	0.01	0.02	1.44
	crops	0.08	309.61	15.18	7.18	8.34	340.38
	bare ground	0.02	73.52	213.76	67.92	10.53	365.75
	Trees	0.03	14.61	31.98	311.13	2.92	360.66
	built-up area	0.09	7.88	5.95	2.42	82.84	99.17
total 2024		1.53	405.70	266.87	388.66	104.65	

The following bar chart (Fig.61) illustrates the area change of various classes of land use and land cover (LULC) from 2016 to 2024.

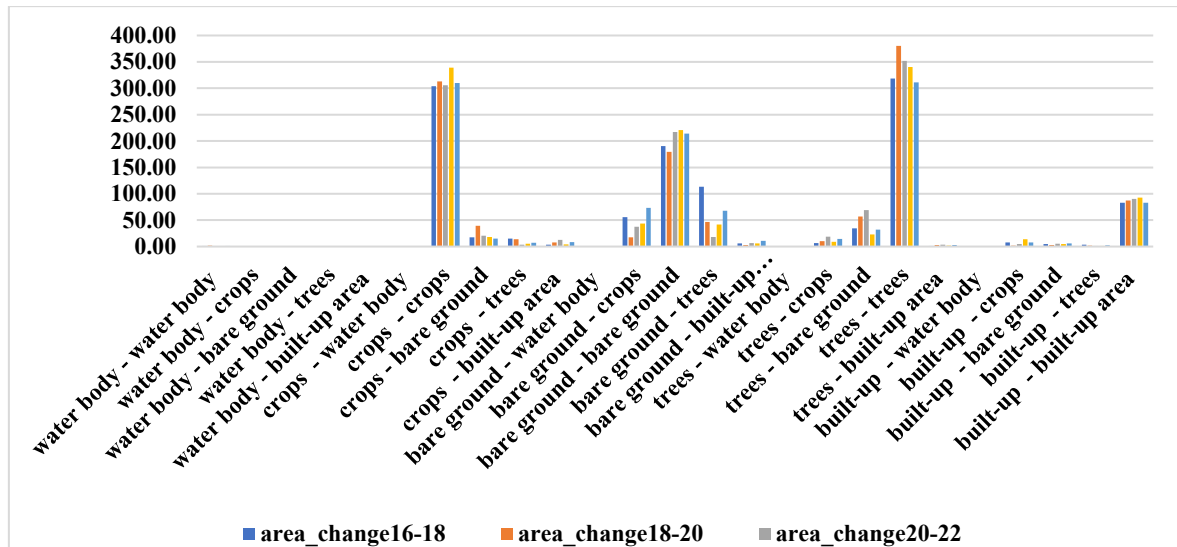


Figure 58: the area changes of various classes of LULC from 2016 to 2024.

The classes of the LULC index have changed over the years. The increase in built-up areas indicates that the infrastructure is rising, which indicates the population is growing, while the degradation of trees is attributed to deforestation and fires. The findings revealed that deforestation and cover loss affected the Constantinois hydrographic basin most. (Zerouali, B et al. 2023)

The augmentation of crops over the years indicates that as the population grows, the demand for food rises, leading to an increase in crop production to achieve food security. However, we must not overlook the associated risks. The risk of soil erosion, rapid urbanization, chaotic construction, and industrial activities has led to increased pollution, all contributing to land degradation and the increase of bare ground. (Lamia, L., & Youcef, L., 2024). For the water bodies, we note the decrease because of the reduction of precipitation due to climate change and the augmentation of water demand

All changes result from numerous causes, specifically human activities that generate gas emissions, leading to global warming and climate change. (Trenberth, K. E. 2018)

3.2. Vegetation land cover

The mean annual of the Normalized Difference vegetation index (NDVI) for the study area is calculated by using the NIR and RED bands (band 5 and 4 for Landsat 8, band 4 and 3 for Landsat 7). The NDVI was calculated using the equation

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

After obtaining the results from GEE we uploaded them in TIF format, for the treatment of the images arc map, 10.8 was used to do a reclassification of the images according to the table 50. Next, the attribute table containing the number of pixels for each class was extracted. From this data, we calculated the percentage (%) and the area (Km²) for each class across the different years of the study.

Table 50: NDVI classes

N°	class	NDVI Range
1	Water	-0.028 - 0.015
2	Built-up area	0.015 - 0.14
3	Barren Land	0.14 - 0.18
4	Shrub and Grassland	0.18 - 0.27
5	Sparse vegetation	0.27 - 0.36
6	Dense vegetation	0.36 - 0.74

The classification results of vegetation land cover based on NDVI calculations from Landsat images (Fig.62) illustrate the spatial distribution of various classes from 2012 to 2024.

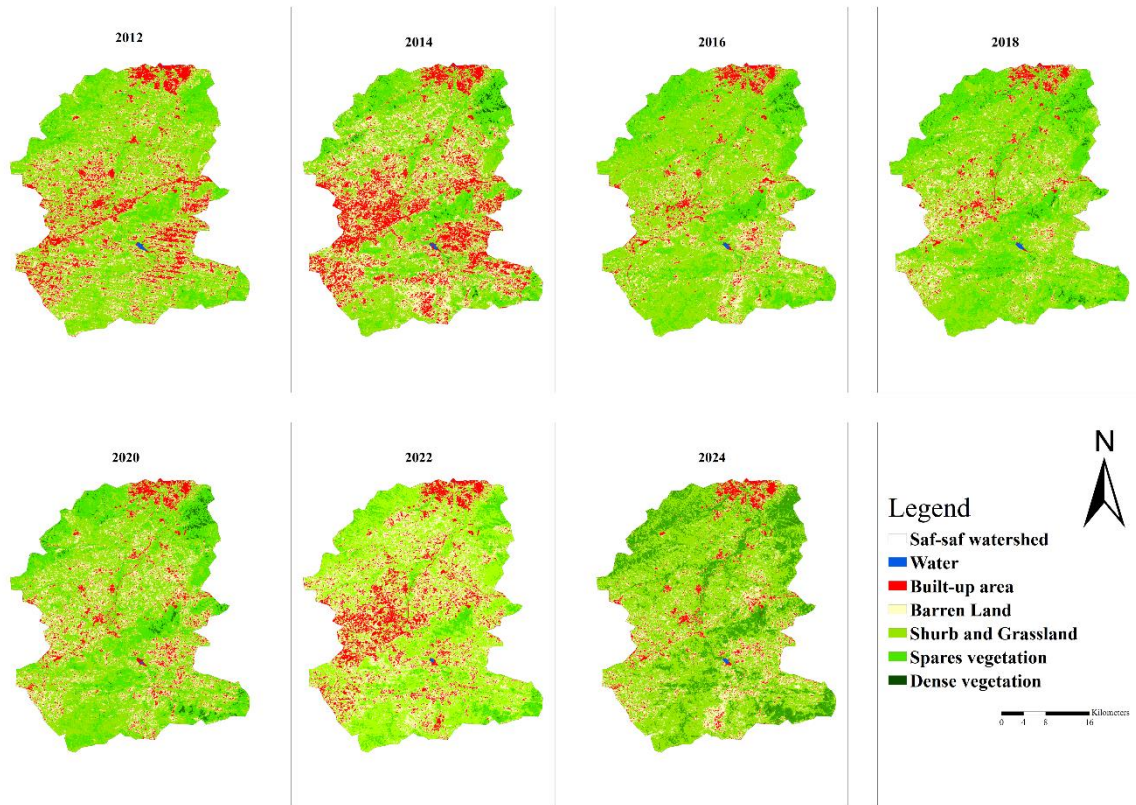


Figure 59: vegetation land cover in the Safsaf watershed from 2012 to 2024

Table 51: area and percentage of vegetation land cover classes of the Safsaf watershed from 2012 to 2024

Ndvi range and classification	Water(-0.028 ; 0.015)		Built-up area(0.0015 ;0.14)		Barren land(0.14 ;0.18)		Shurb and Grassland(0.18 ; 0.27)		Sparse vegetation(0.27 ; 0.36)		Dense vegetation(0.36 ; 0.74)	
	Area (km ²)	Pourcentage(%)	Area (km ²)	Pourcentage(%)	Area (km ²)	Pourcentage(%)	Area (km ²)	Pourcentage(%)	Area (km ²)	Pourcentage(%)	Area (km ²)	Pourcentage(%)
2012	1.25	0.11	166.08	14.22	242.04	20.73	602.02	51.55	155.45	13.31	1.05	0.09
2014	0.83	0.07	227.8	19.5	316.7	27.1	442.5	37.9	172.2	14.8	7.83	0.67
2016	0.85	0.07	71.47	6.12	162.75	13.94	673.54	57.67	251.26	21.51	8.03	0.69
2018	1.05	0.1	58.86	5.04	153.02	13.1	630.44	53.98	310.9	26.62	13.63	1.17
2020	0.37	0.03	85.98	7.36	222.01	19.01	574.7	49.21	267.31	22.89	17.54	1.5
2022	0.47	0.04	160.55	13.75	332.91	28.51	571.61	48.94	101.66	8.7	0.69	0.06
2024	0.74	0.06	68.99	5.91	186.64	15.89	686.5	58.78	220.73	18.9	4.3	0.37

According to the NDVI maps and area estimations for each class (Table 51), changes in water surface area are significant throughout the study period. In 2012, the water surface covered 1.25 km²; this decreased to 0.83 km² in 2014, 0.85 km² in 2016, increased slightly to 1.05 km² in 2018, dropped to 0.37 km² in 2020, and then rose again to 0.47 km² in 2022 and 0.74 km² in 2024.

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Data regarding built-up areas show fluctuations over the years: in 2012, it was 166.8 km²; in 2014, it increased to 227.8 km²; then decreased to 71.47 km² in 2016, further declining to 58.86 km² in 2018, before rising again to 85.98 km² in 2020, and finally reaching 160.55 km² in 2022 and 68.99 km² in 2024.

For barren land, the areas recorded were 242.08 km² in 2012, rising to 316.7 km² in 2014, but then dropping to 162.75 km² in 2016, further declining to 153.02 km² in 2018, before increasing to 222.01 km² in 2020 and reaching 332.91 km² in 2022 and 186.64 km² in 2024.

Shrub and grassland areas showed slight changes over the years, with measurements of 602.02 km² in 2012, 442.5 km² in 2014, 673.54 km² in 2016, 630.44 km² in 2018, 574.7 km² in 2020, 571.61 km² in 2022, and 686.5 km² in 2024.

The sparse vegetation category recorded the following areas: 155.45 km² in 2012, 172.2 km² in 2014, 251.26 km² in 2016, 310.9 km² in 2018, 267.31 km² in 2020, and a notable decline to 101.66 km² in 2022 and 220.73 km² in 2024.

Dense vegetation displayed considerable growth from 2012 to 2024, with areas measuring 1.05 km² in 2012, 7.83 km² in 2014, 8.03 km² in 2016, 13.63 km² in 2018, and 17.54 km² in 2020. However, in 2022, a significant decline was observed at 0.69 km² and 4.3 km² in 2024.

The following bar chart (Fig. 63) shows the distribution of various classes of vegetation land cover over the years from 2012 to 2024.

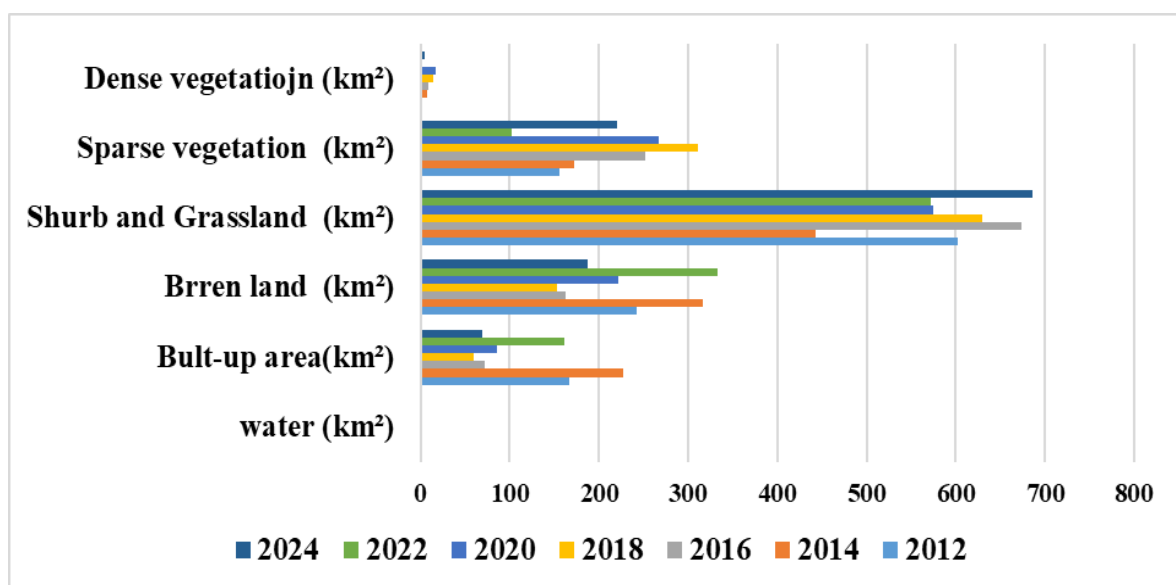


Figure 60: area of vegetation land cover classes from 2012 to 2024

This study based on the variation of different classes of the Safsaf watershed as shown in the Bar chart and the Table that the water surface that represents a dam of Zerdaza declines year over year and the built-up area is fluctuation This results from the increase in population and demand of water and for the decreased of vegetation this is attributable to humans activities, fires, and climate change which resulted in a significant decrease in the percentage of different classes of vegetation. (Meddour-Sahar O, 2015)

3.3. LST variation

The Land Surface Temperature (LST) is essential for evaluating biogeochemical processes concerning surface materials. LST serves as a key parameter in assessing the ecological condition of both rural and urban areas, as it varies with changes in the texture and composition of land surfaces

The mean annual LST calculated from the MOD11A1 dataset using the conversion of land surface temperature (LST) value from kelvin to Celsius utilizing the equation: (Imtiaz et al., 2024)

$$\text{LST_Celsius} = (\text{LST_kelvin} * 0.02) - 273.15$$

The maps in Fig 64 illustrating the mean annual LST demonstrate the yearly variations in temperature throughout the years under investigation. The results in maximum were varied between 30°C and 33.9°C and in minimum between 22°C and 24.6°C.

