

# Hydrogeological Characterization and Groundwater Resources Assessment of the Chtouka Coastal Aquifer (SOUTH-WEST, Morocco)

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**Résumé :** L'aquifère côtier de Chtouka, d'une superficie de 1250 km<sup>2</sup>, se situe au Sud de la ville d'Agadir, dans le bassin du Massa. L'aquifère de Chtouka est constitué par un complexe de formations hétérogènes représentées principalement par les alluvions et les calcaires lacustres Plio-quadernaires qui reposent sur les marnes et les marnes sableuses du Miocène. Ces dernières constituent le substratum de l'aquifère Plio-quadernaire. Les eaux souterraines de la nappe de Chtouka sont destinées principalement à l'usage agricole et pour l'alimentation en eau potable des centres de Biougra et Ait-Amira et des communes rurales de la plaine. Les prélèvements moyens des eaux de la nappe sont estimés à 85 Mm<sup>3</sup>/an, durant la période 2000-2015, et dont 90% correspondent aux prélèvements par pompages agricoles. Ces prélèvements ont engendré un déstockage de 58 Mm<sup>3</sup>/an des réserves en eau de la nappe. Cette dernière est alimentée principalement par l'infiltration des eaux de pluies et en partie par la percolation des excédents des eaux d'irrigation de surface dont le mode gravitaire ne couvre que 2% du périmètre d'irrigation d'une superficie de 17260 ha. L'analyse des chroniques piézométriques, réalisée pour la série d'années 1968-2020, a mis en évidence une baisse généralisée du niveau de la nappe avec des valeurs de rabattement comprises entre 3 et 35 m. Les secteurs les plus affectés par la baisse se situent dans la moitié septentrionale où les valeurs atteignent 35m au nord-ouest, 9 m au nord autour de Biougra-Ait Amira et de l'ordre de 14m au sud. Plus à l'Est, les valeurs des rabattements cumulés enregistrés oscillent autour de 8m. Ces rabattements sont plus faibles dans la zone côtière à l'ouest et ne dépassent guère 3m. La baisse manifeste dans les secteurs nord de la nappe se rapporte à la réduction de la recharge de la nappe suite aux successions des années sèches mais principalement à l'exploitation intensive de la nappe par les pompages agricoles. Au nord-ouest, la baisse du niveau piézométrique de la nappe est modérée par la mise en eau du périmètre irrigué moderne de la grande hydraulique de Massa desservi à partir des eaux du barrage Youssef Ben Tachefine. En vue d'améliorer nos connaissances sur le fonctionnement de la nappe, nous avons réalisé une étude hydrogéologique de la nappe en vue d'identifier et évaluer ces ressources en eau, en termes de piézométrie actualisée et de nouveau bilan, qui ont été très impactés par les dernières sécheresses successives qui ont frappées la région depuis 2014. Cette évaluation actualisée de ces ressources en eau souterraines va aussi contribuer à une gestion meilleure de la nappe de Chtouka et assister le gestionnaire à la prise de bonne décision quant la planification des ressources en eau.

