DROUGHT - PIEZOMETRIC LEVEL OF THE GROUNDWATER AQUIFERS: MIKKES BASIN (MOROCCO)

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ABSTRACT

The Mikkes basin is located at the north center of Morocco. It comprises of three different zones which represent diversified geologies that shelter a phreatic and confined aquifer in Sais basin and a shallow aquifer in the Tabular Middle Atlas. The recharge of aquifers depends on rainfall and evapotranspiration. The drought which the basin has been known since the 80s could have an impact on the reserves of the groundwater aquifers. The magnitude of the annual drought can be clearly illustrated by the increase in air temperature and by the fall in the average of annual rainfall. The rainfall deficit through the period between 1970-1979 and 1980-2000 is around 22 % in the Tabular Atlas and 23 % in the Sais plain. It could be followed by a decline in water levels of the aquifers basin. At the seasonal scale, the monitoring of changes in water table aquifers levels shows that they are supplied directly by infiltration of rainwater, but are considerably discharged by evaporation and exploitation during the dry season. Though the confined aquifer is less sensitive to changes in rainfall, but is more exploited for satisfy water requirements.

Keywords: Morocco; stream Mikkes; aquifer; drought; rainfall; piezometry

1. INTRODUCTION

The importance of water resources is evident, and its management through all levels is imperative, especially in Mediterranean countries which are semi arid where water demand is highly required for irrigation and for the drinking (Papy et al. [1], Mania et al. [2], Grillot et al. [3, 4], Fakir [5]). The water resources which are available in Morocco are limited. They are also subjected to cyclical extremes variations i.e. succession of cycles of severe drought (Alibou [6]). This drought has become more frequent in the recent decades and it will definitely aggravates the overexploitation (MED-EUWI WG [7]). In addition, the drought has attracted great interest because of its relationship to global climate change, which would menace water resources (Arnell [8]). Climate models indicate an increase in temperature and reduction in rainfall for all seasons that will be in year 2050, compared with year 1990. It also shows an increase in variability of rainfall in autumn. The results of modelling of the groundwater indicate an annual decline of water table recharge by precipitation of 40-68 % between climate centred in years between 1990 and 2050. Moreover, the decrease in precipitation, the infiltration and the groundwater recharge in Morocco should the drop in phreatic aquifer level (Van Dijck et al. [9]).

The catchment area of Mikkes basin is located at the north-centre of Morocco. It is bounded on the South by Tabular Middle Atlas, on the North by Prerif and occupied at the centre by the Sais plain (South Rifain Trough). Its area is about 1600 km^2 and its perimeter is about 259 km (Figure 1). The groundwaters of Mikkes basin are considered as a source of drinking water, including the cities of Fez, Meknes, Ifrane and neighbouring centers. The renewal of this resource depends on the groundwater recharge, which is a result of precipitation and evapotranspiration. The aim of this study is to understand the impact of climatic constraint on the degradation of the groundwater in the Mikkes basin.

2. METHODOLOGY

For the study of climate context, two meteorological stations are chosen; one of them is in the Tabular Atlas while the other is in the Sais plain. The Ifrane station (altitude Z = 1600 m) is characterized as Tabular, with complete data of precipitation (from 1970 to 2000) and temperatures (from 1958 to 2000). However, in the Sais plain, the El Hajra station (altitude Z = 215 m), presents this series of precipitations measuring from 1970 to 2000 and temperatures between 1980 and 2000.

In order to have homogeneity, the data analysis for seasonal droughts is studied for the two stations. This study is based on data from the Ifrane station which shows the extent of drought before and after 1980. The El Hajra station in turn is used to compare the extent of drought in the Tabular and in the plain. The magnitude of the drought is characterized in temporal and spatial terms. The temporal variation of groundwater piezometric level in Sais plain has been affected since 1968, while in the Tabular; it has been affected since 1994.

3. CLIMATE CONTEXT OF THE STUDY AREA

The climatological study is used to understand the climate constraints on the groundwater Mikkes basin. It is based on annual precipitation, ombrohtermics diagrams of Gaussen and evapotranspiration (ETR) at the stations of El Hajra and Ifrane, which characterize the Sais plain and the Tabular Atlas.

