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Relationship between River Flow, Rainfall and Groundwater pumpage in Mikkes Basin (Morocco)

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Abstract

This paper investigates the relationship between river flow, rainfall and groundwater pumpage in the Mikkes stream during the period 1968-2009. The Mikkes basin is located in the north center of Morocco and consists of three different zones that represent diversified geologies. This basin includes a phreatic and confined aquifer in Saïs basin and a shallow aquifer in the Tabular Middle Atlas. Analysis of monthly medium flows between 1968 and 2009 shows an approximate oceanic system which is characterized by two hydrological seasons. First a period of high waters in winters which is conditioned by the pluviometric contributions and the second is a low water period in summer which is conditioned by evapotranspiration. The mode of this River can be called a pluvio-evaporal type. The high deficit of the Mikkes stream (between 1968-1979 and 1980-2009) is about 76% and could be the combined effect of drought and groundwater pumpage. Water table variations could be conditioned by climatic changes and regional geology. Actually, the annual water table variations show a drop in ground water levels, which is due to the combined effect of reduction in precipitation that has reduced the natural recharge of groundwater, and the increase in pumping which is increasing year by year for more than 80 years in this region. In addition, free-water tables are much more susceptible to pumpage when compared to the confined aquifer. Thus, the water table and piezometric heads of the Mikkes basin do not demonstrate a uniform sensitivity to the drought. High rainfall between 1995 and 1997 had affected the groundwater levels of Mikkes with an increase in piezometric level. The monthly piezometric variations of free-water table are characterized by a seasonal operation: groundwater recharge and discharge.

Keywords: *Morocco, Stream Mikkes, River flow, Rainfall, Groundwater pumpage.*

1. Introduction

During the last three decades, Morocco has experienced several prolonged droughts. The effect of these years of drought on water availability of basins has greatly exacerbated the deficit in water flow observed since 1970; the beginning of the deficit cycle across the whole country [1]. The area of study covers three different structural sets: El Hajeb-Ifrane Tabular in the South, the Saïs basin in the centre and Prerif Zone in the North (Fig. 1). The 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; ***the Saïs confined aquifer***.

A complex of Plio-quaternary formations (sands and limestones…) rests over this series and holds the superficial groundwater; ***the Saïs phreatic aquifer***. The two groundwater aquifers communicate through the faults and flexures or through the semi - permeable marly layers [2] (Fig. 1). Several studies have been carried out on the groundwater of the Mikkes basin by Belhassan [3, 4, 5, 6 and 7]. Rainfall, stream flow and pumpage are closely related to groundwater levels. This article highlights the relationship between River flows, rainfall and groundwater pumpage in the Mikkes stream.

2. Methodology

In this study two meteorological stations were selected; the first one was in the Tabular Atlas while the other was in the Saïs plain. The Ifrane station (altitude Z = 1600m) was located in the Tabular Atlas and the El Hajra station (altitude Z = 215m) was in the Saïs plain. Precipitations were recorded from 1968 to 2009. To know the system of Rivers draining the study area, the El Hajra hydrometric station was used to monitor the flow in the Sidi Echahed's dam. This station is in operation since 1968 and its altitude is 215m. The variations in the piezometric levels were studied according to time and space. The observations were made at monthly - annual time scales. The

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piezometry was studied in the Tabular Atlas in the only available measuring point: by drilling 1448/22. For the Saïs phreatic aquifer, all piezometers show a similar evolution; thus piezometer data for 199/15 is presented in this study. For the deep confined aquifer, piezometric data for 290/22 is presented which has a long history and a good follow-up.

3. Relationship between river flow and rainfall

The relationship between river flow and rainfall variations was investigated employing the monthly – annual data of (a) river discharge recorded at El Hajra station and (b) the precipitation measured at the Ifrane and El Hajra stations.

3. 1 Monthly flow – rainfall

Study of monthly flow of the Mikkes stream is very useful to know the River regime. Figure 2 shows monthly average flows calculated for a period of 42 years. It shows that there is one precipitation mode, which is of pluvial origin. In times of low water and high water period, the propagation of flow of streams occurs neither under the same conditions, nor by the same proportions, [8]. Monthly distribution of flows is used to classify the flow regime of a river: ***the hydrologic regime***. It summarizes all of its hydrological characteristics and mode of variation. It is defined by variations in its flow usually represented by the graph of the average monthly flow.

The monthly flows of the Mikkes stream generally vary. They start to rise from September to reach the maximum in February (winter) with an average value of 3.86m^3/s. During winter, rivers collect much rainfall and generate an increased flow. However, during summer a decrease in flow is witnessed (low water period), which continues to achieve its minimum in August with an average of 0.62 m^3/s. Monthly flows during dry periods of the year (July, August and September) are low, and they characterize the hydraulic continuity of Mikkes basin. The effects "delay" and "buffer" of the karstic Mikkes basin are highlighted. Thus, the karst basin is characterized by a dry period with a sustained low flow (relatively abundant); with a delay of the direct action of rainfall on surface runoff. One might also note the extent of a base flow of about 620 L/s, i.e. the partial flow of the Mikkes stream which comes mainly from the groundwater basin. These are the geological formations of the subsoil, which have a significant effect on the groundwater contribution (base flow) to the flow of a River by virtue of their storage potential and their transmissivity.

