Advancing water productivity monitoring: WaPLUGIN for the analysis and validation of FAO WaPOR data in QGIS.

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Abstract

The FAO WaPOR (Water Productivity Open Access Portal) is a significant initiative developed by the Food and Agriculture Organization of the United Nations (FAO). It provides extensive datasets derived from remote sensing, specifically aimed at monitoring water productivity in agriculture. The primary goal of WaPOR is to enhance water use efficiency and promote sustainable agricultural practices globally. Given the importance of this datasets and with the objective to streamline access to the datasets for users, we have developed WaPLUGIN. WaPLUGIN is a QGIS plugin designed to help users easily retrieve WaPOR datasets directly into QGIS environment and enables the computation of various performance metrics that are useful to assess efficiency of the irrigation schemes. This plugin is a useful tool which helps users and stakeholders to focus on the interpretation of the datasets and make subsequent decisions. The plugin also helps to download and process the WaPOR data.

1. Introduction

Water scarcity is a global concern, with shortages impacting regions worldwide. A significant portion of available water resources is channeled into agricultural irrigation, essential for food production. However, the efficiency of water use in these irrigation systems often lacks proper monitoring and management. One critical challenge lies in accessing data necessary for effectively using water.

Traditional methods for monitoring agricultural water consumption are hindered by time taken for data acquisition processes which leads to substantial increase in costs and resources. To address this issue, remote sensing technology has emerged as a viable alternative for assessing and monitoring water usage efficiently. Remote sensing data offer rapid and accessible information crucial for improving water management practices, particularly in agriculture.

Recognizing the need for accessible data and tools to enhance water productivity, the Food and Agriculture Organization of the United Nations (FAO) initiated the Water Productivity Open Access Portal (WaPOR). WaPOR provides free access to a diverse range of remote sensing-derived datasets, facilitating real-time monitoring of agricultural productivity across various scales, including both rainfed and irrigated areas (Food and Agriculture Organization of the United Nations (FAO), 2020b).

Since its first release in 2017, WaPOR data has been continuously improved. Currently, two versions of the WaPOR datasets are available. WaPOR version 2, accessible via *WAPOR V2* website, contains datasets spanning from 2009 to 2023, offering three resolutions, namely, continental (L1), national (L2), and sub-national (L3) levels with 250, 100, and 30 m respectively. At L1, data is accessible for Africa and Middle East countries, while L2 covers some partner countries and L3 targets small-scale irrigation schemes. These datasets are available at various time frames, including daily, dekadal, monthly, seasonal, and annual intervals. The latest version, WaPOR version 3, features different methodologies and input parameters aimed at enhancing accuracy. It now provides global coverage at a $300m$ resolution, a national coverage for Africa, the Middle East, Sri Lanka, and Colombia at 100m, and certain sub-national irrigation schemes at $20m$ resolution. Access to both versions is streamlined through the same *FAO* , facilitating ease of access.

By providing near real time information, WaPOR opens the door for service-providers to assist farmers in obtaining more reliable yields and improving their livelihoods. At the same time, irrigation authorities have access to information to modernize their irrigation schemes and government agencies can use this information to promote and increase the efficient use of their natural resources.

Accessing and using WaPOR data, however, can be challenging due to the complexity of data download processes and the need for further analysis in geographic information system (GIS) environments. To streamline these processes and empower users, we have developed WaPLUGIN, a dedicated QGIS plugin designed to seamlessly integrate with WaPOR datasets.

WaPLUGIN simplifies WaPOR data exploration and retrieval directly within QGIS, offering functionalities such as cropping datasets to specific study areas and downloading time series data. This plugin not only facilitates access to both WaPOR version 2 and version 3 datasets but also includes tools for calculating essential performance indicators. These metrics enable users to assess the effectiveness and sustainability of water use in crop production, informing decisions on irrigation techniques, crop selection, and overall land management strategies.

