Islamic Azad University
Mashhad Branch

Hydro-Geological Context of Mikkes Springs and Different Variations of their Flows (Morocco)

K. Belhassan*

UFR: Geology Applied to Hydro-Geological Researches. Faculty of Sciences Dhar Mehraz
B.P. 1796 Fez Atlas. 30 003. Fez. Morocco.
Received 24 April 2010; accepted 28 July 2010

Abstract

The Mikkes basin is located at the north center of Morocco. It comprises three different zones which represent diversified geologies which shelter a phreatic and confined aquifer in the Sais basin and a shallow aquifer in the Tabular Middle Atlas. The springs in the Sais phreatic aquifer have suffered a maximum depletion. The springs with a deep or mixed origin are known as low flow variation springs. Actually, the variations of the fall of spring's flows could be linked to a different hydro-geological context of these springs.

Keywords: *Morocco; Mikkes; Sais phreatic aquifer; Sais confined aquifer; Tabular aquifer; springs; flow; hydro-geological context.*

1. Introduction

A spring is a location where groundwater emerges from the earth's subsurface in an amount large enough to form something resembling a stream. Natural springs may also discharge directly into lakes and oceans [1]. The springs of the river Mikkes basin are natural outlets of aquifers (Plio-Quaternary and Liassic) and supply the tributaries of this river. The influx of water in these springs comes from either Liassic confined aquifer or from the unconfined aquifer or from both (Figures 1 and 2). The purpose of this article is to examine the hydro-geological context of Mikkes springs and its main controlling parameters for these variations of flows. Furthermore this article provides essential information about a sustainable and integrated management of water resources.

2. Different variations of spring's flows

The existence of a spring requires that the subsurface is unable to transmit water as fast as it is supplied so that the potentiometric surface intersects the land surface. A range of geological structures and topographic features can thus bring water to the surface; Bryan [2] provides a more comprehensive discussion. The discharge of large amounts of groundwater requires some combination of a large recharge area, a high recharge rate, and a high permeability for large volumes of water to be concentrated at a single point [3].

The knowledge of piezometric data is of vast interest in many applications, such as assessing groundwater flow direction and identifying recharge zone of the aquifer [4]. The measurement of piezometric levels made in 2005 have established the piezometric map (Figure 3) for all combined levels and shows the main flow direction which is from the south to the north; depending on the basin morphology with a drainage axis at the river. Moreover, the existence of the Ain Taoujdat flexure which is a line of shared groundwater results in a SE-NW flow in the Meknes plateau and a flow from SW-NE in the Sais plain. The Rides Prerifaines are impervious limits where the water shares to the east and west.

The hydraulic gradient shows variations that can be induced by the lithology of the reservoir (Plio-Quaternary formations in the Sais plain and carbonate formations in the Tabular Middle Atlas) and/or by fracturing (more important fracturing in the Tabular Middle Atlas than Sais plain) [5].

At the Sais plain, the average hydraulic gradient is around 1 %; there are two points here which deserve mentioning:

- Near the Ain Taoujdat flexure, the hydraulic gradient becomes higher. This explains the high flows at the level of mixed springs (Darcy's law gives: $Q = K.S.i.$ with Q the flow, K the permeability, S the surface runoff and i the hydraulic gradient. This formula shows that the flow increases with the hydraulic gradient. This is a horizontal flow of groundwater). This zone is conducive for the water infiltration.
- Further north, the hydraulic gradient drops down, which explains the high drying or complete drying up of emergent springs from the Sais phreatic aquifer, and hence the drying up of river Atchane.

----

*Corresponding author.
E-mail address (es): belhassankal@yahoo.fr

The Dayet kachtam piezometric dome appeared to be an area of relatively high effective recharge, which corresponds to supplying area by infiltration of water from the river N'ja and river Atchane.

At Tabular level, in general, the flow is fairly regular from the SE to the NW following the basin morphology, and the NW-SE lineaments. The many faults combined with fractures and cracks of Liassic reservoir give a high permeability to the aquifer formation [5]. Thus, a higher hydraulic gradient (in the order of 3 %) exists in this zone where the Ribaa-Bittit springs emerges (Figures 1, 2 and 3).