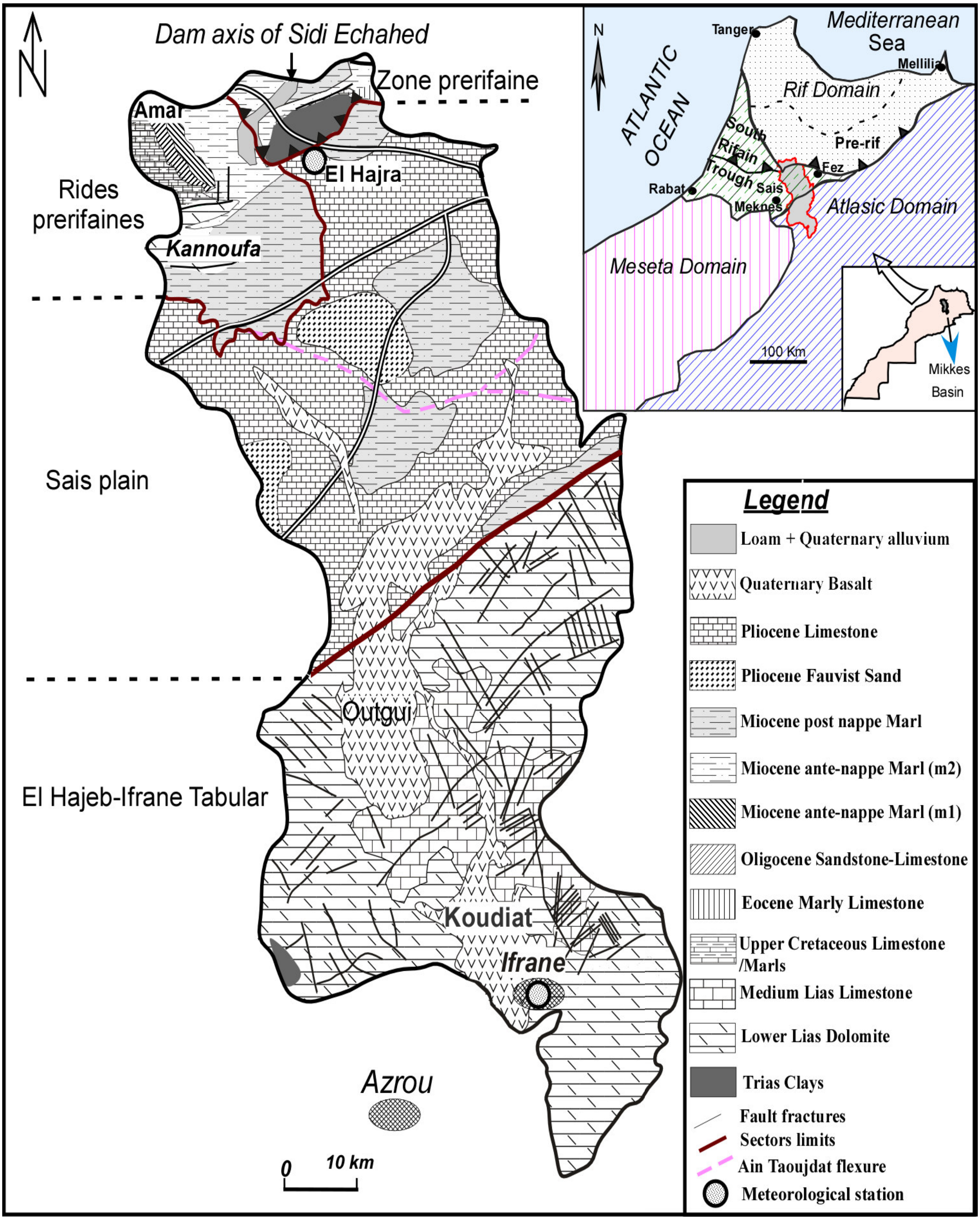

Fig. 1 Geological map of the Mikkes basin (taken from the geological map 1/100000, geology division, Rabat, Morocco, 1975)

3.1 Precipitation

The precipitations are distributed very unevenly in the space and in the time (Figure 2). In the space, from south to north the altitude increases. Thus, the minimum annual rainfall average is registered in the Sais plain (station El Hajra). Throughout in the Mikkes basin, a general decrease in precipitation has been observed. This decline begins since 80 years. In the Tabular, the average annual rainfall recorded through 31 for the years between 1970-2000 was 592 mm. It varies significantly from year to year, ranged between 250 mm in 2000 and 1215 mm in 1996. The annual rainfall average during the period between 1970-1979 was 694 mm, while for the period between 1980-2000, it was 543 mm. The deficit of rainfall in the Tabular is about 22 %. The annual rainfall average which is recorded through 31 years for the period between 1970-2000 was 367 mm. The annual rainfall average has shown inconsistent patterns from year to other, i.e. varying between 165 mm in 1998 to 586 mm in 1995. The annual rainfall average between 1970 and 1979 was 436 mm, while it was 335 mm between 1980 and 2000. The deficit is around 23 %. This downward rainfall is generalized throughout Morocco and it characterizes the drought years, but it is not in the same way in mountain as in plain.

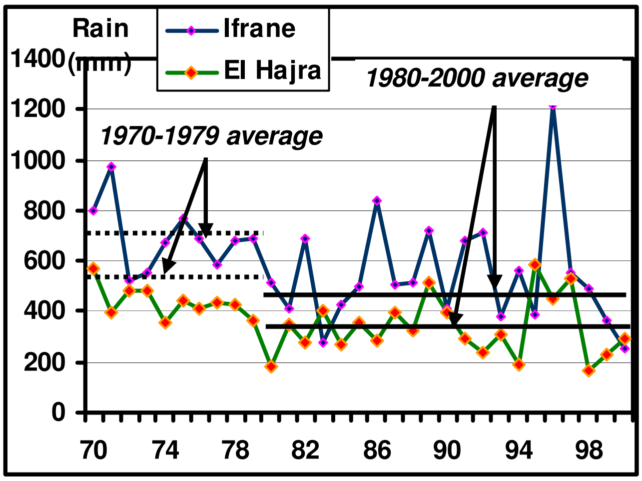

Fig. 2 Annual pluviometry at Ifrane and El Hajra stations (1970-2000)

3.2 Ombrothermic Diagram of Gaussen

By combining the monthly values of precipitation expressed in millimeters (P) and temperatures in centigrade degrees (T), the biologically dry month is defined by the ratio P<2T (Bagnouls and Gaussen [10]). It is important to know if there is a difference of drought between the Tabular Atlas and Sais plain. The ombrothermic diagram in the Tabular for the period between 1958-1979 is shown in Figure 3 while Figure 4 shows it for the years between 1980 and 2000. Whereas the 3rd diagram in the plain for the years between 1980-2000 is shown in Figure 5. The Tabular is represented by Ifrane station, the variability of monthly precipitation for the periods between 1958-1979 and 1980-2000, appears clearly in Figures 3 and 4. The general trend appears in an increase of about 1 °C in temperatures for each month (meaning therefore, the air is warmer). The temperature increase could be the result of climatic changes observed in Morocco (Alibou [6]), while the trend of precipitation is downwards (i.e. less rain), with the exception of July, August and September when a surge in rainfall is projected (floods).

