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Potential impact of drought on Mikkes River flow (Morocco)

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Abstract
Mikkes River Basin is located in the north-center of the Kingdom of Morocco (North-West of Africa). It comprises of three different zones which represent diversified geologies and which shelter a phreatic and confined aquifer in Saïs plain and a shallow aquifer in El Hajeb Ifrane Tabular. This research aims to highlight the potential impact of drought on Mikkes River flow through climate indexes including rainfall, temperature and evapotranspiration during the period 1968-2009. Monitoring the evolution of rainfall, temperatures and evapotranspiration in the Mikkes basin during the period 1968-2009 shows that rainfall decreases, temperature and evapotranspiration increase from South to North of the basin (spatial drought). Also, these climatic indicators highlight a decrease in rainfall, increase in temperatures and evapotranspiration after 1980 (temporal drought). Flow deficit of Mikkes River between the period 1968-1979 and 1980-2009 is around 76%. This high River flow may due to the drought which the region has experienced since 1980 and also to the overexploitation of groundwater resources to satisfy water demands. The Mikkes basin is suffering severe depletion of groundwater piezometric levels, especially in the confined aquifer.
Keywords: *Mikkes River; Morocco; Drought; Rainfall; Temperature; Flow; Piezometric level.*

1. Introduction
Water covers about 70% of the planet, giving it the unique ability to foster and sustain life. Nevertheless, only 2.5% is freshwater. The three major sources of freshwater are rainwater, surface water and groundwater which provides consistent flows to the water bodies and moisture to the soil. Groundwater is an important source of water in arid and semi-arid areas and particularly in the Mikkes basin. Agriculture is the major user of groundwater followed by domestic and industrial sector. Groundwater has advantage over surface water of being tapped when required.

Climate change effects include an increase in air temperature and rising sea-levels, which affect water availability (both as surface water and groundwater: quantity and quality). Climate change causing severe flooding in many regions in the world and contaminates water sources. Also, climate change has contributed to droughts (higher temperatures and increased variability in precipitation), which directly affect availability on freshwater and dependency on groundwater. People in water-scarce areas will increasingly depend on groundwater. Africa is particularly vulnerable to the effects of climate change and global warming.

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Therefore, people living semi-arid climatic zones will suffer more from increased demand on water resources (Belhassan 2021). Many researchers have highlighted the impact of climate change on water resources in several regions, particularly in semi-arid regions (Bader and Latif 2003; Giannini et al. 2003; Hoerling et al. 2006; McCabe et al. 2008; Méndez and Magaña 2010). Morocco is among semi-arid regions which has experienced more intense droughts over the past two decades (Agoumi 2003). In addition, many areas in Morocco became relatively dry between 1961 and 2008 (Driouech 2009). Among many climate factors, temperature and rainfall play a primary role in the river regime (Rossillon 1984). Climate change causes are difficult to identify. However, they can be manifested by long dry periods with consequences of negative effects on the hydrological cycle, environment, and socio-economic activities (Goula et al. 2006; Jehangir Khan et al. 2021). The drought that occurred in Morocco and particularly in the study area since 1980, demonstrated the fragility of its freshwaters (surface water – groundwater). The droughts posed a negative impact on water needs of all socio-economic sectors, especially agriculture, and preservation of terrestrial, and hence, aquatic ecosystems have been subject of several investigations. This investigation was conducted as a regional case study in the north-center of the Kingdom of Morocco "Mikkes basin" to address the potential impact of drought and its effects on Mikkes River flow through the study of (1) rainfall and temperature fluctuations, (2) the river flow analysis for the period 1968-2009; and (3) Piezometric level fluctuations of the Mikkes groundwaters. Mikkes River flow records began in 1968. 2009 is the last update data base (River flow and groundwater piezometric level) from ABHS (Sebou Hydraulic Basin Agency "Fez Morocco").

2. Study Area

The stream Mikkes is regulated by the dam of Sidi Echahed whose watershed is located between the cities of Meknes and Fez. The region contains the cities of Ifrane and Ain Taoujdat. The watershed of the Mikkes is drained by four Tributaries: N'ja and Oued Atchane in right bank, Tizguit and Akkous in left bank. This study zone covers an area of 1600 km2 and its perimeter is ~259 km (Fig 1). The Mikkes basin is divided into three different structural geological parts: El Hajeb-Ifrane Tabular in the South, Saïs plain in the centre and Prerif Zone in the North. El Hajeb-Ifrane Tabular is a free-water table circulating in the dolomitic and limestone formations of the lower and middle Lias outcrops, which is supplied directly by precipitation. Layers of the Trias rock salt separate these formations from the Paleozoic substratum. At the northern limit of the Tabular Atlas, the limestones and dolomitic formations (toward the North) burrow under the Fez- Meknes Neogene basin and rest on the Southern Rif Substratum. Under the Fez - Meknes basin, the structure of the Lias is highly affected by faults and flexures, some of which appear at the surface. The superficial layer is composed of a marly Miocene series keeping the Lias groundwater under pressure, forming the Saïs confined aquifer. A complex of Plio-quaternary formations (sands and limestones…) rests over this series and holds the superficial groundwater, that is, the Saïs phreatic aquifer. The two groundwater aquifers communicate through the faults and flexures or through the semi-permeable marly layers (Belhassan et al. 2009; Belhassan 2010; Belhassan 2011; Rezapour Tabari and Yazdi 2014; Ghasem Shirazi et al. 2014; Belhassan 2020) (Fig 1).

