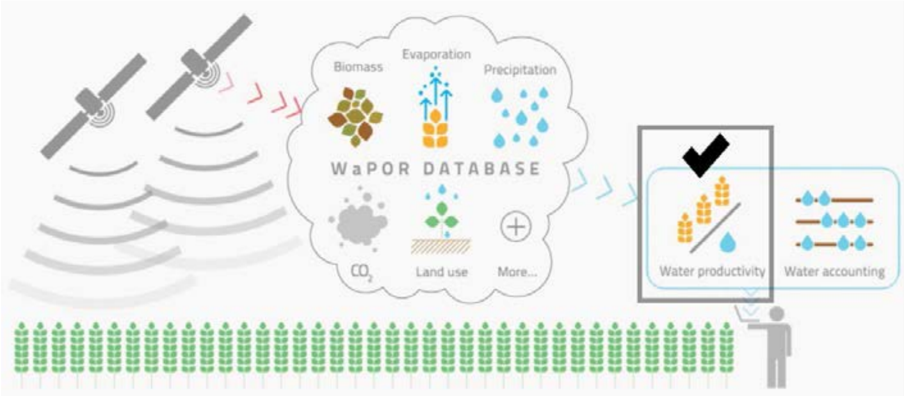
Standardized protocol for the land and water productivity analyses using WaPOR-V2



Water Productivity Improvement in Practice (Water-PIP) – Wonji, Ethiopia

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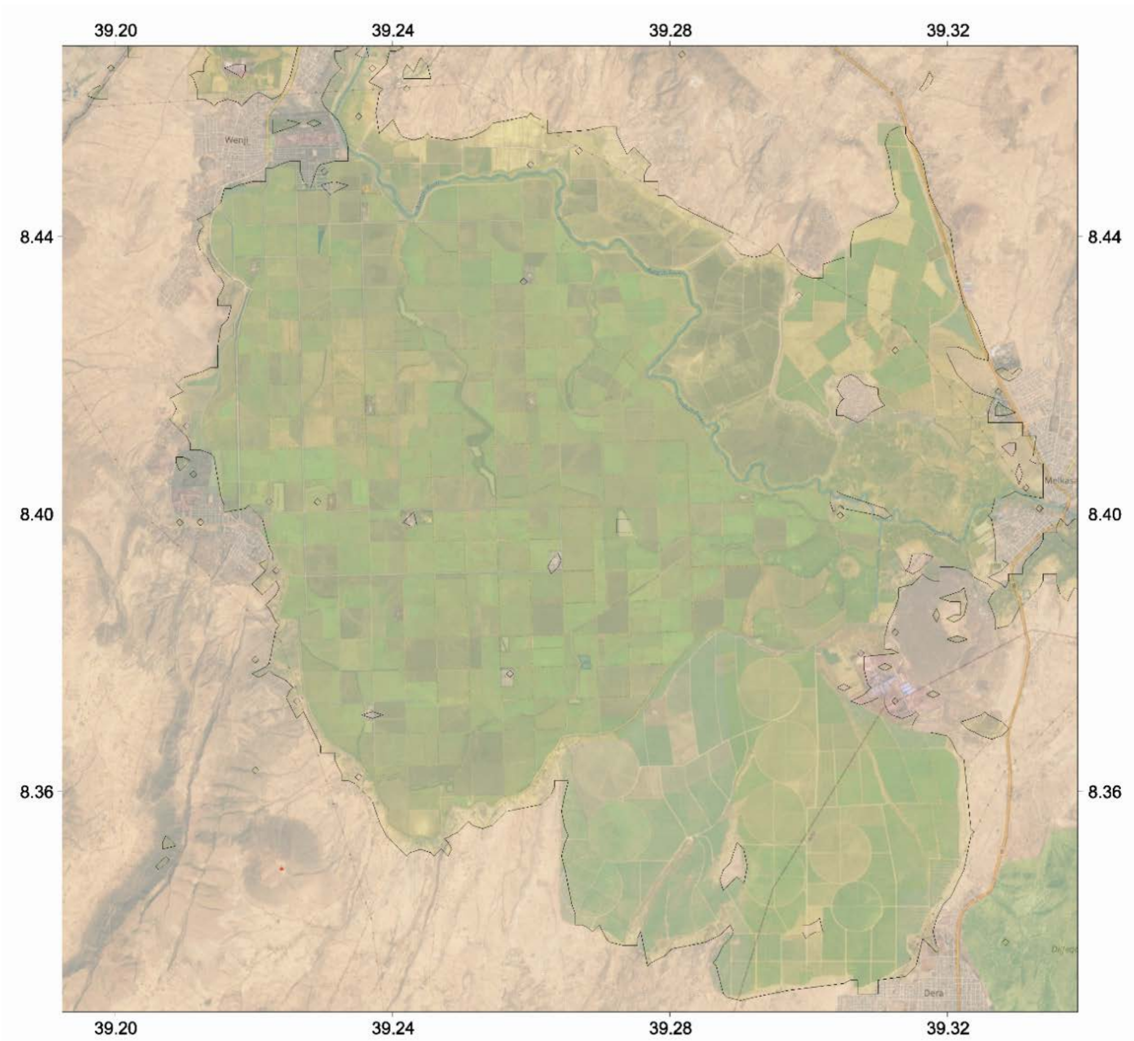


1 Introduction

Productivity is defined as a measure of gains per unit of resource use (Zwart and Bastiaanssen, 2004). For agricultural purposes, the most important indicators are biophysical, economic or social gains compared to the amount of land and water used. The most commonly used productivity indicator in agriculture is yield which defines the biophysical gain per unit of land (also called land productivity). With increasing concerns about the available water resources, water productivity has gained interest.

1.1 Importance

The increased gains per unit of water and land would benefit the farmer and scheme manager as well as being beneficial at the basin level.

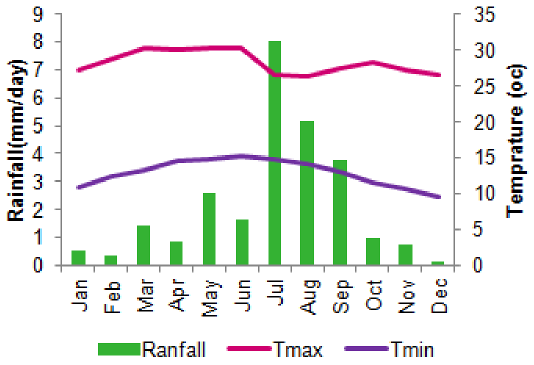
Farmers often aim to maximize the benefit generated per unit of land, as this is their main constraint. While the top priority of the river basin authority is to allocate water resources in an equitable, efficient, and sustainable manner between different water uses / users. Thus, at the river basin level, the interest is to optimize the productivity of water use while maintaining equity and sustainability as core values. Policymakers are often interested to increase production and thus national income as well as increase employment.

1.2 Study area

This exercise focuses on Wonji Shoa large scale sugarcane irrigation scheme located in Upper Awash basin, one of validation sites of level-3 FAO-FRAME project. Wonji Shoa scheme was the first commercial large scale irrigation scheme in Ethiopia, established in 1954 (Dengia, et. al. 2023). The Wonji sugar estate is situated downstream of Koka dam in central rift valley of Ethiopia, 110 km South East of Addis Ababa. The source of irrigation for the scheme is the Awash River, a perennial river. The scheme is situated between $8^{0}34'$-$8^{0}46'$ N and $39^{0}20'$-$39^{0}34'$ E (see also the basemap on the front page of this document) at an average altitude of 1550m asl with an area under sugarcane of over 7000 ha (excluding currently expanded project areas). Wonji plain is characterized by a very gentle and regular topography making it most suitable for irrigation. Sugarcane is grown in the area mostly as monoculture. Legume crops such as crotalaria and haricot bean are grown on heavy clay soils during the fallow period. These legume crops are usually used for increasing the fertility of fallow soils.

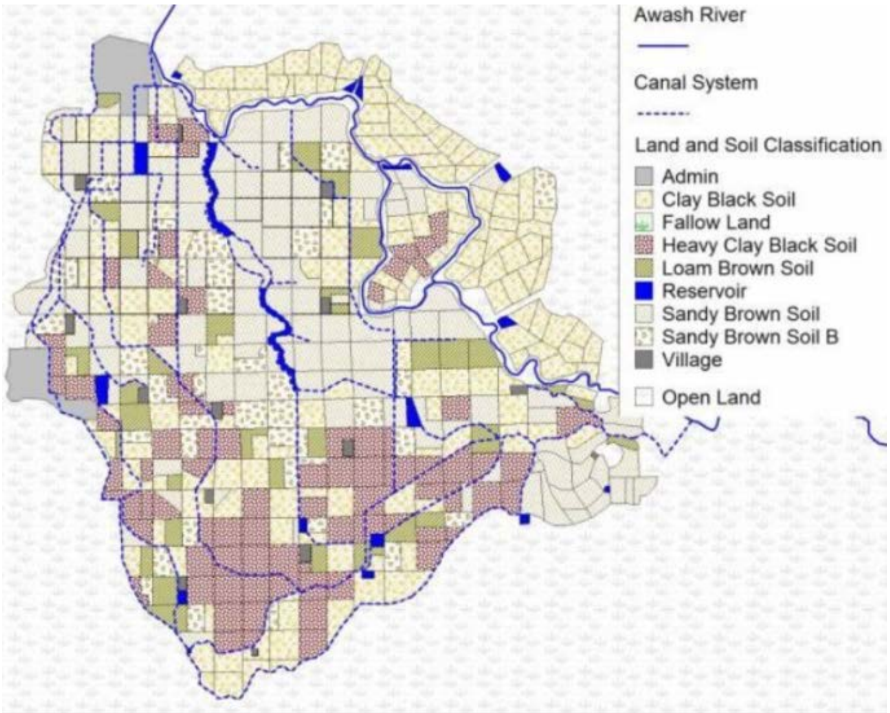
The climate of the area is characterised as semi-arid. The main rainy season takes place between months of May/June to September (figure 1). The rainfall in the area is erratic both in quantity and distribution. The area receives mean annual rainfall of 831 mm with mean annual maximum and minimum temperature of 27°C and 15°C respectively while the peak daily evapotranspiration is around 4.5 mm. In general, the climate of the area is suitable for production of sugarcane.

