Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

# FLOW DEFICIT, EVAPOTRANSPIRATION AND INFILTRATION IN ARID AREAS: THE CASE OF SOUTHERN TELLIAN ATLAS SUB-BASINS, EASTERN ALGERIA

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Received: 07 July 2020 / Accepted: 13 October 2020 / Published online: 01 January 2021

## ABSTRACT

Knowledge of inputs into an aquifer environment still remains a task difficult to identify for a groundwater model implementing software to simulate scenarios over long periods. Due to several related factors such rain and flow regimes, and the geology and morphometry of hydrological units, the water entering in the system is a random parameter. The objective of this study is to assess the flow deficit and the recharge rate in the North of Hodna region. The hydrometric stations network managed by the Agence Nationale des Ressources Hydrauliques (ANRH), sometimes within the same watercourse, presents sufficient series to make comparisons between the flow deficits. Thus, starting from there, taking into account the sub-basins geology, we dissociated the evapotranspiration portion of water input from the infiltration. This method showed an 8% of recharge and 82% of deficit.

**Keywords:** Flow deficit; Evapotranspiration; Hydrogeology; Geology; Hodna; Infiltration.

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doi: http://dx.doi.org/10.4314/jfas.v13i1.29

## 1. INTRODUCTION

The precipitated water that seeps into the subsoil and reaches the groundwater constitutes the groundwater recharge, restoring the water stored in the aquifers. An accurate recharge rate estimation is required to understand, simulate and manage groundwater flow systems [16 and 22]. However, this parameter is generally the least known in groundwater flow models [10]. Groundwater recharge rate estimation methods are applied at various spatial and temporal scales, but they greatly vary in terms of reliability [24]. The recharge quantification is very important, even though difficult to assess, moreover there is no method providing consistent results [10, 16, 22 and 24]. The water balance method could be still useful for the estimation from precipitation, evapotranspiration, infiltration and flow deficit. According to [7], the first estimates of the flow deficit were established in 1843, after the Saône river flood disaster in 1840 (France). Although [7] defines this factor as the difference between rain and flow in mm of lamina, he proposes to calculate this factor by the simple estimation of the actual evapotranspiration, based on the two climatological parameters, rain and temperature, where D = F (P, T) [14]. Therefore, this parameter is assimilated to the actual evapotranspiration. The objective was to determine the violence of flows, probably for civil engineering purposes. The infiltrated amount during the flood is negligible.

Moreover, [23] considers the term $\Delta r$ in his water balance, and variations in reserves negligible for long observation periods. Thereby, he assumes that the evapotranspiration is equivalent to the flow deficit. On the other hand, Thornthwaite uses in his monthly calculation of balance what he calls the Water surplus [8], which is nothing more than a surplus than a reserve of the soil that is fixed to a 100mm lamina [15]. This surplus would be available for the flow of both surface water and groundwater by percolation [26].

However, it must be admitted that the conceptualizationg a subsoil reserve and a percolation as rational and homogeneous in space, ignores the reality of distribution of soils and aquifers structural parameters, such as their permeability. In fact, the wide and deep alluvium aquifers are generated and feeded directly by the banks, even farther away from the leaks to other watersheds or to the sea in the coastal aquifers.

Several techniques have been developed to measure evapotranspiration: by the field water balance formula [18], from weighting on lysimeters [12], or by micrometeorological processes [11], but these techniques may be costly and time-consuming. Evapotranspiration can also be estimated from climatic data, linking evapotranspiration to one or more climatic variables [25]. The performance of different relationships has been assessed in different climates around the world [2 and 6]. The best approximation to estimate evapotranspiration in most climates is the Penman-Monteith equation [17], the standard utilized by the Food and Agriculture Organization of the United Nations (FAO) [1] for assessing evapotranspiration [2]. Furthermore, [14] and [7] propose their methods for the evapotranspiration calculation with a view to establish the annual hydrological balance.