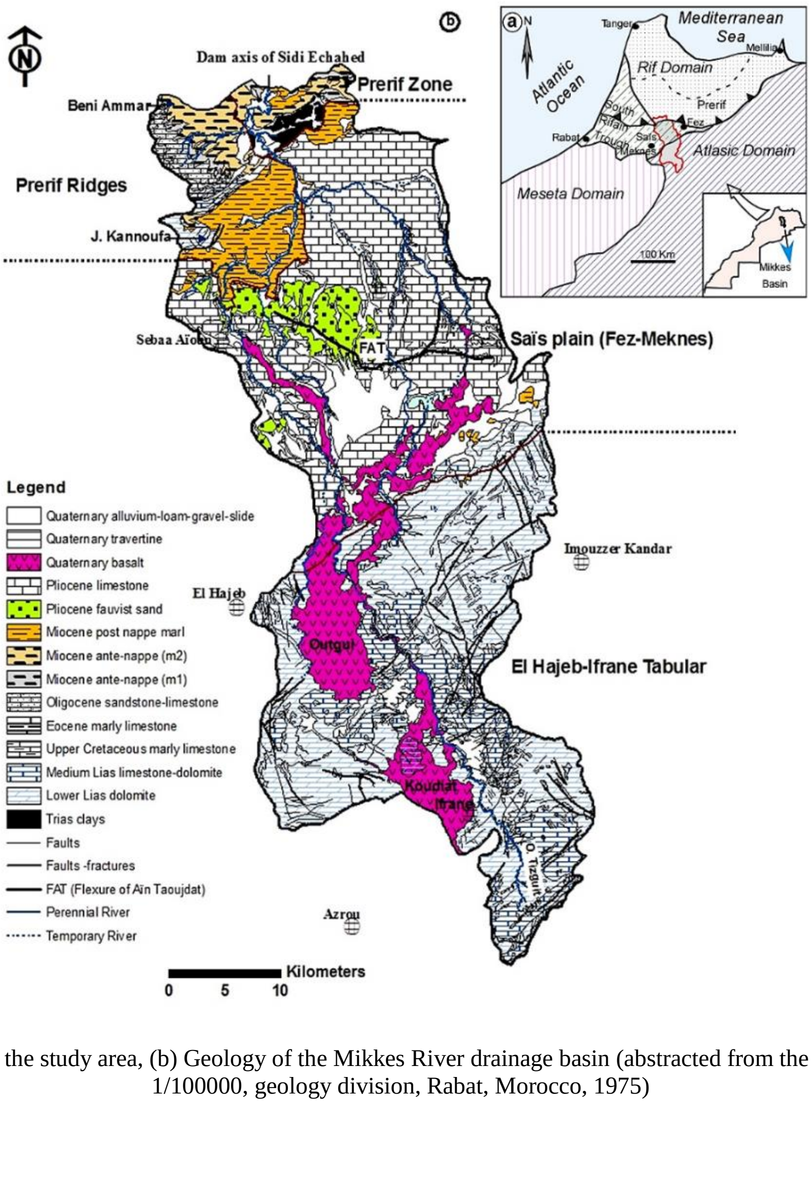

Fig 1. (a) Location of the study area, (b) Geology of the Mikkes River drainage basin (abstracted from the geological map: ref. 1/100000, geology division, Rabat, Morocco, 1975)

The Mikkes basin is affected by a Hercynian accident direction (NE-SW and NW-SE) and other typical alpine (E-W and N-S).
This network favors the infiltration of the water in El Hajeb-Ifrane Tabular upstream of the basin and the drainage of surface waters by rivers in the center and in the north (Tizguit, Atchane, Jdida, Akkous and N'ja). Altitude generally decreases from South (Ifrane station; altitude 1600 m) to North (Sidi Echahed; altitude 190 m). Temperature decreases with higher altitude. However, precipitation increases with it (Table 1).
To test the relationship between these climate variables and altitude, a correlation analysis is performed. The correlation coefficient is a statistical measure that calculates the strength of the relationship between the relative movements of two variables. It takes on values ranging between +1 and -1.
The correlation coefficient between precipitation and elevation is around 0.87 which provides a reliable measure of the strength of the linear relationship. The correlation coefficient between temperature and elevation is equal to -0.99; it is very close to -1, indicating a good inverse relationship between temperature and altitude.
This reflects the influence of topography and elevation on rainfall-temperature variations which may influence also the spatio-temporal drought distribution in the study area.

Table 1. Coordinate system and average data obtained from the meteorological stations in the region of study

Meteorological Station	Altitudes (m)	Longitude (m)	Latitude (m)	Mean rain (1968-09)	Mean temperature (1968-09)
Ifrane	1635	525500	325900	965.4	12.00
Bittit	760	519660	355000	503.9	-
Imouzzer Kandar	1348	535404	348073	605.4	-
Azrou	1508	515077	315836	722.5	-
El Hajra	215	508860	382760	364.9	18.24
Moulay Idriss	550	489000	384000	598.6	17.58
Aïn Taoujdat	465	517300	371800	448.0	-
Fez	579	535722	383646	-	16.63
El Hajeb	1050	504596	344103	570.2	-

3. Materials and Methods

This work focuses on rainfall-temperature fluctuations, ombrothermic diagrams of Gaussen (Orellana et al. 2002), evapotranspiration, river flows and also groundwater level fluctuations in the Mikkes basin.

3.1. Rainfall-temperatures fluctuations

Climate change will cause an intensification of rainfall variability, thus resulting in river flow fluctuations and a higher frequency of droughts.
In this study, rainfall variability is taken from eight stations that have monitored the data for over 42 years: Fez, Moulay Idriss, El Hajra-Mikkes, Aïn Taoujdat, Bittit, El Hajeb, Imouzzer Kandar, Ifrane and Azrou (Fig 2 and Table 1).
Rainfall data is not available for Fez station. The Mikkes mean annual amount of precipitation is calculated by Thiessen method (Thiessen 1911).
The basic concept of this method is to divide the watershed into multiple polygons, each one is around pluviometric station, and then introduce the weighted average factor of each station.
The Thiessen polygon is a commonly used methodology for computing the mean areal precipitation for a catchment from rain gauge observations which was presented by A.H. Thiessen (1911).
This method incorporates the pluviometric measurement of the stations located in the border's areas. However, the forms and features of land surfaces and their effects are ignored when calculating the average depth of rainfall (Fig 2 and Table 2).
The weighted average is calculated by:

$$P_{mean} = \frac{\sum_{i=1}^{i=n} P_i \times S_i}{S_T} = \frac{S_1}{S_T} \times P_1 + \frac{S_2}{S_T} \times P_2 + \ldots + \frac{S_n}{S_T} \times P_n$$

Where P_i is mean annual rainfall at each station (in mm), n is the number of stations, S_i is the surface of each polygon (km²), S_T is the total surface of the Mikkes catchment basin (km²).

