Mapping and Assessment of Evapotranspiration Over an Oasis in Arid Ecosystem Using Remote Sensing and Biophysical Modeling

Khalid Turk, Faisal Zeineldin, and Abdullah S. Aljughaiman

Abstract

This study was conducted in Al-Ahsa Oasis located in the eastern region of Saudi Arabia, aiming to estimate the annual actual evapotranspiration (ETa) for different land use systems based on Landsat-8 satellite data during 2017/2018. Initially, six land use and land cover (LULC) types were identified, namely: date palm, cropland, bare land, urban land, aquatic vegetation, and open water bodies. The surface energy balance algorithm for land (SEBAL) supported by climate data was used to compute the ETa. The SEBAL model outputs were validated using the FAO Penman–Monteith method coupled with field observation and measurements. The annual ETa was varied between 800 and 1400 mm.year^{-1} for date palm, while it was 2000 mm.year^{-1} for open water. An average of 800 mm.year^{-1} was observed in croplands. The study concludes that the ETa produced from the satellite data and the SEBAL model is useful for water resource management at the Oasis scale.

Keywords

Actual evapotranspiration (ETa) • Landsat-8 data • SEBAL model • FAO Penman–Monteith • Al-Ahsa Oasis

1 Introduction

Evapotranspiration (ET) is an essential process for defining the mass and energy relationship between soil, crop, and atmosphere (Allen et al. 2007). The measurement of ET is necessary for water management in arid ecosystems, and it has significant impacts on irrigation water requirement (Bastiaanssen et al. 2000; Anderson et al. 2012; Haj-Amor et al. 2018). Remote sensing and biophysical modeling were used in recent studies to estimate ET in different regions of Saudi Arabia (Madugundu et al. 2017; Elhag and Bahrawi 2017; Mahmoud and Alazba 2016). Al-Ahsa Oasis is one of the major agricultural areas in Saudi Arabia. The hyper-arid climate with an annual rainfall of less than 100 mm.year^{-1} makes groundwater the main source of irrigation in the Oasis. Precise information of the actual evapotranspiration (ETa) is crucial for policymakers and water planners to develop and formulate strategies for agricultural water resources management in Al-Ahsa Oasis. The objective of the study is to assess the potential of Landsat-8 data for estimating the annual ETa under different ecosystems in Al-Ahsa Oasis, Saudi Arabia.

2 Methodology

Landsat-8 satellite data were collected over the study area during Apr. 2017–Mar. 2018 to cover the summer and winter seasons. Also, a global digital elevation model (DEM) was used for topographic and atmospheric corrections (Malbéteau et al. 2017). Climate data were collected from two meteorological stations located in Al-Ahsa Oasis. These data include air temperature, relative humidity, wind speed, and net radiation. Field measurement and observations were collected from three different sampling sites located within the Oasis. LULC were classified using the supervised classification method.

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The surface energy balance algorithm for land (SEBAL) developed by Bastiaanssen et al. (Bastiaanssen et al. 2005) was used to calculate the ETa from satellite images. The SEBAL key input data consist of satellite measurement of surface albedo, leaf area index (LAI), normalized difference vegetation index (NDVI), and surface temperature. The produced ETa by Landsat-8 and SEBAL model was validated using the FAO Penman–Monteith method (Allen et al. 1998).

3 Results and Discussion

3.1 LULC Mapping

The results of LULC are represented in Fig. 1. They show the major LULC classes identified by the acquired 2017/2018 Landsat-8 images, namely date palm, cropland, bare land, urban land, aquatic vegetation, and water. The area occupied by each LULC type within the Oasis boundaries is described in Table 1. The date palm covers about 40% of Al-Ahsa Oasis area since it is the most important land use class for the local and national economy. Croplands used only 19% of the Oasis area; they are dominated by rice and vegetables. The bare land class occupies around 39% of the Oasis area. The overall classification accuracy was 89%, with a Kappa index of 87%, while the user's and producer's accuracies differed with LULC types (Table 1).

3.2 The Annual Actual Evapotranspiration

The annual ETa produced by SEBAL model for the different LULC types in Al-Ahsa Oasis is shown in Fig. 2. The ETa rates of date palm trees ranged from 800 to 1400 mm.year^{-1} during the period Apr. 2017 to Mar. 2018. The annual water consumption for date palm is highly variable, and this might be attributed to the type of irrigation system and the age variations of date palm trees along the Oasis.