The hydrological regime of Rivers is influenced by precipitation, exchange with groundwater and number of sampling points [9]. The curve of monthly flows of the Mikkes stream for a period of 42 years (Fig. 3) shows that it is a simple oceanic pluvial regime characterized by two hydrological seasons: a period of high water and one of low water. The seasonality of the regime is conditioned by the rainfall input and evapotranspiration. The seasonal flow type is a characteristic of climate zones deficit [10]. The regime of this river is classified as pluvio - evaporal. The period of high water in winter is marked by a maximum flow in February with high precipitation. This contributes a positive impact on the flow of Rivers which show a monthly flow of about 76mm. Thus, it appears that the flow curve follows the evolution of the rainfall with two months response time of the watershed: the maximum rainfall in December becoming maximum flow in February. The low-water period is characterized by a minimum flow in August. The corresponding flow is the lowest with an average of about 12mm (Fig. 3).

This is more of a river's drainage from the aquifer rather than a river receiving surface water runoff. The ratio between the lowest and the highest monthly flows is around 16%. Therefore, the monthly changes of flow are very marked. This loss of water flow of the Mikkes stream during the year is mainly caused by less precipitation and high evapotranspiration. It is closely related to temperature on one side and to overexploitation of groundwater on another side. To understand the hydrological response of Mikkes basin, a diagram of correlation between rainfall and monthly flows would be more significant. It is relatively good since its coefficient R is about 0.81 (Fig. 4).

The precipitation is closely related to flow. This shows that either rain determines the flow, or either groundwater is contributing to flow. In general, the hydrological cycle is of the "charge/discharge" with wet winters, corresponding to high flows in River and high positions of groundwater level. Nevertheless, in dry summers, severe low flows in River and low groundwater level are seen.

3. 2 Annual flows – rainfall

Mean annual flow can be calculated from the arithmetic mean of the monthly average flows. According to Remenieras [11], this average should be weighted taking into account the number of actual days of each month. Generally, the regime of the Mikkes stream corresponds to a low flow, i.e. 1.21L/s/km² (1968-2009). Its flow shows temporal variation, which generally tends to decrease. This trend shows a steady fall in flow, which is about 0.1 m^3/s per year on average. The years before 1980, 2008 and 2009 correspond to years, in which flows are above the average recorded between 1968 and 2009 (Q = 1.94 m^3/s). Maximum flow reached a value of 6.81m^3/s in 1968, while flows for other years are below average. These differences in inter-annual flows could be related to drought that occurred in the region after 1980 (Fig. 5).