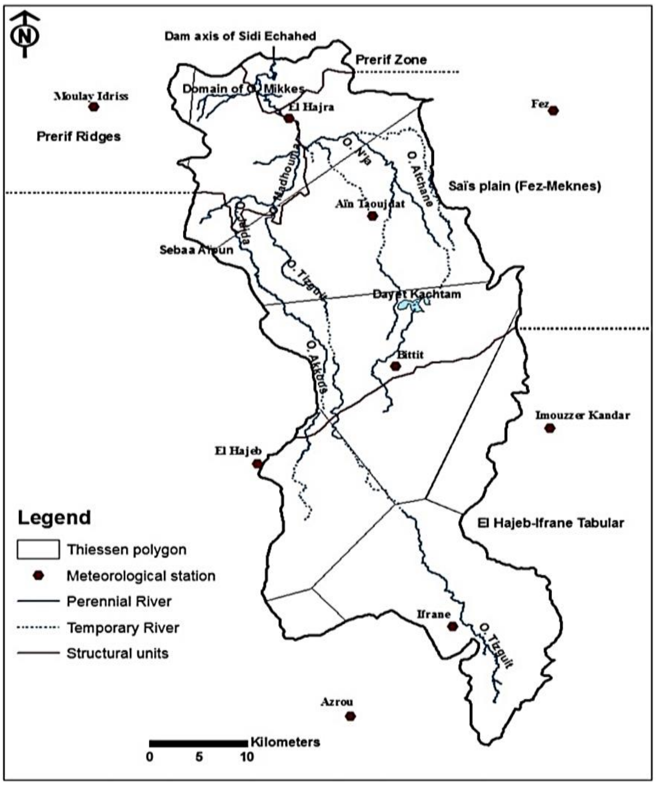

Fig 2. Thiessen polygons map of the study catchment

Table 2. Average depth of precipitation over the catchment basin calculated by Thiessen method (1968-2009)

Station	Area of influence (km^2)	Weighted area (%)	Mean rainfall (mm)
Ifrane	316	20	965.4
Azrou	27	2	722.5
Imouzzer	88	6	605.4
El Hajeb	159	10	570.2
Bittit	375	23	503.9
Moulay Idriss	12	1	598.6
Aïn Taoujdat	329	21	448.0
El Hajra	294	18	364.9

Temperature is a fundamental measurement of climate. It influences evapotranspiration, water salinity and water balance. In this work, the available temperature data are derived the following stations (1968-2009): Fez, Moulay Idriss, El Hajra-Mikkes and Ifrane (Fig 2 and Table 1). To visualize the spatio-temporal drought experienced by the Mikkes catchment area, a temperature comparison was performed using results from these stations for the periods (1968-1979) and (1980-2009) (Tables 3 and 4).

3.2. Ombrothermic diagrams of Gaussen

To better comprehend the spatio-temporal drought experienced by the Mikkes basin, the study area was divided into two parts, i.e. one in the South -El Hajeb Ifrane Tabular- (Ifrane station) and the other in the North -Saïs plain- (El Hajra station) by using Ombrothermic Diagram of Gaussen method (Orellana et al. 2002). In this study, Ombrothermic diagrams of Gaussen summarize the trends in temperature and precipitation for at least 30 years. They allow one to establish the relationship between temperature and precipitation and to determine the length of dry, wet, and extremely wet periods.

3.3. Evapotranspiration

Evapotranspiration constitutes a large percentage of the water cycle in most environments (Wilcox et al. 2003;

Trenberth et al. 2007). In semiarid and arid regions, increased evapotranspiration may shift the fraction of precipitation that runs off as surface water or infiltrates to the subsurface as recharge. The study of the evapotranspiration in the Mikkes basin is primordial to understand well the potential impact of drought on Mikkes River Flow. There are numerous methods to evaluate the real evapotranspiration (ETR) and/or potential evapotranspiration (PET). The Thornthwaite method (Thornthwaite 1948) is the method used in this study (for estimating potential evapotranspiration (PET)) because of its simplicity. The equation only requires mean monthly air temperature and mean daily daylight hours for each month, which can be calculated from latitude. Table 5 summarizes the values of evapotranspiration (PET and ETR) calculated by Thornthwaite method for the periods 1968-79 and 1980-2009 in Ifrane and El Hajra testing stations

Table 3. Temperature variability over the catchment basin (1968-2009)

Station	Ifrane	Fez	Moulay Idriss	El Hajra
T_{mean} (°C)	12.0	16.6	17.6	18.2
T_{Max} (°C)	14.8	18.2	19.7	20.0
T_{Min} (°C)	9.3	15.3	16.1	16.8

Table 4. Temperature variability over the study area during (1968-1979) and (1980-2009)

Periods	Ifrane	Fez	Moulay Idriss	El Hajra	Mean temperature (°C)
1968-79	10.8	16.3	17.1	17.9	15.5
1980-09	12.5	16.8	17.7	18.4	16.3
Difference	1.7	0.5	0.6	0.5	0.8

Table 5. Values of P, T, PET, ETR, WD and WS calculated by Thornthwaite method

Station Name	Ifrane		El Hajra	
Period	**1968-79**	**1980-09**	**1968-79**	**1980-09**
P in mm	1111.6	906.9	463.3	326.0
T in °C	10.80	12.40	17.94	18.30
PET in mm	648.5	705.6	899.7	907
ETR	364	390	342	308
WD (PET -ETR)	284.5	315.6	557.7	599
WS (P-ETR)	747.6	516.9	121.3	18
WS in %	67.3	57	26.2	5.5

3.4. River Flow

When rainfall is less than normal for several weeks, months, or years, the flow of streams and rivers declines. Monthly and annual analysis of the Mikkes River flow over the period 1968-2009 constitute a good indicator to assess the potential impact of droughts on freshwater resources. The hydrometric station of El Hajra, which has been in operation since 1968, is for monitoring flows (Fig 2 and Table 1).

3.5. Groundwater

Variations in precipitation, and pumping affect the height of underground water levels. If a water is pumped at a faster rate than an aquifer is recharged by precipitation or other sources of recharge, water levels can drop. This can happen during drought, due to the extreme deficit of rain. Thus, the piezometric analysis is one of the indicators of climate change and it constitutes a valuable tool to introduce them into River basin management plans by identifying the sectors which are affected by overexploitation. This study is based on piezometric fluctuations of Mikkes groundwaters. In El Hajeb Ifrane Tabular, the available piezometry measure is drilling No IRE 1448/22. In the Saïs phreatic aquifer, all piezometers show a similar evolution. The piezometer data presented in this study over the long period from 1968 to 2009 is drilling No IRE 199/15. While, in the deep confined aquifer, the piezometer No IRE 290/22 is the best piezometer which is shown a good follow-up data (1968-2009).

