

Deterioration of Groundwater in Arid Environments: What Impact in Oasis Dynamics? Case Study of Tafilalet, Morocco

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Abstract—Oases are complex and fragile agro-ecosystems. They have always existed in environments characterized by an arid climate, scarcity of rainfall, high temperatures and high evaporation. These palms have grown up despite the severity of the physical characteristics thanks to the water's existence and irrigation practice. The oases are generally spread along non-perennial rivers (wadis), shallow water table or deep artesian groundwater. However, the sustainability of oasis system is threatened by water scarcity and declining of water table levels particularly in arid areas. Located in the southern east area of Morocco, Tafilalet plain encompasses one of the largest palm groves in the kingdom. In recent years, this area has become increasingly threatened by water shortage and has seen a sharp deterioration under the effect of several combined anthropogenic and climatic factors. The Bayoud disease, successive years of drought, Hassan Addakhil dam construction etc are all factors that have affected both water and phoenicicole heritage of the area. The objective of this study is to understand the interaction between qualitative and quantitative degradation of groundwater resources, and the palm grove dynamics, while reviewing the assumption that groundwater resources contribute in a direct way to the conservation of this oasis agroecosystem. A historical analysis tracing both the oasis dynamics and the groundwater evolution has been established. Data were collected from satellite images, surveys with different actors (farmers, Regional Office for Agricultural Development, Basin agency...). They were complemented by a synthesis of numerous technical reports in the area. The results showed that within 40 years, the thickness of the groundwater table has dropped in 50 %. Along with this, there has been a downsizing of date palm by 50 %. Areas with higher groundwater level were the least affected by the downsizing. So we can say that the shallow groundwater contribute significantly and directly to the water supply of date palm through its root system, and largely ensures the oasis ecosystem sustainability.

Keywords—Oasis dynamics, Arid environments, Groundwater deterioration, Date palm.

I. INTRODUCTION

THE oasis is a specific landscape that characterizes arid areas. It is a complex and fragile agro-ecosystem at the same time. The structure of the oasis landscape depends mainly on the structure of desert-oasis-river components [1]. The existence of the palm grove had always been linked to the

existence of water and the practice of irrigation. They grew along streams and water tables. The presence of date palm symbolizes water in the desert [2]. Thus, the existence of palm groves depends on the sustainability of water resources and underground water potential. For many decades, oases have played a major role in the development of local economies and in maintaining ecological security. Indeed, the oasis ecosystem filled many ecological functions and provide a multitude of ecological goods, natural, economic, social services, [3].

In Morocco, the sustainability of oasis systems is increasingly threatened. During the last century, the oasis system has deteriorated markedly. From the 15 million trees which inhabited the south Atlas oases and whose majority was represented by good varieties, there remains only 4 million trees, much of which are seedlings of variable and poor quality. At the end of the 19th century, Morocco ranked third worldwide among dates producing countries and owned an international prominent portion of dates trade, thanks in particular to the quality of its harvest [4]. In less than a century, Morocco, which was known as a major exporter of date palm products, has become an importer [5]. The palm grove of Tafilalet, which is one of the largest palm groves in Morocco and considered among the largest oases in the world [6] could not escape this decline and witnessed a sharp deterioration. This degradation is caused by multiple factors interacting on each other.

In Tafilalet, natural resources degradation is affected by various factors. It is mainly caused by both natural factors and human activities, which are accentuated by the socio-economic context. These oases are under increasing pressure from human activities on natural resources already depleted by effects of long periods of drought, water shortages, 'Bayoud' disease, etc. The severity of the aforementioned factors varies from one oasis to another depending on each one's specific criteria. However, the common cause of the observed decline in all palm groves is the degradation of water resources, which is essential to the survival of these oases.