The analysis of these springs's flow shows a decreasing trend in general. However, the reactions are different depending on the typology and hydrogeological context, as reflected in the following three cases:

1) Springs have completely dried up in 2005 as at Ain Hijja (IRE N° 112/22), Boukhnafer (IRE N° 125/15), and Ain Chrarda (IRE N° 259/15), which otherwise had flows of 380 L/s, 100 L/s, and 90 L/s respectively, before 1970. They are springs of emergence and discharge of the Plio-Quaternary phreatic aquifer. This has a significant influence on the river and a reduction of its flow.

2) Springs have experienced significant flow falls up to 90 % or more, as in the case of Ain Sidi Chafi (IRE N° 2618/15) whose flow was 130 L/s before 1970, but which dropped to 15 L/s in 2005 and Sidi Allal (IRE N° 909/15) whose flow was 100 L/s before 1970, but which had dropped to just 4 L/s in 2005.

In both cases, this is undoubtedly caused by overexploitation of the aquifer due to intensive agricultural development around this region after 1970.

3) Springs with lower fluctuations in flow, from 15 to 65 % are similar to those which are at Ain Bittit AEP (IRE N° 106/22), whose flow before 1970 was 1900 L/s and 1324 L/s in 2005 and Ain Akkous (IRE N° 114/22), whose flow before 1970 was 400 L/s and 195 L/s in 2005. These are principally the overflow springs of the Liassic Tabular aquifer. The mixed springs are also considered as springs with low fluctuations. This is in the case of Ghara (IRE N° 1156/15), whose flow was 500 L/s before 1970 and 181 L/s in 2005. The hydrothermal springs are considered among the springs of Mikkes basin which have a relatively low drying. In the case of Skhounat spring (IRE N° 872/15), the flow was 200 L/s before 1970 and 140 L/s in 2005.

3. Hydro-geological context of the Mikkes springs

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. Overflow springs which are located in the piedmont are the natural outlets. Triassic Clays and Paleozoic Schist form impermeable substratum of this aquifer. These carbonate formations burrow under the Mio-Plio-Quaternary cover to the right of the South Rifain Trough to become a deep confined aquifer. The depth of the Miocene Marls forming the roof of this aquifer is about 1500 m at drilling point Ain Allah (IRE N° 2370/15). The Plio-Quaternary formations are a phreatic water-table of Sais [5] (Fig. 2).

The springs of emergence and the discharge of the Plio-Quaternary phreatic aquifer had a high reduction in their flow. This phenomenon could be explained by a high runoff, while the infiltration is low. The predominant formations are generally slightly permeable and erodable, thus the flow of emergent springs and the discharge of Sais groundwater have seen the most significant declines [6].

The common occurrence of large springs in carbonate aquifers shows that the flow must be organized in some way that results in convergent flow lines to springs, and the concept of self-organized channel networks as a result of dissolution is the most plausible explanation [7]. The Liassic Tabular Middle Atlas is considered to be a karst aquifer system which is characterised by a complex heterogeneity, created and developed by groundwater flows [8], which in turn determines a high dynamic variability in space and time. The karst system is represented as three distinct zones: epikarst, infiltration zone and saturated or phreatic zone [9]. The epikarst has often a role of a reservoir delaying the karst recharge [10, 11, 9, 12, 13, 14 and 15]. Groundwater flows through the infiltration zone as runoff, or fast infiltration from sinkholes or open fractures, and as diffuse, slow infiltration through the carbonate matrix [16]. In the saturated zone, groundwater flows to the main spring through the conduit system, which collects the water stored: in connected karstic voids [9, 17], or in fissured blocks or the matrix surrounding a conduit network [18, 19]. Generally, springs of the Tabular aquifer present natural exits for the groundwater to the surface of the lithosphere. Springs of the Ribaa-Bittit complex overflow at the contact line of El Hajeb-Ifrane Tabular and Fez-Meknes basin in the North (Figures 1 and 2). Their total mean discharge is 5.2 m^3/s [20]. It is very difficult to precisely classify the karst springs because there are always certain exceptions which invalidate or at least make the classification uncertain [21]. The principal springs are perennial. An intermittent (temporary) spring results often as an out - flow of another more regular spring situated at lower level. The discharge variability analysis shows that each spring is a different case. Their behaviour ranges from very stable to very unstable irrespective of their discharge amount or their altitude. Even springs that were once assumed to be supplied by the same karstic network showed different variability [20].

