Water Productivity Analysis: Rainfed Season 2020-2021

APSAN-Vale project

REPORT 227

CLIENT
Agência de Desenvolvimento do Vale Zambeze (ADVZ)

AUTHORS
Jonna van Opstal
Martijn de Klerk
Vera Hollander
Jack Beard

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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)
Jack Beard – Consultant (j.beard@futurewater.nl)

APSAN-Vale project partners
Resilience B.V.
HUB

Date
September 2021

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) and WaPOR in combination with a water productivity simulation model and field observations. This report shows the water productivity analysis for the rainfed season 2020-2021 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 rainfed growing season of 2020 - 2021 (December to April) for the APSAN-Vale project areas.

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 rainfed growing season a total of 110 flights were performed over 29 farm fields, covering a total of 580 ha. The number of farmers monitored in this report for the field scale water productivity analysis are 27 in total, with 11 in Barue, 10 in Moatize, and 6 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 the 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 27 farmers which were monitored throughout the rainfed season as part of the APSAN-Vale project. Maize water productivity was found to range from 0.38 to 0.66 kg/m^3 in Nhamatanda, 0.55 to 0.75 kg/m^3 in Moatize, and 0.71 to 0.94 kg/m^3 in Báruè. After normalization for climatic conditions, the increase in water productivity was found to be +68% in Báruè, +78% in Moatize, and +57% in Nhamatanda, resulting in an average 62% increase in comparison with the baseline values.

At sub-basin scale an area of 30 ha surrounding each PPC was analyzed. This is a representative area to assess the adoption of practices by the surrounding farming community. The highest water productivity values were found in Báruè. Here the highest values are observed in Catandica II. In Moatize the highest water productivity is found in Moatize III. The lowest values for water productivity are found in Nhamatanda. The biomass water productivity was found to range from 1.76 to 1.87 kg/m^3 in Báruè, 0.96 to 1.38 kg/m^3 in Moatize, and 1.08 to 1.11 kg/m^3 in Nhamatanda.

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 +39%, -5, and +14% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +16% 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 3.5 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.

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[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.

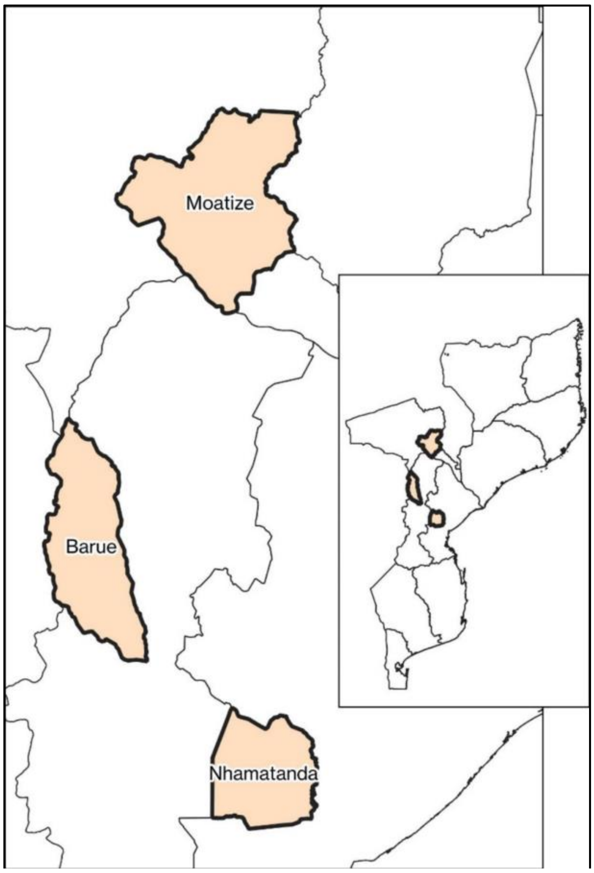


Figure 1. Location districts of APSAN-Vale project activities

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)[3] 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
Goal	0.3	Increased Water Productivity	0%	7.5%	15%	25%
Outcome	1.2	Water footprint for selected crops	0%	7.5%	15%	25%
	1.3	Water productivity for maize	0%	7.5%	15%	25%
	1.4	Biomass water productivity	0%	7.5%	15%	25%
Outputs	1.1.1	# of field level maps	0	30	60	60
	1.1.2	# of sub-basin level maps	0	10	20	20
	1.1.3	# of basin level maps	0	6	12	12

3 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 rainfed season commenced end of November 2020 with the planting of the maize crops, which is the major crop cultivated during this growing season. Other crops were planted in January or February. The season continues till end of April with the harvest occurring early May. The rainfall during this season is erratic with heavy rainfall events, and occasionally resulting in flood damage of access roads and crop loss. 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 27 farmers was used.

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

	Báruè	Moatize	Nhamatanda	Total
Flights taken	53	33	24	110
Farmers monitored	11	10	8	29
Area covered	220 ha	200 ha	160 ha	580 ha
Farmers monitored for WP	11	10	6	27

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 Small commercial farmers (Pequenos Produtores Comercial, PPCs)

For each district several small commercial farmers (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, eleven, ten, and six PPCs respectively were monitored for the water productivity analysis. Figure 2 indicates the locations of the PPCs monitored during the rainfed growing season.

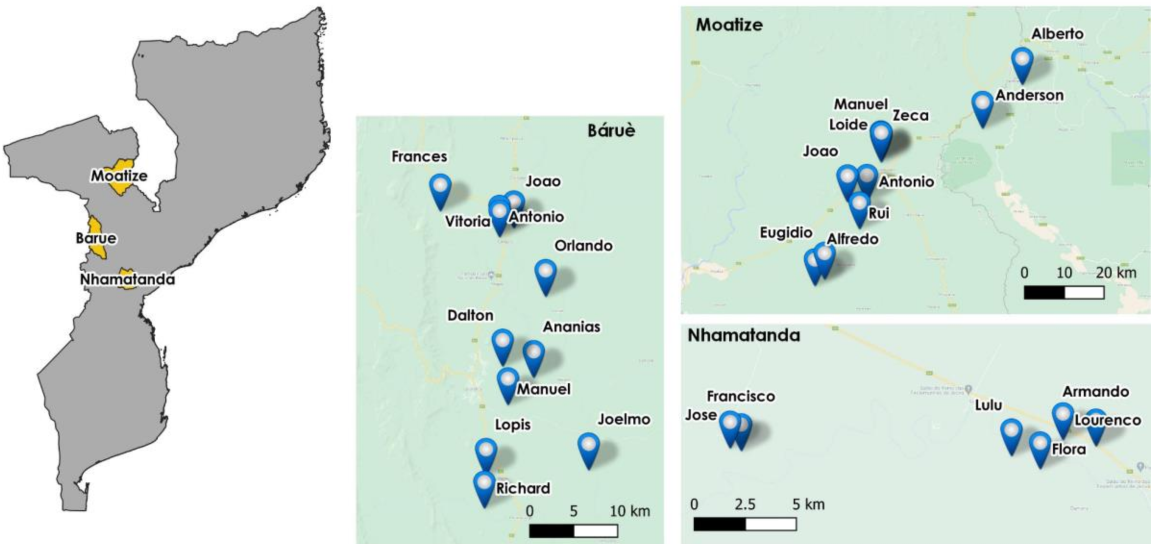


Figure 2. Location of selected PPCs monitored with flying sensor flights during the rainfed season 2020-2021

2.1.2 Sub-basins / local communities

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 this report it is selected to select the sub-basin level at the size 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. This is best monitored at a scale that captures the change of the communities. The area is selected using a buffer surrounding the selected PPCs of approximately 300 ha. The location of these communities are presented in figures 3, 4, and, 5 for Moatize, Nhamatanda, and Báruè respectively. Each have selected 2 to 4 clusters surrounding the PPCs.

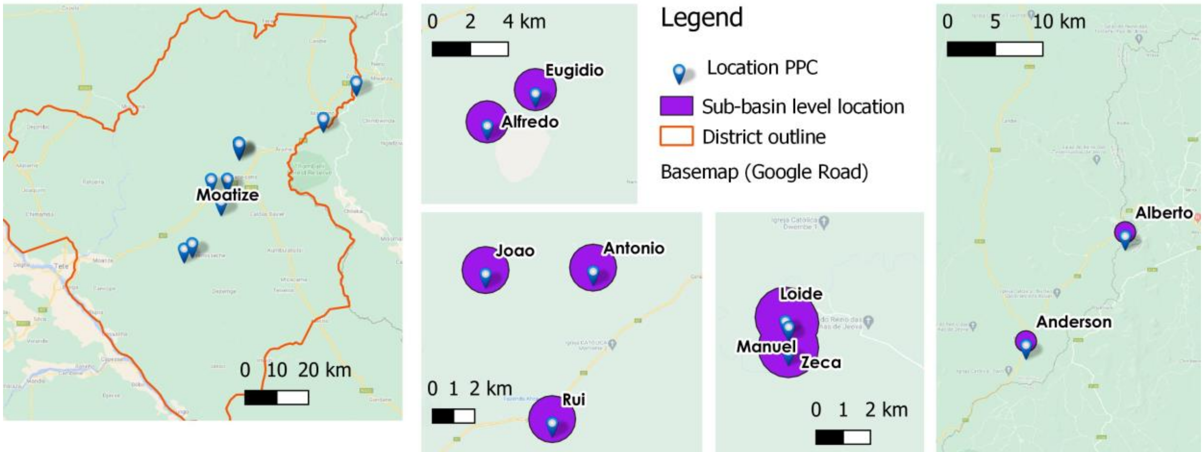


Figure 3. Location and boundaries of local communities (sub-basin level) in Moatize district

