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Research Article

ESTIMATION OF GROUNDWATER RECHARGE IN THE PLAIN OF SIDI BEL ABBÈS, ALGERIA

A. E. Bellaredj

Department of Geology, Faculty of Earth and Universe Sciences, University of Oran 2
Mohamed Ben Ahmed, BP1015, El-M'naouer, 31000, Oran, Algeria

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ABSTRACT

In Sidi Bel abbes, 30% of drinking water needs are met with groundwater. The remaining 70% are transferred from abutting cities. A situation expected to worsen due to predicted precipitation drop and population growth. Thus, identifying and quantifying the parameters of the water budget in the study area is necessary to implement adequate management and exploitation policies. In this paper, we present the full water balance of the plain of Sidi Bel Abbes for the period 2015-2016, combining the natural components of the water cycle and anthropogenic activities. The results show that the actual evapotranspiration and the runoff equal 311mm and 30mm respectively. Infiltration is equivalent to 17% of rainfall and represents 52Mm^3/yr of groundwater recharge. The water deficit between the total inflows and outflows remains considerable (29Mm^3/yr), despite the authorities efforts.

Keywords: Groundwater recharge; Population growth; Precipitation drop; Water balance; Water deficit.

Author Correspondence, e-mail: bellaredj_science@yahoo.com

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1. INTRODUCTION

In arid and semi-arid regions, aquifers represent the main source of water. In the plain of Sidi Bel Abbès (SBA) for example, all irrigation water and an important portion of drinking and industrial water supplies come from underground water reservoirs and specifically from the unconfined plio-quaternary aquifer (PQ-aquifer). Meeting the water demand in arid and semi-arid regions requires the permanent monitoring of their hydrographic basins [1] and one of the most important tools used to achieve this goal is the study of the hydrologic cycle. The terminology water-balance also referred to as the hydrological budget refers to the perpetual recirculatory process moving water between land, water bodies and the atmosphere. Multiple models are used to estimate the water balance, each corresponding to a degree of complexity. However, all models must account for two main parameters: the water stock variation and the actual evapotranspiration [2].

The hydrological balance method refers to a simplified calculation model based on the principle of conservation of mass (water) contained in a certain volume of soil; precipitation = evaporation + runoff (surface, subsurface and underground) + stock changes [3]. Unlike other methods, this approach can be used to approximate groundwater recharge, in areas where mass data is absent.

Groundwater recharge is a very important process in the natural water cycle and its estimation is paramount when dealing with groundwater protection, management and exploitation [4]. Nonetheless, finding simple and cost-efficient methods for its estimation remains a challenge [5].

Multiples methods are found in the bibliography to approximate groundwater recharge; assessment of groundwater level response to short episode rainfall [6-8], using carbon and tritium isotopes [9, 10], the Chloride Mass Balance [11, 12], etc. Unfortunately, all aforementioned methods require a consistent amount of data for their application, most of which is absent in the study area. As a result, an empirical approach based on the hydrological balance method was adopted to 1) quantify all the parameters necessary for of the water balance and 2) estimate the percentage of groundwater recharge in the plain of SBA.

2. RESULTS AND DISCUSSION

The hydrologic balance of the plain of SBA was estimated for an area of approximately 800 km^2, corresponding to the extension of the plio-quaternary aquifer formations (PQ-aquifer) over a period of 12 months (2015/2016) based on the following equations:

$$\sum Q_{in} - \sum Q_{out} = \Delta S \text{.....................}(1)$$

$$\Delta S = A \cdot \Delta h \cdot S \text{................................}(2)$$

$$\sum Q_{in} = P + Q_1 + Q_2 + Q_3 \text{.............}(3)$$

$$\sum Q_{out} = ETR + Q_4 + Q_5 \text{...............}(4)$$

$$P \pm \Delta S = ETR + R + I \text{...........}(5)$$

With: ***ΣQin***: total water inflows; ***ΣQout***: total water outflows; Δ***S***: Stock variation; ***A***: aquifer surface; Δ***h***: head difference; ***S*** : Storativity; ***P*** : precipitation; Q_1: underground and surface flow at the inlet (southern limit of the plain); Q_2: irrigation return; Q_3: wastewaters; Q_4: underground and surface flow at the outlet; Q_5: total withdrawals (for drinking, irrigation and industrial purposes); EP_a: real evapotranspiration; ***R***: runoff (surface); ***I***: infiltration (recharge)

The results of the calculations explained in the experimental section are presented below:

2.1. Precipitation *(P)*

In order to obtain a representative average of rainfall, we collected series from 9 stations, spread throughout the study area (table 3). The results show that the annual mean of rainfall on the plain of SBA is around: ***P*** = 370mm.

2.2. Underground and surface flow at the inlet (Q_1)

The underground flow at the entry of the plain is represented by the discharge of sources. As discussed in the experimental section (hydrogeology), only two major sources: Aïn Mekerrag and Aïn Skhouna, are present in the plain, precisely in the locality of Sidi A li Benyoub. Based on annual discharge values, which decreased by 58% (from 8.2 Mm^3/yr to 3.5 Mm^3/yr) between

1970 and 2007 and assuming a linear evolution, we were able to estimate the underground flow volumes at the inlet for 2016 to equal: 3.2 Mm^3/yr.

Due to lack of data, the surface flow at the entry (estimated at 4.5 Mm^3/yr in 1970, figure 4) was calculated by assuming the same decrease (58%) of the underground flow. i.e., 4 * 42% = 1,9 Mm^3/yr. Thus, the underground and surface flow at the inlet equals (**Q_1**): 3.2 + 1.7 = 5 Mm^3/yr; **Q_1**= 6.25mm.