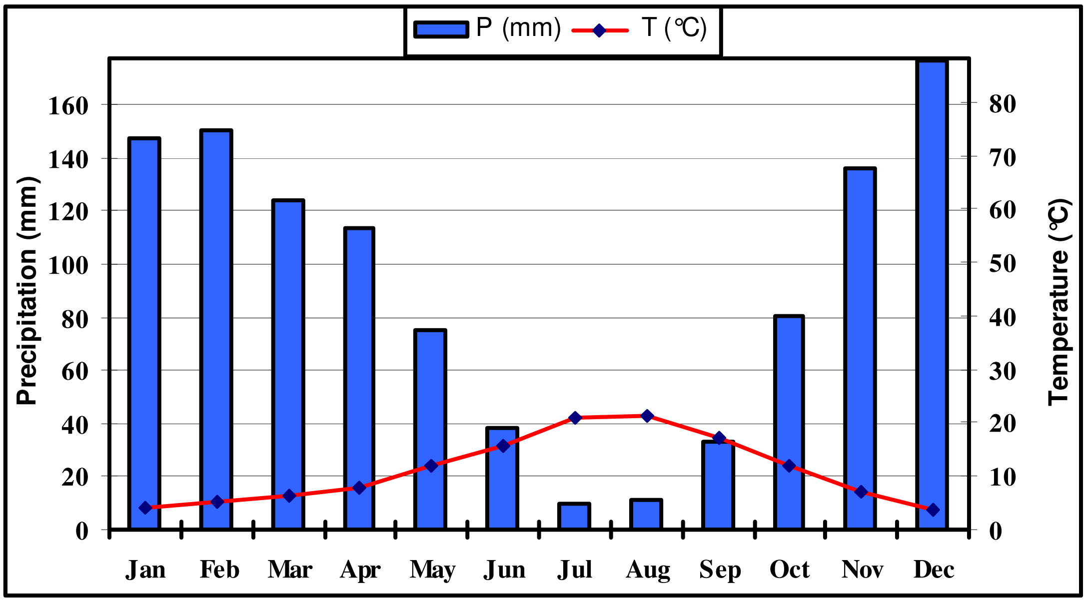

Fig. 3 Ombrothermic diagram at the station of Ifrane (1958-1979)

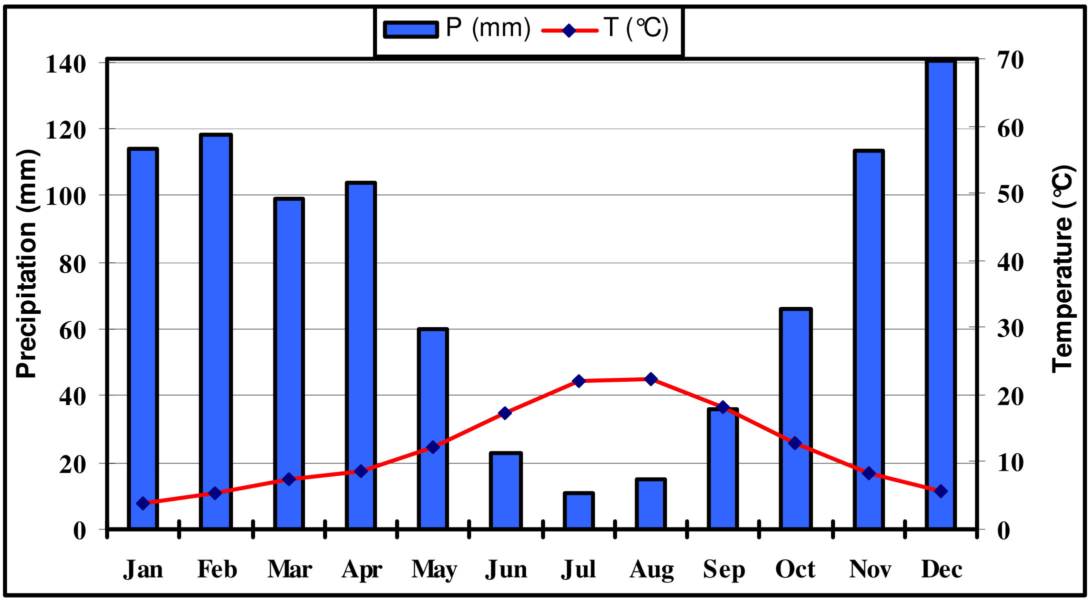

Fig. 4 Ombrothermic diagram at the station of Ifrane (1980-2000)

