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Satellite-Based Water Status Assessment for Date Palm in Al-Hassa Oasis, Saudi Arabia

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Abstract: Date palm is the most widely cultivated fruit tree in the Kingdom of Saudi Arabia (KSA) and commercially is the most important tree in the life of people and their heritage. Groundwater is main source of water for agriculture in the KSA. The limited precipitation and the huge increase in the area of agricultural land have put pressure on groundwater usage. Date palm needs sufficient water of acceptable quality to reach its potential yield. This study conducted in Al-Hassa Oasis located in the Eastern Region of the KSA in order to estimate the actual evapotranspiration (ETa) for date palm using Landsat-8 satellite data during 2017. The Surface Energy Balance Algorithm for Land (SEBAL) supported with climate data was used to compute the ETa. The satellite image provides an excellent spatial coverage over the study area with a temporal overpass of 16 days. The SEBAL model outputs were validated using FAO Penman-Monteith method coupled with field observation and measurements. The results over Al-Hassa Oasis show that the daily ETa values were in the range 7 – 9 mm/day during the summer and about 1 – 5 mm/day in winter. At farm scale, the peak ETa value occurs during July and August (9 mm/day) and reduces to 2 mm/day during December. The validation measure showed a significant agreement level between the SEBAL model and the FAO Penman-Monteith method for the period August – December. The study concludes that the current water resources situation in the Al-Hassa Oasis is critical. Accordingly, on-farm irrigation efficiency requires attention. Moreover, the salinity of the groundwater and soil are high. Therefore, further field investigation is needed with regard to irrigated areas, soil salinity and waterlogging. Hence, the problem can be well defined and the sustainable irrigation measures over the oasis can be identified.

Key words: Actual Evapotranspiration (Eta) · Landsat-8 Data · SEBAL Model · FAO Penman-Monteith Method · Al-Hassa Oasis

INTRODUCTION

The date palm tree (*Phoenix dactylifera*) is one of the oldest known fruit crop in the world, which originated from subtropical regions [1]. Date palm is the most widely cultivated fruit tree in the Kingdom of Saudi Arabia (KSA) and commercially is the most important tree in the life of people and their heritage [2]. The KSA is one of leading countries of date production in the world. It comes second to Egypt with a total production of more than 1.1 million tons from an area of about 172000 ha [1].

Groundwater is main source of water for agriculture in the KSA. The limited precipitation and the huge increase in the area of agricultural land have put pressure on groundwater usage. Date palm needs sufficient water of acceptable quality to reach its potential yield. The amount of irrigation water needed for date palm in most areas of the world is ranging between 13,000 to 36,000 m^3/ha according to FAO manual on crop evapotranspiration [3]. This variation is mainly due to the climatic conditions, ages and varsities of date palm trees and water stresses due to infections and salinity. Irrigation methods and water management for date palm at farm level are critical matters for sustaining date palm water productivity in the long-term.

From the earliest times, different methods were used to calculate the water requirements of different crops. As a result, numerous methods have been developed and adopted for date palms. Some of these methods are more accurate than others and some more convenient to use

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than others, because of the availability of information for the site where the date trees will be planted. The Penman method is widely accepted as the most accurate method of calculating water requirements for crops [3]. This method makes use of daily climatic information (e.g. maximum and minimum temperatures, wind velocity, humidity and radiation per day) to calculate the reference evaporation (ET_o). However, recently remote sensing has been increasingly employed to assess the actual evapotranspiration as a major factor for determining irrigation water requirement for many crops [4-7]. Remote sensing is a cost effective tool for quantifying large-scale agricultural areas along with providing detailed information over the small areas. The obtained information from the satellite data coupled with the biophysical modeling can help in monitoring and managing the water status in date palm orchards. This information is crucial for policy makers and water planers to develop and formulate strategies for the agricultural water resources management in the KSA.

The uncontrolled water flow from artesian wells at Al-Hassa Oasis was assumed to be more than the actual irrigation water needed by the date palm. Accordingly, estimation of evapotranspiration (ET) in the arid land of Al-Hassa Oasis is essential for the water planners and managers to understand the water use and irrigation water needed by the date palm at farm level. The main objectives of the study are to: (1) use Landsat-8 data to estimate the daily ETa for the date palm in Al-Hassa Oasis; (2) assess the potential of Landsat-8 derived ETa for irrigation water required by date palm in comparison to the actual water used.

