Water Productivity Analysis: Irrigation Season 2021

APSAN-Vale project

REPORT 236

CLIENT Agência de Desenvolvimento do Vale Zambeze (ADVZ)

AUTHORS Jonna van Opstal
Martijn de Klerk
Vera Hollander

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Authors
Jonna van Opstal – Senior Water Productivity Expert (j.vanopstal@futurewater.nl)
Martijn de Klerk – Flying Sensor Expert, Project Manager (m.deklerk@futurewater.nl)
Vera Hollander – Water Management Expert (v.hollander@futurewater.nl)

APSAN-Vale project partners
Resilience B.V.
HUB
ThirdEye Limitada

Date
April 2022

ADDRESS
FutureWater B.V.
Costerweg 1V
6702 AA Wageningen
The Netherlands

FutureWater

TELEPHONE +31 317 460 050
WEBSITE www.futurewater.eu

Preface

The APSAN-Vale project has as its overall aim to increase climate resilient agricultural productivity and food security, with a specific objective to increase the water productivity and profitability of smallholder farmers in Mozambique, prioritizing small (family sector) farmers to increase food and nutritional security. This project will demonstrate what the best combinations are of adoption strategies and technological packages, with the largest overall impact in terms of Water Productivity, both at the plot-level, sub-basin as well as basin level. The main role of FutureWater is monitoring water productivity in target areas (both spatial and seasonal/annual variation) using remote sensing data from Flying Sensors (drones), satellite imagery, and WaPOR data portal in combination with a water productivity simulation model and field observations. This report shows the water productivity analysis for the 2021 irrigation season (April – October) in three different locations in Mozambique. This analysis is crucial to evaluate the impact of field interventions on water productivity.

Summary

Farmers are seeking best practices that can achieve higher crop yields, thus profits and food security. With limited resources such as water, the increase of production needs to be considered per unit of water consumed, which is expressed in the term Water Productivity. Water productivity can be used as a performance indicator to monitor changes in an agricultural area (at plot, farm, or irrigation system level). If interventions are implemented, water productivity can indicate if the intervention had a positive or negative impact on the use of water or remained unchanged. This report provides an assessment of the water productivity during the irrigation growing season of 2021 (April to October) for the APSAN-Vale project areas.

Various methods were used to provide a reliable assessment of the water productivity, using the data available from the field, flying sensor imagery and open-access remote sensing datasets from WaPOR and Sentinel 2. With the use of Sentinel 2 data the water productivity method was substantially improved compared to the previous water productivity reports. This satellite remote sensing data was used supplemental to flying sensor imagery to capture more frequently the crop development and fill in the gaps between the 2-to-4-week intervals of the flying sensor imagery intervals. Due to the typical short crop growth periods of irrigation season crops (approximately 2.5 to 3 months), the supplemental data provided by Sentinel 2 imagery is useful for a better determination of the crop curve.

At field scale the crop-specific water productivity is calculated using Flying Sensors (drones) and AquaCrop model simulations. The flying sensors used are equipped with a near-infrared camera for detection of the vegetation status. These images are processed and translated to canopy cover values. In AquaCrop the field data and canopy cover from flying sensors is used to simulate the farming practices for each field, to determine yield and water productivity. At sub-basin and basin scale the biomass water productivity is calculated using data from FAO's water productivity data portal WaPOR (http://wapor.apps.fao.org).

During the 2021 irrigation season a total of 175 flying sensor flights were performed over 29 farm fields, covering a total of 560 ha. In the end, for the water productivity analysis, data from 28 farmers was used: 10 in Báruè, 9 in Moatize, and 9 in Nhamatanda. The results of the flying sensor imagery acquired throughout the season are presented in printed field maps and also shared through our online portal. Over the past year, substantial efforts were made to disseminate the maps made by ThirdEye's AgPilots (or flying sensor operators) for a larger public online, through the APSAN-Vale Flying Sensor portal. The portal can be accessed through https://futurewater.eu/apsanvaleportal/.

The field scale water productivity presented results for 28 farmers which were monitored throughout the irrigation season as part of the APSAN-Vale project. The water productivity was calculated for all major crop types of the irrigation season tomato, cabbage, onion, and potato. Additionally, typical rainfed crops which were also grown in the irrigation season (beans and maize) were also added to the analysis. Tomato water productivity was found to range from 1.57 to 2.95 kg/m^3 in Báruè, 1.79 to 2.96 kg/m^3 in Moatize, and 2.03 kg/m^3 in Nhamatanda. Cabbage water productivity was found to range from 1.73 to 2.76 kg/m^3 in Báruè, 1.44 kg/m^3 in Moatize, and 1.66 to 1.95 kg/m^3 in Nhamatanda. After normalization for climatic conditions, the increase in overall crop specific water productivity (summarized for all major crop types) was found to be +74% in Báruè, +21% in Moatize, and +50% in Nhamatanda, resulting in an average +48% increase in comparison with the baseline values. This is a more positive change with the baseline values compared to the previous irrigation season report (2020).

Furthermore, the water productivity was calculated at sub-basin scale, which is representative for the community of farmers adopting practices being demonstrated and promoted by the selected PPCs (Pequenos Produtores Comercial, small commercial farmers). An area of 300 ha around each selected

PPC is determined to be representative for the area of the sub-basin (or community). At sub-basin scale the water productivity analysis makes use of the WaPOR data portal and calculates the biomass water productivity. The highest water productivity values were found in Báruè; here the highest values are observed in Báruè I of 3.13 kg/m^3. In Moatize the highest water productivity is found in Moatize I. Both high water productivity values in Báruè I and Moatize I are related to upstream locations and the vicinity of mountain ranges. The biomass water productivity was found to range from 2.93 to 3.13 kg/m^3 in Báruè, 1.38 to 2.55 kg/m^3 in Moatize, and 2.06 to 2.13 kg/m^3 in Nhamatanda. The relative change of water productivity compared to the baseline values is +24%, +24% and +17% for Báruè, Moatize, and Nhamatanda, respectively. The overall increase in water productivity estimated at sub-basin (community) level is +22%.

At basin scale the catchment delineation from each district was used as the boundary of the basin. The water productivity was determined using the WaPOR data portal providing values on biomass water productivity. These values are compared with the baseline assessment and determined that an increase of water productivity was achieved of +46%, +27%, and +25% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +33% for all districts together.

The field scale water productivity analysis indicates an improvement of water productivity and achieves the set target for 2021 of +25% as stated in the project logframe. Continuation of this analysis with the adoption of practices will assist in determining effective interventions for improving water productivity and facilitate the upscaling of water productivity improvements.

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1 Introduction

1.1 Water productivity concept

In order to meet the future needs of food and fiber production, developing and developed countries need to focus more on efficient and sustainable use of land and water (Bastiaanssen and Steduto, 2017)[1]. Farmers have been able to gain profit by increasing agricultural production per unit of land. However, it is key to include the water consumption component in agricultural production. This would allow to improve agricultural production per unit of water consumed.

Water productivity consists of two components: production (either as crop yield or biomass) and water consumed. Water consumption occurs through evapotranspiration which is the sum of plant transpiration through the stomata in the leaves, and evaporation that occurs from the soil surface and intercepted water by the leaves (Squire, 2004)[2]. Within this project the use of evapotranspiration (versus irrigation application) was selected, because it represents the component of the water balance that cannot be re-used by downstream users in a river basin context. Return flows from agricultural areas (through runoff or subsurface flow) are available for re-use in the downstream areas if the quality of the water is sufficient. As such, water productivity can be expressed as:

$$Biomass\ water\ productivity\ [kg/m^3] = \frac{Biomass\ production\ [kg]}{Evapotranspiration\ [m^3]}$$

$$Crop\ specific\ water\ productivity\ [kg/m^3] = \frac{Crop\ harvestable\ yield\ [kg]}{Seasonal\ evapotranspiration\ [m^3]}$$

Water productivity can be used as a performance indicator to monitor changes in an agricultural area (at plot, farm, or irrigation system level). If interventions are implemented, water productivity can indicate if the intervention had a positive or negative impact on the use of water or remained unchanged. In addition, spatial information on water productivity can indicate areas that have higher performance (early adopters) and whether practices are taken over by other farmers.

1.2 APSAN-Vale project

1.2.1 Description

The APSAN-Vale project commenced end of 2018 and is a 4.5 year project with the objective to: 'Pilot innovations to increase the Water Productivity and Food security for Climate Resilient smallholder agriculture in the Zambezi valley of Mozambique'. Water productivity is used as an indicator to quantify the impact of the innovations on smallholder agriculture. These innovations can be technical packages (interventions and trainings), and adoption of lessons-learned through farmer-to-farmer communication. Information on water productivity needs to incorporate both temporal and spatial aspects. The temporal changes in water productivity indicates if an intervention resulted in an increase of water productivity. The spatial patterns in water productivity indicates if the knowledge is being adopted in the region and increased the overall water productivity of the locality, and district. Project activities take place in three districts namely: Báruè, Moatize, and Nhamatanda. Within each district, various localities are selected for piloting innovations. The location of the districts and current project activities are shown in Figure 1.

[1] Bastiaanssen, W. G. M. and Steduto, P.: The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize, Sci. Total Environ., 575, 595–611, doi:10.1016/j.scitotenv.2016.09.032, 2017.
[2] Squire, G. L.: Water Productivity in Agriculture: Limits and Opportunities for Improvement. Edited by J. W. Kijne, R. Barker, D. Molden. Wallingford, UK: CABI Publishing (2003), pp. 352, ISBN 0-85199-669-8, Exp. Agric., 40(3), 395–395, doi:10.1017/S0014479704372054, 2004.

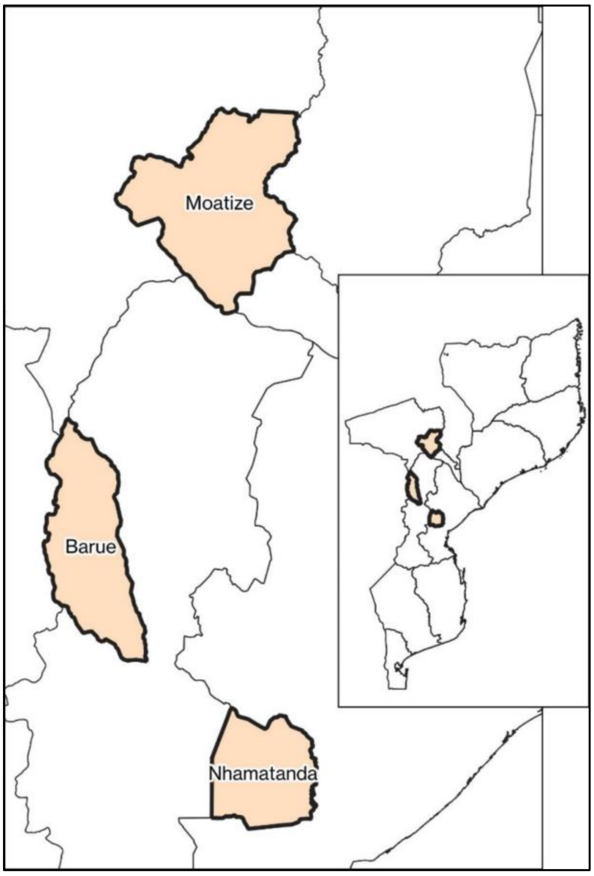


Figure 1. Location districts of APSAN-Vale project activities

1.2.2 Logframe indicators

Within the APSAN-Vale project several logframe indicators are formulated. The indicators linked with the water productivity assessment are listed in Table 1. Some indicators require the calculation of a crop specific water productivity (1.2 and 1.3), whilst other indicators use biomass water productivity (1.4). Also the outputs indicate that water productivity is calculated at field, sub-basin, and basin scales, thus providing the required maps at those different spatial scales. The annual targets for the water productivity outcomes are percentages of increase compared to the baseline assessment (Van Opstal and Kaune, 2020)[1] and are indicated in Table 1 as cumulative values, whereas the output maps are the annual total for each year.

Table 1. Logframe indicators related to Water Productivity.

	#	Indicator	Baseline	Target 2019	Target 2020	Target 2021	Target 2022
Goal	0.3	Increased Water Productivity	0%	7.5%	15%	25%	25%
Outcome	1.2	Water footprint for selected crops	0%	7.5%	15%	25%	25%
	1.3	Water productivity for maize	0%	7.5%	15%	25%	25%
	1.4	Biomass water productivity	0%	7.5%	15%	25%	25%
Outputs	1.1.1	# of field level maps	0	30	60	60	60
	1.1.2	# of sub-basin level maps	0	10	20	20	20
	1.1.3	# of basin level maps	0	6	12	12	12

[1] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195

1.3 Season overview

The irrigation season commenced in April 2021 with the planting of various field crops with main crop types being tomato, cabbage (couve and repolho), onion, and potato. Some typical rainfed crops (beans, maize) were also grown during the irrigation season. The season continues till end of September or early October. Harvest occurs throughout the season at different intervals depending on the growing length of the crops. The flying sensor activities occurred with flights taken once every 3-4 weeks with the total number of flights, flight area, and farmers monitored, presented in Table 2. In the end, for the water productivity analysis, data from 28 farmers was used.

Table 2. Overview of number of flights made and farmers monitored during this season

	Báruè	Moatize	Nhamatanda	Total
Flights taken	73	46	56	175
Farmers monitored	10	10	9	29
Area covered	200 ha	180 ha	180 ha	560 ha
Farmers monitored for WP	10	9	9	28

1.4 Reading guide

This technical report provides the results of the water productivity analysis at field-scale, sub-basin scale, and basin scale using Flying Sensor Imagery, crop modelling, and FAO's WaPOR database. The next chapter (chapter 2) elaborates on the methodology used for conducting the water productivity analysis. Chapter 3 provides an analysis of the meteorological conditions during the growing season and compares with past years. Chapters 4, 5, and 6 provide the results of the water productivity analysis at field, sub-basin, and basin scale respectively. Chapter 7 gives an assessment of the water productivity results and compares with the baseline assessment values. Chapter 8 provides the summarizing and concluding remarks.

2 Methodology

2.1 Project locations

2.1.1 Farm fields

For each district several small commercial farmers (Pequenos Produtores Comercial or PPCs) were selected for the project to implement numerous innovative practices (boas practicas) for boosting water productivity. Most of the selected PPCs were monitored with flying sensor flights. In Báruè, Moatize, and Nhamatanda, ten, nine, and nine PPCs respectively were monitored for the water productivity analysis. Figure 2 indicates the locations of the PPCs monitored during the irrigation season.

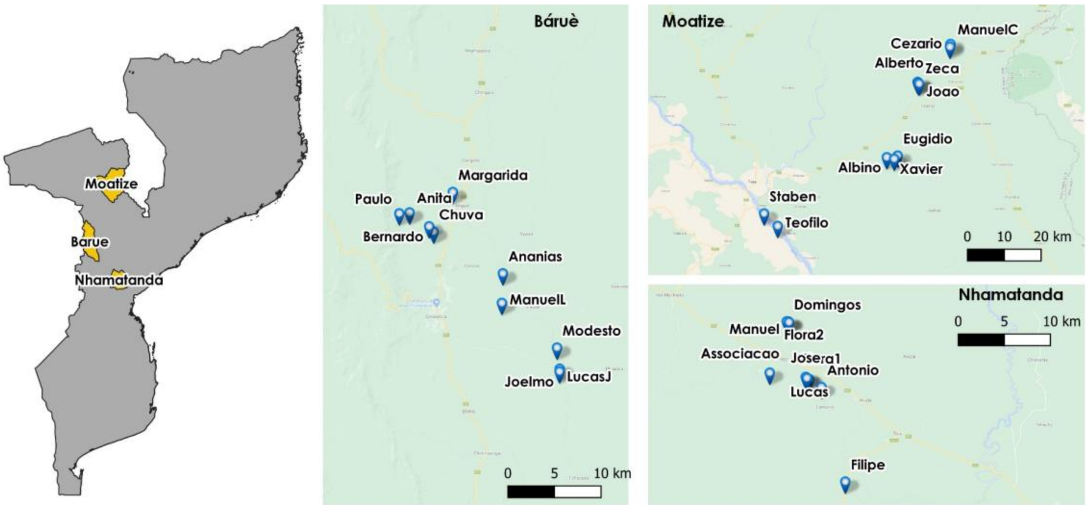


Figure 2. Location of selected PPCs monitored with flying sensor flights during the 2021 irrigation season

2.1.2 Sub-basins

The sub-basin scale is a level between the field scale of the PPCs and the basin scale as described in the next section. For the analysis of the sub-basin level water productivity, a representative size is selected of local communities surrounding the PPCs. The objective of the APSAN-Vale project is to increase water productivity of several communities through knowledge exchange of the interventions being implemented. It is expected that communities surrounding the PPCs will adopt certain best practices. Therefore, increase of water productivity is best monitored at a scale that captures the change of the communities. The sub-basin or community area is selected using a buffer of approximately 300 ha radius surrounding the selected PPCs. The locations of these communities are presented in figures 3, 4, and, 5 for Báruè, Moatize, and Nhamatanda, respectively. Each have selected 3 to 4 clusters at the location of the PPCs.