Each region has its specific water conditions. In arid areas, groundwater is the safest given the scarce rainfall and the dry climate. In Morocco, surface water that feeds oases come from mountains; thus, the scarcity of rainfall causes the decrease of surface waters. Water levels decline in rivers and impellent farmers to use groundwater [7]. Thus, we suppose it is this groundwater that contributed to the persistence of palm groves and ensured their durability until now, in spite of weather conditions severity and physical/human characteristics.

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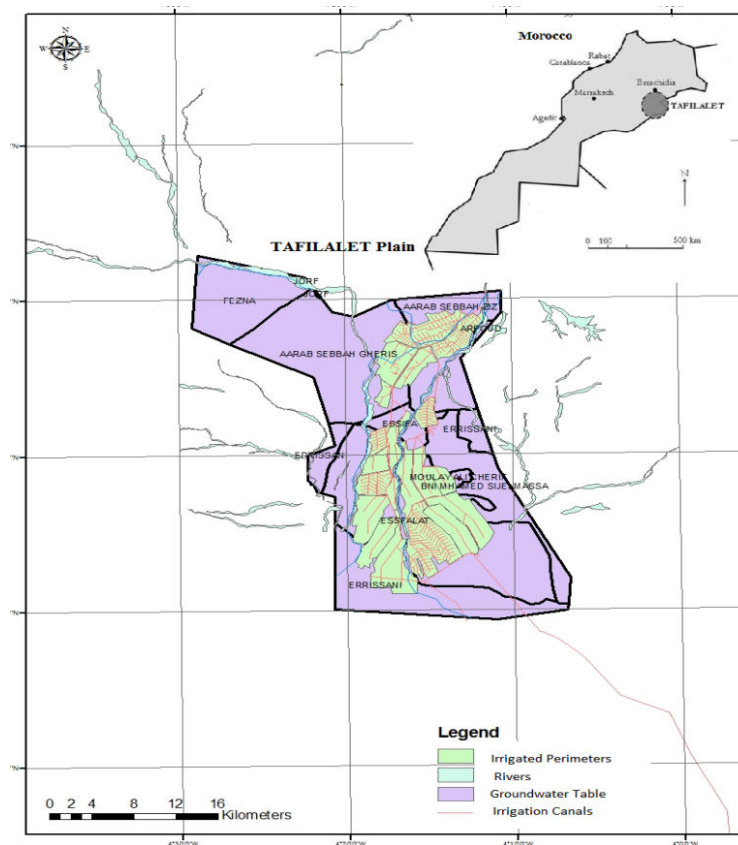


Fig. 1 Located map of Tafilalet plain and localization of groundwater table

This article aims to diagnose the state of Tafilalet palm grove. This objective is realized by making a historic track that resumes both the development of water resources, specifically groundwater resources, and the palm grove dynamics (Agricultural, hydrological, socio-cultural, etc.). It aims to contribute as well to the understanding of the various interactions between groundwater and the date palm (main symbol of the oasis system). Also, it aims to show how the shallow groundwater table has ensured the sustainability of these oases through time.

II. MATERIALS AND METHODS

A. Physical Characteristics of the Study Area

Tafilalet plain (Not to be confused with the great Tafilalet area at large) is located in the extreme south-east of the Moroccan Kingdom. It extends over an estimated area of 700 km² [8]. It is bordered to the north by the Ziz River, to the south by the lower Ziz River, to the east by the river Amerbouh and to the west by the river Ghris (Fig. 1). It is part of the UNESCO biosphere reserve and is a site of biological and ecological interest. The plain extends longitudinally between 30° and 30°31'; it is crossed by the ZIZ valley and the river Ghris to ensure irrigation of oases vegetation, and supply of water table. The cultivated area is of 21,300 ha of which 19,290 ha is irrigated. It is subject to a desert climate, strong continental influence, with very low rainfall not exceeding 85

mm, and having a great spatiotemporal irregularity. The annual rainfall regime shows the existence of two distinct rainy seasons with major floods, Autumn and Spring with a number of rainy days per year, which is very small (10 to 15 days/year). The annual average temperature is around 20°C and is characterized by very high amplitudes going up to 50°C [9]. Average potential evaporation amounts to 2,500 mm/year. However, the existence of palms creates a microclimate, which soothes the harsh climatic conditions and consequently reduces the potential evapotranspiration to 1200 mm/yr. [10]. The maximum evapotranspiration is reached in July (220 mm) and the minimum in January (12 mm) [11]. The low rainfall and potential evapotranspiration ratio requires use of irrigation (pumping, spreading floodwaters, etc.)