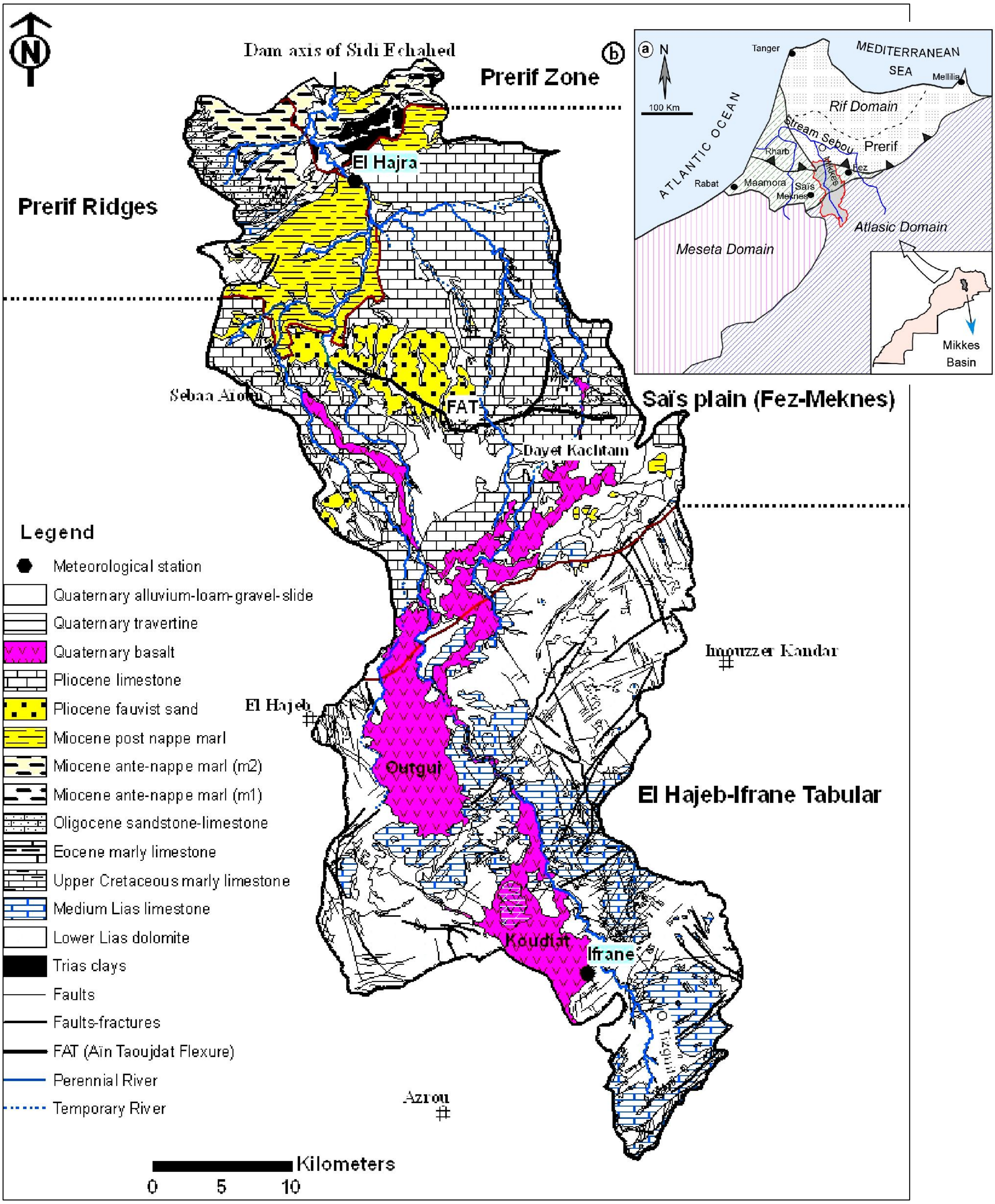

Fig. 1a. Situation of the Mikkes basin**;** 1b. Geological map of the Mikkes basin, (extracted from the geological map 1/100000, Rabat, Morocco, 1975).

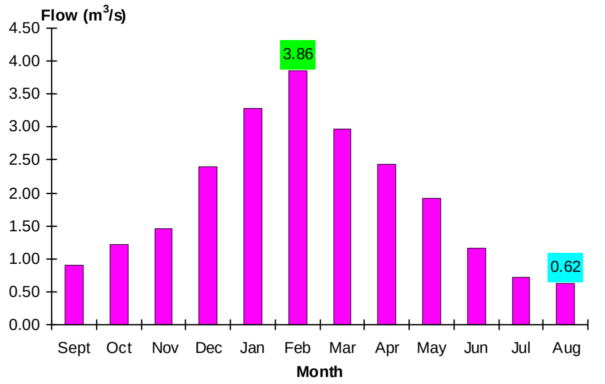

Fig. 2. Monthly average flows of the Mikkes stream (1968-2009).

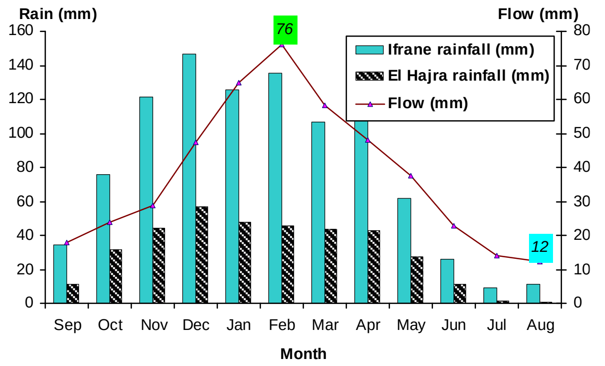

Fig. 3. Monthly rainfall at the Ifrane and El Hajra stations/ monthly flows of the Mikkes stream (1968-2009).

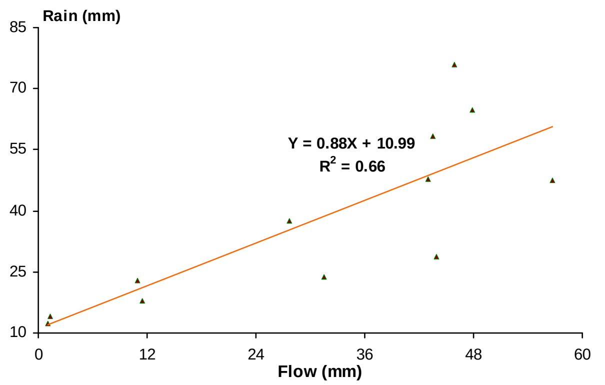

Fig. 4. Correlation between rainfall and monthly average flows of the Mikkes stream (1968 - 2009).

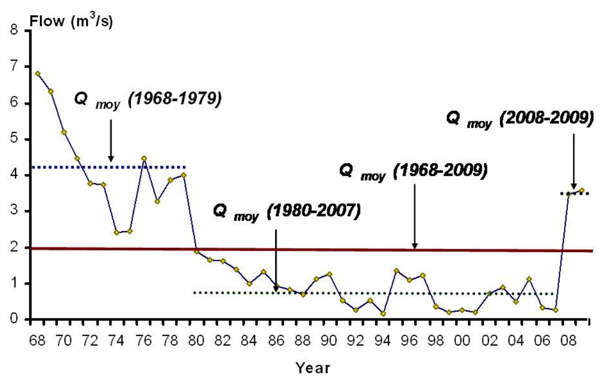

Fig. 5. Annual average flows of the Mikkes stream(1968-2009).

Figure 6 shows the influence of the average annual rainfall on the average annual flow of the Mikkes stream. Most studies on climate variability describe the variability of rainfall and runoff, with a link between these parameters [12, 13,14,15,16 and 17].

