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Original Research Article

Satellite Remote Sensing-Based Irrigation Performance Assessment of the Mustafakemalpaşa Irrigation Area in Bursa, Türkiye

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ABSTRACT

Given the increasing pressure on water for agricultural irrigation, coupled with unpredictable climate conditions, it is critically important to improve irrigation water management for sustain crop production. Satellite remote sensing (RS)-based approaches are helpful for investigating cost-effectively spatio-temporal variations of irrigation performance at scales ranging from individual fields to the entire scheme level. Using Landsat images within the Python module for the Surface Energy Balance Algorithm for Land model, it was investigated the spatiotemporal performance variations of the Mustafakemalpaşa irrigation area during 2020 cropping season. Actual evapotranspiration (ETa), Uniformity of Water Consumption (UWC), and Crop Water Productivity (CWP) performance indicators were evaluated. The results showed that the performance of the Mustafakemalpaşa varied depending on the geographical position in the irrigation area. Our findings highlight the opportunity to improve the uniformity of water consumption in the area. Based on this study, PySEBAL can serve as basis for improved Mustafakemalpaşa irrigation water management in decision support tools.

Keywords: Satellite remote sensing, PySEBAL, irrigation performance

INTRODUCTION

Irrigated agriculture accounts for 20 per cent of total cultivated land and 30-40 per cent of total food production worldwide (Seckler et al., 1998; UN-Water, 2018). Moreover, agriculture is the largest consumer of the water worldwide with more than 70% of the global freshwater withdrawals are required for agricultural production (UNDESAPD, 2014; UN-Water, 2018). However, due to a rapidly growing world population, pressure on water resources, and climate change effects, water resources for irrigation are becoming increasingly scarce in many parts of the world (De Bruin and Stricker, 2000; Wellens et al., 2013). Efficient use of water resources is a pathway to address the irrigation water scarcity challenge for sustain agricultural production. Various studies have been conducted to determine the effects of the transfer of irrigation systems to irrigation unions on irrigation performance (Değirmenci et al, 2017; Kartal et al 2019; Kartal et al 2020).

Assessing irrigation performance is one of the agricultural water management methods commonly use to improve crop water use efficiency. Irrigation performance is evaluated using a variety of methods, ranging from traditional to remote sensing (RS)-based approaches. Traditional methods are typically based on field campaigns, which are time-consuming, costly, and require high data (Bastiaanssen and Bos, 1999; Gorantiwar and Smout, 2005). Novel techniques and approaches are required to make irrigation performance assessment time and cost-efficient. Assessing irrigation performance based on satellite RS have been investigated as a cost-effective and less time-consuming approaches (Bastiaanssen and Bos 1999; Blatchford et al. 2018). Remote sensing model such as the Surface Energy Balance Algorithm for Land (SEBAL) model developed by Bastiaanssen et al (1996) is used to evaluate the spatial-temporal distribution of crop water parameters. Several studies have been carried out to assess the performance of irrigation areas under various environmental and management conditions using RS-based approaches (Zwart and Leclert, 2010; Sawadogo et al 2020).

The aim of this study was to assess the irrigation performance of the Mustafakemalpaşa irrigation area using satellite remote sensing derived indicators.

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MATERIALS AND METHODS

Study Area

Mustafakemalpaşa (MKP) irrigation area is a 16,555 ha, located at 85 km southwest of Bursa province. MKP irrigation area is characterized by a diversity of crop including cereals, vegetables, tuber, and fruit crops. In this study, farmers' fields are used to measure the ETa data at plot basis. Two fields from Yeşilova (Yeşilova-I and Yeşilova-II) and one field from each of Tepecik and Bakırköy villages were selected for the field experiments. Drip irrigation was used in the Yeşilova-I and Bakırköy fields, while furrow irrigation was used in the Yeşilova-II and Tepecik fields (Table 1). Table 2 shows the physical properties of the fields used in this study.

Table 1. Farmers' fields used in this study.