4. Results and discussions

4.1. Rainfall-temperatures fluctuations

There are several studies that demonstrated climate change impacts on runoff (Paturel et al. 1997; Li et al. 2007; Zhang et al. 2014). The climatic characteristics are applied in this investigation, to emphasize the potential impact of drought on Mikkes River flow. The data indicates that the annual river regime is highly irregular, with a coefficient of variation ranging from 28.6 to 34.1%. Fig 3 demonstrates a strong correlation of rainfall among different stations and the high irregularity of average rainfall from one year to another. The average annual rainfall for the eight stations located in three different geological structures indicates a spatio-temporal rainfall variability. Annual rainfall decreases as one goes from the South basin to the North of it. However, at the Prerif Ridges, where the pluviometric station of Moulay Idriss is located (median altitude), the annual rainfall is moderate. As seen in Table 2, using Thiessen Polygon method, the mean annual precipitation over the catchment basin is around 575 mm.

Fig 4 shows the rainfall deviations (%) compared to the average depth of precipitation recorded during the period from 1968 to 2009. It corroborates that the irregular rainfall highlights a significant decline in water inputs since 1981. This graph shows that before the 1980s, the deficit years were few and the years of excess water were frequent, such as in 1971 (42%), 1968 (46%), 1969 (73%) had recorded an excess of water with a percentage over 40% compared with the average experienced between 1968 and 2009.After 1980, there is an overall reduction in precipitations amounts. The data indicates that the three years, 1981, 1998 and 2001, have been remarkably dry and had recorded a deficit of 36% compared with the average experienced between 1968 and 2009. Nevertheless, in the following years, 1982 (23%), 1989 (30%), 1996 (88%), 1997 (26%), 2003 (36%), 2008 (16%) and 2009 (28%), a large amount of rainfall is recorded (Fig 4). The deficit of rainfall in the periods between 1968-1979 (mean rainfall ~668 mm) and 1980-2009 (mean rainfall ~538 mm) was noted to be around 19%.

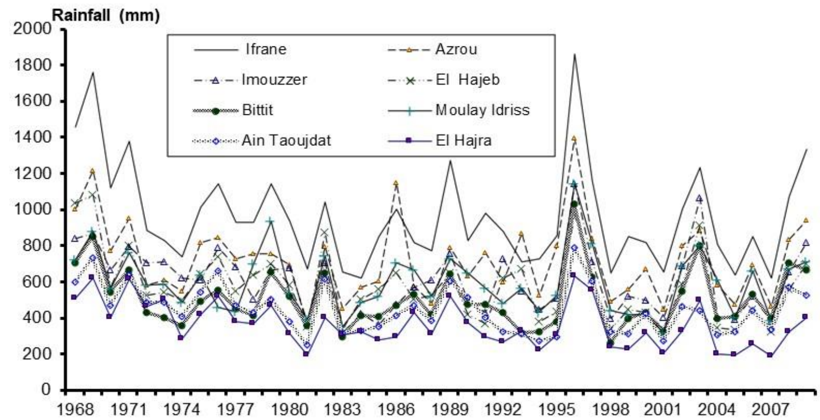

Fig 3. Inter-annual precipitation variations for the eight study stations (1968 - 2009)

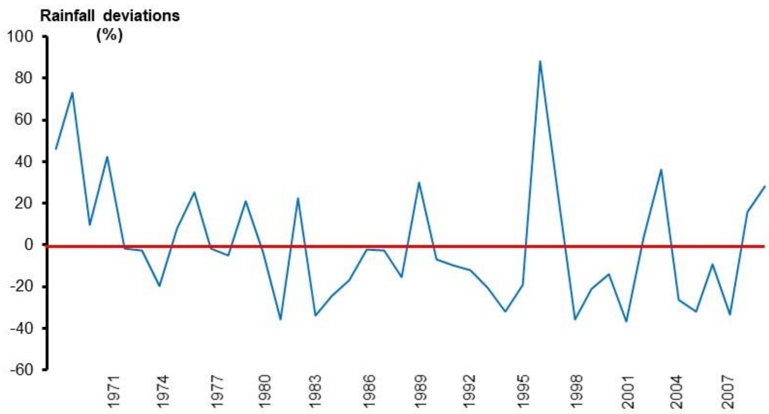

Fig 4. Rainfall deviations in the Mikkes basin (1968-2009)

At Ifrane station, the range in annual temperature is 9.3°C and 14.8°C, and the mean annual temperature is approximately 12°C (1968-2009). At Fez station, the annual temperatures varied between 15.3°C and 18.2°C, and the mean annual temperature is 16.6°C (1968-2009). These values are between 16.1°C and 19.7°C at Moulay Idriss station, where the average annual temperature is 17.6°C (1968-2009). At El Hajra station, the highest recorded temperature is 20°C and the lowest one is 16.8°C, and the mean annual value is approx. 18.2°C, during the said period between 1968-2009 (Table 3). In fact, the temperature has increased, as observed at four stations, between the periods 1968-1979 and 1980-2009. Average annual temperatures have actually increased by 1.7°C in Ifrane, 0.5°C in Fez, 0.6°C at Moulay Idriss and 0.5°C at El Hajra station. Moreover, the mean temperature recorded during the period 1968-1979 at Ifrane is 10.8°C and the one recorded at El Hajra is 17.9°C. A large difference in temperature (1968-1979) recorded in the Saïs plain (El Hajra station; altitude 215 m), and in El Hajeb-Ifrane Tabular (Ifrane station; altitude 1635 m); it is 7.1°C (Table 4).

4.2. Ombrothermic diagrams of Gaussen

The ombrothermic diagram of Ifrane station for the period 1968-1979 is illustrated in Fig 5a, and for a period from 1980-2009 is shown in Fig 5b. The ombrothermic diagram of El Hajra station for the period 1968-1979 is illustrated in Fig 6a, and the ombrothermic diagram during the years 1980 to 2009 is illustrated in Fig 6b.