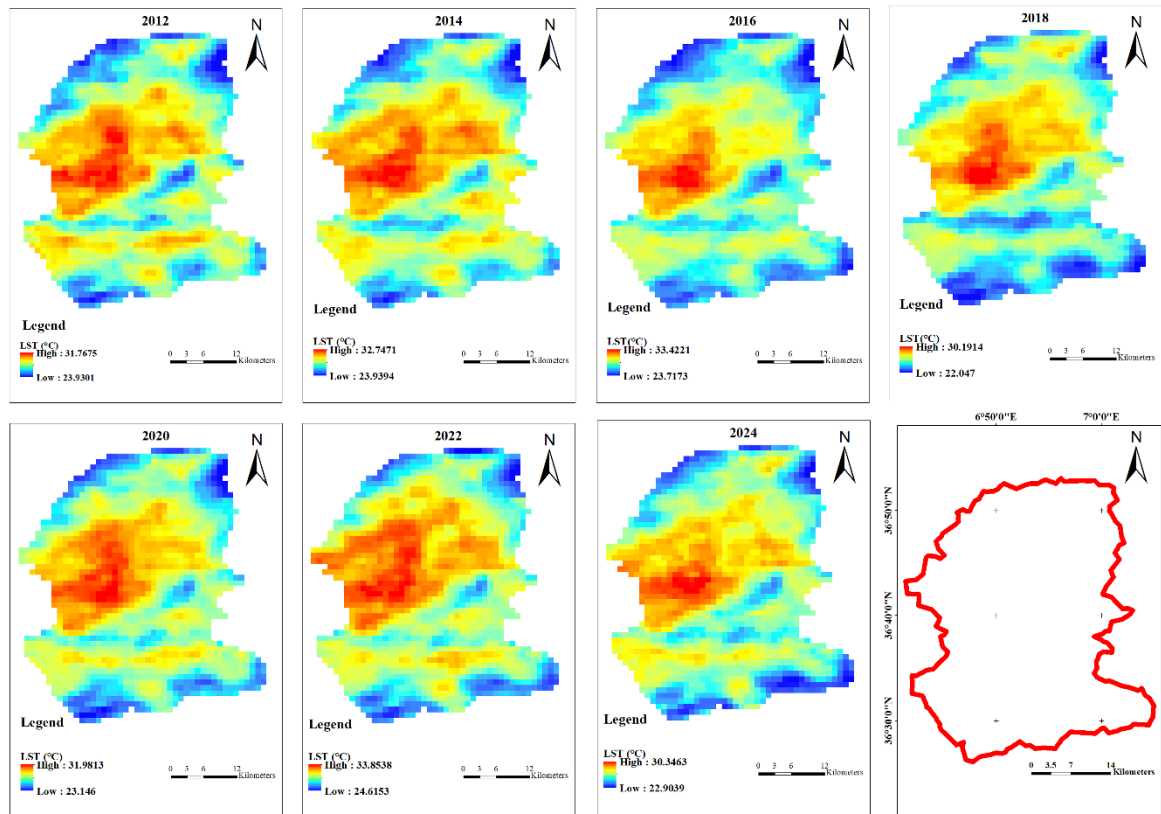


Figure 61: land surface temperature of the Safsaf watershed from 2012 to 2024

The average LST over the years, as presented in the Fig65, indicates varying temperatures from 2012 to 2024, recorded as follows: 28.55°C, 28.93°C, 28.67°C, 26.13°C, 28.19°C, 29.87°C, and 26.84°C.

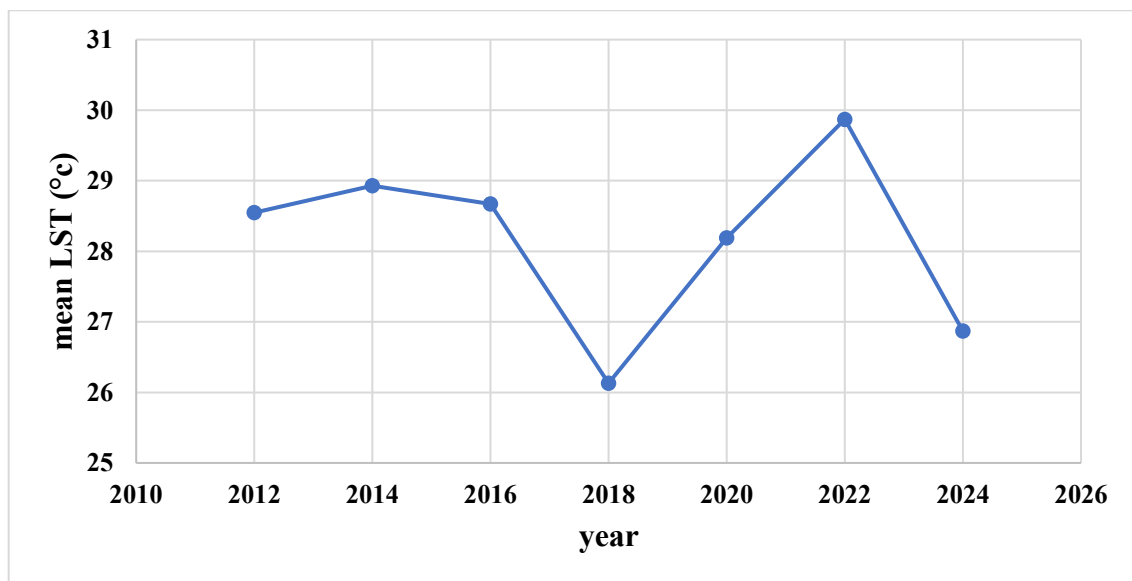


Figure 62: variability of land surface temperature from 2012 to 2024

3.4. NDVI variation

One useful tool for assessing vegetation health is the Normalized Difference Vegetation Index (NDVI), developed by Rouse et al. in 1974.

The average annual NDVI estimated from the MOD09GA dataset with the equations (Fikiru et al, 2023):

$$NDVI = (NIR - RED) / (NIR + RED)$$

From the MOD09GA dataset, the mean annual normalized difference vegetation index (NDVI) was calculated, and the results are represented in Fig. 64, The maps indicated the different values of NDVI with a maximum range between 0.75 and 0.86, and a minimum range from -0.09 to -0.005.

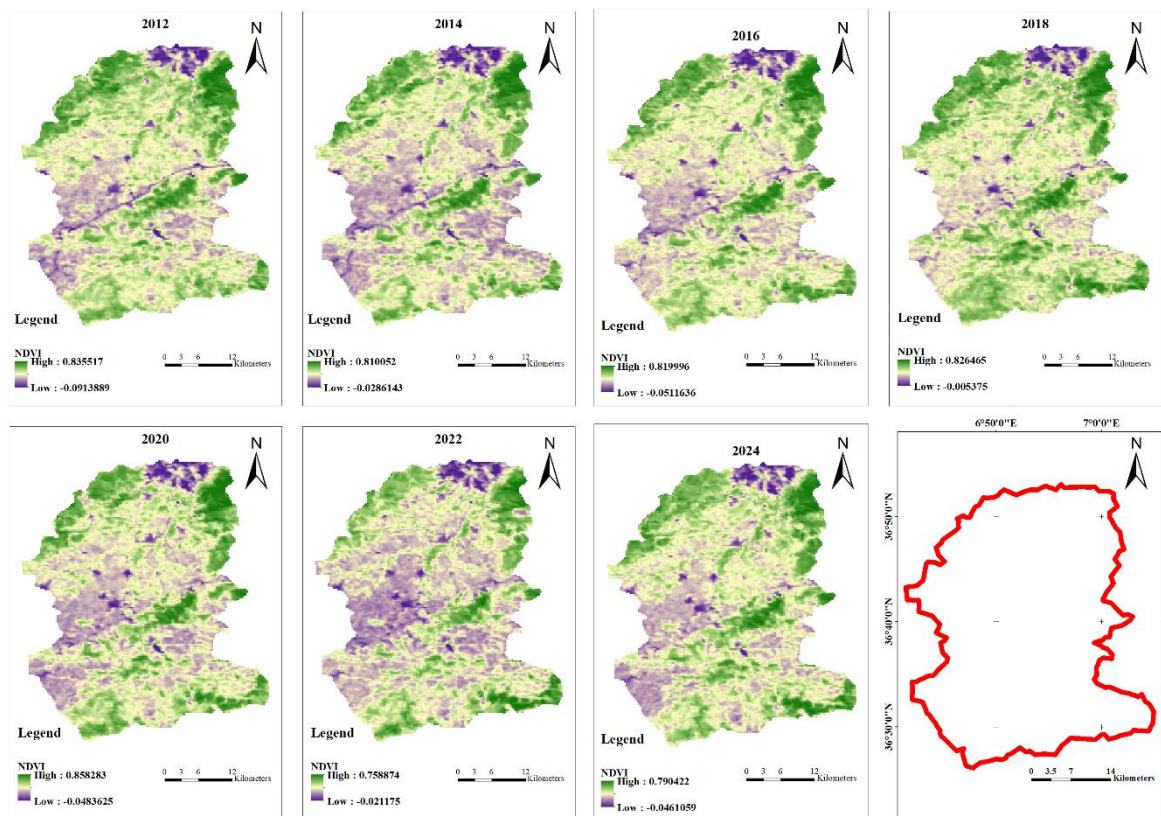


Figure 63: Normalized difference vegetation index in the Safsaf watershed from 2012 to 2024

The average NDVI values as represented in Figure 66 over the years are as follows: 0.53 in 2012, 0.50 in 2014, 0.52 in 2016, 0.56 in 2018, 0.55 in 2020, 0.46 in 2022, and 0.51 in 2024

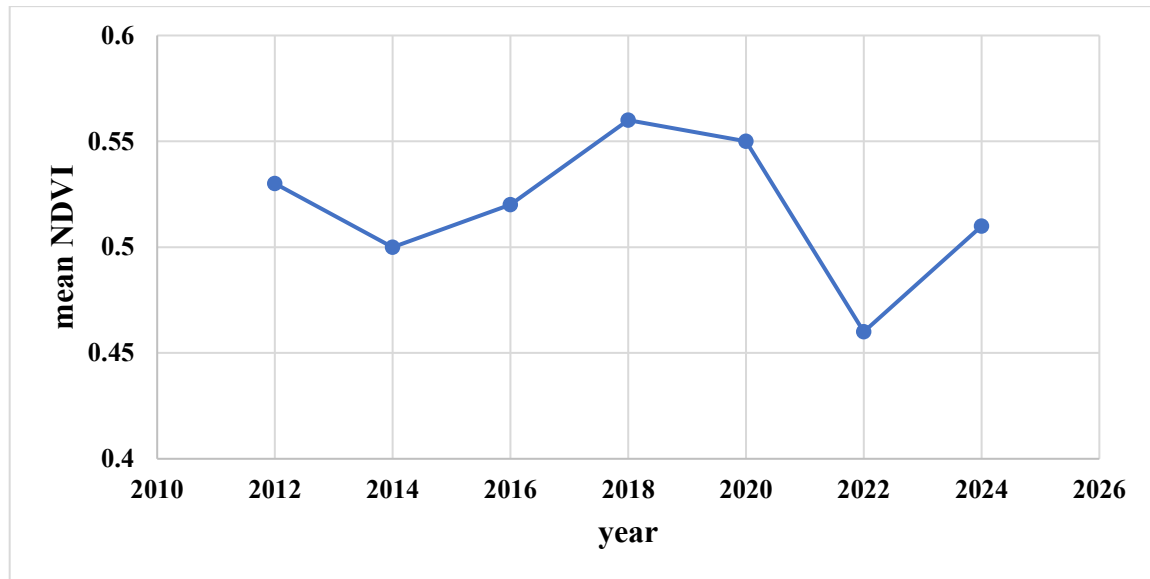


Figure 64: variability of the normalized difference vegetation index from 2012 to 2024

3.5. NDWI variation

The Normalized Difference Water Index (NDWI) effectively studies changes in land cover by monitoring the presence of water

The average annual NDWI estimated from the MOD09GA dataset with the equations (Sobhanil et al. 2022):

$$\text{NDWI} = (\text{Green} - \text{NIR}) / (\text{Green} + \text{NIR})$$

The mean annual variation of the normalized difference water index (NDWI) as estimated by MOD09GA for the study period is illustrated in the accompanying Fig 68, as observed from the results that the maximum NDWI range is from -0.11 to -0.15, while the minimum values vary between -0.45 and -0.52.