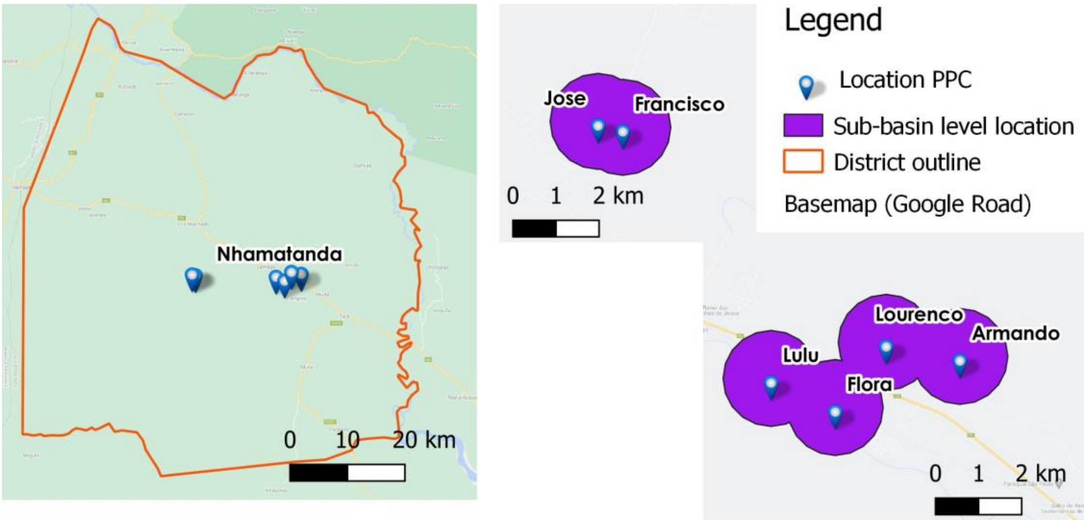


Figure 4. Location and boundaries of local communities (sub-basin level) in Nhamatanda district

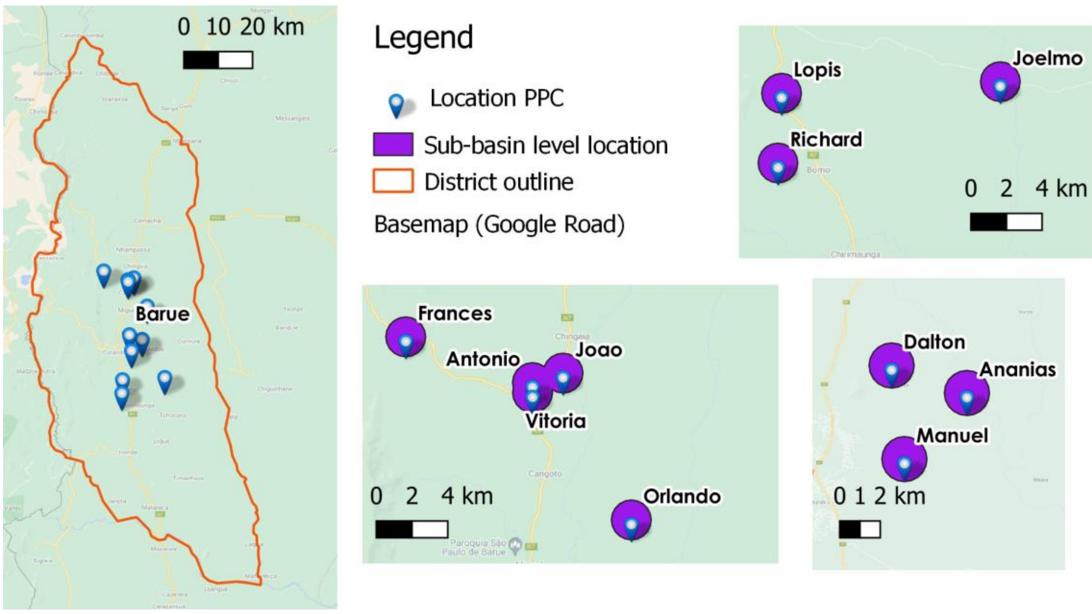


Figure 5. Location and boundaries of local communities (sub-basin level) in Báruè district

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)[4]. The outflow points for the basins are determined by evaluating the location of the project activities in the fields (as shown in Figure 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.

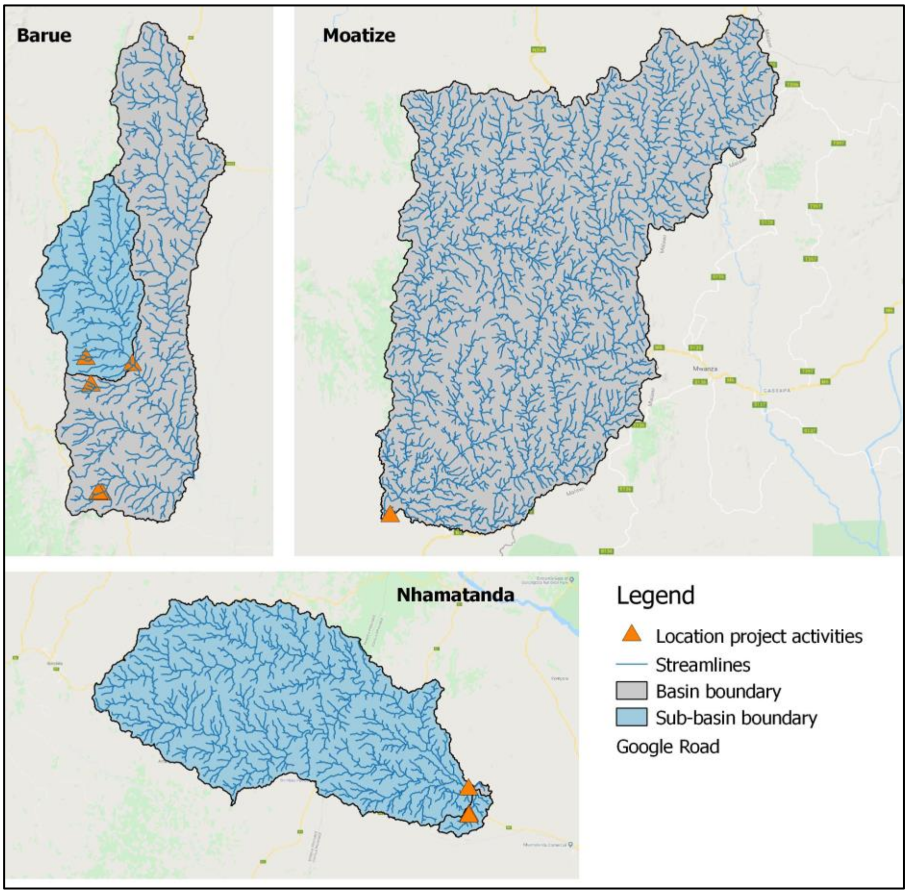


Figure 6. Delineation of basins and streamlines for the three districts

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 (2.2.1).
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).

[4] van der Kwast, H. & Menke, K., QGIS for Hydrological Applications - Recipes for Catchment Hydrology and Water Management, Locate Press, 2019.

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 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 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 imagery (2.3), and crop simulation modelling with AquaCrop (2.4).

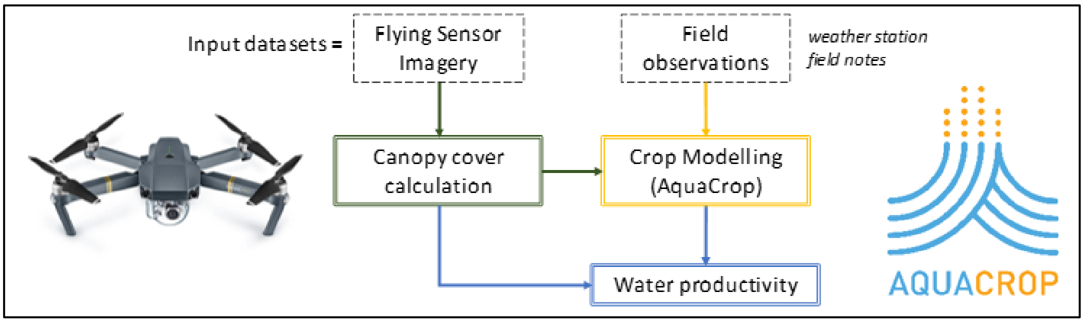


Figure 7. Workflow for calculation of crop specific water productivity analysis

2.2.2 Biomass water productivity

WaPOR is FAO's water productivity data portal 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.