The open water evaporation lost was around 2000 mm.year^{-1}, while an average of 1,600 mm.year^{-1} was evaporated from aquatic vegetation. Nevertheless, croplands showed the lower annual ETa of 800 mm.year^{-1} compared to the date palm. The annual ETa of urban lands is affected

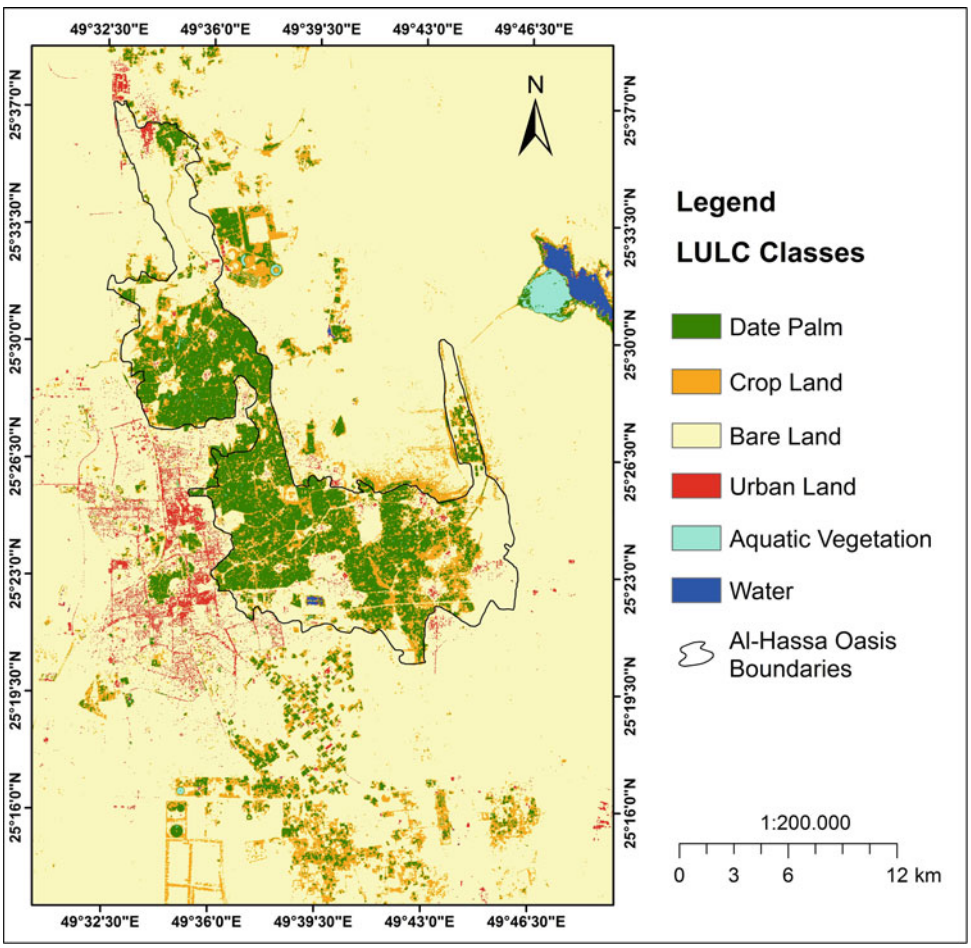

Fig. 1 LULC map of the study area

Table 1 Areas and accuracy assessment of LULC within Al-Ahsa Oasis boundary

LULC	Area		Classification accuracy (%)	
	hectare	%	User's	Producer's
Date palm	8820	40.1	95	94
Cropland	4199	19.1	83	81
Bare land	8636	39.2	95	93
Urban land	278	1.3	82	86
Aquatic vegetation	37	0.2	75	92
Water	30	0.1	100	100
Overall			89	
Kappa statistic			87	

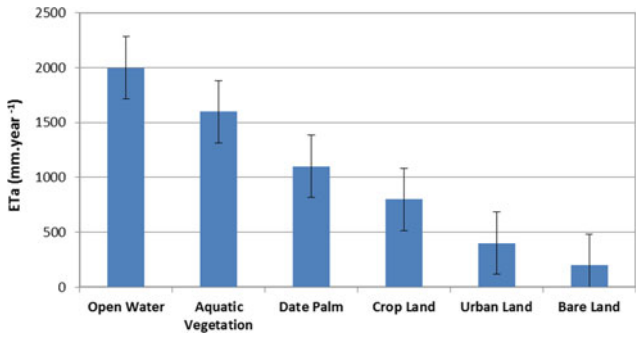

Fig. 2 Annual ETa values produced by SEBAL for the different LULC types in Al-Ahsa Oasis during Apr. 2017 to Mar. 2018. Bars denoted standard error

by the irrigation of trees, lanes, and parks. It is also likely that some more rooted vegetation withdraws groundwater (Mihi et al. 2019).

4 Conclusions

The current water resources situation in Al-Ahsa Oasis is critical because the groundwater used for irrigation is non-renewable. This study demonstrates the power of spatially distributed remote sensing data and the biophysical modeling to quantify the critical processes of the soil-crop-atmosphere continuum. The spatial data produced by Landsat-8 data and SEBAL model will allow a thorough analysis of the irrigation practices for the different growing seasons in Al-Ahsa Oasis and also in regions of similar conditions. However, validation measures for soil moisture are required.

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