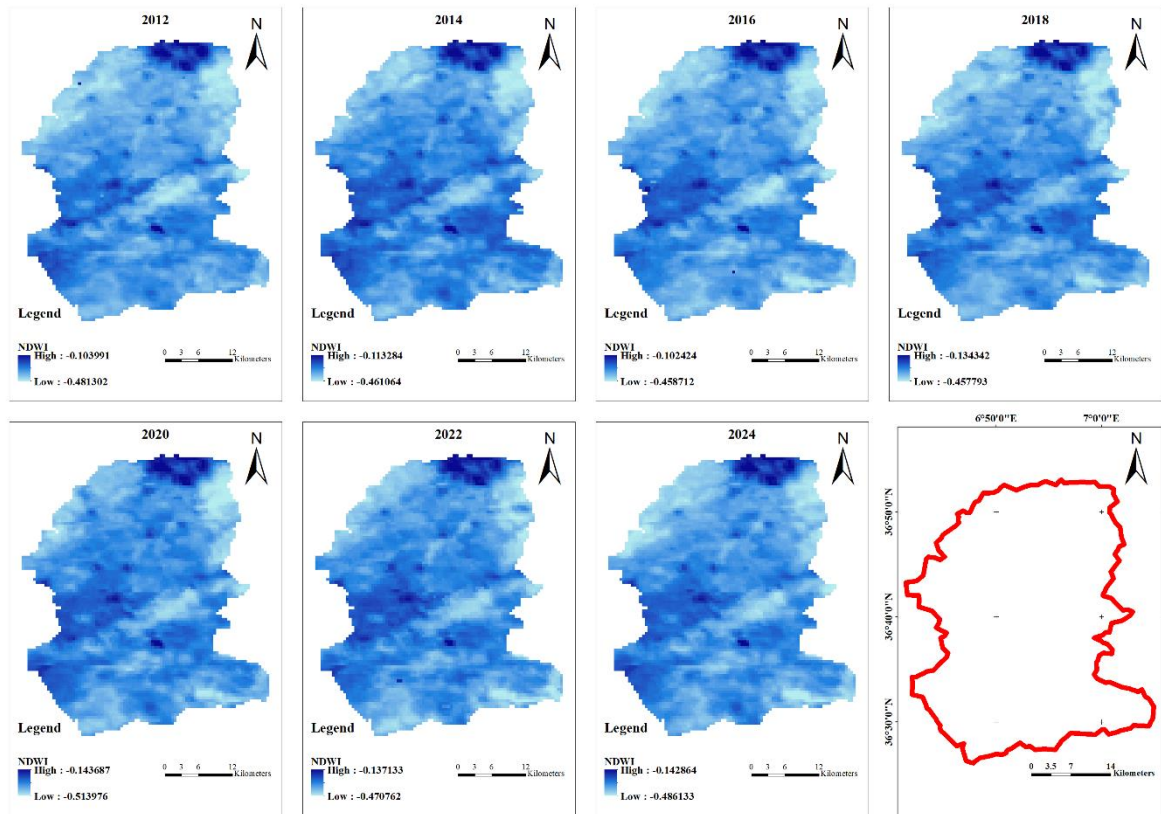


Figure 65: Normalized difference water index in Safsaf watershed from 2012 to 2024

As shown in Fig. 69 the average annual NDWI for each year is in the following order: -0.363 in 2012, -0.352 in 2014, -0.364 in 2016, -0.365 in 2018, -0.393 in 2020, -0.369 in 2022, and -0.39 in 2024

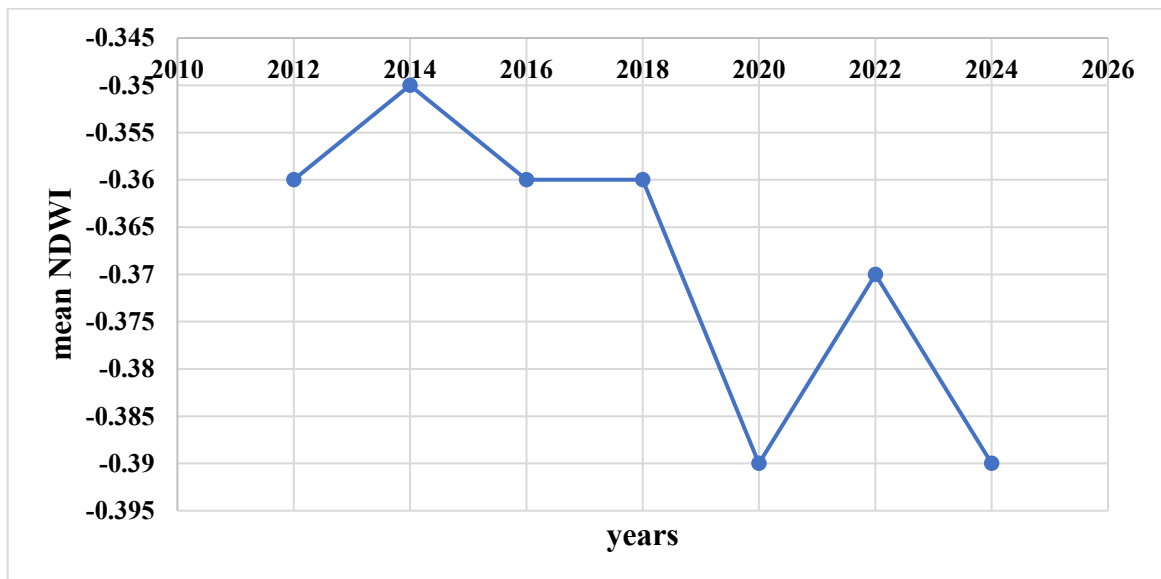


Figure 66: variability of the normalized difference water index from 2012 to 2024

3.6. Precipitation variation

For the climate data, the CHIRPS dataset was used to extract the annual precipitation of the study area.

The maps in Figure 70 show the total annual precipitation of the study area estimated by CHIRPS over the 7 years 2012, 2014, 2016, 2018, 2020, 2022, and 2024. During this period, the maximum precipitation varied from 600 mm to 832 mm, while the minimum values changed between 440 mm and 586 mm.

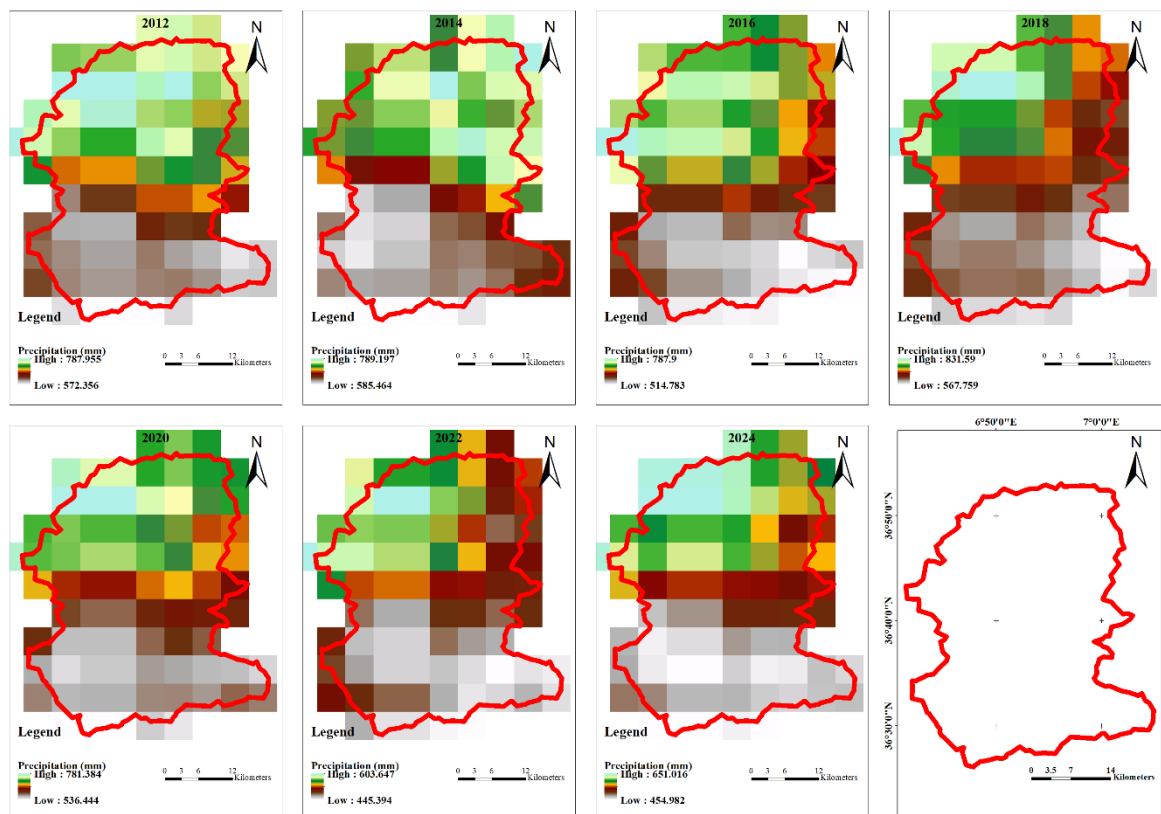


Figure 67: Precipitation in the Safsaf watershed from 2012 to 2024

Figure 71 presents the average annual precipitation for the study duration. The results are as follows: 685.15 mm in 2012, 689.44 mm in 2014, 627.77 mm in 2016, 681.2 mm in 2018, 647.2 mm in 2020, 504.19 mm in 2022, and 533.58 mm in 2024.

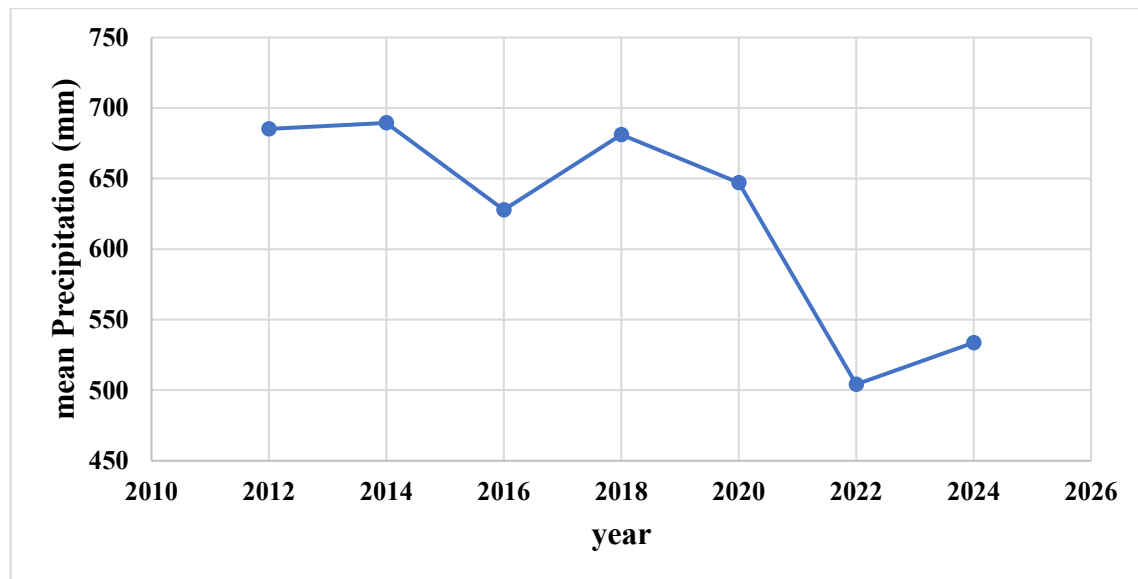


Figure 68: variability of precipitation from 2012 to 2024

The rise in land surface temperature (LST) and the decrease in precipitation can be attributed to several factors, including urbanization, deforestation, and climate change. (Hussain et al., 2024). The increase in LST and the reduction in precipitation may result in higher rates of evapotranspiration, reduced soil moisture, and alterations to the local microclimate. These changes in climate factors can also damage vegetation health. (Ben He et al., 2015). The normalized difference vegetation index (NDVI) values observed over the same period, combined with the rising temperatures in recent years, may have contributed to vegetation stress, leading to lower NDVI values in certain areas. (Kingsley and Bhuiyam, 2024) The fluctuation of NDWI shows from 2012 to 2024, indicating a potential reduction in surface water availability, especially during higher temperatures

4. Correlation with LST

4.1. LST and NDVI

To enhance the analysis of the relationship between mean annual Land Surface Temperature (LST) and mean annual Normalized Difference Vegetation Index (NDVI), Pearson's correlation was employed to calculate the correlation coefficient using the GraphPad statistical tool. The results presented in Fig. 70 illustrate the correlation for each year from 2012 to 2024. The relationship between LST and NDVI reveals a moderate negative correlation, which is statistically significant ($p < 0.0001$). The highest negative Pearson's coefficient was recorded in 2016 ($r = -0.59$), while the lowest was observed in 2018 ($r = -0.52$). These findings indicate that LST and NDVI are moderately negatively correlated; as LST decreases, NDVI tends to increase. (Charrouf, N. et al., 2025)

Table 52: Results of correlation between LST and NDVI

year	LST vs NDVI	
	r	P value
2012	-0.56	<0.0001
2014	-0.57	<0.0001
2016	-0.59	<0.0001
2018	-0.52	<0.0001
2020	-0.58	<0.0001
2022	-0.58	<0.0001
2024	-0.54	<0.0001

The results of Pearson's correlation analysis indicate a moderate negative relationship between Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI). This suggests that higher plant biomass is associated with lower LST values (Hussain et al. 2023, Kingsley and Bhuiyam, 2024), meaning that areas with the lowest NDVI values have sparse plant distribution.

