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A Conceptual Hydrologic Model for Studies of Salinisation in Tunisian Oases

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Abstract: In Tunisian modern oases, secondary salination of irrigated lands is a crucial problem. The visible salt deposits and soil salination processes are the consequence of several factors including the excessive use of saline irrigation water, seepage from earthen canal systems, inefficient irrigation practices and inadequate drainage. Understanding the mechanism of secondary salination is of interest in order to maintain existing oases and thus ensure the sustainability of date production in this part of the country. Therefore, a conceptual, daily, semi-distributed hydrologic model (OASIS_MOD) was developed to analyse the impact of irrigation management on the water table fluctuation, soil salinity and drain discharge and to evaluate measures to control salinity within an oasis ecosystem. The basic processes incorporated in the model are irrigation, infiltration, percolation to the shallow groundwater, soil evaporation, crop transpiration, groundwater flow, capillary rise flux and drain outflow. A 6 year simulation was developed at a 1.5 ha parcel of farmland and using filed measurement of main soil hydraulic properties. The obtained results showed that the cropped soil salinity and water table elevation have three types of variability in time: a daily variability due to irrigation practices, seasonal fluctuation due to climatic conditions and annually variability explained by the increase of cultivated areas. The irrigation interval was found to be important with irrigating once each ten days leading to soil salinity increase during the dry summer season and to a rising water table during the autumn-winter period. The annually increase of the irrigated area caused a decrease of the irrigation water depths and thus an augmentation of the soil and groundwater salinities. The surface area affected by a soil salinity concentration above 15 g/L has increased from 2 % of the study parcel area in June 1992 to about 50 % four years later due to the abandonment of several cultivated basins.

Key words: Oasis • Soil • Water table • Salinity conceptual model

INTRODUCTION

The southern domain of Tunisia extends from the low plains situated south of Gafsa Mountains up to the Sahara boundaries [1]. In this arid zone, oasis agriculture using spring water has been performed since ancient times [2]. The traditional oasis is an ecosystem with particular properties [3]. Typically, several crops such date palms, fruit trees and market gardening are supported on the same field. The cultivation of these three levels together makes a microclimate, commonly called "oasis microclimate". For many centuries, oases were used by authorities to stabilise indigenous semi-nomadic people in areas where water is scarce [4]. A change of the agricultural policies in Tunisia took place in the 1960s creating an intensive modern agriculture in the southern part of the country, in order to maximise the production and the exportation of dates and to promote economic development [5]. The exploitation of two deep groundwater aquifers and the use of water for irrigation have allowed the creation of a new type of oases with new irrigated schemas. Irrigation water allocation, equipment renovation and infrastructure implementation were sponsored by the State to encourage farm development. However, the dry climate and the lack of irrigation knowledge by young farmers induced an excessive use of saline irrigation water. As soils are predominantly sandy and drainage is almost non-existent, the intense irrigation has led to the creation of a perched and saline water table. The shallow groundwater has contributed to salt accumulation through capillary rise and has resulted in the accumulation of salts at the soil surface. Degradation of soil had strong negative impacts on the growth and vigour of palms, resulting in a decrease of date yield and

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deterioration of date quality. As a solution, since 1990 the Tunisian government has started encouraging farmers to replace the earthen irrigation canals with PVC pipes, subsidising 40% to 60% of the total investment. This policy focused on the importance to water saving. Therefore, in 2001, a project called "Amelioration of Irrigated Areas in South Oases (APIOS)" was initiated to install concrete canals for irrigation and subsurface drainage system, the objectives being to improve irrigation frequency, to increase water productivity and to save water resources since they are limited [6]. In order to prevent continuing soil salination within modern Tunisian oases and thus degradation of date production, it is necessary to clarify the mechanism of secondary salination in relation to water management including irrigation and drainage.

Numerical models play an important role in the studies of land salination in areas with irrigation and drainage system [7]. In particular, they help to understand hydrological processes and to derive strategies for salinity control. OASIS_MOD is a conceptual, daily, semi-distributed hydrologic model. It has been developed to predict the daily soil salinity, water table elevation and drain discharge within Tunisian modern oases given the daily irrigation water depth and salinity concentration, rainfall and reference evapotranspiration [8]. The model calibration and validation were carried out at the parcel scale (1.5 ha) because problems related to irrigation management in the oasis scale are very complex with water distribution to parcels being unequal [8].

In this paper, the same conceptual model framework will be used to investigate the possibility of improving irrigation management on the basis of long-term predictions of the impact of irrigation practices on water table fluctuation, soil salinity and drain discharge within the *Segdoud* oasis.

MATERIALS AND METHODS

Experimental Area: *Segdoud* is a modern oasis (new irrigated schemas) located 30 km north-east of *Tozeur* in the southwest of Tunisia (34°14' N; 8°10' E). It is delimited in the north by an urbanised area (*Segdoud* village) and in the south by small dry lake called Sebkha *El Hanek*. The farming system is composed mainly of date palm trees (*Phoenix dactylifera*). Some fruit trees, such as pomegranate, olive and apricot are cultivated inside the earthen irrigation channels. Occasionally, farms cultivate gardening crops in the same field with date palm to satisfy their food needs. The source of irrigation in the oasis is the Continental Intercalary aquifer (CI). This unconfined groundwater is formed by three sub-aquifers, lying between 1,000-2,000 m in depth. Nowadays, the exploitation of the CI aquifer in the *Segdoud* region attains 1.48 Mm^3year^{-1} that represents only 31% of its potential estimated at about 4.73 Mm^3year^{-1}. Soils are classified poorly evolved alluvial soils. They are deep (>1.5 m) and have sandy texture [9]. Organic matter can barely exceed 1%. Gypsum accumulations could be present at medium depths of 40-60 cm and gypsum borne crust is present everywhere at different depths. These soils are in general not suitable to young plantation if soil depth is smaller than 80 cm and if a crust layer or gypsum crusting is present close to the surface (< 40 cm) [10]. *Segdoud* oasis belongs to the superior bioclimatic Saharan story with a temperate winter and a continental climate. The annual mean temperature is about 21.6°C, while the absolute extreme temperatures are 44°C in August and 2.5°C in January [11]. The pluviometric regime is low and irregular; the annual rainfall average is about 96 mm per year. The potential evapotranspiration measured inside Tozeur oasis is about 1643 mm per year [12].