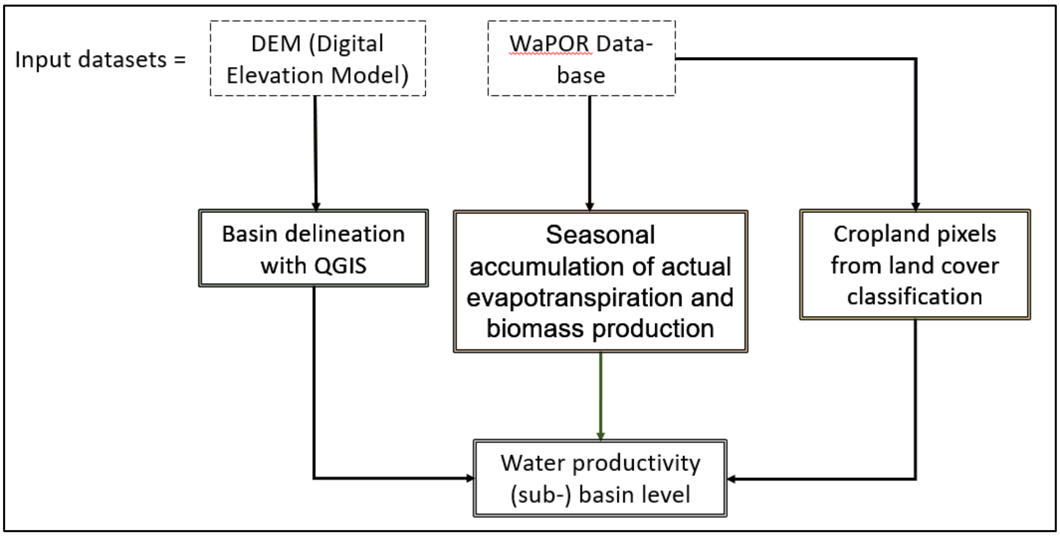


Figure 8. Workflow for biomass water productivity analysis

2.3 Flying Sensor Imagery

2.3.1 Flying sensor equipment

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 wavelength, which is not visible to the human eye. The near infrared (NIR) 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.

Figure 9. Photo of the Flying Sensor in action

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.

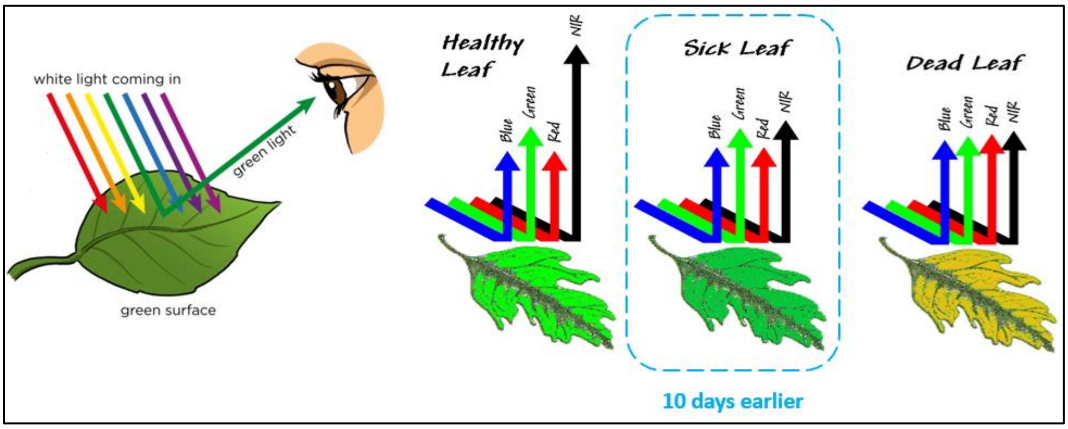


Figure 10. Illustration explaining the response of near infrared (NIR) wavelength to vegetation status

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, Nhamatanda, and Moatize, were 53, 24, and 33, respectively. The total area monitored with the flying sensors was 220 ha., 160 ha., and 200 ha. for Báruè, Nhamatanda, and Moatize respectively.

Table 3. Overview of flights and area during the Rainfed Season of 2020-2021

	Báruè	Moatize	Nhamatanda
November	24–26 November 2020		24 November 2020
December		1-3 December 2020	
January	5-7 January 2021	12-13 January 2021	7 January 2021
February	2-4 February 2021	16-18 February 2021	4 February 2021
March	2-4 March 2021	23-25 March 2021	3, 12 March 2021
April	5-9 April 2021		
Flights taken	53	33	24
Area covered	220 ha	200 ha	160 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.

2.4 Crop simulation modelling

2.4.1 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[5]; Hunink and Droogers, 2010[6], 2011[7]). In addition, AquaCrop has been applied to predict water productivity and crop yield based on flying sensor

[5] 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.
[6] 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.
[7] 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

information (den Besten et al., 2017[8], van Opstal, 2019[9]) and to assess irrigation scheduling scenarios (Goosheh et al., 2018[10]). 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.

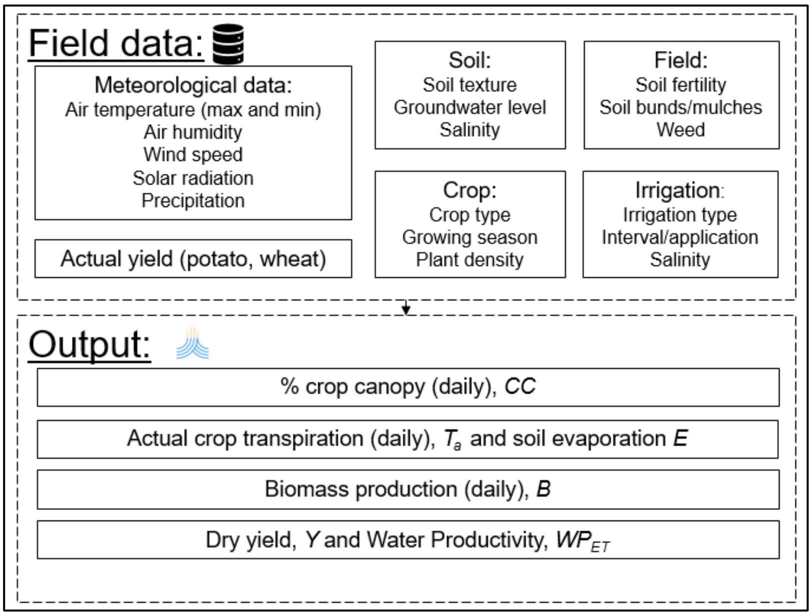


Figure 11. Field data and output simulations of the AquaCrop model

2.4.2 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. The precipitation data experienced some malfunctions in the equipment; therefore, the rainfall data was replaced with CHIRPS data from satellite remote sensing. 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)[11].

[8] den Besten, N., Simons, G. and Hunink, J.: Water Productivity assessment using Flying Sensors and Crop Modelling. Pilot study for Maize in Mozambique, 2017.
[9] Van Opstal, J.D.. 2019. APSAN-Vale Water Productivity Rainfed season 2018/2019. FutureWater Report.
[10] 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.
[11] 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 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 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

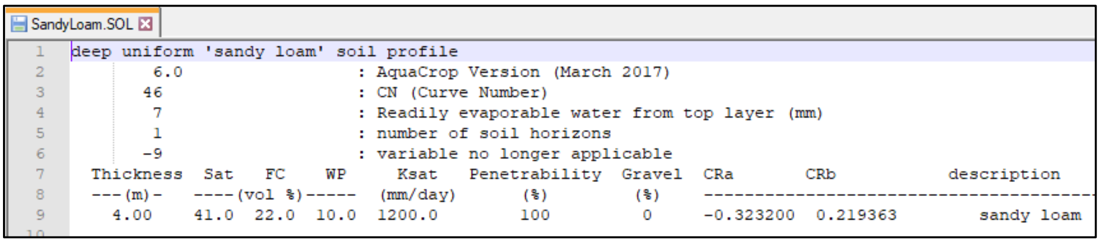
*Growing stages in calendar days.

<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 Bárué 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.

Table 5. Soil texture in each site

Site	Soil texture
Bárué	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 12. Soil characteristic in Moatize

2.4.3 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 curvilinear trend is also simulated in AquaCrop. For the calibration process the canopy cover from the flying sensors is compared with the AquaCrop simulated canopy cover. This is done for the days that the flying sensors has acquired an image. In Table 3 it was noted that for each district four flight moments occurred during the rainfed growing season. Thus, this provides 4 points for determining the curvi-linear relationship. 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 weed cover. After running the various combinations (27 simulation runs total per field) the top simulations (1 – 5) were selected displaying limited error with the canopy cover as observed from the flying sensor images.

2.5 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[12]. The data layers were downloaded for Mozambique and aggregated to find seasonal values for the rainfed season: December 2020 to April 2021.

2.5.1 Actual Evapotranspiration

The actual evapotranspiration is calculated using a surface energy balance algorithm based on the equations of the ETLook model[13]. 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 rainfed season is calculated in QGIS.

2.5.2 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[14]. 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 rainfed 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).

2.5.3 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.

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.

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

2.6 Normalization for annual weather conditions

For the baseline assessment[15] 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 2019) and using reference evapotranspiration (ET_0) as representative for the annual weather conditions. This equation and methodology are described by Bastiaanssen and Steduto (2016)[16], as a method for comparing water productivity between years and regions with different climatic conditions.

$$WP_{norm,2019}\ [kg/m^3] = \frac{WP_{2019}\ \left[\frac{kg}{m^3}\right] \times ET_{0,average\ 2000-2019}\ [mm]}{ET_{0,\ 2019}\ [mm]}$$

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

[16] 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[17] weather stations in each district, meteorological data is measured, and reference evapotranspiration is computed. The five-day average reference evapotranspiration (ET) during the rainfed season is shown in Figure 13. The three districts display a similar pattern in the reference ET. The reference ET is higher at the start of the season approximately 1 – 2 mm/day, and lower during the remainder of the season.