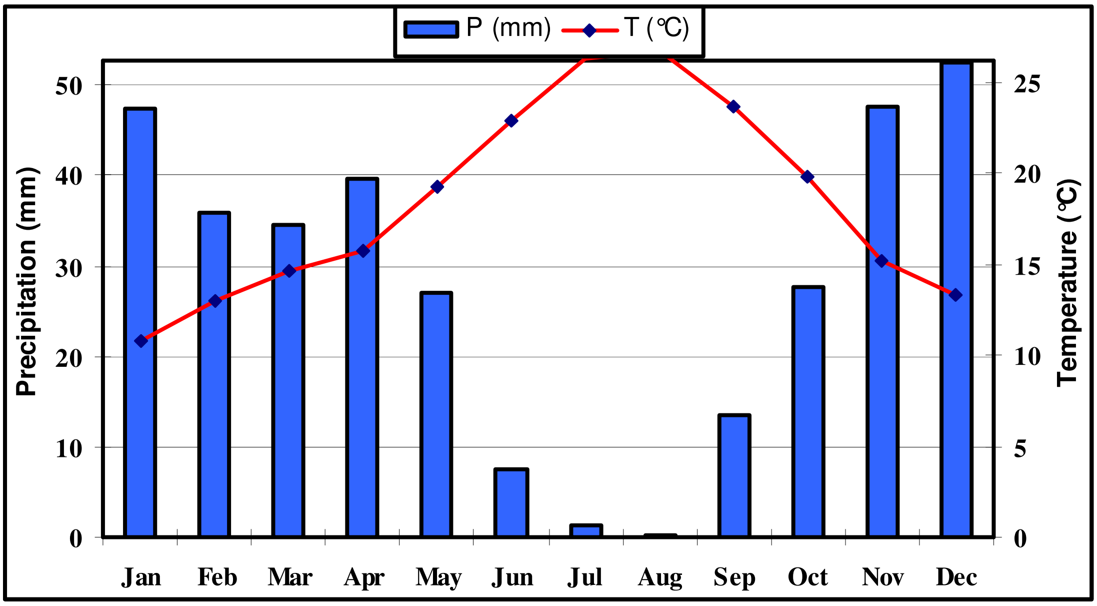

Fig. 5 Ombrothermic diagram at the station of El Hajra (1980-2000)

Therefore, this development is accompanied by an increase in the number of dried months. For the period between 1958-1979, the number of dried months, in the Tabular is three (i.e. July to September, Figure 3), while it is four months from June to September for the period between 1980-2000 (i.e. temporal drought Figure 4), and it is six months in the Sais plain for the period 1980-2000 (i.e. spatial drought Figure 5). Therefore, drought characterizes Mikkes basin as spatio-temporal.

3.3 Evapotranspiration (1980-2000)

The evapotranspiration is one of the main parameters of water balance. The method used for evaluating the real evapotranspiration (ETR) and/or potential (ETP), in this researches paper, is that of Thornthwaite [11]. In order to compare the ETP change in Tabular and Sais plain, Tables 1 and 2 show the monthly evolution of ETP for the two representative stations. The evolution of the monthly ETP at El Hajra and Ifrane is coincided. Nevertheless, the annual reading of potential evapotranspiration (ETP) is greater in El Hajra than the one in Ifrane (i.e. 834 against 633 mm), which is due to thermal differences between the Sais plain and the Tabular Atlas. The real evapotranspiration (ETR), which reflects the actual water sampling through the atmosphere, is relatively stable at both stations: El Hajra (335 mm) and Ifrane (380 mm). Furthermore, the water deficit (DH = ETP - ETR) is disproportionate between the two stations, it is two times higher in El Hajra than Ifrane (i.e. 500 against 253 mm). This shortage of water is needed to satisfy potential evapotranspiration. The confrontation of real evapotranspiration and precipitation is an indication for surplus water (SH = P - ETR) - supplying the flow in all its forms. The surplus water is zero in El Hajra while in Ifrane it shows a considerable amount which is around 520 mm. Thus, the stream Mikkes is supplied by the Tabular Middle Atlas well watered (Tables 1 and 2).

Table 1 Hydric balance of El Hajra (1980-2000)

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
P (mm)	13.44	27.69	47.58	52.39	47.37	35.93	34.52	39.55	27.10	7.61	1.38	0.18	335
ETP (mm)	104.82	74.46	44.46	34.66	22.90	33.12	41.29	47.67	70.59	98.53	128.68	133.12	834
P-ETP	-91.38	-46.78	3.11	17.73	24.47	2.82	-6.77	-8.11	-43.49	-90.92	-127.31	-132.93	-500
RFU	0.00	0.00	3.11	20.84	45.31	48.13	41.36	33.25	0.00	0.00	0.00	0.00	192
ETR	13.44	27.69	44.46	34.66	22.90	33.12	41.29	47.67	60.35	7.61	1.38	0.18	335
Deficit	91.38	46.78	0.00	0.00	0.00	0.00	0.00	0.00	10.24	90.92	127.31	132.93	500
Surplus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

Table 2 Hydric balance of Ifrane (1980-2000)

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
P (mm)	36.81	66.04	113.60	140.31	114.10	118.49	99.01	103.54	60.12	22.86	10.64	14.93	900
ETP (mm)	86.13	54.75	31.07	18.10	11.70	18.02	27.06	33.09	51.44	80.64	110.09	110.90	633
P-ETP	-49.31	11.30	82.52	122.21	102.39	100.47	71.95	70.45	8.68	-57.78	-99.45	-95.97	267
RFU	0.00	11.30	50.00	50.00	50.00	50.00	50.00	50.00	50.00	0.00	0.00	0.00	361
ETR	36.81	54.75	31.07	18.10	11.70	18.02	27.06	33.09	51.44	72.86	10.64	14.93	380
Deficit	49.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.78	99.45	95.97	253
Surplus	0.00	0.00	43.82	122.21	102.39	100.47	71.95	70.45	8.68	0.00	0.00	0.00	520