Irrigation and Subsurface Drainage: *Segdoud* oasis covers about 160 ha; it is divided into 107 parcels of farmland. The parcel is a rectangular area of land, typically 150 m long and 100 m wide. For the palm grove, all the date palms have nearly the same age and have the same degree of pruning. The mean height and diameter of their trunk are, respectively, about 3 and 0.50 m, with a density of 100 palms ha^{-1} and spacing close to 10 m (Fig. 2). The irrigation system includes a series of small level basins (3×3 m, 4×4 m or 5×5 m) within parcels. Water fills one basin and then overflows to other basins in the field. Small ground channels called *suqyyus* within the parcel also help distribute water to basins. As a result of sequentially basin filling, irrigation is probably inefficient and non-uniform. The ground cover around basins is un-cropped and farmers increase annually the basins area into the surrounding area in response to the development of the palm root system.

In the oasis, irrigation follows the traditional flooding practice. This method, delivering abundant amounts of irrigation water, is not well suited for sandy soil. It induces seepage to the groundwater and a high spatial variability of the irrigation inflow from the head of the *suqyyu* to the tail [11].

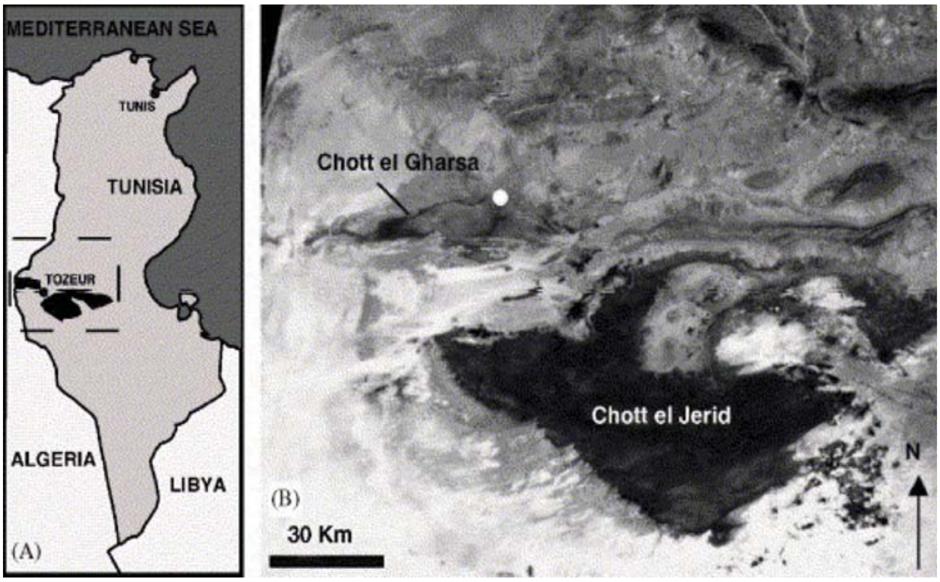

Fig. 1: Geographical location of the *Segdoud* oasis

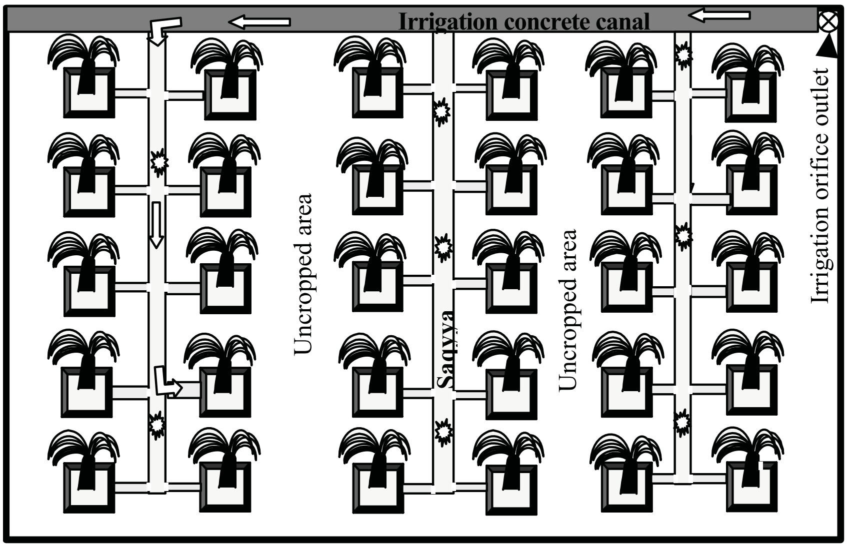

Fig. 2: Topology of irrigation system in the parcel scal

Irrigation started in the oasis in July 1989 and the total cropped area had increased from 10 ha at that time to about 20 ha in May 1995. In 1995, irrigation water was supplied by two deep wells, *Segdoud* CT2 and CT3, screened in the CI aquifer which deliver 36 and 40 L/s respectively. The electric conductivity of groundwater is 6.4 and 4 dS/m respectively. Water from the two wells is mixed in a water tower, then distributed between the eight sectors of the oasis. Irrigation water was sent to the basins through eight pipes, hydrants, concrete and earthen canals. Before 1998, the irrigation water was free of charge and the Tunisian Ministry of Agriculture subsidised 100 % of the total charge. According to the irrigation schedule, the 107 parcels were grouped in seven classes. Each class, including about sixteen parcels, was irrigated during the day. Four parcels belonging to four sectors are irrigated simultaneously and the parcel received an irrigation water discharge ranging from 20 to 30 L s^{-1}. Irrigation water was delivered according to the traditional 'rule of water tern'. The irrigation duration was fixed to 3.3 hours of water per hectare every 7 days in spring and summer seasons and every 15 days