Village name	Area (m^2)	Crop	Irrigation System
Tepecik	11900	Maize	Furrow
Yeşilova I	7850	Maize	Drip
Yeşilova II	13657	Maize	Furrow
Bakırköy	6277	Maize	Drip

Table 2. Farmers' fields physical characteristics used in this study.

	Sand, %	Silt, %	Clay, %	Field Capacity (%)	Wilting point (%)	Bulk density (gr/cm³)
Yeşilova-I	38.4	37.6	24	19.06	11.84	1.39
Yeşilova-II	59.2	24.1	16.7	11.82	6.64	1.52
Tepecik	40.1	27.5	32.4	22.09	12.76	1.33
Bakırköy	40.6	37.5	21.9	16.58	8.82	1.4

Surface Energy Balance Algorithm for Land (SEBAL)

The SEBAL model is based on modelling the surface energy balance using remote sensing data. The PySEBAL model was developed by IHE-Delft Institute for Water Education in Python programming language (Anonymous, 2020). PySEBAL calculates the surface energy balance for the day of RS image acquisition, independently from the land use, based on inputs derived from the satellite images, along with weather and digital elevation model (DEM) data (Bastiaanssen et al., 2002). The outputs of PySEBAL include the actual evapotranspiration (ETa), crop coefficients (Kc) and biomass at the daily time scale (i.e. day of RS image acquisition). For more details on the SEBAL model and procedures to interpolate daily results between the periods and estimate seasonal results, reference is made to Bastiaanssen and Ali (2003), Zwart and Bastiaanssen (2007), Trezza et al. (2018).

Irrigation performance indicators

Three irrigation performance indicators were evaluated in our study: seasonal actual evapotranspiration (ET_a), uniformity of water consumption (UWC), and crop water productivity (CWP).

Seasonal Actual Evapotranspiration

Following Trezza et al. (2018), seasonal ET_a were estimated based on the construction of a crop coefficient curve for every pixel over the study area. The seasonal period from April 23 to September 03, 2020 was considered. The cumulative ET_a was calculated as follows:

$$ET_{a\,(seasonal)} = \sum_{i=m}^{n} [(K_{ci})(ET_{024i})]$$

where $ET_{a\,(seasonal)}$ (expressed in mm) is the ET_a cumulated over a period from days *m* (start of the study period) to *n* (end of the study period); ET_{024i} (in mm) is the reference ET over 24 hours for day *i*; and K_{ci} is the K_c interpolated over day *i* (dimensionless).

Crop Water productivity (CWP)

CWP can be defined as the ratio between a defined crop variable (e.g. yield) and the amount of water depleted (usually limited to crop evapotranspiration) (Kijne 2003), or as the gain in biomass or yield per unit of evapotranspiration or irrigation depth (Perry et al., 1999). In this study the CWP is evaluated as the ratio between biomass and ETa estimated by PySEBAL.

Uniformity of Water Consumption

The uniformity of water consumption was described using the coefficients of variation (CV) of ETa (Bastiaanssen et al., 1996). In our study, we adopted the ranges of CV values as suggested by Molden and Gates (1990) to characterize the uniformity of water consumption across the MKP irrigated area.

Data

Landsat Images

Multi-temporal clear-sky images from the instruments Landsat-7 ETM+ and Landsat-8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) were used in this study (Table 3). These images were downloaded from https://earthexplorer.usgs.gov/ website.

Table 3. Landsat satellite imagery used for assessing MKP irrigation performance.

No	Date	Images Information	Sensor
1	4/20/2020	LE71800322020111NSG00	LE7
2	4/28/2020	LC81800322020119LGN00	LC8
3	5/14/2020	LC81800322020135LGN00	LC8
4	6/7/2020	LE71800322020159NSG00	LE7
5	7/1/2020	LC81800322020183LGN00	LC8
6	7/17/2020	LC81800322020199LGN00	LC8
7	8/26/2020	LE71800322020239NSG00	LE7
8	9/3/2020	LC81800322020247LGN00	LC8

Meteorological Data

In the study, hourly and daily basis of air temperature, wind speed, relative humidity, net radiation data were used. These data were obtained from the data Information Presentation and Sales System (MEVBIS) of the General Directorate of Meteorology of Türkiye. Since there are no net radiation measurements at the Mustafakemalpaşa meteorology station, the net radiation data were taken from the Bursa meteorology station.