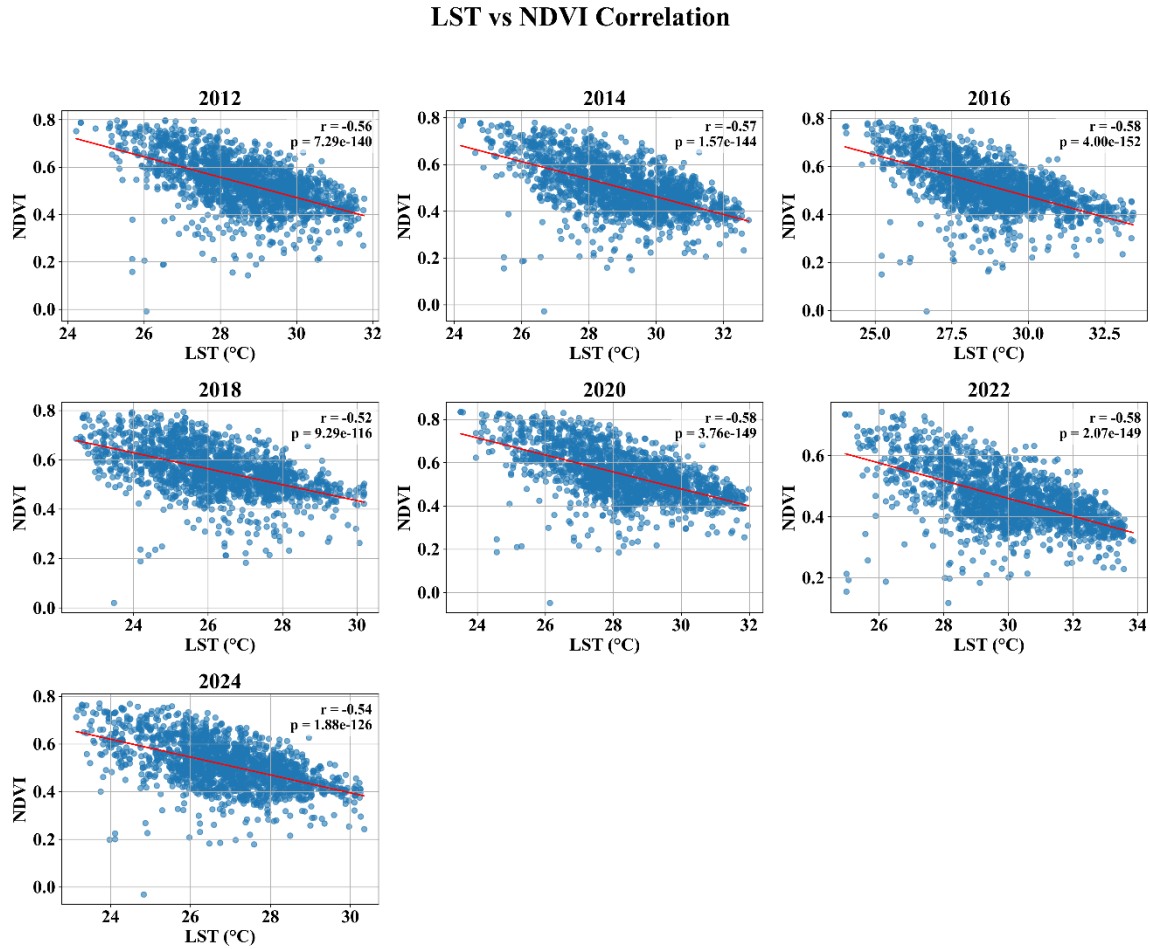


Figure 69: correlation between NDVI and LST in the Safsaf watershed from 2012 to 2024

5. Correlation with precipitation

5.1. Precipitation and NDWI

A correlation between mean annual NDWI and total annual Precipitation is shown in Fig 73 for the years 2012, 2014, 2016, 2018, 2020, 2022, and 2024. Person's correlation was utilized to evaluate the relationship between NDWI and Precipitation using GraphPad. The Fig. 14 indicates that the correlation between NDWI and precipitation is a weak negative correlation with a highly significant correlation ($p < 0.0004$, 0.0001) for all the years except 2022, where the P-value is < 0.0107 . The observed r values for the different years were relatively small, with the highest negative Pearson's coefficient recorded in 2014 ($r = -0.33$) and the lowest in 2022 ($r = -0.67$). As a result, it can be concluded that NDWI has a weak negative association with precipitation, suggesting that precipitation has a statistically significant negative impact on NDWI. (Charrouf, N. et al., 2025)

Additionally, there is a weak negative relationship between the Normalized Difference Water Index (NDWI) and precipitation, indicating that precipitation does not have a strong influence on NDWI. This is likely due to the study area lacking significant water surfaces, except for the Zerdaza Da

Table 53: Results of the correlation between Precipitation and NDWI

year	Precipitation vs NDWI	
	r	P value
2012	-0.30	<0.0001
2014	-0.33	<0.0001
2016	-0.09	<0.0004
2018	-0.23	<0.0001
2020	-0.15	<0.0001
2022	-0.07	<0.0107
2024	-0.17	<0.0001

PREC vs NDWI Correlation

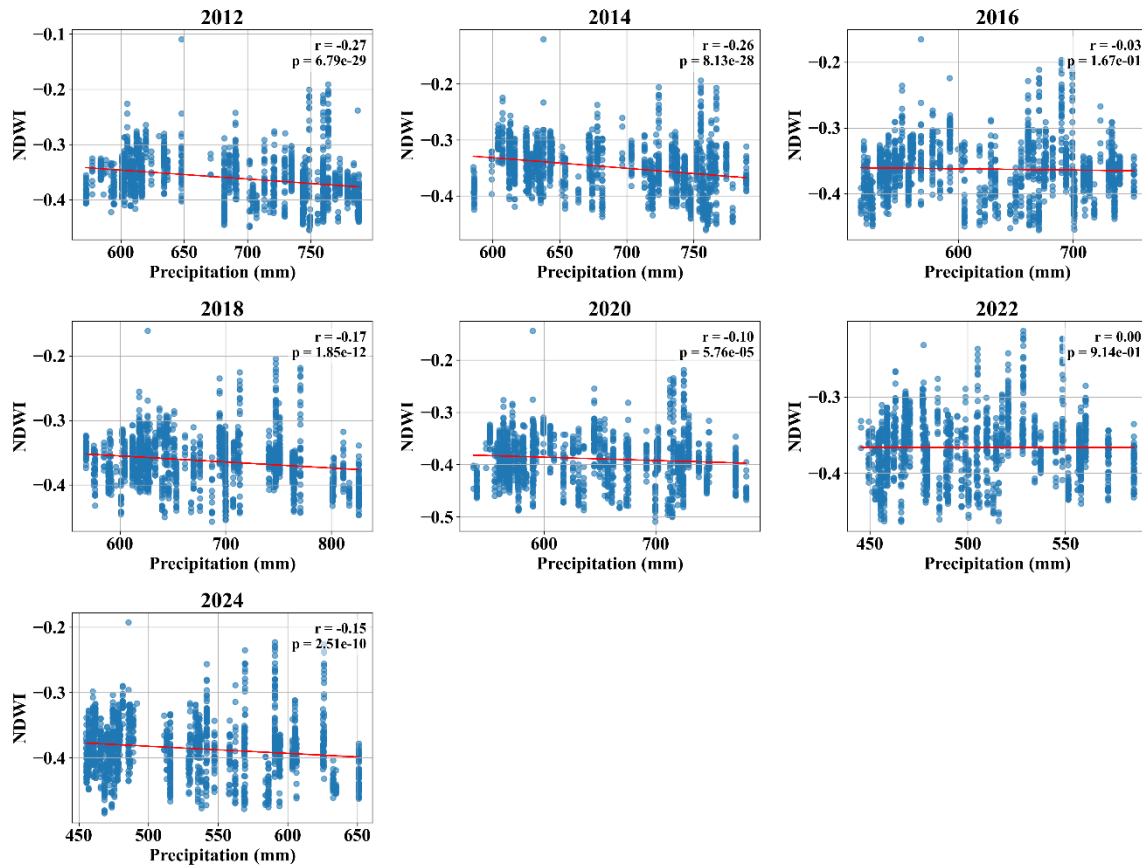


Figure 70: correlation between NDWI and Precipitation in the Safsaf watershed from 2012 to 2024

6. Zerdazas dam surface change

Zerdazas dam is located in zerdaza in the daira of El Harrouch, which is positioned in the southern part of the Safsaf watershed. Following the coordinates, longitude 6.898° and latitude 36.59° , with an elevation of 170 m above sea level. The dam, covering an area of 2 km², plays a crucial role in regulating water flow and providing irrigation and drinking water for various surrounding communities. (Kemoukh, et al . 2024)

Landsat 8 (OLI/TIRS) Surface Reflectance (Collection 2, Level 2, Tier 1) data are used to analyze the Normalized Difference Water Index (NDWI) and the modified normalized difference water index (MNDWI) and detect changes in the surface of Zerdaza Dam for the years 2016, 2018, 2020, 2022, and 2024. Landsat satellites have a spatial resolution of 30 m and a temporal resolution of 16 days.



Figure 71:Zerdaza Dam (Feb/2025)

6.1. Landsat MNDWI

The classification results of the Zerdaza Dam surface based on MNDWI calculations from the Landsat 8 image (Fig. 75) illustrate the spatial distribution of its surface from 2016 to 2024.

The MNDWI was calculated using the equation:

$$\text{MNDWI} = (\text{GREEN} - \text{SWIR1}) / (\text{GREEN} + \text{SWIR1}).$$

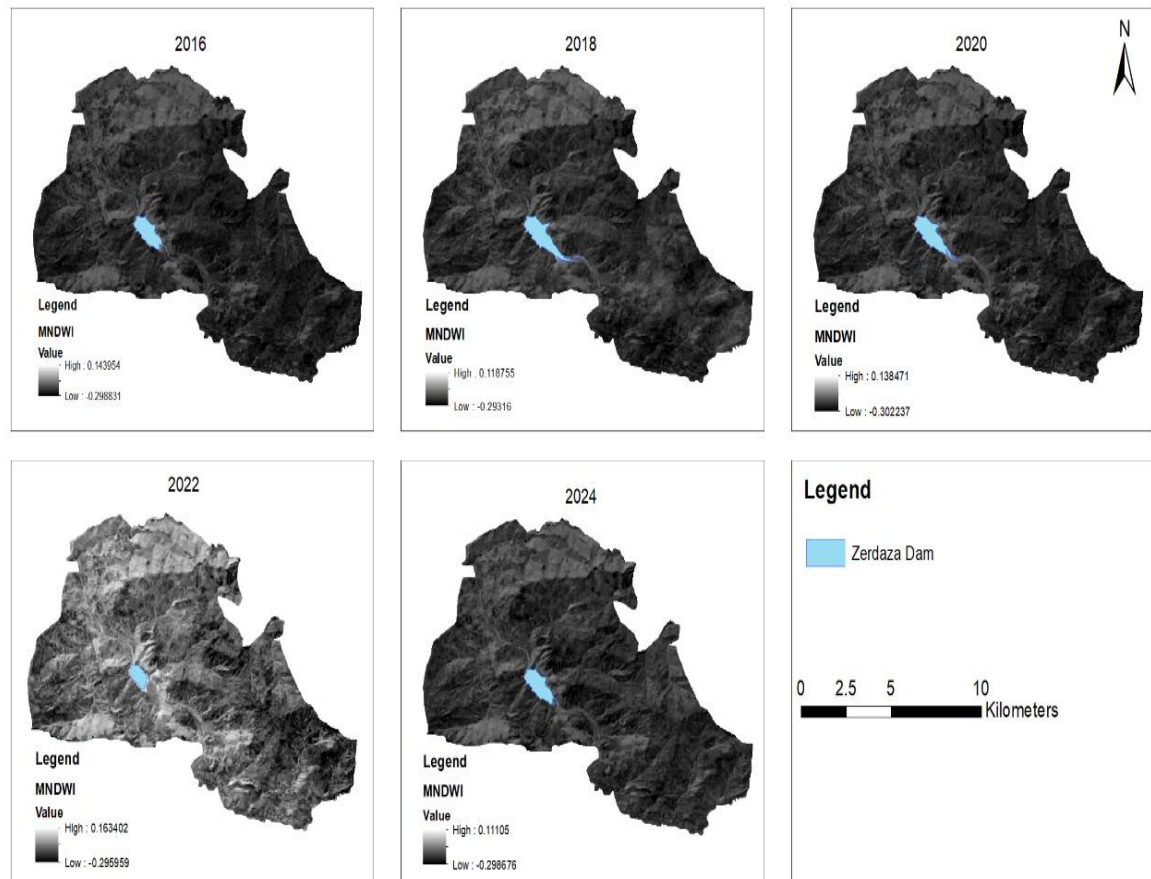


Figure 72: area change of Zerdaza dam based on MNDWI index over the years

6.2. Landsat NDWI

The classification results of the Zerdaza Dam surface based on NDWI index calculations from Landsat images (Fig. 76) illustrate the spatial distribution of its surface from 2016 to 2024.