The links between surface and groundwater play a very important role in hydrology and hydrogeology. While the water table-lake and water table-sea relations are generally not very evolutionary, the water-table relations are, in contrast, more complex and changing over seasons. Infiltration from a stream usually remains high only when its bed is not stabilized (alluvial-erosion) [3]. The influence of a stream on a water table is easily observed by piezometric measurements at different distances from the stream [13].

In this regard, long before us already, the infiltration capacity of a soil was a parameter not foreseen in the first definitions. All this would therefore force to a different conception in the watersheds management considering the evapotranspiration, where both the hydrologist and the hydrogeologist should perhaps take into account of both the real infiltration which is a function of the saturation degree of the subsoil, and the potential one. The case of the sub-basins to the north of the Hodna Plain (northern Algeria), containing an important Mio-Plio-Quaternary aquifer whose recharge is supposed to originate from these slopes, may be an example of dual interest, first of all for dissociating between evapotranspiration and infiltration loss, both integral parts of the flow deficit. Then, the knowledge of the recharge component of the Mio-Plio-Quaternary aquifer becomes controllable.

A more sophisticated water balance approach, which takes into account the spatial and temporal variability of precipitation, runoff, potential evapotranspiration, and morphometric characteristics and lithological and hydrogeological properties of watersheds are needed to address the issue of find out how much flow and recharge deficit occurs in these basins. In this work, the water balance method is applied to examine the potential distribution of I, E and F parameters in El Ham and Lougmane sub-basins.

## 2. MATERIALS AND METHODS

### 2.1. Study Area

Hodna region belongs to the steppic pre-Saharan region, it is marked by a large open depression of 8500 km$^2$, surrounded by the Tellian mountain chain in the north [3], the Atlasian chain in the west and the Aures chain in the east (Figure 1). The plain is occupied by a discontinuous vegetation cover which has undergone very developed erosion due to severe climatic conditions affecting the region. This morphology has allowed the installation of a low endorheic hydrographic network that feeds the Chott El Hodna saline lake laying in the middle of the basin by surface waters, especially during violent and random storms. Chott is subject to excessive evaporation of ground and surface water [3].

The soils are of several types: calcareous alluvial, sandy, stony, silt or clay. On a higher level, along the hydrographic network, more or less encrusted terraces are present, their extent depends on the past and current activity of the wadis, in particular Nessissa, El Ham and Lougmane wadis [4].

The region is primarily known for sheeps and goats rearing. Cattle and poultry farming are poorly developed. Beekeeping is very limited due to the severe winter cold. In agricultural terms, land is mainly used to grow cereals (wheat and barley) and fodder [3].

On three sub-watersheds in the endorheic Hodna basin (Ain Nessissa, El Ham wadi and Lougmane wadi), we dispose of flow series (E) measured in hydrometric stations (Ain Nessissa 1 and 2, South Rocade and Ced Fagues) as well as rainfall series from rainfall stations [21]. The flow deficit is calculated on the measurement series, by the difference (P-E) in mm for each sub-basin.

The difference between the value of the flow deficit of a sub-basin and that of the reference basin with the minimum infiltration (I) (in this particular case it is that of Ain Nessissa where I ≈ 0 but with roughly similar morphometric and climatic characteristics, especially the slope) will be similar to the infiltrated water blade.