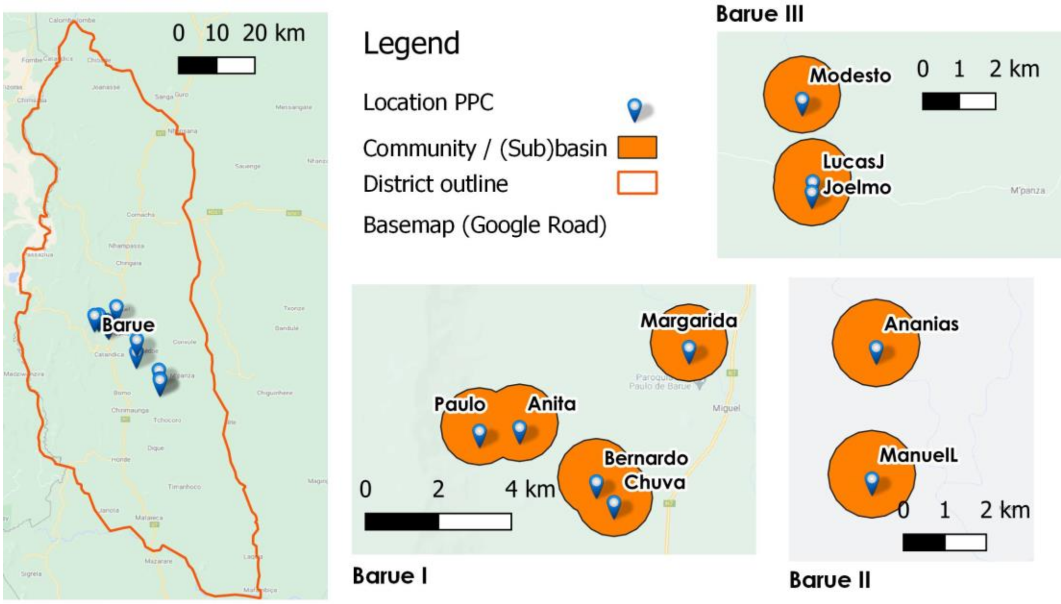


Figure 3. Location and boundaries of sub-basin areas in Báruè

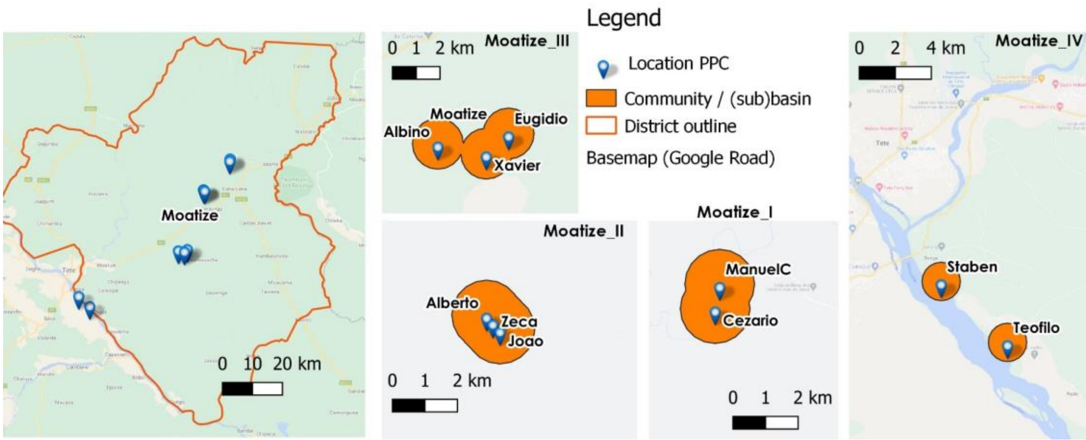


Figure 4. Location and boundaries of sub-basin areas in Moatize

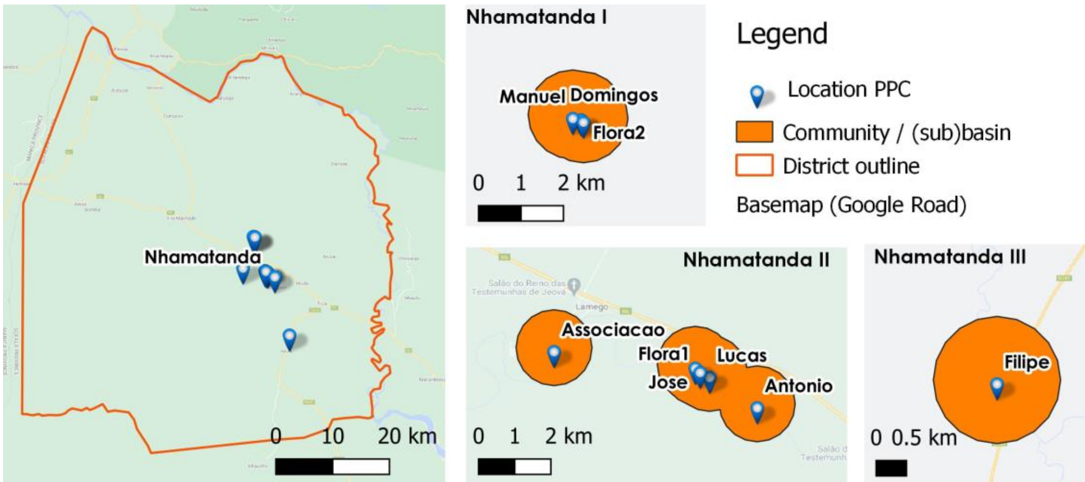


Figure 5. Location and boundaries of sub-basin areas in Nhamatanda

2.1.3 Basins

The basin delineation was performed using a DEM (digital elevation model) at 30m resolution provided by SRTM, and QGIS tools. Details on the steps involved can be reviewed in the manual (Kwast and Menke, 2019)[1]. The outflow points for the basins are determined by evaluating the location of the project activities in the fields, as were determined at the start of the project[2]. The sub-basins are representative for the localities of the project, whereas the basins represent the larger picture of the upstream area. The delineations and locations of project activities are shown in the maps of Figure 6. Measurements of water flow were conducted by project partners at strategic locations in the streams to quantify water abstractions for irrigation.

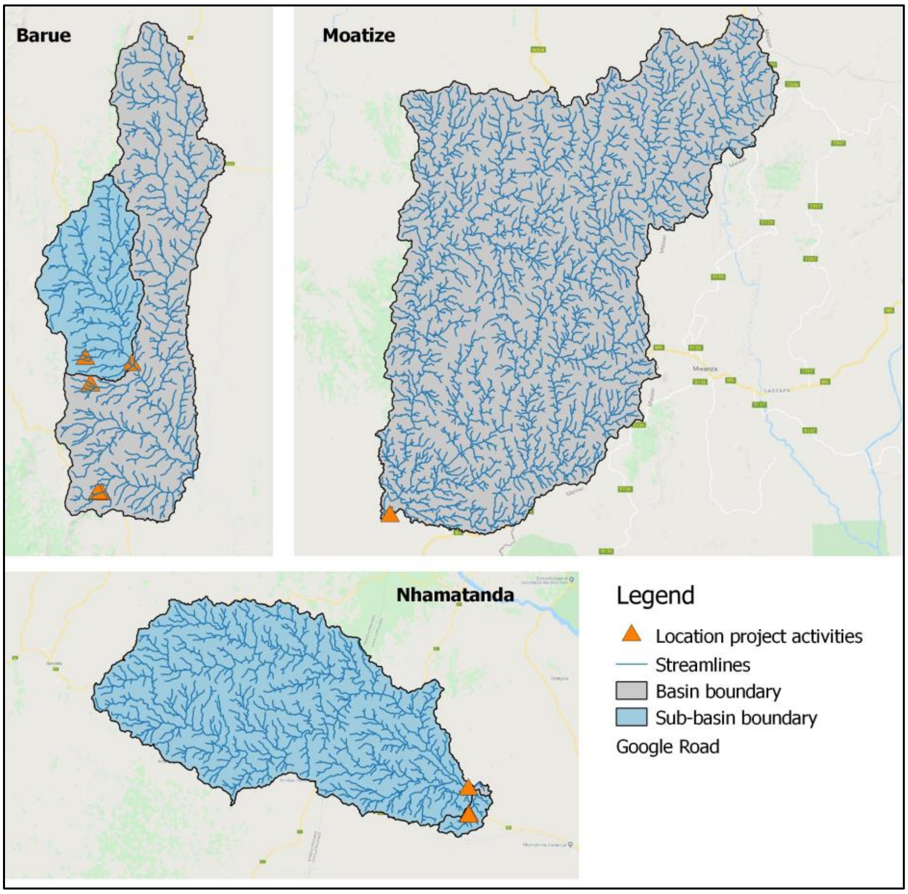


Figure 6. Delineation of basins and streamlines for Báruè, Moatize and Nhamatanda

2.2 Approach

The water productivity analysis follows two approaches for the calculation of water productivity:

1. At field scale the most detailed information is available regarding crop type and management strategies. At this scale a crop specific water productivity is calculated for the selected crops at the three different districts using crop simulation modelling in combination with flying sensor and satellite imagery (2.2.1).

[1] van der Kwast, H. & Menke, K., QGIS for Hydrological Applications - Recipes for Catchment Hydrology and Water Management, Locate Press, 2019.
[2] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.

2. At sub-basin and basin scale limited information is available on the spatial distribution of the crop types. At this scale a biomass water productivity is calculated using data from WaPOR, FAO's Open Access Portal with Water Productivity data (2.2.2).

2.2.1 Crop specific water productivity

Figure 7 displays the workflow for performing the crop specific water productivity analysis. The water productivity is ultimately calculated with AquaCrop. Field data for setting up the AquaCrop simulations are taken from the weather station and field notebooks. Flying sensors capture images at regular intervals to calculate the canopy cover. This dataset is supplemented with satellite (Sentinel 2) imagery for a higher frequency of data (at lower resolution). This information is integrated with the AquaCrop model to calibrate the model and calculate water productivity. The advantage of combining remote sensing observations from flying sensors, satellite data, and simulation modelling, is that spatial insight is gained in the diversity of farm management practices. Thus, for each field the most fitting AquaCrop simulation run is selected to be representative for that field. In the next sections the various methods used are elaborated, namely the flying sensor and satellite imagery (2.3), and crop simulation modelling with AquaCrop (2.4).

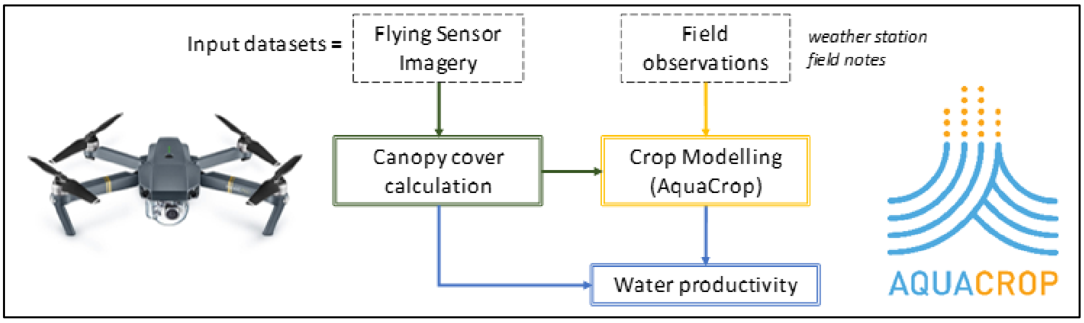


Figure 7. Workflow for calculation of crop specific water productivity analysis

2.2.2 Biomass water productivity

WaPOR is FAO's water productivity data portal (https://wapor.apps.fao.org) containing information on evapotranspiration, biomass production, land cover, and many other layers. Information at basin scale was extracted by deriving a catchment delineation for the selected districts. This was performed using a DEM (digital elevation model). The catchment delineation is shown in figure 6 for the selected areas.
The land cover layer in WaPOR was used to determine the location of croplands in the basins. The procedure for this analysis follows the guidance provided by the WaterPIP project (Water Productivity in Practice) and the workflow is schematically presented in Figure 8. In section 2.5 the WaPOR datasets used for this analysis, is described with more detail. At sub-basin scale similar layers are used for extracting information regarding water productivity.

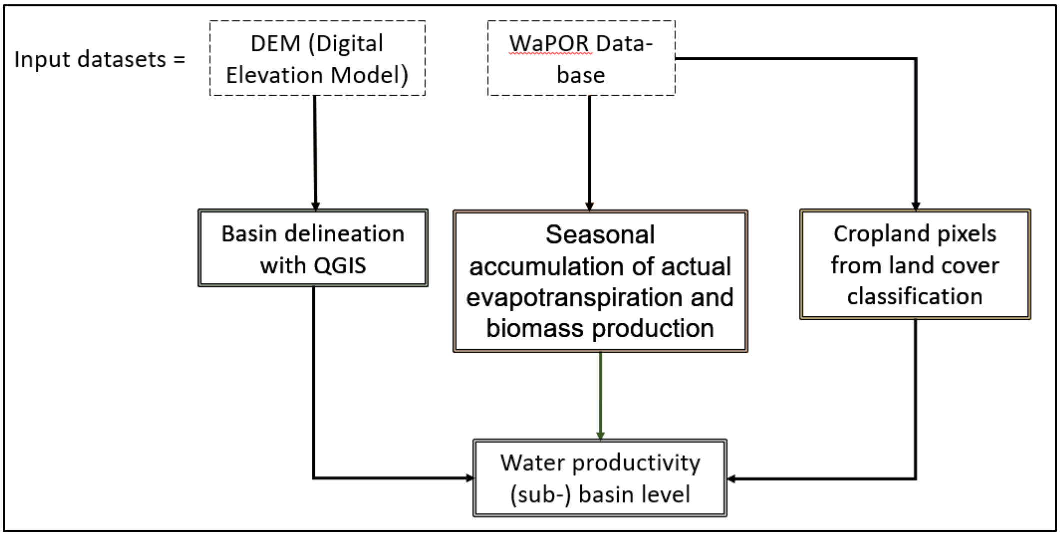


Figure 8. Workflow for biomass water productivity analysis

2.3 Flying Sensor Imagery

2.3.1 Flying sensor equipment

Figure 9. The APSAN-Vale Flying Sensor in action

The Flying Sensor equipment used in APSAN-Vale are a Mavic Pro drone and an additional camera to detect vegetation status. Figure 9 shows a photo of the Flying Sensor used including both cameras. One camera makes RGB (red-green-blue) images, similar to visual images as seen with the human eye. The second camera measures the near-infrared (NIR) wavelength, which is not visible to the human eye. The near-infrared wavelength has a good response to the conditions of the vegetation. Figure 10 gives an illustration of the response to stressed conditions of a leaf. If the leaf is in optimal health the NIR wavelength has a high response. If the leaf is under stressed or sick conditions the NIR wavelength has a lower response. This is already measured by the NIR wavelength before it is visible to the human eye.