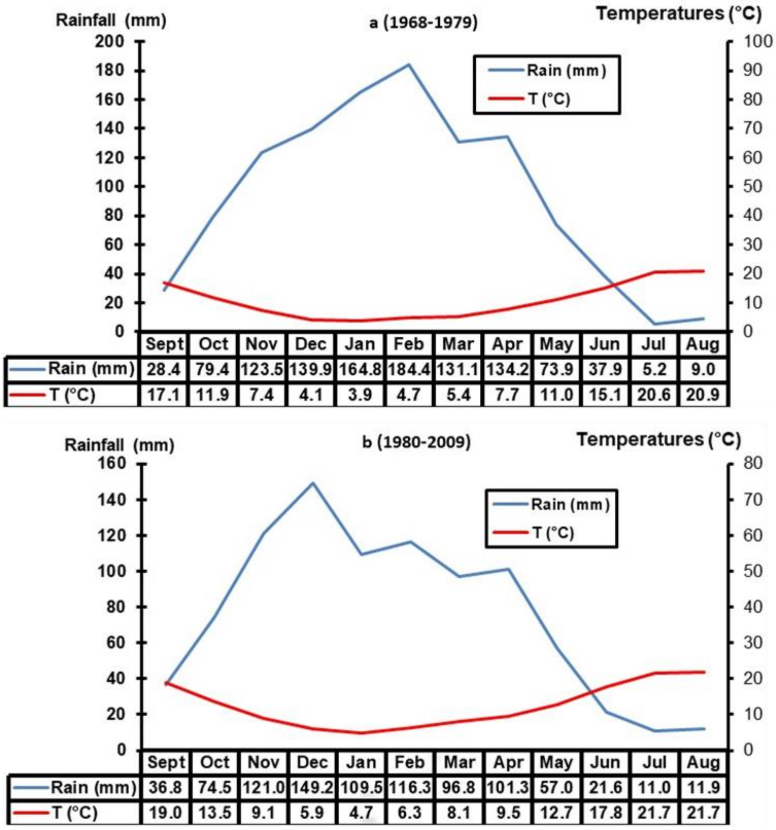

Fig 5a-b. Ombrothermic diagrams for the meteorological station of Ifrane

In the South basin, El Hajeb-Ifrane Tabular (Ifrane station), for the period 1968-1979, the dry season in El Hajeb-Ifrane is from July till September (Fig 5a), and it spans over four months (June to September) during the years 1980 to 2009 (temporal drought) (Fig 5b).

In the North basin, Saïs plain (El Hajra station), between 1968 and 1979, the number of months with lack of precipitation is 5 (June, July, August, September, and October) (Fig 6a) and from 1980 to 2009, the observed drought period is extended to six months; May, June, July, August, September, and October (temporal drought) (Fig 6b).

By comparing the drought periods in both stations Ifrane and El Hajra, it is noticed that the drought period between 1968 and 1979 may last three months in the Southern area and five months in the Northern one. However, between 1980 and 2009, the drought period may last four months in the Southern part, while it may extend up to six months in the Northern region. Therefore, it is deduced that this study area has experienced a spatio-temporal drought (Belhassan 2011). In addition, the rise in temperatures and variable precipitation patterns may increase the river water temperatures and cause low water levels.

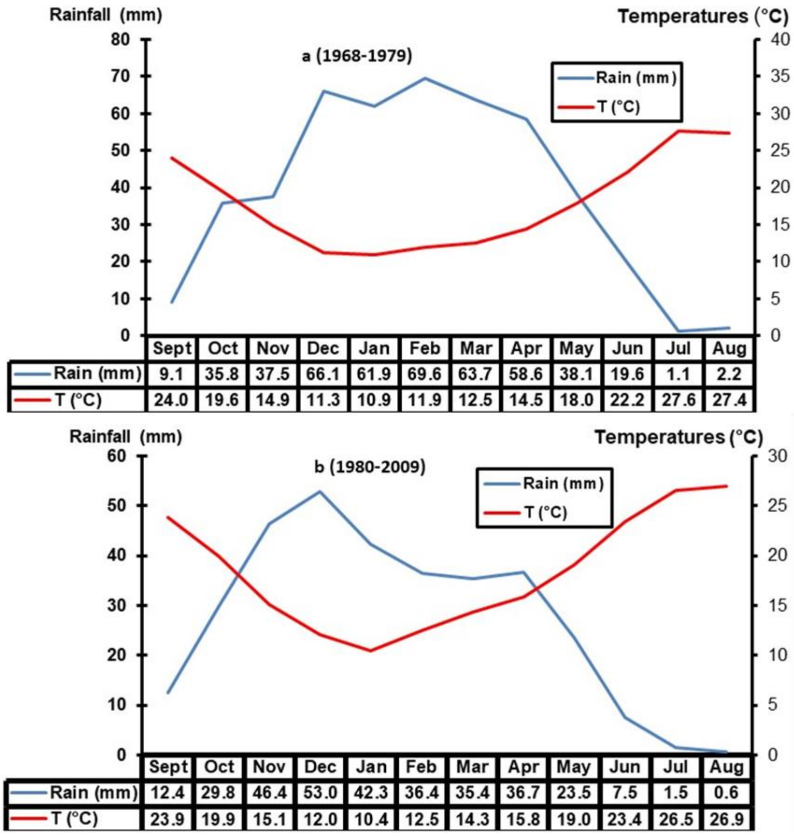

Fig 6a-b. Ombrothermic diagrams for the meteorological station El Hajra

4.3. Evapotranspiration

Assessing and monitoring drought through evapotranspiration in the Mikkes basin is extremely important. The values of P, T, PET, ETR, WD and WS calculated by Thornthwaite method for the study area are shown in Table 5. The results suggest an adverse trend of precipitation, an increase in annual mean temperature and annual PET after the year 1980. This could possibly be due to climate change. Before 1980, water surplus was 67.3% at Ifrane station and 26.2% at El Hajra station and after 1980, water surplus reduced to 57% at Ifrane station and to 5.5% at El Hajra station (Table 5). It is obvious that water surplus (WS) is higher in El Hajeb-Ifrane Tabular because of high amount of precipitations due to:

1. Higher elevation
2. Carbonate formations (viz. limestone and dolomites of Lower Jurassic)
3. Intensive faulting.

All these are factors favorizing water infiltration and water storage (Fig 1). However, water surplus in Saïs plain is low. The plain has lower altitude and rainfall and has geological features consisting of lacustrine limestone and tawny sands of Pliocene and Miocene marls. These catchment characteristics favor more runoffs.