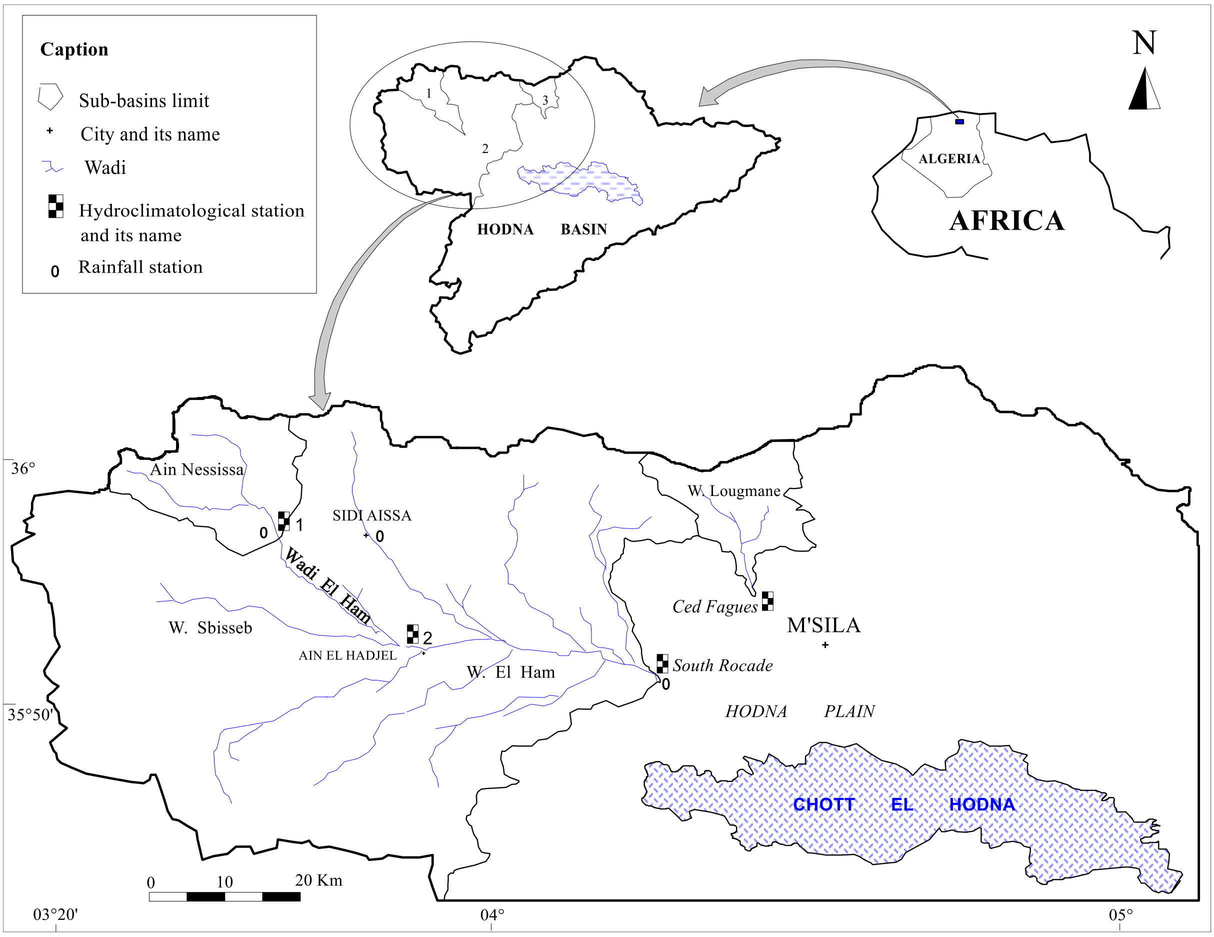



**Fig.1.** Sub-basins and hydro-climatological stations in the study area

### 2.1.1. Geological and Hydrogeological Framework

In this region, where the geology is as vast as it is complex, our objective is to highlight the principal groundwater flow directions relating to the main aquifers, as well as the arrangement of the infiltration formations, in the sub-basins concerned by the study.

First, the convergence of the two Atlases, Tellian and Saharian, has created a basin, which, after filling by the permeable alluviums, contains the bulk of the region's water resources, utilized for agriculture and drinking water purposes [3]. On the other hand, this same frontal shock, which is at the origin of the formation of Aurès chain and Hodna mountains, generated an intense fracturing system in the limestone rocks, sometimes dolomites rocks, of Lias, Barremien, Turonien, Albien, Coniacien and Santonien, forming important karst aquifers throughout the studied sub-basins [1 and 4].

In addition, the sub-basin of the El Ham wadi, encroaches to the south on the pre-Atlas domain, where fracturing on the Albian and Barremien- Bedoulian sandstone levels, covered by dune material, all constituting a trap for the water infiltration in these cracked levels [5,15].

