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Proceeding Paper

Determining the Critical Points of a Basin from the Point of View of Water Productivity and Water Consumption Using the WaPOR Database †

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Abstract: Actual evapotranspiration is one of the major components of the soil water balance equation. Several methods have been presented for estimating actual evapotranspiration, but the older methods are not practical because of their spatial and temporal dependence. Recently, the Food and Agriculture Organization of the United Nations (FAO) created the WaPOR open-access system on water productivity with the aim of covering countries experiencing water crises in Africa and the Middle East, and the estimation of actual evapotranspiration (ETa) is one of its main products. This portal makes it possible to determine water consumption and water productivity on a large scale with minimal time and cost, so it can be used to manage the agricultural sector. The Google Earth Engine System (GEE), introduced by Google in 2010, is an effective remote sensing instrument for gathering important data from satellite imagery. In this study, the actual evapotranspiration maps of the Maroon-Jarahi basin for 2017 were extracted using the methodology introduced by the FAO and provided in the WaPOR database, and the coding was performed in the GEE system. The results showed that the actual evapotranspiration during this period was highest in July and decreased with the onset of the fall season. Limited water resources are a major obstacle to ensuring food security. Considering that the agricultural sector consumes most of the water in Iran and worldwide, water management in the agricultural sector is of great importance. Water productivity is a key indicator in studying and improving agricultural water management as well as one of the Sustainable Development Goals. In this study, the actual evapotranspiration (AET), net primary production (NPP), and water productivity (WP) for the basin were estimated using the WaPOR portal and Google Earth Engine over a 10-day period with a spatial resolution of 250 m (decadal data). Based on the obtained results, areas with low water productivity were identified. By studying the existing cropping patterns, the type of irrigation system used, and the water and soil conditions in these areas, it was possible to investigate the reason for the low water productivity and propose solutions to improve it.

Keywords: irrigation management; water consumption; WaPOR; evapotranspiration

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1. Introduction

The agricultural sector will need to increase food production by 60% in developed countries and 110% in developing countries by 2050 to satisfy future food demand because more than 70% of the world's freshwater is used for irrigation. In recent decades, water resources have declined because of population growth and climate change. Long droughts, increased demand for agricultural products, a lack of water, and the availability of agricultural land are posing serious threats to food production. Therefore, increasing crop production per unit of water consumption, known as crop water productivity, is considered a key strategy for ensuring food security [1]. Water productivity is a key factor in studying the production of agricultural products and the efficiency of water resources [2]. Crop yield and evapotranspiration (ET) are typically used to estimate water productivity. Crop yield is influenced by a variety of factors, including soil fertility, disease control, and agricultural practices, whereas ET changes depending on the type of irrigation and drainage system used as well as the climatology and rainfall patterns [3]. From the field scale to the continental scale, remote sensing is increasingly the best option for determining water output and its components at various temporal and spatial resolutions [4]. The proper scheduling and management of a basin's water resources, which necessitates knowledge of the hydrological behavior of the system, including temporal and spatial changes in crucial components such as the actual ET in the basin, have an impact on the economic, agricultural, and social development of a region. Thus, it is necessary to develop techniques that can correctly determine the actual ET [5].

Due to its complexity, estimating ET is challenging. There are several ways to determine this parameter. Because they can be compared with numerical climate models and have a wider coverage than traditional approaches, remote-sensing-based techniques are more widely used. There are several different remote sensing approaches available for estimating actual ET, including surface energy balance [6,7], Penman–Monteith [8], and experimental methods based on plant indices [9,10]. As mentioned, the use of models based on remote sensing to estimate actual evapotranspiration requires validation and recalibration, which may be problematic because of the lack of observational data. WaPOR ET products have recently been presented by the World Food Organization (FAO). The actual ET rate in the FAO WaPOR product is measured using the ETLook algorithm, and the equations used to calculate the actual ET rate in this algorithm were described in detail in a previous study [11]. To introduce this algorithm, the ETLook model is based on the Penman–Monteith equation, which is generally applied to estimate the total potential ET (including the two components of evaporation and transpiration) using common meteorological data (such as solar radiation, air temperature, vapor pressure, and wind speed) [12]. In the ETLook algorithm, with a slight change from this equation, a combination of remote sensing information (including NDVI, surface albedo, soil moisture, solar radiation, land surface cover, and a digital elevation model) and meteorological data (including temperature, humidity, wind speed, and precipitation) is used to estimate the actual ET, and the results are available to the public for free on the FAO website.

