A high measurement frequency based assessment of shallow groundwater fluctuations in Metouia Oasis, South Tunisia

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Abstract:

The Metouia Oasis (South Tunisia) is increasingly being impacted by high soil salinity, leading to yield losses and ultimately to farmland abandon. In this area shallow groundwater rise is considered the major factor responsible for salt accumulation in soils. However, limited data exist on groundwater fluctuations in Metouia Oasis, despite the criticality of such information for accurate soil salinity assessment. In this study, groundwater behavior was monitored at a high measurement frequency. An observation well was installed and equipped with a water level sensor (Diver DI240, Van Essen Instrument) to record the groundwater fluctuation at 30 minute intervals. The results showed that at seasonal basis, groundwater was characterized by a declining phase during spring and summer seasons followed by a rising phase starting from mid-October. Further, the hydrograph was characterized by several rapid water table rises following recharge events followed by extended periods of water table decline. The hourly observations at daily basis displayed strong evidence of diurnal effects on groundwater patterns. The results from this study suggest that consideration should be given to monitoring water table behavior in Metouia Oasis more frequently in order to capture daily and seasonal patterns.

KEYWORDS shallow groundwater; high frequency monitoring; seasonal; diurnal; Metouia Oasis

INTRODUCTION

An oasis can be defined as an agrarian system; an area where irrigation is necessary and the farming system is highly productive, with the omnipresence of date palm (FAO, 2003). In Tunisia, oases are located in the south and are divided mainly into three categories: continental, littoral and mountainous oases. A common feature between these three categories is that the vegetation is composed of three main layers: palm trees, fruit trees and herbaceous plants. This vegetation has produced a microclimate that contrasts sharply with the harsh climatic conditions of the arid and semi-arid environment in South Tunisia (Selmi et al., 2003). Apart from their agricultural role, these oases have ecological, economic, social, political and strategic dimensions. The oasis ecosystem, however, is fragile and encounters several threats. Among them, soil salinization has become a dominant feature in most Tunisian oases (Marlet et al., 2007). Indeed, the majority of southern Oases in Tunisia encounter a problem of shallow groundwater rise and soil salinization (Ben Aissa et al., 2004). This for instance the case in Metouia Oasis, the subject of the present study, where irrigation practices associated with a poor drainage system has lead to rising shallow and saline groundwater resulting in soil surface salt accumulation. Hatira et al. (2007) conducted a four-year monitoring program (2001–2004) in Metouia Oasis concerning irrigation water and groundwater quality, salinization of soils and drainage efficacy. They concluded that one of the keys of oasis sustainability is better control of shallow groundwater fluctuations. However, despite the importance of water table depth in controlling soil salinity dynamics (Wang et al., 2008), no detailed monitoring of water table fluctuations in Metouia Oasis has been reported. Most studies and projects have monitored water table behavior on a periodic frequency, with manual measurements taken on a monthly basis and are limited to a short duration defined by the length of the project. Thus, a limited basis for estimating the probable short (seasonal), intermediate (several years), and long-term fluctuations in ground-water levels in Metouia Oasis exists. The research presented here focused on the temporal variations of groundwater level fluctuations based on time series analysis but is part of a wider investigation activity aiming at understanding and analyzing causes and effects of the soil salinization problem in Metouia Oasis.

In this study, detailed data of shallow groundwater fluctuations in Metouia Oasis were obtained using high-resolution water table monitoring. The goals of this project were to: (i) observe and analyze patterns of seasonal and daily water table fluctuations that are driven by groundwater recharge and discharge processes, (ii) explore groundwater responses to diurnal variations (iii) provide a more detailed record of shallow groundwater fluctuation in Metouia Oasis than is typical.