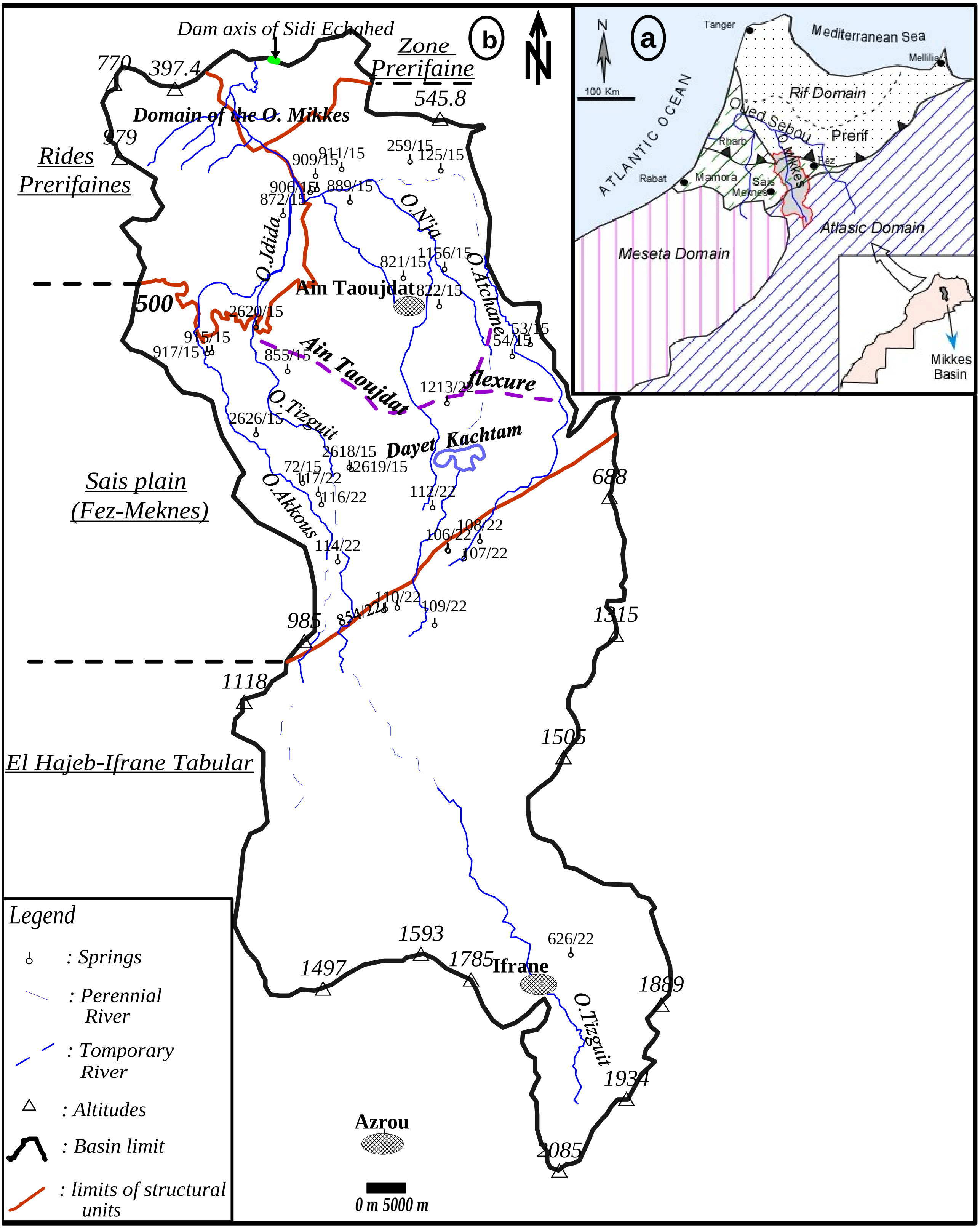

Fig. 1a. Location of the Mikkes basin, b. water system and position of the Mikkes basin springs (taken from the topographic map 1/100000, geology division, Rabat, Morocco, 1943).