Figure 1: Monthly average daily rainfall and temperature (Source: observed climatic data for Wonji during 2007-2016).



The soil texture of the area is generally classified as heavy textured (clay) with high soil moisture holding capacity and coarse textured soils with low water holding capacity. The soil map in figure 2 shows the Wonji scheme without recent expansion (Ruffeis et al., 2006).

Figure 2: Soil type distribution of Wonji plantation



The groundwater table of the area is characterised as shallow and spatially and temporally varying (Dinka & Ndambuki, 2014). They stated that about 90% of the plantation is affected by water logging problems due to shallow ground water table and they revealed that the depth of groundwater table in the plantation is approximately 1.5m on average based on ground water monitoring conducted over the period of 2007-2009. Their study also revealed that there is no significant difference of groundwater table depth between summer (rainy season) and winter (dry season). The shallow groundwater depth in plantation and Wonji area in general is a result of seepage losses from storage reservoirs, channels, lake Koka reservoir and over-irrigation.

Blocked end furrow type of irrigation is used to irrigate sugarcane fields of both estate and out growers except for the newly expanded areas which use centre pivot sprinkler irrigation system. Irrigation is diverted to field canals from Awash River using centrifugal pumps. Irrigation starts from the beginning of October and continues to end of June. Irrigation application volume and intervals vary depending on the type of soil and the growth stage of crop. Generally the gross application rate is 30 lit/sec for low plant canes and 75 lit/sec for high plant canes and ratoons. Duration of irrigation lasts for 9 hr. The interval of irrigation application varies from 15 days for light soil and 30 days for heavy soils. Depending on the condition of rainfall, irrigation is usually delayed for one day for every 5 mm depth of rainfall if rainfall occurs during irrigation season. The long term average evaporative demand of the area is 4.8 mm/day. Irrigation stops roughly about two months prior to harvest (pre harvest drying off) to facilitate movement of vehicles for easy harvesting. Irrigation water quality is generally very good (< 2 ds/m).
Irrigation is applied immediately after planting in order to ensure proper germination of cane and reduce delay in germination. Practices like mulching and soil bunds are not present in the

study area. Weed management practices, soil fertility level, pest and disease control are assumed optimal.

Based on crop production data of 30 plots of Wonji sugar plantation, the fresh cane yield per plot varied from 85 to 186 ton/ha with an average fresh cane yield of 117 ton/ha (Teshite, 2018). Despite high variability this average production is very comparable with worldwide fresh cane yield of 120 ton/ha considered by FAO as a good yield under full irrigation (Steduto et al., 2012). Even though, the achievable yield of sugarcane depends on climate, soil condition, management practice and cultivars, the average cane yield of Wonji area is close to the values reported by industry (International Sugar Organization, 2023).

1.3 WaPOR data

FAO's portal to monitor Water Productivity through Open-access of Remotely sensed derived (WaPOR) is developed "to monitor and improve water and land productivity in agriculture, both rainfed and irrigated, responding therefore to the challenges that are posed by the dwindling of freshwater resources and the need to sustain agricultural production to ensure food security in the face of a changing climate." (https://data.apps.fao.org/catalog/organization/about/wapor).

WaPOR provides a comprehensive catalogue that combines water use (actual evaporation, transpiration and interception), production (net primary production), land use (land cover classification), phenology, climate (precipitation and reference evapotranspiration) and water productivity layers covering sub-Saharan Africa and the Near East and North African regions. The data is available at dekadal time steps and in near real-time for the period between 2009 to present day. WaPOR datasets are available at the continental scale (Level 1 at 250 m), country and river basin (Level 2 at 100 m) and project level (Level 3 at 30 m). WaPOR portal (WaPOR v2.1), was improved from WaPOR v1.0 following the independent quality assessment by IHE Delft and ITC (FAO and IHE, 2019). The methodology used for compiling the WaPOR database is provided in FAO (2020a).

WaPOR Version 3.0 was launched on 4 October 2023 during the Rome Water Dialogue at FAO Headquarters and is available at: https://data.apps.fao.org/wapor/?lang=en. WaPOR v3.0 now provides Level 1 data (at 300m resolution) globally and level 2 data (at 100m resolution) for Africa and Middle East. This allows the easy evaluation of actual evapotranspiration, biomass production and water productivity in any agricultural area in the world. Furthermore, the new version uses datasets with higher spatial and temporal resolution, complementary data to allow higher quality time-series and a new cloud mask procedure that helps increase data quality and usability in agricultural applications. Not all layers as of WaPOR Version 2.1 are currently available within this new portal (see table 1). An example notebook is provided demonstrating the API access to the new WaPOR Version 3 database (chapter 7).

For implementation of the procedure for land and water productivity analysis highlighted below, WaPOR version 2.1 is used.

Table 1: Cloud Optimized Geotiff layers available in Wapor V3.0 as of October 2023

WaPOR-Code	Description
L1-AETI-A	Actual EvapoTranspiration and Interception Annual
L1-AETI-D	Actual EvapoTranspiration and Interception Dekadal
L1-AETI-M	Actual EvapoTranspiration and Interception Monthly
L1-E-A	Evaporation Annual
L1-E-D	Evaporation Dekadal
L1-I-A	Interception Annual
L1-I-D	Interception Dekadal
L1-NPP-D	Net Primary Production Dekadal
L1-NPP-M	Net Primary Production Monthly
L1-RSM-D	Relative Soil Moisture Dekadal
L1-T-A	Transpiration Annual
L1-T-D	Transpiration Dekadal
L2-AETI-A	Actual EvapoTranspiration and Interception Annual
L2-AETI-D	Actual EvapoTranspiration and Interception Dekadal
L2-AETI-M	Actual EvapoTranspiration and Interception Monthly
L2-E-A	Evaporation Annual
L2-E-D	Evaporation Dekadal
L2-I-A	Interception Annual
L2-I-D	Interception Dekadal
L2-NPP-D	Net Primary Production Dekadal
L2-NPP-M	Net Primary Production Monthly
L2-RSM-D	Relative Soil Moisture Dekadal
L2-T-A	Transpiration Annual
L2-T-D	Transpiration Dekadal

1.4 Ground data

Ground data such as the boundary of the farm or irrigation scheme (to download WaPOR data and filter non cropped area), moisture content of fresh biomass (to convert dry matter to biomass), above ground over total biomass (to estimate the above ground biomass), start and end of seasons (to aggregate water and climate data per crop season), harvest index (to derive crop yield from above ground biomass) and crop coefficient (to estimate potential evapotranspiration from reference evapotranspiration) are required or can be taken from literature.

1.5 Protocol: objectives, scope and target audience

The protocol is aimed at guiding users to understand the different layers contained in the FAO Water Productivity Open-access portal (WaPOR) which can be used for land and water productivity analyses. It provides python scripts which can be used to calculate land and water productivity and other performance indicators such as uniformity, efficiency (beneficial fraction), adequacy, relative water deficit as well as estimating productivity gaps. For each step, the protocol provides information about the assumptions used and provides links to reference materials.

Scope: The protocol is tailored to biophysical water productivity with respect to consumed water use and land productivity at areas (fields, and schemes) in similar agro-climatic zones. The protocol can be applied to single water management unit and crop production regardless of the water sources (e.g. from exclusively rainfall (rainfed), or irrigation (augmented through surface water and/or groundwater, or flood /spate). The protocol is developed for agricultural areas with a single crop and same cropping season, which can vary between years. Implementing the protocol beyond fields / scheme level such as a river basin and country levels, which could fall in different agro-climatic zones, require normalization for climate variation – which is outside the scope of the protocol.

Target: The protocol is developed for project leads, irrigation managers and researchers who have a basic understanding of python and agricultural practices.

2 Installation requirements

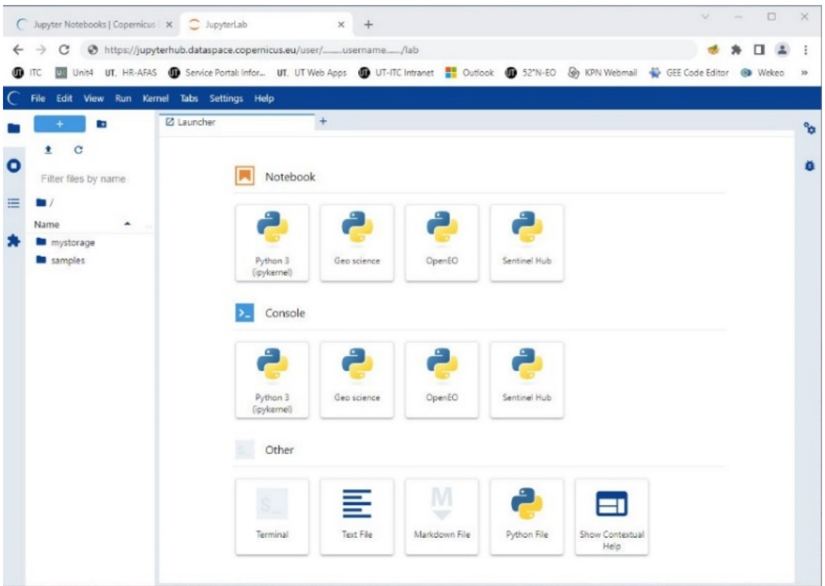
The scripts to download and process the WaPOR data for land and water productivity assessment are developed in the python programming language by IHE. The original scripts can be downloaded from the water accounting repository on GitHub (https://github.com/wateraccounting/WAPORWP) and run in Jupyter Notebook environment. The original notebooks have been modified to enable their use in the Copernicus DataSpace Ecosystem. The following sections describe the installation requirements.