2. Materials and methods

We illustrate in Figure 1, our workflow to use WaPLUGIN. In this chapter, we describe the functions in the plugin and how to use them.
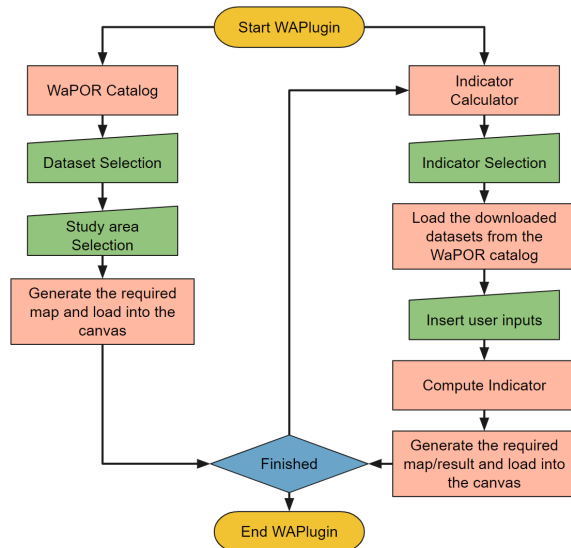

Figure 1. Plugin flowchart.

3. Tabs Description

The plugin has four main tabs: sign-in, WaPOR2 catalog, WaPOR3 catalog and Indicator calculator.

3.1 Sign-In

WaPOR V2 and V3 datasets are hosted on two separate websites with distinct architectures and displays. Although the V2 catalog is also available on the V3 website, we have chosen to maintain a link to the V2 website due to its greater stability. To access WaPOR V2 datasets, users require a personal API obtained from their WaPOR account created on this website: WaPOR V2. Users can copy and paste the API to the sign-in tab of WaPLUGIN to guarantee access to the catalog. To save time, users can store the API in the plugin by clicking "*Save Token*". Subsequently, when using the plugin in the future, simply click "*Load Token*" for automatic sign-in. It's important to note that this API sign-in process is specific to WaPOR V2 data (Figure 2). For accessing WaPOR V3, users can directly navigate to the WaPOR3 Catalogue tab without needing the API.

3.2 WaPOR2 Catalogue

In the WaPOR2 Catalogue tab, users can explore and download the required datasets. This tab is divided into three main parts: Raster Download, Coordinate Selection, and Raster Load (Figure 3).

In the Raster Download section, users can select the necessary information regarding the type and temporal scale of the datasets. This section includes various buttons that facilitate the exploration of all available data on WaPOR V2. To begin, users select the *workspace* from the dropdown menu and choose WaPOR 2 (other datasets are available but are outside the scope of this plugin). They can then use the *level filter* to select the
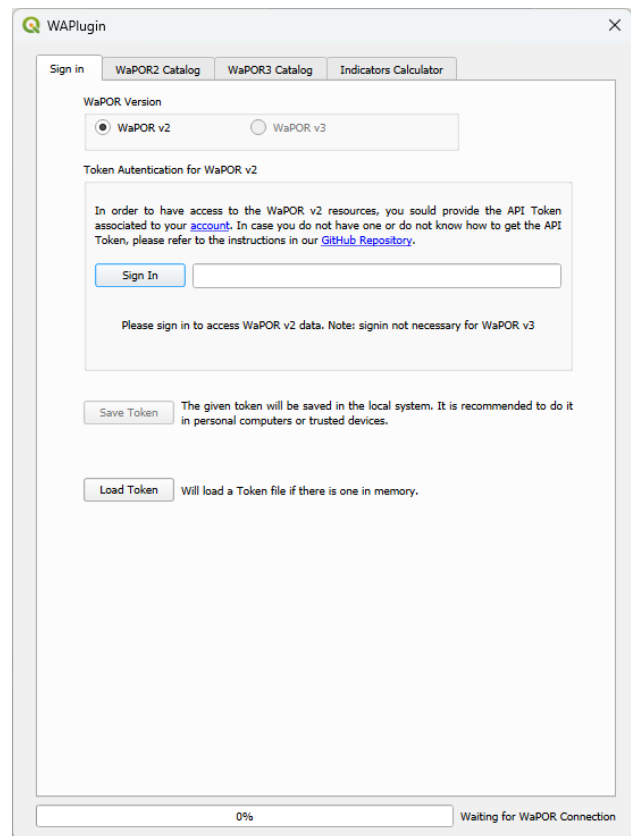