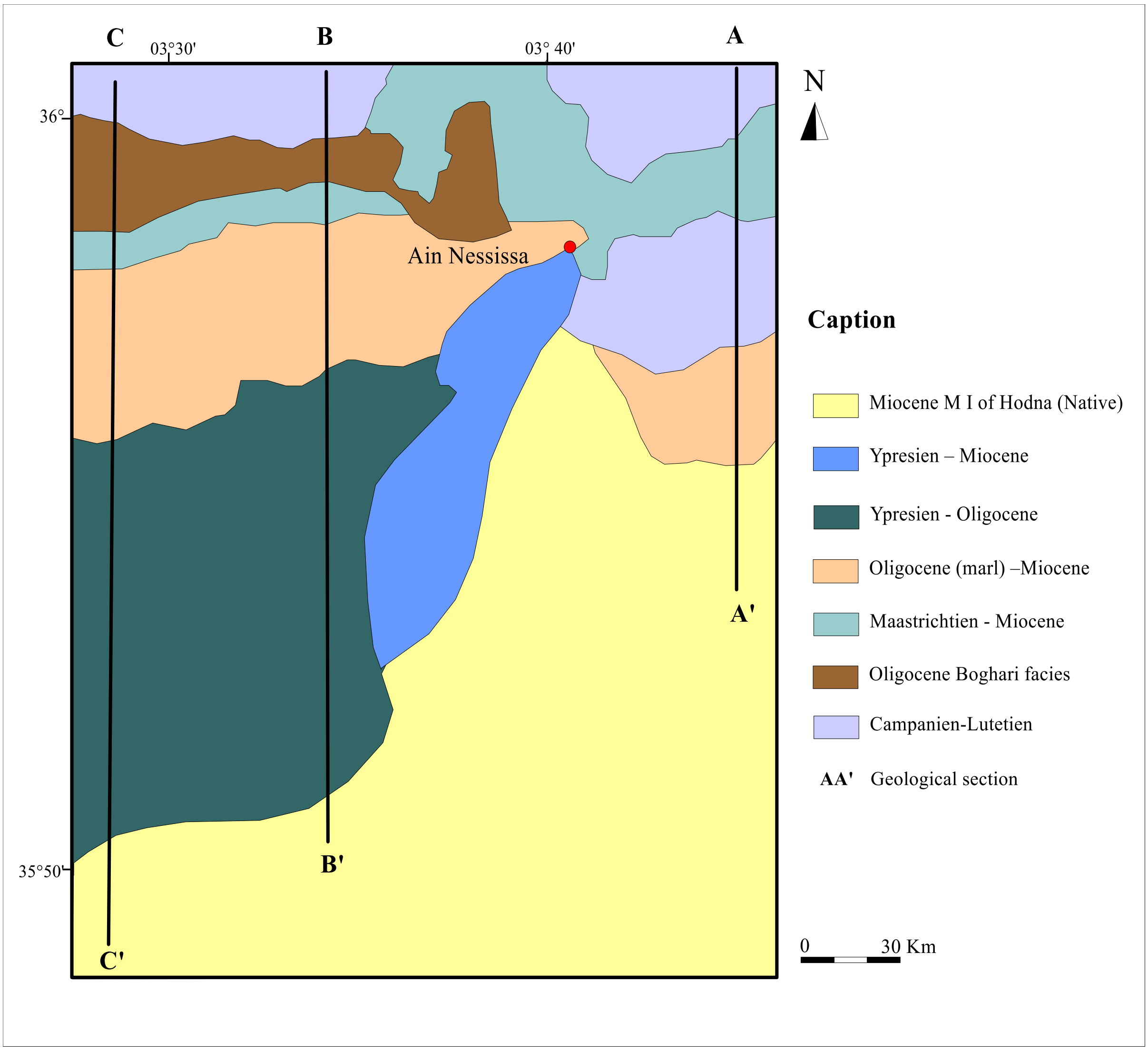



**Fig.2a.** Geology of Ain Nessissa Sub-basin [5]

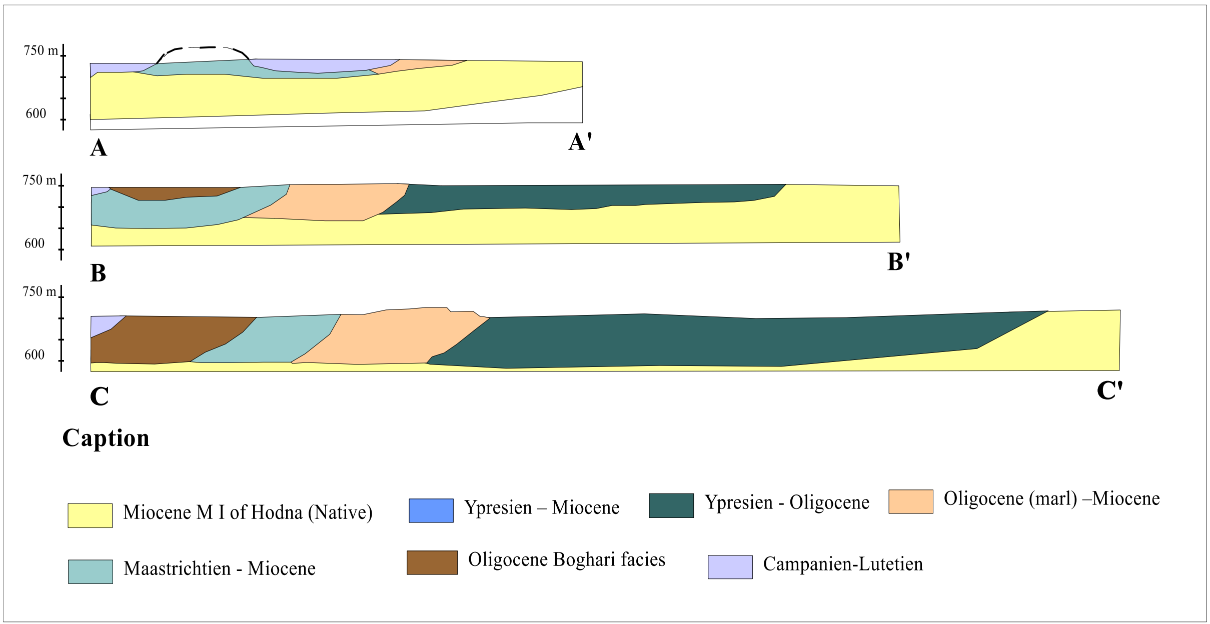



**Fig.2b.** Tectonic sections through the Ain Nessissa sub-basin

The Ain Nessissa sub-basin constitutes the exception on this plain. In fact, this part of the upstream of EL Ham Wadi shows a dominant marly and clay geological formations of Eocene, Oligocene and several Miocene cycles, in addition to an upper Cretaceous devoid of brittle floors, Conic and Santonian (stratigraphic gap), as described by [18] to the Maginot geological cover and the sections based on oil boreholes (Figure 2a and 2b). As a result, this sub-basin, exceptionally, presents almost no possibility of infiltration. Finally, it should be noted that all the fractured rock aquifers in the surrounding massifs (limestone and cracked sandstone) would be in turn a notable source for water supplying to the alluvial aquifer (Figure 3). The elements in favor of this hypothesis are as follows:

- Artesianism, which existed all around the Chott, now partly disappeared, and which leads to believe that the waters originated outside the plain, on the mountains at distinctly higher altitudes. In some places, the water spurting reached 11m at a flow rate of 25 l/s in the 1970s [4].

- The temperature at 22°C, as well as the existence of sulphates of gypsiferous origin on all the waters of boreholes, suggest provenance froms karst levels, through faults still active [3].

- Finally, the electrical conductivitie values in the waters of downstream watercourses on the plain (1800µS), in most areas higher than those of the groundwater (often around 1100µS), confirm the predominance of the water origin of from the core water table (70 to 200 m), by these slopes rather than by these streams, insulated by the waterproof, as the hydrogeophysical section shows (Figure 3).

