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Determining the Critical Points of the 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 old 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 with water crises in Africa and the Middle East, and estimation of actual evapotranspiration (ETa) is one of its main products. The Google Earth Engine System (GEE), introduced by Google in 2010, is a powerful remote sensing tool for extracting useful information from satellite imagery. In this study, the actual evapotranspiration maps of the Maroon-Jarahi basin for 2017 were extracted using the methodology introduced by FAO and provided in the WaPOR database, and the coding was done in the GEE system. The results showed that 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 accounts for most of the water consumption in Iran and worldwide, water management in the agricultural sector is of great importance. Water productivity is a key indicator for studying and improving agricultural water management, as well as one of the Sustainable Development Goals. The aim of this study is to determine the critical points of the Maroon-Jarahi basin from the point of view of water productivity and water consumption using modern remote sensing methods, and find solutions to improve water productivity in these areas. Recently, the Food and Agriculture Organization of the United Nations (FAO) established the WaPOR open-access portal on water productivity to map countries facing water crises in Africa and the Middle East, and 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 little time and cost, so it can be used to manage the agricultural sector. 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 is 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

With more than 70% of the world's freshwater consumed, the agricultural sector will need to increase food production by 60% in developed countries and 110% in developing countries by 2050 to meet future food demand. 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 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 [9]. Water productivity is a key factor in studying the production of agricultural products and the efficiency of water resources [5]. Water productivity is typically estimated using the crop yield and evapotranspiration (ET). Crop yield depends on many factors, such as soil fertility, disease control, and agricultural practices, whereas ET varies with rainfall pattern, soil moisture, type of irrigation and drainage system, and climatology [16]. Remote sensing is becoming the most suitable alternative for assessing water productivity and estimating its components at multiple temporal and spatial resolutions on a pixel-by-pixel basis, from the field scale to the continental scale [12]. However, the economic, agricultural, and social development of a region is affected by the proper scheduling and management of the water resources of the basin, which requires knowledge of the hydrological behavior of the system, including temporal and spatial changes in important components such as actual ET in the basin. Therefore, methods that accurately estimate the actual ET are required [11]. The estimation of ET is difficult owing to its complex nature. Various methods exist to estimate this parameter. Remote sensing-based methods are more popular than classical methods because of their wide coverage and comparability with numerical climate models. There are several different remote sensing approaches for estimating actual ET, including surface energy balance [2,4], Penman-Monteith [7], and experimental methods based on plant indices [10,13]. 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 are described in detail in a previous study [3]. However, to introduce this algorithm, it can be explained that 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) [1]. To introduce this algorithm, it can be explained that the ETLook model is based on the Penman-Monteith equation, in which the general application of this equation is to estimate the amount of total potential evaporation-transpiration (including the two components of evaporation and transpiration) using common meteorological data (such as solar radiation, air temperature, vapor amounts, and wind speed) [1]. However, 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) are 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, the preparation of water productivity maps at the basin scale can be a prerequisite for the spatial identification of areas with good and poor farm management practices and for evaluating the effectiveness of agricultural management strategies [16]. Information on water productivity with accurate spatial resolution is of great importance for understanding the relationship between water and food, monitoring water use efficiency, and pursuing efficiency goals. However, such information is not available in most regions, and field measurements cannot capture spatial trends over large areas because of the nature of spatial heterogeneity at the basin scale and common measurement problems. Therefore, preparing water productivity maps at the basin scale can facilitate solving these problems.

The purpose of this study was to prepare water productivity and actual ET maps to determine critical points from the point of view 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. Description of the Study Area

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 the 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 in an area of 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.