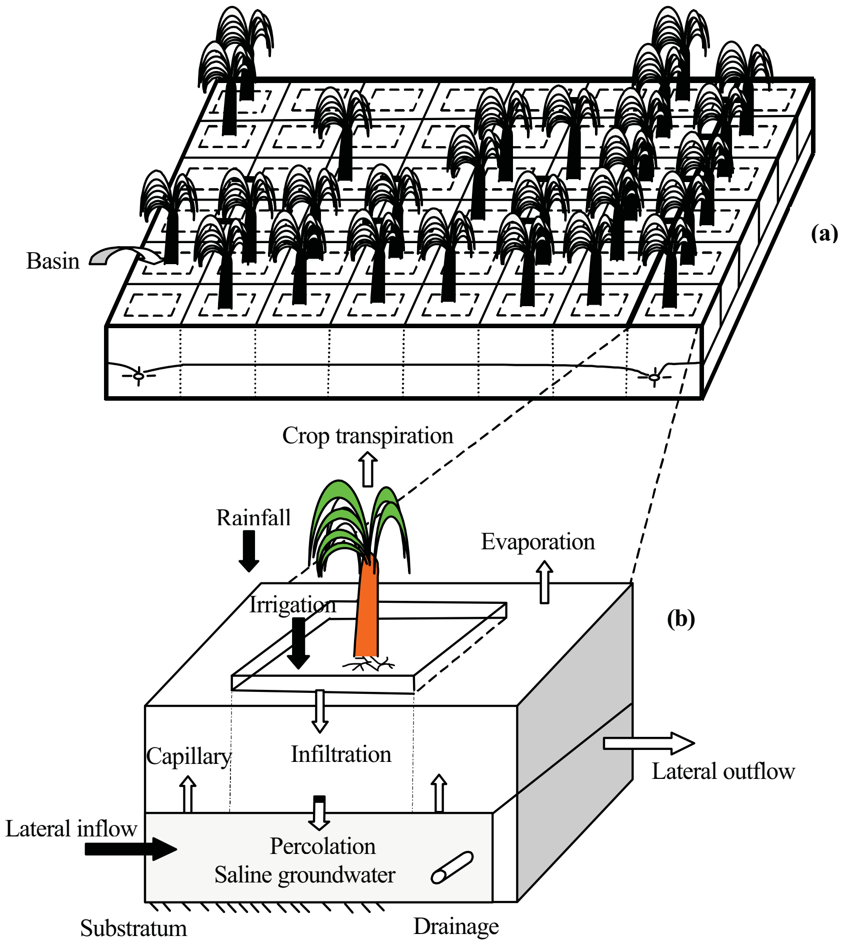

Fig. 3: Schematic representation of OASIS_MOD model structure. (a) Discretisation of the model domain into cultivated units CU. (b) Processes simulated in a single CU [8].

in autumn and winter seasons. The annual irrigation water requirement for *Deglet Nour* date palm at *Tozeur* was estimated at 2365 mm with a maximum of 241 mm in July and August. As the capacity of the irrigation system was estimated at 744 mm, this system cannot cover estimated crop water requirements mainly during the summer season.

The intense irrigation and the poor drainage condition in the oasis have led to a rising water table, mainly during the monsoon months (January, February and March). In March 1995, the average water-table depth was 0.9 m over about half of the area and can be quite shallow during winter in the lower part of the oasis. Drainage was therefore required to ensure that the high saline water table does not encroach into the root zone being initially accomplished by open-ditches. Since 1994, this system was replaced by collectors and tile drains buried a depth of 1.5 m with 100 m spacing. The drainage collectors end in the Sebkha *El Hanek*.

Conceptualisation of Hydrological Processes: Tunisian modern oases are typically highly heterogeneous, with several crop levels, various soil types, a range of irrigation schemas and different drainage systems [13]. The oasis ecosystem is divided into parcels of farmland and each parcel is connected to a network of irrigation and drainage canals. Each parcel is subdivided in square surface elements of uniform parameters, called cultivated units CUs (Fig. 3). The number of CUs depends on the surface properties, the number of cultivated basins and availability of data related to the soil and groundwater properties. Within a CU, the soil properties are assumed to be homogeneous and the groundwater level is considered uniform. Cus thus define the actual spatial