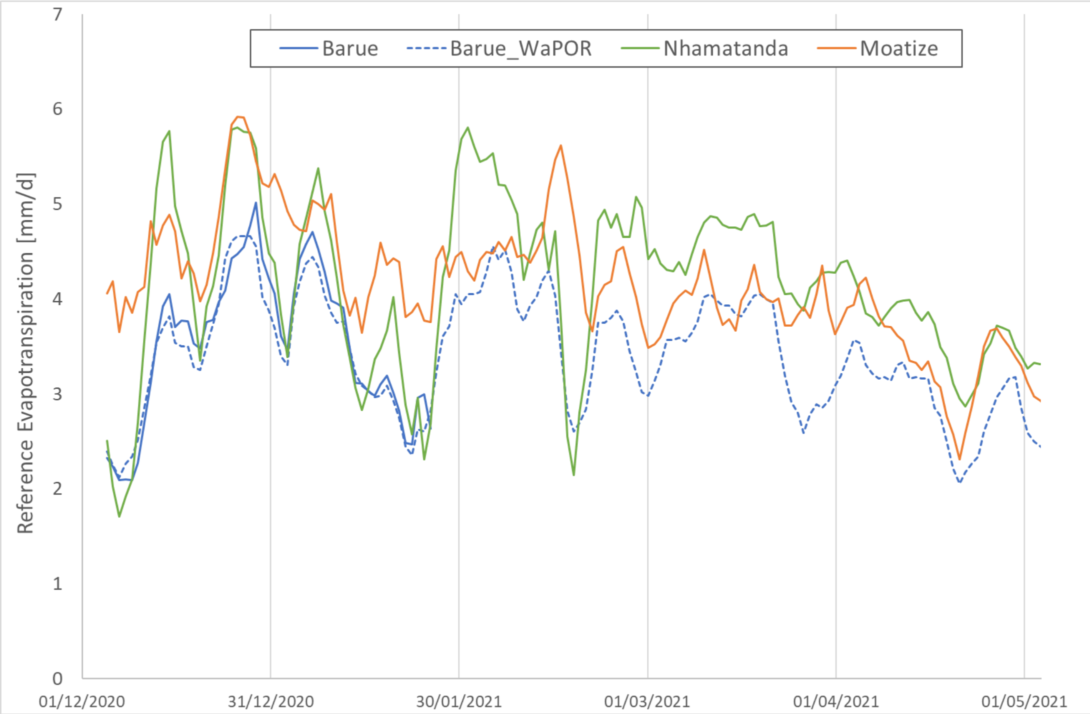


Figure 13. Five day average reference evapotranspiration for the three districts during the rainfed season 2020-2021 from TAHMO stations and supplemented with WaPOR data for Bàrué

The weather conditions during the 2020-2021 rainfed 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 2020 monthly values and displayed in Figure 14. All results are derived from the satellite data products, therefore avoiding dissimilarities due to different measuring methods.

Figure 14 shows that the reference ET for Báruè was slightly lower each month this season compared to the long term average. The same accounts for Moatize, except for the months March and April. For Nhamatanda the reference ET was higher each month, in particular during the first months. This can have impact on the crop modelling results which have weather data as input. Note, that water productivity is calculated with evapotranspiration in the denominator which is partly determined by the reference evapotranspiration during the season.

The total seasonal reference ET is presented in Table 6 for this season and the long-term average for the rainfed season. These values are used in the normalization of the water productivity results as presented in section 2.6 of this document.

[17] https://tahmo.org/

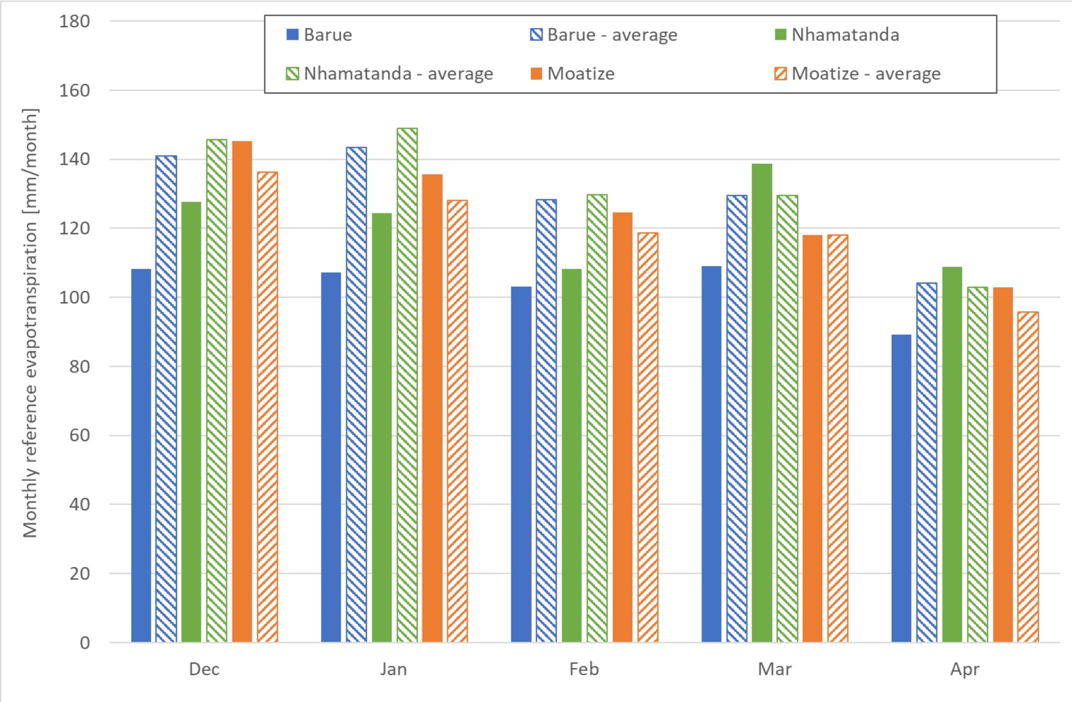


Figure 14. Comparison of 2020-2021 monthly reference evapotranspiration with long-term average (2009-2018) with WaPOR data portal product

Table 6. Seasonal total reference evapotranspiration for the three districts during 2020-2021 rain season, and long-term average (2001-2018) rainfed season

	Báruè	Moatize	Nhamatanda
Reference ET 2020-2021 [mm]	517	626	608
Reference ET Average [mm]	647	597	657

3.2 Precipitation

The rainfed season is characterized by heavy and erratic rainfall events. The rainfall recorded at the TAHMO stations displayed some equipment malfunctions, therefore the satellite data of CHIRPS is used for all three districts. as presented in Figures 15. This figure displays the daily precipitation and indicates several rainfall events occurring with intensities up to 85 mm/day. The high intensity rainfall events were mainly observed in Nhamatanda and Báruè.

Figure 16 displays the monthly and seasonal total precipitation for each district and compares with the long-term average (2001-2018) using satellite data. The figure shows that during the period of December to February the precipitation in Báruè was (way) above the long-term average. For the other districts the precipitation was similar to the long-term average, except for Nhamatanda in February (higher) and March (lower). The farmers monitored during the rainfed season, depend solely on precipitation as the source of water for the soil and crops. Therefore, the precipitation during the season can be a limiting factor for the production of the area.

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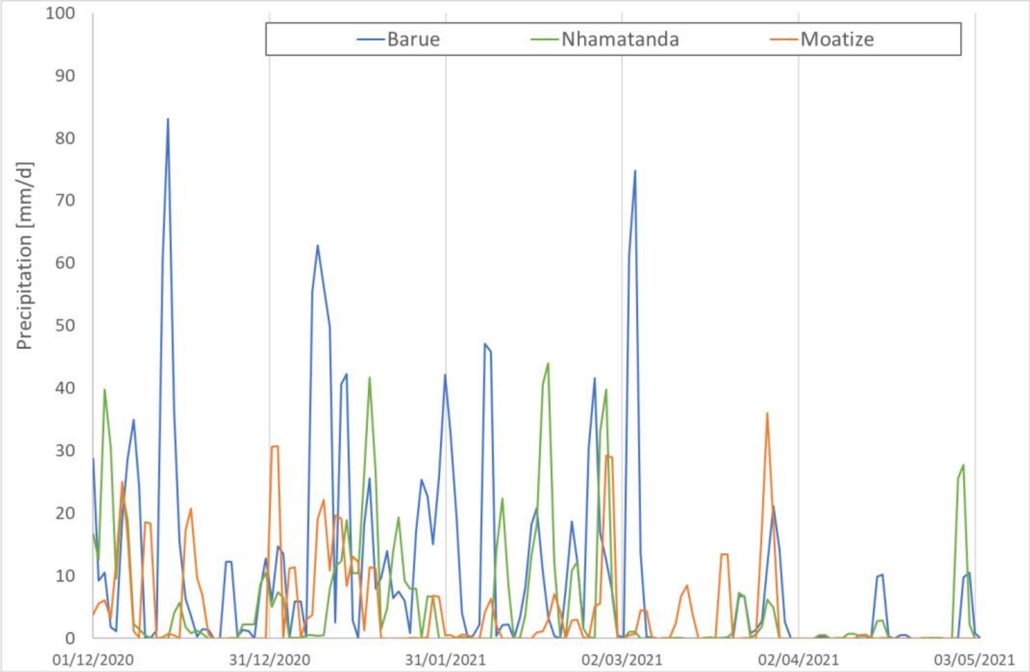