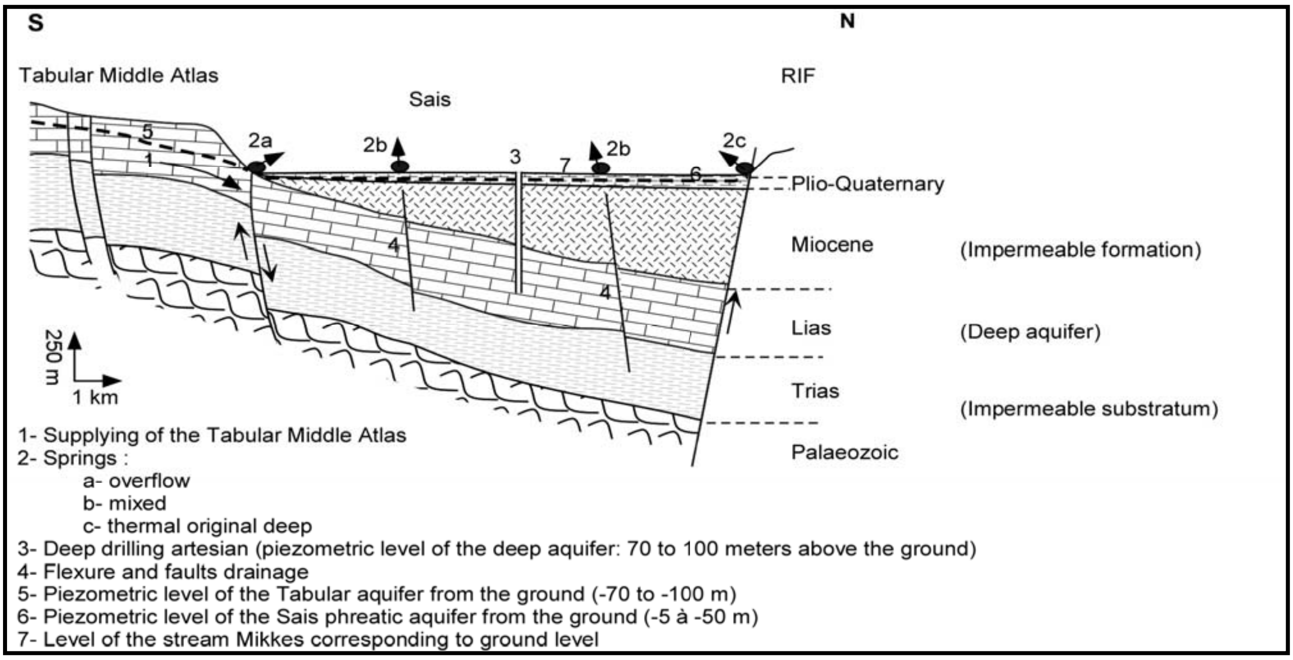

Fig. 2. Diagram showing the hydrogeological context of the Mikkes springs

Thus, overexploitation has less influence on the flow of these springs. The Bittit spring (IRE N° 106/22) is the most significant of all springs of Tabular which has an average annual discharge of 1.3 m^3/s [22, 23 and 24]. The hydrogeologic system of Bittit has a very significant storage capacity, allowing storage of a significant recharge from rainfall and snow melting, without causing brutal floods. High storage capacities reflect high fracture porosity due to intense tectonic jointing. Water which slowly passes through such a jointed aquifer is delivered by a long-term, low-discharge runoff [25]. Thus, the spring discharge is indeed quite constant all the year around. The presence of Sandy Dolomites at the base of the Liassic aquifer suggests the existence of an aquifer with interstitial porosity and relatively slow flow. However, in spite of the great storage capacity of this karstic aquifer, the springs' discharge shows a regular and significant lowering tendency due to a long drought period that considerably reduced the aquifer recharge [26]. Actually; this karst system is different from aquifers in porous milieu. The contributions of these springs to the river are estimated around 79 % during the years between 1935-1988 and the contribution of the groundwater is approx. 21 % [27].Thus, the flow of the Tabular springs have low declines.