2.1 The Copernicus DataSpace Ecosystem – processing data in the cloud

Navigate, using your web browser, to the Copernicus DataSpace Ecosystem, available at the following URL: https://dataspace.copernicus.eu/. If you don't have an account already, select the option 'Login' and 'Register'. Complete the registration form and register and 'sign in'. You will receive a verification email (also check your spam!) and once the link in this email is confirmed you should be able to login with the provided email address and password.

Review the information provided under the dropdown menus 'explore data', 'ecosystem' and 'analyse data'. Having reviewed the information provided, under the dropdown menu 'analyse data', select the option 'Jupyter Notebooks' and 'Access Jupyter Notebooks', click the box 'sign in with keycloak', select a preferred server option, e.g. 'large server' and press 'Start'. A new virtual processing environment instance is created. You will be directed to your local resources, which are automatically created and are consisting of 2 folders, 'my storage' and 'samples'.

Figure 3: Starting the Jupyter Notebook environment in the Copernicus Data Space Ecosystem



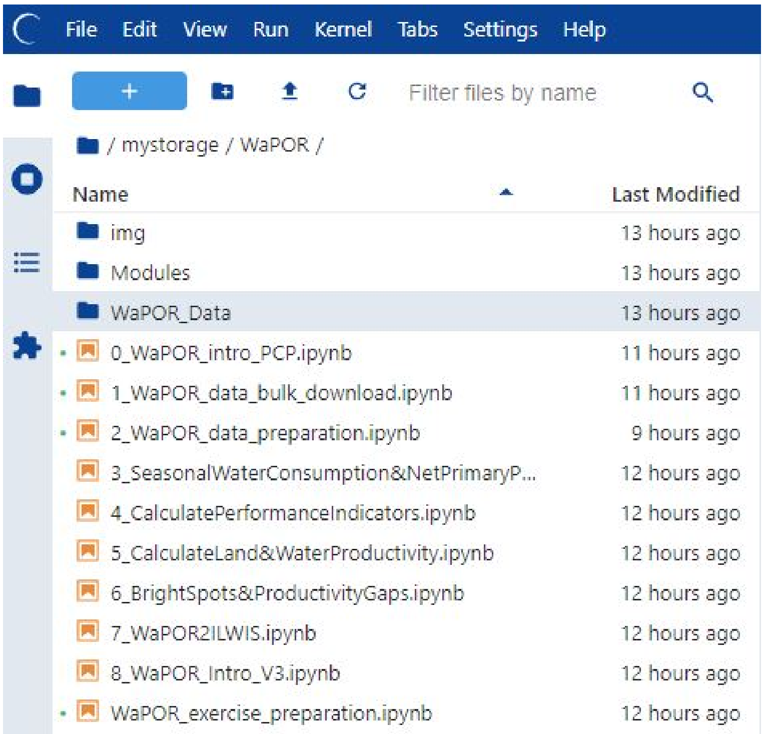
2.2 Installing the required resources

Within the Copernicus Data Space Ecosystem, the system is 'cleaned' on a daily basis, but files situated within the folder 'mystorage' are retained. This storage area, having a size of 10 GB, is preserved when you logout. It will be kept for up to 15 days from your last login, and you will receive a notification to log in to the Jupyter Hub to reset the timer if you want to keep the data preserved. If you do not log in, then after 15 days your files will be deleted.

A notebook entitled 'WaPOR_exercise_preparation.ipynb' (see Appendix B for script / code listing) is uploading all required training resources, like software tools, notebooks and sample-data. Upload this notebook from: https://filetransfer.itc.nl/pub/52n/WaPOR_Wonji/ in the folder 'mystorage/WaPOR'. Execute all the code fields in this notebook and wait until all the files have been retrieved, unzipped, etc. Upon completion of this notebook, you have obtained the following folder structure in your folder 'mystorage/WaPOR', see also figure 4:

- Installation Jupyter Notebook "WaPOR_exercise_preparation.ipynb" (see also Appendix B) and 9 additional notebooks in the root of the folder /WaPOR;
- 3 additional folders have been created:
  - WaPOR_Data, containing the sample data for this exercise (dekadal PCP, RET, AETI, NPP, T and annual LCC);
  - Modules, containing the WaPOR site package and required resources in the sub-folders /WaPOR, /GIS_functions and /Data, as well as additional software (including latest version of ILWISPy for python 3.11 and required libraries) in the sub-folder / Software;
  - Some graphics, required in the notebooks are stored in the folder /img.

Figure 4: Overview of WaPOR folder, containing notebooks and directories



3 API access and get yourself familiar with WaPOR database

Notebook: 0_WaPOR_Intro_PCP.ipynb
Step 0a: Register in WaPOR Portal and obtain WaPOR API Token
Step 0b: Import modules/libraries
Step 0c: Familiarize yourself with WaPOR Catalogue
Step 0d: Process and download WaPOR data for the study area extent

Before you can access the data you have to obtain the WaPOR API Token. API Token is used to authorize access to the WaPOR API. To get an API Token follow the steps below:

Step 1: Sign up/Log in an account on WaPOR portal

Go to https://wapor.apps.fao.org/, click Sign in. If you don't have an account, create a new account, then log in.

Step 2: Create API Token

After logging in, go to My WaPOR > My Profile. Under API Token, click Generate API Token. The API Token is the user's personal key and should be stored and kept private. Best practise is to save the Token in a text file, as it needs to be inserted when requesting access to the WaPOR data base (see also figure 4). In case of losing the API Token, revoke the old token and create a new one.

To provide a short introduction to the WaPOR v2.1 database use is made of the python based WaPOR module. After login into the Copernicus DataSpace Ecosystem, navigate to the folder ‘WaPOR’ and open the notebook ‘0_WaPOR_Intro_PCP.ipynb’. Start executing this notebook. After the installation of GDAL, Pyshp (for reading shapefiles), Pandas (tabular data analysis) and Matplotlib (will initially take some time!), the notebook will continue with the import of a number of other libraries required, including WaPOR. When this code field is executed, a popup window will appear and you will need to insert (paste) your WaPOR Token in here and press <Enter>.

Figure 4: Inserting the WaPOR Token for access to the WaPOR Catalogue

```
import os                          # module for interacting with the operating system
import shapefile                   # module for reading shapefile
import matplotlib.pyplot as plt    # module for plotting
import sys
import pandas as pd
import warnings
import numpy as np
np.warnings = warnings

folder = os.getcwd()+'/Modules'
sys.path.append(folder)     #add folder with local modules to system paths   #change working dire
import WaPOR                # Import local module in 'Modules' folder

Insert WAPOR API Token: ↑↓ for history. Search history with c-↑/
```

As a last step, manually the environment variable for the GDAL projection library is defined. Now you are able to access, process and retrieve data from the WaPOR database.

First the full catalogue is retrieved, using the default (first few and last few records) and a Pandas dataframe based full listing. Subsequently for one of the level 1 data layers, the meta data information of the satellite derived precipitation at dekadal time step 'L1_PCP_D', is inspected into more detail. This precipitation data is delivered on a daily basis. The source of this dataset is CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) quasi-global rainfall dataset, starting from 1981 up to near present. The value of each pixel represents the average daily amount of precipitation expressed in mm (1mm=1l/m^2 or 1mm=10m^3/ha) for a given dekad. The data is provided in near real time from January 2009 to present. For further details see http://chg.geog.ucsb.edu/data/chirps but also consult the 'cube-info' as given when executing the respective code fields in the notebook.

To download data using the WaPOR API, the Token has to be provided as well as a the system storage location. If interested in a specific geographic area a shapefile can be provided as well as the bounding coordinates of the area of interest. A plot can be made of the shapefile for verification and a specific time step should be provided. A download link is created to retrieve the raster dataset requested, as a GeoTiff. Activating the link, the data will be retrieved and is transferred into your local 'Downloads' folder.