Figure 2. Sign-in tab in WaPLUGIN.

desired spatial resolution (L1, L2, L3). Similarly, the *time filter* can be used to filter the data, displaying all temporal steps available in WaPOR V2, including daily, dekadal, monthly, seasonal, and annual. Users also have the option to filter the datasets based on *country* using the dropdown menu, which provides access to a list of partner countries of WaPOR V2 with data available at 100m and 30m for some areas within these countries. It's important to note that not all these filters need to be activated simultaneously.

Once the spatial resolution is set, users need to select the *Raster Type* using the dropdown menu, which displays all the available layers and filters them based on the previous selections. Next to the raster type menu, a *details* button is available, providing a complete description of the selected dataset, including the conversion factors needed to correct the downloaded datasets. This feature helps users better understand the data they are working with. Details about the methodology used to produce WaPOR V2 dataset are available in the FAO WaPOR database methodology report (Food and Agriculture Organization of the United Nations (FAO), 2020a).

After selecting the raster type, users need to choose the time frame for their rasters. The *time frame from* and *time frame until* buttons are automatically populated once the layer type is selected or the time filter is applied. Multiple rasters can then be downloaded simultaneously.

In the next section, the *coordinate selection* allows users to define the spatial extent of the rasters they need to download. Users can choose either the *canvas extent*, which is limited to the windows displayed in the QGIS map canvas, or they can clip the data based on a *shapefile*. The shapefile dropdown menu
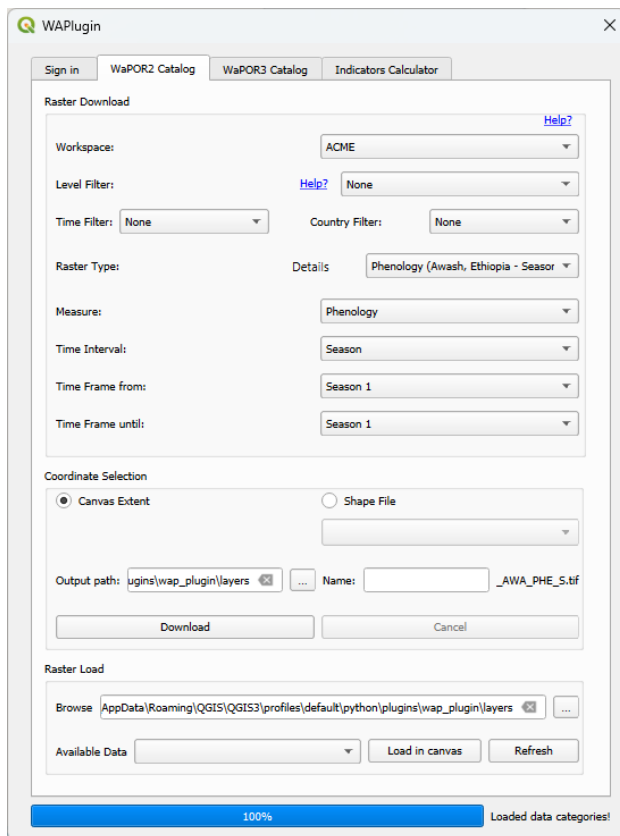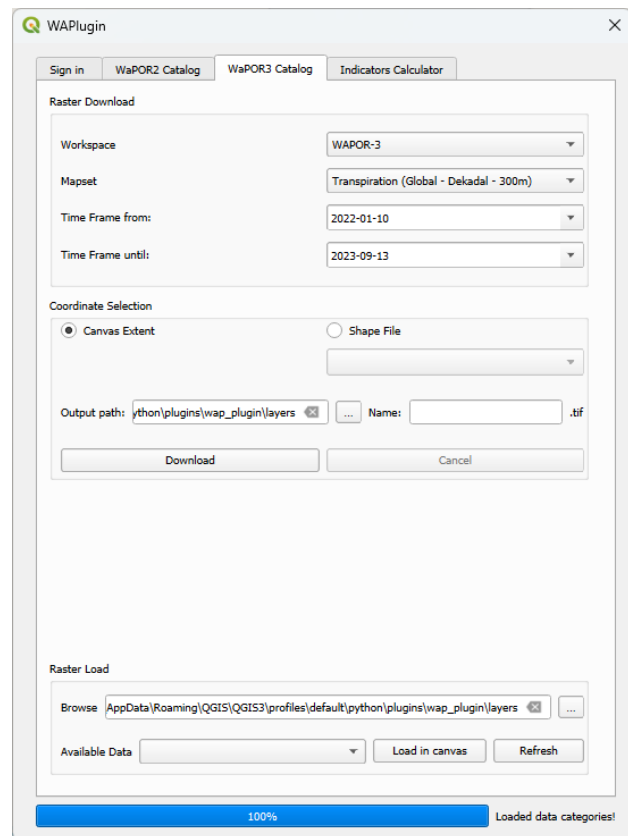
Figure 3. WaPOR V2 tab in WaPLUGIN.