Figure 15. Daily precipitation for 2020-2021 from TAHMO weather stations

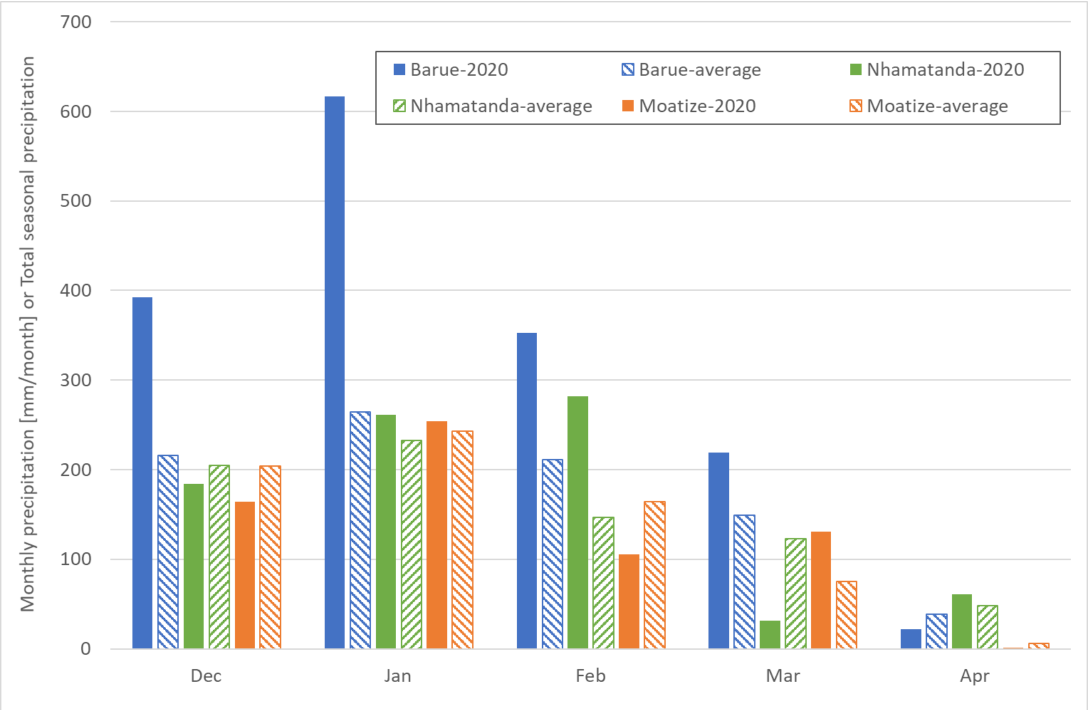

Figure 16. Comparison of 2020-2021 monthly precipitation with long-term average (2001-2018) with CHIRPS

4 Field scale Water Productivity results

4.1 Flying sensor imagery

4.1.1 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 are shown in the figure below, Figure 17. These maps indicate the field boundaries, area of the field, crop type, and name of the farmer including the registered code as used in mWater for field monitoring. 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.

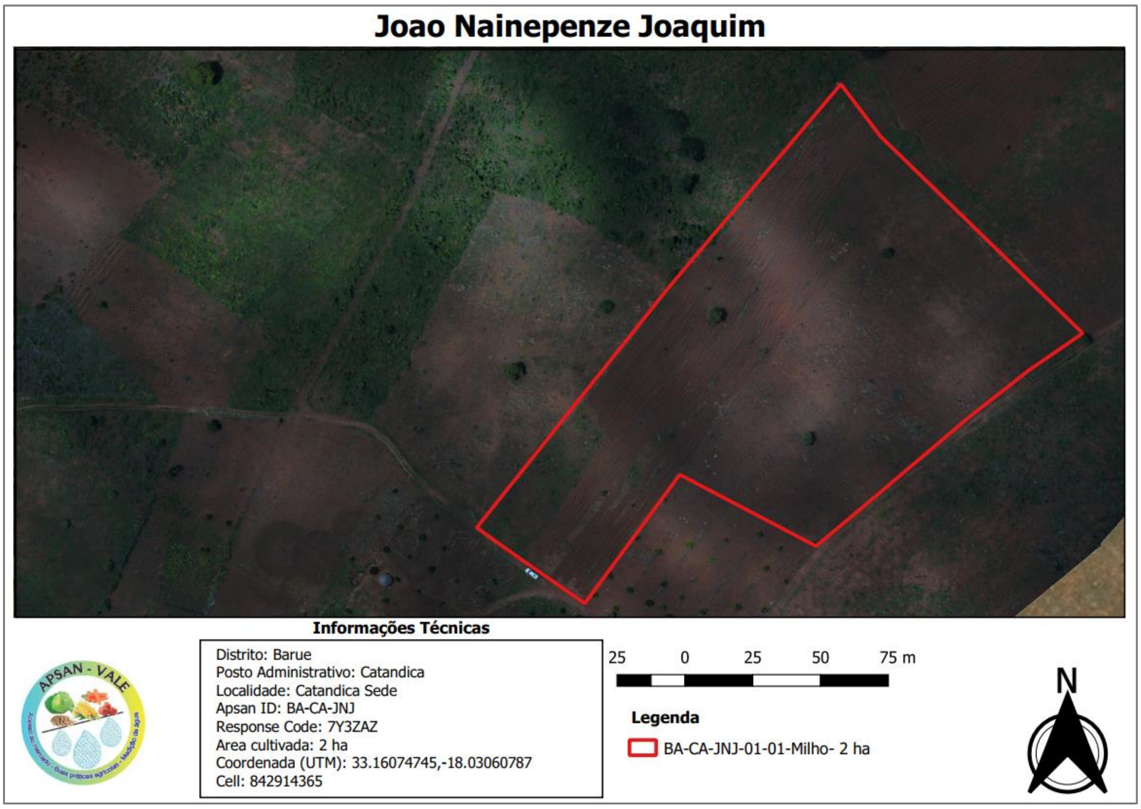

Figure 17. Field registration map of PPC (small commercial farmer) Joao Nainepenze Joaquim (example)

4.1.2 Field maps for vegetation monitoring

The second set of maps were shared during the growing season to monitor the crop growth. Images are shown from two or three flights to indicate the development of the crop. An example of a field map is shown on the next page, Figure 18. The visual image (RGB, red-green-blue) is indicated for easier interpretation as this is more understandable. The vegetation status is indicated in red colors indicating low vegetation cover, and green colors indicating high vegetation cover.

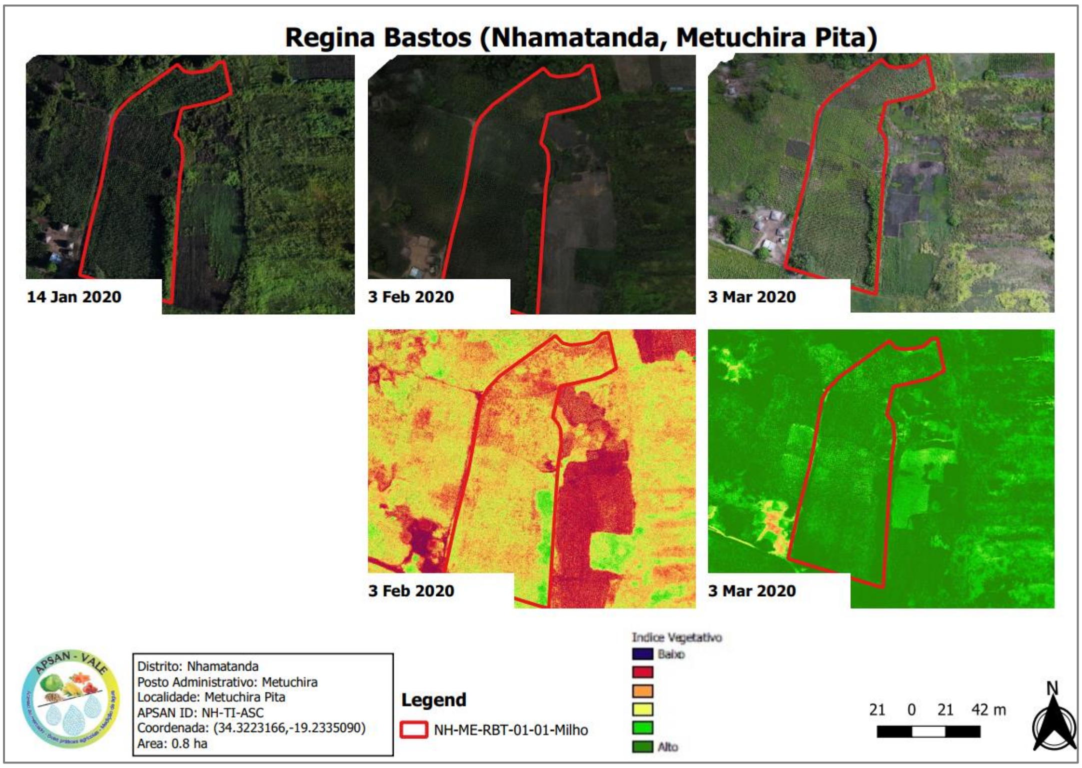

Figure 18. Development of the vegetation status of PPC (small commercial farmer) Regina Bastos in Nhamatanda, Metuchira Pita (example)

4.1.3 APSAN-Vale Flying Sensor portal

The information from the flying sensor imagery is disseminated through printed maps (as described in the previous sections), and through an online data portal. All visual and vegetation status maps can be found in the online portal. Over the past year, substantial efforts were made to disseminate the maps made by the 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/.