On-farm management practices play an important role in improving water productivity. Therefore, in order to spatially identify regions with appropriate and poor farm management practices and to assess the efficacy of crop management strategies, the creation of water productivity maps at the basin scale may be necessary [3]. To know the relationship between water and food, tracking water productivity, and following efficiency objectives, information on water productivity with precise spatial resolution is of vital importance. However, due to the nature of spatial variability at the basin scale and general measurement problems, such data are not readily accessible in the majority of regions, and field measurements are unable to capture spatial trends over large areas. Therefore, preparing water productivity maps at the basin scale can help with solving these problems.

The purpose of this study was to prepare water productivity and actual ET maps to determine critical points from the viewpoints of water consumption and water productivity in the Maroon-Jarahi basin and to provide management solutions to increase water productivity in the basin.

2. Materials and Methods

2.1. Area of Study

The Maroon-Jarahi basin (Figure 1) has an area of 24,307 km^2. Most of this basin is located in Khuzestan Province. The long-term average water flow of the Maroon River in Khuzestan Province is equal to 2105 million m^3. The length of the Maroon-Jarahi River in the whole area is 691 km, with an average slope of 14%. There are more than 20,000 ha of palm gardens in the Maroon-Jarhi basin, 75% of which are in the Shadgan region, downstream of the basin. Intensive rice cultivation is carried out on over 14,000 ha in this basin, 65% of which is located upstream of the basin. At the same time, more than 15,000 ha of palm trees in Shadgan are under water stress, although the cultivation of 4800 ha of paddy downstream of the basin in Shadgan adds to this water stress.

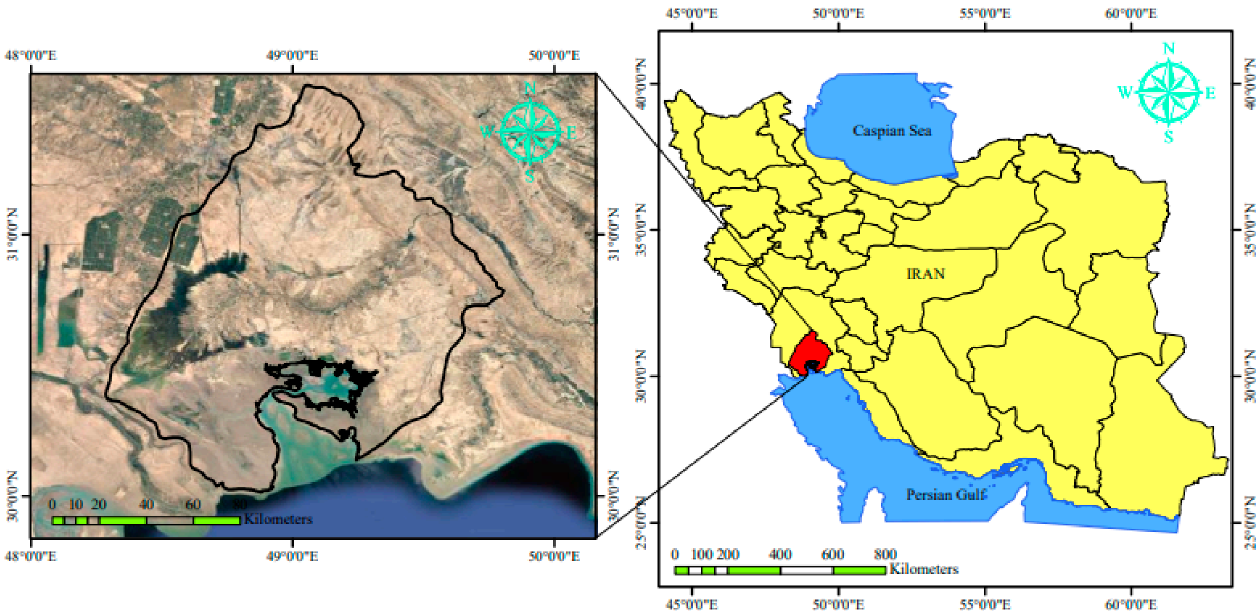

Figure 1. Study area and locations of major agricultural sites in the Maroon-Jarahi basin.