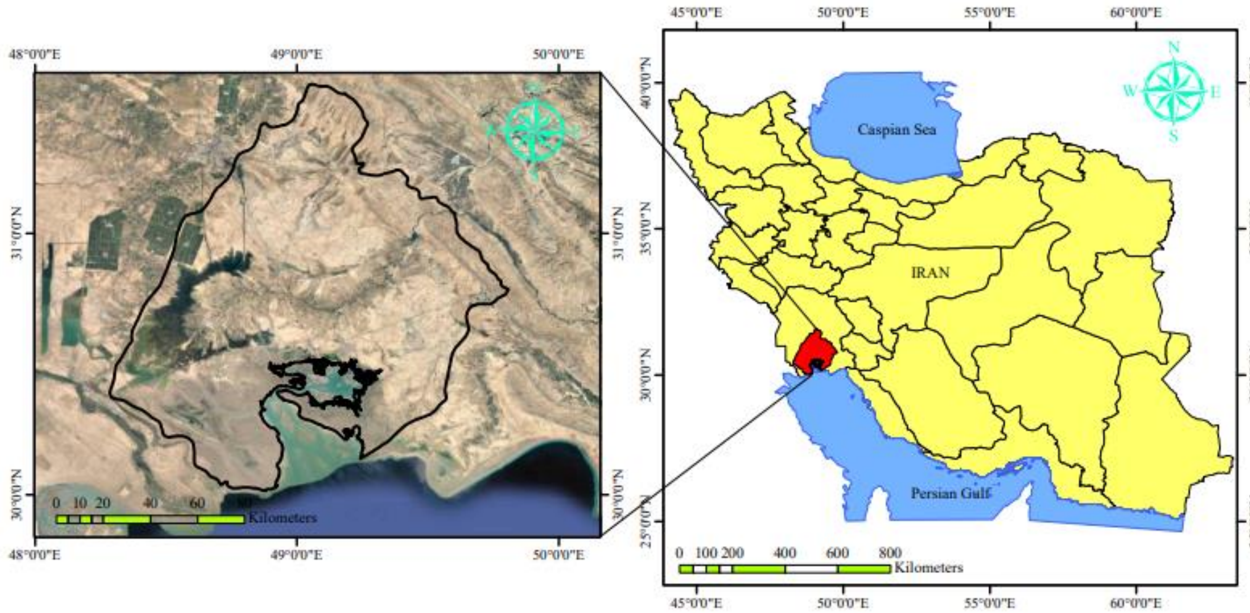

Figure 1. Study area and locations of major agricultural sites in the Maroon-Jarahi basin.

2.2. ETLook Model

The ETLook model solves two versions of the Penman-Monteith equation: one for soil evaporation (E) and one for canopy transpiration (T):

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

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

The two equations differ with respect to the net available radiation (Rn, oil and $Rn, canopy$) as well as the aerodynamic and surface resistance. Furthermore, the soil heat flux (G) is not taken into account for transpiration. The main concepts of the ETLook model are illustrated in a schematic representation in Figure 2 [7].

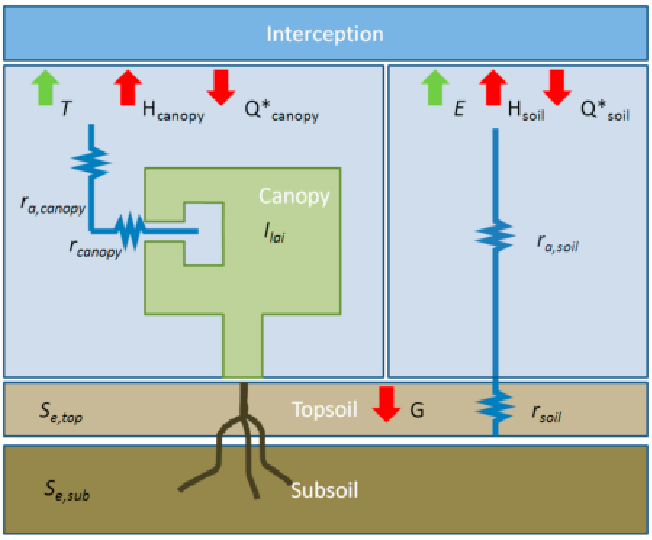

Figure 2. Conceptual diagram of ETLook algorithm [7].

2.3. Net Primary Production

Net primary production (NPP) is a fundamental characteristic of an ecosystem that expresses the conversion of carbon dioxide into biomass driven by photosynthesis. NPP is part of a family of definitions that describe carbon fluxes between the ecosystem and the atmosphere. The NPP was derived from satellite imagery and meteorological data. The core of the methodology is detailed in Veroustraete et al. [15], and its practical implementation is described by Eerens et al. [6]. These methodologies were improved within the framework of the Copernicus Global Land Component, with the most important change being the incorporation of biome-specific light use efficiency (LUEs).

NPP was delivered for all three levels on a dekadal basis, where pixel values represent the average daily NPP for that specific dekad in gC/m²/day. In some cases, such as for agricultural purposes, it is more appropriate to measure Dry Matter Production (DMP) (in kg DM/ha/day). NPP can be converted to DMP using a constant scaling factor of 0.45 gC/gDM. Therefore, 1 gC/m²/day (NPP) = 22,222 kg DM/ha/day (DMP). Typical values for NPP vary within the region between 0 and 5.4 gC/m²/day (NPP) or 0 and 120 kgDM/ha/day (DMP), although higher values can occur (theoretically up to 320 kgDM/ha/day) [7]. In this study, net primary production (NPP) data were downloaded from WaPOR and Google Earth Engine (GEE) systems at a pixel resolution of 250 m.