Tafilalet plain soils belong to the poorly developed sub-desert and alluvial soil class. Cultivated soils are of silty alluvial clay due to irrigation with flood waters for many previous centuries [12]. Salinization is widespread in the Tafilalet. The deposition of salts due to evaporation results in a higher surface salinity and a trend towards alkalization [13]. Apart from irrigated areas, soils are poorly developed because of severe weather conditions.

The Tafilalet oasis consists of a set of neighboring palm groves. The applied agricultural system includes two to three layers: date palm trees, fruit trees and surface cropping which are generally cereals, legumes, fodder and vegetables. The

number of layers depends on the availability of water. Similarly, intercropped agriculture depends on the water quality [14]. In this area, the most spread irrigation system is flood irrigation system. Dripping irrigation is practiced very little [15].

B. Characterization of Water Resources

In Tafilalet, water resources come mainly from groundwater and the contributions of major rivers. Water resources are characterized as follows:

1. Surface Water Resources

The Tafilalet plain is dominated by watershed of Ziz and Gheris. The hydrographic system is limited to two main wadis that are Ziz and Gheris that originate in the High Atlas and cross the northern region in the South. These two rivers become very close inside the plain without the convergence of their main arteries (Fig. 1). The annual pattern of the wadis is characterized by two flood periods in autumn and spring separated by two periods of low water in winter and summer. The water releases are periodically performed from Hassan Addakhil Dam. The bed of Ziz Wadi is as an adductor canal which vehicles these artificial floods to the upstream perimeter over a length of 75 km. The number of water releases is variable (1 to 3 water release per year). On average, the Tafilalet palm grove receives a volume of 123 million m³ from dam water releases and diverted water from the intermediate basins. The scarcity of rainfall in Tafilalet plain causes a low participation in the reconstruction of surface resources of water. The use of groundwater resources is essential to meet the shortfall in irrigation water.

2. Groundwater Resources

The water table of Tafilalet is the only underground water resource that supplies the Tafilalet palm grove. It has almost the same dimensions as the plain (Fig. 1). It is of paramount importance in maintaining and developing the oasis system. It is the most easily accessible water resources but also the most vulnerable to drought and pollution phenomena. It's a quaternary alluvial water table which extends over an area of 630 km² [8]. Following its location, this water table is the convergence point of the most groundwater of Ziz-Ghriss basin. This water table is considered as farmer's creation, for centuries. Farmers have created this water table by their irrigation mode, based mainly on the spreading of water's flood, so it is considered as an underground reservoir from outside water supplies to the region. It is based on an impermeable primary substratum whose depth varies between 5 and 30 m. This substratum prevents draining water by underflow [12]. Also, the presence of a rocky sill at its downstream prevents natural drainage. Quaternary geological formations which shelter the water table are very heterogeneous Quaternary geological formations that harbor the web are very heterogeneous and have highly variable degrees of permeability with a trend to decrease from upstream to downstream (permeability ranges from 10⁻⁶ m/s to 5.10⁻² m/s) [9].

C. Methodology

The methodology is based on a diachronic approach combining surveys, measurements and observation on field with an analysis of archival documents on zone. A data set was collected at institutional body (Office of Agricultural Development, Basin Agency, Center for Agricultural Work ...) and supplemented by surveys of farmers with measurements on the field on the scale of the entire palm grove. The number of farmers was to investigate is 200 farmers. The measurements were based primarily on groundwater levels in wells and water salinity. A pageant from 1954 to the present was carried out to understand the dynamics of the palm grove highlighting the major events that marked this dynamic.