**Mots-clés :** Aquifère côtier de Chtouka ; Eaux souterraines ; Hydrogéologie, Piézométrie, Rabattement, bilan.

**Abstract:** The coastal aquifer of Chtouka, with an area of 1250 km<sup>2</sup>, is located south of Agadir city in the Massa basin. The Chtouka aquifer is made up of a complex of heterogeneous formations mainly represented by alluvium and Plio-Quaternary lacustrine limestones which rest on the marls and sandy marls of the Miocene, which constitutes the substratum of this aquifer. The groundwater of the Chtouka aquifer is mainly used for agricultural and drinking water supply of Biougra, Ait Amira centers, and the rural communes of the plain. The average water withdrawals from the groundwater during the period of 2000-2015 are estimated at 85 Mm<sup>3</sup>/year, of which 90% corresponds to withdrawals by agricultural pumping. These withdrawals generated 58 Mm<sup>3</sup>/year which has led to a depletion of the groundwater reserves. The aquifer reservoir is mainly supplied by the infiltration of rainwater and partly by the irrigation water percolation by gravity which covers only 2% of the irrigation perimeter with a surface area of 17260 ha. The analysis of piezometric records, carried out for the series of years 1968-2020, showed a general decrease of groundwater level with drawdown values between 3 and 35 m. The sectors most affected by this decrease are located in the northern half where values reach 35 m in the northwest, 9 m in the north around Biougra - Ait Amira, and around 14 m in the south. Further east, the recorded cumulative drawdown values oscillate around 8 m. These drawdowns are lower in the coastal zone to the west and hardly exceed 3 m. The obvious drop in the northern sectors of the study area is due to the reduction in groundwater recharge following the succession of dry years, but mainly due to the intensive exploitation of groundwater by agricultural pumping. In the northwest, the drop in the piezometric level is moderated by the impoundment of the modern irrigated perimeter of the Massa large hydraulics, served from the Youssef Ben Tachefine dam water reservoir. To improve our knowledge and our relevant understanding of this aquifer's functioning, a hydrogeological study was carried out to identify and assess these water resources, in terms of updated piezometric and new balance. Indeed, the aquifer was greatly impacted by the last successive droughts which have hit the region since 2014. This updated assessment of these groundwater resources will contribute to better management of the Chtouka aquifer and will assist the manager in making the right decision regarding water resources planning.

**1. Introduction :**

The chtouka water table is among the most important water tables in the Souss Massa region. It contributes to the drinking water supply of the town of Biougra and Ait Amira and the neighboring centers as well as the irrigation of agricultural land.

The Chtouka plain is the main greengrocer area in Morocco; it concentrates 30% of the area of early vegetables in Morocco and represents nearly 50% of total national production and provides the bulk of national exports of early vegetables. [1]

The objectives of this study are to characterize the chtouka water table, develop a database and carry out a hydrogeological study of the water table, evaluation of groundwater resources.

**2. Material and methods:**

**2.1 Situation of the Study Area:**

The coastal aquifer of Chtouka is located south of the city of Agadir, in the Massa basin. It is limited:

- ✚ West by the Atlantic Ocean, a western outlet for groundwater
- ✚ East by feed limit with the Anti Atlas ;
- ✚ To the south by the boundary with the Wadi Massa , constituting a water drainage line ;
- ✚ To the north by the hydraulic limit with the Sous water table. (Figure 1)

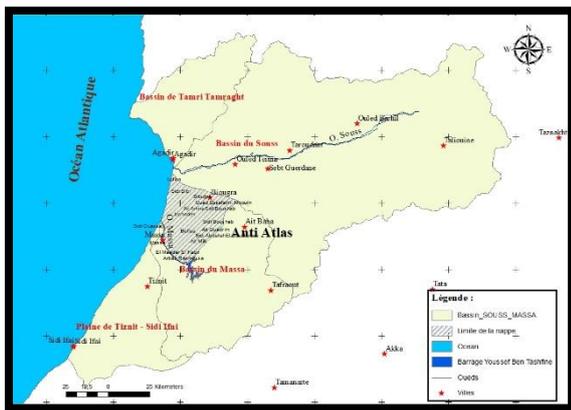


Figure 1: Location of the study area

**2.2 Hydrology**

The Massa watershed is broken down into 6 sub-basins with a total area of approximately 6,100 km<sup>2</sup>. It is drained by the Wadi Massa and its tributaries: the wadis of Amaghouz and Assaka, which both originate in the Atlantic part of the Anti-Atlas, which constitute the Major hydrographic element in the region of Massa. (Figure 2, Table 1)

The Principal wadi that drains the chtouka slick is Wadi Massa

	Sub-basin name	Area (Km <sup>2</sup> )	Perimeter (Km)	Gravel index	Equivalent length	Equivalent width (km)
<b>BV O. Massa</b>	Sfa	321.49	176.2	2.75	84.29	7.3
	Takatt	471.52	126.35	1.63	54.53	14.93
	El Maar Lakbir	149.37	72.14	1.65	31.3	8.28
<b>Mas sa Rest ant</b>	Amaghouz	142.16	178.65	1.33	68.6	31.83
	Massa	262.10	226.25	1.24	80.61	46.34
	Tazeroual	113.04	225.36	1.88	1010.55	20.06

Tableau 1: Characteristics of the Massa sub-basins [2]