4. GEOLOGICAL AND HYDROGEOLOGICAL CONTEXTS

The hydrogeological context of the different regional structures implies the existence of three groundwater tables. El Hajeb-Ifrane Tabular is a free-water table circulating in the Limestones and Dolomites, which is supplied directly by precipitation. Triassic Clays and Paleozoic Schist form impermeable substratum of this aquifer. These carbonate formations burrow under the Mio-Plio-Quaternary cover in the right of South Rifain Trough which forms a deep confined aquifer. The depth of the Miocene Marls forming the impermeable roof of this aquifer is about 1500 m in contact with Rides prerifaines at drilling point Ain Allah (IRE N° 2370/15) (Belhassan et al. [12]). The fractured rocks constitute the groundwater reservoirs (Rafik and Bouamoud [13]). The main parameters for the migration of fluids in fractured rocks are the main geological characteristics of the fracturing, drainage, topography and rainfall (Murthy [14], Sree Devi et al. [15], Ligtenberg [16], Ettazarini [17]). The data of pumping tests show that the Liasic reservoirs -Sais and Tabular- have transmissivities ranging between 10^{-5} to 10^{-1} m^2/s with a geometric average of 10^{-3} m^2/s. The Plio-Quaternary formations as they are in the phreatic groundwater of the Plio-Quaternary -Sais aquifer- (Figure 1). The thickness of this aquifer varies from a few meters to 120 m. This Plio-Quaternary reservoir has transmissivities ranging between 10^{-5} m^2/s to 10^{-2} m^2/s with a geometric average of 10^{-4} m^2/s (ABHS [18]).

5. PIEZOMETRIC FLUCTUATIONS

The study of piezometric variations of the groundwater Mikkes basin was conducted to understand the impact of climatic parameters on the groundwater resource. The variations in the piezometric levels were followed in time and space. The observations were made at both annual and monthly time scales. The piezometry was followed in the Tabular in the only available measure: by drilling 1448/22. For the Sais phreatic aquifer, all piezometers show a similar evolution and only piezometer data 199/15 is presented. For deep confined aquifer, piezometric data 290/22 is presented with long history and a good follow-up.

5.1 The annual piezometric fluctuations

The supplying regime of aquifers is submitted to the rate and speed of infiltration, which depends essentially on the vertical permeability of the land. The height and rhythm of rainfall play a role which can be more or less considerable depending on the depth and type of the aquifer horizon (i.e. confined or free). The piezometric surface of the free-water table, in natural conditions, fluctuations in levels, often important, directly related to the rhythm of rainfall and the intensity of evapotranspiration (Castany [19]).

For the Tabular aquifer, piezometer 1448/22 (Figure 6) shows a decrease of 7 m between 1994 and 2002. Starting from 1995, a significant rise in water level of the water table coincides with that of rainfall. The piezometric level shifts from 1490.45 m in 1995 to 1496.74 m in 1997. This demonstrates that in this sector, the rain infiltration has a large effect on water supply. The surplus water in Ifrane has a considerable amount of 520 mm, representing approximately 58 % of the total rainfall during the period between 1980-2000.

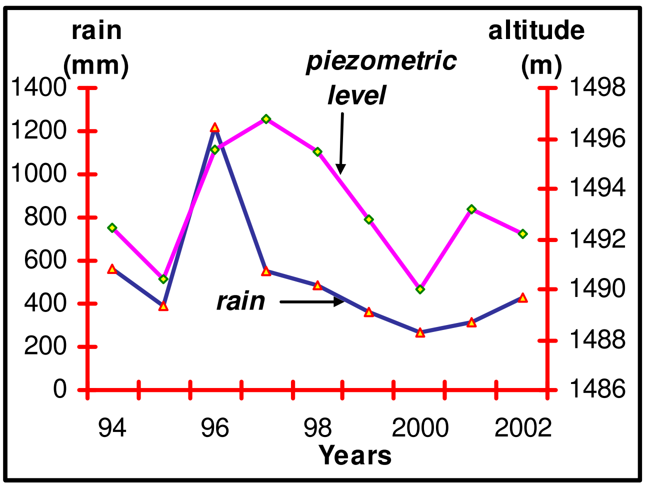

Fig. 6 Relation between annual rain and annual piezometric level of the Tabular aquifer (1994-2002)

It is established that more than half of the precipitation contributes the renewal of water supplies. This may be explained by significant infiltration, predominantly of permeable carbonate formations recognized in the Tabular Middle Atlas and strong fracturing of land (Figure 1). Whereas for the year 2001 and despite an increase in rainfall, the level of free-water table declines. The rain infiltration has a lesser effect on the supply of water table due to overexploitation of the reservoir and results in an imbalance between the exploitation and supplying; the excessive increase of numbers of the sampling which has experienced the region in 2001 (ABHS [18]).

For the Sais phreatic aquifer, the piezometric level has remained stable for the years between 1968 and 1980. The decline in water level after 1980 was about 38 cm/year (Figure 7). This sharp drop in water level of the aquifer was associated with high stress climate constraint, which the region has known by for 80 years accompanied by an increase in sampling for water supply (drinking and irrigation). The evapotranspiration observed at the El Hajra station for the period between 1980-2000 was 100 % of the total rainfall and the surplus is zero (i.e. no renewal). So that, any rainfall deficit is considered as a mark on the evolution of underground water resources because of evapo-transpiratoires times so that the succession of deficit through years leads to a depletion of the water. The water table has risen approximately 4 m, from 1995 to 1997, in response to effective recharge. This enhancement is also reflected by the thickness of the saturated zone is much more important. As knowing that renewals of this water table is zero during the period 1980-2000. So, the increase of water level superficial aquifer can be direct, (i.e. by the infiltration of rainfall; water excess of years between 1995-1997. However, this is could be on premise of a supply connection between the Tabular groundwater and the superficial aquifer, and/or a hydraulic connexion between the level of that aquifer and the deep confined aquifer.