The NDWI was calculated using the equation:

$$NDWI = (GREEN - NIR) / (GREEN + NIR).$$

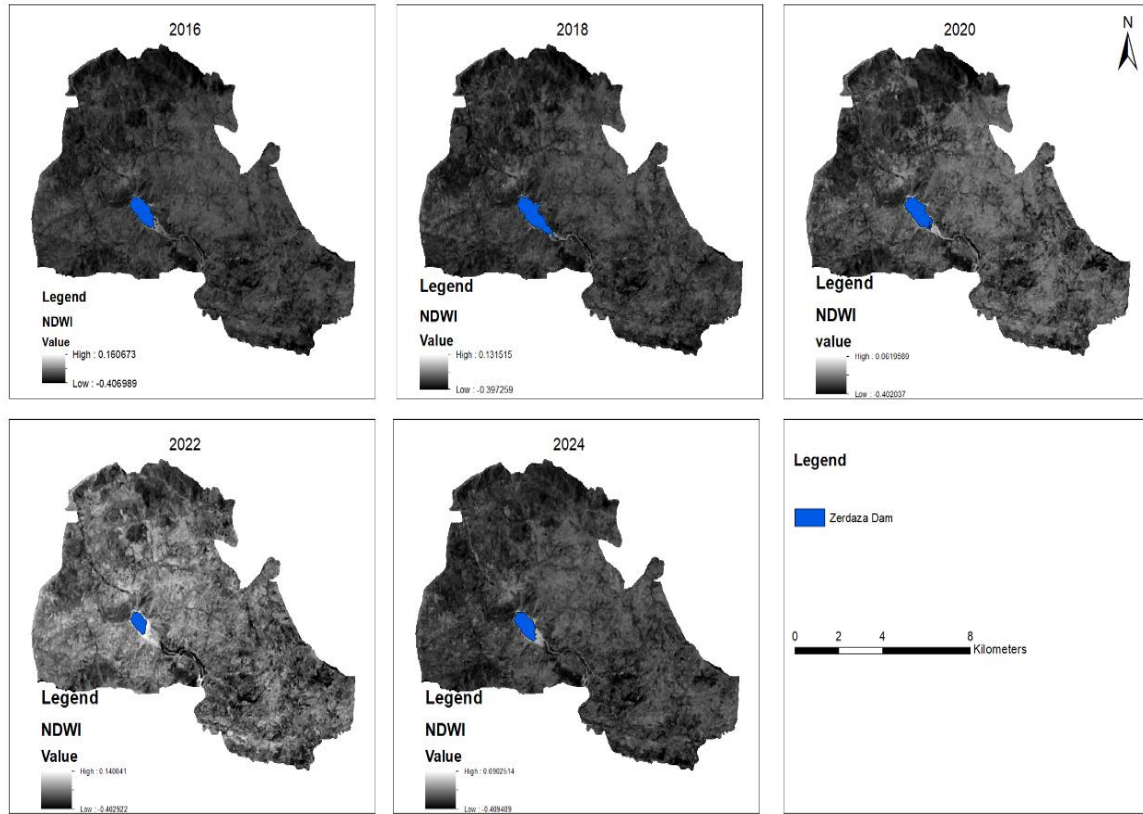


Figure 73: area change of the Zerdaza dam based on the NDWI index over the years

We have three data sources to compare the surface area of Zerdaza Dam: Landsat MNDWI and NDWI data, and NADT data. To conduct this comparison, we selected 2016, 2018, 2020, 2022, and 2024.

In 2016, the surface area of the dam was 0.84 km², according to the MNDWI index, 0.75 km² according to the NDWI index, and 0.89 km² according to the NADT.

In 2018, the surface area of the dam was 1.15 km², according to the MNDWI index, 1.07 km² according to the NDWI index, and 1.16 km² according to the NADT.

In 2020, the surface area of the dam was 1.04 km², according to the MNDWI index, 0.863 km² according to the NDWI index, and 1.14 km² according to the NADT.

In 2022, the surface area of the dam was 0.464 km², according to the MNDWI index, 0.42 km² according to the NDWI index, and 0.62 km² according to the NADT.

In 2024, the surface area of the dam was 0.88 km² according to the MNDWI index, 0.73 km² according to the NDWI index, and 0.87 km² according to the NADT.

Table 54: area change of Zerdaza dam based on the NDWI, MNDWI index, and NADT over the years

YEAR	2016	2018	2020	2022	2024
MNDWI index(km ²)	0.84	1.15	1.04	0.464	0.88
NDWI index(km ²)	0.75	1.07	0.863	0.42	0.73
NADT (km ²)	0.89	1.16	1.14	0.62	0.87

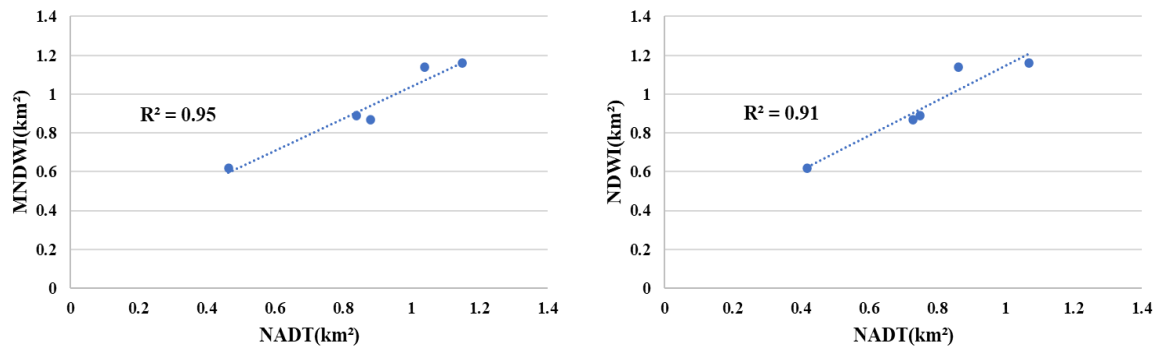


Figure 74: Correlation results between MNDWI, NDWI, and NADT

For the Zerdaza Dam, regarding the surface comparison between the MNDWI and NDWI indices and the NADT data, we note that the MNDWI index provides better results than the NDWI index according to R^2 . We observed the degradation of the dam's surface due to the decrease in precipitation, especially in 2022. According to the NADT, the water from the dam in 2022 was used solely for drinking water supply and not for irrigation.

The Zerdaza dam surface calculation using the NDWI and MNDWI indices and compared to NADT information revealed that the MNDWI index provides superior results compared to the NDWI index, with changes in the dam surface attributed to decreased precipitation and its utilization towards citizens.

Conclusion

Algeria, part of the Mediterranean hot spot, is highly vulnerable to climate change. Experts project a medium-term rise in temperature of 2 °C, a 20-30% reduction in rainfall, and more frequent and intense droughts. To address this, and to ensure water availability, prevent soil erosion, and promote sustainable development, the country has adopted a climate adaptation and GHG mitigation strategy. This strategy focuses on all sectors, especially the energy sector, which accounts for over 70% of GHG emissions.

Chapter 5 _____ The impact of climate change on vegetation and water resources

The Safsaf watershed has experienced notable changes in various vegetation and LULC classes, driven by factors such as climate change and human activities. Variations in LST, NDVI, NDWI, and Precipitation—caused by climate change and other factors indicate that future climate adaptation strategies should emphasize water resource management and address rising temperatures.

The correlation analysis reveals a moderate negative relationship between LST and NDVI, suggesting that higher temperatures tend to reduce vegetation. The correlation between NDWI and Precipitation is weak and negative, implying that Precipitation does not significantly affect NDWI in this region because our study area has a very limited water surface.

General Conclusion

Two critical parameters influence plant production: temperature and rainfall, including both quantity and distribution, during the various stages of the plant growth cycle. Climate change is expected to significantly reduce soil water reserves due to decreased rainfall and heightened evaporation from both plants and soil, exacerbated by rising temperatures. Particularly for Algeria, projections from multiple climate models indicate a decline in rainfall coupled with increased temperatures, which poses serious threats to crops and soil health. The primary consequence is intensified water stress, leading to reduced agricultural yields.

The effects of climate change on plants are not uniform; they vary according to crop type. Elevated temperatures lead to increased soil evaporation, which in turn raises soil salinity and contributes to soil degradation. Furthermore, higher temperatures can shift seasonal patterns, resulting in drier winters and wetter springs with altered rainfall distribution. This could shorten the agricultural season, necessitating adaptations such as the development of new crop varieties, changes in farming methods, and revisions to planting and harvesting schedules.

This study focuses on the implications of climate change for the irrigation areas within the Safsaf basin. The Oued Saf-Saf watershed, located in northeastern Algeria, lies between latitudes 36° and 37° North and longitudes 6°30' and 7° East. It is part of the Constantinois coastal basins and has an elongated shape, encompassing an area of 1167.9 km² with a compactness index of 1.56. The region is characterized by its rugged terrain and an average drainage density of 0.443 km/km², ranging from an elevation high of 1,162 meters to a low of 2 meters at the watershed outlet.

Geologically, the Safsaf region is made up of three distinct stratigraphic and structural units: the Kabyle basement, which primarily consists of Paleozoic metamorphic formations; the Permo-Triassic formations that create the Kabyle ridge; and the Mauritanian, Massylian flysch, and Numidian nappe found between the two main units. Tectonically, the region has undergone three significant phases, starting from early activity during the Cretaceous-Paleocene, transitioning through the Late Lutetian phase (from the upper Lutetian to upper Priabonian), and culminating in the Late Oligocene to Miocene phase (spanning late Oligocene to the Aquitanian).

Climatically, the Safsaf area experiences a temperate climate featuring harsh winters and hot summers. Annual precipitation ranges from 599 to 747 mm, subject to variation depending on the specific measurement station. Average monthly temperatures hover around 18.4 °C, with infiltration rates recorded between 36.83 mm and 66.6 mm.

Irrigation in the Safsaf region employs three primary techniques: gravity, sprinkler, and drip irrigation. In response to the challenges brought about by climate change and drought, which have resulted in critically low surface water levels in reservoirs and valleys, it has become increasingly imperative to adopt more efficient irrigation methods. Moreover, the growing population density intensifies the demand for crop production, as indicated by the data from previous tables. In this context, drip irrigation stands out as the most effective approach for conserving water while ensuring significant agricultural yields.

This method minimizes water waste by delivering precise amounts directly to the roots of plants, thereby enhancing water use efficiency and fostering healthier crop growth. Compared to other irrigation techniques, drip irrigation offers numerous advantages, including reduced evaporation losses, diminished weed growth, and the ability to apply fertilizers directly to the root zone, thereby maximizing productivity.

Implementing drip irrigation systems in the Safsaf perimeter could substantially mitigate the effects of water scarcity, promote sustainable agricultural practices, and effectively meet the increasing food demands of a growing population.

Based on the land suitability analysis, from the 362.2 km² assessed in the watershed, areas are classified according to their agricultural potential: 221.8 km² are moderately suitable, while 267.3 km² fall into the marginally suitable category. Additionally, 218 km² are currently deemed unsuitable, with 61.13 km² categorized as permanently unsuitable. Given the challenges posed by climate change and drought—resulting in diminished surface water levels in reservoirs and waterways, combined with a rising population demanding more crops—the study identifies drip irrigation as the most efficient method for minimizing water waste while maximizing agricultural productivity.

The findings from this study indicate that land use in the Safsaf watershed comprises five primary classes: water bodies (including Zerdaza Dam and the basin's wadi), cultivated crops, barren ground (comprising rocks or unplanted soil), forested sections, and urbanized areas. Each class occupies different proportions of the total area.

Correlation analysis reveals a moderate negative relationship between Land Surface Temperature (LST) and the Normalized Difference Vegetation Index (NDVI), suggesting that higher temperatures may negatively impact plant growth. Additionally, a weak negative correlation is noted between NDWI and precipitation, signifying that rainfall has minimal influence on NDWI within this area.

In light of the water scarcity challenge, it is crucial to implement robust policies focused on water conservation and efficient utilization. Key hurdles include ensuring the safety of the population and maintaining economic stability, as water security has a direct impact on food security. While significant progress has been achieved in mobilizing water resources for domestic and agricultural use, further advancements are essential in the agricultural sector.

Algeria possesses the potential to address the challenges of climate change successfully, contingent upon fulfilling several conditions: fostering skilled human capital, fully utilizing existing resources, promoting coordinated initiatives, and establishing effective governance structures.