Figure 4. WaPOR V3 tab in WaPLUGIN.

displays all the vector files in the user's QGIS project. It's important to note that for L3 data download, the map canvas needs to be zoomed into the study area or the country of interest. The plugin recommends using the *QuickMapServices* plugin to access base maps and easily locate the study area. The plugin automatically creates a *layers* file that will store the downloaded data. Another file can be selected using the *output path* option. By default, the plugin saves the data with a default suffix as "[Name] [level] [place] [raster type] [time filter].tif". The [Name] can be modified by the users. After setting the parameters, users click on the download button. The progress bar shows the progress of the raster download.

In the third section, the *Raster Load* enables users to load the downloaded layers into the QGIS canvas without closing the plugin. Once the download is complete, users can select the folder that has been used to store the downloaded data. This option is automatically set to the path of the layers folder created by the plugin. In the *available data* dropdown menu, users will find all the rasters that have been downloaded and are available for loading. Once the desired raster is selected, the " *load in canvas* " button loads the rasters into the QGIS map canvas. The *refresh* button is used when downloading other datasets to display them as available data.

3.3 WaPORV3 Catalogue

In this tab, users can access and download data from the version 3 catalogue. Please note that this release is new (December 2023) and the platform and code are still being finalized. Unlike the WaPORV2 catalogue, accessing this catalogue does not require an API (Figure 4).

The structure of this tab is similar to the WaPORV2 catalogue, with the exception of the *Raster Download* section, which currently offers fewer options. This is because the WaPOR version 3 catalogue is still under construction. Additional options, including *Time* and *Country Filters* , will be added as soon as the V3 catalogue becomes stable. For now, in this tab, users need to set the *Workspace* to "WAPOR-3" and then use the *Mapset* to select the desired layer. The layer names include the Level (Global, National, Sub-national), the time scale (Dekadal, Annual, Monthly, Daily), and the resolution (300m, 100m, and 20m). Users can then select the time frame by setting the start and end dates for their downloads using the *Time Frame From* and *Time Frame Until* buttons. The coordinate selection and raster load functions are already described in the V2 catalogue.

3.4 Indicators Calculator

In this tab, users can compute various performance indicators based on the WaPOR datasets that have been downloaded. The tab consists of four main sections: Indicator selection, formula parameters, indicator computation and raster load (Figure 5).