MATERIALS AND METHODS

Study Area: Al-Hassa Oasis is one of the main and old agricultural centers in Saudi Arabia. The study area located about 300 km east of the capital Riyad and 70 km west of the Arabian Gulf (Fig. 1). It covers an area of about 200 km^2. Date palm plantation is main agricultural

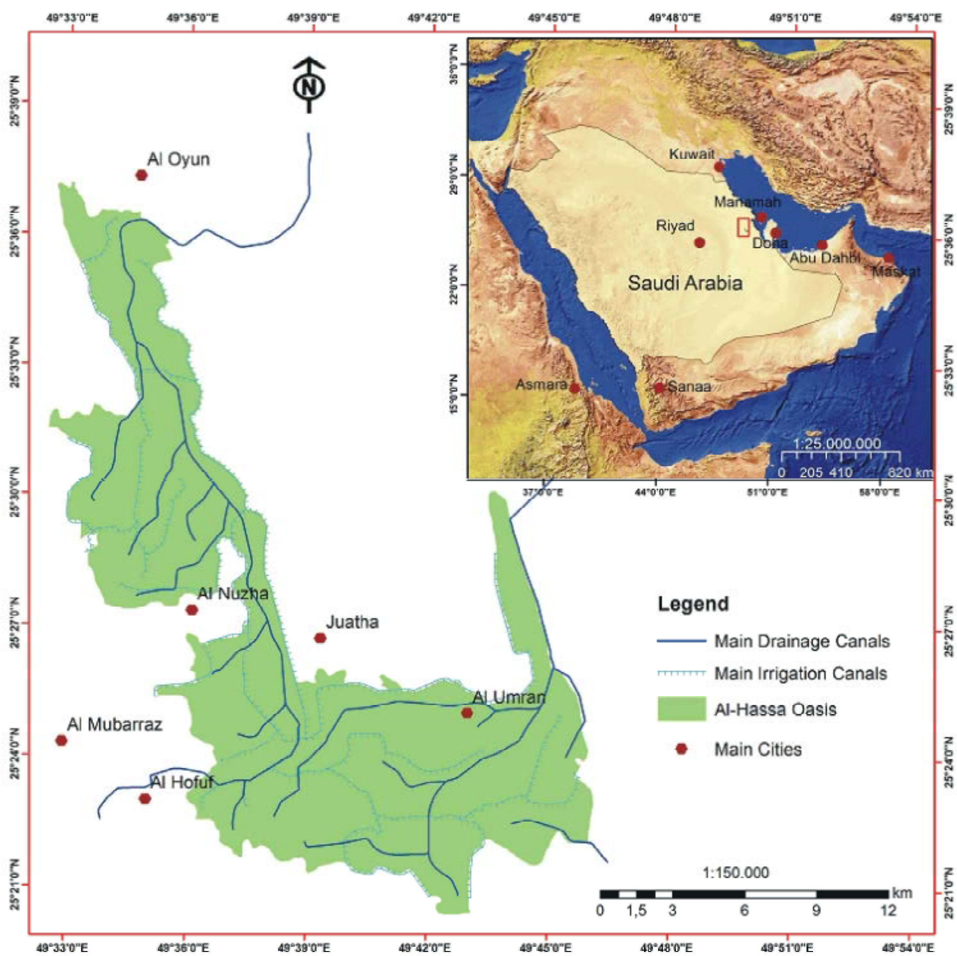

Fig. 1: Location of the study area.

Table 1: Specification of Landsat-8 data used in this study

Sensor	Bands	Spectral Range	Pixel Size
Resolution			
Multi-spectral (OLI)	1,2,3,4,5,6,7,9	0.40 - 2.45 μm	30 m
Panchromatic (OLI)	8	0.50 - 0.650 μm	15 m
Thermal (TIRS)	10, 11	10.50 - 12.50 μm	100 m

activity in the area and the number of the cultivated date palms is around three millions [8]. Irrigation networks in Al-Hassa Oasis were put into operation since 1971 to irrigate more than 22000 farms. The area has a hyper-arid climate with high temperature in summer, exceeds 45°C and low in winter sometimes reaches 0°C. It characterized with low annual rainfall of about 50mm and high potential evaporation ranges from 2,100 mm and 2,600 mm [9].