Another advantage of using the Flying Sensors in this project is the flexibility for imagery capture and the high-spatial resolution of the acquired imagery. The flying sensors can make flights when required at the desired intervals. For this project the frequency of imagery acquisition was aimed at once every 3 weeks, which best captures the crop development stages. This interval was sometimes longer due to weather conditions or logistics. The spatial resolution of the imagery is 4-8 cm, providing sufficient detail to capture the spatial variation of small holder agriculture.

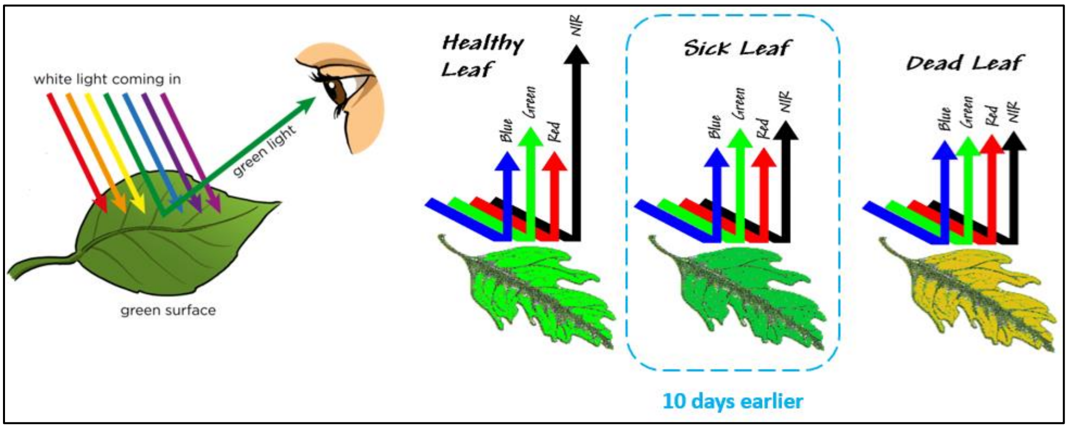


Figure 10. Illustration explaining the response of near-infrared (NIR) wavelength to vegetation status

2.3.2 Imagery acquisition

Flying sensor images were acquired at regular intervals throughout the growing season. In table 3 an overview is provided of the number of flights performed and on which date (sometimes spread over 2 or 3 days). The total number of flights for Báruè, Moatize, and Nhamatanda, were 73, 46, and 56, respectively. The total area monitored with the flying sensors was 200 ha, 180 ha, and 180 ha for Báruè, Moatize, and Nhamatanda, respectively.

Table 3. Overview of flights and area during the Irrigation Season of 2021

	Báruè	Moatize	Nhamatanda
May	4–6 May 2021 17–19 May 2021	11-12 May 2021	20 May 2021
June	7-10 June 2021		1-2 June 2021 15-16 June 2021
July	14-17 July 2021	6-7 July 2021 27-29 July 2021	16 July 2021
August	4-5 August 2021 19-20 August 2021	25-27 August 2021	3-4 August 2021 16-17 August 2021
September	1-3 September 2021 15-17 September 2021	8-10 September 2021 29-30 September 2021	1-3 September 2021 14-15 September 2021
October	19-21 October 2021		
Flights taken	73	46	56
Area covered	200 ha	180 ha	180 ha

2.3.3 Imagery processing

The imagery acquired by the Flying Sensors undergoes further processing. Firstly, the single images for each flight are stitched together to form an ortho mosaic. These are then georeferenced so it can be used in further geospatial analysis. These steps are performed using software packages: Agisoft Metashape, and QGIS (geospatial software).

The next processing steps are required to achieve a time series of canopy cover maps. Several steps were calculated using R coding to make the processing more efficient. The NIR band of the image is used to determine the vegetation pixels of each image using the ‘kmeans’ R package for automatic imagery classification. Manually the user determines which class is appointed as vegetation. This information is then used to calculate the canopy cover, which is an indication of the vegetation cover over a surface in percentage, and is in the same category as other vegetation indices commonly used in remote sensing e.g. Leaf Area Index (LAI) or Normalized Difference Vegetation Index (NDVI). Full vegetation cover will result in a canopy cover of 100%. A grid of 1x1 meter (=1 m^2) is overlaid over a crop field. The number of vegetation pixels (of 0.05x0.05 meter = 0.0025 m^2) is counted to determine the percentage of the grid that is covered by vegetation, thus the canopy cover. This information is used in combination with crop modelling to determine the crop yield, and water productivity.

2.3.4 Field maps for registration

At the start of the season the first flight imagery was used to register the fields of the selected PPCs for monitoring. An example of one of these maps, from PPC Ananias, is shown in Figure 11. These maps indicate the field boundaries, area of the field, crop type, and name of the farmer including the registered code as used in the field monitoring and notes. The maps were added to the field book (caderno de campo) of each PPC. Changes in fields and crop types could be corrected in following maps.

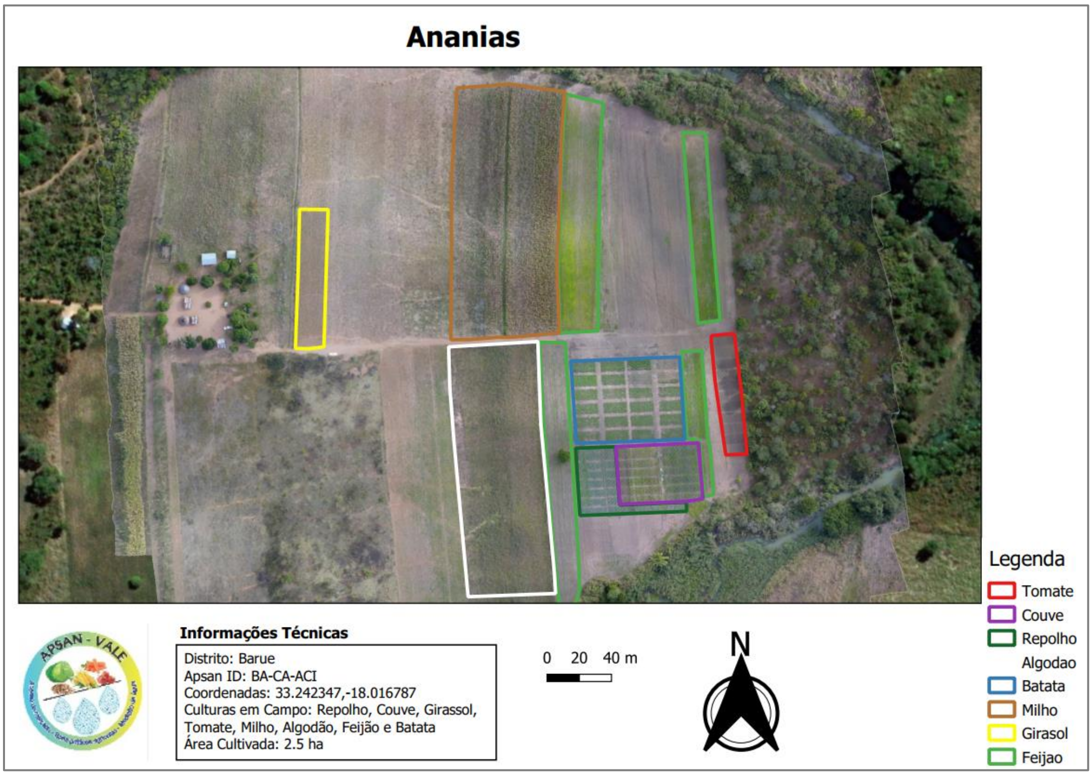


Figure 11. Field registration map of PPC Ananias for the 2021 irrigation season

2.3.5 Field maps for vegetation monitoring

During the season maps were made with the flying sensor cameras (RGB and near-infrared) for monitoring the vegetation during the crop growing season. Visual images (RGB, red-green-blue) are easier for interpretation as the colors seen are understandable and the same as can be observed with the naked eye. The vegetation status is indicated in red colors indicating low vegetation cover, and green colors indicating high vegetation cover.

These maps are provided to the farmers during the field season and published online in the APSAN-Vale Flying Sensor portal. All visual and vegetation status maps can be found in the online portal. Substantial efforts were made to disseminate the maps made by ThirdEye's AgPilots for a larger public online, through the APSAN-Vale Flying Sensor portal. The portal can be accessed through https://futurewater.eu/apsanvaleportal/.

Ever since the early development of the APSAN-Vale portal, updates are being implemented to make sure the portal serves the needs and wishes of ThirdEye's AgPilots and farmers. The flying sensor maps are uploaded to the portal automatically after they have been processed by ThirdEye's AgPilots. In this way, the operating team can easily access the maps in the field to observe areas of higher or lower water productivity, by using a tablet, laptop or smartphone. A screenshot of the updated portal is shown in Figure 12. The possibility of downloading the information (maps and notes) into a pdf file that can be handed out by the operator to the farmer is operational and includes additional features such as weather forecasts and market information.

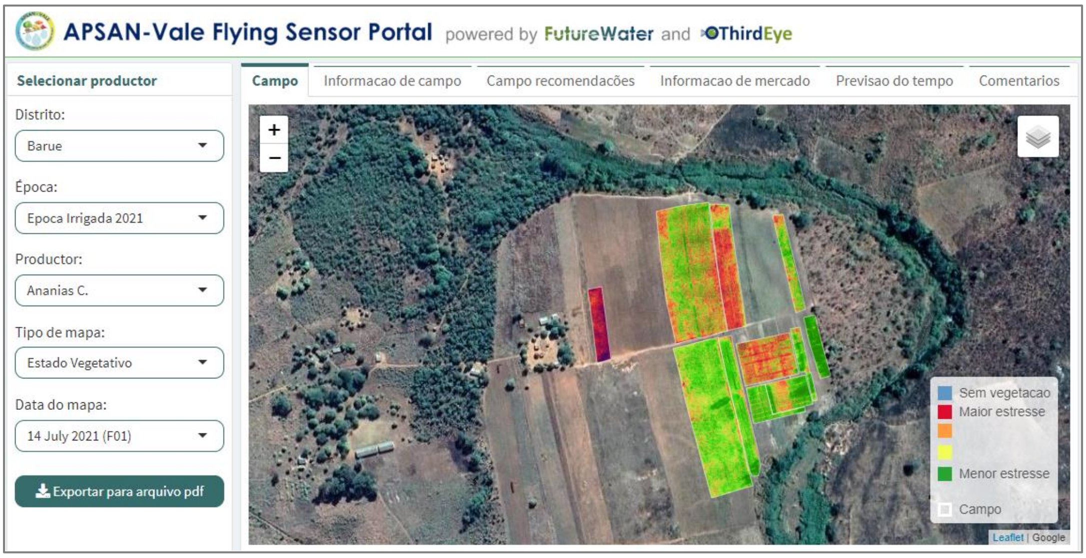


Figure 12. Screenshot of the updated APSAN-Vale Flying Sensor Portal, showing the option to select a map on the left side, the vegetation status map in de middle and additional information on the top tabs

2.3.6 Supplemental Sentinel 2 data

Sentinel 2 is an open-access satellite platform providing imagery every 3 to 5 days at a spatial resolution of 10x10m. This resolution is sufficient for capturing the crop development of agricultural fields but too coarse for determining detailed within-field spatial variations. These within-field spatial variations can be monitored with flying sensor imagery at a higher resolution. Sentinel 2 data is used supplemental to the flying sensor imagery to capture more frequently the crop development and fill in the gaps between the 2-to-4-week intervals of the flying sensor imagery intervals (as indicated in Table 3). Due to the typical short crop growth periods of irrigation season crops (approximately 2.5 to 3 months), the supplemental data provided by Sentinel 2 imagery is useful for a better determination of the crop curve.

The Sentinel 2 imagery is first processed to cloud-free imagery through the quality bands provided with the imagery dataset. The NDVI is calculated and used to determine the fraction of vegetational cover by determining the NDVI for bare soil and fully vegetative cover fields. The fraction of vegetational cover is similar to the canopy cover derived from the flying sensor imagery. Processing of the Sentinel 2 imagery was conducted using the cloud computing of Google Earth Engine (https://earthengine.google.com/).

2.4 Canopy cover

Flying sensor images were used to determine the canopy cover of 1x1 meter pixels in each field of the selected PPCs. Fields that observe full cover by vegetation will result in high values for canopy cover. Flying sensor imagery were taken at regular (2-4 weeks) intervals, thus give a good presentation of the crop development throughout the season by computing the canopy cover.

Supplemental to the flying sensor canopy cover results, canopy cover (or fraction of vegetational cover) is estimated using Sentinel 2 imagery (satellite data). This satellite imagery is available every 3 to 5 days with several cloud-free images available during the irrigation season due to clear-sky conditions. The regular intervals provided by Sentinel 2 imagery provides a better estimation of the crop curve during the growing season. In combination with the flying sensor imagery, which provides high resolution data relevant for small-scale agriculture, the crop curve can be established with sufficient accuracy.

In Figure 13 the curvilinear crop development is shown derived from Sentinel 2 imagery for a cabbage field in Nhamatanda. The planting date noted in the fieldbook is on 21 June, which is also depicted as the moment of increased vegetational cover. The peak cover is approximately at 85% (0.85 fractional cover) on 1 August 2021, after which the crop is senescing and prepared for harvest.

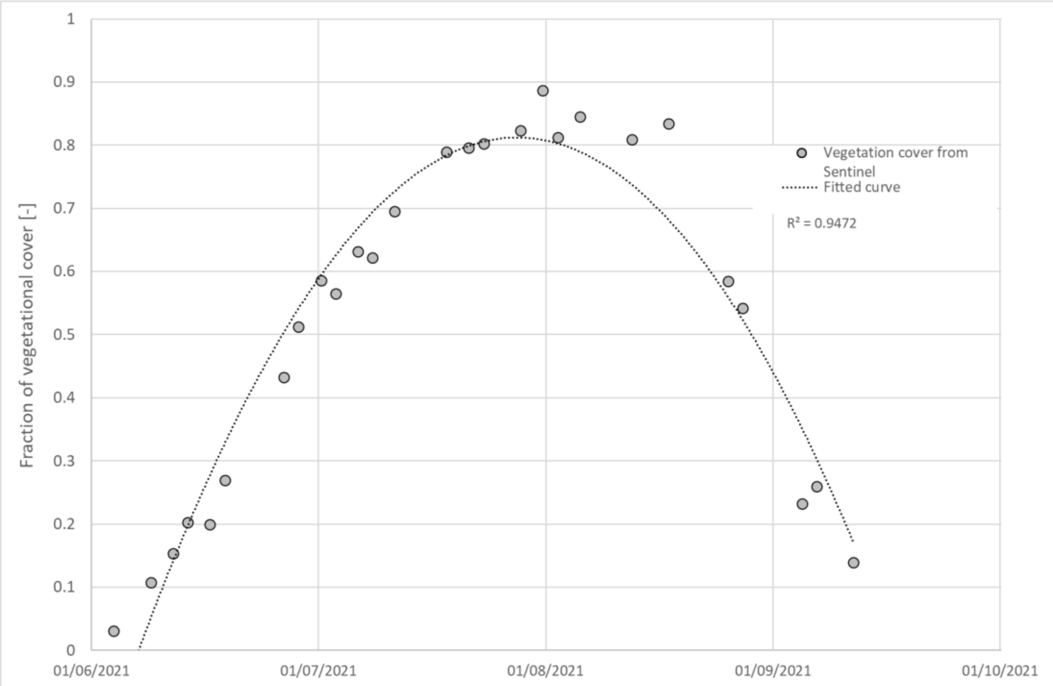


Figure 13. Vegetational cover from Sentinel 2 images with fitted curve (curvilinear) for cabbage crop in Nhamatanda (PPC Filipe) with planting date on 21 June 2021

2.5 Crop simulation modelling

2.5.1 AquaCrop

The AquaCrop model was selected for simulating the crop growth and water consumption, which is based on FAO principles as are reported in FAO Irrigation and Drainage Papers #56 and #66. It simulates both crop development and the water balance, resulting in crop water productivity results.