In the indicator selection section, users can choose the indicator they want to compute from a dropdown menu. Currently, there are 6 available indicators: *Equity, Beneficial Fraction, Adequacy, Overall Consumption Ratio, Field Application Ratio (efficiency), and Depleted Fraction.* These indicators are designed to evaluate water use in agricultural plots using data derived from remote sensing techniques. Details about the equation and datsets required for each indicator are displayed after the indicator's selection. More details about these indicators are widely available in the literature ((Bos et al., 2005), (Molden et al., 1998),(Steduto et al., 2012)).
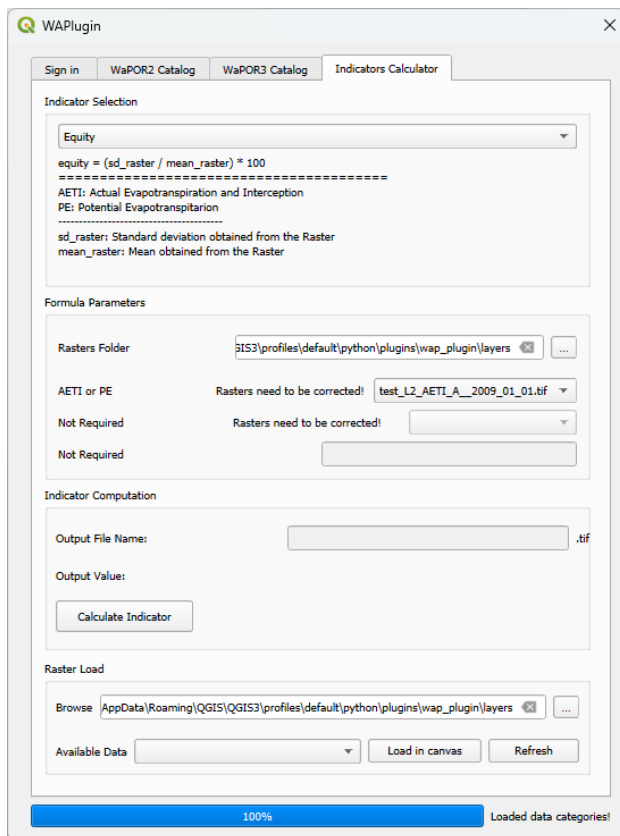
Figure 5. Indicator calculator tab in WaPLUGIN.

In the formula parameters section, users set the rasters required to calculate the indicator. They need to specify the path to the *Rasters folder* containing the downloaded data, which is automatically set to the layers folder created by the plugin. Note that all the required rasters to compute the indicators need to be in the same folder. A list of parameters is displayed, representing the rasters needed for the indicator calculation. These fields are automatically populated based on the required raster types. It is important to note that all input rasters need to be corrected using the conversion factor before using them for indicators computation. These conversions are only required for data downloaded from the WaPOR2 catalogue and can be retrieved from the *details* button next the raster type. If the indicators are computed from the WaPOR3 catalogue there is no need to correct the rasters as it is automatically corrected after data download. Some indicators may require additional inputs derived from ground-based data. Therefore, users need prior knowledge about the irrigation schemes and crop types to compute these indicators. Several studies on computing performance indicators from WaPOR datasets are available ((Chukalla et al., 2021), (Blatchford et al., 2020)). Additionally, the IHE Delft Institute for Water Education offers open courses on the use of WaPOR data for water productivity assessments (from ocw).

The output format can be either a scalar or a raster. In the indicator computation section, users need to provide an *output file name* for the raster file that will store the computed indicator. This raster will be saved in the same folder as the input parameters once the " *Calculate Indicator* " button is clicked. If the output is a scalar, the value will be displayed in the plugin next to the *output value* field. The indicator rasters can be loaded into the QGIS canvas for further analysis through the raster load section.

The plugin only detects the rasters downloaded from the plugin. However, if users want to upload a raster from another source and use it as an input parameter to compute the indicators, this raster name should follow this structure [Name] [level] [place] [raster type] [time filter].tif so it can be detected by the plugin.

3.5 Future Features

The plugin is undergoing development to introduce new features that will enhance its functionality. These upcoming features include:

- *Expanded Indicators:* A new list of indicators based on remote sensing data will be added to the plugin. This will provide users with a broader range of options to assess water use efficiency and productivity in agricultural plots.