ETa field measurement

In this study, daily ETa on field basis was derived using the water balance equation as follow;

$$ETa = I + P \pm \Delta S - D$$

where, ETa (mm) is the actual evapotranspiration, I(mm) is the irrigation water (mm), P (mm) is the precipitation (mm), ΔS (mm) is the water storage change (mm), and D (mm) is the deep infiltration (mm).

The satellite overpass days were specified, and it was ensured that no irrigation was applied and no precipitation was recorded during these periods. Thus, during the satellite overpass days, the infiltration, irrigation, and precipitation waters were assumed to be zero. Under these conditions, the ETa is driven by the soil water storage change (ΔS), which is estimated by the following equation.

$$\Delta S = RU_o - RU_f$$

where, RU_o refers to the amount of moisture in the soil the day before the satellite overpass day, and RU_f refers to the amount of moisture in the soil on satellite overpass day. Soil samples were taken before and the satellite overpass days to encompass image acquisition day. The moisture value was determined by gravimetric method. For each field, soil samples were taken from three points to determine the soil moisture content. The average value of these points is considered as soil moisture at field basis (Sawadogo et al 2020).

Statistical Analysis

Statistical comparison between actual evapotranspiration obtained by the PySEBAL model and by the field measurement was done using the root mean square error (RMSE), and the coefficient of determination (R^2).

RESULTS AND DISCUSSION

Seasonal actual evapotranspiration

Seasonal ETa in MKP irrigation area varies between 3.73 and 882 mm (Fig 1). Lower ETa values were observed in the southeast, while higher ETa values were obtained in the southwest of the area. ETa spatial variability in MKP may be related to soil type and the crops grown during the study period. Although satellite remote sensing cannot explain the causes of such ETa spatial variations in the MKP irrigation area, it can be used to identify areas with good and poor water management practices. Our findings could be used by water managers and decision-makers to improve water management in the area.

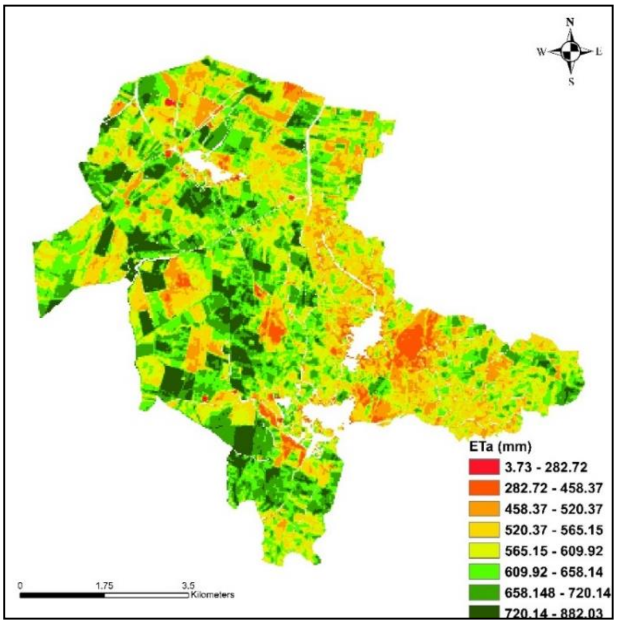

Figure 1. Spatial distribution of seasonal ETa in MKP irrigation area.

Crop Water Productivity

The crop water productivity ranges from 0 to 6.58 kg.m^{-3} (Fig 2). Depending on the geographical location in the area, lower values of the water productivity are observed in the irrigation area western part, while higher values are observed in the irrigation area southern part. The spatial variability of water productivity in the MKP irrigated area can be mainly explained by the crop diversity observed in the irrigation area during the study period.