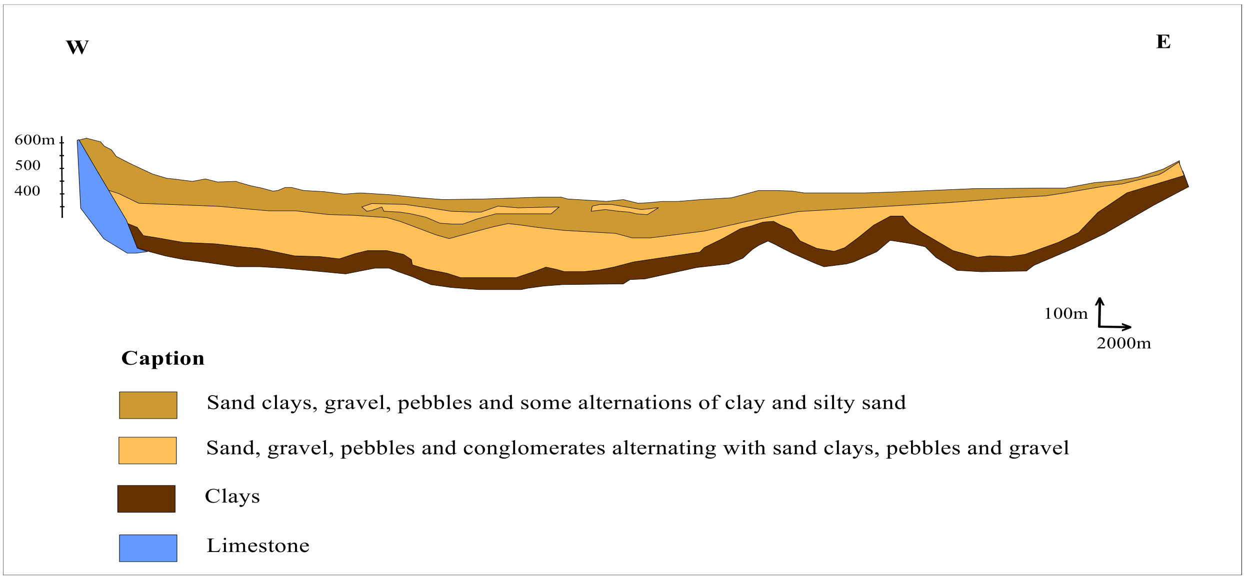



**Fig.3.** Hydro-geophysical section (West-East) of the North of the Hodna basin [3]

### 2.1.2. Morphometric characteristics of sub-basins

The calculated shape characteristics are as shown in Table 1.

**Table. 1.** Morphometric characteristics of studied sub-basins

| Sub-basin | Ain Nessissa | El Ham wadi | Lougmane wadi |
|---|---|---|---|
| Perimeter (km) | 84.7 | 334.4 | 75 |
| Area ($km^2$) | 460 | 5600 | 334 |
| Compactness index | 1.17 | 1.26 | 1.21 |
| Equivalent rectangle length | 27.28 | 39.64 | 28.22 |
| Equivalent rectangle width | 15.08 | 1.11 | 11.76 |
| Slope index | 0.028 | 0.026 | 0.029 |

This data shows that Lougmane and Ain Nessissa sub-basins are closer to El Ham wadi one, already in terms of area, but also in terms of compactness and slope index (Figure 4)