2.3. Irrigation returns (Q_2)

In order to calculate the return volumes from irrigation, we had to estimate first the water volumes allocated for agriculture for the year 2016 and then, the mean water demand per hectare, based on the type and irrigated surface of each crop.

After the synthesis of all data we were able to reconstruct the evolution of irrigation water volumes from 1970 to 2016 (figure 1).

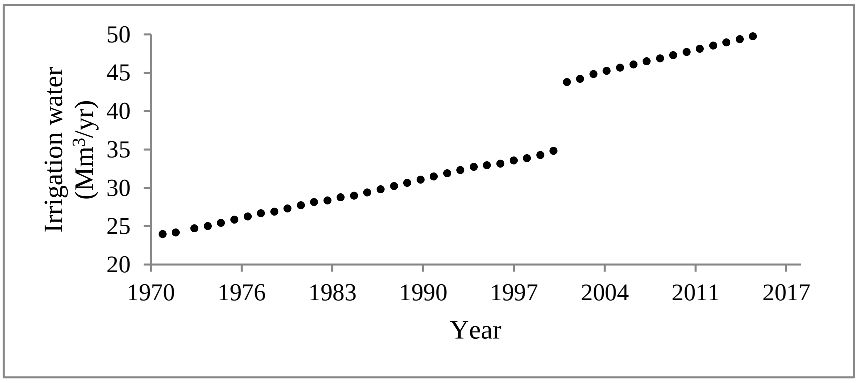

Fig.1. Evolution of irrigation water needs in the plain of SBA

Figure 1 shows that irrigation water needs approach 50 Mm^3/yr in 2016, for an area of approximately 8900 ha; the overall consumption calculated based on an average mean consumption of 5067 m^3/ha (table 6) equals 45 Mm^3/yr. Thus, the irrigation water volumes returning to the PQA equal (**Q_2**): 50 - 45 = 5 Mm^3/yr = 6.25mm.

2.4. Wastewater (Q_3)

The volume of wastewaters in the plain of SBA represents the sum of treated and untreated wastewaters (**Q_3**): 21600 + 21750 = 43350 m^3/d; **Q_3** = 20mm.

2.5. Actual evapotranspiration (ET_R)

The estimation of the ET_R was made using thornthwaite water balance method [13], based calculated *EUR* (easily usable reserve) and monthly ET_p (potential evapotaspiration) values.

Table 1. Monthly ET_p (mm) values on the plain of SBA

S	O	N	D	J	F	M	A	M	J	J	A	Year
96	67	39	26	19	22	32	46	62	91	121	129	750

Table 2. Plain of SBA water balance based Thornthwaite method [13]

	Sep	Oct	Nov	Dec	Jan	Fev	Mar	Apr	Mai	Jun	Jul	Aug
P	15	33	48	53	51	50	44	38	30	8	2	3
ET_P	96	67	39	26	19	22	32	46	62	91	121	129
EUR	0	0	9	36	44	44	44	36	4	0	0	0
ET_R	15	33	39	26	19	22	32	46	62	12	2	3
Deficit	81	34								79	119	126
Flow					24	28	12					

Table 2 shows that the annual actual evapotranspiration on the plain of SBA equals ET_R = 311mm. the agricultural deficit is 439mm/yr, spreading from June to October, with a maximum of 126mm in August. The *EUR* is formed from November to Mai. The surplus months are those of January, February and March with a flow volume of 64mm.

2.6. Underground and surface flows at the outlet (Q_4)

The PQ-aquifer has only one outlet, located in the “Rocher” district, north of the city of SBA, where most of the PQ-aquifer waters are drained by the Mekerra-R (figure 4). Therefore, the water volumes exiting the PQ-aquifer were estimated Based on:

- gauging differences of the Mekerra-R, between the stations: Sidi Ali Benyoub (River upstream and inlet of the PQ-aquifer) and Rocher (River downstream and outlet of the PQ-aquifer),
- sum of flows derived from the Mekerra-R for irrigation purposes,
- flow derived from the Mekerra-R toward the Sarno dam)

Q_4 = difference in Mekerra-R flows between SA Benyoub and SBA stations + flows derived from Mekerra-R for agriculture + flow derived from the Mekerra-R to the Sarno dam)

Q_4 : [(800-124) + (587) + (4)] = 1251 l/s

$\boldsymbol{Q_4}$ **= 49mm**

2.7. Total withdrawals (Q_5)

The PQ-aquifer has been overexploited for several years. This has led to a consequent drop of piezometric levels throughout the plain of SBA [14]. According to official estimates for 2016, the total withdrawals for drinking water were equal to 12.5 Mm^3/yr (68% deficit compared with drinking water needs).

Based on irrigated surface evolution and mean water demand per hectare for communally cultivated cultures, irrigation needs for 2016 were evaluated to be 50 Mm^3/yr (figure 1). This volume is in accordance with official estimates regarding water volumes used for agriculture in the plain of SBA [15].