2.2. ETLook Model

The Penman–Monteith equation is solved twice by the ETLook model: once for soil evaporation (E) and once for canopy transpiration (T):

$$\lambda E = \frac{\delta(R_{n,soil} - G) + \rho_{air} C_p \frac{(e_s - e_a)}{r_{a,soil}}}{\delta + \gamma\left(1 + \frac{r_{s,soil}}{r_{a,soil}}\right)} \tag{1}$$

$$\lambda T = \frac{\delta\left(R_{n,canopy}\right) + \rho_a C_p \frac{(e_s - e_a)}{r_{a,canopy}}}{\delta + \gamma\left(1 + \frac{r_{s,canopy}}{r_{a,canopy}}\right)} \tag{2}$$

Regarding the net available radiation ($R_{n,soil}$ and $R_{n,canopy}$), as well as the aerodynamic and surface resistance, the two formulae are different. Additionally, for transpiration, the earth heat flow (G) is not considered. Figure 2 shows a graphic illustration of the key ideas of the ETLook model [8].

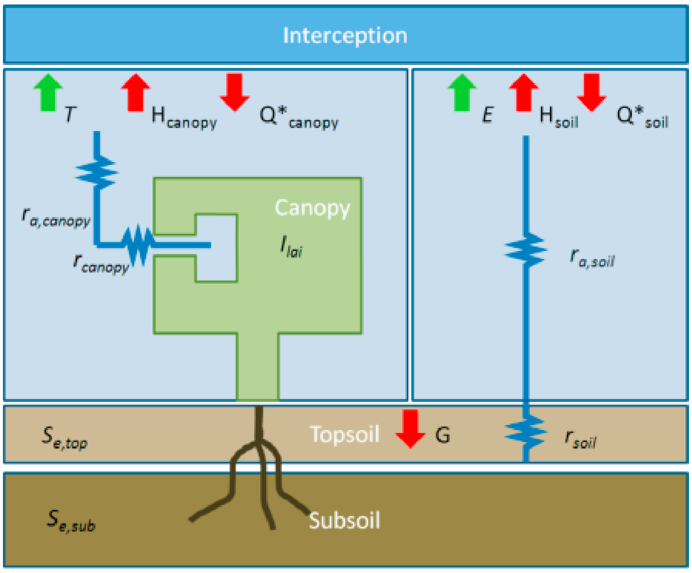

Figure 2. Conceptual diagram of ETLook algorithm (adapted with permission from Ref. [8]. 2018, FAO).

2.3. Net Primary Production

The most important feature of an ecosystem is its net primary production (NPP), which describes how photosynthesis transforms carbon dioxide into biomass. The term NPP refers to a group of definitions that define the exchange of carbon between an ecosystem and the atmosphere. Satellite images and meteorological data are used to derive the NPP. Veroustraete et al. [13] provided a detailed explanation of the methodology's basic concepts, and Eerens et al. [14] provided information on how it is implemented in practice. The Copernicus Global Land Component enhanced these methods, with the inclusion of biome-specific light use efficiency (LUE) being the most significant improvement. All three levels of the NPP were provided on a decadal basis, with pixel values representing the average daily NPP for that particular decade in gC/m^2/day. Sometimes it is more appropriate to measure dry matter production (DMP), such as for agricultural objectives (in kg DM/ha/day). The DMP can be calculated by multiplying the NPP by a constant of 0.45 gC/gDM. Therefore, 1 gC/m^2/day (NPP) = 22,222 kg DM/ha/day (DMP). Although greater values (theoretically up to 320 kgDM/ha/day) can occur, typical NPP values range between 0 and 5.4 g C/m^2/day (NPP) or 0 and 120 kgDM/ha/day (DMP) [8]. In this study, net primary production (NPP) data were downloaded from the WaPOR and Google Earth Engine (GEE) systems at a pixel resolution of 250 m.