The mixed springs are also considered as springs with low fluctuations. These emergent springs are generally linked to the presence of faults or flexures and their flows vary in proportion with the deep aquifer and the surface aquifer (Fig. 2). In addition, the relationship between massive Limestone and Dolomites of Lias, permeability and groundwater flow shows a good demonstration of the importance of mixed springs of the Mikkes River, which result in a higher drainage. In fact, the quantities of extractable water in the deep aquifers are much less than the calculated reserves. Indeed, the depth of pumping water is economically and technically limited to 250 meters or less. This means that the water from the large deep groundwater(in the order of thousands of meters) can deliver a small portion of their reserves under pressure, but the rapid fall of piezometric level stops very quickly the possibility of exploitation. Furthermore, mixed springs flows have low declines.

The hydrothermal springs are mixed springs of the Mikkes basin which are relatively low drying due to the water which comes from great depths (deep aquifer). In general, thermal springs commonly occur along fault zones owing to enhanced vertical permeability afforded by fracture zones [28]. The speed of rising is rather fast so that the temperature has no time to equilibrate with the temperature of the enclosing surface. Theoretically, waters in these springs could be derived from precipitation, infiltrated down fairly deep into the crust through fractures, and is warmed up "convectively" by other fractures (Figure 2). Water convection along the Prerif thrust front, and the structural unit boundaries should favour the emergence of the most important thermal springs [29]. The Prerif is considered a post-tectonic basin where Upper Miocene sediments and Jurassic to Middle Miocene chaotic blocks have accumulated [29]; the main formations are made up of marl, clay and carbonate sediments. Triassic saline domes, are widespread over a large area and are also found at different depths in the Couloir Prerif [30].