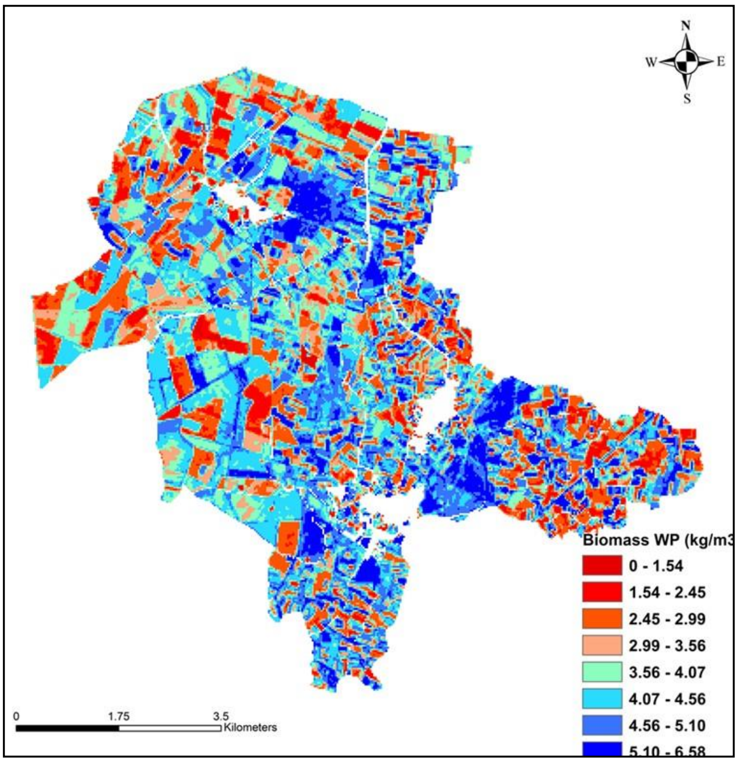

Figure 2. The spatial distribution of water productivity in MKP irrigation area.

Uniformity of Water Consumption (UWC)

Figure 3 shows the temporal variation of uniformity of water consumption in the MKP irrigated area. The uniformity of water consumption ranged from 9% to 18%. These findings should be interpreted with caution, especially since the portion of excess water removed by drainage is not considered. According to this result, there are opportunities for improving the uniformity of water consumption in the area.

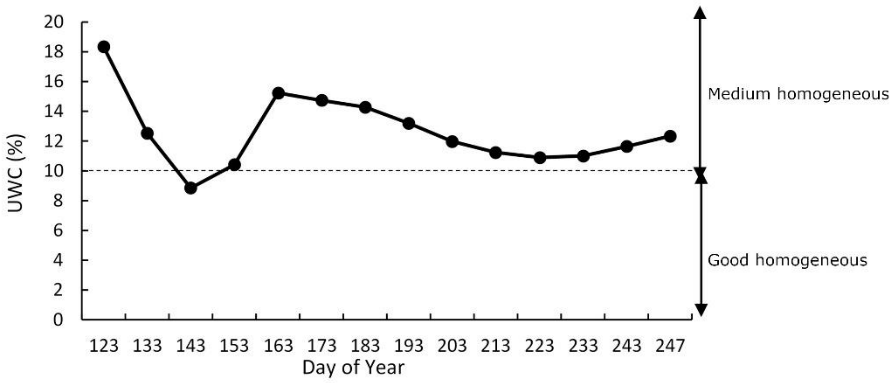

Figure 3. Temporal variation of Uniformity of Water Consumption (UWC).

Comparison of ETa by the PySEBAL Model with ETa by field measurement

The actual evapotranspiration calculated by PySEBAL was compared with the actual evapotranspiration determined in the field. The linear relationship between PySEBAL ET_a and field measured ET_a is given in Figure 4. Overall, poor agreements between ETa from PySEBAL and field measurement were found: RMSE of 1.9 mm.day^{-1} and R^2 of 0.47. The findings of this study can be attributed to a variety of factors, including the soil sample limitations and field boundary influences on ETa.