MATERIALS AND METHODS

Overview of the study area

The Metouia Oasis (33°58’00.12”N-10°00’02.55”E) with an area of approximately 266 ha is located in the North part of the Governorate of Gabes (South East Tunisia) (Figure 1). The climate is predominantly arid with a dry season during June–August. There is no season for rain. In fact, over the years, precipitation shows a very erratic pattern in which relatively moist years of more than 300 mm alternate with dry years of less than 150 mm of annual rainfall. Rain occurs only rarely during the dry season. The standard

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precipitation index, SPI (McKee et al., 1993), calculated for the historical rainfall period between 1971 and 2008 was used to assess long-term climatic variability in Metouia Oasis. The predominance of negative values of SPI throughout the rainfall period 1971–2008 shows that drought conditions are dominant features of the oasis climate. During the year 2009, total rainfall measured in Metouia Oasis (147 mm) was similar to the long-term average (146 mm) and suggests that climate conditions during this study (conducted from March to November 2009) were representative of typical Metouia Oasis conditions. Figure 2 depicts the monthly variations in air temperature and pan evaporation measured during the year 2009 at Gabes station (12 km from Metouia Oasis) and shows significant parallel changes characterized by a decreasing trend from September to January followed by an increasing trend starting from January.

The soils in Metouia Oasis are gypsiferous and saline with sandy texture. One of the main features of the soil profile is the omnipresence of gypsum in most of its forms. The depth of the gypsum crust varies between 0 and 4 m (Hatira et al., 2007). The soil features are presently dominated by salt accumulation, water logging and gypsum accumulation processes affecting the soil profile either totally or partially. Soil salinization in Metouia Oasis is a result of upward movement and evapoconcentration of soluble salts present in the shallow groundwater (Hatira et al., 2005). The average water table depth is about 1.5 m and the groundwater flow direction is from northwest and southwest toward the east. The farming system is composed of the three traditional distinct layers of date palm trees (Phoenix dactylifera), fruit trees and fodder crops. The water for irrigation comes from 4 wells. The EC of this water is between 4 and 5 mS/cm and the pH is almost 7.6 (Hatira et al., 2007). The irrigation management within Metouia Oasis is based on water allocation. The irrigation network operates on rotation delivery, and flood irrigation is the main irrigation method practiced by farmers.

The observation site is located in the eastern part of Metouia Oasis bordered by three farmlands to the north, south and west sides and by a drainage canal to the east. Being in the lowest part of the oasis the site is prone to receiving most of the shallow groundwater flow. When we first visited the site, it was an abandoned farmland invaded by salt-tolerant weeds with visible salt accumulation at the soil surface. The site remained at this state until October 2009. From this date the farmer decided to use it for crop production (mainly barley). Accordingly, the site received two irrigations: the first at the end of October 2009 and the second on November 12, 2009.

**Shallow groundwater monitoring system**

Water table depths (z) were measured using a water level sensor (Diver DI240, Van Essen Instrument) in a 2.2 m hand-augured well installed in the monitored site. The water level sensor has an accuracy of ±0.1% at operating temperature and a long-term stability of ±1 cm. It determines the height of a water column by measuring the water pressure with the built-in pressure sensor. Below the water surface the pressure of water is added. Since the air pressure variations for Metouia Oasis covering the whole study period were not available we used those measured in Dhraa Tamar area (Middle West Tunisia) having quite similar behavior. A barometer (Baro-Diver, Van Essen Instrument) was used to measure the air pressure variations. This device also allows air temperature measurements which are used to auto-compensate the pressure sensor measurements for temperature influences. Based on the measured pressure, the height of the water column above the Diver’s pressure sensor was determined. The compensated values were related to soil surface considered as reference level. Water levels in the observation well were monitored at 30 min intervals for a period of 250 days from March 10, 2009 till November 13 of the same year. A total of 11892 water level readings were obtained.