Several crop growth models have been developed to simulate crop yield and water productivity. The model selection depends on the application scale and the ability to constrain model parameter uncertainty. AquaCrop is a widely used crop model developed by FAO, which simulates the yield response to water using physically-based parameters. It has been used in climate change impact studies in various parts of the world (Hunink et al., 2014[1]; Hunink and Droogers, 2010[2], 2011[3]). In addition,

[1] Hunink, J. E., Droogers, P. and Tran-mai, K.: Past and Future Trends in Crop Production and Food Demand and Supply in the Lower Mekong Basin., 2014.
[2] Hunink, J. E. and Droogers, P.: Climate Change Impact Assessment on Crop Production in Albania. World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems, FutureWater Report 105., 2010.
[3] Hunink, J. E. and Droogers, P.: Climate Change Impact Assessment on Crop Production in Uzbekistan. World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems, FutureWater Report 106., 2011

AquaCrop has been applied to predict water productivity and crop yield based on flying sensor information (den Besten et al., 2017[1], van Opstal, 2019[2]) and to assess irrigation scheduling scenarios (Goosheh et al., 2018[3]). It is specially recommended for small scale farm level application. In addition, it is an open source model which is freely available for application. Hence, the appropriate model for APSAN-Vale purposes.

FAO has pre-established model parameters to simulate the canopy cover, actual crop transpiration and soil evaporation, biomass and crop yield for a growth period from sowing to harvest (Figure 11). In this work, selected model parameters were tuned based on observations. Tuned model parameters included plant density, length of the growth period, increase in canopy cover, decrease in canopy cover, harvest index, fertility stress and cover of weeds.

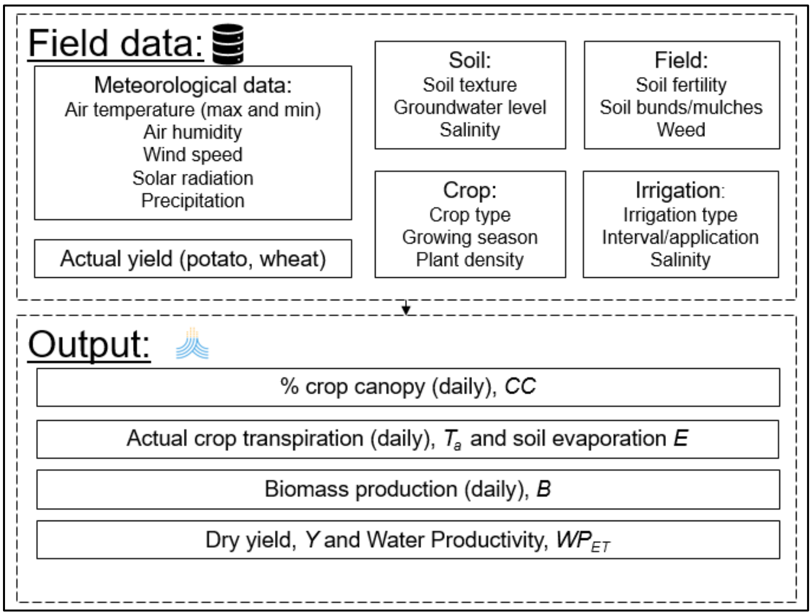


Figure 14. Field data and output simulations of the AquaCrop model

2.5.2 Input data

Weather

Weather data is required as input for the model, which was derived from different sources. Weather stations (from TAHMO) were installed at each district office to represent the weather conditions in the area. These stations were operational from February / March 2019 and throughout the project. If any malfunctions occurred in the equipment during the growing season, the weather data is supplemented with open-access remote sensing weather data available such as CHIRPS data for precipitation. In addition, the long-term average weather data was acquired from WaPOR, and GLDAS satellite data products. This is explained in the baseline assessment report (FutureWater Report 195)[4].

[1] den Besten, N., Simons, G. and Hunink, J.: Water Productivity assessment using Flying Sensors and Crop Modelling. Pilot study for Maize in Mozambique, 2017.
[2] Van Opstal, J.D.. 2019. APSAN-Vale Water Productivity Rainfed season 2018/2019. FutureWater Report.
[3] Goosheh, M., Pazira, E., Gholami, A., Andarzian, B. and Panahpour, E.: Improving Irrigation Scheduling of Wheat to Increase Water Productivity in Shallow Groundwater Conditions Using Aquacrop, Irrig. Drain., 0(0), doi:10.1002/ird.2288, 2018.
[4] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.

Field data

The next step for the AquaCrop simulations is to collect basic crop information from the selected sites (Báruè, Moatize and Nhamatanda). Basic information about planting dates, plant density, total growth length (length of the crop cycle), and crop yield is key to obtain reliable AquaCrop simulations. Several of these parameters are specific for each field. Therefore, the notes taken in the fieldbook of the PPCs were copied and linked to specific fields (indicated with polygons or shape files) to make the simulation tailored to the situation of the PPC. In Annex 1 the input data on management decisions can be found.

In the AquaCrop model several crop parameters must be used in order to simulate crop specific canopy cover, transpiration, biomass and yield during the growth season to finally determine the water productivity. Crop specific parameters were obtained from the original crop files available in the AquaCrop model. Crop files in Growing Degree Days mode (°C days) were used. The Growing Degree Days accounts for effects of temperature regimes on phenology. For Cabbage and Onion, we obtained the crop parameter information from other studies (Agbemabiese et al., 2017; Pawar et al., 2017; Pérez-Ortolá et al., 2015; Wellens et al., 2013).

Specific crop model parameters must be tuned to obtain accurate crop yields. In Table 4 the calibrated crop model parameters per crop are shown. These parameters include the Harvest Index, HI (%), Increase in Canopy Cover, CGC (-), Decrease in Canopy Cover, CDC (-), and the length of specific growing stages (e.g. sowing to emergence, sowing to maximum rooting depth, etc). HI is a known parameter to convert biomass into crop yield. CGC is a measure of the intrinsic ability of the canopy to expand. After the canopy begins to senesce, the canopy cover is reduced progressively by applying an empirical canopy decline coefficient (CDC). HI, CGS and CDC vary depending on the crop variety and seed quality. The length of specific growing stages is used in Growing Degree Days mode (°C days) for Maize, Sorghum, Bean, Rice, Tomato, and Potato. For Cabbage and Onion, the calendar days mode is used based on the mentioned studies. The length of the growing stages was tuned based on the collected information of the length of the crop cycle (from planting to harvest in Annex 1).

Table 4. Calibrated parameters for selected crops in Báruè, Moatize and Nhamatanda

	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage*	Onion*
HI (%)	20	10	30	50	60	80	50	40
CGC (-)	0.0050	0.0048	0.0049	0.0084	0.0075	0.0162	0.1190	0.1190
CDC (-)	0.0040	0.0039	0.0044	0.0060	0.0040	0.0020	0.1000	0.1000
From sowing to emergence (°C days)	132	210	88	40	43	310	2	6
From sowing to maximum rooting depth (°C days)	2324	2453	1332	296	891	1672	40	77
From sowing to start senescence (°C days)	2310	2447	1354	1040	1553	1525	86	45
From sowing to maturity (length of crop cycle) (°C days)	2805	2728	1947	1520	1933	1977	100	85

From sowing to flowering (°C days)	1452	1613	834	920	525	852	28	67
Length of the flowering stage (°C days)	297	474	349	280	750	1	40	18

*Growing stages in calendar days.

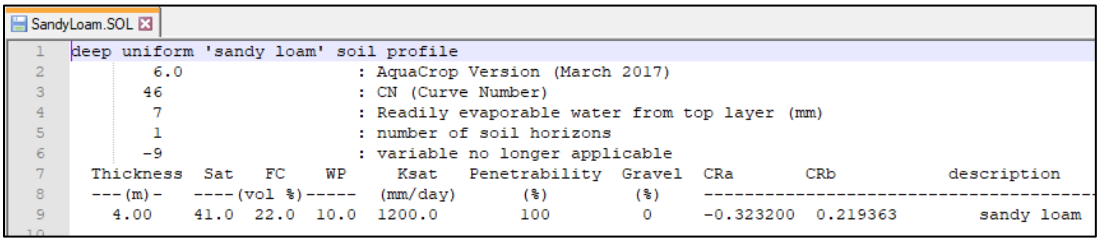
<u>Soil and field management information</u>

According to collected field information the soil texture of each site was determined. The hydraulic properties of the soil are correlated with the soil texture. The AquaCrop model includes pre-established hydraulic properties such as Field Capacity (FC) and Wilting Point (WP) for each soil texture. Field Capacity and Wilting Point values are key to determine the soil water storage capacity and determine the water stress thresholds. In Table 5 the soil textures obtained for each site are shown. The soil type for Báruè was updated in the past season following new field data acquired. In Figure 12, an example of FC and WP values (FC=22%, WP=10%) used in the AquaCrop model are shown for sandy loam.

The irrigation management is simulated by entering the irrigation method (sprinkler, drip, or surface) and the estimated wetted surface, which is derived depending on the irrigation method. Various simulations are conducted to capture different levels of maximum allowable depletion: 25, 40, and 50 mm. For each irrigation event, the water applied is the amount of irrigation water applied is sufficient for the soil moisture to return to field capacity. This simulation of irrigation events is similar to what is observed in field practices of the PPCs.

Table 5. Soil texture in each site

Site	Soil texture
Báruè	Sandy Clay Loam
Moatize	Sandy Loam
Nhamatanda	Sandy Clay


SandyLoam.SOL

```
deep uniform 'sandy loam' soil profile
        6.0                 : AquaCrop Version (March 2017)
       46                   : CN (Curve Number)
        7                   : Readily evaporable water from top layer (mm)
        1                   : number of soil horizons
       -9                   : variable no longer applicable
  Thickness  Sat   FC    WP     Ksat   Penetrability  Gravel  CRa       CRb           description
  ---(m)-   ----(vol %)-----  (mm/day)      (%)        (%)    -----------------------------------------
    4.00    41.0  22.0  10.0  1200.0        100          0    -0.323200  0.219363        sandy loam
```

Figure 15. Soil characteristic in Moatize

2.5.3 Calibration process

The canopy cover follows a positive curvilinear trend throughout the growing season, representing the crop development until full cover. The flying sensors monitor the canopy cover throughout the growing season and thus capture at frequent intervals part of the curvilinear trend. This data is supplemented with additional data points from Sentinel 2. This curvilinear trend of the crop development is also simulated in AquaCrop. For the calibration process the canopy cover from the flying sensors and Sentinel 2 data is compared with the AquaCrop simulated canopy cover. The maximum canopy cover is used to compare with the AquaCrop simulations.

The AquaCrop model is set-up using the modules and input data as was listed in the previous sections. A number of farm management parameters are selected that can be variable. These are particularly the variables that are sensitive in AquaCrop and cannot be accurately measured in the field. The parameters selected for calibration are plant density, fertilizer stress, and maximum allowable soil water depletion (for irrigation events). After running the various combinations (27 simulation runs total per field) the top simulations were selected displaying limited error with the canopy cover as observed from the flying sensor images.

2.6 WaPOR datasets

The FAO WaPOR database contains several datasets derived with satellite remote sensing and is available through the open access data portal: https://wapor.apps.fao.org. The layers used from WaPOR are: actual and reference evapotranspiration (ET), biomass production, water productivity, precipitation, and land cover. Detailed information on the methodology is found in the reference documents of WaPOR[1]. The data layers were downloaded for Mozambique and aggregated to find seasonal values for the irrigation season: April 2021 to October 2021.

2.6.1 Actual Evapotranspiration

The actual evapotranspiration is calculated using a surface energy balance algorithm based on the equations of the ETLook model[2]. It uses a satellite platform with both multi-spectral and thermal imagery acquisition. In additional, meteorological data from remote sensing data products is used as input. The energy balance components are calculated with the specified algorithm: net radiation, soil heat flux, and sensible heat flux. The latent heat flux is calculated as residual to the energy balance and represents the evapotranspiration (ET) component of the energy balance.

The WaPOR actual ET dataset used in this report is from Level II (100 meter) for each decadal (10 days). A sum for the irrigation season is calculated in QGIS.

2.6.2 Biomass production

Biomass production was calculated using the decadal net primary production (NPP) data layer from WaPOR. The NPP data is calculated in WaPOR using a light use efficiency model[3]. This model determines the amount of photosynthetic radiation that arrives at a surface and the amount that is absorbed by vegetation depending on the amount of vegetational cover and (non-)stress conditions. This indicates the result of the photosynthesis process in NPP or dry matter biomass production. The biomass production from WaPOR is summed for the irrigation season. Note that WaPOR calculates biomass production for C3 crops, which are the majority of the crops grown globally. However, determining biomass production for C4 crops (e.g. maize, sugarcane) requires a multiplication of approximately 1.8 (=4.5/2.5) to correct for the difference in light use efficiency between the two crops. Crop yield can thereafter be calculated using the harvest index, which is specific for each crop type and crop variety (cultivar).

2.6.3 Supplemental layers

WaPOR also provides a precipitation data product, namely CHIRPS data. This provides spatial precipitation data at 5 km. resolution at daily time steps. This data is used supplemental to the weather station data to fill in data gaps where the weather station data was not installed.

In addition, reference evapotranspiration (ET) is also provided by the WaPOR data portal at 20 km. resolution and at daily time steps. A time series of this dataset is used as the required weather input data to the crop modelling.

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[1] WaPOR Database Methodology: Level 1 data (September 2018) http://www.fao.org/3/I7315EN/i7315en.pdf
[2] Bastiaanssen et al. (2012)
[3] Hilker et al. (2008) and several other publications

Lastly, the land cover map in WaPOR is used to identify the pixels containing croplands. This is used to calculate the biomass water productivity for croplands, thus excluding the pixels of natural vegetation and urban areas.

2.7 Normalization for annual weather conditions

For the baseline assessment[1] a period of 17 years was used for the field scale analysis (2001 – 2017) and 10 years for the basin scale analysis (2009 – 2018). The period for the basin scale analysis was shorter due to the data availability of WaPOR. Both periods are deemed sufficient for capturing the inter-annual variability in weather conditions with both dry and wet years existing within a time frame of 10 years. The statistical results from this baseline analysis will therefore be representative for the variety of weather conditions.

In further analysis of this project, water productivity values are normalized for weather conditions to determine if changes in water productivity are a result of weather conditions or the impact of the project innovations. The normalization of water productivity values is calculated by using the equation below (as example using the year 2021) and using reference evapotranspiration (ET_0) as representative for the annual weather conditions. This equation and methodology are described by Bastiaanssen and Steduto (2016)[2], as a method for comparing water productivity between years and regions with different climatic conditions.

$$WP_{norm,2019}\ [kg/m^3] = \frac{WP_{2021}\ \left[\frac{kg}{m^3}\right] \times ET_{0,average\ 2001-2018}\ [mm]}{ET_{0,\ 2021}\ [mm]}$$

[1] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.
[2] Bastiaanssen, W. G. M., & Steduto, P. (2016). The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize. Science of The Total Environment, 575, 595–611. https://doi.org/10.1016/j.scitotenv.2016.09.032

3 Seasonal weather results

3.1 Reference evapotranspiration

At the TAHMO[1] weather stations in each district, meteorological data is measured, and reference evapotranspiration is computed. The five-day average reference evapotranspiration (ET) during the 2021 irrigation season is shown in Figure 16. For Báruè the data for solar radiation consisted of gaps, therefore the reference ET could not be computed. For this location the WaPOR reference ET data was used. In Moatize gaps in the weather data was supplemented with WaPOR reference ET data. The three districts display a similar pattern in the reference ET. The reference ET was similar throughout the season varying between 2 to 4 mm/day. Towards the end of the season, in September and October, the reference ET increased slight for all locations up to 5 to 6 mm/day.