Bibliographic Reference

- Adedeji, O. et al. (2014).** Global Climate Change. *Journal of Geoscience and Environment Protection*, 2, 114-122
- Allouche, M. (2015).** The DPSIR model for the management of an irrigated perimeter in the Saf-Saf Skikda basin (North-East Algeria). Magister's thesis. Univ. Annaba. 262p.
- AMEL, M. (2011).** *Estimation of reference floods for Flood Risk Prevention Plans. Cas du bassin versant du Saf Saf, NE algérien (Doctoral dissertation, Université d'Annaba-Badji Mokhtar).*
- Bakhtache, R., & Hadjene, O. (2023).** The impact of climate change on the agricultural and hydraulic sectors in Algeria (2010/2022). 95-80 , (1)14 , *مجلة دفاتر اقتصادية*.
- Boucenna, N. (2007).** Impact de la décharge publique sur la qualité des eaux souterraines : cas de Zef-Zef, Skikda (Doctoral dissertation, Annaba).
- Boundi, A. (2021).** Resilience to climate change: conversion from gravity to localized irrigation in semi-arid zones (Doctoral dissertation, Faculty of Science and Technology of Béni Mellal; Université Moulay Slimane-Maroc).
- Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (1990).** Irrigation methods. FAO, *Italy*.
- Charrouf, N., Zighmi, K., Amel, M., Benmarce, K., Hadji, R., Hamed, Y., ... & Farid, Z. (2025).** ASSESSING CLIMATE CHANGE IMPACTS ON VEGETATION AND WATER DYNAMICS IN SEMI-ARID WATERSHEDS USING REMOTE SENSING TECHNIQUES. *Studia Quaternaria*, 42, 61-73.
- Coutagne A. (1939).** In search of a method and a formula to measure and express the evaporative power of the atmosphere. *Meteorology*, November-December, pp. 288-292.
- D. G. de l'Environnement (2001).** Development of the national climate change strategy and action plan.
- Daccache, A., & Lamaddalena, N. (2010, June).** Climate change impacts on pressurised irrigation systems. In *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* (Vol. 163, No. 2, pp. 97-105). Thomas Telford Ltd.
- Dehghan, Z., Fathian, F., & Eslamian, S. (2019).** Climate change impact on agriculture and the irrigation network. In *Climate Change-Resilient Agriculture and Agroforestry: Ecosystem Services and Sustainability* (pp. 333-354). Cham: Springer International Publishing.
- Effat HA, Hassan OA (2013).** Designing and evaluating three alternative highway routes using the analytical hierarchy process and the least-cost path analysis, application in the Sinai Peninsula, Egypt. *Egypt J Remote Sens Space Sci* 16(2):141–151
- Feizizadeh B, Jankowski P, Blaschke T (2014)** A GIS-based spatially explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. *Comput Geosci* 64:81–95

Gelata, F. T., Jiqin, H., Chaka Gameda, S., & Wubishet Asefa, B. (2023). Application of GIS using NDVI and LST estimation to measure climate variability-induced drought risk assessment in Ethiopia. *Journal of Water and Climate Change*, 14(7), 2479-2489.

Gravelius H. (1914). Grundrifi der gesamten Gewässerkunde, Band 1: h'lufikunde (Compendium of Hydrology, vol. 1: Rivers, in German). Goschen, Berlin, Germany

Guha, S., Govil, H., Taloor, A. K., Gill, N., & Dey, A. (2022). Land surface temperature and spectral indices: A seasonal study of Raipur City. *Geodesy and Geodynamics*, 13(1), 72-82.

HARBI, S et OUADDAH, M (1996). Contribution to the study of the West SAFSAF watershed - impact of erosion on water availability

He, B., Chen, A., Wang, H., & Wang, Q. (2015). Dynamic response of satellite-derived vegetation growth to climate change in the Three North Shelter Forest Region in China. *Remote Sensing*, 7(8), 9998-10016.

Hussain, S., Mubeen, M., Nasim, W., Mumtaz, F., Abdo, H. G., Mostafazadeh, R., & Fahad, S. (2024). Assessment of future prediction of urban growth and climate change in the district of Multan, Pakistan, using the CA-Markov method. *Urban Climate*, 53, 101766.

Imtiaz, F., Farooque, A. A., Randhawa, G. S., Wang, X., Esau, T. J., Acharya, B., & Garmdareh, S. E. H. (2024). An inclusive approach to crop soil moisture estimation: Leveraging satellite thermal infrared bands and vegetation indices on Google Earth Engine. *Agricultural Water Management*, 306, 109172.

Khelfaoui, F. (2014). *Qualité et gestion intégrée des ressources en eau dans le bassin versant du Saf-Saf (Nord-Est algérien)*. Doctoral dissertation, Université Badji Mokhtar Annaba, Algeria.

Kanjin, K., & Alam, B. M. (2024). Assessing changes in land cover, NDVI, and LST in the Sundarbans mangrove forest in Bangladesh and India: A GIS and remote sensing approach. *Remote Sensing Applications: Society and Environment*, 36, 101289.

Kemoukh, S., Athamena, A., Djaiz, F., Belalite, H., & Athamena, M. (2024). The salinity origin of the surface water in the watershed dam zardezas, eastern Algeria. *Analele Universităţii Din Oradea, Seria Geografie*, 34(1), 44-63.

Lakhdari, H. (2009). The consequences of climate change on agricultural development in Algeria: what adaptation strategies in the face of water scarcity?. *Revue des sciences économiques de gestion et sciences commerciales*, 19.

Lamia, L., & Youcef, L. (2024). Comparative Spatio-Temporal Dynamics of Urban Sprawl in Algerian Cities Skikda and Tébessa (1985-2024) Using GIS and Landsat Imagery. *Journal of Contemporary Urban Affairs*, 8(2), 404-420.

Li, C., van Donkelaar, A., Hammer, M. S., McDuffie, E. E., Burnett, R. T., Spadaro, J. V., ... & Martin, R. V. (2023). Reversal of trends in global fine particulate matter air pollution. *Nature communications*, 14(1), 5349.

Maou, A., Souadnia, S., Faqeih, K., AlAmri, A., Hadji, R., Alamri, S. M., ... & Altwaiher, J. (2025). Assessing flash flood occurrences and hazard zones along the

Mediterranean coasts: a GIS and mapping techniques approach in the Wadi Saf Saf Basin, Northeast Algeria. *Frontiers in Earth Science*, 13, 1594364.

Martonne EMM. (1940). Treatise on Physical Geography. Sixth revised and corrected edition. Volume one. General notions, Climate, Hydrography. Edition Armand Colin, p.496.

Miller, W., Collins, M. G., Steiner, F. R., & Cook, E. (1998). An approach for greenway suitability analysis. *Landscape and Urban Planning*, 42(2-4), 91-105.

Ministry of the Environment and Renewable Energies, Plan national climat, 2019 (web: <https://www.me.gov.dz/fr/telechargement/plan-national-climat>)

Ministry of the Environment and Renewable Energy, Algeria's first biennial update report to the United Nations Framework Convention on Climate Change, 2023

Mohammed, T., & Al-Amin, A. Q. (2018). Climate change and water resources in Algeria: vulnerability, impact, and adaptation strategy. *Economic and Environmental Studies (E&ES)*, 18(1), 411-429.

Moharir, K. N., Pande, C. B., Gautam, V. K., Dash, S. S., Mishra, A. P., Yadav, K. K., ... & Elsayabi, M. (2025). Estimation of land surface temperature and LULC changes impact on groundwater resources in the semi-arid region of Madhya Pradesh, India. *Advances in Space Research*, 75(1), 233-247.

Monograph of the wilaya of SKIKDA: National Agency for Land Intermediation and Regulation

Naikoo, M. W., Rihan, M., & Ishtiaque, M. (2020). Analyses of land use land cover (LULC) change and built-up expansion in the suburb of a metropolitan city: Spatio-temporal analysis of Delhi NCR using Landsat datasets. *Journal of Urban Management*, 9(3), 347-359.

Nikolaou, G., Neocleous, D., Christou, A., Kitta, E., & Katsoulas, N. (2020). Implementing sustainable irrigation in water-scarce regions under the impact of climate change. *Agronomy*, 10(8), 1120.

Park S, Jeon S, Kim S, Choi C (2011) Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea. *Landsc Urban Plan* 99(2):104–114

Phocaides, A. (2008). Manual of pressure irrigation techniques.

Raoult, J. F. (1975). Paleogeographic and structural evolution of the Alpine chain between the Gulf of Skikda and Constantine (eastern Algeria). *Bulletin de la Société géologique de France*, 7(3), 394-409.

Raoult, J.F., (1974). Geology of the Central Numidic Range (Northern Constantinois, Algeria). *Mem. Soc. Géol. Fr.* 121, 163.

Richardson, K., Steffen, W., Schellnhuber, H. J., Alcamo, J., Barker, T., Kammen, D. M., ... & Wæver, O. (2009, March). Synthesis report. In *Climate change: Global risks, challenges & decisions. Summary of the Copenhagen climate change congress* (pp. 10-12).

Saaty TL (1977) A scaling method for priorities in hierarchical structures. *J Math Psychol* 15:234–281

Saaty TL (1980). The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill International, New York

Sahnoune, F., Belhamel, M., Zemat, M., & Kerbach, R. (2013). Climate change in Algeria: vulnerability and strategy of mitigation and adaptation. *Energy Procedia*, 36, 1286-1294.

Thornthwaite C.W. (1948). An approach toward a rational classification of climate. *Geographical Review*, January 1948, p.55-94.

Tixeront B. (1961). Note on water development in southern Tunisia

Trenberth, K. E. (2018). Climate change caused by human activities is happening, and it already has major consequences. *Journal of energy & natural resources law*, 36(4), 463-481.

Turc L. (1961). Assessment of irrigation water requirements. Potential evapotranspiration (updated simplified climatic formula). *Annales Agronomiques*, 12 (1), p.13-49.

United Nations Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022: Summary of Results. UN DESA/POP/2022/TR/NO. 3.

Verdeil p. (1988). An abacus for calculating the flow deficit in Algeria. Communication at the Earth Sciences Seminar, Algiers, p.2

Vila, J. M. (1980). The Alpine chain of eastern Algeria and the Algerian-Tunisian border. Doctoral thesis in science, Pierre and Marie Curie University.

Vila, J. M. (1980). 1:500,000-scale structural map of the Alpine chain of eastern Algeria and the Algerian-Tunisian confines

Zerouali, B., Santos, C. A. G., do Nascimento, T. V. M., & da Silva, R. M. (2023). A cloud-integrated GIS for forest cover loss and land use change monitoring using statistical methods and geospatial technology over northern Algeria. *Journal of Environmental Management*, 341, 118029.

Zerouali, B., Santos, C. A. G., do Nascimento, T. V. M., & da Silva, R. M. (2023). A cloud-integrated GIS for forest cover loss and land use change monitoring using statistical methods and geospatial technology over northern Algeria. *Journal of Environmental Management*, 341, 118029.

Zheng, Y., Tang, L., & Wang, H. (2021). An improved approach for monitoring urban built-up areas by combining NPP-VIIRS nighttime light, NDVI, NDWI, and NDBI. *Journal of Cleaner Production*, 328, 129488.

Website :

Administrative organization of the territory:
<https://interieur.gov.dz/Monographie/index.php?wil=21>

U.S. Environmental Protection Agency. (n.d.). *Global Greenhouse Gas Overview*.
<https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview>

U.S. Environmental Protection Agency. *Agriculture Sector Emissions*. Dernière mise à jour le 31 mars 2025. <https://www.epa.gov/ghgemissions/agriculture-sector-emissions>.

World Bank. (n.d.). *Algeria – ERA5 Historical*. In *Climate Change Knowledge Portal*, from <https://climateknowledgeportal.worldbank.org/country/algeria/era5-historical>

World Meteorological Organization, *Greenhouse gases*, (web: <https://wmo.int/topics/greenhouse-gases>).

ANNEXE

Table 01: Population data for the municipalities in the Saf-Saf basin

Wilaya	Skikda							
Daira	Skikda		Azzaba		Elhadaiek		Sidi mezhriche	
Commune	skikda	hamadi krouma	elghedir	es sebt	elhadaiek	bouchtata	sidi mezhriche	ain bou ziane
Population 2010 (Res)	167286	31874	6767	15873	18722	9606	26638	10031
Population 2020 (Res)	202567	37637	7989	18902	22288	11415	31686	11872
Area (km ²)	52	31	46	244	48	112	95	76
Density 2010(Res/km ²)	3217.0	1028.2	147.1	65.1	390.0	85.8	280.4	132.0
Density 2020(Res/km ²)	3895.5	1214.1	173.7	77.5	464.3	101.9	333.5	156.2
Daira	Ramdan djamel		Elharrouch					
Commune	ramdan djamel	beni bachir	Elharrouch	emjez addchich	zerdaza	ouled hbaba	Salah Bouchaour	
Population 2010 (Res)	28375	10021	51072	20995	12997	8537	30929	
Population 2020 (Res)	36466	11932	60654	24855	15546	10363	36851	
Area (km ²)	144	42	96	77	102	199	96	
Density 2010(Res/km ²)	197.0	238.6	532.0	272.7	127.4	42.9	322.2	
Density 2020(Res/km ²)	253.2	284.1	631.8	322.8	152.4	52.1	383.9	