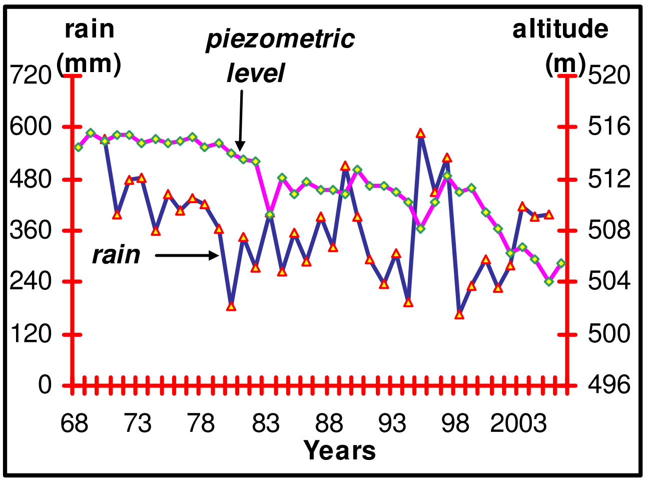

Fig. 7 Relation between annual rain and annual piezometric level of the phreatic Sais aquifer (1968-2006)

For the deep confined aquifer, the monitoring of piezometric fluctuations shows a sharp decline in water levels since the beginning of 80s (Figure 8). The variation of water level is around 2.3 m/ year on average; primarily due to the drought suffered by the region during these years, and exploitation of the groundwater. However, higher precipitation seems to be the reason for rise of about 4 m in the piezometric level after 1995. The overexploitation of this confined aquifer - for drinking or irrigation, caused the drop in artesian pressure and subsequent decline in piezometric levels in the water table. The annual destocking average is estimated at more than 100 Mm^3/year since 1980, resulting in an overall deficit of about 2 Milliards m^3. The overexploitation of groundwater resources - short and medium term drinking-water supply Fez and Meknes cities. Moreover, the disappearance of artesian on whole drilling and the drying up of springs will constrain ONEP (National Office of Drinking Water) to be equipped with means exhaust for artesian drilling initially and to review appropriate case of their replacement. Such degradation of the resources will have an adverse impact on the heavy investments at the irrigation sector, also it will affect tourism investments that established without taking into account the social and economical consequences that may bring it forth (ABHS [20]).

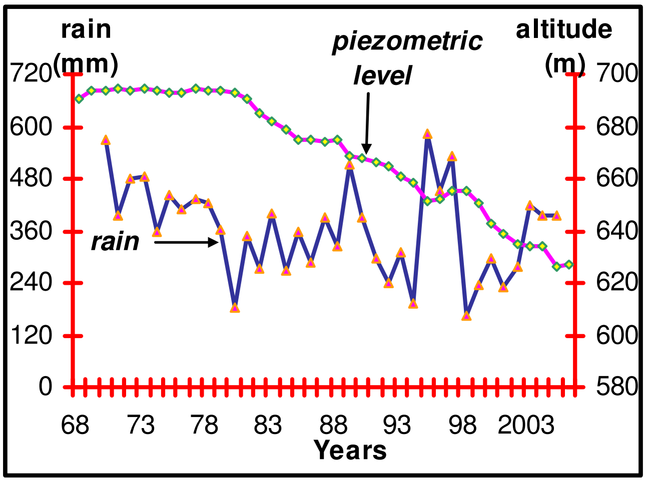

Fig. 8 Relation between annual rain and annual piezometric level of the confined aquifer deep (1968-2006)

Generally, the fall in water levels at different water tables is related to rainfall deficit that this region has been experiencing for 80 years which is accompanied by the increase in water demands. Free-water table are much more susceptible to discharge compared to the confined aquifer (Urbano et al. [21]). As a result, the water table of the Mikkes basin does not demonstrate a uniform sensitivity to the drought:

- The Sais phreatic water-table is supplied directly by precipitation. The recharge is comparable from one year to another. It shows fluctuations called "annual".
- The water table of El Hajeb Ifrane Tabular is sensitive to multi-year droughts; therefore, fluctuations in this sector follow the multi-year cycles.

- The Sais confined aquifer is the least sensitive to variations in rainfall because it is not directly supplied by precipitation. Nevertheless, it has been exploited the most in the Mikkes basin, to satisfy the drinking and irrigation demands.

Between 1995 and 1998, the different sectors of the Mikkes basin demonstrated similar rise in piezometric, on premise of inter water-table relations of the basin. The rainfall directly influences the level of the Tabular aquifer by direct infiltration, permeable carbonate formations and strong fracturing (Figure 1) and as known that the Liasic confined aquifer is the extension of Tabular. Thus, the Tabular Middle Atlas supplies the Sais deep aquifer, and by aboucher the Sais phreatic water-table.

The correlation between the piezometric level of the phreatic aquifer and the piezometric level of the deep Liasic aquifer shows a value of 0.92 (i.e. a positive correlation (Figure 9)). Actually, despite that the two Sais aquifers are separated by a thick series Marls Miocene age but they are in direct/indirect communication. Due to limited outcrop Liasic, the rainfall recharge quantity that can occur is quite low. However, in the adjacent area to Tabular Atlas, where the Miocene is thin and/or does not exist even, the Liasic is in direct contact with the Plio-Quaternary. In these areas, where the piezometer Liasic is less than the Plio-Quaternary, a drainance may occur from the Plio-Quaternary, which represents the water supply for the Liasic. The total volume of the vertical flowing is low, especially when it's compared to the flow of Liasic drainance to Plio-Quaternary. The Drainance of the Plio-Quaternary to Lias may be important in places - the drainance is a vertical flowing through a semi-impermeable layer which can be ascending or descending according to the relative position of the piezometric levels of the phreatic aquifer and deep aquifer- (Mac Donald [22]).