- *Data Validation:* A data validation feature is being developed to improve the accuracy of computed indicators. Users will be able to validate WaPOR datasets by incorporating ground-based measurements into the plugin. This validation process will enhance the reliability and precision of the computed indicators.

These upcoming features aim to enhance the plugin's capabilities, provide greater flexibility to users, and ensure more accurate assessments of water use efficiency and productivity in agriculture.

4. Case Study

To showcase the capabilities of WaPLUGIN, we focused on analyzing irrigation plots within the Xenavane sugarcane plantation in Mozambique. This specific area was chosen because valuable information about the crop type, irrigation scheme, and cropping seasons was accessible through the freely available GitHub repository at WAPORWP.

For this study, we have selected two plots one using center pivots irrigation and the second using a mixed irrigation technique. The aim is to evaluates how these two techniques affect water and crop productivity Figure 6.
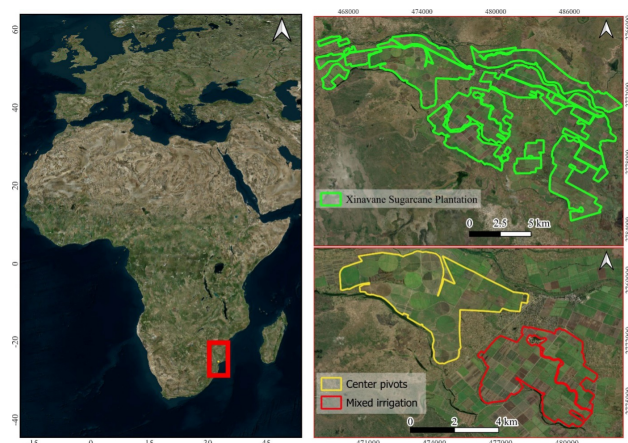

Figure 6. Location of Xenavane sugarecane plantation.

4.1 Temporal assessment of Actual Evapotranspiration and Interception

Actual Evapotranspiration and Interception (AETI) is an important dataset for monitoring crop health and water management in agriculture. By comparing AETI with Potential Evapo-Transpiration (PET), farmers can detect water stress, optimize irrigation schedules, and assess crop health, including factors like disease and nutrient deficiencies. AETI data also aids in quantifying water use efficiency, predicting yield based on water availability, and evaluating the environmental impact of agricultural practices (Tran et al., 2023).

To evaluate the changes in AETI within our study area, we acquired monthly AETI rasters at 100m resolution specifically cropped to our selected plots using a shapefile for each plot. This data spans from October 2018 to May 2019 and was obtained from WaPOR V2. We applied a conversion factor of 0.1 Using the batch processing in QGIS's raster calculator, we corrected all eight rasters.

Figure 7 depicts the fluctuation of AETI across the eight-month period. The AETI values for both plots range between 20 and 250 mm. Notably, AETI values show a consistent increase over time, peaking in March 2019, which aligns with the maximum growth stage and irrigation activity of the crops. Subsequently, the values gradually decrease, indicating a shift in water demand and crop conditions as the season progresses. This trend underscores the dynamic nature of water usage in relation to crop growth cycles and irrigation practices within the study area.

4.2 Performance indicators

In the same area, we examined performance indicators aimed at assessing water use efficiency in irrigation schemes. Our analysis focused on a cropping season spanning from October 2018 to September 2019. Detailed information on the datasets used is provided in Table 1. Each dataset consisted of dekadal rasters (36 rasters per layer), downloaded using the canvas extent due to small plot size unable to contain pixels at 250m resolution. Using the r.series tool in QGIS, we aggregated these rasters to generate seasonal rasters for each data type. Correcting for each data type's conversion factor, we named the resulting rasters according to the plugin's format and then calculated all five indicators. To visualize differences between irrigation schemes, we cropped the resulting indicator rasters to both plots, and the results are presented in Figure 8.

| WaPOR Layer | Resolution | | Conversion Factor |
	Spatial	Temporal	
AETI	$100m$	Dekadal	0.1
T	$100m$	(10/2018	0.1
RET	$20km$	to	0.1
PCP	$5km$	09/2019)	0.1

Table 1. Margin settings for A4 size page.