Data: A series of Landsat-8 satellite data were collected over the study area during 2017/2018 from the United States Geological Survey (USGS) web site (https://earthexplorer.usgs.gov/). One satellite image can be obtained every 16 days. The main characteristics of these data are shown in Table (1).

Climate data were collected from two meteorological stations located in Al-Hassa Oasis. These data include: air temperature, relative humidity, wind speed, net radiation and vapor pressure. All climate data were collected on hourly and daily base.

Also field observations and measurement were recorded, including: irrigation time, irrigation intervals and the amount of applied water for irrigation at farm level.

Surface Energy Balance Algorithm for Land (SEBAL): The SEBAL algorithm is an energy-partitioning algorithm over the land surface, which estimates the actual evapotranspiration from satellite images [10]. The minimum input requirements are routine meteorological station data. The satellite image provides an excellent spatial coverage, while the temporal coverage is limited to the time of the satellite overpass (2 weeks for Landsat). So, the derived parameters need to be extrapolated to daily and monthly values using various techniques.

The SEBAL algorithm computes the latent heat flux as the residue of the energy balance equation [10, 11, 12]:

$$\lambda ET_a = R_n - G_0 - H \quad (1)$$

where Rn is the net radiation over the surface (W/m2), G0 is the soil heat flux (W/m2), H is the sensible heat flux (W/m2), λETa is the latent heat flux (W/m2) and λ is the latent heat of vaporization (J/Kg).

The net radiation (Rn) was calculated using surface reflectance and surface temperature (Ts) derived from satellite imagery. Rn computed as:

$$R_n = R_s \downarrow - \propto R_s \downarrow + R_L \downarrow - R_L \uparrow - (1 - \varepsilon_0)\, R_L \downarrow \quad (2)$$

where Rs↓ is the incoming short wave radiation (W/m2) (solar radiation), ☐ surface albedo (dimensionless), RL↓ is the incoming long wave radiation (W/m2), RL↑ is the outgoing long wave radiation (W/m2) and å0 is the surface thermal emissivity (dimensionless).

The soil heat flux (G) is the magnitude of the heat flux stored or released into the soil. G was computed using the following equations described by [13, 14].

$$G/R_n = 0.05 + 0.18\, e^{-0.521\, LAI} \qquad LAI \geq 0.5 \quad (3)$$

$$G/R_n = 1.80\, (Ts - 273.16)\, R_n + 0.084 \quad LAI < 0.5 \quad (4)$$

The sensible heat flux (H) was determined using the aerodynamic based heat transfer equation as follows:

$$H = \rho_{air} + C_p\, dT/r_{ah} \quad (5)$$

where: ρ_{air} is the air density (kg/m3), Cp is the air specific heat (1004 J/kg/K), dT is the temperature difference between two heights z1 (0.1 m) and z2 (2 m) and rah is the aerodynamic resistance to heat transfer (s m/1).

The instantaneous values of ET were computed for each pixel as:

$$Et_{inst} = 3600\, LE/\lambda_{\rho w} \quad (6)$$

where ET_{inst} is the hourly instantaneous ET (mm/h), 3600 is used to convert to hours, LE is the latent heat flux (W/m) consumed by ET, ρw is the density of water (1000 kg m-3) and λ is the latent heat of evaporation (j/kg), which was computed as:

$$\lambda = [2.501 - 0.000236\, (T_s - 273.15) \times 16^6] \quad (7)$$

The reference ET fraction (ETrF) or crop coefficient (Kc) was calculated based on ET_{inst} for each pixel and ETr was obtained from local ground weather stations.

$Et_rF = ET_{inst}/ET_r$ (8)

The daily values of ET (ET24) (mm/day) for each pixel was calculated as follows:

$Et_a = Et_rF \times Et_r\ 24$ (9)

All SEBAL scripts were performed using the Spatial Modeler Tool of the ERDAS IMAGINE 9.2 software. Maps visualization was made using the ArcGIS 10.2 software.

Validation and Statistical Analysis: The produced ETa by Landsat-8 and SEBAL model was validated using the FAO Penman-Monteith method (equation 10) [3]. This equation used to calculate the reference crop evaporation (ETo) from the actual climate data in the study area. Consequently, the date palm water requirement was computed using equation 11 [3].