4.4. River flow

Climate change may induce drought in the Mikkes River basin, causing decrease in rainfall and increase in temperatures and evapotranspiration. These meteorological drivers of drought may cause subsequent hydrological drought, more specifically on river flows. Fig 7 shows the relation between monthly rainfall and flow for the years 1968 to 2009. It demonstrates that the river flow patterns closely follow precipitation patterns. The seasonal flow regime is controlled by precipitation and evapotranspiration. Thus, the Mikkes River has a pluvio-evaporal regime with two distinct periods (Belhassan 2011). One period of high-water flow in winter, which occurs during December, January and February. This period is with high amount of precipitation of around 243 mm which resulted in a runoff of about 9.56 m^3/s. Also, the prolonged rainfall (moderate to large amounts of precipitation) over a winter – spring periods have led rainfall to infiltrate and add moisture to the soil. When the soil is totally saturated, any additional precipitation will run off. Therefore, more rainfall will become surface runoff in winter and spring periods. The month of February recorded the highest mean stream flow of 3.86 m^3/s. During winter, Mikkes River collects much runoff from precipitations and generates an increased amount in its flows. Therefore, the flow curve follows the precipitation pattern with two months delay time (Fig 7 and Table 6). Other periods of low-water levels occurred during summer, i.e. from July to August, which was marked by a significant decrease in rainfall.

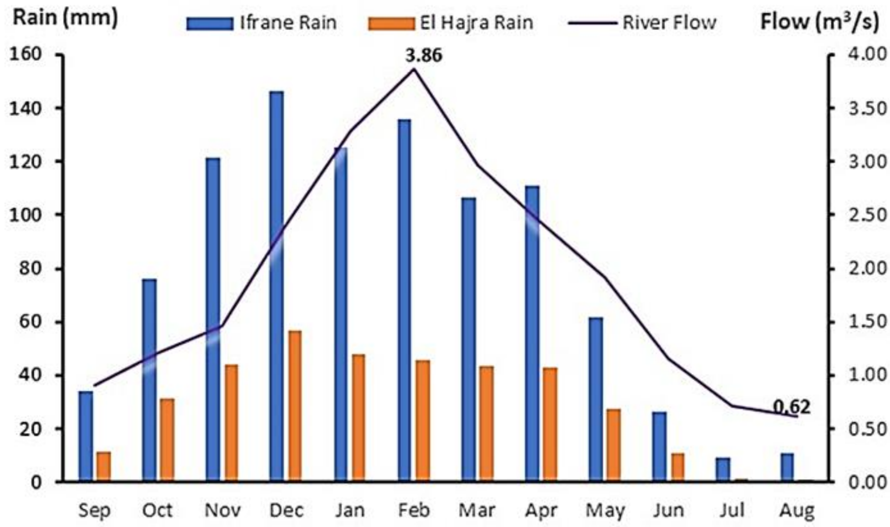

Fig 7. Monthly rainfall-runoff relationship (1968-2009)

Table 6. Seasonal rainfall – runoff relationship for 42 years (1968-2009)

Season	Flow (m^3/s)	Flow (%)	Rain (mm)	Rain (%)
Autumn	3.58	16	143	24
Winter	9.56	42	243	41
Spring	7.32	32	185	31
Summer	2.5	11	26	4

Mean rainfall between June and August, for 42 years (1968-2009) is about 26 mm. However, the relative runoff is 2.5 m^3/s. It should be mentioned that Mikkes River flow is the result of surface and subsurface flow (baseflow). The month of August recorded the lowest stream-flows of approx. 0.62 m^3/s in average, as this flow value is a baseflow, which reveals the contributions of water from the ground (Fig 7 and Table 6). The river has a sustained flow in summer, i.e. "base flow" which comes from the Mikkes groundwater discharges.

This baseflow seems to have greater influence on the hydrological response of the Mikkes River during the period with lack of rain. To evaluate the potential impact of drought on the Mikkes River flow, change in average annual runoff is a good indicator. The mean annual flow of Mikkes River from 1968 to 2009 is around 1.21 L/s/km² (Q_{mean} = 1.94 m^3/s; the average involves 365 daily values in each water year). Fig 8 shows an annual flow variation, which demonstrates a general decreasing. Before 1980, mean annual flows have been identified to be higher than the mean flows recorded between 1968 and 2009. However, since 1980, with the exception of years 2008 and 2009, the mean annual flows are lower than the mean flows recorded during the period 1968 – 2009. Therefore, the discharge rate of the river may be related to rainfall depletion since 1980 and also to the overexploitation of Mikkes groundwaters. The annual rainfall-runoff relationship is illustrated in Fig 9.

Before 1980 and in the following years, 1995, 1996, 1997, 2008 and 2009 (wet years), the streamflow patterns closely follow rainfall patterns in Ifrane and El Hajra stations. Rainfall causes the river flows to rise, however, over the period 1980-2009 (except the two years 2008 and 2009), a change in rainfall-runoff relationship is perceived.

This could be attributed to potential impact of drought. The increase in temperatures and evapotranspiration could influence the transformation of rainfall to runoff, or catchment characteristics, such as soil condition and groundwater levels.By comparing rainfall deficit and flow deficit between the periods of 1968-79 and 1980-2009, rainfall deficit is around 18% at El Hajeb-Ifrane Tabular and 30% in Saïs plain (spatio-temporal drought), while the river flow deficit is around 76%. Indeed, the drop in flow (4.23 m^3/s to 1.20 m^3/s) is higher than its rainfall in both stations (Table 7). Climate change could have affected the droughts in the region, causing the decrease in rainfall and increase in temperature and consequently higher river discharge. Furthermore, the high flow deficit could be the consequence of the over-exploitation of Mikkes groundwater observed since 1980 and thus high depletion in its piezometric levels (Belhassan et al. 2010).