**RESULTS AND DISCUSSION**

Figure 3 shows the groundwater fluctuations in Metouia Oasis within the monitoring period (March through November, 2009). It can be seen that over the whole study period the water table fluctuated in a range from 0.56 m (4/19/09) to 1.58 m (10/16/09) below the soil surface. We identify two different phases of short-term seasonal groundwater-level fluctuations. The first is a declining phase of the groundwater level which was observed between March and mid-October 2009 controlled mostly by the increase of the
water uptakes by soil evaporation and crop transpiration during spring and summer seasons. The second phase had an upward trend which began from 16 October 2009 corresponding to the start of fall and winter seasons. In fact, these seasonal variations of groundwater level coincide with the seasonal course of air temperature and pan evaporation as shown in Figure 2. A similar trend of shallow groundwater fluctuation in Metouia Oasis was observed in several other Tunisian oases (e.g. Ben Aissa et al., 2004; Askri et al., 2010). For instance, Askri et al. (2010) monitored groundwater fluctuation in Segdoud Oasis (South West Tunisia) and reported that at seasonal basis the hydrographs showed two different phases (declining and inclining) induced by climatic conditions.

A more detailed analysis of water table variations in Metouia Oasis throughout the monitoring period reveals that the water table fluctuation pattern was characterized by frequent rapid rises (e.g. 60 cm rise on 4/18/09, 56 cm rise on 8/8/09) in response to water input. The water table followed a triangular fluctuation characterized by a rapid water table rise followed by a slower rate of decline. Such behavior is in agreement with that observed in Fatnassa Oasis in South Tunisia where several groundwater peaks were detected and were attributed to the intense irrigation in upstream palm plantation (Askri et al., 2010). In our observation site, at least 15 major recharge events were observed, corresponding to: (i) three major rainfall periods occurring in April (10 mm), May (7 mm) and September (37 mm), (ii) the inflow from the surrounding intensively irrigated areas (irrigation is occurring daily in Metouia Oasis) and (iii) the two onsite irrigation events in October and November 2009. Following these recharge events the water table responded relatively quickly to water input. The rate of water table rise ranged between 0.0005 mm s\(^{-1}\) and 0.3 mm s\(^{-1}\) throughout the monitoring period. Furthermore, the onsite irrigation at the end of October 2009 gave the largest water table rise with speed in excess of 0.3 mm s\(^{-1}\). Such disproportionate rise was observed by many researchers in a variety of shallow groundwater systems (e.g. O’Brien, 1982; Abdul and Gillham, 1984; Cartwright et al., 2006). They showed that shallow water tables can often rise disproportionately compared to the volume of infiltrated water. This rise has been attributed by numerous researchers to one of two major phenomena. The first, known as the Lisse effect, occurs when infiltration caused by intense rain seals the surface soil layer to airflow, trapping and compressing air under pressure in the unsaturated zone (Helfots and DeWitt, 1987; Weeks, 2002). The second is the reverse Wieringermeer effect (RWE) dealing with the case where the capillary fringe extends from the water table almost to the ground surface leading to a limited or no storage capacity in the zone between water table and soil surface as well as a specific yield approaching zero value. In these conditions the pores within the capillary fringe are saturated and the addition of a very small amount of water relieves the tensions in the capillaries resulting in a rapid and high water table rise to the land surface (Gillham, 1984; Novakowski and Gillham, 1988; Horn, 2006). Overall, the groundwater fluctuation in Metouia Oasis shown in Figure 2 is more consistent with the reverse Wieringermeer effect. The water table rise was not only observed during rainfall but also during water inflow from surrounding irrigated area. In this condition the occurrence of an advancing infiltration front (a major condition for Lisse effect occurrence) is unlikely. Nevertheless, it is worth noting that further investigations especially concerning continuous soil moisture monitoring between water table and soil surface are needed to confirm the occurrence of RWE in Metouia Oasis.

Given that the saline shallow groundwater in Metouia Oasis is a major contributor to soil salinization (Hatira et al., 2007), monitoring groundwater levels is therefore a reasonable and practical way of assessing changes in salinity risks. Since the groundwater is highly dynamic, a series of frequent measurements taken regularly is needed and will allow a more effective salinity risk assessment and provide technical advices on oasis management. A single measurement taken once a month (the monitoring method often used by the responsible services) will show only the groundwater depth at that point in time and would underestimate the depth reached by water table. Consequently, this will lead to an underestimation of salinity risk. Furthermore, the frequency of major groundwater peaks during our monitoring period was about 17 days on average. Accordingly, we suggest that if daily monitoring is not possible, the interval between measurements should not exceed two weeks. Also, measurement of water table level

![Graph](image_url)

Figure 3. Observed shallow groundwater fluctuations in Metouia Oasis from March to November 2009. Water table levels were recorded at 30 min intervals.
is highly recommended after rainfall or irrigation events.