Figure 8.a showcases the Overall Consumed Ratio (OCR), which assesses the extent to which irrigation water meets crop requirements in the irrigated area, assuming minimal non-irrigation water inputs (Bos and Nugteren, 1974). It's calculated as (AETI-PCP) / Vws, where AETI represents actual evapotranspiration and interception, PCP is precipitation, and Vws is the volume of irrigation water (mm) available to prevent crop stress. Lower OCR values indicate a non-consumed fraction of water that may raise the groundwater table if applied to the field. Conversely,
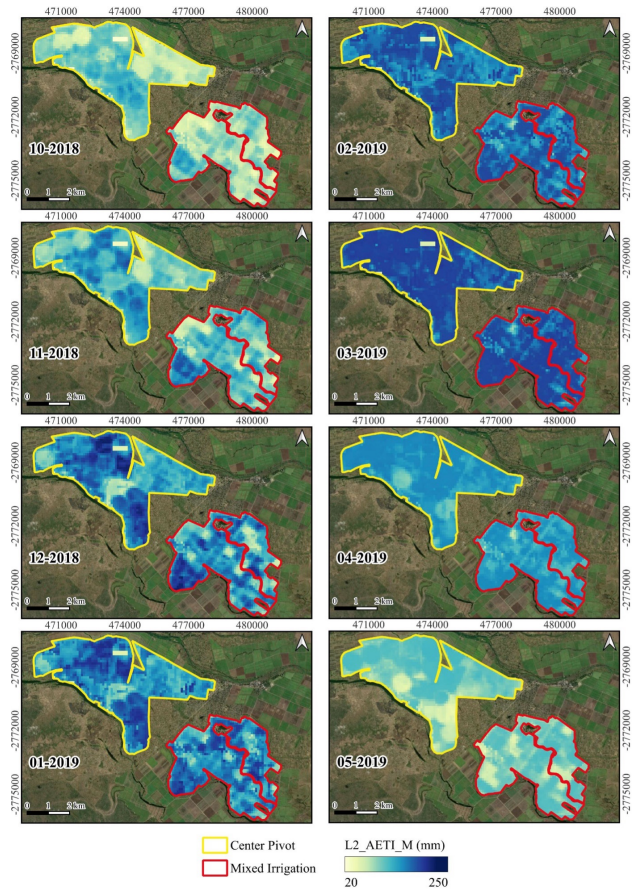

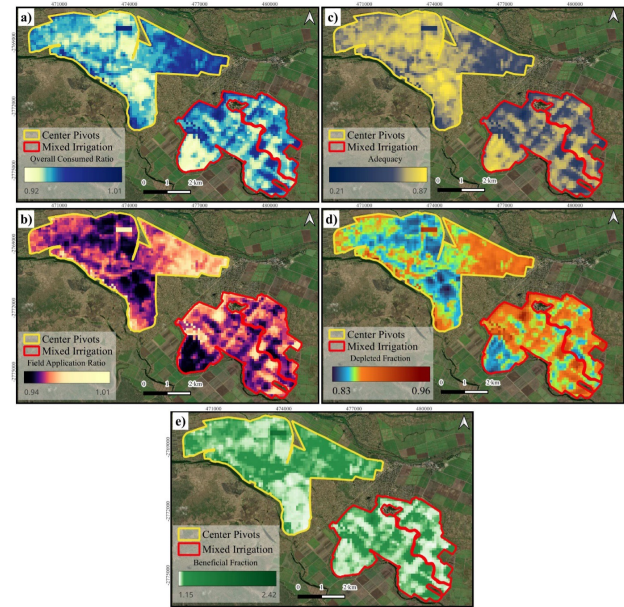Figure 7. Temporal variation of AETI from October 2018 to May 2019.

Figure 8. Spatial distrubution of performance indicators: a) Overall Consumed Ratio; b) Field Application Ratio; c) Adequacy; d) Depleted Fraction; e) Beneficial Fraction.