III. RESULTS AND DISCUSSION

A. The Dynamics of the Oasis between 1954 and 2013

The palm grove of Tafilalet is one of the largest palm groves across Morocco. Earlier, it was considered among the wider and denser oasis in the world [6]. The vast palm grove of Tafilalet is formed by a set of surrounding palm groves. The two main palm groves are Rissani and Tizimi-Maadid-left bank of Siffa (commonly referred Tafilalet) and the small secondary palm groves are Ouled-Zohra and right bank of Siffa. There are three types of palm groves:

- Dense palm groves that are well irrigated by perennial waters (pumping, Khettara :An ancient irrigation system consisting of a tunnel dug at a very slight upward gradient into rising ground so that water from deep within the earth runs out to the surface).
- Clear palm groves regularly irrigated by flooding or dam water releases (at least one irrigation per year)
- Rainfed palm groves that are rarely irrigated by rainfall or flooding. The synthesis of existing data and data obtained from the surveys was used to trace the history of Tafilalet palm grove evolution. In 1950, the number of palm trees was nearly 1 million. In 20 years the number decreases to 700,000 of palm trees. In 1985, there were 560,000 palms trees, which presents 50 % drop in staff in less than 40 years. New extensions have settled in the region, which also explains the increase in staff from the 90s. However, the traditional palm grove continued to deteriorate. A comparison of two maps that we have realized in two different periods (1962 and 2012) clearly shows the transformation of a dense palm grove to a clearing and scattered palm grove (Fig. 2). From these maps, we observed that the high degradation is localized in the palm grove of Tafilalet itself (Rissani Area). The annual rate of degradation that we calculated at the palm grove is at 2.7%, while the plants renewal is at 0.3%. This degradation is caused by several factors. Bayoud disease presents itself as the main cause of this decline. According to [5], the Bayoud has downsized palms over two thirds. Indeed, the farmers we surveyed said that 80 % of missing palms are dead because of this disease that continues to spread throughout the area.

The scarcity of available water resources for irrigation and the succession of long drought periods are factors that have significantly contributed to this decline, whether directly or indirectly. Volumes provided by the Hassan Addakhil dam water releases remains very low and cover only 50 % of the demand in best cases (Fig. 3). Prolonged droughts have led to the partial drying of over 500,000 palm trees [16]. Water table levels significantly lowered. This has led to the drying up of wells and khetaras. The number of wells has halved (some

wells have dried up, others are abandoned). Also, a mass migration was recorded after long periods of drought since 1970 (more than 50 % of the population left to cities and abroad). This had resulted to the abandonment of several lands and also to the scarcity of labor. In addition to the above factors, there are other problems like aging plantations, salinisation, and desertification, which is very present in Tafilalet under the influence of climate variability and land human activities.