Before 1980, generally, the flow evolution follows that of rainfall in the basin (Ifrane and El Hajra stations). Nevertheless, after 1980, it stands out. The years 1995, 1996, 1997, 2008 and 2009 were wet years in the Mikkes basin, which are followed by a peak of the river flow (the influence of rainfall on runoff).

Rainfall and flow are not well linked, which supposes that the flows come from rain and other resources (groundwater). Thus, low correlation coefficients (R = 0.61) can be explained by the fact that the permeable lithology of the basin (especially in El Hajeb-Ifrane Tabular) favours the infiltration of a part of the rainwater. It is responsible for reducing the annual flow of runoff and consequently the correlation coefficient is low (Fig. 7).

Between the periods 1968-1979 and 1980-2009, the decrease in the rate of flows of Mikkes River is around 76%. The rate of decrease in annual rainfall is about 18% at Tabular Atlas and 30% in Saïs plain. Indeed, the drop in flows (83mm to 20mm), is more important than rainfall (463 to 326mm). This should be linked on one hand, to drought (accompanied by higher temperatures, thus higher evapotranspiration) which has a negative effect on the flow of the Mikkes stream with different magnitudes across the basin (Table 1). On the other hand, it is linked to the demographic, agricultural and industrial development, which had a negative impact on water resources.

This impact resulted in a reduction of natural water flows, leading to the overexploitation of groundwater. This has led to the disruption of balance of the system by the drying up of springs, the continued decline in water levels of groundwater and reducing surface water inputs.

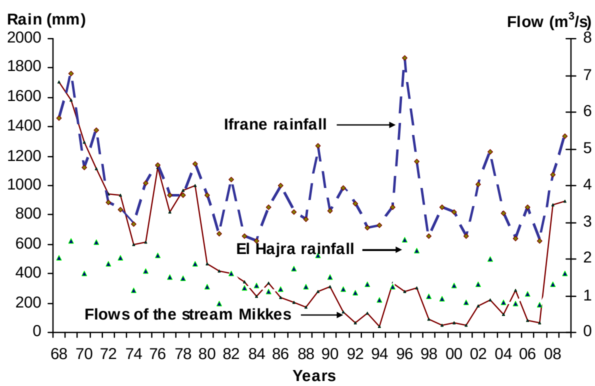

Fig. 6. Annual precipitation at the Ifrane and El Hajra stations/annual flows of the Mikkes stream (1968-2009).

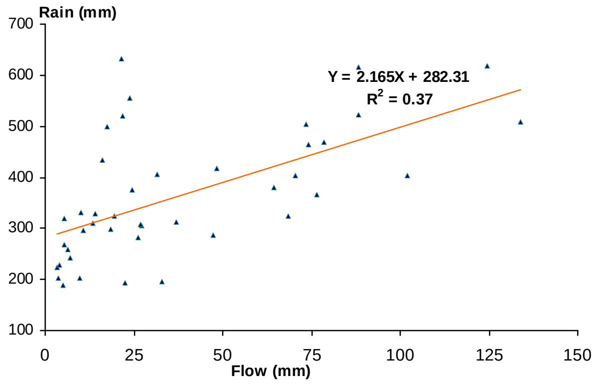

Fig. 7. Correlation between the rainfall and the annual average flows of the Mikkes stream (1968 - 2009).

4. Relationship between Rainfall and Water Table Variations

The relationship between rainfall and water table variations was investigated employing monthly – annual data of (a) precipitation measured at Ifrane and El Hajra stations and piezometric level variations recorded at drilling points N°IRE 1448/22, 199/15 and 290/22 .

4. 1 Monthly rainfall - water table variations

The monthly measurements of piezometric levels of Mikkes groundwater basin have shown a seasonal evolution of the groundwater supply.

For the Tabular free-water table, its regime is simple which is marked by the “rise in water level” phase and “fall in water level” phase. The maximum piezometric in level is reached in February, after a maximum rainfall in December. Then, the piezometric level drops in parallel with the drop of rainfall from December. During the rainy season, groundwater is recharged by infiltration of rainfall. However, in the dry season, the water table is discharged and its level drops because there are inputs from the infiltration of rainfall. This reduction in groundwater levels is the essential fact of evapotranspiration (Fig. 8).

For the Saïs phreatic aquifer, the hydro-geological regime is characterized by a simple regime of alternating periods of rise and fall in water level (Fig. 9). It is possible to observe a reversal of the direction of exchange depending on the season: during period of low water, the river drains the aquifer and in times of high water, it feeds the groundwater.