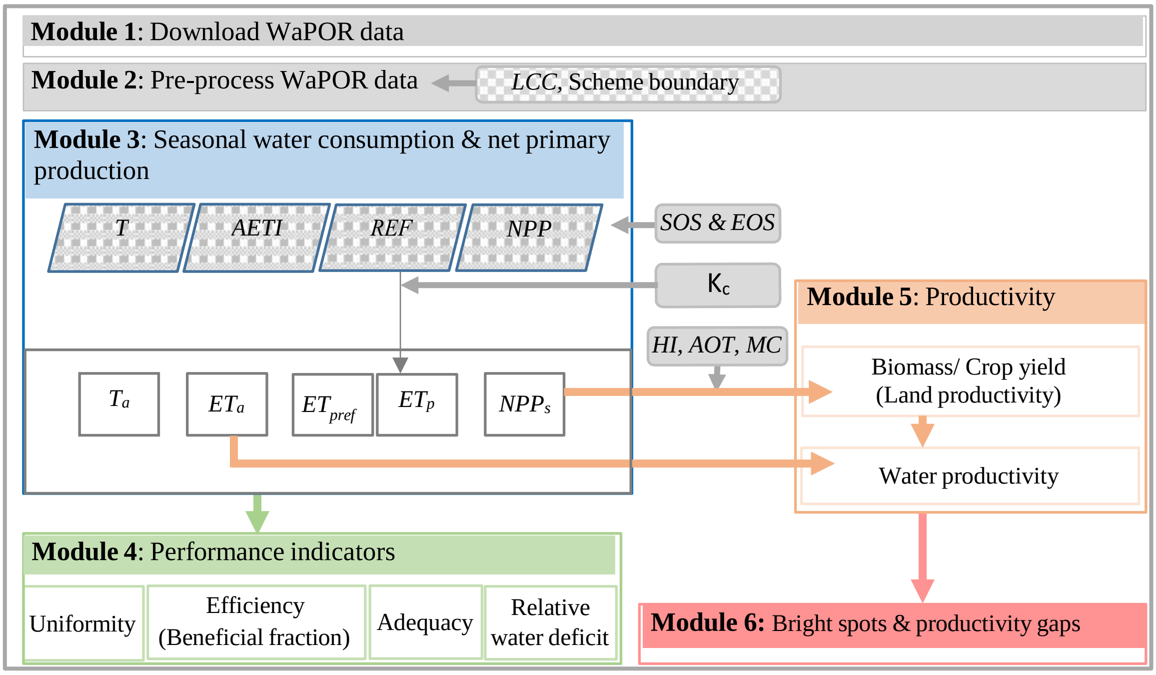
Another option shown is to derive area time series statistics (average, minimum, maximum and range) for each time step within the specified time range, based on the dimensions of the area of interest specified. The data can be saved to the system storage folder specified as a '*.csv' file. If interested in a specific location, the X and Y coordinate can be provided and for the time range provided a data value, here the average rainfall on daily basis, is provided. Pandas is used to obtain the 10 day accumulated precipitation. The results obtained are compared with observations derived from a nearby climatological station. The short term yearly mean precipitation is compared between the in-situ and satellite derived precipitation. Finally a simple graphical representation, using matplotlib, is created to visualize the full time series retrieved.

To get yourself more familiar with the data available, check the cube-information of some other data layers, download a single time step map, as well as area average statistics using the provided shapefile and X,Y point location and check the graphical representation.

4 Structure of the Standardized protocol for land and water productivity analyses using WaPOR

The protocol has six modules, which are described into more detail in the following sections. For each of the modules, a Jupyter notebook was developed, containing the scripts. Module 1 focuses on downloading WaPOR data on actual water consumption (ET), actual transpiration, reference evapotranspiration and net primary production. In Module 2, the pre-processing of the data to match the spatial resolution and remove non-crop pixels is conducted. In Module 3, the seasonal water consumption (transpiration, actual evapotranspiration, reference evapotranspiration and potential evapotranspiration) and seasonal net primary production are computed. In Module 4, different performance indicators are calculated. In Module 5, land and water productivity are computed. Finally in Module 6, bright spots and productivity gaps are calculated, see also the flowchart in figure 5.

Figure 5. Flow chart for downloading WaPOR data and calculate performance indicators, land and water productivity and productivity gaps



4.1 Download WaPOR data (Module 1)

Notebook: 1_WaPOR_data_bulk_download.ipynb
Step 1a: Import modules/libraries
Step 1b: Read the geographical extent of the study area
Step 1c: Bulk-download WaPOR data for the study area extent

The main objective of this module is to download the relevant data for the water productivity analysis protocol in the correct units. For these analyses, we need to download 6 different WaPOR layers (Table 2). The precipitation and reference evapotranspiration layer are available at 5 and 20 km resolution respectively. The other four layers, actual evapotranspiration and interception, transpiration, net primary production and land cover classification are all available at three different resolutions (250, 100 and 30 m). All layers, except land cover classification, are available at dekadal, monthly and yearly temporal resolution. The land cover classification at 30 m is available at dekadal and annual resolution and at 250 and 100 m resolution it is available at annual resolution. For the analyses we are using the dekadal data set, except land cover classification which is an annual data set. The WaPOR data is available for Africa and the Near East at 250 m resolution. The availability of the higher resolution data (100 and 30m) is dependent on your location (Table 3).

Table 2: WaPOR data used for the Water Productivity analyses

No.	WaPOR Data	Spatial resolution	Temporal resolution	Unit	Temporal coverage
1	Actual Evapotranspiration & interception (AETI)	250/100/30 m	Dekadal	mm d^{-1}	2009-present
2	Transpiration (T)	250/100/30 m	Dekadal	mm d^{-1}	2009-present
3	Net Primary Production (NPP)	250/100/30 m	Dekadal	gC $m^{-2}d^{-1}$	2009-present
4	Land cover classification (LCC)	250/100/30 m	Annual		2009-present
5	Precipitation (PCP)	5 km	Dekadal	mm d^{-1}	2009-present
6	Reference Evapotranspiration (RET)	20 km	Dekadal	mm d^{-1}	2009-present

Table 3: Spatial resolution and extent of the three WaPOR Levels – WaPOR Version 2.1

Level	Spatial resolution	Extent
1	250m	Africa and Near East
2	100m	Countries: Morocco, Tunisia, Egypt, Lebanon, Syrian Arab Republic, Jordan, Ghana, Kenya, South Sudan, Mali, Benin, Ethiopia, Rwanda, Burundi, Mozambique, Uganda, West Bank and Gaza Strip, Yemen, Iraq, Niger and Sudan. River basins: Jordan / Litani, Nile, Awash and Niger
3	30m	Bekaa (Lebanon), Koga and Awash (Ethiopia), Office du Niger (Mali), Zankalon (Egypt), Busia County (Kenya), Lamego (Mozambique) and Gezira (Sudan).

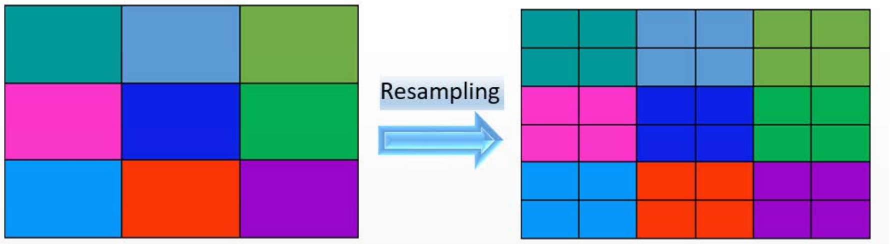
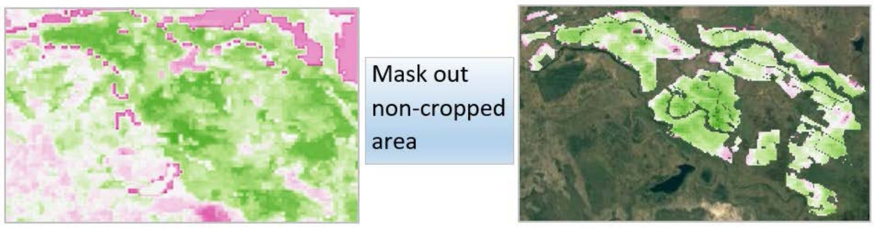
The scripts in this step first determine the geographical extent of the study area. By reading the shapefile of the area, it will use the outer extent to download the relevant data. The scripts for the bulk download correct the data for the conversion factor and correct for the units from an average daily value to the total amount in a dekade by multiplying by the number of days in a dekade. An example of the download script is provided in box 1.

Box 1: Example of bulk download script

```
WaPOR.AET_dekadal(output_dir, Startdate='2009-01-01', Enddate='2022-12-
         31',  latlim=[ymin, ymax], lonlim=[xmin, xmax],level=2,
         version = 2, Waitbar = 1)
```

The script is pre-set at downloading dekadal data from 1 January 2009 to 31 December 2022 and for level 2. These settings can be manually changed to fit your purpose. One can adjust the dates. If there is no level 2 data available at your site, or you have level 3 data available you can change the setting. There is also a facility to directly download monthly and yearly data, this can be done by changing the extension 'dekadal' to 'monthly' or 'yearly'. The script is pre-set to download WaPOR version 2, if there is another version available this can be easily changed. The settings which can be changed are highlighted red in box 1.

4.2 Pre-processing WaPOR data (Module 2)

Notebook: 2_WaPOR_data_preparation.ipynb	
Step 2a: Import modules/libraries	
Step 2b: Resample raster data	
Step 2c: Filter non-cropped area using land cover map and project boundary	

The main objective of this module is to prepare the data for analyses. Firstly, all data is sampled to the same resolution, even though many of the datasets are available at the same resolution, more coarse data such as reference evapotranspiration and precipitation need to be resampled.

In the example case, we identified the area for analysis using a shapefile (project boundary) to crop out the area of investigation, this is followed by a procedure to mask out non-irrigated areas. Of course there are different ways to extract the area for analyses, which can be applied, but these are not elaborated upon in this protocol.

For the analyses it is important to select a homogeneous area with one single crop type and similar crop season.