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} U2(es - ea)}{\Delta + \gamma(1 + 0.34U_2)} \quad (11)$$

where: ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ m-2 day-1], G = soil heat flux density [MJ m-2 day-1], T = mean daily air temperature at 2 m height [°C], U_2 = wind speed at 2 m height [m s-1], es = saturation vapour pressure [kPa], ea = actual vapour pressure [kPa], (es – ea) = saturation vapour pressure deficit [kPa], Δ = slope vapour pressure curve [kPa °C-1], g = psychrometric constant [kPa °C-1] and Kc = crop factor.

Kc values were set between 0.9 and 0.95 based on [15] CropWat study for Al-Hassa Oasis.

The Microsoft Excel 2010 software was used for statistical analysis and charts of the data [16].

RESULTS AND DISCUSSIONS

Actual ET of Date Palm over Al-Hassa Oasis: More than 80% of the irrigated areas exist within Al-Hassa Oasis is covered with date palm gardens. Therefore, most of ETa values occur within the oasis boundaries in (Fig. 2) are for the date palms. From (Fig. 2) it can be seen that the Eta values are higher during July, August and September compared to October, November and December. This indicates that the amount of irrigation water needed for date palm is much higher in summer compared to winter time. The ETa amounts for the summer time observed to be in the range 7 – 9 mm/day, while it was 1 – 5 mm/day during the winter. The variation in the ETa values along Al-Hassa Oasis for the different seasons is mainly due to the age of the date palm trees, the density of the trees, trees varieties and the water supply schedule.

The ETa values for the open water bodies (i.e. Al Asfar Lake) observed to be between 8 – 10 mm/day in summer and about 3 – 7 mm/day in winter (Fig. 2). This indicates that the highest ETa rates are associated with open water bodies. Nevertheless, the temporal patterns of the ETa and the potential evapotranspiration (ETp) for the date palm are showing similar values along the period July – December (Fig. 3). This similarity indicates that more irrigation water is supplied to the date palm than necessary.

Actual ET of Date Palm at Farm Level in Al-Hassa Oasis: Fig. 4 displays the ETa of a selected date palm farm in Al-Hassa oasis. It is obvious that the peak ETa value occurs during July and August (9 mm/day; Fig. 5) and reduces to approximately 2 mm/day during December (Fig. 5). The variability of the ETa values at farm level during the summer and winter seasons are mainly attributed to the water distribution, soil salinity, drainage and agricultural practices and their impact on moisture and salinity in the root zone.

The resulted ETa at farm scale provides good indicators about the date palm irrigation requirement for the different growing seasons. However, the irrigation water requirements should consider the leakage losses, distribution losses on the farm, runoff losses and leaching requirement. The level of salinity of both ground and waste water determine the amount of water needed for leaching. Therefore, the actual application rate of irrigation water for date palms should be sufficient to meet the minimum leaching potential for groundwater and also should include 20% losses from canals and the gardens.

The validation measurement for ETa at farm scale between the SEBAL model and the FAO Penman-Monteith method is shown in Fig. 6. There is a significant agreement level can be observed between the two methods for the period August – December. Nevertheless, during July there is slight difference between the two methods. This difference might be due to the calculation of the ETo and Kc, the SEBAL model does not require information on Kc because the biophysical properties underlying the ETp computations are estimated as part of the SEBAL process. However for the FAO Penman-Monteith method, the average Kc is slightly lower than