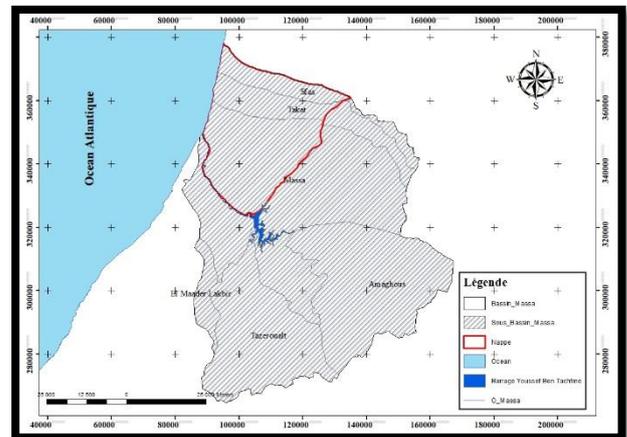


Figure 2: Location of sub-basins

**2.3 Use of groundwater**

Groundwater from the water table is used for agricultural use and to supply drinking water

**2.3.1 Agricultural use**

The Chtouka water table constitutes the main water resource for agricultural use and for supplying drinking water to the centers of Biougra , Ait Amira ,and the rural communes of the plain.

The chtouka region is endowed with significant hydro-agricultural equipment and three irrigated perimeters:

**The Modern public perimeter of Massa** with an area of 18,050 ha which is located about forty kilometers south of the city of Agadir. This perimeter was filled with water between July 1974 and December 1975. It benefits from a surface water allocation from the Youssef Ben Tachafine dam of 75 Mm<sup>3</sup>. Most of the total area (97%) is Melk land. The remaining 3% is collective land.[1]

**The Tassila and Oughzifen** perimeters with an area of 1200 ha. They benefit from a surface water allocation of 10 Mm<sup>3</sup> from the Youssef Ben Tachafine dam. [1]

**The private perimeter** of Chtouka covers an average area of 10,000 ha, mainly to the north of the public perimeter, and to the west in the buffer zone of the Massa Natural Park. The private sector, mainly in the North (Sidi Bibi, Ait Amira, Biougra) is characterized by the importance of market gardening (> 70%), in particular greenhouse market gardening. [1]

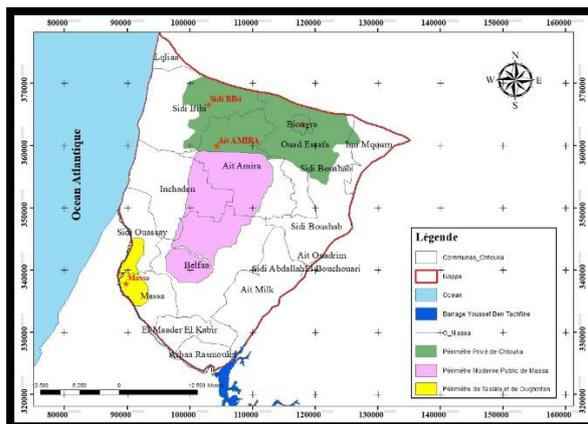


Figure 3 : Situation of the irrigation schemes of the Chtouka plain

### 2.3.2 Drinking water supply

The municipalities and centers of the Chtouka plain are supplied by wells and boreholes. The volume taken in 2011 is 2.5 Mm<sup>3</sup>. With the same rate of change observed, this volume would be 3 Mm.

### 2.4 Geology

The main aquifer is made up of dune sandstones with sandy pasts and levels of lacustrine limestone intercalated from the Upper Quaternary and Villafranchien. In the northern part of Chtouka, the following facies can be distinguished: [3]

- ✚ The Late Quaternary consists of dunes about 10-12 km wide along the coastline, and up to more than 100 m thick [3]
- ✚ The middle and lower Quaternary (Villafranchien) is made up of dune and limestone sandstones 20 to 100 m thick, containing in intercalation a level of lake limestone that can be more or less marly from 2 to 25 m thick . At the base, we find conglomerate or lacustrine deposits and sandstone formations. [3]
- ✚ The Pliocene and Miocene are represented by a formation of fluvio-lacustrine origin, made up of marly-sands, marls, and limestones. Their thickness varies from 50 to more than 500 m. In the Biougra region, this formation passes laterally towards the east to gravel and gravel with marly-sandy cement, which decreases its permeability. [3]
- ✚ The Eocene is made up of limestones and sand-clay marls.