4.3 Compute Seasonal Water Consumption & Net Primary Production (Module 3)

Notebook: 3_SeasonalWaterConsumption&NetPrimaryProduction.ipynb
Step 3a: Import modules/libraries
Step 3b: Defining function and crop season
Step 3b: Calculate seasonal T, ET, RET, ETp, NPP

For agricultural purposes the seasonal values are important, these are calculated by summing the dekadal amounts over a specified cropping season, defined by a start and end of crop season (SOS and EOS) (equation 1).

$$X_s = \sum_{SOS}^{EOS} X \qquad \text{Equation 1}$$

Where X_S is the seasonal amount in mm/season for P, ET_a, T, REF, ETp or NPP, X is the dekadal amount for P, ET_a, T, REF or NPP in mm/dekad. A local function is defined for calculating the seasonal values. The SOS and EOS are user-defined. Table 4 shows an example of such a crop season table which is used for the calculations. Table 4 is input data in excel format (df_SosEos.xlsx), which is read into Module 3 of the script. Users could edit the dates (starting of season (SOS) and ending of season (EOS)). The rows should end on the last month of the ending of season (EOS).

Table 4: Example SOS and EOS table, assuming a growing period of 12 months

	Seasons	SOS	EOS
0	1	2009-10-01	2010-09-30
1	2	2010-10-01	2011-09-30
2	3	2011-10-01	2012-09-30
3	4	2012-10-01	2013-09-30
4	5	2013-10-01	2014-09-30
5	6	2014-10-01	2015-09-30
6	7	2015-10-01	2016-09-30
7	8	2016-10-01	2017-09-30
8	9	2017-10-01	2018-09-30
9	10	2018-10-01	2019-09-30
1	11	2019-10-01	2020-09-30
1	12	2020-10-01	2021-09-30
1	13	2021-10-01	2022-09-30

ETp is calculated by multiplying crop coefficient (Kc) by reference evapotranspiration at monthly as well as seasonal time steps. Edit only the **'Kc'** values and the corresponding **'Months'** in the **df_Kc.xlsx** file in the data folder (Table 5), which is read into Module 3 of the script. The rows should end on the last month of the late-season stage.

Table 5: Example Kc table

	A	B	C
1	**Months**	**Kc**	Crops stage
2	October	0.400	Initial
3	November	0.613	
4	December	1.038	
5	January	1.250	
6	February	1.250	
7	March	1.250	
8	April	1.250	
9	May	1.250	
10	June	1.250	
11	July	1.083	
12	August	1.000	
13	September	0.833	Late-season

4.4 Calculate performance indicators (Module 4)

Notebook:
Step 4a: Import modules/libraries
Step 4b: Calculate Uniformity
Step 4c: Calculate Efficiency (Beneficial fraction)
Step 4d: Calculate Adequacy
Step 4e: Calculate Relative Water Deficit

This module is used to calculate a number of performance indicators, namely uniformity, beneficial fraction, adequacy and relative water deficit.

Uniformity and Equity

Uniformity measures the evenness of the irrigation application in different parts of a field. This can be calculated by assessing the spatial uniformity of seasonal ET pixels that are within a field or plot of land.

Equity is the measure of equitable distribution of water to different users (i.e. farmers), which can be water users at a tertiary unit or among tertiary units under a particular secondary canal. Ideally, for equity, pixel values must be aggregated and averaged per field (or a block if comparisons are made between blocks), to arrive with an average seasonal ET per unit of area in each field. The coefficient variation of these values would then can be taken as an indication of equity in the scheme. In the absence of plot (or block) boundaries, the spatial uniformity of evapotranspiration per unit area (pixel) bases can be used to measure uniformity or equity. It is calculated as the coefficients of variation (CV) of seasonal ET_a in the area of interest. A CV of 0 to 10 % is defined as good uniformity, CV of 10 to 25 % as fair uniformity and CV > 25 % as poor uniformity (Bastiaanssen et al., 1996; Molden and Gates, 1990; Karimi et al., 2019).

$$CV_{ET} = \frac{SD}{\sigma} * 100\% \qquad \text{Equation 2}$$

With SD being the standard deviation and σ the mean of evapotranspiration.

Beneficial fraction (BF) is an indication of the efficiency of on-farm water and agronomic practices in converting water use to crop growth. It is the percentage of the water that is consumed as transpiration compared to overall field water consumption (ET_a). Beneficial fraction is calculated as follow (equation 3):

$$BF = \frac{T_a}{ET_a} \qquad \text{Equation 3}$$

Where T_a and ET_a are seasonal transpiration and actual evapotranspiration.

Adequacy (A) is the measure of the degree of agreement between available water and crop water requirements in an irrigation system (Bastiaanssen and Bos, 1999; Clemmens and Molden, 2007). It is calculated as the relative evapotranspiration, which is the ratio of actual evapotranspiration over potential evaporation (Equation 4) (Kharrou et al., 2013; Karimi et al., 2019)

$$A = \frac{ET_a}{ET_p} \qquad \text{Equation 4}$$

Where ET_a and ET_p are the actual and potential evapotranspiration in mm/season. Potential evaporation is estimated as the product of average k_c and *RET* as in Equation 5.

$$ET_p = \sum_i^n kc_i * RET_i \qquad \text{Equation 5}$$

Where ET_a, is the potential evapotranspiration in mm/season, Kc and *RET* are the crop coefficient and reference evapotranspiration in mm/month. i months from the first month at the initial stage of the crop to last month (n) at the end of the crop season.

Relative Water Deficit (RWD) provides an indication of the level of water shortage found in the irrigation system. It is calculated using the equation described in FAO 66 (Steduto et al., 2012) by applying for a mono-crop system, where the actual ET is compared to the maximum ET (equation 6).

$$RWD = 1 - \frac{ET_a}{ET_x} \qquad \text{Equation 6}$$

With

$$ET_x, the\ \max ET = 99\ percentile\ of\ ET_a \qquad \text{Equation 7}$$

4.5 Land and water productivity (Module 5)

Notebook: 5_CalculateLand&WaterProductivity.ipynb
Step 5a: Import modules/libraries
Step 5b: Calculate land productivity: i) biomass and ii) crop yield
Step 5c: Calculate i) biomass water productivity and ii) crop water productivity

This step is used to calculate the seasonal land and water productivity for the study area.

Land productivity is defined as the above-ground biomass production or yield in ton/ha/season, which are estimated from the seasonal net primary production using the following equations:

$$B = AOT * f_c * \frac{NPP*22.222}{(1-mc)}$$ Equation 8

$$Y = HI * B$$ Equation 9

The parameters used in these equations are crop-specific and vary under different climatic conditions. There are several resource documents that can be consulted to obtain these parameters (Table 6). It is important to keep in mind that these parameters are based on literature and therefore stresses and management practices affecting the H_I and m_c cannot be incorporated. If there is local information, it is better to use that information.

Table 6: overview of parameters used for calculating biomass and yield

Parameter	Definition	Unit	Source documents
AOT	above ground over total biomass production ratio	[-]	Appendix A
f_c	Light use efficiency correction factor: the ratio between the actual LUE and the LUE applied for the NPP data in WaPOR	[-]	Appendix A and WaPOR database methodology document of Version 2 release (FAO, 2020a)
HI	harvest index	[-]	Appendix A, page 182 in Villalobos and Fereres (2016), AquaCrop Annexes: http://www.fao.org/fileadmin/user_upload/faowater/docs/Annexes.pdf
m_c	moisture content in the fresh biomass	[-]	Appendix A, page 495 in Villalobos and Fereres (2016)

Validation
Comparison WaPOR data and results vs observed (if available) is recommended. It helps to fine-tune the crop parameters to get results closer to the observed one. The comparison can be done with the aid of visual graph interpretation (against 1:1 line), coefficient of determination, and coefficient of correlation.

Note: It is recommended to interpret the WaPOR data and results using quality layer.

Biomass (WPb) and crop water (WPc) productivity is estimated as the ratio of above-ground biomass or yield over actual evapotranspiration (Equation 10 and 11):

$$WP_b = \frac{B}{ET_a} \quad \text{Equation 10}$$

$$WP_c = \frac{Y}{ET_a} \quad \text{Equation 11}$$

To obtain *WP* $_{(b)}$ in kg/m^3/season from *B* in kg/ha and ET_a in mm/season, the unit conversion factor of 0.1 is used in the equation. Likewise $WP_{(c)}$ is obtained from *Y.*

Table 7: Summary of irrigation performance assessment criteria and indicators, calculation of performance indicators

Criteria	Indicator	Equation
Adequacy	Relative evapotranspiration (RET)	$RET = \frac{ET_{a,s}}{ET_{p,s}}$
	Relative water deficit (RWD)	$RET = 1 - \frac{ET_{a,s}}{ET_x}$ $ET_x = ET_{p,s}\ or\ 99\ percentile\ of\ ET_{a,s}$
Equity	CV of ET	Accumulated seasonal average ETa per field inside the scheme/block
Uniformity	CV of ET	Accumulated seasonal average ETa per pixel inside a field
Productivity	Biomass production	$B = AOT * f_c * \frac{NPP * 22.222}{(1 - mc)}$
	Yield	Yield = B*HI
	Biomass WP	$WP_b = \frac{B}{ET_{a,s}}$
	Crop WP	$WP_y = \frac{Y_a}{ET_{a,s}}$
Efficiency	Beneficial fraction (BF)	$BF = \frac{T_{a,s}}{ET_{p,s}}$

4.6 Productivity gaps and production projection (Module 6)

Notebook: 6_BrightSpots&ProductivityGaps.ipynb
Step 6a: Import modules/libraries
Step 6b: Calculate the target productivity
Step 6c: Identify bright spots
Step 6d: Calculate productivity gaps

The **target productivity** is a target for land and water productivity which is attainable under the local climatic conditions. This step of the script describes how the target is set and how bright spots are identified and how the productivity gap (related to the target) is estimated.