Q_5: 12.5+ 50 = 62.5 Mm^3

Q_5 = 78mm

Total inflow (ΣQin) = 402mm	**Total outflow ($\Sigma Qout$) = 438mm**
$P + Q_1 + Q_3 + Q_2 = 370 + 6.12 + 6.25 + 20$	$ET_R + Q_4 + Q_5 = 311 + 49 + 78$

2.8. Stock variation (ΔS)

The variation of the aquifer stock was computed as shown in equations (1 & 2), using the area ($800 km^2$), average storage coefficient (15%) and the mean annual head drop (0.25m/yr) of the PQ-aquifer (head difference response to short rainfall episodes is unavailable) [14]:

$$\Delta \mathrm{S}_1: \left(800 \cdot 10^6\right) \bullet (0,15) \bullet (0,25) = 30 Mm^3/yr; \Delta \mathrm{S}_1 = 37mm$$

$$\Delta \mathrm{S}_2 = \Sigma Qin - \Sigma Qout; \Delta \mathrm{S}_2 = 36mm$$

$$\Delta \mathrm{S}_1 \approx \Delta \mathrm{S}_2$$

2.9. Runoff and infiltration

The runoff (R) and the infiltration (I) were estimated using:

- the simplified hydrological balance (P ± ΔS = ETR + R + I) and
- Tixeront-Berkaloff's formula: $R = \dfrac{(P)^3}{3ET_p{}^2}$

R = 30mm (8% of rainfall).

With:

$I = P - (ETR + R) \pm \Delta S$

$I = 370 + 36 - (311 + 30) = 65$mm (17% of rain).

Thus, the annual direct recharge by precipitations of the PQ-aquifer (800km^2) is 52Mm^3/yr.

3. EXPERIMENTAL

3.1. Description of the study area

The city of Sidi Bel Abbès (SBA) located between the longitudes 0˚00’ and 1˚00' West and the latitudes 35˚30' and 34˚30' North, is home to one of Algeria’s most fertile plains. The agriculture, mostly groundwater based due to the semi-arid climate characterizing the area is one of the strongest pillars of the city’s economy. The plain of SBA has an average altitude of 600m and covers a surface of about 1150 km^2. The plain is a large bowl filled with materials from the Piocène-Quaternary surmounting a Mio-Pliocene substratum of gray green clays and marls. The unconfined Plio-Quaternary aquifer (PQ-aquifer) formed by very heterogeneous alluviums, represents the major groundwater reservoir in the plain with an average thickness of 80m and an approximate 800 Km^2 surface. The hydrographic hair is not dense; only two major wadis are present, i.e., the Mekerra-R and the Tissaf. The land cover in the Mekerra-R watershed is subjected to accelerated degradation due to anarchic construction extension, pasturage overexploitation and multiplication of fires. The soil in the plain is predominantly humus limestone.

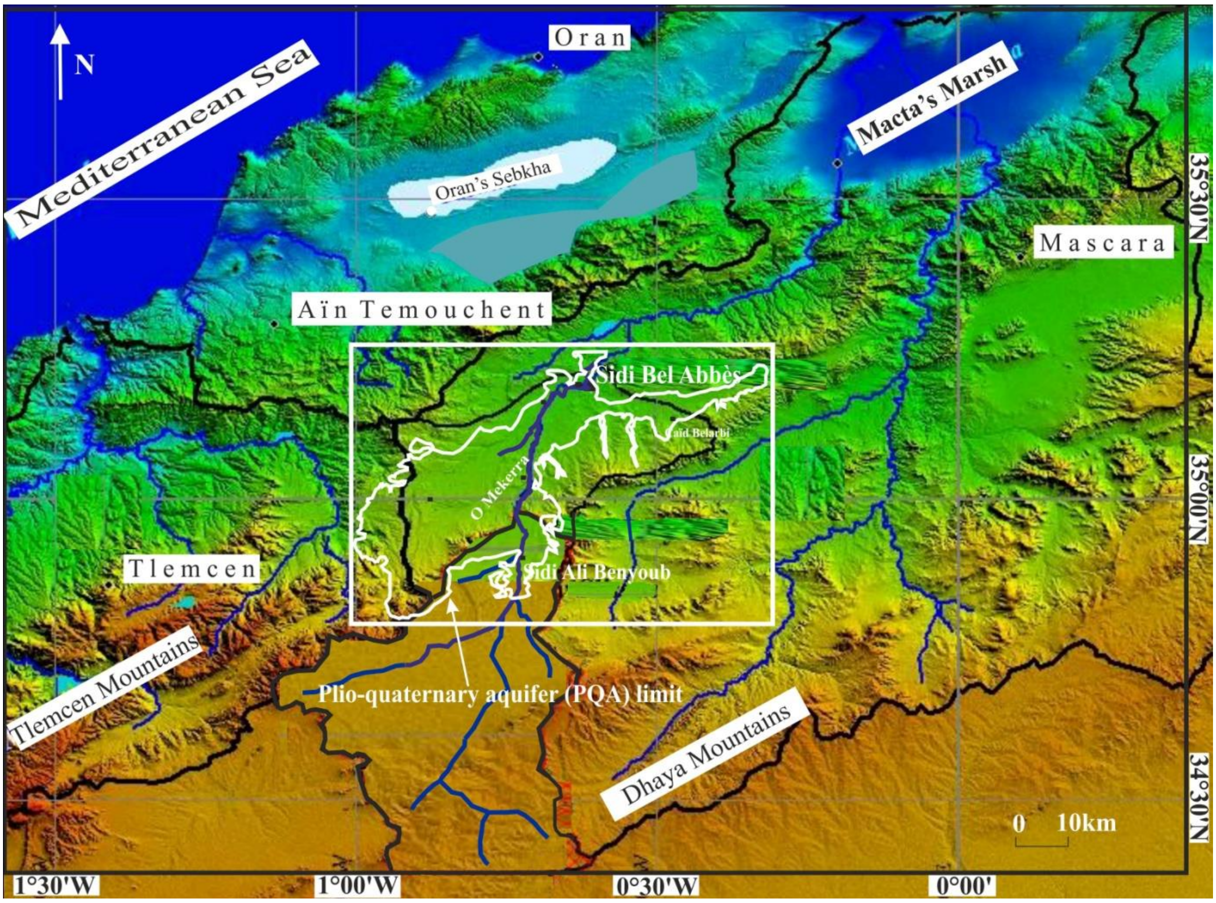

Fig.2. General localization of the study area

3.2. Water balance

The main components of the water balance are the precipitations (p), the runoff (R), the infiltration (I), the evapotranspiration (ET) and the anthropogenic inputs and outputs.