The maximum piezometric level of Saïs phreatic groundwater is reached in April-May-June, after rising rainfall. The piezometric decline begins at the end of regular rainfall and reaches a minimum in July, August and September. The season of low- water corresponds on one hand, to the discharge of groundwater; the lower precipitation and increased evapotranspiration. On the other hand, the discharge of the groundwater reservoir can also be linked to increased exploitation during this season. By comparing the hydro-geological regime of the Saïs phreatic aquifer and of the Tabular aquifer, it is noticed that the maximum piezometric level of Tabular groundwater follows immediately that of the rainfall. While for the Saïs phreatic aquifer, the rise of the piezometric level reaches its maximum after 3 months. This could be explained by:

- The different geological formations characterizing each reservoir basin influences the flow of water. In the Saïs plain, the formations characterizing the reservoir are Plio-Quaternary (sand and limestones ...) that promote runoff (high drainage density). In Tabular Atlas, the reservoir is dominated by strongly fractured Lias limestone and Lias dolomite which results in high permeability and high infiltration. Actually, recharging of this Tabular aquifer immediately follows precipitation.
- The Saïs plain is almost in semi-arid area. The rainfall of 30 to 40mm in one month does not cause a high effective recharge to Saïs phreatic aquifer, which is due to high evapotranspiration (ET). Thus, it is evident, that groundwater recharge is mainly from the occasional runoff; water flowing in the nearest Mikkes stream rather than the rainfall. Therefore, the Saïs piezometer is responding to river-flow rather than to the rainfall.

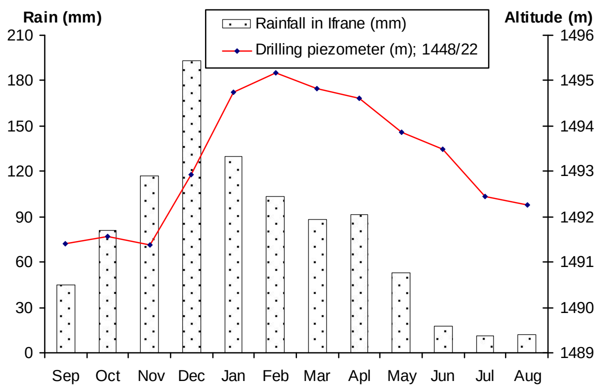

Fig. 8. Relation between the monthly rainfall and monthly level of the Tabular aquifer (1994-2009).

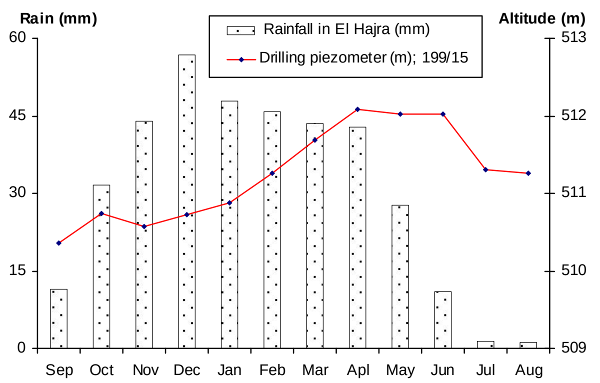

Fig. 9. Relation between the monthly rainfall and monthly level of Saïs phreatic aquifer (1968- 2009).

Table 1. Water deficits of the Mikkes stream.

Period	P. Ifrane (mm)	P. El Hajra (mm)	Flow (mm)
1(68-79)	1112	463	83
2(80-09)	907	326	20
Proportion (2/1)	82	70	24
Deficit (%)	18	30	76

For the Saïs deep aquifer, it is a confined groundwater; it does not have an obvious sensitivity to variation in precipitation. Its exploitation by artesian drilling to satisfy the water needs prevents a demonstration of the clear emergence of a relation between rainfall and groundwater level. The rainfall episodes are imperceptible on the piezometric curve (Fig. 10). The rise in the piezometric level is a function of distance from the outcrop (long time of soil transport) and exchanges between local groundwater.

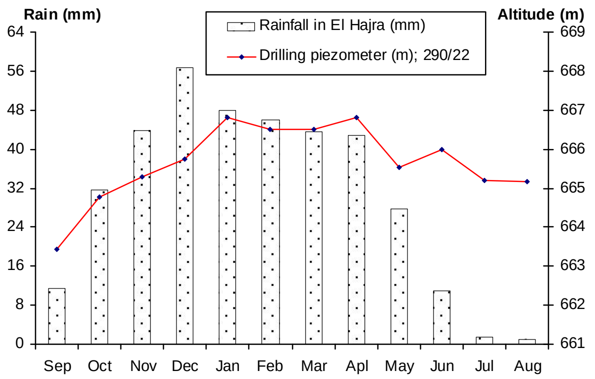

Fig. 10. Relation between the monthly rainfall and monthly level of the confined aquifer (1968-2009).

4. 2 Annual rainfall - water table variations

For the Tabular aquifer, piezometer 1448/22 (Fig. 11) shows a maximum piezometric level in order of 1498m in 2009 and a minimum of about 1487m in 2005. Thus, this shows a decrease of 11m through the period for years between 2005 and 2009. Starting from 1995 a significant rise in the level of the free-water table coincides with an increase in rainfall of the corresponding period. The piezometric level had shifted from 1490.45m in 1995 to 1496.74m in 1997. This demonstrates that in this sector, the rain infiltration has a large effect on water supply. This may be explained by significant infiltration, predominantly of permeable carbonate formations recognized in the Tabular Middle Atlas and strong fracturing of land (Fig. 1). Groundwater of the Tabular Middle Atlas is only from the original meteoric precipitation (rain and snow: 35 to 40%), which infiltrates into the limestone karst and reappears mainly at the periphery of the Tabular Middle Atlas in contact with the Lias and Trias [18]. The years 2008 and 2009 were wet years in Morocco, particularly in the Mikkes basin. The rainfall is significant and is followed by a significant increase in the level of the Tabular aquifer; groundwater level rises from 1489.15m in 2008 to 1498.35m in 2009.