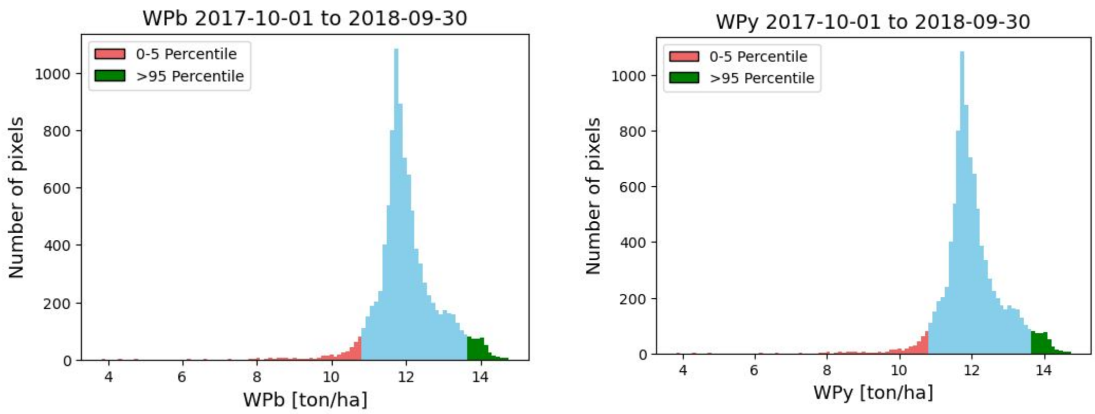
The target can be set for individual years to incorporate specific wet or dry conditions during that particular year. In our case we set the target at the 95 percentile of the land or water productivity for each year (Figure 6), this can be changed in the script. The corresponding ET_a is also defined as the target ET_a.

Box 2: Example of calculating target land and water productivity using percentile

```
# targets biomass productivity
Target_biomass = round(np.nanpercentile(Biomass, 95), 0)#Yield at 95
percentile
```

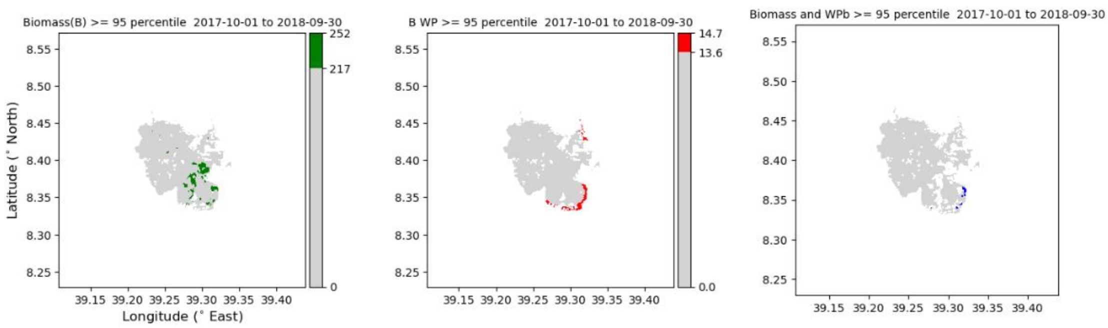
```
# targets crop productivity
Target_yield = round(np.nanpercentile(Crop_yield, 95), 0)#Yield at 95
percentile
```

Figure 8: WPb and WPy distribution and 95 percentile



The **bright spots** are fields that have both land and water productivity equal to or greater than the targets. The location of the bright spots is then mapped for the individual targets (biomass or yield and water productivity as well as areas where both targets are exceeded (Figure 9).

Figure 9: Example of results of the bright spot analyses



Productivity gap is defined as the difference between productivity at the plot level and the target productivity. The production gap is defined as the sum of the land productivity gaps of a particular crop over area. The potential increase in biomass/ yield production of a particular crop in an area of interest is calculated by adding the productivity gap across the area (Equation 12a, b).

$$BP_b = \sum_i^n (B_i - B_t), \quad B_i < B_t \qquad \text{Equation 12a}$$

$$YP_b = \sum_i^n (Y_i - Y_t), \quad Y_i < Y_t \qquad \text{Equation 12b}$$

Where BP_b and YP_b are the projected increase in biomass and crop production in ton/ha/season. B_i and Y_i are biomass and crop yield of a plot i in ton/ha/season. B_t and Y_t are target biomass and crop yield in ton/ha/season.

5 Example: Protocol applied at Wonji irrigation scheme

5.1 Data

Case: crop = sugarcane, country = Ethiopia, project = Wonji

WaPOR and local data of Table 8 are used to implement the protocol. The Level 2 data used in this study include actual evapotranspiration and interception and net primary production at a dekadal timescale and annual land cover classification. In addition, dekadal precipitation at 5 km resolution, dekadal reference evapotranspiration at 25 km resolution. The precipitation and reference evapotranspiration datasets were downscaled to 100 m resolution.

Table 8: Data use as input to implement the protocol at the example case study

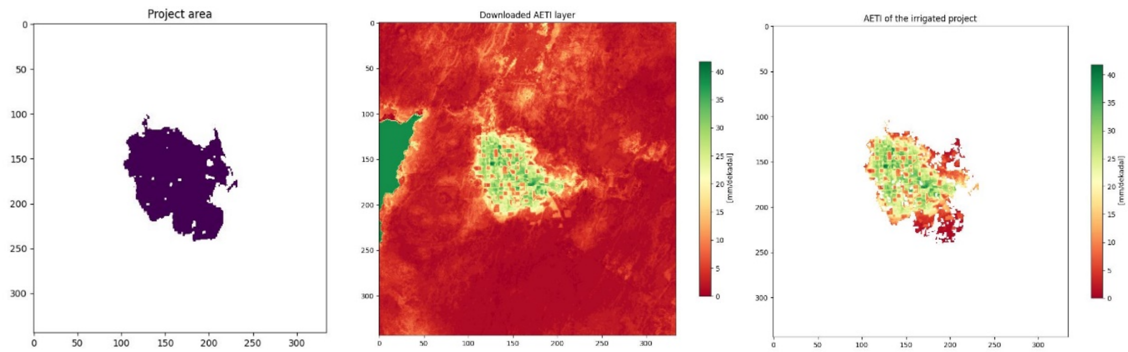
No.	WaPOR data	Spatial resolution	Temporary resolution	Temporal coverage
1	Actual evapotranspiration & interception (*AETI*)	100 m	Dekadal	(2009-2022)
2	Transpiration (*T*)	100 m		
3	Net primary production (*NPP*)	100 m		
4	Precipitation (*P*)	5 km		
5	Reference evapotranspiration (*REF*)	25 km		
6	Land cover classification (*LCC*)	100 m	Annual	
	Local data			
7	Boundary of case study is delineated from Google Earth and Wonji project			
8	Start of season (*SOS*) and end of season (*EOS*), 1 October to 30 September			
9	Moisture content (m_c) of fresh crop biomass = 0.59 (Yilma et al., 2017)			
10	Ratio of Light use efficiency (LUE) of C4 and C3 crops = 1.8 (Villalobos and Fereres, 2016)			
11	The ratio of above ground over total biomass (AOT) = 0.8 (Smith et al., 2005)			
12	Crop coefficient (k_c) at initial, mid-season and harvest are 0.4, 1.25 and 0.75, respectively (Allen et al., 1998; Doorenbos and Kassam, 1979)			
13	The duration of the initial, development, mid-season and late-season stages are 30 days, 60 days, 180 days and 95 days (Allen et al., 1998; Doorenbos and Kassam, 1979)			

5.2 WaPOR data consistency

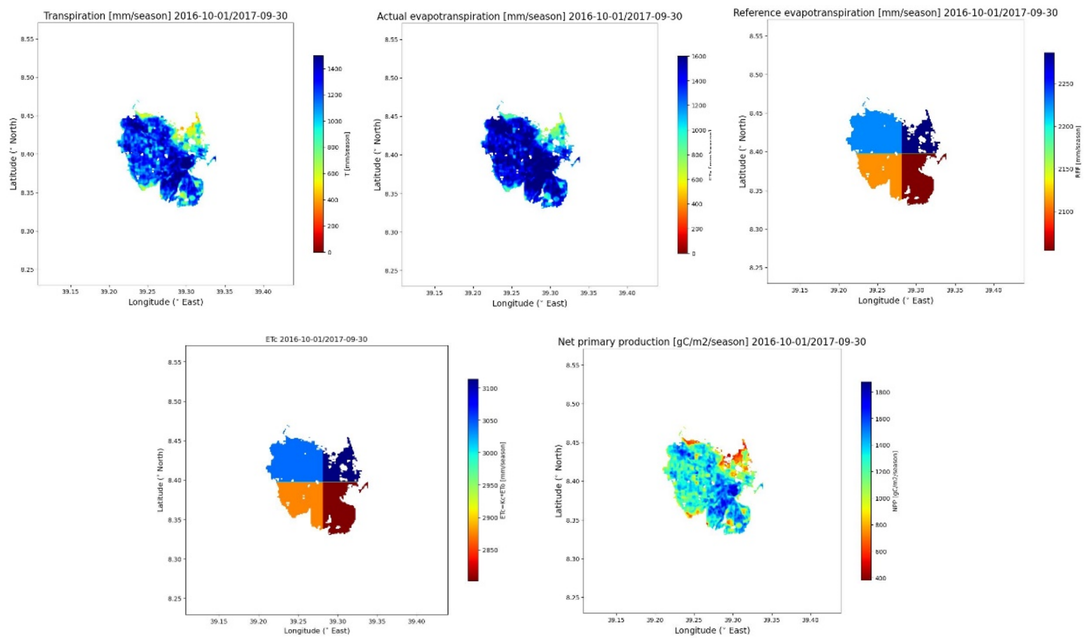
The Level 2 data source of the WaPOR data is not consistent throughout the 10 years. Before 2014, the data is derived from the MODIS satellite (250 m resolution), which is resampled to 100 m. In 2014, PROBA-V came into orbit, which provides the WaPOR L2 data for the period after 2014. As from 2020 use is made of Sentinel 2. The analyses over other areas shows a clear break 2009-2013 and 2014 onwards in the data (e.g., the noise in the biomass-transpiration and biomasses relationship are much even with patch of scatter pixels, such as high biomass at zero transpiration which cannot be explained agronomical).