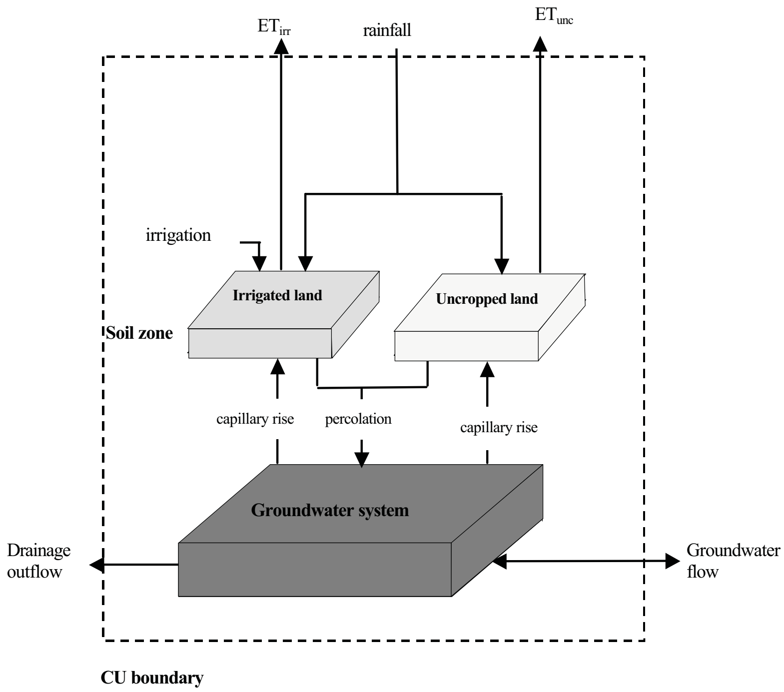

Fig. 3: Flow diagram of OASIS_MOD model [8]

resolution of the model. As shown in Fig. 3 the unsaturated zone within a single CU has two parts, the irrigated land inside basins and the non-irrigated land in the surrounding area. The groundwater provides the pathway for the movement of excess water from the irrigated land to the non-irrigated land [14].

A simple schematisation of a single CU is the reservoir model as illustrated in Fig. 4. The first reservoir corresponds to the irrigated land inside basins. Here the input variables are evapotranspiration, irrigation and rainfall. The second reservoir is the non-irrigated land in the surrounding area. Rainfall and evapotranspiration are the main driving forces for this reservoir. The third reservoir is the shallow groundwater. The last reservoir is the lower boundary of the model and represents the observed water table elevation. The basic processes incorporated in the model at the CU scale are irrigation, rainfall, infiltration, percolation to groundwater, evapotranspiration, groundwater flow, capillary rise and drainage discharge. Fig. 4 illustrates these components within a single CU during a specified period of time, which is usually selected as 1 day. Two hydrological phases operate sequentially in the OASIS_MOD model. Initially, there is a slow daily infiltration phase and then an even slower evaporation phase. These two phases occur each day, but at vastly different rates [15].

During the infiltration phase the movement of water is assumed to occur only in the liquid phase. The irrigated land is supplied with water by irrigation, rainfall and capillary rise fluxes. The last two processes are the main source of water for the non-irrigated land. When the soil water content reaches field capacity (defined at 5 kPa), the water on excess drains through the bottom of the soil zone to become potential recharge to the shallow groundwater. The groundwater aquifer receives percolation from the irrigated and non-irrigated lands. It can contribute, via capillary fluxes to soil evaporation and crop transpiration. In Tunisian oases, the capillary rise is the main cause of salt accumulation in the root zone whenever the water table is close to the ground surface [13]. The capillary rise induces the soil water movement in the liquid phase. Thus it was assumed to occur during the infiltration phase. The model simulates two groundwater flow processes in addition to capillary rise. The first represents the effect of a drainage system (ditches or pipe drainage). The second aims to capture the impact of hydraulic heads on groundwater flow among CUs.

During the daily evaporation phase crop transpiration and soil evaporation dry out water stored within the irrigated and non-irrigated lands. These two processes induce the transfer of water in the form of vapour from the land surface including soil and crop to the atmosphere.

Table 1: Morphological features of one CU

Feature	Unit	Description
A^*	m^2	Area of cultivated basic
A^{tot}	m^2	Area of cultivated unit (CU)
h_{SUB}	m	Substratum depth of the shallow groundwater
h_{drain}	m	Reference level for groundwater drainage
h_{downs}	m	Reference level for downstream groundwater flow

Table 2: Model parameters of one CU

Parameter	Unit	Description
P_{max}	m/day	Maximum percolation rate
W_{sat}	M	Soil water storage at saturation
W_{FC}	M	Soil water storage at field capacity
W_P	M	Soil water storage at permanent wilting point
K_c	-	Crop coefficient
β	m^{n+1}/day	Parameter related to the soil texture
N	-	Parameter related to the soil texture
λ	day• 1	Inverse of the drainage resistance
γ	day• 1	Groundwater flow coefficient
μ	-	Specific yield of the shallow groundwater

Model of Results: Operation of the model requires basic input data for each cultivated unit, which consist of (a) meteorological data including the daily values of reference evapotranspiration and rainfall; (b) irrigation data including discharge, duration and salinity concentration; (c) initial water storages and salinity concentrations in various reservoirs of the CU; (d) groundwater inflow from upstream areas and its salinity concentration. The model output can be classified into three main groups: (i) water stored in various reservoirs of the CU including groundwater level (ii) flow processes including infiltration, percolation to the shallow groundwater, capillary rise flux, drain discharge, groundwater flow and actual evapotranspiration (iii) salinity concentrations in solutions within various reservoirs of the CU and the salinity of the drain discharge solution.

The model requires both morphological features and physical properties. The morphological parameters are listed in Table 1 and encompass for each CU: the CU and the basin areas, the substratum depth of the groundwater aquifer and the reference levels for downstream groundwater flow and drainage system.

The basin areas can be obtained from field survey. The substratum depth of the groundwater can be obtained using field measurements or deduced from geological maps. The reference level for downstream groundwater flow can be estimated from the historic of the water table elevation. The physical proprieties of the soil and the groundwater are listed in Table 2; most entries can be deduced from physical considerations, either literature reviews or field and laboratory measurements (Rodriguez et al., 2008).