2.4. Crop Water Productivity

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

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

Actual evapotranspiration and interception (ETIa) data is downloaded in 250-m-pixel resolution from WaPOR and the Google Earth Engine system. The ETIa is the sum of soil evaporation (E), canopy transpiration (T), and evaporation from rainfall intercepted by leaves (I) [7].

2.5. Land Use/Land Cover Map

One of the parameters influencing ET and the hydrological cycle is the land use in the basin. To compare ET, knowledge of terrain type is essential. In this study, the land-type map of Khwaja Nasir Toosi University [8] in 13 classes was used to understand the different uses and evaluate ET in different areas. Figure 2 shows a land cover map of the studied basin.

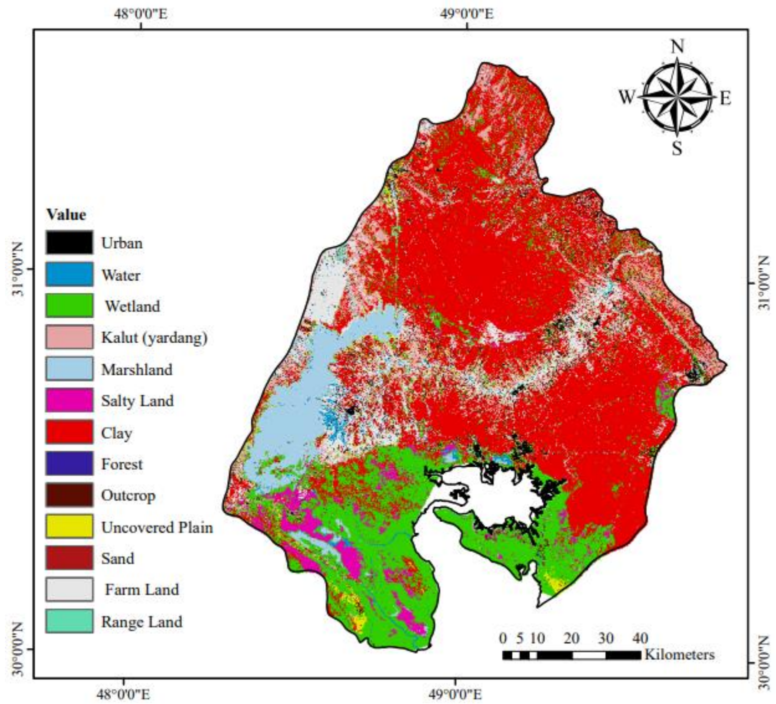

Figure 3. Landuse/LandCover map of the Maroon-Jarahi basin.

3. Results and Discussion

3.1. Actual Evapotranspiration

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

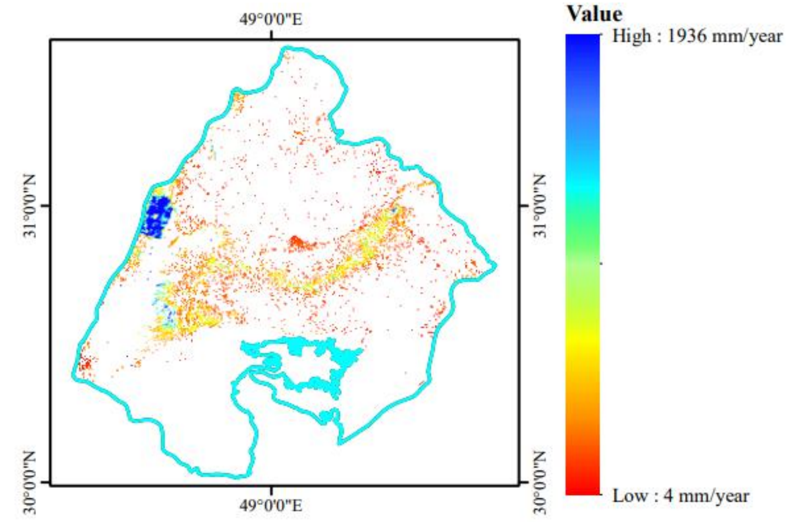

Figure 4. Actual ETI from WaPOR in 2017.

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.