2.4. Crop Water Productivity

Crop water productivity (CWP) is calculated as the yield (Y) divided by actual evapotranspiration and interceptions (ETIa). A low ETIa and a high yield cause high water productivity because the plant is producing a lot while not using much water. A high ETIa and low yield cause low water productivity because the plant is not producing much while using a lot of water. CWP was calculated for the study region using the yield (NPP) map and ETIa from Equation (3):

$$\mathrm{CWP}(\mathrm{kg/m^3}) = \frac{\mathrm{Yield}(\mathrm{kg/ha})}{\mathrm{ETIa}(\mathrm{mm})} \tag{3}$$

Actual evapotranspiration and interception (ETIa) data were downloaded in 250 m pixel resolution from the WaPOR and Google Earth Engine systems. The total amount of soil evaporation (E), canopy transpiration (T), and evaporation from raindrops caught by leaves (I) is known as the ETIa [8,15].

2.5. Land Use/Land Cover Map

The basin land use or land cover is one of the factors affecting ET and the hydrological cycle. Knowing the different types of terrain is important for comparing ET. The land-use map of Khwaja Nasir Toosi University [16] with 13 classes was used in this research to assess ET in various locations and to comprehend its various uses. A map of the studied basin's land cover is shown in Figure 3.

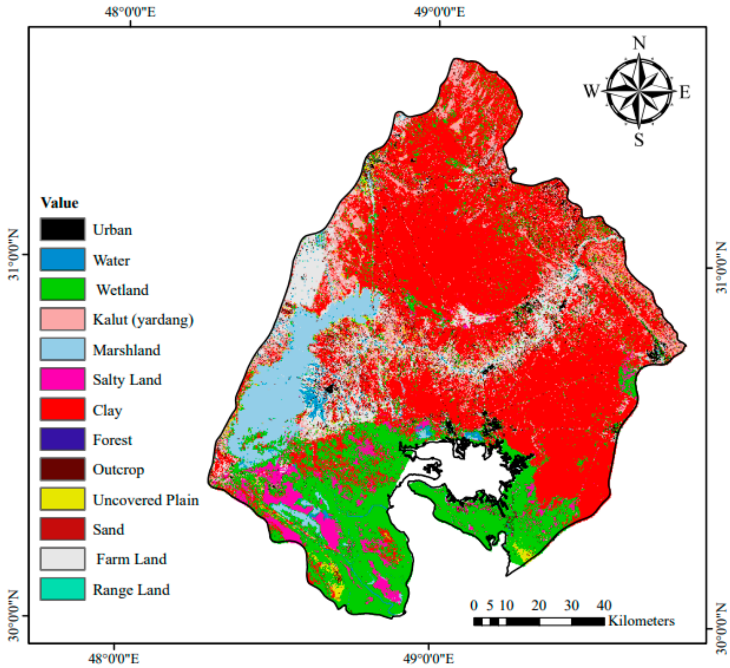

Figure 3. Land use/land cover map of the Maroon-Jarahi basin.

3. Results and Discussion

3.1. Actual Evapotranspiration and Interception

For a better spatial and temporal analysis of the actual evapotranspiration and interception in the Maroon-Jarahi basin, an annual evapotranspiration and interception map for the agricultural class is shown in Figure 4. Irrigated lands are shown in blue, and nonirrigated lands with the least evapotranspiration are shown in red. Compared with nonirrigated lands, irrigated lands occupied a smaller area of the basin.