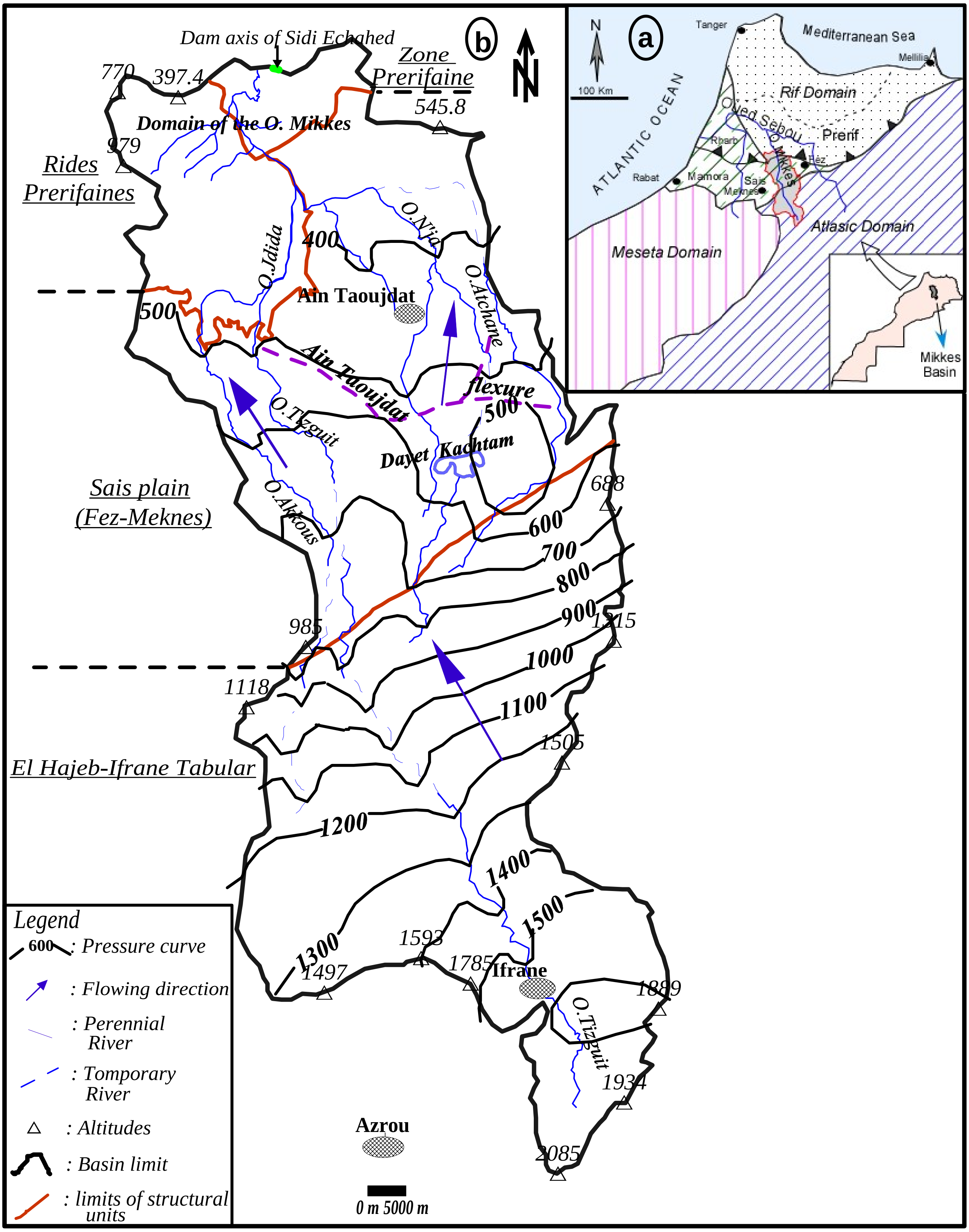

Fig. 3a. Location of the Mikkes basin, b. Water system and piezometric map 2005 of the Mikkes free-water table (taken from the topographic map 1/100000, geology division, Rabat, Morocco, 1943).

The Tabular Atlas, mainly made up of Mesozoic carbonate rocks, together with the regional tectonic structures of the Prerif, represents the main infiltration area that supplies the deep aquifers [5]. In addition, the thermal water during its ascent loses some of its deep-seated features. In particular, temperature is the emergence for various reasons (adiabatic relaxation of the deep gas, mixing with surface cold water, formation of clogging deposits of phyllosilcates, etc) [31, 32, 33 and 34]. Furthermore, the ascending water of the hydrothermal springs (given its geological and hydrological conditions) is always influenced by the vertical drainage resulting from the mixing of waters of the different reservoir levels. Although the thermal water is a mixture of the deep - warm water and the cold - surface water, re-equilibration upon cooling and/or mixing processes, (which affects the estimated temperatures at depth) cannot be excluded in the waters from the Prerif. Hence, the calculated temperature can only be assumed as indicative [35]. The average temperature of Skhounat (IRE N° 872/15) is around 38 °C.

It is clear that the springs in the Sais phreatic aquifer have suffered the maximum depletion. The springs with a deep or mixed origin are known as low flow variation springs. This can be explained by the relative position of the piezometric level and the river level. The Sais phreatic aquifer whose depth does not exceed 100 m is easily influenced by rainfall. While the confined deep aquifer with depths of more than 1000 m, is less influenced by the rainfall. On the other hand, the difference in geological features of these reservoirs affects the runoff coefficient. This results in a drop in pressure for the confined aquifer (without influencing the flow of springs), and reduced level of saturation for the aquifers (Sais phreatic and Tabular), thus drying up of subordinate springs.

4. Conclusions

As Brune [36] noted, "The study of springs is a borderline discipline, because springs are the transition from groundwater to surface water. Hence they have been studied to some extent by groundwater specialists and to some extent by surface-water specialists." The piezometric map of Mikkes established in 2005 shows a general direction of flow from the south to the north, with variable hydraulic gradient from upstream to downstream. Thus, a difference in variations of springs' flow occurs. The springs from the Liassic groundwater are springs with low fluctuations in the flows, while springs of emergence and discharge of the surface-water table of Sais have shown very significant declines.

References

[1] Church, T. M., 1996, An underground route for the water cycle: Nature, v. 380, p. 579-580.

[2] Bryan, K., 1919, Classification of springs: Journal of Geology, v. 27, p. 522-561.

[3] Manga, M., 2001, Using springs to study groundwater flow and active geologic processes: Annual Review of Earth and Planetary Sciences, v. 29, p. 201-228.