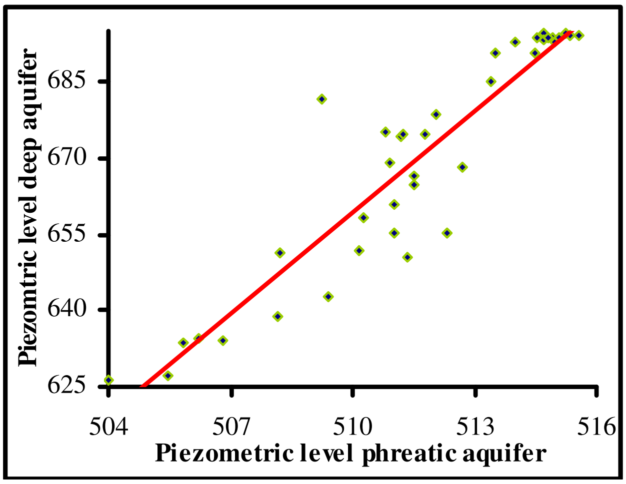

Fig. 9 Relation between piezometric level phreatic Sais and deep Sais (1968-2006), r=0.92

5.2 The monthly piezometric fluctuations

The monthly free-water table levels of Mikkes basin show a seasonal evolution of the groundwater reserves (Figures 10 and 11). The depth of the aquifer controls the magnitude of the seasonal flow of groundwater (Vidon and Hill [23], Dahl et al. [24]). Hydraulic fluctuations depend on the seasonal variation of natural recharge of the rainfall infiltration (El Yaouti et al. [25]).

For the Tabular free-water table, its regime is simple and it is marked by a phase of rising in water level and the phase of lower level. The piezometric peak of free-water table is reached in February after heavy rainfall in December. The piezometric drops in parallel with drop in rainfall. During the rainy season, the aquifer is recharged by infiltration of rainwater, whereas during the dry season it is discharged to even lower levels as a result of not getting corresponding rainfall infiltration. Such reduction in level of this aquifer is a direct result of evapotranspiration and the increase of exploitation during the dry season (Figure 10).

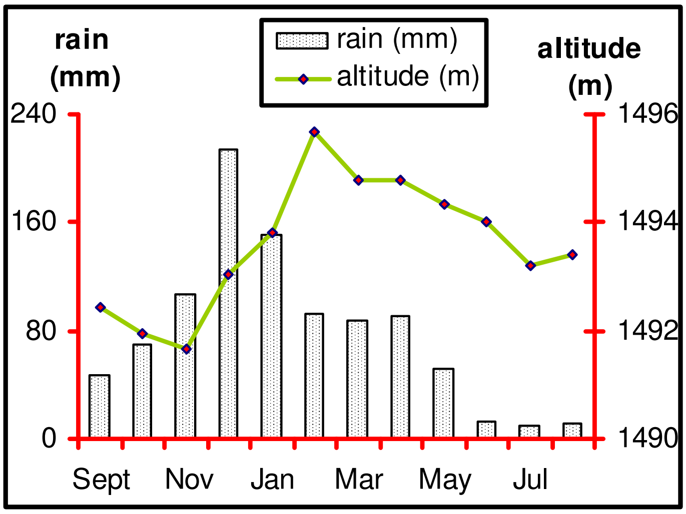

Fig. 10 Relation between monthly rain and monthly piezometric level of the Tabular aquifer (1994-2002)

The hydrogeological regime of the phreatic water-table is characterized by a simple regime (i.e. alternating a period of rising water level and dropping water levels). The maximum amount of piezometric free-water table is reached in April, May and June, after an increase in rainfall. The piezometric decline begins at the end of regular rainfall to reach its minimum in July, August and September. The high water season (October to February) is demonstrated by recharge of aquifer. The heavy rains saturate the soil, thus causing the percolation of water (effective rainfall). The process of percolation of water corresponding to three stages of development of water production: (1) infiltration entrains to a saturation of the upper soil resulting in the compression of the capillary fringe, (2) the potential increase of groundwater and (3) an increase in the infiltration of groundwater into channels through the transmission of the combined pressure of the groundwater crest and the flow of macropores (Herrmann [26], Buttle [27], Herrmann [28]). The long season of low water corresponds to the aquifer discharge; mainly due to evapotranspiration and drainage of rivers. This has caused the excessive use of groundwater pumping, resulting in water-table decline during the dry season (Figure 11). Such decrease in the water level can cause loss of soil moisture and that the restoration of the water table level after cessation of pumping can only partially compensate for this loss. Moreover, it is shown that a residual loss continues until the soil is returned to field capacity (Hedges and Walley [29]).