Table 02: Monthly precipitation Zerdaza dam station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	67.65	60.45	61.05	76.55	51	18.25	16.15	16.1	26.16	74.88	62.2	56.18
1976	81.2	107.3	83	65.2	40	13.7	31.9	18.4	61	121.2	0	27.1
1977	54.1	13.6	39.1	87.9	62	22.8	0.4	13.8	2.5	14.3	90.2	7.6
1978	96.9	81.5	58.6	66.3	41.4	12.8	0.5	17	3.5	35.3	97.8	23.7
1979	77.9	119.7	94.1	166.7	17.2	44.9	7.1	1.7	58.7	43	63.1	39.7
1980	66	53.1	80	56.9	60.1	0.6	0	3	5.1	160.6	59.9	182.8
1981	95.9	69.3	116.8	37.9	23	33.9	0	31.4	12.8	26.5	42.6	93.8
1982	116.7	98	116.2	76	70.7	1	14	0.2	25	136.8	193.7	107.3
1983	14.3	17.9	68.8	12.8	25.5	9.7	0	5.1	23.2	46.8	104.1	51.3
1984	178.2	280.8	48.1	51.9	18.7	13.1	0	0.3	42.3	0	18.5	422.5
1985	129.5	46.5	159	38.5	46.3	0	0	0	25.6	30.5	29	32
1986	132.5	41	98.5	35	8.5	18	144	0	26	110	140	121
1987	52.5	169.5	49.5	45.5	70.7	1	14	0.2	0	30.3	68.8	27.3
1988	77.9	67.9	39.3	24.2	38.6	41	5.6	0	45.2	1.5	71.4	204.8
1989	56.3	51.8	35.6	56.7	4.9	12.4	2.71	14.7	43.5	78.2	33.7	49.3
1990	155.8	0.3	74.8	54.4	55.9	20.5	6.4	1.7	1	18.5	125.4	169.5
1991	59.5	104.9	110.3	82	31.8	21.9	0	15.5	23	106.7	29.5	19.2
1992	60.9	60.6	99.5	121.1	99.2	8.3	13.9	0	1.4	17.7	73.2	246.5
1993	112.5	29.3	43.8	21.7	68.4	10.1	0	2.9	23.2	28.1	15	139.7
1994	58.3	52.2	7	64.8	9.7	0	0	0	15.7	66.6	10.5	97.7
1995	225.3	18.1	106.6	23.5	3	40.3	0.4	3.4	59.9	21.4	37.2	50.3
1996	106.6	191.8	58	71.7	50.2	10.5	1.2	6.3	34.3	36.3	30	82.2
1997	45.8	22.7	38.8	44.5	12.4	29.1	0	5.3	47.9	53.7	90.8	130.9
1998	21	92.8	44.9	54.3	51.9	5	0	14.9	76	39.5	171.4	62.5
1999	115.6	70.6	39.9	31	37	17.2	6.4	0.2	6	32.2	56.1	145.4
2000	40.5	25.4	30.7	21.8	83.2	5.1	0	6.4	9	36.9	31.8	32.7
2001	112.1	74.1	9.9	52.6	28.1	0	0	1.1	35.2	8.2	80.9	36.2
2002	35.1	91.8	24.6	57.9	8.4	2.3	24.6	22.5	20.1	24.3	136.1	118
2003	199	115.9	31.3	129.4	30.1	0	0.5	0	86.5	34	27.7	155.3
2004	135.3	24.6	62.2	68.8	101.1	47.3	0	1.7	41.7	19.8	249.7	190.1
2005	91.1	137.6	65.5	124.2	3.8	0.2	3.6	4.5	17.9	22	25	180.7
2006	136.7	121.1	37.8	11	30.8	3.7	1	4.4	30.3	46.6	37.6	168.3
2007	15	53.1	260.1	63.8	13.7	32.8	0.3	0.3	40.7	63	77.7	208.5
2008	11.3	31.9	74	55.3	37.3	6	8.5	4.5	52.8	20.4	63.1	50.4
2009	226.5	76.9	54.4	109.2	52.3	0	5	11	136.6	65.7	49	48.4
2010	160.8	42.2	62.2	23.4	51.2	15.8	0	9.5	15.3	79.9	150	56.3
2011	32.6	245.3	88.6	70.7	32.6	23.1	2.6	0	9.1	140.3	98.4	83.2
2012	89.24	179	151.2	70.5	1.5	12.1	0	0	101.6	27.3	44.2	77.4
2013	93.8	134.9	60.3	34.6	24.8	0	0	24.9	83.7	46.4	211.1	66.5
2014	80.6	409.8	130.5	56.2	32.48	10.2	1.52	9.08	69.26	71.92	110.54	66.36
2015	106.57	206.04	106.95	54	35.44	9.52	3.7	23.98	37.14	84.92	94.62	74.5
2016	63	23.8	140.3	69.1	37.1	9.7	7.5	0	13.1	28.6	39.9	19.5
2017	160.4	36.3	0	39	7	29.8	0	6.5	7.6	14.9	131.2	126.7
2018	46.1	78.2	92.9	50.7	81.8	4	0	107.4	40.7	218.4	17.9	30.2
2019	166.6	57	138.3	37.6	45.6	0	0	6	81.5	129.2	157.4	39.8
2020	46.6	0	112	65.2	5.7	4.1	11	0	42.8	33.5	126.7	156.3
2021	59.2	28.9	60.8	90.4	25	0	0	7.5	33.7	14.4	30.3	56.1
2022	51	15.1	53.4	19	54.7	0	0	0	27.1	25.8	55.7	22.3
2023	89.3	11.1	48.4	12.3	147.4	127.3	0	0	0	11	227.4	170.7
2024	86.937	86.624	88.355	49.35	47.222	19.462	2.372	16.046	13.55	18.4	141.55	96.5

Table 03: Monthly precipitation at Skikda port station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	59.05	84.8	77.55	21.8	52.65	16.4	0.25	22.55	4.2	25	186.3	81.2
1976	25.6	55.8	72.7	9.2	58.2	6.2	0	21.3	22.6	18.6	139	52.8
1977	92.5	113.8	82.4	34.4	47.1	26.6	0.5	23.8	24	11	151	22
1978	54	44	17	67	62	19	0	21	9	81	139	51
1979	124	116	62	77	37	8	0	1	51	73	112	38
1980	111	169	95	211	13	20	10	3	19	88	151	240
1981	48	30	94	74	56	1	0	1.7	14	67	37	188
1982	87	101	51	39	17	21	1	46	14.5	100	232	156
1983	141	128	121	59	37	0	0.5	12	85	91	119	62
1984	21	37	70	13	23	0.7	0.5	8	68	148	27	343
1985	204	161	104	52	22	14	0	0.9	42	22	66	50
1986	148	76	172	21	29	0	0	0.2	24	86	149	157
1987	162	82	88	56	12	18	13	3	30	14	116	50
1988	140	246	89	36	82	4	11	1	58	4	130	147
1989	111	111	55	36	37	24	0	1	33	83	69	100
1990	48	53	23	148	2	9	5	0	0	66	123	326
1991	157	1	75	65	22	31	4	41	49	118	51	30
1992	89	104	103	34	25	5	0	13	9	38	39	237
1993	109	87	120	144	60	28	7	1	36	85	40	136
1994	53	78	63	39	69	6	1	1	58	102	6	170
1995	116	120	0	142	12	0	1	4	100	9	48	55.1
1996	219	25	10.7	32.2	3	19	0	12	38	95	49	102
1997	65	192	59.3	92	46.4	14	1	4	69	190	174	148.2
1998	66	13.3	18	34.2	7	27	0	4	25	81	26	198
1999	55.1	82	104.2	43	57.3	129.2	11	0	29.5	25	106.1	238
2000	116.7	116	72.4	32	15	4	1	8	18	52	36.7	102
2001	61	20	21	16	116	43	0	5	65	2	103	95
2002	150	87	11	48	28	0	0	5	35.9	85	244	215
2003	47.5	121.6	21.4	59.1	10.1	1	22.1	30.6	114	47	37	169
2004	276	114	35	99	14	2	0	0	55.5	26.2	285.8	165.4
2005	159.3	182	65.2	101.4	6.8	99	0.3	64.4	34.4	25.5	90.3	181
2006	127.1	58	41.1	15.4	7.8	8.5	9	1	29	65	24.1	229
2007	23.3	56	141	62	24	33	2	6	50	74	96	144
2008	32	24	171	14.6	60	4.3	1	0.3	81	67.1	84	119
2009	251	110	90	107	59.8	0	2	8	203	83.3	119	137
2010	133	54.8	85	28.5	78	28.6	0.4	5	21	164	164.3	79.3
2011	57.4	54.6	75.8	48.4	39.9	8.8	7.9	0	33.6	125.2	64.1	125
2012	56.5	192.3	72.2	117.4	1.8	1.1	0.4	51.9	62.6	28.5	72.1	68
2013	132.2	200.1	69.8	45	52.4	14.1	2.6	50.8	89.9	82.4	215.7	53.9
2014	92	48.1	175.1	14.6	11.1	6.6	0	0	82.02	96.68	127.04	92.64
2015	149.6	141.7	101.7	14.1	30.6	5.9	2.4	9.7	59.2	114.4	107.7	39.6
2016	92.3	90.5	139.5	64.8	43.7	6.7	2.2	0	44.8	55.2	78.5	80.8
2017	137	75.9	15.2	26.8	12.4	12.1	0	4.8	23.3	54.4	140.5	189.2
2018	55.6	76.4	143.3	58.4	53.8	6.7	0	19	46.2	179	69.8	62.4
2019	123	92.4	99.4	36.9	45.8	4.8	0	14.5	112.5	93.7	146.1	145.3
2020	57.4	19.2	154.7	47.6	16.4	8.7	2.7	5.1	64.7	54.1	128.7	156.6
2021	105.7	43.6	66.1	56.3	36.8	7.2	0	5.7	34.3	48	68	99.9
2022	90.9	34.9	80.6	35.7	39.5	4.2	0	0	44.6	51	100.7	66.1
2023	126.8	41	39.7	26	114.3	28.5	0	0	13.9	21.6	134.2	83
2024	103.03	66.39	101.54	38.11	40.44	9.15	0.73	5.88	29.3	36.3	117.5	74.6

Table 04: Monthly precipitation Ramdan Djamel station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	67.1	50.5	54.55	53.45	48.25	16.35	5.8	12.1	13	7	104.9	66.5
1976	89.9	89.5	79.4	49.3	34	11.9	11.1	12.8	31.2	204	125.6	38.1
1977	44.3	11.5	29.7	57.6	62.5	20.8	0.5	11.4	7.5	11.6	94.1	9.9
1978	79.5	78.8	44.2	57.7	61.6	12.4	0	0.7	2.3	36.1	94.5	19.9
1979	53.7	103.2	95.3	160.7	8.8	30.1	10.2	0.4	13.2	56.4	55.9	37.2
1980	48.5	48	61.2	56.1	50.7	0	0	0	17.9	55	61.8	163.8
1981	62.1	71.1	41.3	40.2	11.3	25.5	4.8	26.7	32.2	29	28.9	112.1
1982	131.3	114.7	102.8	57.6	30.7	9.7	3	0	7.5	138.3	136	74.9
1983	13.4	25.5	54.6	7	20.3	0	1.5	5.6	35.5	25.3	84.5	53.8
1984	165.7	190.6	57	24.7	16.4	9.7	0	0	52.7	150.3	23.7	427.8
1985	118.1	70.4	137.9	39.2	32	15.1	0	0	28.1	19.6	46	48.3
1986	134	49.6	78.5	39.5	9.2	7.5	6.5	0	32.7	102.2	147.3	147.7
1987	62.3	143.7	69.9	44.9	60.9	10	4.3	0	17	40.5	75.8	22.1
1988	64.9	51.6	37.9	23.8	22.9	31.6	9.6	0	35.9	1.5	55.4	160.6
1989	36	50.5	46.1	54.3	1	9.1	2.1	4.3	24	58.2	49.4	69.6
1990	153.3	1.6	25.6	52.4	30.8	13.4	3	15.6	0	32.5	90.5	147.6
1991	69.3	73.8	102.4	45.4	16.2	13.6	0	2	53	115.5	34.6	18.1
1992	59.9	62.9	135	103.8	67.5	19.4	15	0	2.2	45.7	51.2	175.3
1993	106.9	37.1	46.8	21.4	54.4	0	0	1.6	17	36.2	24.4	104.1
1994	90	68.1	36	84.9	9.8	0	0	0	25.9	76.7	10	110
1995	222.8	21.5	81.8	34.6	5.3	31	0	4.6	79	9.4	49.1	50.6
1996	76.5	127.7	40.7	73.4	44.4	11.2	2.1	7.3	51.2	51.8	34.2	70.3
1997	45.7	13	51	32.2	9.8	19.4	0	18	42	94.7	81.5	85.1
1998	27.2	55.6	31.1	37.3	53.6	6	0	6.3	29.5	31.6	181.2	39
1999	122.7	46.4	54.7	27.2	22	8	4.6	2.3	10.3	24.7	60	131.4
2000	24.4	31.7	22.2	17.6	92.7	6.7	0	9.8	0.9	28.4	37.8	60.6
2001	127.1	82.6	8.2	31.6	22.6	0	0	0.9	69.9	6.4	53.6	59.5
2002	28.8	95.7	16.6	31.1	11.2	1.6	40.2	26.1	14.5	43.9	196.1	128.9
2003	227.8	96.2	22.8	116.7	21.9	0	0	0	67.7	42.6	19.1	230.9
2004	85.1	16.8	57.8	78.3	65.1	28.3	0.5	3.1	34.6	32.1	233.9	149.7
2005	111.9	107.1	36.9	105.7	3.9	7.9	0.1	11.6	18.5	25.9	70.3	116.4
2006	116.8	91.4	39.2	8.2	14.3	0.3	0	7.5	29.5	99.2	45.5	177.8
2007	23.8	32.1	59	50.5	11.8	14.7	0.4	1	25.7	75.9	69.1	134.7
2008	8.8	22.8	124.9	2.5	40.8	6.5	6.7	0	36.8	28	52.7	47.5
2009	167.9	51.3	54.6	105.6	65	0	0.1	2.5	158.8	61.8	53.6	64.2
2010	126.2	29.4	59.3	51.3	61.9	15.1	1.6	5.3	5.8	69.3	131.9	49.9
2011	24.1	198.5	92.1	34.7	35.3	11.9	10.7	0.1	12.4	82.8	124.4	86.3
2012	62.1	105	60.8	71	3	6.8	0.4	78.6	47.9	63.56	86.34	76.52
2013	151.4	204.5	104.3	45.3	32	7.3	3	27.5	63.9	61.2	184.3	101.2
2014	112.5	60	204.9	29	28.3	10.2	2.6	0	26.4	49.8	55.7	186.4
2015	166.2	153.3	102.6	16.5	30.7	8.2	0	9.8	53.9	106.8	105.2	36.8
2016	93.8	100.3	142.4	70.7	40	9.7	2.7	0	44.6	46.8	83.5	79.7
2017	112.1	73	15.3	34.8	14.4	15.1	3.3	5.1	20.2	57	137.9	162.6
2018	44.7	67.8	137.3	61.4	66.7	8.3	0	20.2	37.7	169.6	71.2	60.6
2019	129.3	84.9	109.6	40.3	47.1	6.8	0	15.4	108.6	77.8	141.2	137.6
2020	58.6	20.1	169.6	60.4	15.8	11.4	2.9	6.3	50.8	47.5	130.9	148.2
2021	83.5	46	77.6	62.7	39	10.5	0	6.6	28.6	41.3	68.3	95.1
2022	83.8	39.7	87.8	44.1	36.5	5.3	0	0	39.1	50.3	100.7	57.7
2023	111.3	42.9	39.7	26.8	104.2	39.6	0	5.1	14.4	21.7	146.6	127.8
2024	74.1	136.9	49.5	29.9	26.9	7.2	0	10.1	26.8	36	123.7	92.7