For the Saïs phreatic aquifer, the piezometric level has remained stable for the years between 1968 and 1980. The decrease in water level after 1980 varies from one piezometer to another. This drop in piezometric level started to increase since 1998 in the central area. An average value of 1m/year can be used for this aquifer [19]. In piezometer level at N°IRE199/15, the decline in water level after 1980 was about 33 cm/year (Fig. 12). This sharp drop in water level of the aquifer was associated with high stress climate constraint, which the region has experienced for more than 80 years accompanied by an increase in sampling for water supply (drinking and irrigation). The evapo-transpiration calculated by Thornthwaite's method at El Hajra station for the period 1968-2009 is 89% of the total rainfall. Thus, the surplus water (Thornthwaite balance method) is only 11% of inter-annual rainfall (1968-2009). Between the periods 1968-1979 and 1980-2009, the rainfall had dropped from 463mm (1968-1979) to 32mm (1980-2009). Thus, the excess water decreases from 26% (1968-1979) to 6% (1980-2009) [20].

Between 1995 and 1997, the groundwater level had risen about 4m after a sharp increase in rainfall at the Mikkes basin in 1996. The wet years 2008 and 2009 were accompanied by an increase in the piezometric groundwater level, which rose from 504.61m to in 2008 to 507.48m in 2009 (Fig. 12). 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 Tabular aquifer and Saïs phreatic aquifer and (3) the existence of a relationship between the level of this Saïs superficial groundwater and the Saïs deep groundwater.

The deep artesian confined aquifer: It is the aquifer most affected by exploitation in the Mikkes Basin. The piezometer N° IRE 290/22 particularly can be considered as a representative for over-exploited samples in the Fèz-Meknes groundwater and which has performed sampling of water supply for drinking and irrigation. Therefore, it reinforces the negative balance of this aquifer [19]. The monitoring of piezometric fluctuations shows a sharp decline in water levels since the beginning of 80s (Fig. 13). The variation of water level is around 2.87 m/year on average; primarily due to the drought that this region had suffered during the 80's and due to the exploitation of the groundwater. In addition, the general decline in groundwater levels results in a decline in artesian pressure, drilling point N° IRE 2365/15 (Fig. 14).

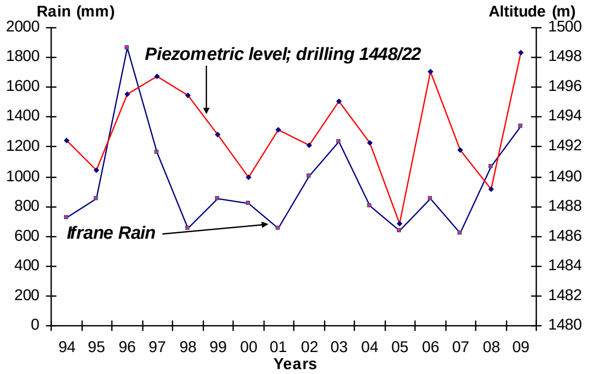

Fig. 11. Relation between rain and the piezometric level of the Tabular aquifer (1994-2009).

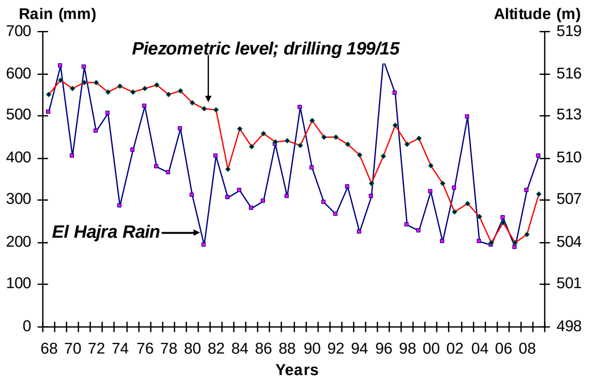

Fig. 12. Relation between rain and the piezometric level of the Saïs phreatic aquifer (1968-2009).

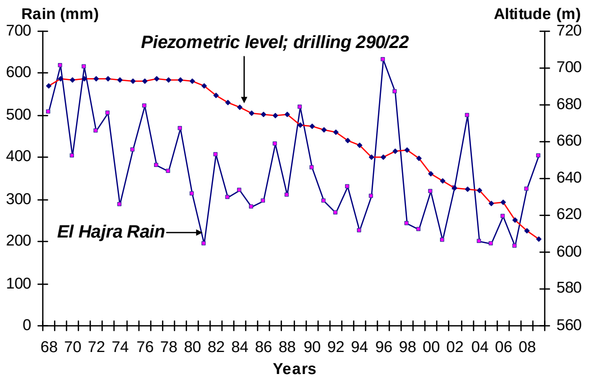

Fig. 13. Relation between rain and the piezometric level of the deep aquifer (1968-2009).