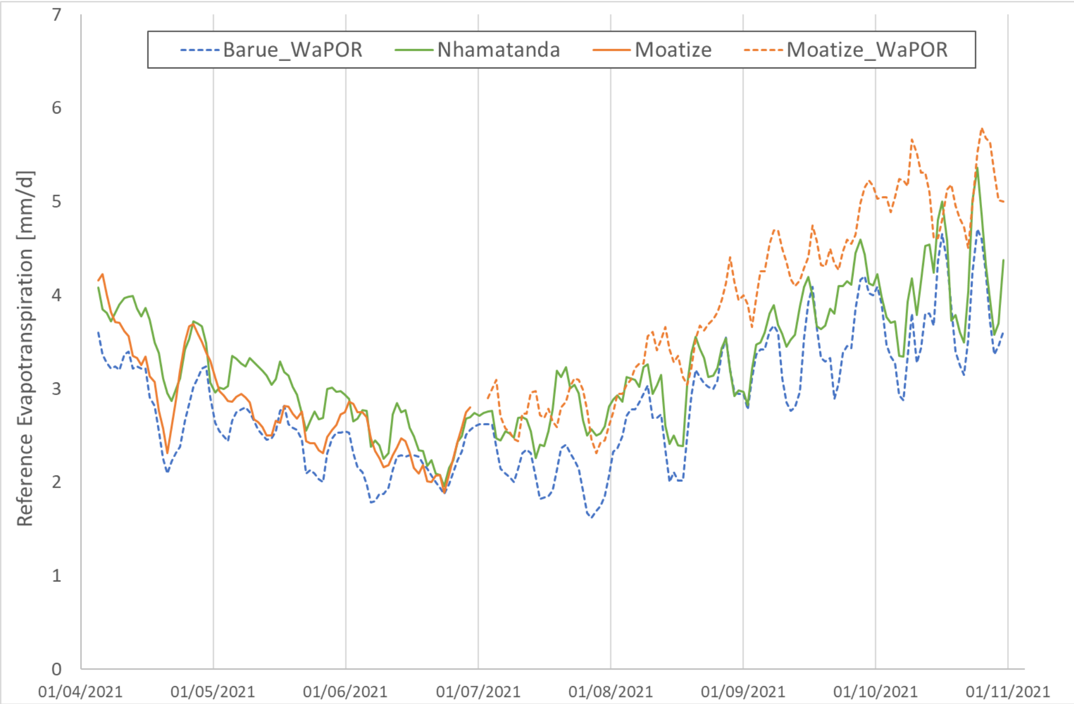

Figure 16. Five day average reference evapotranspiration for Moatize and Nhamatanda during the 2021 irrigation season from TAHMO stations and supplemented WaPOR data for Moatize and Báruè.

The weather conditions during the 2021 irrigation season are compared with the historical dataset from 2001 to 2018, as used in the baseline assessment. This historical dataset covers a multitude of weather conditions, both dry and wet years, and therefore is a good representation of 'normal' weather conditions. The average monthly reference evapotranspiration is compared with the 2021 monthly values and displayed in Figure 17.

Figure 17 shows that the reference ET during the first months of the 2021 season (April to August) were similar compared to the long-term average reference ET. In the months September and August the reference ET was higher than average for all districts and most notably for Báruè and Moatize. The total seasonal reference ET is presented in Table 6 for this 2021 season and the long-term average for the irrigation season. These values are used in the normalization of the water productivity results as described in section 2.7 of this document.

[1] https://tahmo.org/

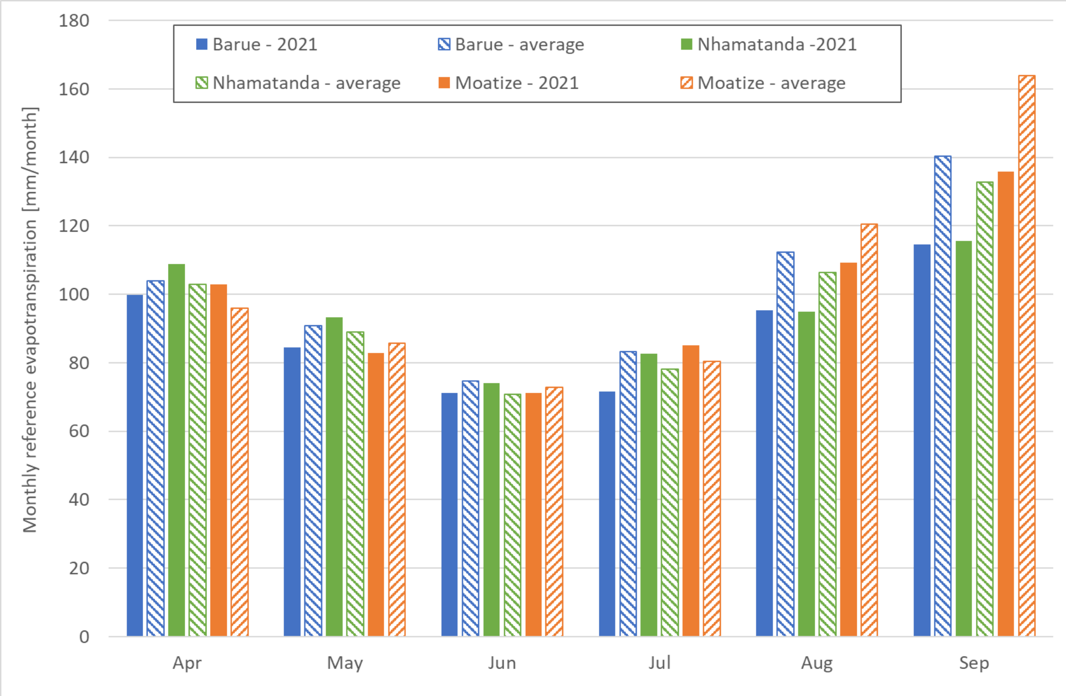

Figure 17. Comparison of 2021 monthly reference evapotranspiration with long-term average (2009-2018)

Table 6. Seasonal total reference evapotranspiration for Báruè, Moatize and Nhamatanda during the 2021 (April to September) and long-term average (2001-2018) irrigation season

Reference ET [mm]	Báruè	Moatize	Nhamatanda
2021 irrigation season	537	587	569
2001- 2018 long-term average	605	619	580

3.2 Precipitation

During the irrigation season the rainfall is typically low in this region. The rainfall is recorded at the TAHMO stations. During the season some malfunctions occurred at the station of Báruè, therefore satellite data from CHIRPS (as provided through the WaPOR portal) is used. The data from the 2021 irrigation season is presented in Figure 18. The figure displays some rainfall events still occurring in April after which the precipitation was negligible (approximately 5 mm) the rest of the season.

Figure 19 displays the monthly total precipitation for each district and compares with the long-term average (2001-2018) using satellite data. The figure shows that in April the precipitation was lower than average for Báruè whilst it was higher than average for Nhamatanda. The rest of the season the monthly precipitation shows values similar to the long-term average with Moatize displaying almost negligible precipitation amounts. In Table 7 an overview is provided of the total seasonal precipitation for the 2021 irrigation season and long-term average (2001-2018). Both Báruè and Moatize display below average values, whilst Nhamatanda shows slightly higher precipitation than the average. During the irrigation season farmers depend on irrigation for the cultivation of their crops, therefore limited rainfall during the season does not necessarily have a negative impact on the crop production. The precipitation during the rain season (2020-2021), as presented in the Rainfed Season Water Productivity Report[1], displayed sufficient rainfall for all three districts compared to the average. Therefore, it is assumed that water was not limiting during the growing season.

[1] Van Opstal, J.D., M. de Klerk, V.R. Hollander, J.E. Beard. 2021. APSAN-Vale Water Productivity Analysis: Rainfed Season 2020-2021. FutureWater Report 227

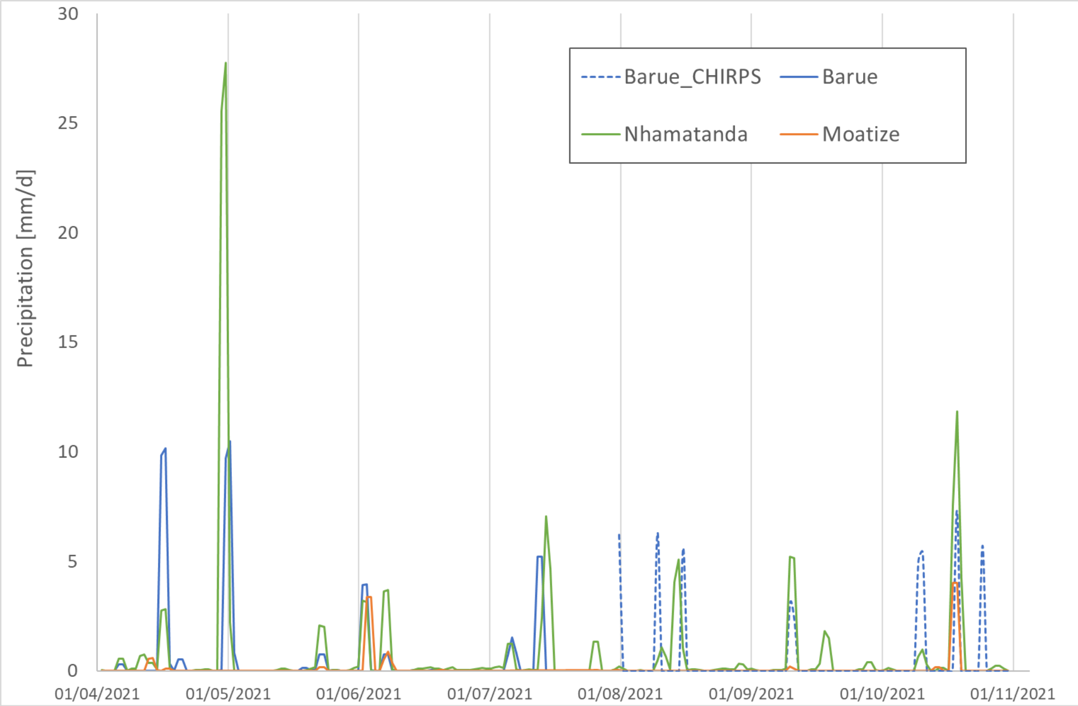

Figure 18. Daily precipitation for the 2021 irrigation season from TAHMO weather stations, supplemented with CHIRPS (satellite) data for Báruè for August to October, 2021

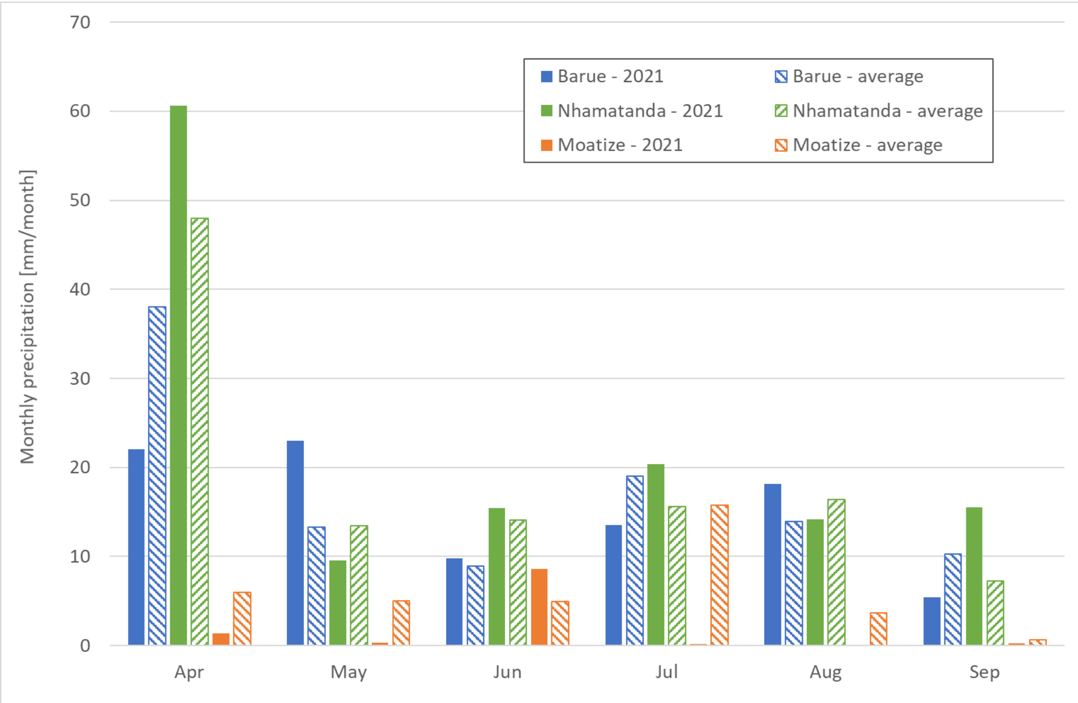

Figure 19. Comparison of 2021 monthly precipitation with long-term average (2001-2018) from CHIRPS

Table 7. Seasonal precipitation for Báruè, Moatize and Nhamatanda during the 2021 (April to September) and long-term average (2001-2018) irrigation season

Precipitation [mm]	Báruè	Moatize	Nhamatanda
2021 irrigation season	92	11	136
2001-2018 long-term average	103	36	115

4 Field scale Water Productivity results

In AquaCrop simulations are performed to present the crop development and farm management of each PPC monitored throughout this season. The management decisions and other input data is presented in Annex 1 for each farmer. The canopy cover from the flying sensors and satellite imagery (Sentinel 2) is combined with the AquaCrop simulations to determine the water productivity and crop yield results. For Báruè, Moatize and Nhamatanda the results of the water productivity are presented in Tables 8, 9, and 10, respectively. In these tables the crop water productivity is presented per major crop type: cabbage, tomato, onion, potato, beans, and maize. The latter two crop types are usually rainfed crops therefore are not compared with baseline values, which were calculated for the rainfed season in the baseline assessment. In the result tables, the water productivity is normalized for the weather conditions using the reference ET from Table 6 (Chapter 3), and methodology as described in section 2.6 of this document. A comparison is made with the baseline assessment values for crop water productivity as presented in FutureWater Report 195[1]. The assumption is that these PPCs in the baseline had a commercial objective and achieved relatively higher productivity in comparison to the average of all farmers. Therefore, the baseline value used for comparison is the 75th percentile[2], indicating that the baseline is higher than the average (median) value. In the results the crop yield is also presented, which is the dry harvestable yield as computed by AquaCrop.

4.1 Báruè

Table 8 presents the results of the water productivity analysis for Báruè farmers. The increase in water productivity was positive for all fields and all crops compared to the irrigation season baseline values. Large increases were detected for the two potato fields of +66% to +82% compared to the baseline. For cabbage the increase in water productivity compared to the baseline varied from +28% to +65%. The largest improvements are noted for the three tomato fields from +65% to +211%.

Table 8. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Báruè farmers

PPC code	Name	Crop type	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with baseline*	Dry crop yield [ton/ha]
AP_BA_ACI-01-03	Ananias	Potato	3.51	3.95	+66%	5.36
AP_BA_MA-01-01	Margarida	Potato	3.85	4.34	+82%	5.70
AP_BA_ACI-01-04	Ananias	Cabbage	2.05	2.31	+37%	3.41
AP_BA_ACI-01-07	Ananias	Cabbage	2.20	2.47	+47%	3.47
AP-BA-CF-01-02	Chuva	Cabbage	2.45	2.76	+65%	3.48
AP-BA-BV-01-02	Bernardo	Cabbage	1.53	1.73	+33%	2.74
AP_BA_JDR-01-02	Joelmo	Cabbage	2.42	2.73	+62%	3.55
AP-BA-LJ-01-01	LucasJ	Cabbage	1.91	2.16	+28%	3.51
AP_BA_ML-01-02	ManuelL	Cabbage	2.34	2.63	+57%	3.47
AP_BA_MD-01-02	Modesto	Cabbage	1.99	2.25	+34%	3.19
AP-BA-CF-01-01	Chuva	Beans	1.12	1.26	NA	2.33
AP-BA-CF-01-03	Chuva	Beans	1.17	1.31	NA	2.33
AP-BA-CF-01-04	Chuva	Beans	1.07	1.20	NA	2.13
AP-BA-CF-01-05	Chuva	Beans	1.13	1.28	NA	2.33
AP_BA_ACI-01-05	Ananias	Beans	1.17	1.32	NA	2.41
AP_BA_ACI-01-06	Ananias	Beans	1.21	1.36	NA	2.51

[1] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.
[2] This is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. In this case, 25% of the observations are found above the 75th percentile.