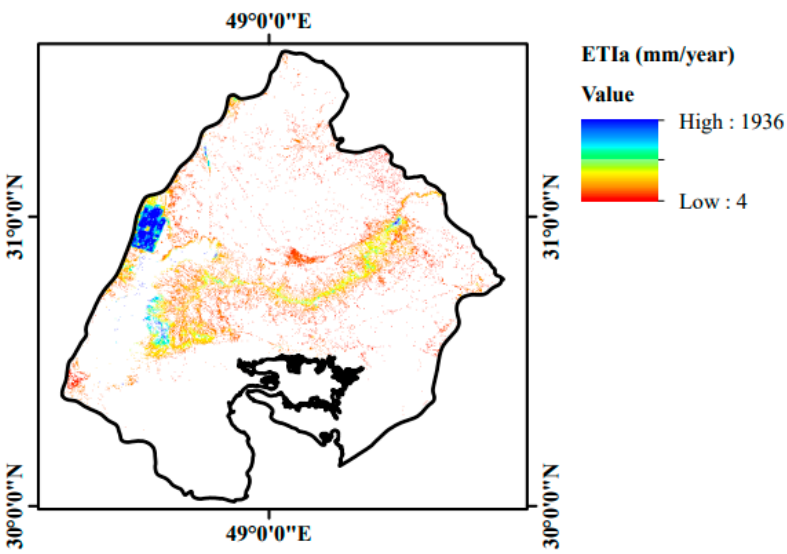

Figure 4. Actual ETI from WaPOR in 2017.

The normalized difference vegetation index (NDVI) for Maroon-Jarahi basin in 2017 (Figure 5) shows good agreement between pixels with high evapotranspiration and pixels with high NDVI values. In other words, areas with higher vegetation cover had higher evapotranspiration.

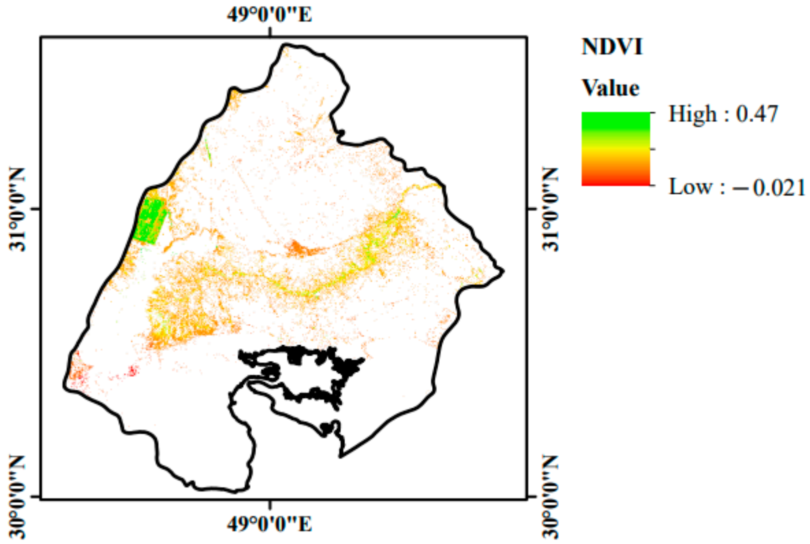

Figure 5. Year-averaged NDVI in 2017 using the MODIS product.

3.2. Net Primary Production

Figure 6 shows the spatial changes in the net primary production at the level of the Maroon-Jarahi basin area, which indicates the conversion of carbon dioxide caused by photosynthesis into biomass. The blue points represent the highest NPP, and the red points represent the lowest NPP at the basin level.

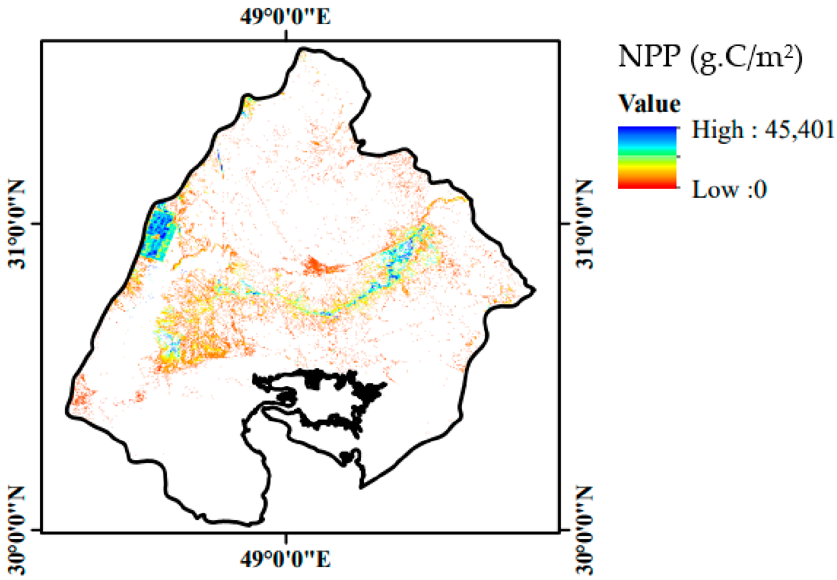

Figure 6. NPP from the WaPOR in 2017.