[4] Chenini, I., Ben Mammou, A., Moncef Turki, M. and Mercier, E., 2009, Piezometric levels as possible indicator of aquifer structure: analysis of the data from Maknassy basin aquifer system (Central Tunisia): Springer, Arabian Journal of Geosciences, DOI 10.1007/s12517-009-0050-4.

[5] Belhassan. K., Hessane, M.A. and Essahlaoui, A., 2009, Exchange Groundwater - River: Stream Mikkes Basin (Morocco): Research Journal of Earth Sciences, v.1 (2), p. 51-61.

[6] Belhassan, K., Hessane, M.A., Fassi Fihri, O. and El Rhaouti, S., 2007, Interactions between Surface Waters and Groundwater in the Oued Mikkes Basin, Morocco, Marrakech: The first Moroccan Association of Petroleum Geologists (MAPG) International Convention Conference and Exhibition, 201p.

[7] Worthington SRH, Ford DC., 2009, Self-organized permeability in carbonate aquifers: Ground Water, v. 47, p. 326-336.

[8] Bakalowicz, M., 2005, Karst groundwater: a challenge for new resources: Journal of Hydrogeology, v. 13, p. 148-160.

[9] Mangin, A., 1975, Contribution à l’étude hydrodynamique des aquifères karstiques. 3ème partie. Constitution et fonctionnement des aquifères karstiques (Contribution to the hydrodynamics study of karst aquifers. 3rd part. Constitution and functioning of karst aquifers): Annals of Speleology, University of Dijon, v. 30 (1), p. 21-124.

[10] Mangin, A., 1974a, Contribution à l’étude hydrodynamique des aquifères karstiques. 1ère partie. Généralités sur le karst et les lois d’écoulement utilisées (Contribution to the hydrodynamics study of karst aquifers. 1st part. Generalities on the karst and the laws of used flowing): Annals of Speleology, University of Dijon, v. 29 (3), p. 283-332.

[11] Mangin, A., 1974b, Contribution à l’étude hydrodynamique des aquifères karstiques. 2ème partie. Concepts méthodologiques adoptés. Systèmes karstiques étudiés (Contribution to the hydrodynamics study of karst aquifers. 2nd part. Methodological concepts adopted. Karst systems studied): Annals of Speleology, University of Dijon, v. 29 (4), p. 495-601.

[12] Bakalowicz, M., 1995, La zone d’infiltration des aquifères karstiques: méthodes d’étude, structure et fonctionnement (Infiltration area of karst aquifers: methods of study, structure and comportement) : Hydrogéologie, v. 4, p. 3-21.

[13] Perrin, J., 2003, A conceptual model of flow and transport in a karst aquifer based on spatial and temporal variations of natural tracers, PhD. thesis, Neuchâtel University, Neuchâtel, Suisse.

[14] Einsield, F., 2005, Flow system dynamics and water storage of a fissured-porous karst aquifer characterized by artificial and environmental tracers: Journal of Hydrology, v. 279, p.312-321.

[15] Aquilina, L., Ladouche and B., Dorfliger, N., 2006, Water storage and transfer in the epikarst of karstic systems