In order to elucidate the diurnal groundwater fluctuation in Metouia Oasis, water table fluctuations were examined in detail by evaluating hourly water table behavior on a daily basis. The difference between water level measurements taken each hour was calculated and then averaged across the monitoring period to determine the hourly water table change in each month (Figure 4). Because the shallow water table responded rapidly to recharge events, a brief period following intense recharge periods was not considered in the analysis. It can be seen in Figure 4 that the hourly changes in water table levels showed an evident diurnal variation throughout the day. In general, the daily water level patterns were characterized throughout the study period by an upward trend from about 0:00 to 7:00, then a decline from about 7:00 to 16~17:00 and lastly an upward trend from about 18:00 to 23:00. This pattern coincides with the daily course of air temperature variations as shown in Figure 4. Accordingly, because actual evapotranspiration is related to air temperature (Weiß and Menzel, 2008) it can be inferred that the diurnal variations of shallow groundwater levels in Metouia Oasis were mainly induced by evapotranspiration (ET) effect. In this context Hatira et al. (2005) reported that the shallow groundwater in Metouia Oasis is subject to high evapotranspiration. This situation is consistent with that observed by Shilling and Kiniry (2007) who reported similar behavior of shallow groundwater in the Walnut Creek watershed, Iowa, USA. Moreover, the comparison between daytime (12:00 to 18:00) and nighttime (0:00 to 6:00) water table signals in Metouia Oasis revealed, as expected, a downward trend during daytime induced by the high evaporative demand and an upward trend during nighttime when less evapotranspiration is occurring. This pattern is comparable to other shallow groundwater environments where the diurnal cycle was directly linked with evapotranspiration as the plants try to meet their water demands from the soil moisture or directly from the groundwater via their root systems (Gribovszki et al., 2010). Table I summarizes the rate of water table changes during daytime and nighttime in Metouia Oasis. The groundwater level rose during nighttime with a maximum rate of 1.7 mm h\(^{-1}\) in June and a minimum rate of 0.5 mm h\(^{-1}\) in March. The rate of groundwater decline during the day ranged between a maximum of 2.1 mm h\(^{-1}\) in July and a minimum of 0.9 mm h\(^{-1}\) during August. Nonetheless, although the daily groundwater fluctuation in Metouia Oasis showed a clear diurnal variation, some deviations from this general pattern could be observed (Figure 4). These fluctuations were likely triggered by anthropogenic activities (mainly irrigation) in the neighboring areas close to the observation site. During these periods natural effects were masked by artificially induced ones.
CONCLUSION

Intensive sampling of short-term fluctuations of shallow groundwater in Metouia Oasis was conducted over a period of 250 days. The analysis of the groundwater hydrograph shows a dynamic groundwater level fluctuation which was the consequence of climatic conditions as well as several hydrological processes taking place in the observation site and in the surrounding areas. The groundwater fluctuation pattern was characterized by a declining phase and a rising one with frequent rapid rises within each of the two phases. Additionally, the investigation of hourly changes in water table levels at daily basis showed that groundwater level followed a diurnal variation characterized by a downward trend during daytime and an upward trend, with lesser magnitude, during nighttime.

Our data document detailed groundwater monitoring in Metouia Oasis at an hourly, daily and seasonal basis. These results may contribute to improve current environmental assessment studies and projects in the oasis which are often based on groundwater monitoring at monthly basis. Such frequency may not capture the dynamics and the magnitude of water table fluctuations and consequently may lead to an underestimation of soil salinization risk induced by saline shallow groundwater.

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