After a rainy episode, the separation between the infiltration (supplying underground reservoirs) and the runoff (in the hydrographic network) flows at ground level comes just after the interception. The distribution and intensity of the two flows will depend on the type/regime of precipitations, land cover, soil moisture and characteristics, geology and topography of the studied area. The most difficult parameter to measure when calculating a water balance is the evapotranspiration (ET), because it is tributary of climate parameters (precipitation, temperature, solar radiation and wind), vegetation cover (vegetative state and groth rate, canopy and interception), and soil water storage [16]. The ET is the result of two processes. The first refers to the transpiration of the vegetation cover and the second to the evaporation of water form plants, water bodies and the ground (when water is liquid, its transition to gas is called evaporation, when it's solid (snow, ice), the procedure is rather referred to as sublimation). The evaporation acts on the first 15-20 cm of the soil. Below this threshold, its plants transpiration that contributes greatly to the ET; we differentiate: **the potential evapotranspiration (*FTE or* ET_p)**: all water losses by evaporation and transpiration from a reference plant cover (generally grass) covering totally the ground, having a uniform height of a few centimeters, abundantly supplied with water and at its maximum vegetative stage; **the maximum evapotranspiration** **(ET_m)**: defined for a given culture over its different vegetative stages of development, when water is sufficient and agronomic conditions are optimal; **the real or actual evapotranspiration (ET_r *or* ET_a)**: sum of the quantities of water evaporated from the soil and the vegetation when the soil is at its present humidity and plants at a stage of optimal physiological development. The anthropogenic inflows and outflows materialize respectively in the form of water transfers from neighboring cities and withdrawals.

In order to calculate the different components of the water balance for the study area, a thorough investigation of the land cover/soil characteristics (interception, runoff and infiltration), topography/hydrology (flow and water levels of rivers), hydrogeology (formations thickness and type, aquifers nature, head fluctuations, hydrodynamic properties, hydraulic gradients), climate (rainfall regime, temperatures, solar radiation, evapotranspiration) and anthropogenic activities (withdrawals, water derivations form neighboring cities, wastewaters) was conducted.

3.2.1. Climatology

The plain of SBA has a semi-arid climate, humid/cold during winter and dry/hot in the summer. Since the early 70s, the average rainfall rarely reaches 400 mm/yr.

Table 3. Annual precipitation means in the plain of SBA

Station	X (km)	Y (km)	Z (m)	Period	mean (mm)
SBA	194.1	215.0	480	1918-1928/1935-1958/ 1968-2006	353
B. Badis	170.8	190.8	710	1917-2006	450
S. Boussidi	178.2	206.1	600	1942-1961/1968-2006	437
Lamtar	181.1	202.8	565	1942-1961/1968-2006	362
H. Zahana	172.7	198.2	650	1914-1961/1973-2006	423
S. Lahcene	191.2	212.9	500	1942/1973-2006	261
C. Belarbi	212.9	210.7	550	1973-2006	313
Tabia	186.8	196.7	615	1942-1947/1973-2006	357

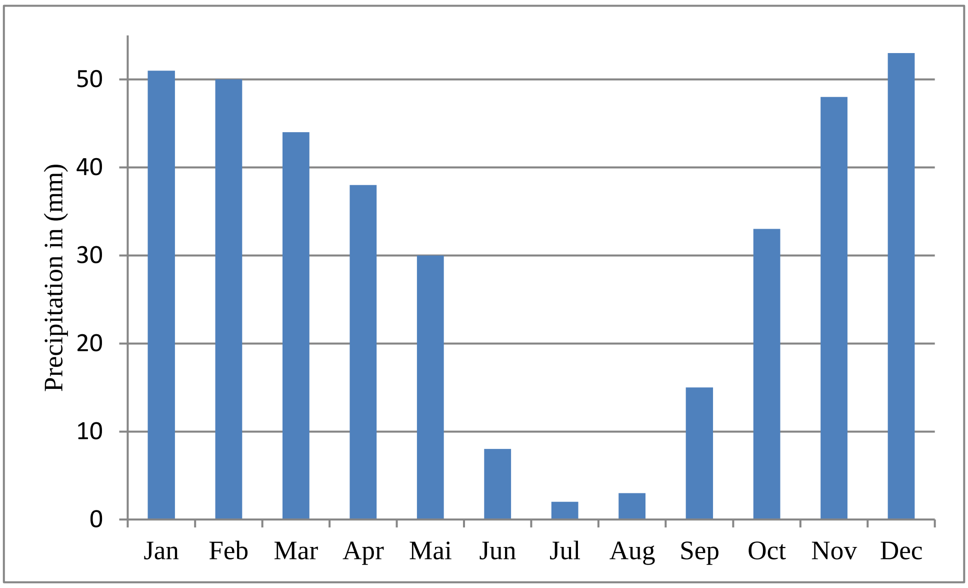

Fig.3. Mean Monthly precipitation in the plain of SBA

Table 4. monthly temperatures in the plain of SBA (ANRH, 1987 – 2012)

Mois	Sep	Oct	Nov	Déc	Jan	Fév	Mar	Avr	Mai	Jui	Juil	Aoû
T (°c)	22	17.5	13	10	8.5	9	11.5	14	17	21	25	26

Based on table 4, we were able to calculate the monthly potential and real evapotranspiration on the plain of SBA using Thornthwaite method [13]. This simple method is based on monthly estimates of the ET_p, easily usable reserve (*EUR*) and precipitation to compute a monthly site-specific water balance from which an approximation of the ET_r is obtained.