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 the operators and farmers. The flying sensor maps are uploaded to the portal automatically after they have been processed by the local operators. 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 19. Currently, the possibility of downloading all this new information into a pdf file that can be handed out by the operator to the farmer is being updated as well. Therefore the “download to pdf” functionality is currently out of service but will be up and running again soon. In this way, the maps can be downloaded in the office (or anywhere with a sufficient internet connection) and then be used offline in the field.

Figure 19. 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 some example comments in the right section

4.2 Canopy cover

All 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 was taken at regular (3-4 weeks) intervals, thus give a good presentation of the crop development throughout the season by computing the canopy cover. Results of a maize field of PPC Lopes in Moatize is presented in Figure 20 for four flight dates during the season, as an example. For the three maize plots (*parcelas*) belonging to Lopes, the right plot displays less canopy cover throughout the season, whilst the other two plots indicate more vegetation. For all plots a peak occurs in January of the vegetation.

Figure 20. Canopy cover development over a maize field (PPC Lopes in Moatize) for four flight dates (example)

After determining the canopy cover for all fields, a curvilinear relationship is developed, presenting the crop development during the growing season.

Curvilinear graphs are shown for three APSAN-Vale farmers in Moatize Figures 21, 22 and 23. The graph shows that the peak of canopy cover occurs around 100 to 120 days after planting. The maximum canopy cover is 60%, 75% and 75%, respectively. These values are derived using the equation of the polynomial fit. The canopy cover results are used in combination with the AquaCrop simulations to determine the water productivity and crop yield befitting the farm field conditions.

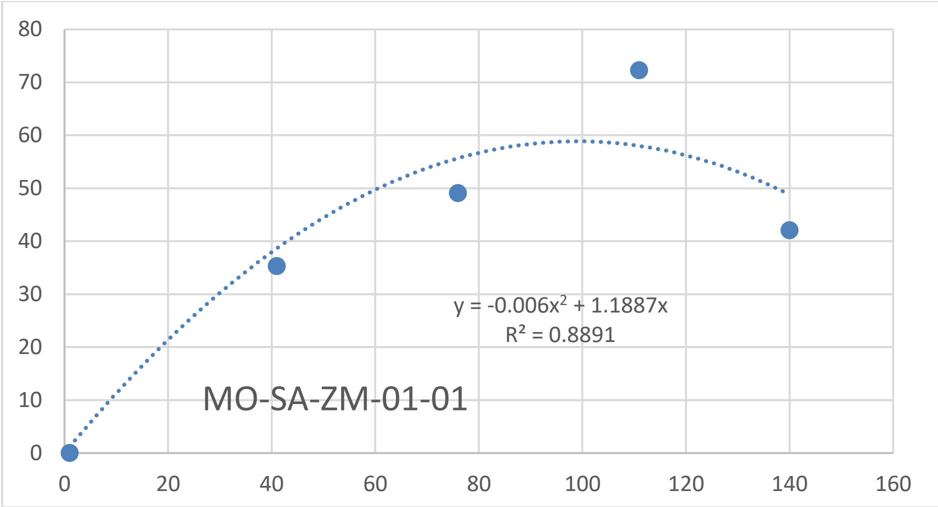

Figure 21. Canopy cover curvilinear of PPC Zeca Marcelino in Moatize using the canopy cover determined from five flying sensor flights (indicated with circles) and the planting date (indicated as first circle at day 0)

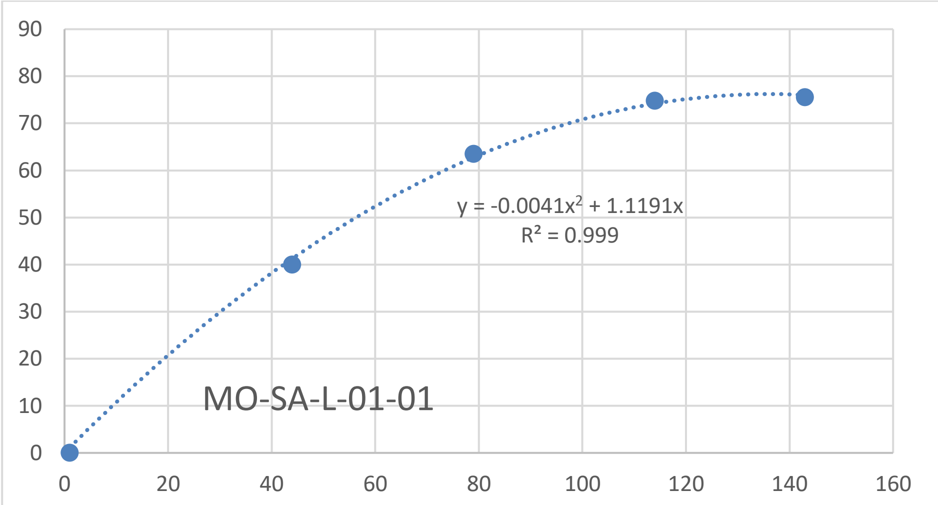

Figure 22. Canopy cover curve of PPC Loide Gonsalves in Moatize using data from five flights (indicated as circles) and the planting date (indicated as first circle at day 0)

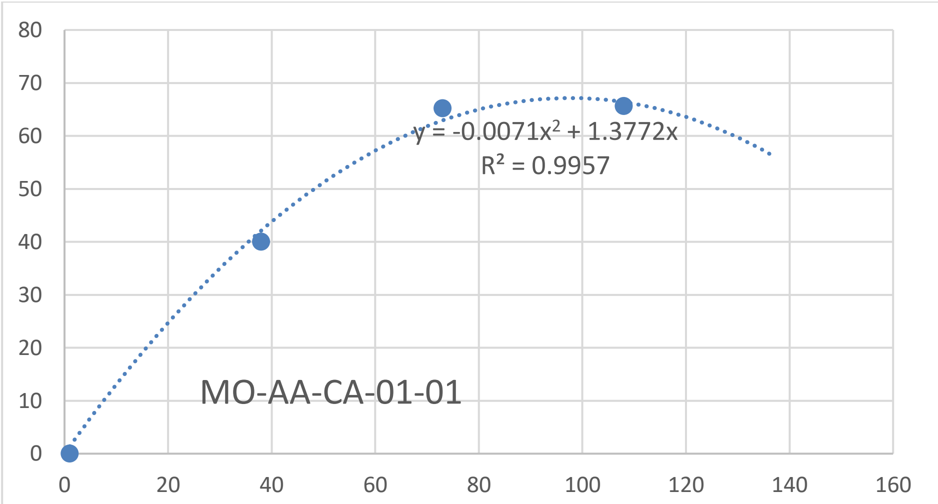

Figure 23. Canopy cover curve of PPC Alfredo Assis in Moatize using data from four flights (indicated as circles) and the planting date (indicated as first circle at day 0)

4.3 Water Productivity from AquaCrop

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 is combined with the AquaCrop simulations to determine the water productivity and crop yield results. For Nhamatanda, Moatize, and Báruè the results of the water productivity are presented in Tables 7, 8, and 9, respectively. In these tables the maize water productivity is presented. In addition, 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 maize water productivity as presented in FutureWater Report 195[18]. 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[19], 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 maize yield (cobs) as computed by AquaCrop.

In Table 7 the water productivity and crop yield results for Nhamatanda are presented. The water productivity ranges from 0.38 to 0.66 kg/m^3. The normalized water productivity due to the correction for relatively higher reference evapotranspiration this year in comparison with the long-term average. The baseline for maize water productivity in Nhamatanda is 0.33 kg/m^3, thus giving an increase of water productivity from 6% to 86%. An improvement in water productivity is expected, for these farmers implemented several good agricultural practices that enhance production and improve water management. The baseline assessment showed very limited practices being implemented. Thus, major improvements in water productivity is expected. In addition, higher reference evapotranspiration during this year, compared with the long-term average, gave a higher water productivity value. This could indicate that during a relatively dry (and hot) year farmers may be more efficient with their water use giving higher water productivity values. The crop yield presented in Table 7 ranges from 1.42 to 2.80 ton/ha. Note that the highest water productivity values do not necessary result in the highest crop yield.