AP-BA-BV-01-01	Bernardo	Beans	0.91	1.02	NA	2.12
AP-BA-PGM-01-01	Paulo	Beans	0.78	0.88	NA	2.10
AP_BA_JDR-01-03	Joelmo	Beans	1.30	1.47	NA	2.88
AP_BA_MD-01-03	Modesto	Maize	1.40	1.58	NA	3.56
AP-BA-AB-01-01	Anita	Maize	1.14	1.28	NA	3.29
AP_BA_ACI-01-08	Ananias	Tomato	1.57	1.77	+65%	2.49
AP-BA-PGM-01-02	Paulo	Tomato	2.95	3.33	+211%	8.19
AP_BA_MD-01-04	Modesto	Tomato	2.82	3.17	+196%	6.31

* Note: NA indicates when irrigation season baseline values are not available for these crop types

For Báruè, the water productivity results from AquaCrop, calibrated with the canopy cover data, are presented in field maps in Figure 20. For each PPC and crop type, the water productivity values for the 2021 irrigation season are presented including the change with the baseline and the area in ha. The water productivity values range from medium (yellow) to high (light green) to very high (dark green).

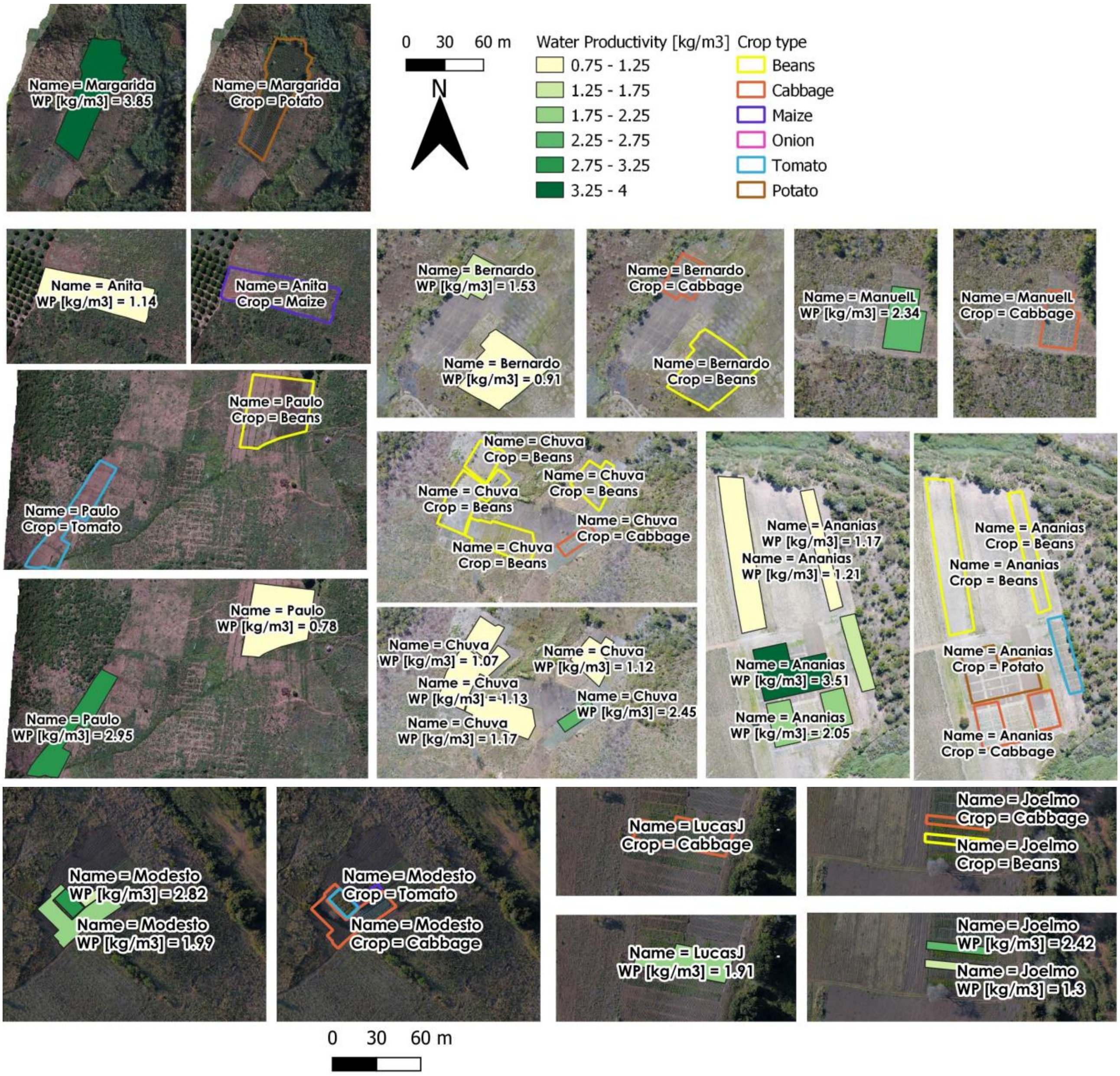

Figure 20. Field water productivity maps of farmers in Báruè for the 2021 irrigation season

4.2 Moatize

In Table 9 the results are presented for the water productivity analysis of Moatize farmers. The majority of the farmers grow tomato crops. The increase in water productivity was positive for all fields and all crops compared to the irrigation season baseline values. The water productivity improvements found of tomato compared to the baseline was varied from +5% to +75%. Even for the same farmer (for example Staben and Girio) there were large differences in water productivity values likely depending on the location and the planting date. For beans the water productivity values are similar for the different PPCs. The water productivity for cabbage and onion from PPC Cezario increased with +7% and +18%, respectively.

Table 9. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Moatize farmers

PPC code	Name	Crop type	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with baseline*	Dry crop yield [ton/ha]
MO-MA-AC-01-01	Alberto	Tomato	1.79	1.89	+5%	2.73
MO-MA-GM-01-01	Girio	Tomato	2.59	2.73	+52%	7.44
MO-MA-GM-01-01	Girio	Tomato	2.72	2.87	+60%	8.08
MO-SA-ZM-01-01	Zeca	Tomato	2.96	3.13	+75%	8.29
MO-SA-CA-01-01	Cezario	Tomato	2.03	2.14	+19%	3.96
MO-CA-AB-01-01	Albino	Tomato	2.53	2.67	+49%	4.72
MO-MA-JC-01-02	Joao	Tomato	2.62	2.76	+54%	5.05
MO-CA-XT-01-03	Xavier	Tomato	2.68	2.83	+58%	4.98
MO-BE-SJ-01-01	Staben	Tomato	1.80	1.89	+6%	2.58
MO-BE-SJ-01-02	Staben	Tomato	2.02	2.13	+19%	5.15
MO-BE-T-01-02	Teofilo	Tomato	2.29	2.42	+35%	3.98
MO-SA-MC-01-01	ManuelC	Beans	0.82	0.87	NA	1.32
MO-SA-CA-01-08	Cezario	Beans	1.22	1.29	NA	2.17
MO-CA-XT-01-01	Xavier	Beans	1.10	1.16	NA	1.77
MO-SA-CA-01-06	Cezario	Beans	1.18	1.25	NA	2.02
MO-SA-CA-01-02	Cezario	Onion	0.91	0.96	+18%	1.15
MO-SA-CA-01-07	Cezario	Cabbage	1.36	1.44	+7%	2.54

* Note: NA indicates when irrigation season baseline values are not available for these crop types

For Moatize, the water productivity results from AquaCrop, calibrated with the canopy cover data, are presented in field maps in Figure 21. For each PPC and crop type, the water productivity values for the 2021 irrigation season are presented including the change with the baseline and the area in ha. The water productivity values range from medium (yellow) to high (light green) to very high (dark green).

Figure 21. Field water productivity maps of farmers in Moatize for the 2021 irrigation season

4.3 Nhamatanda

In Table 10 the results of the water productivity analysis are presented for the PPCs located in the district of Nhamatanda. The results indicate that for all fields and crops included in this analysis the water productivity increased compared to the baseline assessment. For the five fields with cabbage the water productivity improvements were similar ranging from +21% to +42%. For the onion fields high water productivity improvements were found in the fields belonging to LucasB and Flora. For beans the higher water productivity values are also found with LucasB, Flora, and the highest for Antonio. In a follow-up report these values are compared with the interventions implemented in these fields to assess the impact of the different "good agricultural practices" that were applied. For tomato and maize there was one field for each crop, therefore this does not give insight on the spatial distribution between PPCs .

Table 10. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Nhamatanda farmers

PPC code	Name	Crop type	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with baseline*	Dry crop yield [ton/ha]
AP_NH_AS_01_02	Associacao	Tomato	1.99	2.03	+60%	4.54
AP_NH_JA_01_01	Jose	Beans	0.64	0.65	NA	1.04
AP_NH_FM_01_01	Flora 1	Beans	0.81	0.83	NA	1.56
AP_NH_AM_01_01	Antonio	Beans	0.97	0.99	NA	2.01
AP_NH_LB_01_03	LucasB	Beans	0.81	0.83	NA	1.54
AP_NH_LB_01_02	LucasB	Cabbage	1.91	1.95	+42%	3.32
AP_NH_FMA_01_05	Filipe	Cabbage	1.71	1.74	+27%	3.21
AP_NH_DP_01_03	Domingos	Cabbage	1.83	1.87	+36%	2.79
AP_NH_FM_02_01	Flora 2	Cabbage	1.82	1.86	+35%	3.55
AP_NH_MD_01_01	ManuelD	Cabbage	1.63	1.66	+21%	3.06
AP_NH_FM_02_02	Flora 2	Onion	0.79	0.80	+93%	1.12
AP_NH_MD_01_01	ManuelD	Onion	0.60	0.62	+48%	0.90
AP_NH_LB_01_04	LucasB	Onion	0.78	0.80	+92%	1.16
AP_NH_FMA_01_01	Filipe	Maize	1.20	1.23	NA	2.62

* Note: NA indicates when irrigation season baseline values are not available for these crop types

For Nhamatanda, the water productivity results from AquaCrop, calibrated with the canopy cover data, are presented in field maps in Figure 22. For each PPC and crop type, the water productivity values for the 2021 irrigation season are presented including the change with the baseline and the area in ha. The water productivity values range from medium (yellow) to high (light green) to very high (dark green).

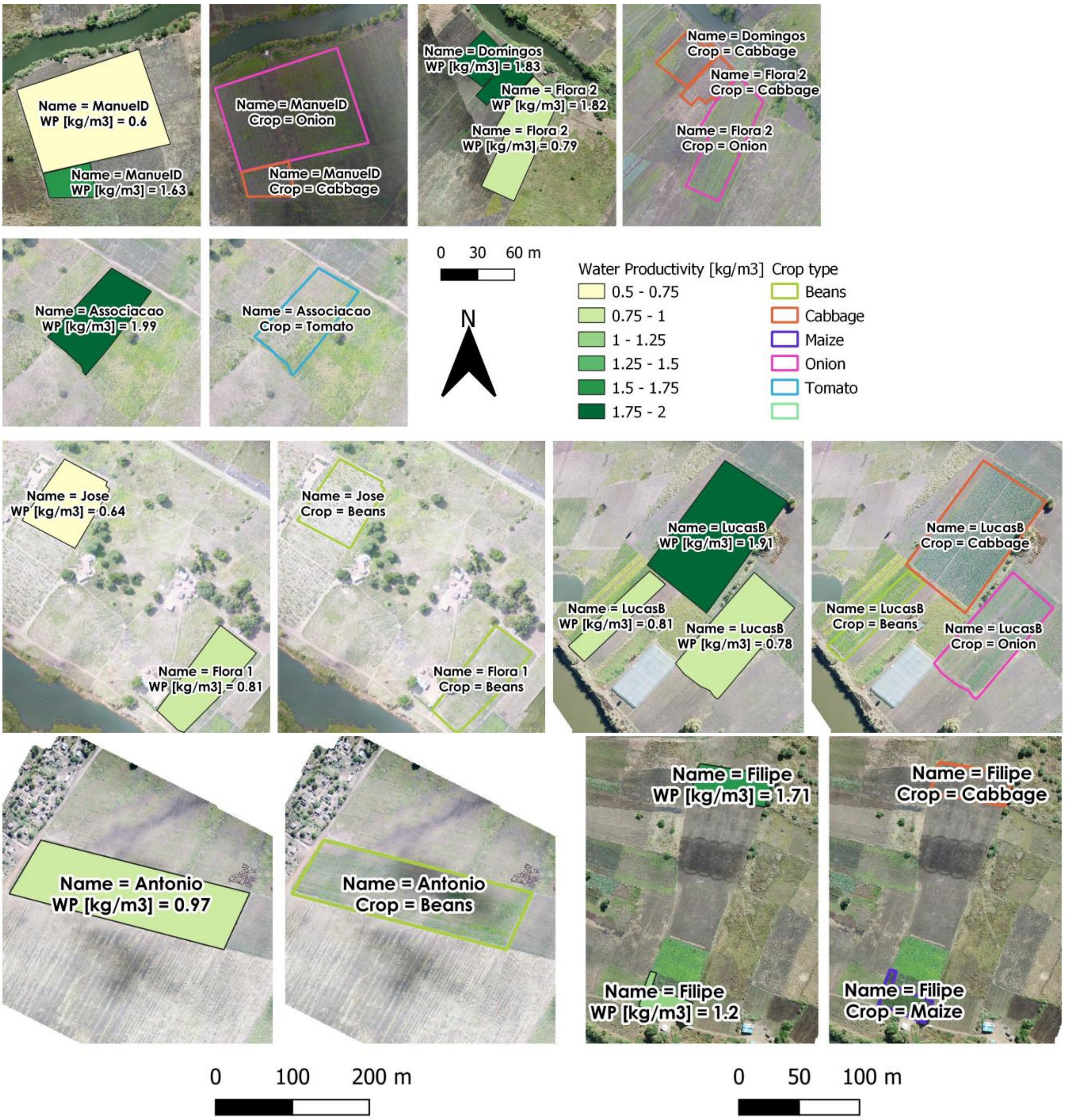

Figure 22. Field water productivity maps of farmers in Nhamatanda for the 2021 irrigation season

5 Sub-basin scale Water Productivity results

The sub-basin scale is described as the level between the field scale of the selected PPCs and the basin scale delineated for each district. The sub-basin scale was determined to be a 300 ha radius around each selected PPC as described in section 2.1.2 of this document and presented in Figures 3, 4, and 5.

Data from the WaPOR portal was achieved for the 2021 irrigation season for the months April to September. The data products downloaded from WaPOR were Actual Evapotranspiration (in mm) and Net Primary Production, which was converted to Above Ground Biomass Production (in ton/ha). These data products were used to calculate the biomass water productivity for each sub-basin location.

Results are presented in Table 11 for each location. The highest water productivity values are consistently found in Báruè, most probably due to the favourable climate in this region and/or improved communital uptake. Here the highest values are observed in Báruè I which is located most upstream and closer to the mountain range (see Figure 3). The lowest values for water productivity are found in Moatize for the communities located closest to the river (see Figure 4). At this location the actual ET may be higher due to the high ET from the water bodies. The highest water productivity for Moatize is found in Moatize I, which is located upstream and closer to the mountains. For Nhamatanda the water productivity values are at a similar range. These communities are also located closer to each other and on similar terrain (see Figure 5).