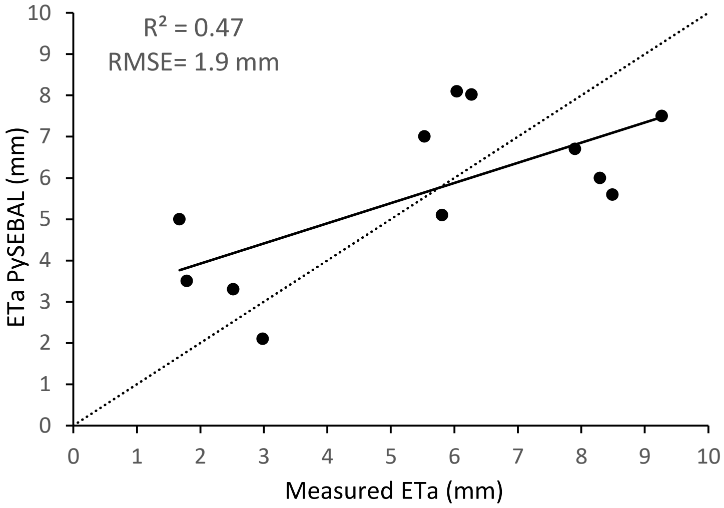

Figure 4. PySEBAL and measured ET_a.

The ETa in the field was determined using samples taken from three different points. This may not accurately represent the spatial variability of ETa in the parcel as show in Figure 5. Field boundary influences on ETa cannot be neglected when implementing remote sensing approaches (Singh et al. 2008), which is in live with this study results. Based on the findings of this study, we can recommend a large crop production area with spatially homogeneous water distribution for field ETa estimation in order to avoid both soil sample limitation and field boundary influences on ETa.

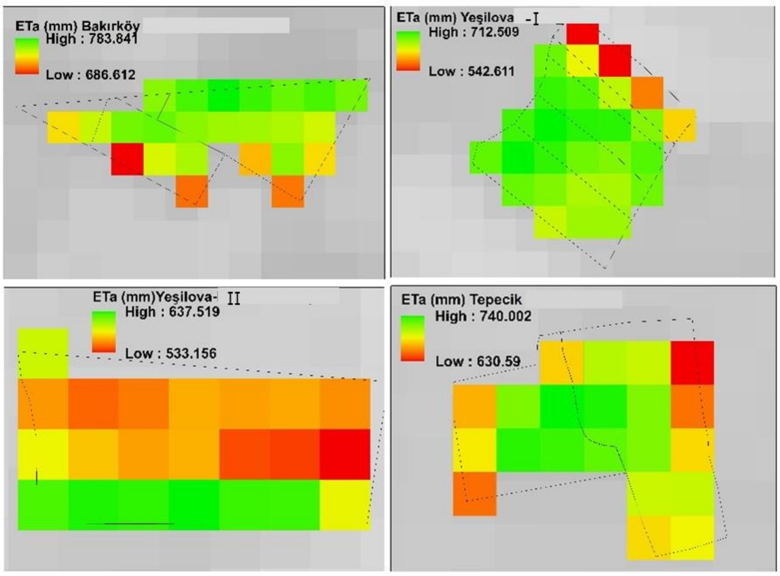

Figure 5. Spatial variation of ET_a at field scale.

CONCLUSIONS

The purpose of this study is to evaluate the performance of the MKP irrigated area using satellite remote sensing approaches. This study highlight the opportunity to improve the uniformity of water consumption in the MKP irrigated area. When compared to field measurements, PySEBAL, ETa was fairly estimated throughout the crop growth season. Therefore, future studies could focus on ETa field measurements in the MKP for better ETa estimation by taking into account field boundary influences on ETa as well as soil sample limitations. Our findings highlight the efficiency of RS approaches for estimating irrigation performance and could be used to develop targeted strategies for improved irrigation water use in the MKP irrigated area.

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