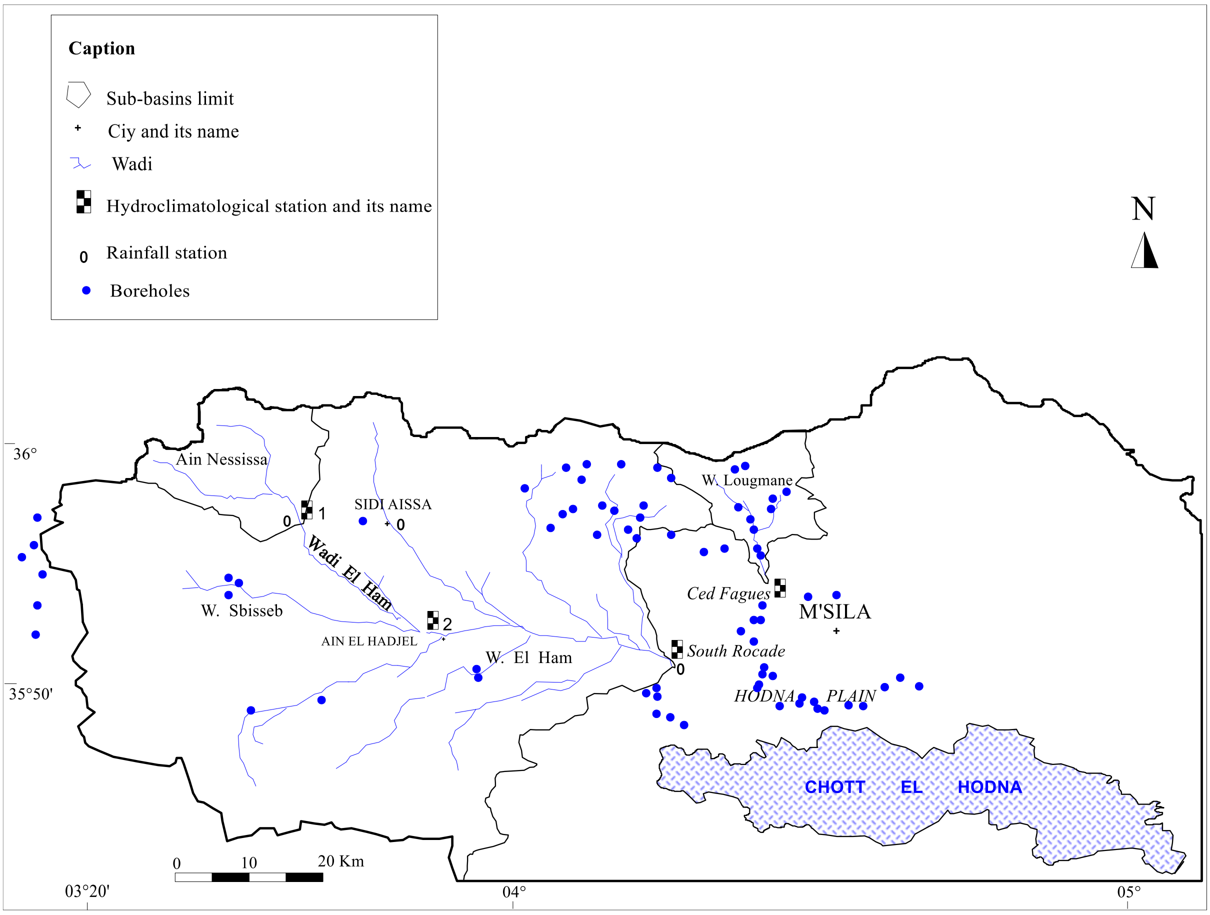



**Fig.4.** Boreholes distribution at sub-basin level

## 3. RESULTS AND DISCUSSION

### 3.1. Rainfall and Rainfall Averaging

The climate is arid with annual rainfall averages between 200-350 mm and a temperature of 19 °C [3]. For the sub-basins, the method of calculating the rainfall mean is that of the isohytes [22] (Table 2). The selected items are those that worked during the run-off period (1999-2011).

**Table. 2.** Annual averages of precipitation per basin in mm/year (period 1999-2011) [20]

| Sub-basin | Rainfall station used | Average |
|---|---|---|
| El Ham wadi | South Rocade, Ain Nessissa1 and Sidi Aissa | 300 |
| Ain Nessissa | South Rocade, Ain Nessissa1 and Sidi Aissa | 310 |
| Ain Nessissa | Sidi Aissa and Ain Nessissa1 | 327 |
| Lougmane wadi | Sidi Aissa and Ain Nessissa1 | 309 |

### 3.2. Flow and rainfall deficit

The calculations result of the rainfall deficits are as shown in Table 3.