Table 05: Monthly precipitation at the Elharrouch station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	52.05	51.7	51.3	51.9	47.85	17.45	16.85	15.65	19.2	22.6	107.4	47.8
1976	48.2	87.9	88.4	42.3	35.5	8.3	33.7	11.7	57.2	82	79.1	19.7
1977	55.9	15.5	14.2	61.5	60.2	26.6	0	19.6	5.1	0	109.7	7.2
1978	101.3	89.9	41.7	61.2	69.7	0.4	0	30.8	7.2	26.6	105.9	19.4
1979	61.3	111.9	77.5	155	5.5	38.4	4.2	0.6	48.9	51.2	54.2	48.7
1980	46.7	46.5	61.8	57.8	52.4	0.6	1.7	3	19.3	19.9	36.7	139.1
1981	65.8	68.9	57.7	21.1	11.6	35	0	21.4	11.5	22.2	34.7	95.8
1982	83.8	75.5	128	57.6	23.4	7.3	0	0	9.8	158.9	198.4	101.2
1983	10.4	27.2	25.7	7.3	14.1	2.4	0	1.2	28.3	36	88.2	42.2
1984	112.3	118.3	17.7	19.2	4.5	8.3	0	8.3	36.5	133.8	16.3	379.6
1985	85.2	46.9	159.8	35.2	36.8	2.1	0	0	55.8	24.6	26.9	30.8
1986	108.4	39.8	98	37	8.6	11.6	5.2	0.4	28.2	105.1	135.3	130.4
1987	71	152.3	51.8	25.9	79.7	0	5.5	0.3	0.3	29.5	66.3	21.6
1988	62.8	56	33.3	19.1	20.1	21	7.1	0	98.2	1.3	72.8	215
1989	50.1	39.3	33.4	55.5	6	18.1	4.6	4.5	30.6	52.1	45.8	62
1990	141.8	1.1	27.7	75	39	21.1	3.1	3.1	0	19.1	92.4	148.3
1991	43.3	79.3	130.3	65.9	48.8	26.6	0	4.3	42.7	128.8	28	217
1992	55.2	71.1	136.3	86.7	81.6	14.3	8.7	0	44.4	34.4	74.1	231.7
1993	78.3	51.7	28.3	17.8	11	10.2	0	1.2	12.8	49.9	20.7	101.3
1994	61	59.8	16.1	87.9	9	25	0	0	28.1	88.5	20.1	114.1
1995	254.2	25.4	112.6	36.8	5.8	38.3	0	2.7	76	29.6	59.8	28.6
1996	102.8	227	46.6	78.2	46.2	17.1	1.5	2.7	39.6	35.1	34.7	76
1997	68.7	28.8	42.7	52.2	20.4	10.6	0	26.7	53.4	89.4	92.8	124.1
1998	27.2	74.4	49.5	67.8	80.7	3.3	0	8	69.4	50.1	184.2	45
1999	70.7	38	37.2	17.9	8.3	8.8	5.9	5.3	14.7	14.8	65.6	146.9
2000	24.3	23.8	23.5	17.6	100.7	6.5	0	12.7	1.9	53.3	29.7	50.3
2001	144.5	55.9	18.4	57.9	33.1	0	0	0.3	65.4	4.9	75.3	31.5
2002	31.4	89.4	17.9	52.6	8.4	2.7	25.9	29.6	14.3	59	162.8	103.1
2003	237.8	81.7	30.4	117.3	19.5	0.2	0	0	80	34.8	21.6	162.4
2004	70.8	15.1	54.9	84.5	77.9	37.7	0	7.5	34.6	44.2	219.2	155.9
2005	89.9	126.9	43.8	105.5	0	0	1.6	2.3	11.9	15.4	26.4	112.1
2006	117	85.9	39.4	5.2	48	2.6	0	2.9	35.9	39.1	25.7	169.9
2007	21.3	48.5	182.8	56.5	9.3	22.4	0.6	3.4	31.4	61	55.4	128.4
2008	8.8	30.8	117.8	17	57.1	11.5	4.3	1.7	60.2	2.1	53.4	45.7
2009	192	57.3	51.9	107.5	66.6	0	3.3	2.5	176.2	58.2	50.8	47.4
2010	125.6	38.5	49.1	28.1	61.8	14.4	0.8	4.3	17.2	63.5	140.6	46.5
2011	27.3	227.1	108.6	46.3	39.2	34.4	4.3	4.2	20.7	127.9	94.9	63.2
2012	45.5	118.2	93.3	50.6	3.6	1.2	0.7	59.5	61.14	62.54	79.02	66.24
2013	138.1	167.7	94.8	43.6	37	8.9	4.2	23.4	47	51.5	130.2	74.4
2014	105.7	48	173.9	26.1	36	12.6	3.3	2.8	21.2	36.4	43.3	115.6
2015	155.1	114.8	90.8	15.6	38.3	9.9	0	11.1	38.6	84.9	80.9	24.2
2016	76.3	83.6	124.3	62.4	48.5	12.9	3.2	0	30.2	36.6	64.6	49.8
2017	107.7	62.8	14.9	35.7	16.6	17.6	0	4.5	14.3	46.3	108.2	107.1
2018	39.2	60.4	113.4	62.3	71.7	9.6	0	20.1	27.7	147.3	54.6	37.5
2019	120.2	79.3	89.8	41	54.2	8.5	3.1	12.9	80.6	75.2	113.2	90
2020	53.2	17.8	142	59	18.1	14.3	1.8	5.6	36.5	36.2	102.7	103.1
2021	69	40.3	56.9	57.7	46.2	11.4	0	6	21.8	35.9	51.2	74.6
2022	72.9	31.6	82.2	39.9	45.9	6.2	0	0	26.9	45	76.3	41.4
2023	93.9	36.5	29.4	27.3	119	46.9	0	0	10.3	20.2	114.9	85.8
2024	63.7	116.5	45.5	29.6	30.5	8.7	0	9.5	18.6	32.6	95.6	63.6

Table 06: Monthly average temperature Sikka port station

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	13.07	12.4	13.61	13.73	18.07	21.8	22.86	25.74	24.07	18.33	14.55	12.5
1976	12.02	11.34	12.51	13.76	16.02	19.84	23.53	24.42	22.6	18.6	13.8	18.8
1977	10.2	15	11.8	14.2	17.7	20.6	23.4	23.8	21.05	20.2	13.2	13.2
1978	18.85	13.5	18.81	15.3	17.8	20.5	23.3	23.26	21.8	17.6	13.6	14.58
1979	10.7	14	13.3	14.2	17.2	20.9	23.9	23.9	21.4	19.8	13.8	12.5
1980	13.9	13.5	13.3	13.44	17.7	21.5	23.34	24.1	22.5	18.2	16.1	10.5
1981	11.6	12.29	12.8	11	16.6	20.3	22	24.2	23.22	19.1	15.1	15.5
1982	9.9	12.5	14.3	16.3	17.8	20.8	22.2	23.6	23.1	20.1	16.4	12.37
1983	13.83	12.89	13.3	14.9	18.12	23.23	27.28	24.55	23.91	20.4	17.87	14.27
1984	11.33	11.2	13.51	16.68	18.81	21.74	27.1	25.1	22.5	19.19	17.77	13.51
1985	12.69	11.76	12.48	15.4	17.3	20.35	24.85	23.6	22.51	20.72	17.92	14.18
1986	11.42	14.83	12.58	16.27	17.8	21.61	24.87	24.09	23.35	21.3	16.6	13
1987	12.55	12.53	13.25	18.3	19.49	20.26	23.78	25.61	23.47	25.38	16.99	15.4
1988	12.47	12.99	12.9	16.2	17.2	21.24	24.74	26.21	22.07	22.07	16.78	12.6
1989	14.49	12.07	14.3	15.85	18.97	21.72	24.76	25.76	23.64	19.81	17.63	16.56
1990	11.83	12.72	15.03	16	17.68	21	24.93	25.9	25.6	22.2	17.1	12
1991	12.6	14.6	14.5	15.4	18.8	22.2	24.4	24.3	24.4	20.5	15.9	12.3
1992	12	11.4	15.4	13.8	15.8	20.2	24.2	25.3	23.9	19.6	16.7	13.9
1993	11.4	11.8	13.4	15.3	17.7	20.4	22.6	24.8	23.3	21	16.1	13.6
1994	11.5	11.1	12.8	15.6	19.2	21.5	24.1	25.4	25.7	21.2	18.3	14.1
1995	12.9	13.4	14	14.4	19.5	21.4	25.1	28.5	23.3	20.9	17.8	16.1
1996	12.6	14.6	13.3	14.5	20	21.4	24.2	25.7	21.8	18.7	17.4	15.6
1997	15.6	10.5	14.7	16.1	18.3	21.3	24.5	25.6	24.2	21.7	17.5	14.9
1998	14.4	13.4	13.2	15.7	19.9	23.4	24.1	26.5	25.7	19.6	15.4	12.8
1999	13.3	13.3	14.5	16.9	18.5	24.4	24.9	25.6	24.6	23.5	15.9	13.6
2000	12.9	11.9	15.2	16.2	20.6	23.2	25.7	27.9	24.6	21.3	17.7	15.3
2001	10.5	12.9	14.2	17.3	19.5	22.2	26.2	27	24	23.3	16.6	13.7
2002	14.2	13.1	18	16.1	19	23.6	25.4	27.3	23.3	21.1	17.9	14.8
2003	12.1	13.6	15.6	13.5	19.3	22.9	24.9	25.4	24.6	22.1	17.2	13.1
2004	12.5	11.9	13.5	17.2	19.4	25.6	28.3	29.2	23.7	22.4	15.1	13.6
2005	10.2	10.1	13.3	16.4	20.1	23.7	26.4	25.7	23.4	21.7	17.5	12.8
2006	11.1	12	14.9	18.2	21	23.1	26.7	26.1	24	22.8	18.4	14
2007	13.7	14.5	13.4	18.4	20.2	22.7	25.5	26.4	23.9	20.7	15.9	18.9
2008	13.1	13.3	14	17.5	19.8	22.5	26.3	26.7	24	21.1	16.1	12.7
2009	12.6	21.1	13.5	15.6	20.6	23.3	26.6	26.8	24.2	20.2	17.1	15.6
2010	13.2	14.2	14.9	16.7	18.4	21.7	25.4	25.3	23.5	20.5	16.7	14.1
2011	12.5	12.2	14.7	17.2	19.2	22.1	25.8	26.6	24.6	20.7	17.6	13.9
2012	12.5	9.5	14.3	16.6	18.9	24	25.3	27.6	21	21.7	16.8	13.9
2013	12.6	11.2	15.8	16.4	18.1	20.5	24.9	25.6	23.9	23.2	16	10.5
2014	13.8	14	13.6	17	18.57	23.29	24.2	26.13	23.44	21.26	16.84	13.6
2015	10.7	9.8	12.4	15.2	19.2	22.3	26.0	26.0	23.1	20.1	15.4	12.5
2016	12.6	12.8	12.6	15.9	18.0	21.8	24.6	24.4	22.9	21.5	16.4	13.6
2017	10.0	12.5	13.8	15.0	19.5	23.5	25.8	26.6	22.6	19.3	14.5	11.5
2018	12.2	10.4	13.3	15.6	17.1	21.4	25.7	25.1	24.4	19.5	15.7	12.9
2019	10.5	10.9	12.9	14.8	16.7	22.8	25.9	26.5	23.7	20.4	14.9	14.0
2020	11.5	12.8	13.3	15.8	19.8	22.1	25.5	26.4	22.9	18.7	16.8	12.5
2021	12.0	13.7	12.8	15.2	18.8	23.0	26.0	26.9	25.3	19.3	14.9	12.2
2022	10.1	11.8	13.7	15.1	19.3	24.6	26.6	26.7	25.4	22.0	17.2	15.2
2023	11.0	11.1	14.0	15.7	17.3	22.6	28.4	25.8	24.8	22.8	17.3	13.4
2024	12.7	13.1	14.7	15.8	19.0	23.5	26.0	26.7	25.1	22.4	17.2	14.3