Available Data: The rainfall, pan evaporation, wind speed and temperature data are obtained at a daily time step from a meteorological station, located at *Tozeur*. The reference evapotranspiration is calculated with the Penman-Monteith equation [16]. Mean value of the irrigation water salinity concentration is of about 4 g/L. The groundwater aquifer at *Segdoud* is composed of alternate sand and sandy clay layers [9]. We assumed that palm trees are the only crop cultivated inside the oasis. The crop-specific parameter (K_c) is derived from the literature [16] and was adjusted for local conditions on the base of model calibration [8].

The model calibration and validation were carried out at the parcel scale because problems related to irrigation management in the oasis scale are very complex mainly the water distribution to parcels which is unequal [8]. The controlled parcel experiments selected for this study is located at northeast edge of the oasis at a high altitude in order to reduce the influence of neighbouring parcels on the water table fluctuation. In 1995, this parcel was provide with a drainage system, consisting of three pipes 250 m long, buried at a depth of 1 m and spaced intervals of about 70 m. Saturated hydraulic conductivity (Ks) and volumetric water content at saturation (θ_{SAT}), field capacity (θ_{FC}) and permanent wilting point (θ_{WP}) are obtained in laboratory from soil samples taken in the field at depths of 10 and 60 cm. Table 3 presents the values of these properties for each soil layer. The soil water storages at saturation (W_{SAT}), field capacity (W_{FC}) and permanent wilting point (W_{WP}) are obtained using the values of the soil thickness and water contents. Soil water holding properties are found to be uniform over the first meter of depth, with a typical plant water availability of 80-100 mm/m. This range of water availability is higher than the main daily potential evpotranspiration which is about 4.5 mm/day. Sand with water stored in the soil zone at saturation (438 mm/m), at field capacity (140 mm/m) and at wilting point (54 mm/m) is assumed representative of the test parcel for simulation. The maximum percolation rate (P_{max}), which is derived through measurement of the saturated hydraulic conductivity varies between 0.96 and 3.36 m/day. An average of 2 m/day is deemed appropriate for the soil in the test parcel.

Numerical Experiment: The application of the model at the oasis scale provides estimates, with good accuracy, of the irrigation water depth and frequency at each parcel separately. The lack of available irrigation data at 10,000 basins that constitute the cultivated area inside the oasis is problematic for the model application at the oasis scale. For instance, the model will help to anticipate the effects of irrigation interval and climatic conditions on soil salinity and water table elevation at the parcel scale (1.5 ha). In the *Segdoud* oasis, an irrigation schema with 5h_25min duration is planned with regular irrigation interval (10-14 days). OASIS_MOD model was used in a hypothetical scenario to simulate the impact of this irrigation interval on the water and salt dynamics within a parcel for the period from July 1989 to December 1996. In the scarce data, the initial soil water content is assumed at permanent wilting point. An arbitrary initial water table depth value of 2.1 m is used for each CU. This value was measured on May 1995 in an uncropped area located upstream of the oasis. The initial soil and groundwater salinity concentrations are assumed 3 g/L. This value was obtained in a laboratory on soil samples taken in the field on April 1986 [17].

RESULTS AND DISCUSSION

The Cropped Soil: Fig. 4 shows the time variability of the simulated soil salinity concentration and water stored in an irrigated land close the irrigation outlet from 29 May to 08 July, 1995. It is clear that the soil salinity increases as the soil water storage decreases. The soil salinity can vary from day to day because it largely depends on meteorological conditions and irrigation practices. It changes from 13 g/L before irrigation to about 9 g/L one day after irrigation stop. This decreasing trend is produced by irrigation with fresh water, due to leaching (Patel et al., 2000). In the test parcel, the mixing of 4 g/L irrigation water with a soil solution of 13 g/L leads to its dilution. During the summer season (June to August), the duration of this decreasing trend is of about one day after irrigation event. With time, the soil water continues to be removed by evapotranspiration, the dilution effect diminishes and the soil salinity beings to increase with time. The soil salinity reached seven days after irrigation is a similar value to the soil salinity before irrigation. During the summer season, the average increasing rate of the soil salinity concentration is about 0.5 g/L/day. The effect of irrigation is also clear in the soil water storage. Before irrigation, this storage is less than the storage at field capacity. When irrigation occurs, the soil water storage increases and attains maximum value of about 200 mm which represents about 50 % of the storage at saturation. After irrigation stops, the soil water storage decreases due to the percolation and to evapotranspiration. Three days later, the soil water content attains the field capacity and thus the percolation process cesses.

If an irrigation interval of about ten days is maintained constant during the year, the monthly average of irrigated soil salinity shows cyclical seasonal fluctuations with higher values during the summer season and lower values after the autumn-winter rains (Fig. 5).

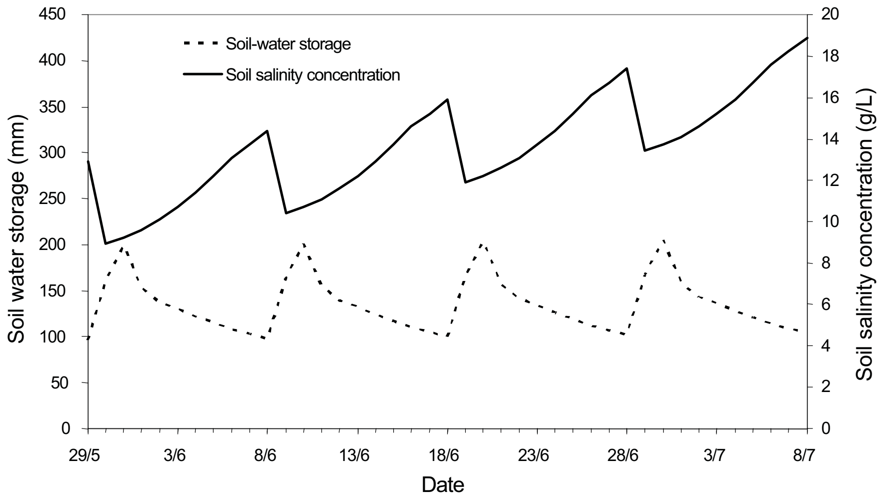

Fig. 4: Simulated daily water storage and salinity concentration of irrigated land from 29 May to 08 July 1995