5.3 Results

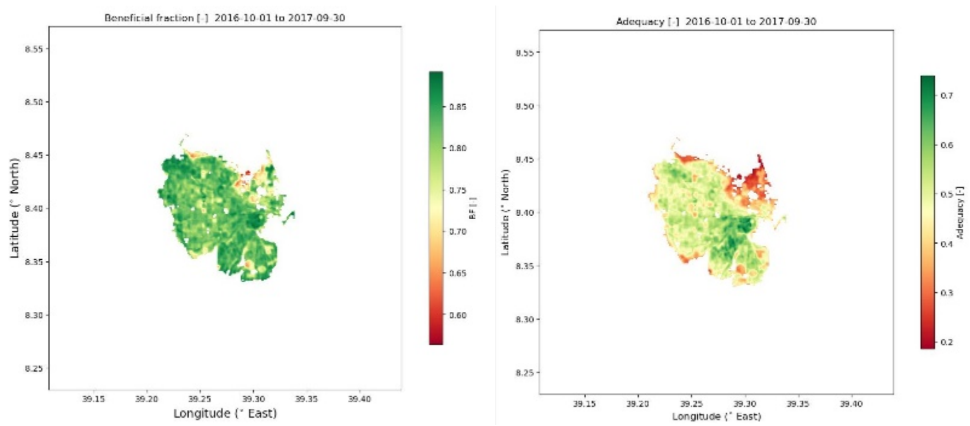
Module 2: Project area (a), the downloaded actual evapotranspiration layer (b) and actual evapotranspiration after the non-irrigated crop area is filtered (c)



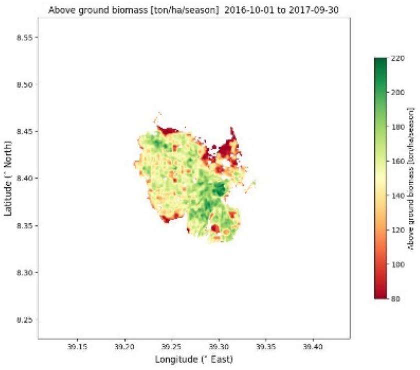
Module 3: Seasonal water consumption and net primary production

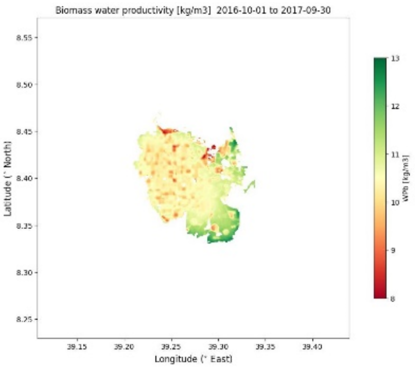


Module 4: Performance indicators

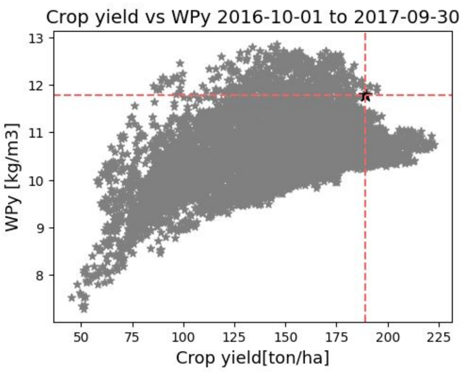


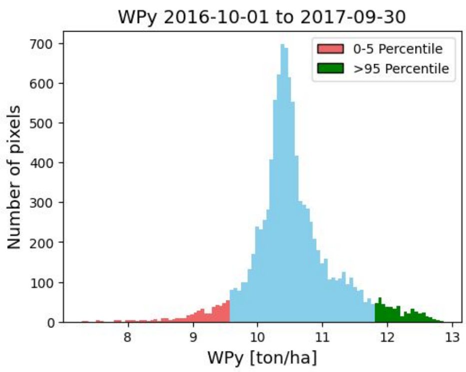
Module 5: Productivity

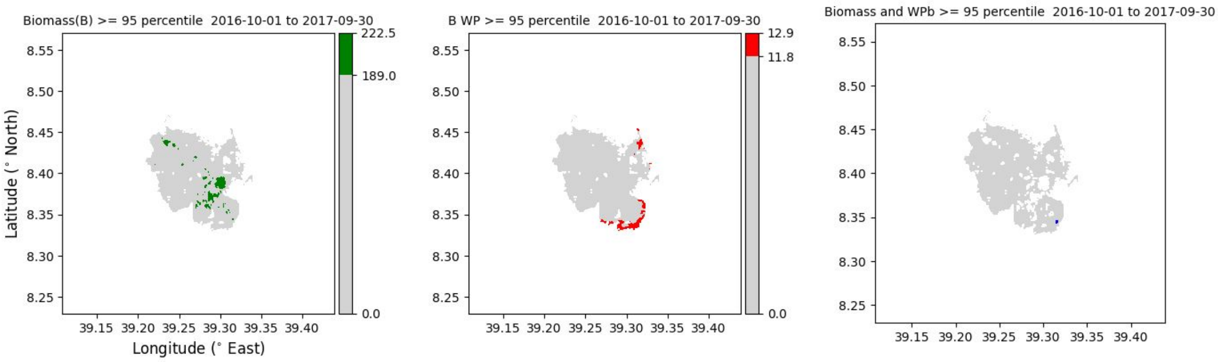


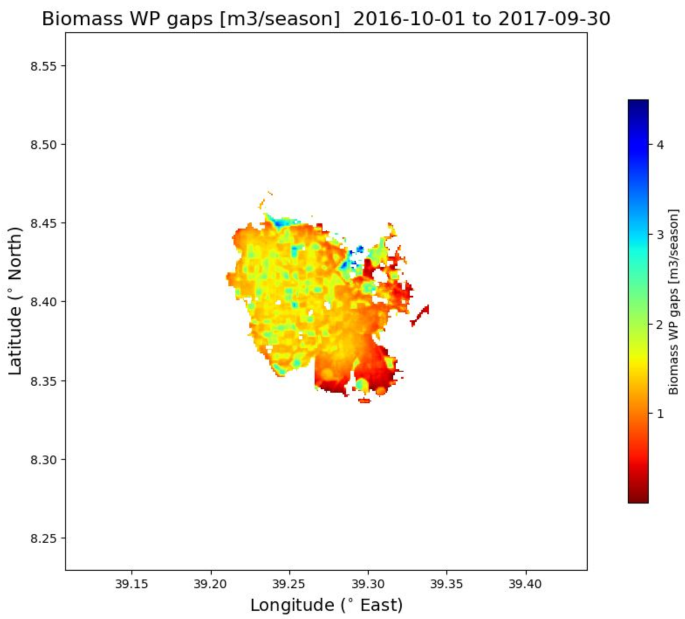


Module 6: Productivity gaps and bright spots









6 WaPOR Data Visualization

Notebook: 7_WaPOR2ILWIS.ipynb
Step 7a: Import modules/libraries
Step 7b: Creating MapList
Step 7c: Visualize data as animation

Within this notebook use is going to be made of ILWISPy, a python based site package offering Remote Sensing and GIS capabilities. First all required resources are loaded, like OpenEO, ILWISpy, Matplotlib as well a number of other libraries. The data folders are assigned, here the folder '/WaPOR_Data/4L2_Yield' is used as example, you can select another folder.

First a list is created of all the Yield*.tif files contained within the folder. A definition, called 'makeMaplist' is prepared to create a mapstack. The number of layers, size and projection / coordinate information assigned is reviewed and the variable 'band_data' is stored as an ILWIS maplist. You can download the maplist and visualize the data in ILWIS386, which can be downloaded from https://filetransfer.itc.nl/pub/52n/ILWIS386/Software/.

The data can also be visualized in the notebook, first the statistics are calculated, only for the irrigated areas. Then the data is transformed into a Numpy array. Some of the variables, like min and max thresholds as well as the numpy array, are stored in memory for later use. When dealing with time series data an animated sequence is an appropriate way to visualize your data and here 'ffmpeg' is used for this purpose. The animation created can be saved on disk.

Providing further contextual information, e.g. background geographical information can be done manually (adding a layer) in a desktop GIS. Within this notebook use is made of Cartopy. Given some compatibility issues, the notebook instance is stopped and restarted, the variables stored in memory are restored and a new animation is created, now using as background 'OpenStreetMap'. This animation can be saved as a MP4. The Notebook itself can be exported as HTML (using the menu option > File > Save and Export Notebook As..> HTML). Check your 'Downloads' folder and open the notebook.html and check the animations.