- When $P > ET_p$, there is a surplus (P - ET_p) which is allocated first to the *EUR*. When the EUR is full, the surplus goes to the flow Q

- When $P < ET_p$,all the rain (*P)* is supposed to have evaporated and water is subtracted from the EUR (until it is drained) in order to satisfy the ET_r.

$$ET_p = 16 \cdot \left(\frac{10t}{I_t}\right)^a \cdot k$$

$$a = 0,492 + 1792 \cdot 10^{-5} \cdot I_t - 771 \cdot 10^{-7} \cdot I_t^2 + 675 \cdot 10^{-9} I_t^3$$

$$I_t = \sum_{t_{january}}^{t_{December}} \left(\frac{t}{5}\right)^{1.514}$$

Where:

ET_p: potential monthly evapotranspiration (mm), for a 12 (h/d) radiation.

I_t: annual thermal index

t: average monthly temperature (°C)

k: correction factor, function of the duration of day and the number of days per month

Table 5. Monthly ET_p (mm) values on the plain of SBA

S	O	N	D	J	F	M	A	M	J	J	A	Year
96	67	39	26	19	22	32	46	62	91	121	129	750

The useful water reserve is the amount of water that the soil can retain and restitute to the plant. It is the difference between the humidity at field capacity (*FC*: maximum quantity of water that a soil can retain by capillary forces, without said water being enough in excess to percolate) and the humidity at the permanent wilting point (*PWP*: water content of a soil below which the plant can no longer overcome the tension exerted by capillary forces to meet its water needs). The *UR* is composed of the Easily Usable Reserve (*EUR*) and the Survival Reserve (*SR*), beyond which, the *WP* is reached.

The useful reserve depends on the rooting depth of the plant, the apparent density and soil texture. The *UR* can be estimated using either Beauchamp's formula [17] or Jamagne et al.**,** triangle of textures [18].

$$UR = \left(\frac{H_{FC} - H_{WP}}{100}\right) \cdot h \cdot D_a$$

$$UR = Ur_{/cm} \cdot h$$

H_{FC}: humidity at field capacity (mm), ***H_{WP}***: humidity at wilting point (mm), ***D_a***: apparent density; ***$Ur_{/cm}$***: useful reserve per cm of soil; Ur: useful reserve (mm); ***h***: rooting depth (mm): estimated at 40cm (average root depth of certain crops frequently cultivated in the SBA plain: potato (45cm), bean (30cm), cabbage (45cm), peas (30cm), etc. [19]

3.2.2. Hydrology

The influence of precipitation is clearly felt on the evolution of flows in the Mekerra-R throughout the year. The highest flows are recorded from the beginning of Autumn until

October. We then observe a decrease until February and then a re-increase in flows from the month of March. This is largely due to snow caps, which, settling on the heights between December and February, do not start to melt until the end of March.

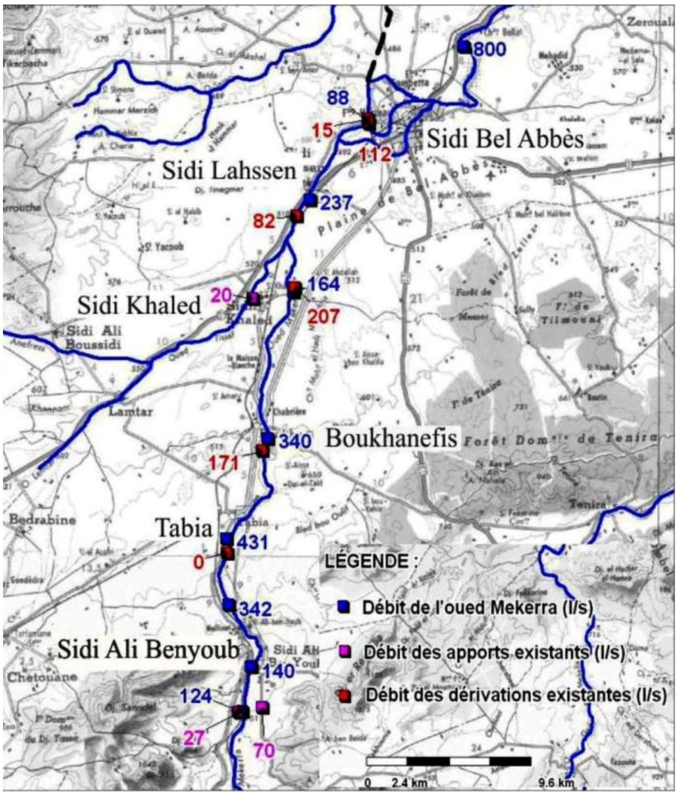

Fig.4. Interaction between the PQ-aquifer and the Mekerra-R [20]

From figure 4, it appears that the flow of the Mekerra-R increases from the entry of the plain (South of Sidi Ali Benyoub) until Tabia; arriving at Boukhanefis, the flow decreases by 80 l / s, passing from 430 to 340 l/s. This slight decrease in flows from the Oued (the 80l / s reduction in the flow of the Mekerra-R does not correspond to the flows of 171 l/s subtracted from the Oued by the diversions) is due to the rise of pressured water from the PQ-aquifer (through outcroping fissured Pliocene conglomerates), which becomes semi-confinned between Sidi Ali Benyoub and Boukhanefis. From Boukhanefis to Sidi Khled, the flow of Oued Mekerra is halved due to the many diversions (207 l/s) intended for irrigation. From Sidi Khaled to Sidi Lahssen, it appears that the aquifer/river exchanges are not very important, due to an increasingly clayey sedimentation of the Oued bed. Moreover, contributions of 20 l/s pouring from Oued Tissaf in the Mekerra-R are registered. Between Sidi Lahssen and the Outlet (Rocher district), it is clear that the Mekerra-R drains most of the Plio-Quaternary aquifer waters (the flow of the Mekerra-R almost triples in less than 15 km, going from 237 l/s to 800l/s, that is without taking into account the flow rates of the diversions).