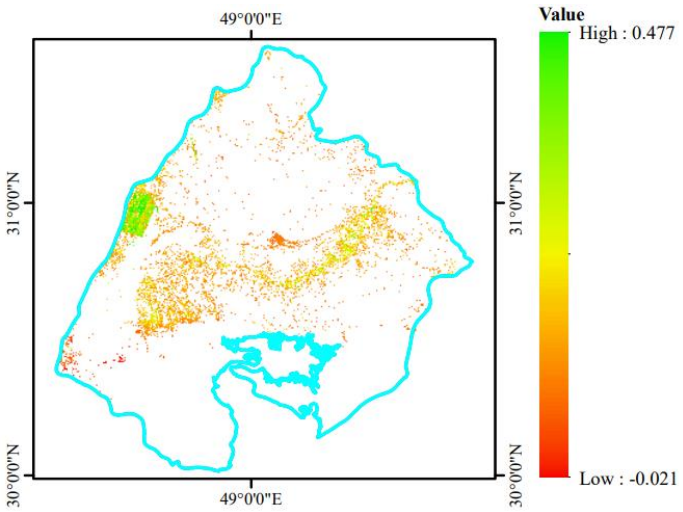

Figure 5. Year-averaged NDVI in 2017 using the MODIS product.

3.2. Net Primary Production

Figure 6 shows the spatial changes in 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.

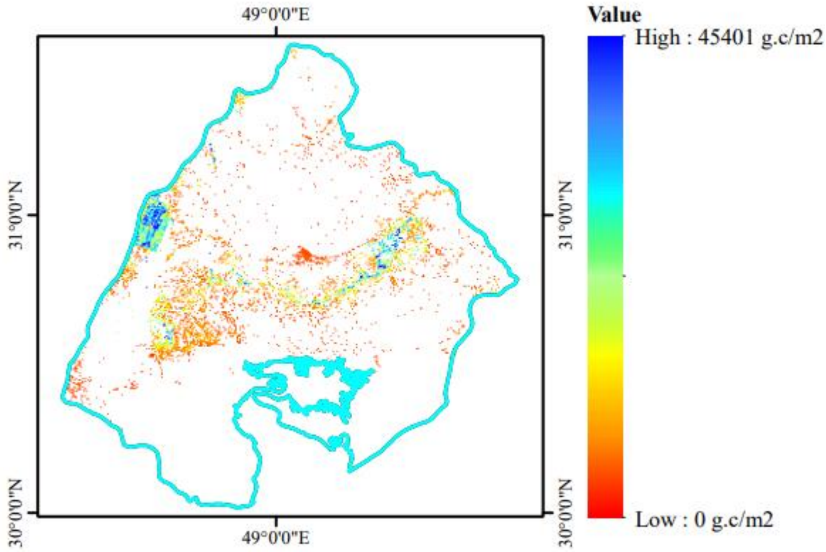

Figure 6. NPP from the WaPOR in 2017.

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 lands 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 showed 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.

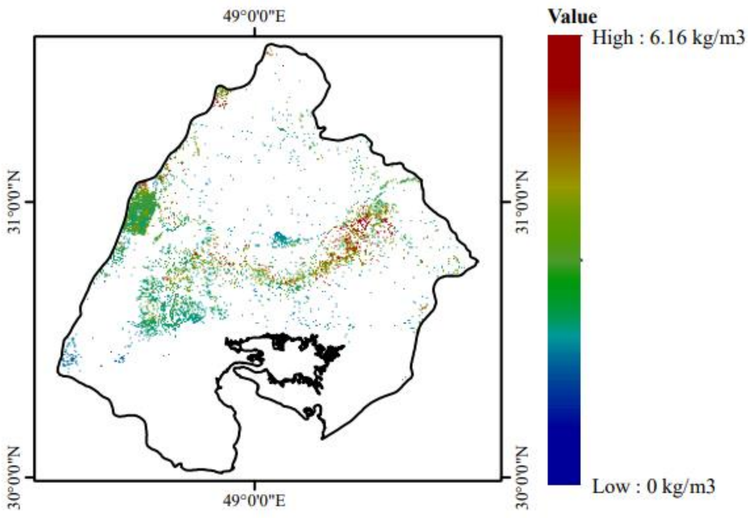

Figure 7. Water productivity map of the Maroon-Jarahi basin.

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 main objective of this study was to address the situation in areas with low WP values and high evapotranspiration rates in the Maroon-Jarahi basin, which are considered critical points. 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 thus adopt a similar approach in low-productivity areas to increase productivity in the future. Given the high level of water consumption in 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. Regulated deficit irrigation
5. Using subsurface drip irrigation

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

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