However, the higher precipitation through the period (1995-1997) seems to be the reason for the 4m increase in the piezometric level. It is obvious that rainfall promotes the rise in piezometric level of confined aquifer. Consequently, interactions between the three Mikkes groundwater are reported. While, for the years 2008 and 2009 which are considered wet years, they had no effect on increasing the level of deep groundwater. The aquifers of the Mikkes basin do not demonstrate a uniform sensitivity to the drought due to the following reasons:

- The free-water table of El Hajeb Ifrane Tabular is sensitive to multi-year droughts; therefore, the fluctuations in this sector follow the multi-year cycles.
- The Saïs phreatic water-table is supplied directly by precipitation. The recharge is comparable from one year to another. It shows fluctuations called "annual".
- The Saïs confined aquifer is the least sensitive to variations in rainfall because it is not directly supplied by precipitation. Nevertheless, it has been the most exploited in the Mikkes basin, to satisfy the drinking and irrigation demands.

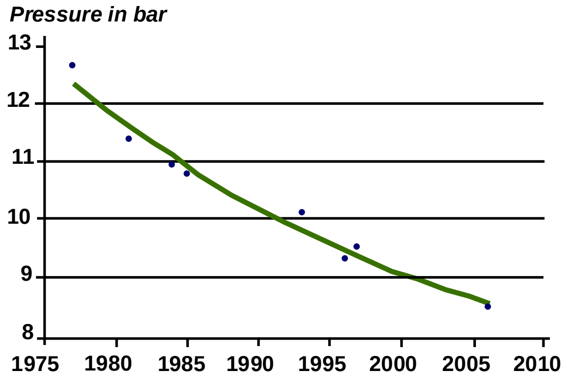

Fig. 14. Decline in artesian pressure of the Fez-Meknes confined aquifer.

5. Relationship between River Flow, Rainfall and Groundwater Pumpage

Sampling points have grown steadily since the 1980s (Tables 2, 3 and 4). The rate increased sharply during 2000s, where there has been the construction of 147 sampling points per year [21]. Table 2 shows an average cumulative number of sampling pumpage and discharge of Tabular water table during the period 1995-2001. Between 1995 and 2001, the number of sampling pumpage increases and the water table level falls by an average of 3.8m. The relationship between pumpage and groundwater level demonstrates a high negative correlation coefficient, which is around –0.9. Actually, Tabular groundwater levels respond to the growth in pumpage. Table 3 shows an average cumulative number of sampling pumpage and discharge of Saïs phreatic aquifer during the period “before 1970 and after 2000s”, in which the number of sampling pumpage increases and the water table level falls by an average 7.35m. The relationship between pumpage and Saïs water table level demonstrates a high negative correlation coefficient, which is about –0.95. Therefore, the Saïs phreatic water table levels respond to the growth in pumpage.

Table 4 shows an average cumulative number of sampling pumpage and discharge of the Saïs confined aquifer from 1952 to 2001, in which the number of sampling pumpage increases and the water table level falls by an average of 52.17m. The relationship between pumpage and the Saïs confined groundwater level demonstrates a high negative correlation coefficient, which is around –0.96. Thus, the growth pumpage caused a great decrease in the levels of the Saïs confined aquifer.

For better characterizing the relationship between river flow, rainfall and groundwater pumpage in the Mikkes stream, the annual hydraulicity, which involves the inter-annual module for the period 1968-2009, is shown in Figure 15. Lapointe [22] defined the annual hydraulicity as: the hydraulicity is the difference between the module of the year considered and the module considered for the inter-annual period (1968-2009) as a percentage of the latter.

Before 1980, hydraulicity values were positive. Nevertheless, after 1980, with the exception of 2008 and 2009 the values become negative. Generally, the years 1980 to 2007 had a low flow with negative values of hydraulicity, which confirms that those years were dry. This phenomenon could be attributed to the following facts:

1. Tabular surface layers were almost saturated with water before 1980. This saturation was mainly due to two factors: on one hand, the high rainfall which was around 668 mm/year (Thiessen average) corresponding to an average annual flow of 4.23m^3/s [20]. On the other hand, the number of samples did not exceed a few hundred in the Saïs aquifer and a few dozen at the Liasic aquifer (Saïs deep aquifer and the El Hajeb-Ifrane Tabular). This had an influence on the distribution of infiltration/runoff. Indeed, a high aquifer promotes the runoff and therefore a positive hydraulicity. After 1980 (with the exception of 2008 and 2009) there was a decrease in the piezometric level resulting in the desaturation of superficial layers of Tabular aquifer triggered by low rainfall and an increase in the number of sample points for drinking water and irrigation purposes (Tables 2, 3 and 4). The average annual rainfall during the period 1980-2009 was about 538mm/year (Thiessen average) and corresponds to an average annual flow of about 2.1m^3/s during this same period; the groundwater resources of Mikkes basin have been overexploited [20]). The samples in 2001 exceeded thousands of water points in Saïs phreatic water-table and hundreds at Liasic aquifers (Tables 2, 3 and 4), and low rainfall promoted infiltration depending on runoff water, which resulted in negative hydraulicity. In short, the relation rainfall-flow depends on the water status of the unsaturated zones of the aquifer [7].
2. The cycle is like this: Prior to 1980s, when groundwater was not much in use, the water table (phreatic) and piezometric levels (confined) were high and the Mikkes River flow included runoff from the rainfall plus contribution from the groundwater. It is likely that before 1980 the Fez-Mekens confined aquifer with a high pressure of 12bars was leaking into the phreatic aquifer and the phreatic aquifer was supplying water to the river flow. The River was thus gaining from the groundwater. After 1980, the water table (phreatic) and the piezometric levels (confined) got depleted and the River flow started contributing to the ground water (mainly to the phreatic aquifer). The hydraulicity became negative and the Mikkes River became a losing river.