3.2.3. Hydrogeology

The plain of SBA is a large bawl filled with very heterogeneous alluviums from the plio-quaternary surmounting clays and marls of the Mio-Pliocene. The plain is bordered by two mountains series, the Tessala to the North and the Tlemcen-Saïda mountains to the South. As for the eastern western Borders, they are respectively represented by the miocene Marl series of Bou Henifia (city of Mascara) and the serravalian Marl hills. In terms of groundwater potential, only one major groundwater reservoir is present, i.e., the PQ-aquifer. The Plio-Quaternary alluviums constitute a very heterogeneous unconfined aquifer, mainly recharge by direct precipitations infiltration and to a lesser degree by four adjacent aquifers (the Limestones of Zigyne, the Llimestones of Sidi Ali Boussidi, the Pliocene Sandstones of Ténira and the Dolomite rocks and Llimestones of Sidi Ali Benyoub). From a quantitative point of view, the PQ-aquifer is one of the largest groundwater reservoirs in Algeria. Indeed, The aquifer occupies an area of approximately 800 km^2, and has a mean thickness of 80m [14]. From a qualitative stand however, the aquifer waters are continuously degraded, mostly due to anthropogenic activities.

According to Lerolle [21], the values of the vertical permeability oscillate between 5.10^{-9} m/s for the alluvial deposits and conglomerates and 8.10^{-8} m/s for the conglomerate channal (downream of Oued Tissaf). As for the permeability of the pliocene sandstones and eocene limestones, they are quite low, due to the significant presence of clay in the two formations. With respect to storage coefficients, the areas with the highest storage potential (S = 25 to 30%) are located along the rivers Mekerra-R and Tissaf, especially between around Sidi Khaled, Bedrabine, Tabia and Sidi Ali Benyoub [14].

Only two major sources are present in the study area, Aïn Mekarreg and Aïn Skhouna. According to Sourisseau's September 1972 study [22], the annual discharge of the two sources was equal to 7.8 10^6 m^3/yr. In 2007, the instant flows were 50 l/s for Aïn Skhouna and 60l/s for

Aïn Mekarreg.