Fig. 2 Oasis density variation from 1962 to 2012

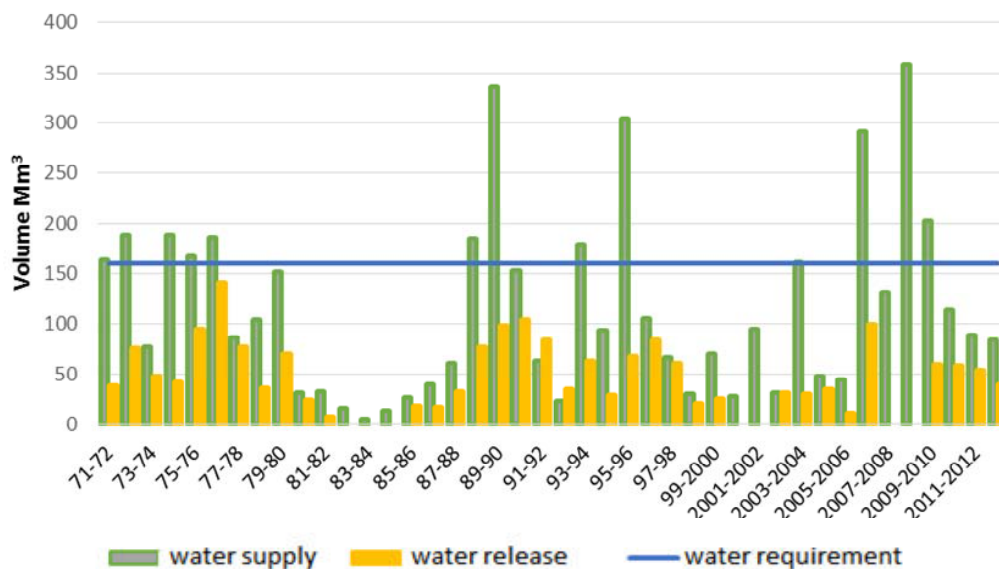


Fig. 3 Evolution of water supply and water release in Hassan Addakhil dam

B. Water Table Dynamics between 1954 and 2013

Tafilalet water table is considered the work of farmers who, for centuries, have formed by their mode of irrigation, mainly based on the spreading of flood waters, an underground reservoir from external inputs of water [17]-[8]. During our surveys, a series of piezometry measurement was carried out.

From the results, we found that the depth decreases from the center to the periphery; it reached the lowest levels in the downstream and south-east of the plain. The depths vary between 4 m and 24 m with an average depth of 13 m. During periods of maximum refill, depth ranges between 1 m and 18 m, and sometimes water table flush to the ground surface (case

of the Maadid perimeter). Water table is very salty at its greatest extent, but the concentration range is very wide and generally varies with levels of 1 to 20 g/l. At Tizimi perimeter, the water table is highly mineralized and its concentration is between 3 g/l and 5 g/l, it increases towards the northern and southern limits (up to 12g/l). Along the Ziz River, we find fresher water (1-3 g/l), related to the contribution of the sub-flow and to the infiltration of floodwaters less concentrated. The series of measurements carried out revealed salinity concentrations between 0.5 g/l and 13 g/l. Only 4 % of water in water table has a concentration of less than 2 g/l, 80 % has a concentration greater than 5 g/l, which slightly exceeds the limit of usability for irrigation. Also we found that the concentration increases from upstream to downstream. Tafilalet water table is primarily fed by the infiltrations of

surface waters spread during the irrigations (dam water releases and floods coming from the wadis of Ziz and Ghris) which constitute the 4/5 of its refill [8]. The refill by infiltration of rainwater is very weak. For discharge, it is characterized by exploitation for irrigation (pumping stations, wells, khattara ...) with low evacuations as emergencies. Evapotranspiration is the large share of output of the water table; it is almost 3/4 of the discharge [8]. The evapotranspiration coefficient is very high; this is explained by the particular conditions of Tafilalet. Losses by evapotranspiration are reflected on the one hand, by direct sampling of the roots and by evaporation from the soil surface following the process of capillary ascent of water. During its evolution, water table has gone through several landmark events that affected its dynamics.