during high flow periods: Journal of Hydrology, v. 327, p. 472-485.
[16] Fleury, P., Plagnes, V. and Bakalowicz, M., 2007, Modelling of the functioning of karst aquifers with a reservoir model: Application to Fontaine de Vaucluse (South of France): Journal of Hydrology, v. 345, p. 38-49.
[17] Bakalowicz, M. and Mangin, A., 1980, L'aquifère karstique, sa définition, ses caractéristiques et son identification (The karst aquifer, its definition, its characteristics and its identification): Occasional Memoir, Geological Society France, v. 11, p. 71-79.
[18] Drogue, C., 1974, Structure of karst aquifers based on the results of drilling: Comptes Rendus of Sciences Academies, series III, Paris, France, v. 278, p. 2621-2624.
[19] Kiraly, L., 1975, Rapport sur l'état actuel des connaissances dans le domaine des caractères physiques des roches karstiques (Report on the current state of knowledge in the field of physical characteristics of karstic rocks). In: Burger A, Dubertret L (Editors), Hydrogeology of karstic terrains: I.A.H, International Union of Geological Sciences, Series B,v. 3, p. 53-67.
[20] Latati, A., 1985, Thoughts on karst water resources in the Middle Atlas Mountains Morocco. Karst Water. Resources (Proceedings of the Ankara - Antalya Symposium, July 1985): I.A.H.S, Publications, no, 161.
[21] Bonacci, O., 1987. Karst Hydrology: Springer Verlag, Berlin, Germany.
[22] Benjbarra, A., 1987, Observations sur les sources de la plaine de Fès-Meknès (Comments on the springs of the Fez-Meknes plain): La revue eau et développement, édition DRPE (Direction Hydraulique de l'Eau Potable), Maroc, p. 31-37.
[23] Amraoui, F., 2001, The karst aquifer of the Middle Atlas Tabular: Problem of turbidity affecting the springs of the Ribaa-Bittit complex (Morocco), Proceedings of the 7th Conference on Limestone Hydrology and Fissured Media, Besancon, France: Sciences et Techniques de L'environnement, v. 113, p. 45-48.
[24] Amraoui, F., Razack, M. and Bouchaou, L., 2003, Turbidity dynamics in karstic systems. Example of Ribaa and Bittit springs in the Middle Atlas (Morocco): Journal of Hydrology Sciences, v. 48, p. 971-984.
[25] Decker, K., Heinrich, M., Klein, P., Kociu, A., Lipiarski, P., Pirkl, H., Rank, D. and Wimmer, H., 1998. Karst springs, groundwater and surface water in the calcareous Alp: assessing quality and reliance of long-term water supply: I.A.H.S, v. 248, p. 149-156.
[26] Amraoui, F., Razack M., and Bouchaou, L., 2004, Comportment of the karst spring which is subjected to a prolonged drought: Bittit spring (Morocco), Geology Sciences, v. 336, p. 1099-1109.
[27] DRHS (Direction Régionale d'Hydraulique de Sebou), 1989, Exploration des eaux profondes, approche des infiltrations dans le Causse Moyen Atlasique, application d'un modèle global à réservoirs (Exploration of deep-water, approach of infiltrations in the Tabular Middle Atlas, application of global model to reservoirs) : Technical Report, Mor project 86/004, Morocco, 75p.
[28] Rowland Joel, C., Manga, M. and Rose Tim, P., 2007, Local variations in spring geochemistry: evidence for poorly inter-connected flow paths in fault zones: Geological Society of America Abstracts with Programs, v. 39 (6), p. 37.
[29] Rimi, A., Chalouan, A. and Bahi, L., 1998, Heat flow in the westernmost part of the Alpine Mediterranean system (the Rif Morocco): Elsevier, Tectonophysics, v. 285, p. 135-146.
[30] Saadi, M., Hilali, E.A., Bensaid, M., Boudda, A. and Dahmani, M., 1985, Carte géologique du Maroc (Geological map of Morocco), scale 1/1000000: Geology Service of Morocco, Notes-Memories No. 260.
[31] Ellis, A.J., 1970, Quantitative interpretation of chemical characteristics of hydrothermal system: Geothermics, v. 2, p. 516-528.
[32] Arnorsson, S., Gunnlaugsson, E. and Svavarsson, H., 1983, The elements of geothermal waters in Iceland: III Chemical geothermometry in geothermal investigations: Geochimica et Cosmochimica Acta, v. 47, p. 567-577.
[33]Giggenbach, W.F., 1991, Chemical techniques in geothermal exploration, In UNITAR/UNDP Guidebook: Application of Geochemistry in Geothermal Reservoir Development, (ed. by F. D'Amore), p. 253-273.
[34] Bouri, S., Lahlou Mimi, A., Beni Akhy, R., Tajina, S., Bellouti, F. and Ben Dhia, H., 1998, Les potentialités hydrogéothermiques de la Tunisie centre-nord Africa (Hydrogeothermics potential of the Tunisia Africa north-central): Geosciences Review, v. 5, p. 339-355.
[35] Cidua, R. and Bahaj, S., 2000, Geochemistry of thermal waters from Morocco: Geothermic, v. 29, p. 407-430.
[36] Brune, G., 2002, Springs of Texas. Texas A&M, University Press, College Station, TX.