Table 11. Water productivity results of sub-basin analysis using WaPOR data portal

District	Sub-basin	Actual Evapo-transpiration [mm]	Biomass Production [ton/ha]	Biomass water productivity [kg/m^3]
Báruè	Báruè I	422	13	3.13
	Báruè II	385	12	3.09
	Báruè III	419	12	2.93
	Average	**409**	**12**	**3.05**
Moatize	Moatize I	366	9	2.55
	Moatize II	280	7	2.40
	Moatize III	259	5	1.96
	Moatize IV	410	6	1.38
	Average	**329**	**7**	**2.07**
Nhamatanda	Nhamatanda I	540	12	2.13
	Nhamatanda II	475	10	2.16
	Nhamatanda III	419	9	2.06
	Average	**478**	**10**	**2.12**

The maps of the sub-basin water productivity results are presented in Figures 23, 24, and 25 for Báruè, Moatize, and Nhamatanda respectively.

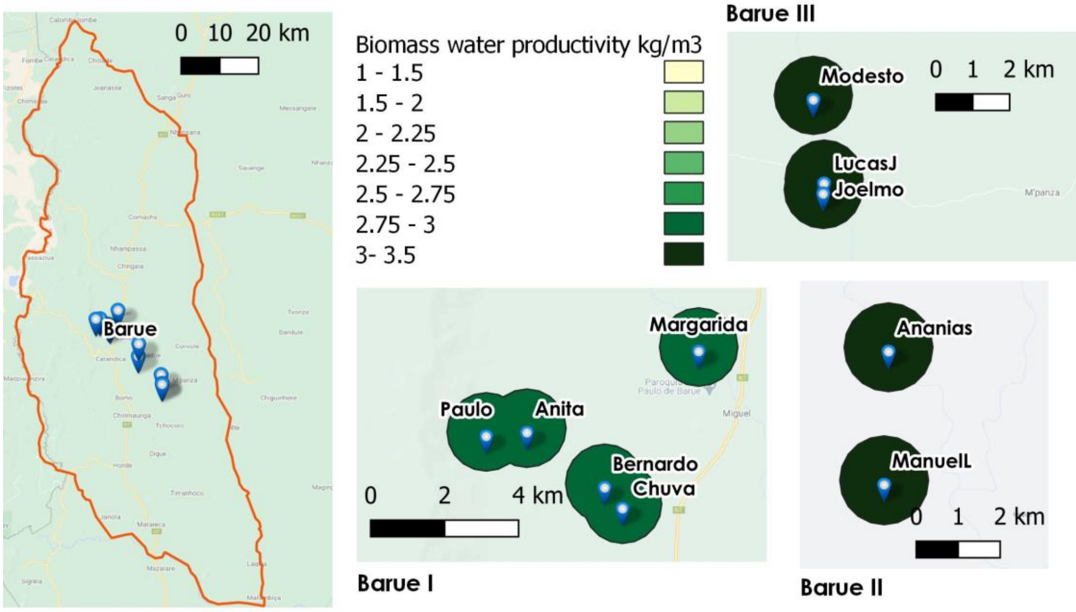

Figure 23. Biomass water productivity (kg/m^3) for sub-basins in Báruè for the 2021 irrigation season

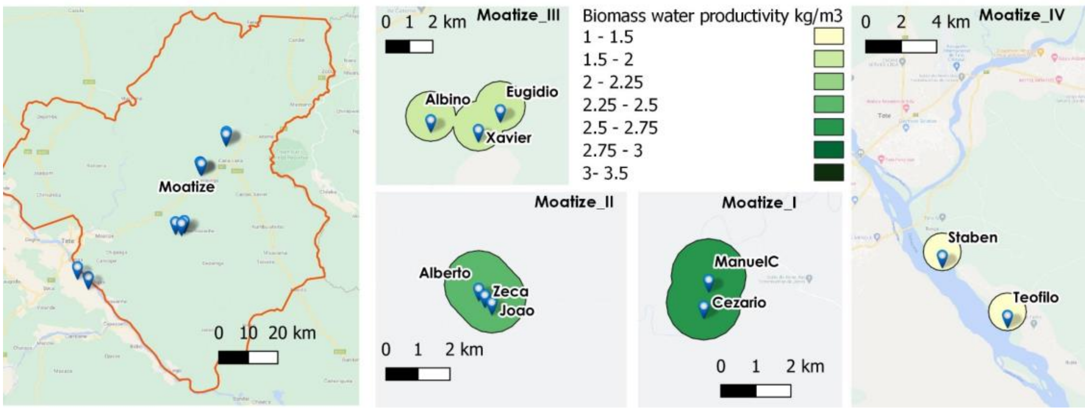

Figure 24. Biomass water productivity (kg/m^3) for sub-basins in Moatize for the 2021 irrigation season

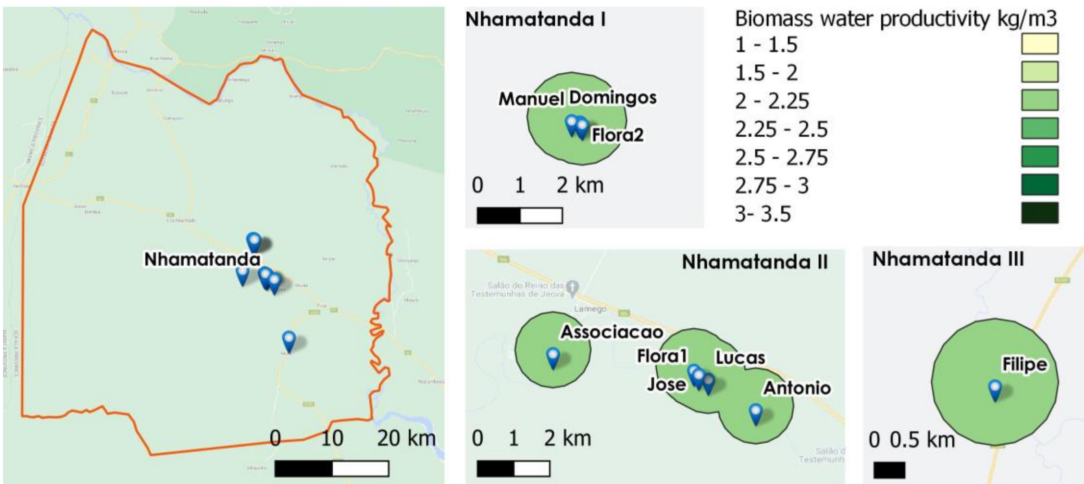

Figure 25. Biomass water productivity (kg/m^3) for sub-basins in Nhamatanda for the 2021 irrigation season

6 Basin scale Water Productivity results

The basins were delineated for each district as shown in Figure 6 based on hydrological streamlines. These delineations were used with the WaPOR data portal to determine the biomass water productivity for each location. Table 12 provides an overview of the statistics found for actual evapotranspiration, biomass production, and water productivity for each basin, after masking out only the cropland pixels using the landcover layer provided in WaPOR. Báruè displays the highest biomass production of the area, followed by Nhamatanda and Moatize. The water productivity was also highest for Báruè, followed by Moatize, and lastly Nhamatanda.

Table 12. Overview of statistics of actual evapotranspiration, biomass production, and water productivity for the basins of Báruè, Moatize and Nhamatanda

		Báruè	Moatize	Nhamatanda
Actual evapotranspiration [mm]	Average mean	472	444	500
	10th percentile	380	359	424
	90th percentile	566	527	583
Biomass production [ton/ha]	Average mean	9.2	7.9	8.0
	10th percentile	7.2	6.2	6.6
	90th percentile	11.2	9.6	9.7
Water productivity [kg/m^3]	Average mean	1.95	1.78	1.61
	10th percentile	1.82	1.62	1.52
	90th percentile	2.07	1.96	1.70

Figure 26 displays the water productivity maps of each basin. In Báruè, the water productivity shows even distribution. In Moatize the upstream area (north-east) displays higher water productivity values than downstream. These areas are also closer to the mountain range, which could influence the local weather conditions. The same occurs in Báruè, where the higher water productivity values are observed closer to the mountain range (West). The number of cropland pixels in Nhamatanda are limited, therefore less spatial variation can be observed.

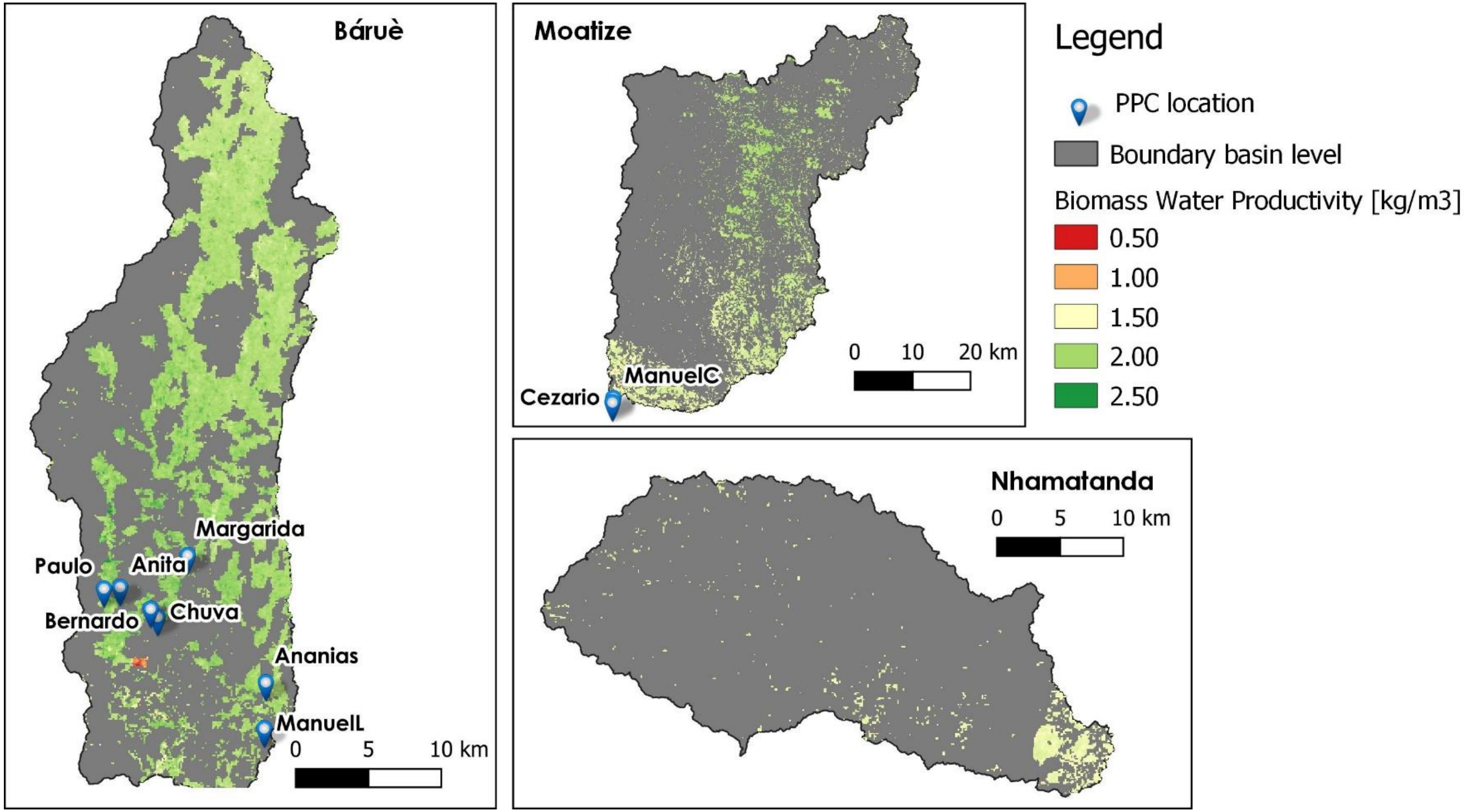

Figure 26. Seasonal biomass water productivity (kg/m^3) at basin scale for cropland pixels in Báruè, Moatize and Nhamatanda for the 2021 irrigation season

7 Seasonal Water Productivity assessment

The baseline assessment water productivity report[1] provided the average water productivity during an 17 year period (2001 – 2017). This is considered to be the baseline of the water productivity for the project locations, without any interventions placed by APSAN-Vale activities. During the irrigation season the project worked with several PPCs to improve the water productivity of their farm and subsequently also various PPEs (smallholder farmers) and surrounding communities by introducing interventions and training the communities on good agricultural practices.

Assessment of the water productivity is performed at three levels. Firstly, the change of water productivity due to specific interventions at the field of the PPCs is assessed. This level is considered the local scale of changing water productivity. Secondly, the change of water productivity of the surrounding communities is assessed. This will be influenced by neighbouring PPEs and communities adopting the interventions. This level is considered the increase of the overall water productivity of the region or sub-basin scale. During this season the activities were focused on a selection of PPCs and a number of communities. Lastly, the basin level is used to monitor the water productivity on a larger scale. However, it is expected that limited impact of the project is directly measured at basin scale due to the expanse of the area.

The following sections elaborate on the change in water productivity on the different scales in comparison with the baseline; and the change in overall water productivity using the WaPOR database to assess for a larger area. Assessments make use of normalizing the water productivity for the seasonal weather conditions as explained in section 2.6 of this report. Thus, changes in water productivity linked to the seasonal weather is reduced in the assessment. The water productivity assessment at the level of the PPC is presented followed by the overall water productivity assessment at the level of the sub-basins or communities, and the basin level.

7.1 Field scale

Chapter 4 of this report presents the results of the field scale water productivity values. An overview of this analysis is provided in Table 15 for each district indicating the overall increase in water productivity for each crop type. Tables 13 and 14 provide an overview of the results for tomato and cabbage, respectively. The values represent the normalized crop water productivity values. The overall increase is calculated by comparing the average (mean) of the normalized water productivity, with the 75th percentile[2] of the baseline. The assumption is that the PPCs are above average farmers (in the top 25%) compared to the agricultural systems used in the baseline assessment, which is also explained in section 4.3. The overall average improvement in water productivity achieved at field scale of the PPCs is +48%. The highest increase was observed in Báruè and lowest in Moatize. However, overall the improvements in water productivity indicate a good achievement of the targets set in the logframe as presented in section 1.2.2 of this report. In comparison with the previous irrigation season (2020)[3], which reported a field scale water productivity increase of +33%, this irrigation season shows a notable change of improvements and positive impact of the project.

[1] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.
[2] This is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. In this case, 25% of the observations are found above the 75th percentile.
[3] Van Opstal, J.D., M. de Klerk, A. Kaune, C. Nolet, J.E. Beard. 2021. Water Productivity Analysis: Irrigation Season 2020. FutureWater Report 218.

Table 13. Normalized tomato water productivity (in kg/m³) for the 2021 irrigation season compared to the baseline

	Báruè	Moatize	Nhamatanda	Overall
Baseline water productivity				
Range	0.65 – 1.19	1.50 – 2.25	1.02 – 1.35	
75th Percentile	1.07	1.95	1.27	
Irrigation season 2021 water productivity				
Range	1.57 – 2.95	1.79 – 2.96		
Average (mean)	2.76	2.37	2.03	
Relative change with baseline (%)	+158%	+22%	+60%	**+52%**

Table 14. Normalized cabbage water productivity (in kg/m³) for the 2021 irrigation season compared to the baseline

	Báruè	Moatize	Nhamatanda	Overall
Baseline water productivity				
Range	1.02 - 1.82	0.81 – 1.54	0.78 – 1.55	
75th Percentile	1.68	1.34	1.37	
Irrigation season 2021 water productivity				
Range	1.73 – 2.76		1.66 – 1.95	
Average (mean)	2.38	1.44	1.82	
Relative change with baseline (%)	+42%	+7%	+32%	**+36%**

Table 15. Overall change in water productivity for the 2021 irrigation season compared to the baseline for all major irrigation season crop types weighted by number of plots as indicated between brackets

	Báruè	Moatize	Nhamatanda	Overall
Tomato	+158% (3)	+22% (11)	+60% (1)	
Cabbage	+42% (8)	+7% (1)	+32% (5)	
Potato	+74% (2)			
Onion		+18% (1)	+78% (3)	
Overall change	+74%	+21%	+50%	**+48%**

7.2 Sub-basin scale

The sub-basin community scale water productivity was calculated using the 300 ha areas surrounding PPCs and the water productivity values as provided on the WaPOR data portal. The baseline values were not included for this spatial level in the baseline assessment report. For a baseline the data from WaPOR is used and the average values for 2015 to 2020 for the irrigation season (April – September). Table 16 presents the results of the baseline and comparison with the 2021 irrigation season results. The overall increase of water productivity was observed to be +24% for Báruè and Moatize, and 17% for Nhamatanda. This indicates positive impact is achieved in the areas surrounding the PPCs and ultimately good practices are adopted to improve water productivity. The overall increase in water productivity is +22%, which is lower than the field scale water productivity due to the spatial scale being larger. It is assumed that the adoption of good agricultural practices is more dispersed at a large spatial scale.