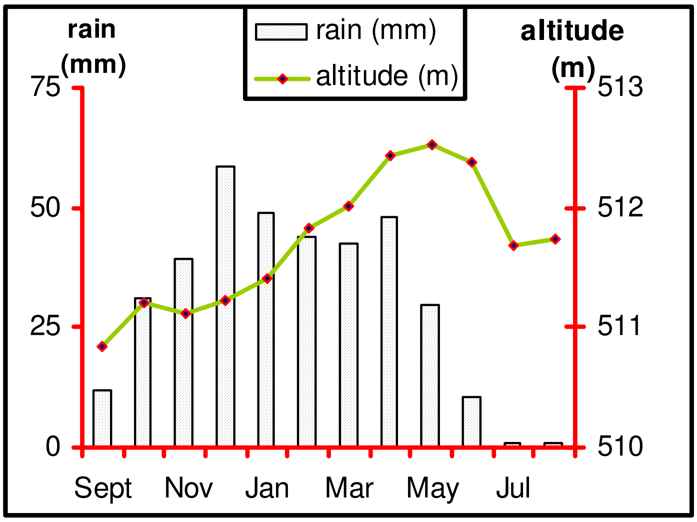

Fig. 11 Relation between monthly rain and monthly piezometric level of the phreatic Sais aquifer (1970-2000)

By comparing the hydrogeological regime of the Sais phreatic water-table and the Tabular aquifer, the piezometric peak of the Tabular aquifer follow directly the one of the rainfall. While the Sais surface-water table, the raised water levels reach the maximum level only after three months. The differentiation in geological formations of each reservoir basin influences the flowing. At the Sais sector, the phreatic water-table is characterized by Plio-Quaternary formations (i.e. Sands, Conglomerates and Limestone lake, etc.) favouring runoff, which making it susceptible to climatic conditions (e.g. evapotranspiration). At the Tabular sector, the Liasic reservoir is deep and dominated by Limestones and Dolomites of the Lias and strong fracturing, which favours the infiltration (Figure 1). In fact, Tabular aquifer recharge follows immediately precipitation evolution. But its duration is less important than the phreatic water-table.

The Sais deep water-table is a confined aquifer, therefore, it does not show much sensitivity to variations in annual rainfall and its recharge is very slow as well (Figure 12).

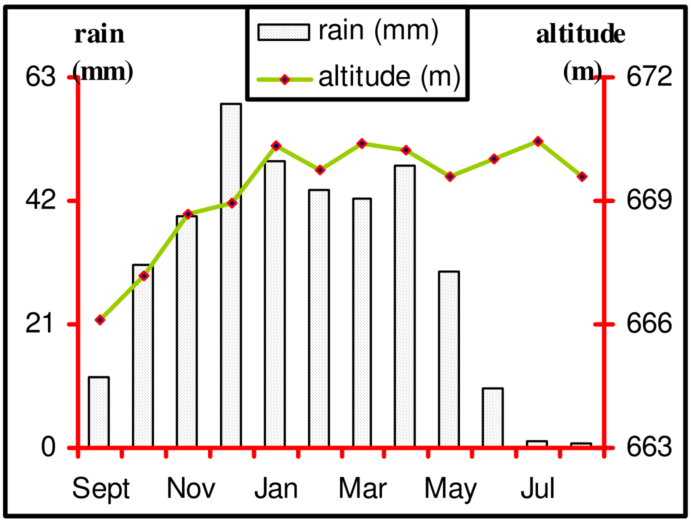

Fig. 12 Relation between monthly rain and monthly piezometric level of the confined aquifer deep (1970-2000)

In addition, its over-exploitation by the artesian drilling to satisfy the increasing water needs affects the relationship between rainfall and piezometric level adversely. The rainy periods are imperceptible on the piezometric curve. This also explains that the confined aquifer is immediately reacted to the rainfall (i.e. transfer of pressure) than a free-water table which recharge is deferred and progressive (i.e. transfer of material) (Pinault and Bichot [30]). The rising water levels are a function of the distance from the outcrop (longer time of transport in the soil).

6. CONCLUSION

The semi-arid climate of the Mikkes basin is mainly characterized by significant irregularity in rainfall during the year and on year-to-year basis. The seasonal rhythm is unimodal; generally characterized by a strong contrast between winter season -marked by high precipitations and little evapotranspiration- and summer season -having little rainfall but high evapotranspiration-. The magnitude of the temporal seasonal drought has been uniform in the Tabular (i.e. it was three dried months (per year) for the period between 1958-1980, which got increased to four months through the period between 1980-2000. The magnitude of the spatial seasonal drought for the years between 1980-2000 is distinct in the Sais (i.e. 6 dried months), whereas it was 4 months at the Tabular.

The droughts that hitting the region since 1980 had an adverse impact on water of the Sais plain and Tabular Atlas. It ensued in marked reduction of natural water, which triggering excessive groundwater exploitation and led to continuous decline in levels of groundwater. Nevertheless, at annual scale, the drought does not show a uniform sensitivity on premise of peculiar geology of each reservoir, for instance, the phreatic water-table shows annual fluctuations, whereas the Tabular aquifer shows cyclical fluctuations, and the deep confined aquifer does not show a clear sensitivity to drought. However, heavy rainfall since 1995 is reciprocated by piezometric increase, at times reaching 4 m in Mikkes aquifers explaining the inter-groundwater interactions. In addition, these developments illustrate the contrasting changes in the hydrological regime of groundwater and the importance of the infiltration of irrigation water in the aquifer supplying. On the monthly scale, climatic impact is reflected as the seasonal changes in water table levels. Such seasonal oscillations are mainly related to climatic parameters, (i.e. rainfall and evapotranspiration). The rising in water level which occurs during the rainy season reflects the existence of an effective infiltration which arises at the seasonal scale.

A detailed study focusing on climate, hydrology and groundwater extractions provides a better understanding of the relationship observed between the declining groundwater levels and its association with reduction in base flow (Ivkovic et al. [31]).

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