Table 7. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile = 0.33 kg/m^3) for Nhamatanda farmers

PPC code	Name	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with Baseline	Dry crop yield [ton/ha]
AP_NH_AM_01_01	Armando	0.66	0.61	86%	2.80
AP_NH_LF_01_02	Lulu	0.38	0.35	6%	1.42
AP_NH_FB_01_01	Francisco	0.56	0.52	58%	2.03
AP_NH_FM_01_01	Flora	0.60	0.56	68%	2.60
AP_NH_JS_01_01	Jose	0.64	0.59	78%	2.63
AP_NH_LL_01_01	Lourenço	0.52	0.48	45%	2.03

Table 8 presents the results of water productivity for Moatize selected PPCs. The values range from 0.55 to 0.75 kg/m^3 and the increase compared to the baseline is 57% to 112%. The variation in water productivity values between farmers was less diverse in this group compared to Nhamatanda. This is likely due to similar practices being implemented. The crop yield results from AquaCrop range from 2.19 ton/ha to 3.43 ton/ha.

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

[19] 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.

Table 8. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile = 0.37 kg/m³) for Moatize farmers

PPC code	Name	Water Productivity [kg/m³]	Normalized Water Productivity [kg/m³]	% change with Baseline	Dry crop yield [ton/ha]
MO-ZO-AL-01-01	Alberto	0.75	0.78	112%	3.43
MO-ZO-AC-01-01	Anderson	0.68	0.72	94%	3.05
MO-SA-ZM-01-01	Zeca	0.67	0.70	89%	2.85
MO-SA-MC-01-01	Manuel	0.64	0.67	81%	2.76
MO-SA-L-01-01	Loide	0.68	0.71	92%	2.82
MO-SA-L-01-02	Loide	0.64	0.67	82%	2.56
MO-SA-L-01-03	Loide	0.64	0.67	81%	2.73
MO-MA-AC-01-01	Antonio	0.56	0.58	57%	2.36
MO-MA-JC-01-01	Joao	0.60	0.62	69%	2.28
MO-MA-JC-01-02	Joao	0.57	0.60	62%	2.19
MO-MA-JC-01-03	Joao	0.64	0.68	83%	2.20
MO-MA-JC-01-04	Joao	0.57	0.60	62%	2.19
MO-MA-JC-01-05	Joao	0.57	0.59	61%	2.37
MO-MA-JC-01-06	Joao	0.55	0.57	55%	2.22
MO-MA-RC-01-01	Rui	0.67	0.70	89%	2.87
MO-CA-EP-01-01	Eugidio	0.60	0.63	71%	2.48
MO-AA-CA-01-01	Alfredo	0.67	0.70	90%	2.76

Table 9 presents the water productivity results of the selected PPCs in Báruè. The water productivity values range from 0.71 to 0.94 kg/m³. In the baseline assessment the water productivity for Báruè was the highest being 0.41 kg/m³. This is mainly due to the favorable weather conditions being close to the mountain range, thus having regular rainfall events. The same occurred during this season, with precipitation being above the long-term average, and the reference evapotranspiration being lower than the average. After normalization, the comparison with the baseline gave a change of 39% to 84%. The crop yield ranged from 1.96 to 3.03 ton/ha, thus displaying the lowest yields of the three districts. Despite the regular rain events, likely the cooler conditions could result to lower production, limiting the photosynthesis process for biomass production. Additionally, management practices, and local biophysical conditions such as the soil type influences the crop yield.

Table 9. Results of AquaCrop water productivity and dry crop yield, and percent change of water productivity compared to baseline (75th percentile = 0.41 kg/m³) for Báruè farmers

PPC code	Name	Water Productivity [kg/m³]	Normalized Water Productivity [kg/m³]	% change with Baseline	Dry crop yield [ton/ha]
AP_BA_ARM-01-01	Antonio	0.92	0.73	79%	2.88
AP_BA_DDC-01-01	Dalton	0.93	0.74	81%	2.96
AP_BA_FLM-01-01	Frances	0.80	0.64	56%	2.32
AP_BA_LSM-01-01	Lopis	0.91	0.73	78%	3.03
AP_BA_OJ-01-01	Orlando	0.89	0.71	74%	2.56
AP_BA_RET-01-01	Richard	0.78	0.63	52%	2.57
AP_BA_JLC-01-01	Joao	0.71	0.57	39%	1.96
AP_BA_VT-01-01	Vitoria	0.85	0.68	66%	2.43
AP_BA_ACI-01-01	Ananias	0.94	0.75	83%	2.16
AP_BA_ML-01-01	Manuel	0.78	0.62	51%	2.26
AP_BA_JDR-01-01	Joelmo	0.94	0.75	84%	2.94

4.4 Field water productivity maps

The water productivity results from AquaCrop and the Flying Sensor imagery are presented in field maps of water productivity in Figures 24, 25, and 26, for Nhamatanda, Báruè, and Moatize, respectively. For each PPC, the water productivity values are presented including the change with the baseline and the area in ha. The water productivity values range from medium (yellow) to high (light to dark green). The majority of the farmers monitored during this season displayed medium high, to very high improvements of water productivity compared to the baseline.

Figure 24. Field water productivity maps of Nhamatanda farmers including maize water productivity, percent increase compared to the baseline (75th percentile)

Figure 25. Field water productivity maps of Báruè farmers including maize water productivity, percent increase compared to the baseline (75th percentile)

Figure 26. Field water productivity maps of Moatize farmers including maize water productivity, and percent increase compared to the baseline (75th percentile)

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. area 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 rainfed season 2020-2021: December 2020 to April 2021. 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 10 for each location.

The highest water productivity values are consistently found in Báruè, due to the favourable climate in this region. Here the highest values are observed in Catandica II. The lowest values for water productivity are found in Nhamatanda. In Moatize the highest water productivity is found in Moatize III.

Table 10. 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	Catandica I	480	8.9	1.85
	Catandica II	470	8.8	1.87
	Catandica III	503	8.8	1.76
	Average	**484**	**8.8**	**1.82**
Moatize	Moatize I	521	5.0	0.96
	Moatize II	478	5.5	1.14
	Moatize III	505	7.0	1.38
	Moatize IV	NA	NA	NA
	Average	**501**	**5.8**	**1.16**
Nhamatanda	Nhamatanda I	547	6.1	1.11
	Nhamatanda II	579	6.2	1.08
	Average	**563**	**6.1**	**1.09**

6 Basin scale Water Productivity results

The (sub-)basins were delineated for each district as shown in Figure 6. These delineations were used with the WaPOR data portal to determine the biomass water productivity for each location. Table 11 provides an overview of the statistics found for water productivity, evapotranspiration, and biomass production for each basin and masking out only the cropland pixels. The water productivity was highest for Báruè, followed by Moatize, and lastly Nhamatanda. Báruè displays the highest biomass production of the area.

Table 11. Overview of statistics of water productivity, evapotranspiration, and biomass production for the basins of selected project districts

		Báruè	Moatize	Nhamatanda
Actual evapotrans-piration [mm]	Average mean	576	507	601
	10th percentile	488	414	524
	90th percentile	656	606	699
Biomass production [ton/ha]	Average mean	10.3	7.9	7.5
	10th percentile	8.3	6.5	6.2
	90th percentile	12.4	9.4	9.2
Water productivity [kg/m^3]	Average mean	1.78	1.57	1.24
	10th percentile	1.64	1.39	1.16
	90th percentile	1.94	1.75	1.41

Figure 27 displays the water productivity maps of each basin. In Báruè, the water productivity shows even distribution. In Moatize the upstream area 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. The number of cropland pixels in Nhamatanda are limited, therefore less spatial variation can be observed.

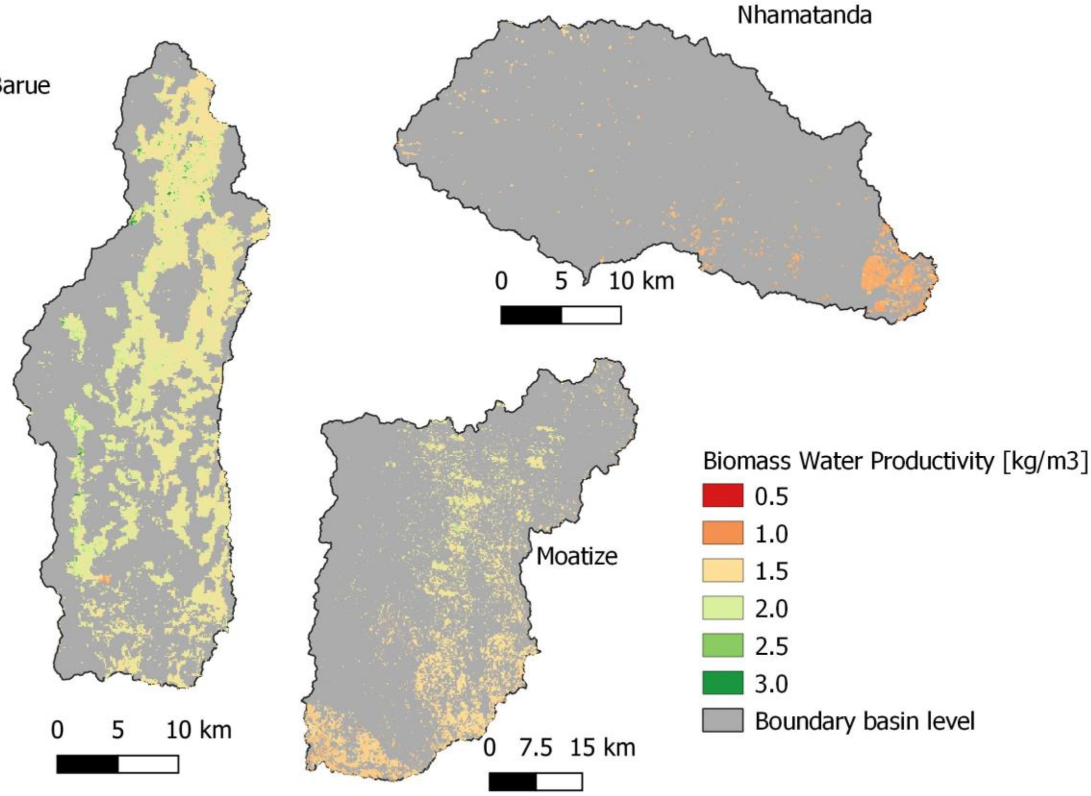

Figure 27. Seasonal biomass water productivity for cropland pixels in Moatize, Báruè and Nhamatanda at basin scale using WaPOR data portal

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 rainfed season the project worked with several PPCs to improve the water productivity of their farm and subsequently also various PPE's (smallholder farmers) and surrounding communities.