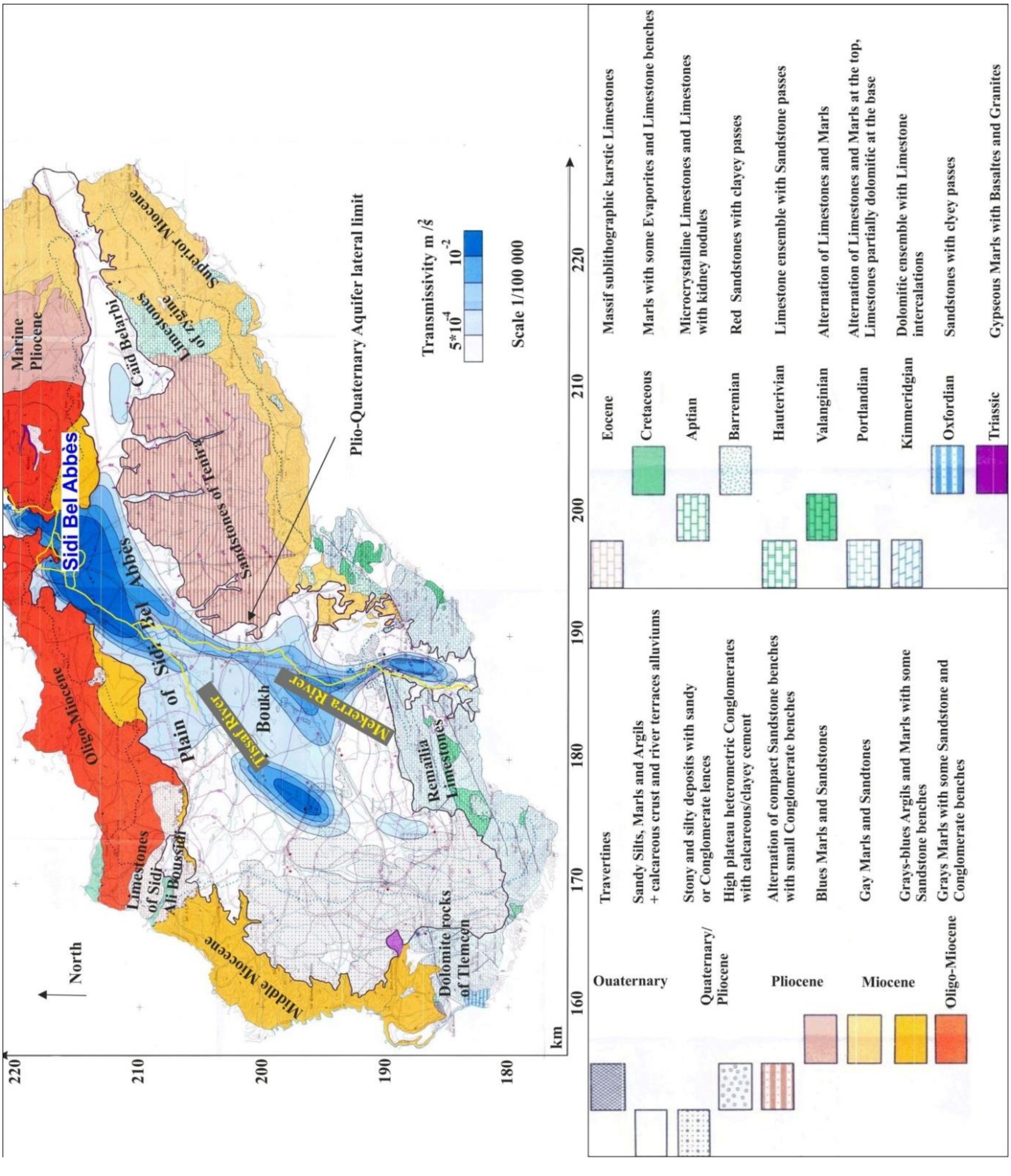

Fig.5. Hydrogeologic map of the plain of SBA [23]

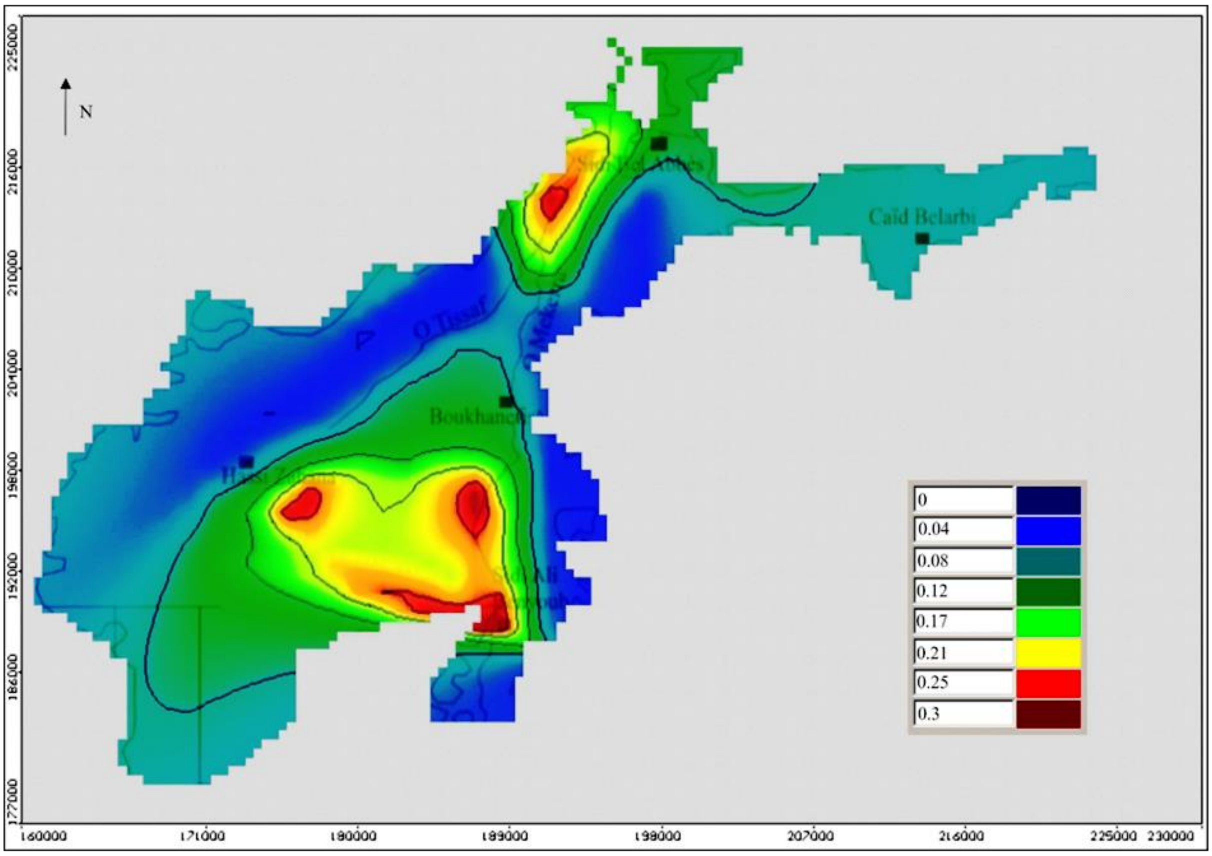

Fig.6. Storativity variation in the plain of SBA [24]

3.2.4. Anthropogenic activities

In the city of SBA, water used for irrigation and industrial purposes is exclusively derived from groundwater, whereas most of drinking water supplies come from dams and desalination stations in neighboring cities (Mascara (85km) and Tlemcen (90km)). Considerable amounts of the water volumes cited above return without treatment to the PQ-aquifer, primarily due to the deficiency of sanitization networks/treatment plants, and over irrigation. The return reaching the PQ-aquifer corresponds for drinking and industrial water to the volumes of untreated/treated wastewaters and for agriculture to the difference between irrigation water and real evapotranspiration.