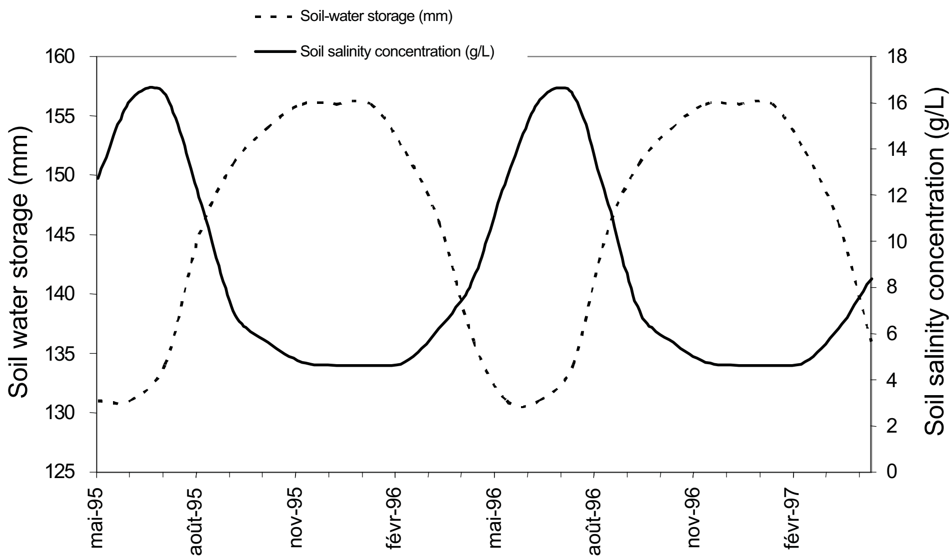

Fig. 5: Simulated monthly averages of (a) water storage and salinity concentration of irrigated land from May

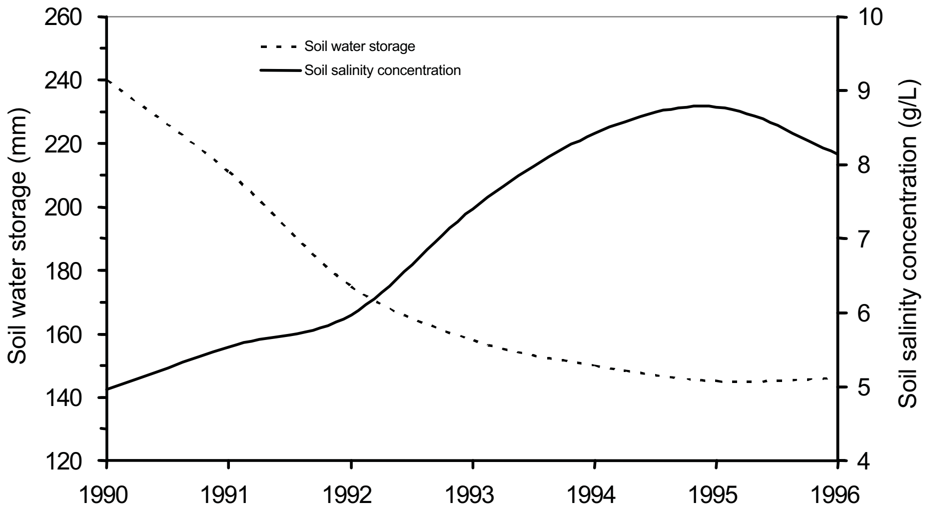

Fig. 6: Simulated annually averages of (a) water storage and salinity concentration of irrigated land over the 07 years (1990- 1996)

These fluctuations are explained by the rising of salts normally contained in the soil and by the amount of salts added through irrigation during the spring-summer period when evapotranspiration prevails and by leaching of the salts during the autumn-winter period, when percolation prevails (Tedeschi et al., 2002). During the last period, fresh water may be available in very limited quantities during the few rainfall events. In arid and semi-arid zones, this fresh water can be used to flush out salts accumulated in the root zone during the summer season [13]. Using an irrigation interval of about ten days leads to soil salinity increases during the summer season. During monsoon months, using this interval maintains the soil salinity at about 5 g/L. This can be very useful to define irrigation strategies with saline water (e.g. amount of saline water applied in each irrigation, time between two irrigations) that can avoid risks of irreversible salination of these sandy soils [18].

The simulated results show significant inter-annual variability of the soil water storage and salinity concentration due to variability in irrigation water depth and reference evapotranspiration (Fig. 6).