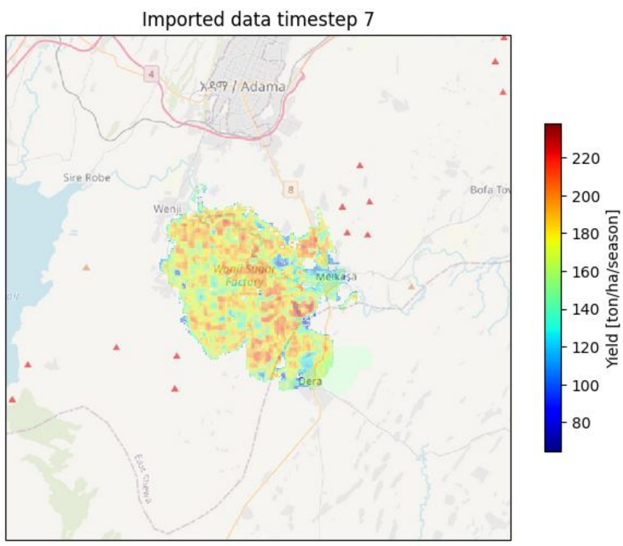


Figure 10: Sample time step with OSM as background

7 WaPOR Version 3 access

Notebook: 8_WaPOR_Intro_V3.ipynb
Step 8a: Import modules/libraries
Step 8b: Retrieve WaPOR Version 3 Catalogue
Step 8c: Downloading a subset
Step 8d: Create a time series and show as animation

Finally we are going to have a look at WaPOR version 3. After installation of Gdal, OpenEO and ILWISPy and some other libraries, the packages are imported. Once this is done, the Base_URL is loaded. This, together with the definition 'collect_responses' is required to get a listing of all mapsets currently available. Further specifications are possible, e.g. using the 'mapset_code' indicating the mapset of interest, e.g. 'L2-AETI-D'. Once the links are provided to the dataset, these can be manually downloaded.

In order to download a subset of the data into a specified folder we define the subset parameters, like the url, bounding_box, bands, output format and the location to store the data, etc. Then 'gdal_translate' is being used in conjunction with the option f"/vsicurl/{tif_url}" to handle files stored on network, like cloud storage services.

In this way not only single maps but also time series can be retrieved. The time series of the subset retrieved is stored as an ILWIS map-stack, with the name 'Wonji_2022_V3.mpl' and is consisting of 36 layers having dekadal time step interval. The data is loaded as an ILWIS raster. Statistics to obtain the stretch thresholds for visualization are calculated. The data is converted to a numpy array and for visualization as an amination matplotlip – imshow is used.

8 References

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Appendices

Appendix A: Default crop parameters used in WaPOR portal (FAO, 2020b)

Crop	Harvest index	Above ground over total biomass	Moisture content ratio
Cotton	0.2	0.8	0.15
Barley	0.3	0.85	0.15
Wheat	0.48	0.85	0.15
Maize (grain)	0.35	0.93	0.26
Sorghum	0.25	0.8	0.2
Rice	0.43	0.75	0.15
Tef	0.24	0.75	0.15
Sugarcane (ratoon)	1	1	0.7

Appendix B: Installation and Setup resources in the Copernicus DataSpace Ecosystem

WaPOR_exercise_preparation

Before you execute this notebook, ensure that within the Copernicus DataSpace Ecosystem you have created a folder 'WaPOR' under the folder 'mystorage' and this notebook ('WaPOR_exercise_preparation.ipynb') is situated under /mystorage/WaPOR

[ ]:
```
import os
import glob
from zipfile import ZipFile
```

[ ]:
```
# list the current working directory - the location of this notebook
rd = os.getcwd()
print(rd)
```

Retrieve Software tools and notebooks

[ ]:
```
#Install WaPOR module and other software tools, target folder is located within␣
↪the WaPOR folder
SW = 'Modules'
os.chdir(rd)
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(SW):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(SW)
```

[ ]:
```
Modules_dir = (rd)+'/Modules/'
print(Modules_dir)
os.chdir(Modules_dir)
!wget -r -np -nH --cut-dirs=4 -R "index.html*" https://filetransfer.itc.nl/pub/
↪52n/WaPOR_Wonji/WaPOR_SW/Modules.zip
```

[ ]:
```
# unzip file Modules.zip
zips = glob.glob(Modules_dir +'/'+'Modules.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
```

```
        z.extractall()
print('Done!')
```

[ ]:
```
# run this code field to remove the downloaded zip files
!rm -rf Modules.zip
```

[ ]:
```
#install ancillary files needed in notebooks (like pictures), target folder is␣
↪located within the root of the WaPOR folder
ANCIL = 'img'
os.chdir(rd)
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(ANCIL):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(ANCIL)

os.chdir(ANCIL)
!wget -r -np -nH --cut-dirs=4 -R "index.html*" https://filetransfer.itc.nl/pub/
↪52n/WaPOR_Wonji/WaPOR_SW/img.zip
```

[ ]:
```
# unzip file
unzip_dir = (rd)+'/img'
os.chdir(unzip_dir)
zips = glob.glob('img.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

[ ]:
```
# run this code field to remove the downloaded zip files
!rm -rf img.zip
```

[ ]:
```
#Retrieve Notebooks, target destination is within the root of WaPOR folder
rdir = rd
os.chdir(rd)
print(rd)

!wget -r -np -nH --cut-dirs=4 -R "index.html*" https://filetransfer.itc.nl/pub/
↪52n/WaPOR_Wonji/Notebooks/Notebooks.zip
```

[ ]:
```
# unzip file
unzip_dir = (rd)
os.chdir(unzip_dir)
zips = glob.glob('Notebooks.zip')
```

```
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

[ ]:
```
# run this code field to remove the downloaded zip file
!rm -rf Notebooks.zip
```

Retrieve WaPOR data for the Wonji area Preparing a new folder structure to store the sample data

[ ]:
```
#install Wonji Sample data
DATA = 'WaPOR_Data'
os.chdir(rd)
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(DATA):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(DATA)
```

[ ]:
```
#download clipped Wonji sample data, target folder is located within the WaPOR␣
↪folder
dst_dir = (rd) +'/WaPOR_Data/'
print(dst_dir)

os.chdir(dst_dir)
cwd = os.getcwd()
print(cwd)

file_listing = os.listdir()
print(file_listing)
```

Retrieve sample data for the Wonji exercise from given URL resource link

[ ]:
```
!wget -r -np -nH --cut-dirs=3 -R "index.html*" https://filetransfer.itc.nl/pub/
↪52n/WaPOR_Wonji/Wonji_WaPOR_Data/
```

Prepare Land Cover Classification (LCC) data If you have already conducted the notebook '1_WaPOR_data_bulk_download.ipynb' and processed the LCC then there is no need to execute the code field below, continue with the next data resource, and unzip the Reference Evapotranspiration

[ ]:
```

```

```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

LCC = 'WAPOR.v2_yearly_L2_LCC_A'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(LCC):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(LCC)

os.chdir(LCC)
LCC = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/*_LCC_A.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Prepare Reference Evapotranspiration (RET) data

[ ]:
```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

RET = 'WAPOR.v2_dekadal_L1_RET_D'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(RET):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(RET)

os.chdir(RET)
RET = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/*_RET_D.zip')
for zip in zips:
```

```
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Prepare Precipitation (PCP) data

[ ]:
```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

PCP = 'WAPOR.v2_dekadal_L1_PCP_D'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(PCP):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(PCP)

os.chdir(PCP)
PCP = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/*_L1_PCP_D.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Prepare Actual Evapotranspiration and Interception (AETI) data

[ ]:
```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

AETI = 'WAPOR.v2_dekadal_L2_AETI_D'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(AETI):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(AETI)
```

```
os.chdir(AETI)
AETI = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/WAPOR.v2_dekadal_L2_AETI_D.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Prepare Transpiration (T) data

[ ]:
```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

TRP = 'WAPOR.v2_dekadal_L2_T_D'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))

if os.path.isdir(TRP):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(TRP)

os.chdir(TRP)
TRP = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/WAPOR.v2_dekadal_L2_T_D.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Prepare Net Primary Productivity (NPP) data

[ ]:
```
#within the folder 'WaPOR_Data' a new folder is created if not already␣
↪available with same foldername as the zipfile name.
#the data contained within this zipfile is unzipped within this new folder␣
↪created

NPP = 'WAPOR.v2_dekadal_L2_NPP_D'
os.chdir(rd + '/' + 'WaPOR_Data')
print("current dir is: %s" % (os.getcwd()))
```

```python
if os.path.isdir(NPP):
    print("Folder exists")
else:
    print("Folder doesn't exists and is created")
    os.mkdir(NPP)

os.chdir(NPP)
NPP = os.getcwd()

zips = glob.glob(cwd +'/'+'Wonji_WaPOR_Data/WAPOR.v2_dekadal_L2_NPP_D.zip')
for zip in zips:
    print('Extracting', zip)
    with ZipFile(zip, 'r') as z:
        z.extractall()
print('Done!')
```

Check the availability of your downloaded / unzipped resources before you continue!

[ ]:
```python
# run this code field to remove the downloaded zip files
os.chdir(rd + '/' + 'WaPOR_Data')
!rm -rf Wonji_WaPOR_Data
```