3.3. Crop Water Productivity Mapping

Figure 7 shows the spatial changes in water productivity in the Maroon-Jarahi basin. In Figure 7, the red dots indicate low WP values, indicating land where agricultural and irrigation management practices have not been performed properly. The blue points indicate fields with high WP values. However, the water productivity map shows that agricultural and irrigation management can significantly improve water productivity. The blue points indicate that farmers properly considered in-farm management to maximize the yield per drop of water.

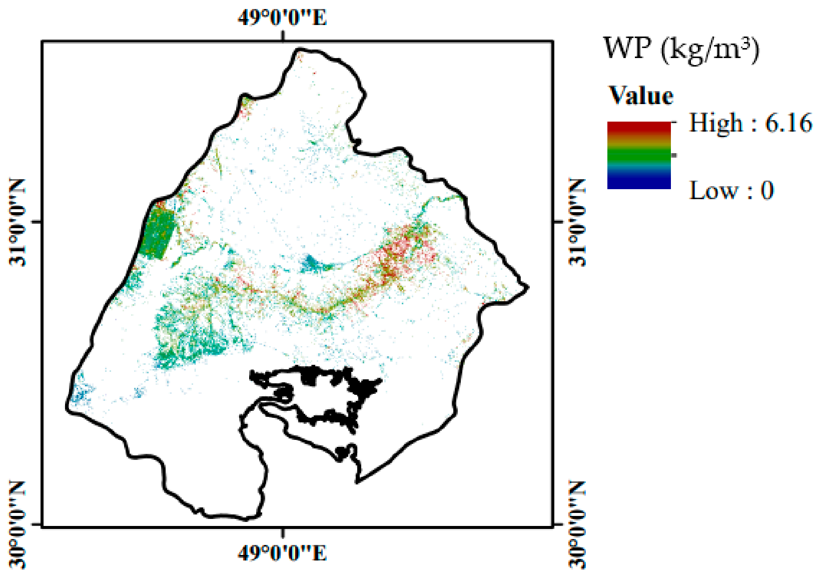

Figure 7. Water productivity map of the Maroon-Jarahi basin.

4. Conclusions

The excessive use of water in the agricultural sector can cause serious problems in arid and semiarid regions. Water consumption is strongly correlated with the amount of ET; therefore, ET estimation can provide valuable information for water consumption planning and management. The Maroon-Jarahi basin's situation in regions with low WP values and high evapotranspiration rates, which are regarded as critical points, was the main focus of this study. The preparation of evapotranspiration and water productivity maps can help local farmers and decision makers identify the best agricultural practices used in high-productivity fields and adopt a similar approach in low-productivity areas to increase productivity in the future. Given the high level of water consumption for agriculture, using remote sensing to monitor agricultural water productivity can help identify gaps in water productivity and evaluate potential solutions to address those gaps.

The irrigation water management system in the Maroon-Jarahi basin agriculture project has not been developed or modified since the beginning of the project. Therefore, one of the management tools of the project can be remote sensing technology used in water allocation, crop water requirement assessment, and water productivity monitoring to identify productivity gaps and develop appropriate solutions to address them.

According to the results obtained after determining the critical points from the point of view of water consumption and water productivity, it is possible to propose management strategies to reduce water consumption for the studied basin, and some of these strategies are as follows:

1. Using different types of mulch to reduce evaporation;
2. Using transplantation;
3. Land leveling;
4. Regulating deficit irrigation;
5. Using subsurface drip irrigation.

These factors can help reduce water consumption and increase water productivity.

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