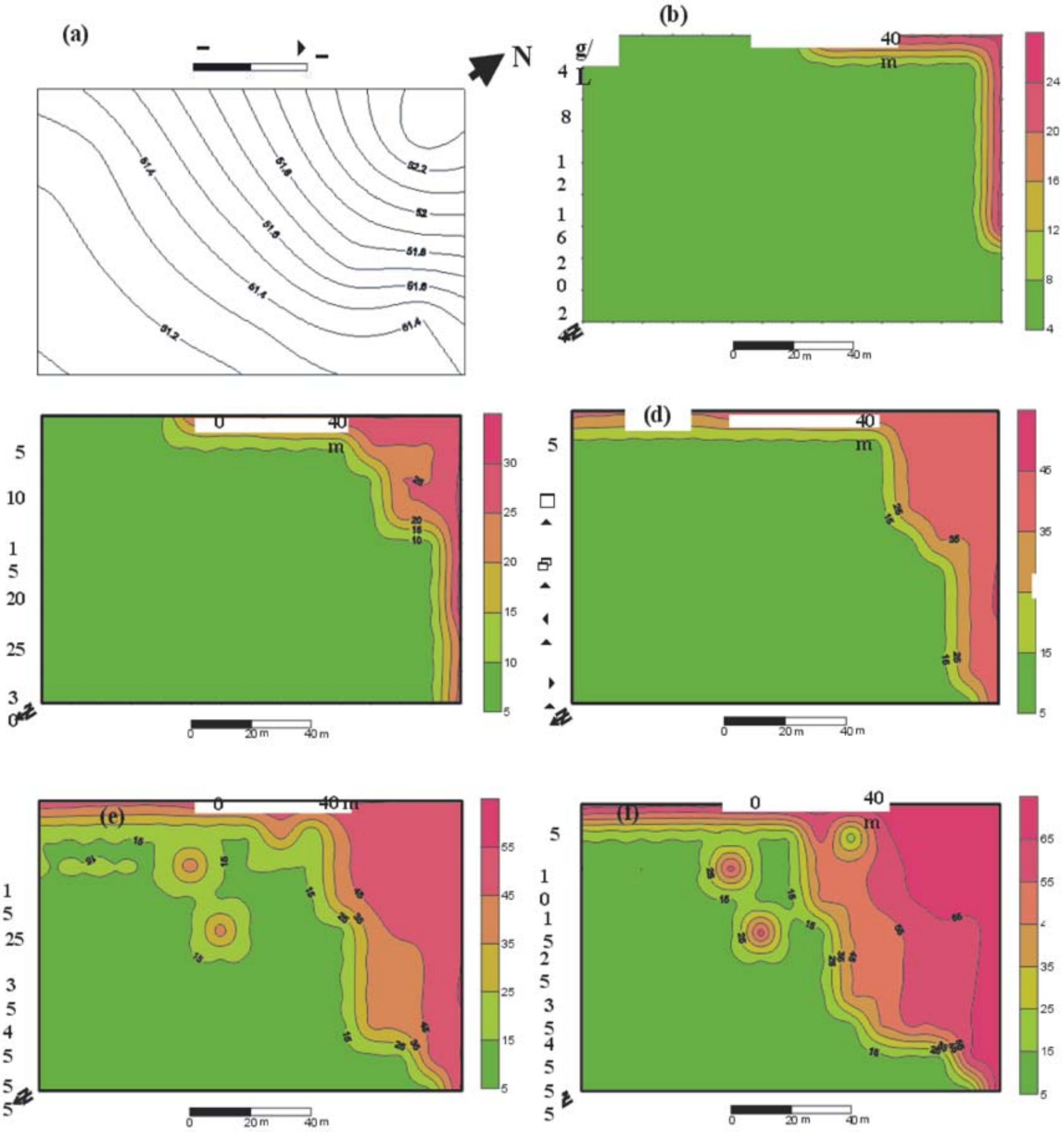

Fig. 7: Spatial distribution of measured water table elevation in 19 May 1995 (a) and simulated soil salinity concentration (g/L) with OASIS_MOD in the study parcel, on five dates: (b) 30-06-1990, (c) 30-06-1992, (d) 30 -06-1993, (e) 30-06-1994, (f) 30-06-1996

The annually averages of soil water storage decreased from 240 mm in 1990 to 146 mm in 1995 due to the reduction of the irrigation water allocation. During this period, the irrigated area inside the test parcel has increased from 600 to about 1200 m^2 resulting in a decrease in the average irrigation water depth from 120 to 60 mm per irrigation event. The annually averages of soil salinity have increased from 3 g/L in 1989 to 9 g/L in 1995 due to the decrease in leaching. This increasing trend has already been observed in the experimental parcel of Ksar Gheriss, situated in the center of Tunisia [19]. The experiment, which is one of the few long-term experiments being conducted in Tunisia, was monitored between 1964 and 1969 on a sandy soil and using saline irrigation water (4 g/L). The obtained results showed that using an irrigation interval of 10 days has led to soil salinity increases from 3 mmhos/cm in September 1965 to about 10 mmhos/cm in July 1968. In July 1989,

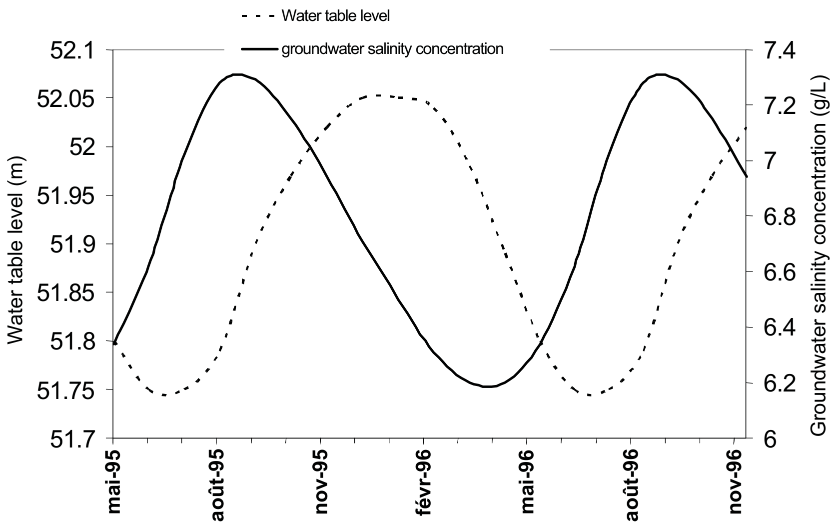

Fig. 8: Simulated monthly averages of water table elevation and salinity concentration of the groundwater (May 1995- November 1996)