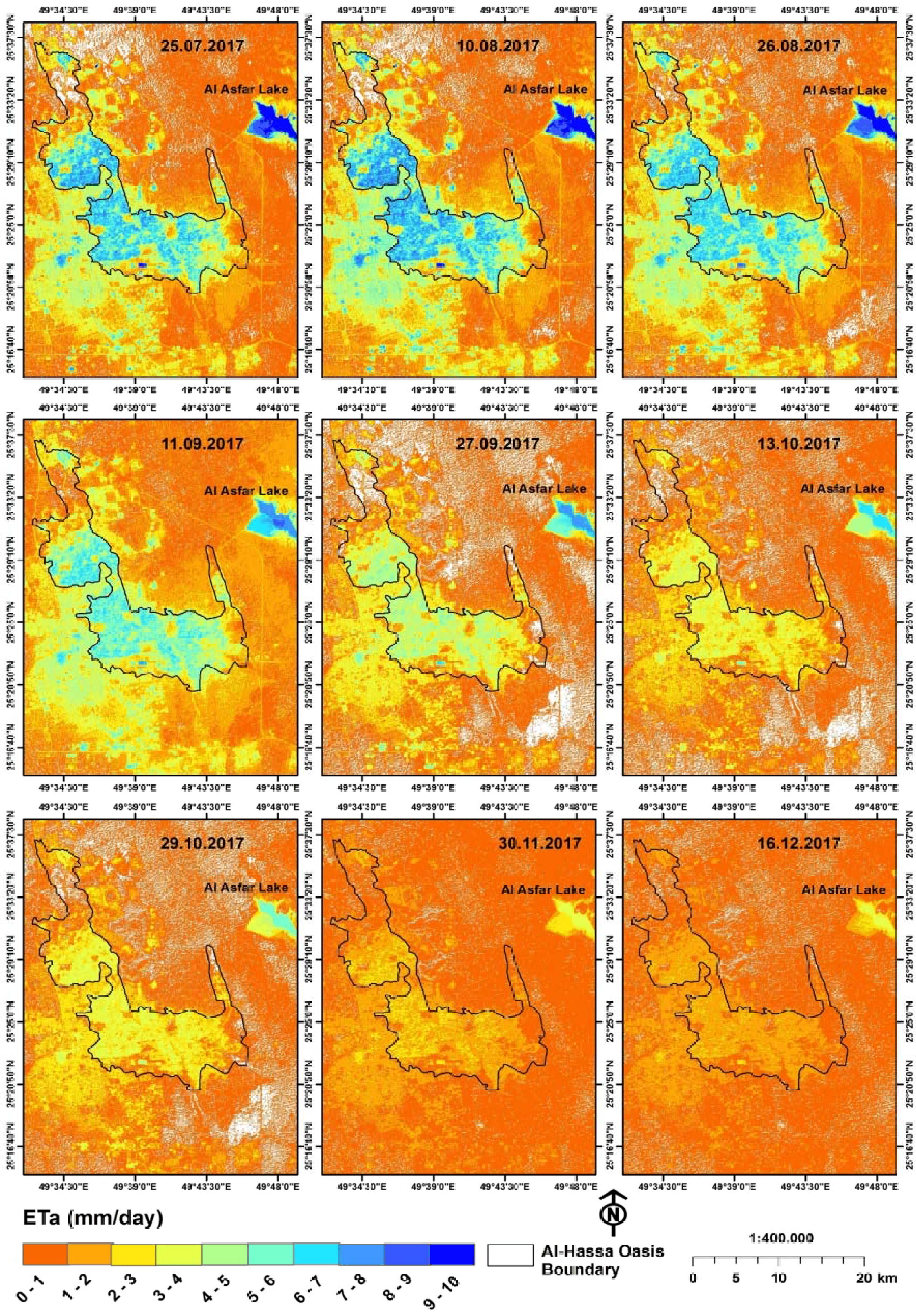

Fig. 2: Actual ET maps of Al-Hassa Oasis during July – December 2017.

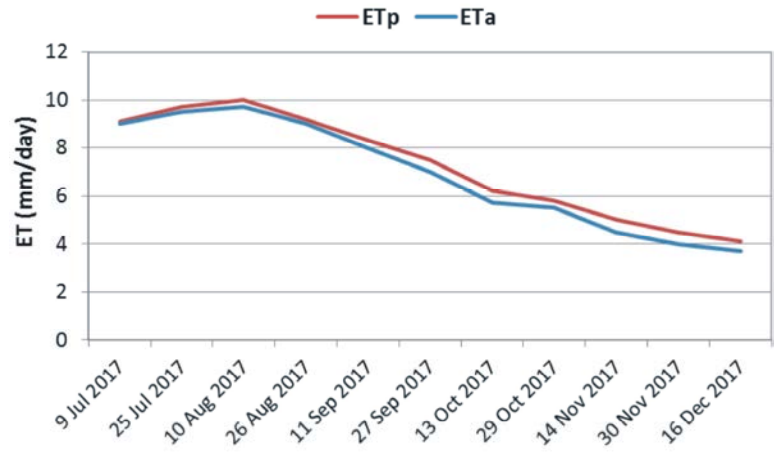

Fig. 3: Temporal trend of ETp and ETa of date palm in Al-Hassa Oasis for the period July – December 2017.