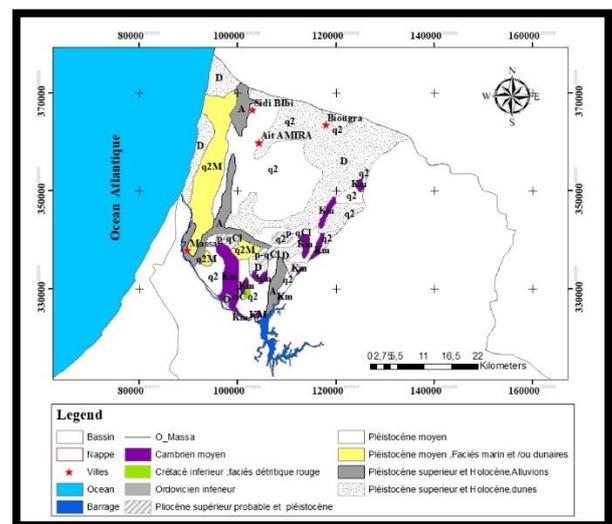


Figure 4: Geological map of the chtouka water table (Extract from the geological map of Morocco 1/100000)

### 2.5 Hydrodynamics of the chtouka study area

The hydrodynamic characteristics (permeability, transmissivity (T), and storage coefficient) are known thanks on the one hand to pumping tests provided by the Regional Directorate of Hydraulics (DRH) of the SOUSS and on the other hand, to the results of the calibration of the hydrodynamic model of the Sous aquifer.

The main results are:

#### 2.5.1 Transmissivity

At the watershed level, the transmissivity values vary from  $10^{-3}$  to  $5.10^{-2} \text{ m}^2 / \text{s}$ , and the highest values are located around Biougra. This would be linked to the formation of Plio-Quaternary deposits by poorly rolled gravel and gravel (Hydraulic Basin Agency of Souss Massa, 2006); the lowest values are in the foothills of the Anti-Atlas.

The great variability of transmissivity reflecting the heterogeneity of the aquifer

### 2.5.2 Permeability

The permeability values which are calculated from the transmissivity values and the water slices or strainer heights are generally between  $5.10^{-6}$  and  $2.10^{-3} \text{ m} / \text{s}$ . The most permeable areas are located along the Souss valley around Inezgane, then up to Ouled Teima. The areas of low permeability are located in the foothills of the Anti-Atlas.[1]

### 2.5.3 Piezometric

Analysis of the available piezometric data (maps and piezometers) shows that the water table for 40 years has suffered a chronic deficit over the entire plain. The piezometric network has evolved a lot. . It currently consists of around ten piezometers, of which 2 piezometers are located in the public irrigated perimeter.

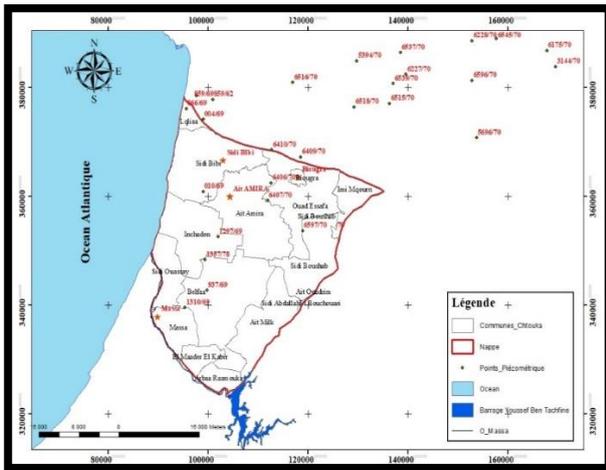


Figure 5: Piezometric Network Tracking Map

The piezometric level in the chtouka sheet has experienced a drop of around ten meters over several decades. This decrease on a reservoir of this size represents significant annual volumes.

The internal evolution of the piezometric varies differently from one sector to another.