when irrigation started in the Segdoud oasis, the irrigation discharge and duration were enough to ensure the irrigation of all basins. Over the years, the basins area has increased, so that the irrigation allocation was insufficient to bring water to all basins. This problem has led to the abandonment of several basins located in southern portion of the test parcel. Thirteen basins are assumed abandoned annually during the period between July 1990 and 1994. The simulated soil salinity in the test parcel for June 1990, 1992, 1993, 1994 and 1996 in the settings appear in Fig. 7. The results show remarkable differences in the salinity conditions across the test parcel. High saline soil dominates the southern portion of the parcel. This contrasts with the northern portion characterised by relatively low soil salinity. Several basins located in the first portion are assumed abandoned since July 1991. Thus, soils are less well leached in the absence of irrigation. The soil salinity within these abandoned areas rise constantly until equilibrium is reached between input of salt by capillary rise and leaching after heavy rainfall. Fig. 7 shows two isolated areas of relatively high soil salinity that develop since June 1994 and 1996. These areas represent two basins that where abandoned in July 1993. The same figure shows an isolate area of relatively low soil salinity within the high salinity southern portion of the test parcel in June 1996. This area represents a cultivated basin which was maintained irrigated until June 1996. The simulation showed that the soil salinity increases yearly in the whole parcel area. The highest increasing rate occurred in the southern portion. The area of soils affected by salination increases yearly as observed by the increase in the number of abandoned basins. In June 1992, only about 2% of the whole parcel area had the soil salinity higher than 15 g/L. The area affected by that level of soil salinity has increased to about 50 % of the whole parcel area in June 1996.

The Groundwater: Fig. 8 shows the predicted monthly average water table elevation and groundwater salinity from June 1995 to December 1996. It is clear that these two characteristics have a cyclical seasonal variation. The water table elevation has an increasing trend from August to February as the result of the evapotranspiration decrease. During this wet period, the soil water content is above the field capacity and thus the percolation rate attained maximum values. The lower water table elevation occurs during the summer season due to increased evapotranspiration. Groundwater salinity has a different trend and increases from May to September. During this hot and dry period, the accumulated salts in the soil profile are frequently carried back to the groundwater after addition of irrigation water to the land surface. The groundwater salinity has a decreasing trend from October to April. During this rainy period, the soil salinity attains minimal value. Thus the percolation process may induce the dilution of the groundwater solution.

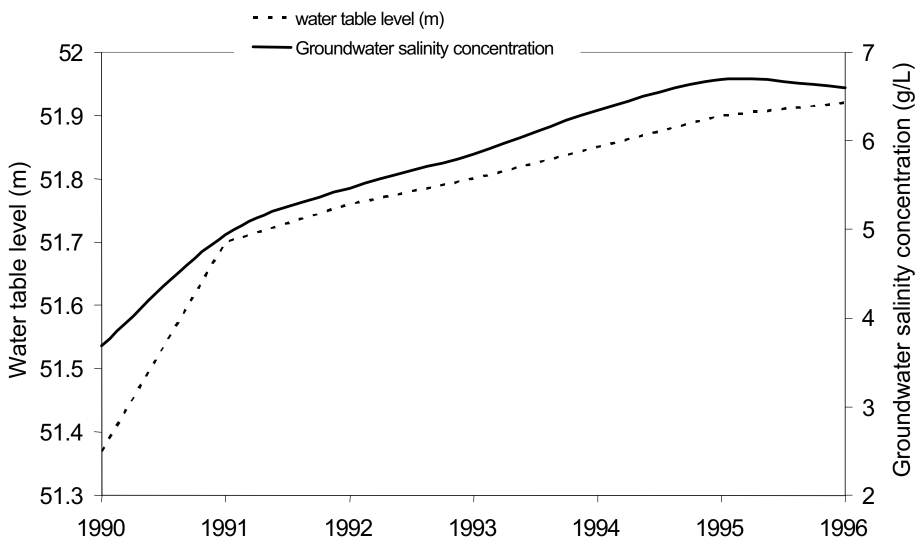

Fig. 9: Simulated annually averages of water table elevation and salinity concentration of the groundwater from 1990 to 1996.

The annual average water table elevation simulated by OASIS_MOD model shows an increasing trend from the year 1990 to 1995 (Fig. 9). This trend is explained by the increase of the cultivated area inside the test parcel.

As the irrigation water depth is marinated constant through years, the annual increase of cultivated area inside the test parcel may increase the amount of water that drains to the shallow groundwater. The annual average groundwater salinity has increased from 3 g/L in 1989 to about 7 g/L in 1995 as a consequence of the soil salinity increase.

The increasing trend of the annual averages water table elevation and groundwater salinity has been noticed by [20]. The observed water table depth has decreased in the test parcel from 1.07 m in September 1994 to 0.91 m in 1995. During this period the observed groundwater salinity has increased from 6.8 to 7.4 g/L.

CONCLUSIONS

This study provided an opportunity to better understand the temporal and spatial variations of irrigated soil and groundwater within an oasis ecosystem by using a conceptual hydrologic model. The simulation results obtained at the parcel scale showed that the soil salinity in modern Tunisian oases depends on three main factors: climate condition, availability and management of irrigation water. Irrigation interval was found to have an important effect on the components of the water and salt balances in the soil zone and on the water table elevation. Using an irrigation interval of approximately 10 days causes decrease soil-water storage and increase soil salinity during the spring and summer seasons. Using this same frequency leads to groundwater level increase during the autumn and winter seasons. Thus a higher irrigation frequency during the summer season should result in higher water storage and less salt accumulation in the soil zone. A lower irrigation interval during the autumn and winter seasons should cause a water table decrease.

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