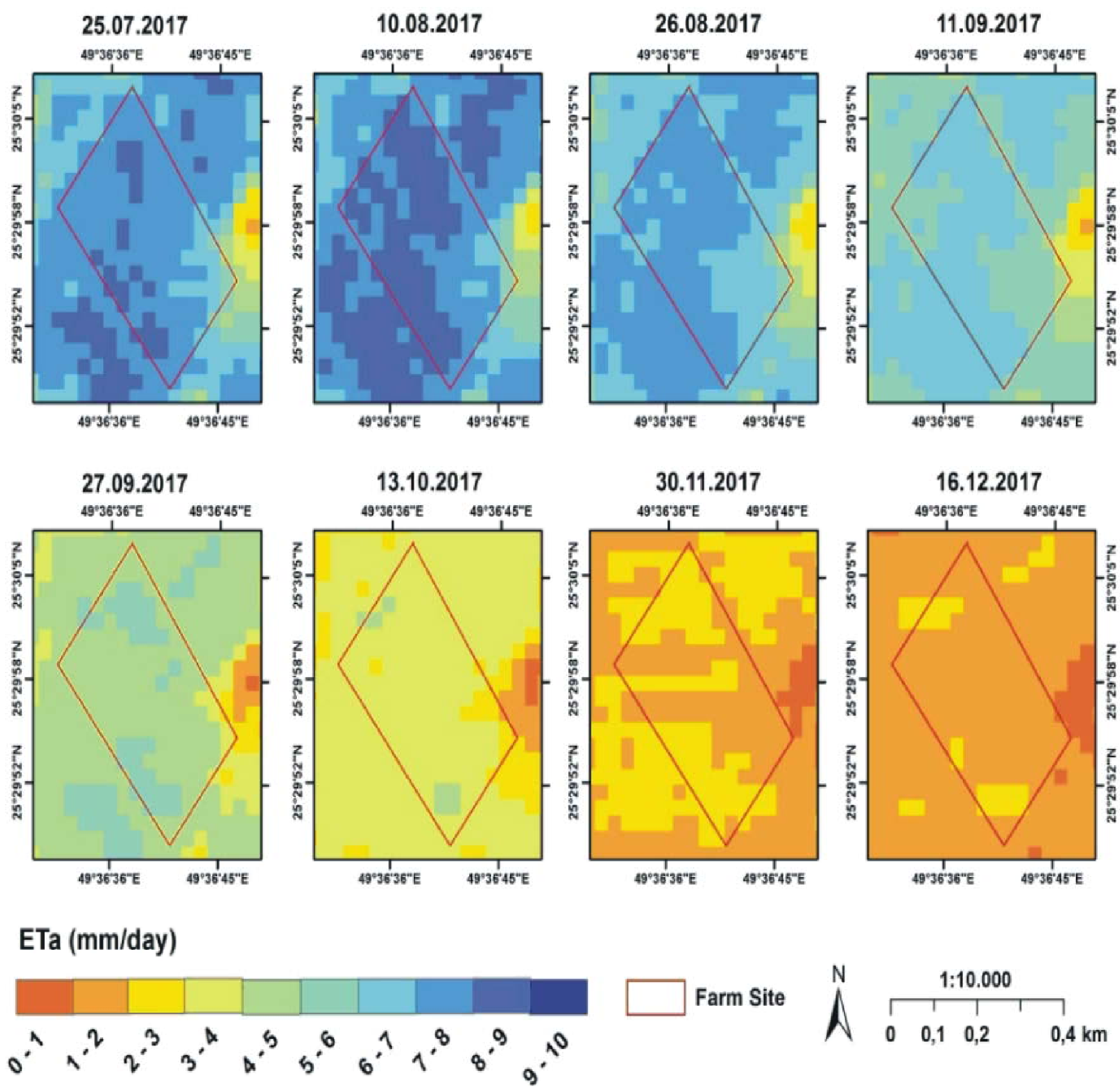

Fig. 4: Actual ET maps for Date Palm at Farm Scale in Al-Hassa Oasis during July – December 2017.