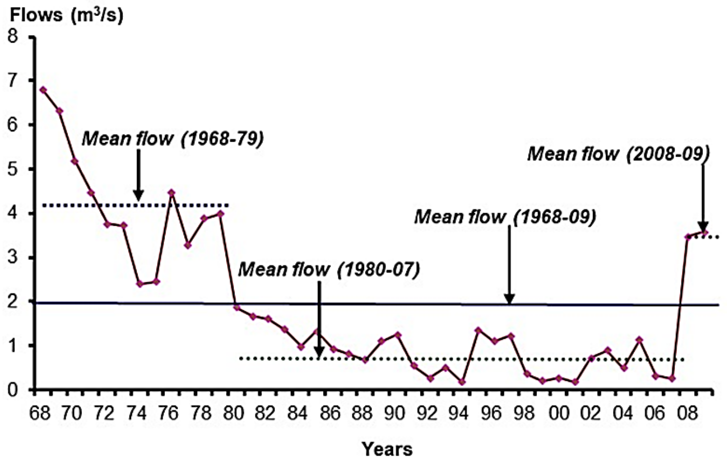

Fig 8. Annual flows of the Mikkes River (1968-2009)

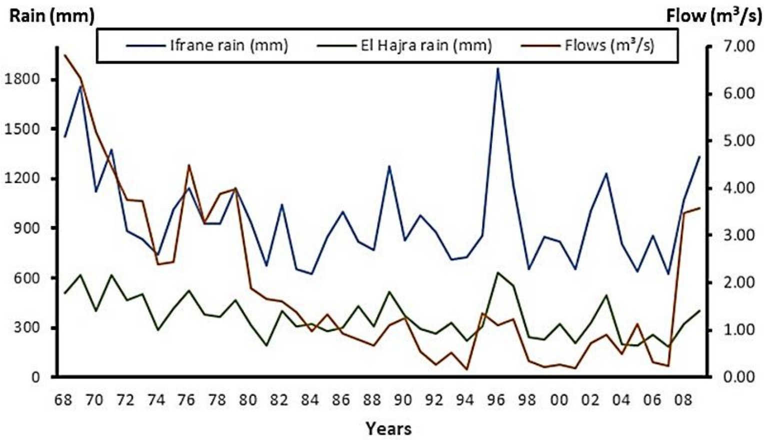

Fig 9. Mean annual rainfall-runoff relationship (1968-2009)

Table 7. Rainfall-flow deficits of the Mikkes River

Period	Ifrane Rain (mm)	El Hajra Rain (mm)	River Flows (m^3/s)
1968-79	1111.6	463.3	4.23
1980-09	906.9	326.0	1.02
Deficit (%)	18	30	76

4.5. Groundwater

Groundwater recharge has been highly affected by climate variability including climatic extremes as droughts. Also, the demand of increasing population is mounting pressure on the available groundwater. Morocco and particularly the study area is heavily reliant on groundwater resources, harnessing half of its demand for its irrigation needs, drinking and domestic purposes. This section aims to analyse the annual piezometric fluctuations of Mikkes groundwater for better understanding the potential impact of drought on Mikkes River flow with an estimated river flow deficit of around 76%.

In El Hajeb Ifrane Tabular aquifer, the piezometer 1448/22 (Fig 10) shows a maximum piezometric level in order of 1498 m in 2009 and a minimum of about 1487 m in 2005. Thus, this shows an increase of 11 m during the period from 2005 to 2009. Starting from 1995, a significant rise in level of the free-water table coincides with an increase in rainfall in the corresponding period (Fig 3 and 10). The piezometric level had shifted from 1490.45 m in 1995 to 1496.74 m in 1997. This demonstrates that in this sector, the more permeable the soil surface is, the more easily water can infiltrate and thereby, the rain infiltration has a large effect on water supply. The years 2008 and 2009 were wet years in Morocco, particularly in the Mikkes basin (Fig 3 and 4). The rainfall is significant and is followed by a significant increase in the piezometric level of El Hajeb Ifrane

Tabular aquifer where groundwater level rises from 1489.15 in 2008 to 1498.35 m in 2009 (Fig 3, 4 and 10).

In Saïs phreatic aquifer, piezometric evolution of different piezometers in this sector has remained stable during the period between 1968 and 1980. This drop in piezometric level started to increase since 1998 in the central area. An average value of 1 m/year can be used for this aquifer (ABHS 2008). The piezometer 199/15 shows a decline in water level after 1980 which was about 33 cm/year (Fig 10). This sharp drop in water level of this aquifer was associated with high stress climate constraint, which the region has experienced since the early 1980s accompanied by an increase in sampling for water supply (drinking and irrigation). Between 1995 and 1997, the groundwater level had risen about 4 m after a sharp increase in rainfall at the Mikkes basin in 1996 (Fig 3 and 10). The wet years 2008 and 2009 were, accompanied by an increase in the piezometric level, which increases from 504.61 m in 2008 to 507.48 m in 2009 (Fig 3 and 10). Actually, this increase in water level is considered as direct-indirect and could be explained by: (1) direct infiltration of precipitation, (2) the existence of a relationship between the El Hajeb Ifrane Tabular aquifer and the Saïs phreatic aquifer and (3) the existence of a relationship between two aquifers of the Saïs plain (phreatic and confined).

In Saïs deep artesian confined aquifer, the piezometric analysis of several piezometers in this sector shows that Saïs deep aquifer is the most affected by exploitation. The piezometer 290/22 can be considered as the best piezometer to monitor the Saïs confined aquifer level. It shows a sharp decline in water levels of around 2.87 m/year in average since the beginning of 80s (Fig 10). Generally, the declining piezometric level of other piezometers in the Saïs plain is less than what the piezometer 290/22 (other piezometers show decline which around 1.5 m/year (ABHS 2008)) recorded and this greater depletion is primarily due to the drought that this region has experienced since 1980, and also due to the overexploitation of this aquifer to satisfy water needs in drinking, irrigation or industries (Belhassan et al. 2010). However, the higher precipitation during the period 1995-1998 seems to be the reason for the 4 m increase in the piezometric level (Fig 3 and 10). It is obvious that rainfall promotes the rise in piezometric level of confined aquifer. Consequently, interactions between Mikkes groundwater are reported. While, the wet years 2008 and 2009 had no effect in increasing piezometric level of this aquifer. Also, the Saïs phreatic aquifer has a lower inter-annual decrease in piezometric level than the deep aquifer. This could be explained by the overexploitation of this Saïs artesian reservoir.