#### Evolution of the piezometric level:

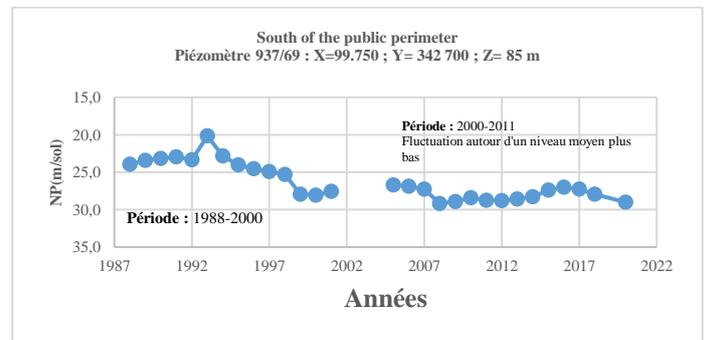
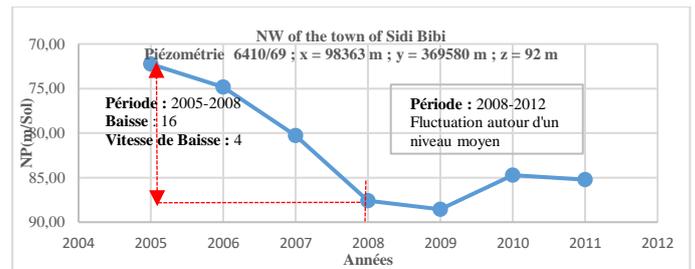
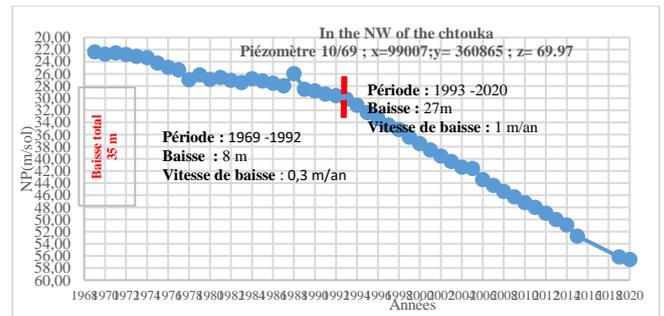
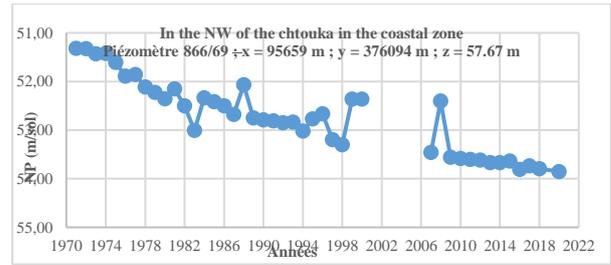


Figure 6: Piezometric history

Under the coastal zone, at the level of the piezometer at Mzar (866/69), the groundwater regime is still falling but with a low amplitude. It fell by 3 m between 1970 and 2015 but the water table has been stable since 2017.

In the northern part, the water table has been declining since 1969. The drops are of the order of 35 m between 1969 and 2020 to the west of Ait Amira (Piezometer 10/69), but the level piezometric has been stable there since 2016.

In the north-western part, at piezometer 6410/69 in the town of Sidi Bibi, the level of the water table fell by 16

m between 2005 and 2008 (4 m / year) and fluctuated around an average level on the 2008-2011 period.

South of the public perimeter of Massa, the piezometric changes step by step. Indeed, the piezometer 937/69 indicates an average level of the water table over the period 1988-2000, followed by a lower average level over the period 2000-2020. The difference between the two levels is 5 m.

Based on piezometric maps developed since the 1960s; the structure of the general flow is controlled by:

- ✚ Feeding of the water table by the edge inputs
- ✚ A central drainage axis corresponding to the Oued Souss valley;
- ✚ A watershed that separates underground flows to the Souss Oued on the one hand, and the ocean on the other.