We had two choices to estimate the mean annual volume of wastewater. **The first**, estimating the volume of wastewater as a ratio of domestic water. Usually, a percentage of 80% is considered. **Drinking water supplies** were estimated in 2016 [15] around 107000 m^3/d (Wilaya of SBA, 2016) for a population of roughly 680 000 inhabitants, i.e., 157 l/d/h. Thus, **the first** approach gives a wastewater volume of 31 Mm^3/yr. This demarche seems fairly unreasonable and simplistic, especially when considering the parameters conditioning the real amount of domestic water returns from one location to another (population density, time of year, rainfall rate, state of the sanitation network, type and capacity of treatment plants, soil and sub-soil characteristics, etc.). **The second** choice was to refer to the data provided by the public services concerned, i.e., the National Water Resources Agency (ANRH) and the Direction of Hydraulics (DHW) according to which, the average daily volume of wastewater (not the peak and diurnal flows which are calculated for the sizing of sanitation and treatment facilities) is equivalent to 43350 m3/d (treated: 21750 m3/d / untreated: 21600 m3/d) [15, 25]. We decided to go with the second choice because of three essential factors:

- the losses of the supply network (more than 50% leakage) which reduce the daily supply and therefore the volumes actually reaching the population and the resulting volume of wastewater.
- the disruption of the daily allowance (which is not constant throughout the year) either because of low rainfall or during the summer period (as specified in the text, the town of SBA depends on the neighboring towns for the AEP)
- the study of sanitation facilities (deficiency of the sanitation network in urban areas and its replacement by septic tanks in the countryside in addition to the poor management of wastewater treatment plants) allowed us to conclude that the volumes of water used data provided by the ANRH and the DHW better reflect the realities on the ground in comparison with the approximations that we have calculated

In order to estimate irrigation water returns in the plain of SBA, we had to calculate water volumes allocated for irrigation first, then identify crops frequently cultivated and finally estimate the mean water consumption per hectare in the plain of SBA.

According to a study conducted in 1947 (ANRH document), water volumes intended for irrigation were equal to 19.5 Mm^3/yr. They reach 24 5 Mm^3/yr according to of the BIRH inventory in 1972 and 18.6 5 Mm^3/yr in 1976 based on Lerolle' study, who attributed the difference between his assessment and that of the 1972 BIRH inventory to excessive irrigation [21, 26]. According to the ANRH, those volumes were equal to 35 Mm^3/yr in 2006. This estimate seems to be inferior to the real values observed in the field, especially after the launch of the RGAA (Recensement Général Agricole de l'Algérie) in 2001 which saw the irrigated area in the plain almost triple between 1999 and 2016 (going from 3030 to 8911 ha) and consequently so did the water volumes used [15]. Based on the available punctual data, the relatively constant growth rate of the irrigated area (around 0.8%) and assuming a linear evolution (not disturbed by potential unforeseen events), we were able to estimate the volume of water allocated to irrigation at around 50 Mm^3/yr.

Before estimating the average water consumption per hectare, we had to identify the most frequent cultures in the plain of SBA, which are : Arboriculture (Fig, Pear, apple, Apricot, Peach, Plum, Olive and vineyard), Market-garden (Green bean and pea, Artichoke, Tomato, Pepper, Potato, Garlic, Melon and Watermelon), Forage (Beetroot, Cabbage), Cereals (Wheat and corn) and Industrial (Cotton, Sugar beet and Sunflower).

The estimation of the average water demand per hectare parameter is a complicated task. It is highly tributary of culture type, soil nature, irrigation water salinity and climate regime. Unfortunately, data relating to this parameter in the study area is very scares. The only data available date back to the studies carried out by the SOGEAH, namely: the general study of agricultural irrigation and sanitation areas in Algeria (1969) and the agrology study (1970). On the other hand, all recent data mainly focuses on the evolution of the useful agricultural-irrigated area and to a lesser degree on the volume of water used for agriculture. Due to the lack of data, we were forced to use the SOGREAH data to calculate the annual estimate of the water consumption per hectare in the plain of SBA (Table 6).

Table 6. Water demand per hectare for communally cultivated crops in the plain of SBA [27]

Cultures	Vines and olive trees	Fruit	Cereals	Citrus	Vegetables	Fodder
Water demand m^3/ha	2400	4800	1600	6400	10000	5200

4. CONCLUSION

This study estimated groundwater recharge in a typical semi-arid region, using the water balance method. In addition to the natural parameters of the water cycle, the contribution of anthropogenic activities to the water balance was considered for the first time in the study area. The results reflect a clear deficit (29Mm^3/yr) between the total inflows (precipitations, underground and surface flow at the inlet, irrigation water returns, and wastewater) and outflows (actual evapotranspiration, underground and surface flows at the outlet and total withdrawals) and translate an annual negative water balance. Groundwater head decline equal on average to 0.25m/yr is not attributed only to harsh climatic conditions, but also to anthropogenic activities, specifically the unregulated withdrawals for drinking and irrigation purposes. The calculated returns from irrigation waters showed a significant decrease between 1970 and 2016 going from 11Mm^3/yr to 5Mm^3/yr, due to the adaption of modern irrigation techniques (mostly drip irrigation and sprinkler systems). The domestic water returns also registered an important decline, thanks to the extension of the sanitization network (city coverage went from 73% in 1999 to 98% in 2016) and the boost of the daily wastewater treatment capacity (15000 m^3/d in 1999 to 21750 m^3/d in 2016). On the other hand, groundwater recharge is mainly tributary of precipitations and evaporation. Precipitations rarely exceed 400mm, most of which return to the atmosphere via evapotranspiration (310mm). Consequently, high piezometric levels correspond with wet months (November to March) and low piezometric levels with dry months (April to October), indicating the rapid response of groundwater levels to precipitation events in the plain of SBA. Groundwater recharge is appreciable (17% of rainfall) due to favorable soil characteristics (permeability and infiltration) and aquifers hydrodynamic proprieties, especially along the Mekerra-R (large presence of thick and permeable horizons of coarse deposits). The surface runoff equals 8% of rainfall and is only noticeable from January to Mars (throughout the rest of the year, only wastewaters flow in the Mekerra-R). The easily usable reserve (*EUR)* fills-up from November to January where it reaches a maximum of 44mm. It is then gradually drained and completely emptied by June.

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