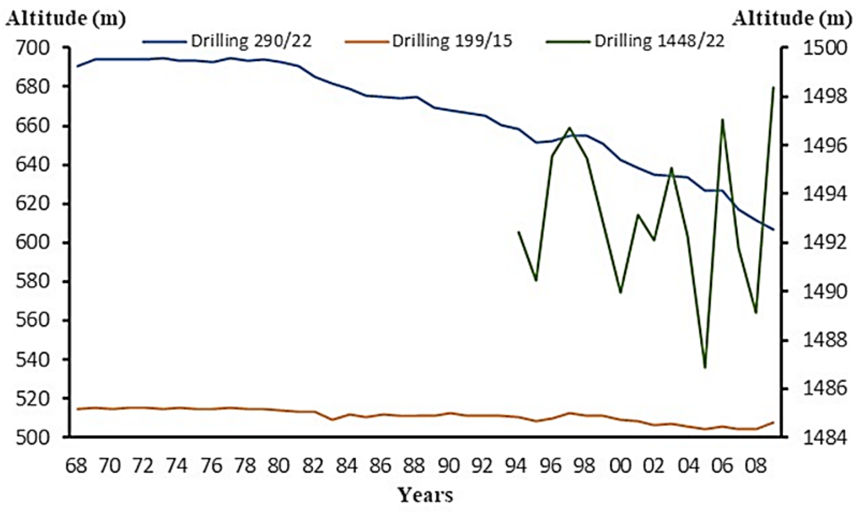

Fig 10. Piezometric level of Mikkes groundwaters

4.6. Mikkes River Regimes

From 1968 to 2009, discharge of Mikkes River changes over time following the rainfall event. Table 8 shows three different regimes: the first regime (1968-79) is humid, the second (1980-2007) is dry and the third regime (2008-2009) is humid. These different regimes of Mikkes River in different phases have many explanations, which may be attributed to the fact that El Hajeb–Ifrane Tabular soil moisture in unsaturated soil layers were almost saturated with water before 1980 (humid period). This is because of the following factors:

1. High precipitation, which was about 668 mm/year and high river flow that was around 4.23 m^3/s.
2. Controlled groundwater exploitation.

These factors regulate the rainfall distribution. Indeed, high rainfall and high-water levels in the Mikkes aquifers promote runoff (Belhassan et al. 2009).

During the period 1980-2007 (dry period), there are two factors, which contribute to desaturation of soil moisture in unsaturated soil layers of El Hajeb-Ifrane Tabular aquifer as follows:

1. Drought accompanied with depletion in rainfall and rise in temperatures and evapotranspiration; the mean annual precipitation was around 526 mm/year and the mean annual river flow was about 0.84 m^3/s.
2. Demand for the Mikkes reservoirs resources is increasing since 1980, which causes high depletion in the piezometric levels. The piezometric level depletion of Saïs unconfined aquifer is around 1 m/year and about 1.5 m/year in Saïs confined aquifer (ABHS 2008). This greater depletion is a result of over-exploitation of the Mikkes aquifers. The pumping in 2001 exceeded thousands of pumping bore wells including drilling in Saïs unconfined aquifer and hundreds of drillings at Saïs confined aquifer and shallow water table of El Hajeb - Ifrane Tabular (Belhassan at al. 2010).

Consequently, the soil moisture in unsaturated layers of El Hajeb-Ifrane Tabular aquifer has led to low rainfall to infiltrate rather than causing runoff. This results in an increase in the water permeability coefficient due to an increase of water content.

Table 8. Different regimes of the Mikkes River for different periods

Periods	Rain (mm)	River flows (m^3/s)	Variation with mean flow (%)	Climate
1968-79	668	4.23	118	Humid
1980-07	526	0.84	-57	Dry
2008-09	701	3.53	82	Humid

In these two years of 2008 and 2009 (humid period), the high rainfall of around 701 mm/year recorded influences runoff rates and volumes. As the precipitation intensity exceeds the infiltration rate of the soil, the surface runoff is generated rapidly, resulting in mean annual flow of about 3.53 m^3/s. Rainfall causes an increase in the river flow.

Therefore, precipitation deficits are a recognized main driver of drought leading to soil-moisture decrease and the rainfall-runoff relationship in the Mikkes basin depends on water status of the soil moisture in unsaturated zone of El Hajeb – Ifrane Tabular water table.

5. Conclusion

The Mikkes basin is principally characterized by spatio-temporal variability of rainfall and temperature and highlights a significant decline in water inputs since 1981. The deficit of rainfall between the periods of 1968-1979 and 1980-2009 (the resurgence of years at high temperature) is around 19%. Comparing the ombrothermic diagrams of Ifrane and El Hajra stations, the dry season during the period from 1968 to 1979 lasts three months in El Hajeb-Ifrane Tabular and five months in Saïs plain (spatial drought). In El Hajeb-Ifrane Tabular during the period from 1980 to 2009, the dry season months lasts four months, and it extends to six months in Saïs plain (spatial drought). The Mikkes basin appears to be characterized by spatio-temporal drought. The estimated evapotranspiration in the Mikkes basin reveals increase in temperature and evapotranspiration and thereby a water surplus (WS) depletion. Monitoring monthly flows during the period 1968 to 2009, show a pluvio-evaporal regime with two periods. The first period is in winter with high water flow starting from December and reaching its maximum in February, the month with the highest winter rainfall. The second period is in summer with low water flow from July to August, induced by low precipitation relative to high evapotranspiration. Annual river flow shows a deficit of about 76% between the periods of 1968-1979 and 1980-2009 (temporal drought). This high River flow deficit appears to be the result of potential drought impact which is aggravated by the overexploitation of the Mikkes reservoirs to satisfy water resources requirements such as potable water and agriculture. The overexploitation of the Mikkes groundwater caused a significant fall in piezometric levels, especially that of the confined aquifer, which is the main water supply in the basin. Continued overexploitation may lead to the destruction of the water resources. This obliges us to take quick actions to effectively manage Mikkes basin.

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