The general direction of groundwater flow is east to the west. In the Chtouka Plain, the direction of flow to the west. In the Chtouka Plain, the direction of flow is first South-East North-West, then it tends to curve towards the West as it approaches the Ocean

### 2.6 Assessment of the Chtouka water table:

Entrées (Mm <sup>3</sup> /an)		Sorties (Mm <sup>3</sup> /an)	
Direct infiltration	17,5	Pump-off (AEPI)	7,2
Contribution of the N'sfa wadi	2		
Upward drainage	10	Pump-off (irrigation)	100
Irrigation water return	28,4	Flow to the ocean	3
Intakes by Anti Atlas abouchement	1,7	Exits by drains and sources (Oued Massa )	2,2
<b>Total Entries</b>	<b>59,6</b>	<b>Total Outputs</b>	<b>112,4</b>
<b>Bilan</b>	<b>-52,8</b>		

Tableau 2 : Assessment of the chtouka slick 2013[4]

Entrées (Mm <sup>3</sup> /an)		Sorties (Mm <sup>3</sup> /an)	
Direct infiltration	3.5	Pump-off (AEPI)	7.2
Contribution of the N'sfa wadi	2		
Upward drainage	10	Pump-off (irrigation)	78
Irrigation water return	15.7	Flow to the ocean	3
Intakes by Anti Atlas abouchement	1.7	Exits by drains and sources (Oued Massa )	2.2
<b>Total Entries</b>	<b>33</b>	<b>Total Outputs</b>	<b>90.5</b>
<b>Bilan</b>	<b>-58</b>		

Tableau 3 : Assessment of the chtouka slick 2015

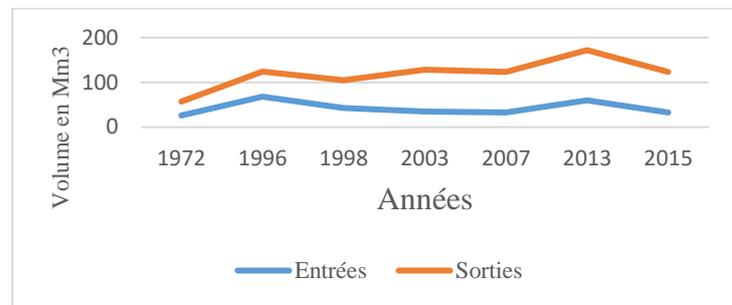


Figure 7 : Evolution of the assessment for Chtouka water table

The water balance of the water table depends, to a large extent, on the infiltration of local (on the plain) and distant (from the Anti-Atlas) precipitation, irrigation water from the Youssef Ben Tachfine dam, and upward drainage from deep water tables

The assessment of the chtouka slick for the year 2014-2015 shows a deficit of 58 Mm<sup>3</sup>, while this deficit estimated under the PDAIRE for the year 1998-1999 was only 18 Mm<sup>3</sup>. This increase in deficit can be explained by the increase in withdrawals due to the extension of the private perimeters of Chtouka Nord, the area of which increased from 2131 ha in 1998-1999 (PDAIRE) to 10,000 ha.

The aquifer withdrawals are evaluated at 85 Mm<sup>3</sup> and constitute the main outlet of the aquifer [5]

### 3. Conclusion

The open water table constitutes the main water resource of the multilayer system of the Chtouka plain. It is essentially contained in a heterogeneous Plio-quadernary filling, made up of dune sandstones, marly sands, lacustrine limestones, and poorly rolled gravel and pebbles. The hydrodynamic characteristics show variations to the heterogeneity of the reservoir.

The general direction of groundwater flow is east to west. In the Chtouka Plain, the direction of flow is first

South-East North-West, then it tends to curve towards the West as it approaches the Ocean.

The temporal evolution of the piezometric makes it possible to highlight a generalized drawdown of the water table. This is generated by the combined effect of two main factors: the rainfall deficit and the overexploitation of the water table for agricultural and domestic needs.

The evolution of the hydrogeological balance of the water table depends largely on the infiltration of local (on the plain) and distant (from the Anti-Atlas) precipitation, irrigation water from the YBT dam, and the recycling of underground waters. The groundwater balance therefore shows the predominant part of withdrawals by pumping. This balance sheet shows an annual deficit of more than 50 Mm<sup>3</sup>. With this deficit, the Chtouka water table is in a degraded quantitative state. This observed quantitative state is confirmed by an unfavorable interannual evolution of the piezometric.

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