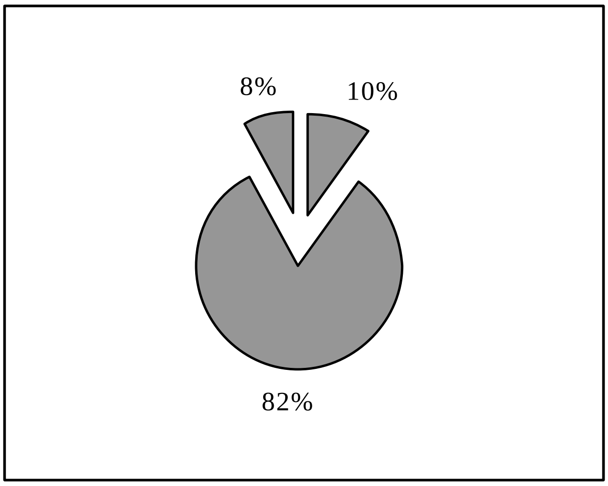
**Table. 3.** Inputs and rainfall deficits (1999-2011) [20]

| Sub-basin | El Ham wadi | Ain Nessissa | Lougmane wadi |
|---|---|---|---|
| Area ($km^2$) | 5600 | 460 | 334 |
| Inputs ($Mm^3$) | 40.62 | 34.07 | 10.778 |
| Inputs (mm) | 7.3 | 74 | 32 |
| Rain (mm) | 300 | 327 | 309 |
| Rainfall deficit (mm) | 292.8 | 253 | 277 |
| Difference / Ain Nessissa (mm) | 35.6 | 0 | 24 |

The gap in the deficit relative to the sub-base (last row in Table 3) would represent the share due to infiltration. But the value of 35.6 mm for El Ham wadi at South Rocade seems too relevant and would be largely due to the climatic factor. Indeed, the area swallowed from this basin can have much stronger energy flows than Ain Nessissa, which increased the deficit through evaporation. The comparison would be more appropriate between Ain Nessissa and Lougmane Wadi, two basins with the same latitudes and altitudes.

Therefore, all precautions taken, we prefer to retain as an infiltrated water blade that of the gap with Lougmane wadi, which would be then of the 24 mm order, representina nearly 8% on the average rain (Figure 5).

Taking into account the inventory of M'Sila’s hydraulic services, the whole boreholes in this sub-basin provide 91 l/s, giving a blade value of 8.5 mm and a residual blade of 15.5 mm, or 5.2 $Hm^3$/year [10].




Evapotranspiration: 82% Flow: 10% Infiltration: 08%

**Fig.5.** Lougmane Wadi's Water Balance

## 4. CONCLUSION

The establishment of the water balance necessary to understand the functioning of a hydraulic system takes into account climatic parameters such as rain, evapotranspiration, flow and infiltration that constitute the water cycle. The water recharge of underground reservoirs is conditioned mainly by meteorological precipitation.

The rainfall deficit calculating is made possible nowadays on the rivers with available intake series, contrary to some times in the past when it was necessary to go through the evaluation of the evapotranspiration for the flow estimating.

However, we have to be careful not to attribute this factor solely to the quantities linked to evapotranspiration. When possible, it is still necessary to attempt for each region, to measure the gap between the deficits compared to a reference sub-basin with impermeable geology, in order to approach the term of infiltration.

In addition, in order to approximate the residual quantity in the sub-basin, assumed as potential input into the alluvial aquifer, the total exploited water volume from the the borehole is deduced.

In the study area, infiltration represents 8% of the total rainfall, a flow of 10% while the rate of flow deficit is of the order of 82%. An empirical method like this should be improved with other mathematical models provided the data are available to achieve broad scientific understanding and sustainable management of arid basin aquifers in Hodna and elsewhere.

This could have important implications for recharging and resource management. Spatial variability is integral because the potential recharge in the basins will control the flow of surface water to the aquifers of arid regions basins. So, it is necessary to develop and use more detailed modeling approaches (like INFIL) in order to achieve this goal.

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**How to cite this article**:
Amroune A, Grine R, Guastaldi E. Flow deficit, evapotranspiration and infiltration in arid areas: the case of southern tellian atlas sub-basins, eastern algeria. J. Fundam. Appl. Sci., 2021, 13*(1), 533-546.*