The conclusion should clearly state that the hydraulicity of the Mikkes River has become negative from 1980 to 2007 because for the same average rainfall, there is more recharge from surface water to groundwater. This is due to the extensive pumpage of ground water and the resultant drop in water table and piezometric levels (Tables 2, 3 and 4). The surface water flow gets reduced because of the increased contribution to groundwater. This could be a typical example of an "effluent river" becoming an "influent river" in which a 'gaining river' becomes a 'losing river' by contributing to groundwater recharge at the cost of its surface flow.

Table 2. Relationship between piezometric level of Tabular water table / number of samples (1995-2001).

Year	Cumulative number	Altitude (m)
1995	64	1495
96	67	1496.8
97	72	1495.2
98	76	1492.5
99	85	1491
2000	87	1493
2001	92	1491.2

Table 3. Relationship between piezometric level of Saïs phreatic aquifer / number of samples (before 1970 - >2000).

Year	Cumulative number	Altitude (m)
before 1970	30	515.54
1970-80	61	514.89
1980-90	314	511.89
1990-2000	954	510.86
>2000	1266	508.19

Table 4. Relationship between piezometric level of Saïs confined aquifer / number of samples (1952-2001).

Year	Cumulative number	Altitude (m)
1952	2	690.81
'55	3	690.81
'78	4	693.60
'81	5	690.64
'82	11	684.95
'84	12	678.58
'85	16	675.17
'86	23	674.69
'88	33	674.73
'89	36	668.98
'90	38	668.20
'91	40	666.48
'94	41	658.21
'95	42	651.52
'96	44	651.80
'98	46	655.17
'99	50	650.69
2001	59	638.64

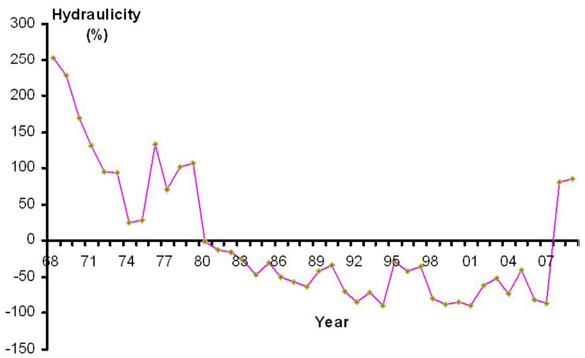

Fig. 15. Distribution of the annual flow of the Mikkes stream 1968-2009).

6. Conclusions

The basin of the Mikkes stream is one of the Morocco basins, which have experienced long dry periods. Since 1980, there has been a steady decline in rainfall and therefore, a reduction in the River flow has occurred. The regime of the Mikkes River is an approximate oceanic system supported by the groundwater with a low discharge, which is about 1.21L/s/km².

Monitoring measurements of the monthly flows during the period 1968-2009, show that the period of high water occurs from the month of December with a maximum flow in February. This is primarily due to increased winter precipitation. The period of low water in summer is manifested by a low flow and is caused mainly by low rainfall and high evapotranspiration. It is also caused by the increasing number of samples. Indeed, this river is rain-evaporal type. The water infiltrates into the Lias limestones and resurfaces as springs (base flow is about 620 L/s).

Calculation of the hydraulicity shows that for the years before 1980, 2008 and 2009 the values of hydraulicity were positive, while after 1980 the values become negative in spite of the heavy rainfall recorded for some years between them. The negative hydraulicity is the result of increase in number of samples after 1980, which became numerous in the beginning of 2000s. This fact constitutes the disruption of hydrological regime and thus the behaviour of aquifers.

According to the study of variations in groundwater level and comparing it with variations of the average rainfall amounts in the Mikkes basin, we can make the following conclusions:

1. On the monthly scale, piezometric variations of free-water table (Saïs phreatic aquifer and Tabular aquifer), are characterized by a seasonal operation: a groundwater discharge during the dry season and a groundwater recharge during the rainy season.
2. On the annual scale, generally, the continued decline of groundwater levels in aquifers is linked to the decline in rainfall and it is also linked to the exploitation of its aquifers. Heavy rainfall in the years 1995, 1996 and 1997 resulted in an increase of about 4m in the Saïs groundwater level and 6m for the Tabular free-water table, which explains the interconnection between these aquifers. The years 2008 and 2009 (wet years) are accompanied by an increase in the free-water table level (Saïs phreatic aquifer and Tabular aquifer). However, the confined aquifer level continues to decline. This decline is explained by the overexploitation of this reservoir. Actually, the aquifers of the Mikkes basin do not demonstrate a uniform sensitivity to the drought.

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