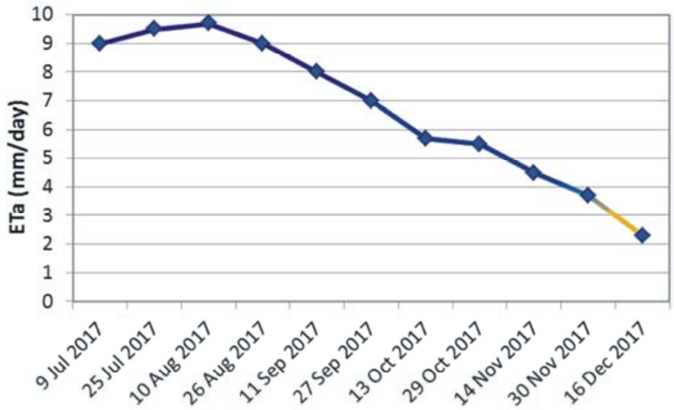

Fig. 5: Trends of ETa at Farm Scale in Al-Hassa Oasis during July – December 2017.

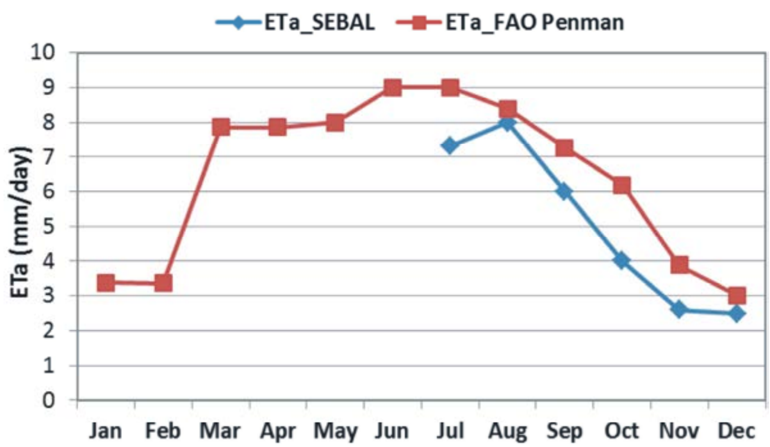

Fig. 6: Comparison of the Estimated ETa between SEBAL Model and FAO Penman-Monteith Method.

that set in the methodology (i.e. 0.9 – 0.95) due to the dust on date palm trees from desert sands and absence of rainfall. Crop coefficient values of date palm estimated to be in range of 0.8 to 0.99 in most its cultivated areas of Saudi Arabia [17]. However, [18] indicated that crop coefficient of date palm trees varies during the growing season from 0.5 to1.18 based on the stage of growth.

Moreover during the summer period of extreme high temperatures (up to 47 °C) and vapour pressure deficits that exceeds 40 mill bars, the date palm stomata will partially close to prevent cell moisture depletion and plant wilting. Hence, the stomatal resistance during the summer increases and this affects both the ETa and ETp because it is not related to moisture conditions of the root zone. Also, date palms experience heat and air humidity stress during the hot summer climate. In addition, although date palm trees need sufficient amount of water to produce commercial yield [19], but high evapotranspiration rates coupled with presence of shallow ground water at critical level depth (<1.5 m) lead to soil salinization [20].

CONCLUSIONS

The current water resources situation in Al Hassa is critical. The salinity of the groundwater is hazardous, even for a salt tolerant crop like date palms. The date production is hampered by this high soil salinity. However, waste water irrigation was negligible in 1990 and has grown to 25 million m^3 in 2007 [21]. The shallow and impermeable layers of Al Hassa lead to poor drainage. On-farm irrigation efficiency in Al Hassa thus requires attention. High irrigation efficiency with low percolation losses can induce soil salinization, whereas a low efficiency on the contrary creates a hazard for water logging.

The actual crop water consumption (i.e. ETa for date palm) is proposed by this study in order to sustain irrigated agriculture in Al-Hassa Oasis. However, the spatial distribution of the agro-hydrological processes and total water use patterns need to be understood. Therefore, this study will continue to find consistent and reliable spatial information on: areas irrigated, over and under irrigated areas, soil salinity and waterlogged areas will define the extent of the problems, the causes, what actions to take and to remedy it.

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