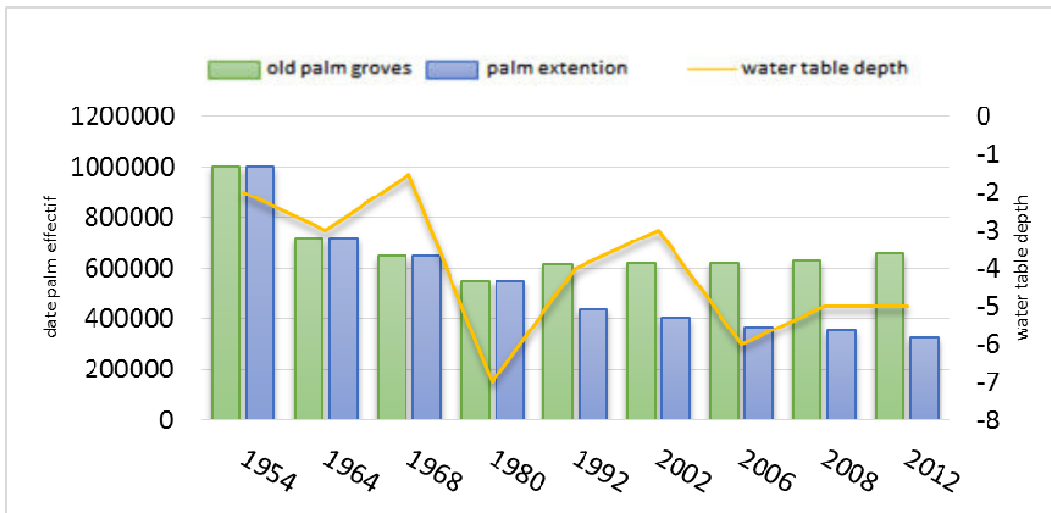


Fig. 4 Interaction between the palm grove dynamic and groundwater table evolution

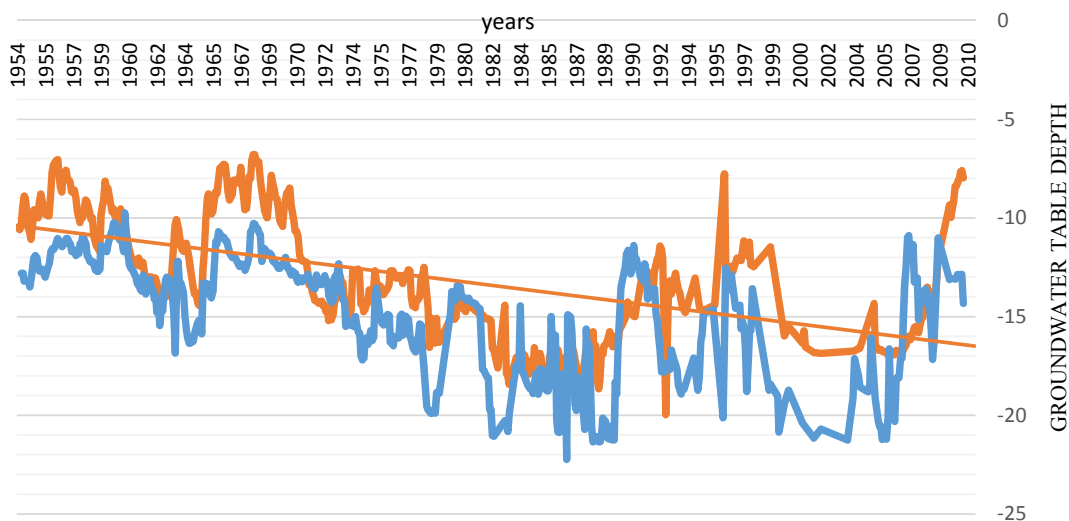


Fig. 5 Depth variation of Tafilalet groundwater table

- Before 1970, the devastating floods of 1965 have contributed to a remarkable increase in piezometric levels. Hydrogeological studies at this time highlighted a permanent state of permanent overfeeding of the water table and a gradual increase in salt concentration in water table and soil in the long term (especially in the absence a natural drainage). All these considerations have shown the need for artificial drainage in water table to remove salty water out of the plain [12].
- 1970-1980: This period witnessed the completion of the drain in 1972. Commissioning drain coincided with a cyclical drought that lasted 10 years. During this period, the pumped volume increased to compensate for the lack of water. The combination of all these factors caused a catastrophic drop in groundwater levels, which has led to the drying up of wells and several khetaras and of course a winnowing of artificial drain following complaints of farmers on the decline of their palms.
- 1980-2002: in 1980, after a drought that lasted almost 10 years, the commissioning of Hassan Addakhil dam contributed to the increase of piezometric levels. In 1985, some new extensions began to settle close by the traditional palm grove, thus creating a new dynamic in the area.
- 2002-2012: The groundwater levels fluctuated between years and contributions. In 2008, groundwater levels have increased remarkably due to heavy rainfall recorded (dam spill off for the first time). This helped in the revitalization of several wells, springs and khetaras.