Table 16. Biomass water productivity (kg/m^3) for the 2021 irrigation season at sub-basin scale compared to the baseline of 2015-2020 as derived from the WaPOR data portal

	Báruè	Moatize	Nhamatanda	Overall
Baseline average 2015 – 2020	2.77	1.76	1.85	
Irrigation season 2021	3.05	2.07	2.12	
Irrigation season 2021 (normalized)	3.44	2.18	2.16	
Relative change with baseline (%)	+24%	+24%	+17%	**+22%**

7.3 Basin scale

The assessment of water productivity at basin scale was performed using the WaPOR results from chapter 6. These indicate the water productivity values for cropland pixels at the selected basins of the project for the irrigation season. Table 17 presents the values of biomass water productivity after normalizing for the 2021 weather conditions and comparing with the baseline values. An average increase of biomass water productivity of +33% was perceived, ranging from +25% to +46% for the different districts. The previous irrigation season report (2020)[1] indicated an overall biomass water productivity increase of +25%, indicating that the 2021 irrigation season had an even higher increase in water productivity at basin scale. This is a positive trend and requires further investigation to determine to what magnitude the increase is related to the field interventions and adoption by the community.

Table 17. Biomass water productivity (kg/m^3) for the 2021 irrigation season at basin scale compared to the baseline

	Báruè	Moatize	Nhamatanda	Overall
Baseline average 2001-2018	1.50	1.48	1.31	
Irrigation season 2021	1.95	1.78	1.61	
Irrigation season 2021 (normalized)	2.20	1.88	1.64	
Relative change with baseline (%)	+46%	+27%	+25%	**+33%**

[1] Van Opstal, J.D., M. de Klerk, A. Kaune, C. Nolet, J.E. Beard. 2021. Water Productivity Analysis: Irrigation Season 2020. FutureWater Report 218.

8 Concluding remarks

The water productivity results as presented in this report provide insight of the impact of the project activities both at field, sub-basin (community) and basin scale. Various methods were used to provide a reliable assessment of the water productivity, using the data available from the field, flying sensor imagery and open-access remote sensing datasets from WaPOR and Sentinel 2.

The field scale water productivity presented results for 28 farmers which were monitored throughout the irrigation season as part of the APSAN-Vale project. The water productivity was calculated for all major crop types of the irrigation season tomato, cabbage, onion, and potato. Additionally, typical rainfed crops which were also grown in the irrigation season (beans and maize) were also added to the analysis. Tomato water productivity was found to range from 1.57 to 2.95 kg/m^3 in Báruè, 1.79 to 2.96 kg/m^3 in Moatize, and 2.03 kg/m^3 in Nhamatanda. Cabbage water productivity was found to range from 1.73 to 2.76 kg/m^3 in Báruè, 1.44 kg/m^3 in Moatize, and 1.66 to 1.95 kg/m^3 in Nhamatanda. After normalization for climatic conditions, the increase in overall crop specific water productivity (summarized for all major crop types) was found to be +74% in Báruè, +21% in Moatize, and +50% in Nhamatanda, resulting in an average +48% increase in comparison with the baseline values. This is a more positive change with the baseline values compared to the previous irrigation season report (2020).

The results of field water productivity of 28 farmers, give a good indication of trends in high and low water productivity. These can be combined with the monitoring data from APSAN-Vale partners indicating the adoption of practices of these farmers and the trainings that were attended. In a follow-up report a preliminary analysis will be provided on determining the impact of interventions on the crop yield and water productivity.

Furthermore, the water productivity was calculated at sub-basin scale, which is representative for the community of farmers adopting practices being demonstrated and promoted by the selected PPCs. An area of 300 ha around each selected PPC is determined to be representative for the area of the sub-basin (or community). At sub-basin scale the water productivity analysis makes use of the WaPOR data portal and calculates the biomass water productivity. The highest water productivity values were found in Báruè; here the highest values are observed in Báruè I of 3.13 kg/m^3. In Moatize the highest water productivity is found in Moatize I. Both high water productivity values in Báruè I and Moatize I are related to upstream locations and the vicinity of mountain ranges. The biomass water productivity was found to range from 2.93 to 3.13 kg/m^3 in Báruè, 1.38 to 2.55 kg/m^3 in Moatize, and 2.06 to 2.13 kg/m^3 in Nhamatanda. The relative change of water productivity compared to the baseline values is +24%, +24% and +17% for Báruè, Moatize, and Nhamatanda, respectively. The overall increase in water productivity estimated at sub-basin (community) level is +22%.

At basin scale the catchment delineation from each district was used as the boundary of the basin. The water productivity was determined using the WaPOR data portal providing values on biomass water productivity. These values are compared with the baseline assessment and determined that an increase of water productivity was achieved of +46%, +27%, and +25% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +33% for all districts together.

The field scale water productivity analysis indicates an improvement of water productivity and achieves the set target for 2021 of +25% as stated in the project logframe. Continuation of this analysis with the adoption of practices will assist in determining effective interventions for improving water productivity and facilitate the upscaling of water productivity improvements.

Annex 1 – Overview of input data

Table 18. Field input data for Báruè

		Crop						Field mgt				Irrigation
ID plot	Name	Crop type (EN)	Crop type (PT)	Planting date	Harvest date (estimated)	Duration [days] (estimated)	Planting density [cm x cm per plant]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation method
AP_BA_ACI-01-03	Ananias	Potato	Batata	2-Apr-2021	*30/Jul*	*119*	60x40	optimal	no	Low	no	Sprinklers
AP_BA_ACI-01-04	Ananias	Cabbage	Couve	25-Apr-2021	*04/Aug*	*101*	45x40	optimal	no	Low	no	Sprinklers
AP_BA_ACI-01-05	Ananias	Beans	Feijao	*15-Apr-2021*	*01/Jul*	*77*	50x10	optimal	no	Low	no	Sprinklers
AP_BA_ACI-01-05	Ananias	Beans	Feija	*15-Apr-2021*	*01/Jul*	*77*	50x10	optimal	no	Low	no	Sprinklers
AP_BA_ACI-01-07	Ananias	Cabbage	Repolho	21-Apr-2021	*15/Aug*	*116*	70x60	optimal	no	Low	no	Sprinklers
AP_BA_ACI-01-08	Ananias	Tomato	Tomate	14-May-2021	*03/Aug*	*81*	85x60	optimal	no	Low	no	Sprinklers
AP-BA-AB-01-01	Anita	Maize	Milho	20-Jul-2021	*15/Nov*	*118*	90x60	optimal	no	Low	yes	Sprinklers
AP-BA-BV-01-01	Bernardo	Beans	Feijao	18-Jun-2021	*30/Sep*	*104*	50x10	optimal	no	Low	no	Gravity
AP-BA-BV-01-02	Bernardo	Cabbage	Repolho	12-Jul-2021	*25/Sep*	*75*	70x60	optimal	no	Low	no	Gravity
AP-BA-CF-01-01	Chuva	Beans	Feijao	*1-May-2021*	*10/Aug*	*101*	50x10	optimal	no	Low	no	Gravity
AP-BA-CF-01-01	Chuva	Beans	Feijao	*1-May-2021*	*10/Aug*	*101*	50x10	optimal	no	Low	no	Gravity
AP-BA-CF-01-01	Chuva	Beans	Feijao	2-Apr-2021	*01/Jul*	*90*	50x10	optimal	no	Low	no	Gravity
AP-BA-CF-01-01	Chuva	Beans	Feijao	2-Apr-2021	*01/Jul*	*90*	50x10	optimal	no	Low	no	Gravity
AP-BA-CF-01-02	Chuva	Cabbage	Repolho	4-May-2021	*20/Aug*	*108*	70x60	optimal	no	Low	no	Gravity
AP-BA-PGM-01-01	Paulo	Beans	Feijao	27-Jul-2021	*30/Oct*	*95*	50x10	optimal	no	Moderate	no	Gravity
AP-BA-PGM-01-02	Paulo	Tomato	Tomate	14-Jun-2021	15/Sep	*93*	85x60	optimal	no	Moderate	no	Gravity
AP_BA_JDR-01-02	Joelmo	Cabbage	Couve	3-May-2021	*25/Aug*	*114*	45x40	optimal	no	Moderate	no	Gravity
AP_BA_JDR-01-03	Joelmo	Beans	Feijao	4-May-2021	*05/Sep*	*124*	50x10	optimal	no	Moderate	no	Gravity
AP-BA-LJ-01-01	Lucas	Cabbage	Repolho	16-Jun-2021	*15/Sep*	*91*	70x60	optimal	no	Moderate	no	Gravity
AP_BA_ML-01-02	Manuel	Cabbage	Repolho	22-Jun-2021	*30/Aug*	*69*	70x60	optimal	no	Low	no	Gravity
AP_BA_MA-01-01	Margarida	Potato	Batata	22-Apr-2021	*15/Aug*	*115*	60x40	optimal	no	Moderate	no	Gravity
AP_BA_MD-01-02	Modesto	Cabbage	Repolho	10-Apr-2021	*01/Jul*	*82*	70x60	optimal	no	Low	no	Gravity
AP_BA_MD-01-03	Modesto	Maize	Milho	12-May-2021	*20/Sep*	*131*	90x60	optimal	no	Low	no	Gravity
AP_BA_MD-01-04	Modesto	Tomato	Tomate	24-Apr-2021	*15/Aug*	*113*	85x60	optimal	no	Low	no	Gravity

Table 19. Field input data for Moatize

		Crop						Field mgt				Irrigation
ID plot	**Name**	**Crop type (EN)**	**Crop type (PT)**	**Planting date**	**Harvest date (estimated)**	**Duration [days] (estimated)**	**Planting density [cm x cm per plant]**	**Fertilizer use (low, moderate, optimal)**	**Mulching yes/no**	**Weed mgt (low, moderate, high)**	**Runoff mgt (yes/no)**	**Irrigation method**
MO-MA-AC-01-01	Alberto	Tomato	Tomate	10/Apr	03/Jul	84	85x60	Optimal	no	Low	no	Gravity
MO-MA-GM-01-01	Girio	Tomato	Tomate	*30/Apr*	05/Sep	128	85x60	Optimal	no	Low	no	Gravity
MO-MA-GM-01-01	Girio	Tomato	Tomate	*30/Apr*	05/Sep	128	85x60	Optimal	no	Low	no	Gravity
MO-SA-ZM-01-01	Zeca	Tomato	Tomate	15/Apr	15/Jul	91	85x60	Optimal	no	Low	no	Gravity
MO-SA-MC-01-01	Manuel	Beans	Feijao	23/May	09/Aug	78	50x10	Optimal	no	Low	no	Gravity
MO-SA-CA-01-02	Cezario	Onion	Cebola	*20/May*	20/Aug	92	20x15	Optimal	no	Low	no	Gravity
MO-SA-CA-01-01	Cezario	Tomato	Tomate	*30/May*	*15/Aug*	77	85x60	Optimal	no	Low	no	Gravity
MO-SA-CA-01-04	Cezario	Beans	Feijao	25/Mar	25/Jun	92	90x40	Optimal	no	Low	no	Gravity
MO-SA-CA-01-05	Cezario	Cabbage	Couve	*01/Jul*	*15/Sep*	76	45x40	Optimal	no	Low	no	Gravity
MO-SA-CA-01-04	Cezario	Beans	Feijao	25/Mar	25/Jun	92	90x40	Optimal	no	Low	no	Gravity
MO-CA-AB-01-01	Albino	Tomato	Tomate	10/Apr	20/Jul	101	80x60	Optimal	no	Low	no	Gravity
MO-MA-JC-01-02	Joao	Tomato	Tomate	15/Apr	25/Jul	101	80x60	optimal	no	Low	no	Gravity
MO-CA-XT-01-01	Xavier	Beans	Feijao	10/Apr	20/Jul	101	50x10	optimal	no	Low	no	Sprinklers
MO-CA-XT-01-03	Xavier	Tomato	Tomate	10/Feb	*05/Jun*	115	85x60	optimal	no	Low	no	Sprinklers
MO-BE-SJ-01-0	Staben	Tomato	Tomate	10/Apr	14/Jul	95	85x65	optimal	no	Low	no	Gravity
MO-BE-SJ-01-0	Staben	Tomato	Tomate	15/Jun	01/Sep	78	85x65	optimal	no	Low	no	Gravity
MO-BE-T-01-02	Teofilo	Tomato	Tomate	10/Apr	15/Jul	96	80x65	Optimal	no	Low	no	Gravity

Table 20. Input field data for Nhamatanda

			Crop						Field mgt			Irrigation		
ID plot	Name	Name farmer	Crop type (EN)	Crop type (PT)	Planting date	Harvest date (estimated)	Duration [days] (estimated)	Planting density [cm x cm per plant]	Fertilizer use (low, moderate, optimal)	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)	Irrigation method	Irrigation interval (days)
AP_NH_AS_01_02	Associacao	Associacao	Tomato	Tomate	10/Apr	15/Jul	96	85-60	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_JA_01_01	Jose	Jose Anderson	Beans	Feijao Vulgar	*05/May*	20/Jul	76	50-10	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_FM_01_01	Flora	Flora Mustico	Beans	Feijao Vulgar	15/Apr	*01/Jul*	77	50*10	Optimal	High	no	yes	Aspersao	7 dias
AP_NH_LB_01_02	Lucas	Lucas Bernardo	Cabbage	Repolho	06/May	20/Aug	106	50-50	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_LB_01_03	Lucas	Lucas Bernardo	Beans	Feijao Vulgar	15/May	05/Aug	82	50-10	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_LB_01_04	Lucas	Lucas Bernardo	Onion	Cebola	21/Apr	*15/Jul*	85	20-15	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_AM_01_01	Antonio	Antonio Mussanharuca	Beans	Feijao Vulgar	11/May	14/Aug	95	50-10	Optimal	Moderate	no	yes	Aspersao	7 dias
AP_NH_FMA_01_01	Filipe	Filipe Mateus	Maize	Milho	05/Apr	05/Jul	91	80-50	Optimal	Moderate	no	yes	Aspersao	7 dias
AP_NH_FMA_01_05	Filipe	Filipe Mateus	Cabbage	Repolho	21/Jun	10/Sep	81	50-50	Optimal	Moderate	no	yes	Aspersao	7 dias
AP_NH_DP_01_03	Domingos	Domingos Pedro	Cabbage	Couve	10/May	20/Jul	71	50-40	Optimal	Low	no	yes	sulcos	7 dias
AP_NH_FM_01_01	Flora	Flora Mustico 2	Cabbage	Repolho	05/Apr	05/Aug	122	50-50	Optimal	Low	no	yes	sulcos	7 dias
AP_NH_FM_01_02	Flora	Flora Mustico 2	Onion	Cebola	25/Jun	05/Sep	72	20-15	Optimal	Low	no	yes	sulcos	7 dias
AP_NH_MD_01_01	Manuel	Manuel Dique	Onion	Cebola	15/Jun	10/Sep	87	20-15	Optimal	Moderate	no	yes	sulcos	7 dias
AP_NH_MD_01_01	Manuel	Manuel Dique	Cabbage	Repolho	25/Apr	20/Aug	117	50-50	Optimal	Moderate	no	yes	sulcos	7 dias