OCR values above 0.6 necessitate groundwater pumping and storage to avoid water scarcity (Bos, 1997). In our study area, OCR ranges from 0.92 to 1.01, with lower values observed in

plots using center pivot irrigation techniques.

Figure 8.b presents the Field Application Ratio (FAR), which mirrors the structure of the Overall Consumed Ratio but uses the volume of water delivered to the fields in mm as follows (AETI-PCP) / Vwd (on Assembling Irrigation Efficiency Data, 1978). The value of (AETI-PCP) is influenced by crop characteristics, climate conditions, and the interval between water applications, leading to variability in the FAR based on actual irrigation water delivery. This delivery, in turn, relies on factors like the reliability of water service, farmer expertise in irrigation, and the efficiency of water application technology. In our study area, FAR values range from 0.94 to 1, with lower values observed in plots utilizing center pivot irrigation methods.

Figure 8.c exhibits the Adequacy (A) indicator, which gauges the balance between available water and crop water needs in an irrigation system ((Bastiaanssen and Bos, 1999), (Clemmens and Molden, 2007)). A is calculated as the ratio of seasonal AETI to seasonal Potential Evapotranspiration, determined by multiplying the Reference Evapotranspiration layer by a crop coefficient (Kc) specific to the crop type. Good performance falls within the range of $0.8 < A \leq 1$, acceptable performance within $0.68 < A \leq 0.8$, and poor performance when $A \leq 0.68$ (Karimi et al., 2019). In our study area, adequacy values span from 0.21 to 0.87, with the highest values observed in plots utilizing center pivot irrigation schemes. This suggests better agreement between available water and crop water requirements in those areas.

Figure 8.d presents the Depleted Fraction (DF), a diagnostic indicator useful in water-scarce areas that compares components of the water balance in an irrigated region. It relates actual evapotranspiration to the sum of precipitation and surface water inflows, calculated as DF = AETI / (PCP + Vc), where AETI represents actual evapotranspiration and Interception, PCP is precipitation, and Vc is the volume of surface water inflows. In semi-arid and arid regions, a critical DF value typically ranges from 0.5 to 0.7, with an average around 0.6 (Bastiaanssen et al., 2001). A DF value of 0.6 suggests that some available water is stored, affecting the groundwater table. In our study, DF values range from 0.83 to 0.96, with the highest values observed in the mixed irrigation plot, indicating non efficient water management.

Figure 8.e illustrates the Beneficial Fraction (BF), which quantifies the water amount depleted from the root zone via crop transpiration and soil evaporation. BF is calculated as the ratio of seasonal evapotranspiration to seasonal transpiration. In our study area, BF values range from 1.15 to 2.42, with lower values observed in certain pivot irrigation systems. This indicates varying levels of efficiency in water uptake by crops and soil evaporation across different irrigation methods within the study area.

5. Conlusion

Monitoring water use in agriculture is crucial for ensuring its sustainability, as it directly impacts crop growth and land productivity. Thanks to advancements in remote sensing products and technologies, we now have access to high-resolution datasets that provide near real-time information. These datasets enable us to accurately monitor water use and crop growth, leading to more informed decision-making in agricultural practices. Among these datasets, WaPOR stands out as a significant provider of open-source data for agricultural water monitoring. WaPLUGIN, designed to seamlessly integrate WaPOR datasets into QGIS, saves time and allows users to focus on in-depth analysis. The included performance indicator calculator in WaPLUGIN further enhances its utility by simplifying the computation of key factors that assess water use efficiency. As WaPLUGIN continues to evolve, it promises to serve as a vital link between valuable WaPOR datasets and QGIS, facilitating widespread monitoring and improvement of water and land productivity globally.

Data availibility: All the remote-sensing-derived WaPOR datasets can be freely obtained from the WaPOR portal or directly into QGIS using WaPLUGIN. The boundary (shapefile) of the case study can be acquired from the GitHub repository of WaPLUGIN at this link

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