Through its history, we find that Tafilalet water tables very sensitive and depends highly on climatic and hydrological conditions (Fig. 5). It witnessed a widespread dewatering, of about 2 m in the piedmont area and of 3 to 6 meters in the South. This situation has led to the drying up of wells and khetaras and directly affected the agricultural production This groundwater has been subjected to numerous pressures which caused an imbalance; not only was it affected by drought and scarcity of rainfall and therefore a limitation of the contributions, but it was also subject of high discharge either directly through pumping irrigation water, or indirectly through evapotranspiration losses. A 50 % decrease in the thickness of the groundwater was recorded between 1961 and 2006.

C. Interaction between the Groundwater Evolution and the Palm Grove Dynamics

The groundwater evolution and the palm grove dynamics are bound by a close relationship, which can have ping-pong effect (Fig. 4). Any change in the groundwater induces a change in the palm grove affecting in its turn the groundwater. This led us to a multitude of causal interactions. Scarcity and sometimes lack of perennial water in the plain makes usage of groundwater a primary necessity. Tafilalet groundwater is considered as the water resource base, and even the most reliable to ensure irrigation water throughout the oasis (For example, Hassan Addakhil dam restitutions do not even cover

50 % of the palm grove needs). It provides direct supply to the palm grove not only through the various extraction methods (pumping khetaras ...), but also through their well-developed root system. During drought consecutive long periods, and in addition to the Bayoud disease disaster, thousands of palm trees have survived thanks to the presence of the groundwater.

Indeed, in dry conditions, such as the case of Tafilalet, groundwater can contribute from 60 % to 70 % of crops needs of water [18]. This was confirmed by farmers, who ensured drought does not kill the palm trees, and thanks to their root system, the palm can fetch water from water table in considerable depths. This is what has been observed in a plot of palms which has never been irrigated, and which water table was 13 m deep. Therefore, we can say that water table has clearly contributed to the maintenance and sustainability of oasis system. This confirms what reference [19] said on the fact that groundwater resources have contributed significantly to the economic development and population growth. However, the saline nature of this groundwater hampers any development and hinders the rehabilitation of the palm grove. Indeed, the salinity does not encourage farmers to plant new palms, as young plants cannot tolerate very high salinity. In addition, this problem affects farmlands and reduces their fertility, which leads to a subsequent increase in the area of bare land. Therefore, groundwater levels will drop and salinity will increase following the aggravation of evaporation, which has a significant share in all direct water discharge process. This will consequently affect the palm grove development and drag us into a vicious circle.

IV. CONCLUSION

Groundwater is the basic resource for survival in arid areas. This invisible resource is not only a resource that provides water for irrigation. It's also a resource that feeds directly the date palm, symbol of oasis system. As a result, the sustainability of this system depends entirely on the groundwater resources. However, water tables are subjected to global, local and regional drastic changes. In recent years, the balance between supply and demand for water has become more difficult. Indeed, in response to climate change affecting the region, the extracted water volumes are constantly increasing. This resulted in lower water levels and higher concentrations of salt along with high rates of evaporation. The new extension dynamics of the oasis and the government vision for the development on phoenicicol sector raises higher demands opposite to a threatened, very limited and very sensitive resource to any change in the physical or social order. This requires a review of adopted policies by integrating a global vision that takes into account all the components of the oasis system and more specifically the groundwater resource as the first factor of production.

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