Assessment of the water productivity is performed at two 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 PPE's and communities adopting the interventions. This level is considered the increase of the overall water productivity of the region or basin scale. During this season the activities were focused on a selection of PPCs and a number of communities.

The following sections elaborates on the change in water productivity of the PPC in comparison with the baseline report; and the change in overall water productivity using the WaPOR database to assess for a larger area. Both assessments make use of normalizing the water productivity for the seasonal weather conditions as explained in section 2.6 of this document. 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 basin.

7.1 Water productivity assessment at field level

Chapter 4 of this report presents the results of the field scale water productivity values. An overview of this analysis is provided in Table 12 indicating for each district the baseline values, and the range of water productivity values during this season (2020-2021 season) using the results from the selected PPCs as presented in Chapter 4. The values represent the normalized maize 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 in above average 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 68%. The highest increase was observed in Moatize and lowest in Báruè. 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 document.

Table 12. Normalized maize water productivity (in kg/m^3) for rainfed season 2020 – 2021 compared to the baseline

	Báruè	Moatize	Nhamatanda	Average
Baseline				
Range	0.25 – 0.44	0.23 – 0.41	0.21 – 0.37	
75th Percentile	0.41	0.37	0.33	
Rainfed season 2020-2021				
Range	0.57 – 0.75	0.57 – 0.78	0.35 – 0.61	
Average (mean)	0.69	0.66	0.52	
Relative change (%)	+68%	+78%	+57%	+68%

[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.

7.2 Water productivity assessment at 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 rainfed season. Table 13 presents the values of biomass water productivity after normalizing for the 2020-2021 weather conditions and comparing with the baseline values. An average increase of biomass water productivity of 16% was perceived, ranging from -5% to +39%. 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 and will reflect in the upcoming 'Interventions impact' reports.

Table 13. Biomass water productivity (kg/m^3) for rainfed season 2020-2021 at basin scale compared to the baseline

	Báruè	Moatize	Nhamatanda	Average
Rainfed season 2020-2021	1.78	1.57	1.24	
Rainfed season 2020-2021 (Normalized)	2.23	1.49	1.34	
Baseline	1.61	1.57	1.18	
Relative change (%)	+39%	-5%	+14%	+16%

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 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.

The field scale water productivity presented results for 27 farmers which were monitored throughout the rainfed season as part of the APSAN-Vale project. Maize water productivity was found to range from 0.38 to 0.66 kg/m^3 in Nhamatanda, 0.55 to 0.75 kg/m^3 in Moatize, and 0.71 to 0.94 kg/m^3 in Báruè. After normalization for climatic conditions, the increase in water productivity was found to be +68% in Báruè, +78% in Moatize, and +57% in Nhamatanda, resulting in an average 62% increase in comparison with the baseline values.

The results of field water productivity of 27 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 30ha around each selected PPC is determined to be representative for the area of the sub-basin. This can be adjusted in following seasons, guided by more field information on the spread of adoption of practices. 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 Catandica II. In Moatize the highest water productivity is found in Moatize III. The lowest values for water productivity are found in Nhamatanda. The biomass water productivity was found to range from 1.76 to 1.87 kg/m^3 in Báruè, 0.96 to 1.38 kg/m^3 in Moatize, and 1.08 to 1.11 kg/m^3 in Nhamatanda.

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 +39%, -5, and +14% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +16% 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

						Soil		Crop					Field mgt				Irrigation
Year	Irrigation / rainfed	Region	ID plot	Lat	Lon	Soil texture (sandyloam, etc)	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Growing length	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)
2020-2021	Rainfed	Moatize	MO-ZO-AL-01-01	-15.600	34.441	sandy loam	low	Maize	Milho	30/Nov	141	3.7	Optimal	no	High	no	no
2020-2021	Rainfed	Moatize	MO-ZO-AC-01-01	-15.703	34.348	sandy loam	low	Maize	Milho	01/Dec	135	3.7	Moderate	no	Moderate	no	no
2020-2021	Rainfed	Moatize	MO-SA-ZM-01-01	-15.703	34.349	sandy loam	low	Maize	Milho	04/Dec	132	2.8	Moderate	no	Moderate	no	no
2020-2021	Rainfed	Moatize	MO-SA-MC-01-01	-15.775	34.111	sandy loam	low	Maize	Milho	03/Dec	133	2.8	Moderate	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-SA-L-01-01	-15.771	34.110	sandy loam	low	Maize	Milho	01/Dec	135	2.8	Moderate	yes	Low	no	no
2020-2021	Rainfed	Moatize	MO-SA-L-01-02	-15.771	34.110	sandy loam	low	Maize	Milho	10/Dec	126	2.8	Moderate	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-SA-L-01-03	-15.771	34.110	sandy loam	low	Maize	Milho	04/Dec	132	2.8	Moderate	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-AC-01-01	-15.874	34.078	sandy loam	Moderate	Maize	Milho	27/Nov	125	2.8	Low	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-01	-15.877	34.032	sandy loam	Moderate	Maize	Milho	15/Nov	120	2.8	Low	no	Moderate	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-02	-15.877	34.032	sandy loam	Moderate	Maize	Milho	15/Nov	120	2.8	Low	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-03	-15.877	34.032	sandy loam	Moderate	Maize	Milho	31/Dec	120	2.8	Low	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-04	-15.877	34.032	sandy loam	Moderate	Maize	Milho	15/Nov	120	2.8	Low	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-05	-15.877	34.032	sandy loam	Moderate	Maize	Milho	29/Nov	123	2.8	Low	no	Moderate	no	no
2020-2021	Rainfed	Moatize	MO-MA-JC-01-06	-15.877	34.032	sandy loam	Moderate	Maize	Milho	01/Dec	121	2.8	Low	no	Low	no	no
2020-2021	Rainfed	Moatize	MO-MA-RC-01-01	-15.939	34.059	sandy loam	low	Maize	Milho	03/Dec	133	2.8	moderate	no	moderate	no	no
2020-2021	Rainfed	Moatize	MO-CA-EP-01-01	-16.058	33.978	sandy loam	Moderate	Maize	Milho	06/Dec	130	2.8	low	no	low	no	no
2020-2021	Rainfed	Moatize	MO-AA-CA-01-01	-16.074	33.955	sandy loam	Moderate	Maize	Milho	07/Dec	129	2.8	moderate	no	moderate	no	no

						Soil		Crop					Field mgt				Irrigation
Year	Irrigation / rainfed	Region	ID plot	Lat	Lon	Soil texture (sandyloam, etc)	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Growing length [days]	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)
2020-2021	Rainfed	Nhamatanda	AP_NH_AM_01_01	-19.341	34.370	sandy clay	low	Maize	Milho	01/Nov	139	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Nhamatanda	AP_NH_LF_01_02	-19.344	34.332	sandy clay	low	Maize	Milho	20/Nov	110	2.5	Optimal	no	Low	no	no
2020-2021	Rainfed	Nhamatanda	AP_NH_FB_01_01	-19.343	34.207	sandy clay	low	Maize	Milho	01/Nov	120	2.5	Optimal	no	Low	no	no
2020-2021	Rainfed	Nhamatanda	AP_NH_FM_01_01	-19.350	34.346	sandy clay	low	Maize	Milho	24/Nov	126	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Nhamatanda	AP_NH_JS_01_01	-19.341	34.202	sandy clay	moderate	Maize	Milho	24/Nov	128	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Nhamatanda	AP_NH_LL_01_01	-19.337	34.357	sandy clay	low	Maize	Milho	20/Dec	116	2.5	Optimal	no	high	no	no

						Soil		Crop					Field mgt				Irrigation
Year	Irrigation / rainfed	Region	ID plot	Lat	Lon	Soil texture	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Growing length [days]	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)
2020-2021	Rainfed	Barue	AP_BA_ARM-01-01	-17.860	33.203	sandy clay	low	Maize	Milho	03/Dec	143	2.5	Low	no	Low	no	no
2020-2021	Rainfed	Barue	AP_BA_DDC-01-01	-18.005	33.207	sandy clay	low	Maize	Milho	28/Nov	140	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_FLM-01-01	-17.837	33.139	sandy clay	low	Maize	Milho	02/Dec	127	2.5	Optimal	no	High	no	no
2020-2021	Rainfed	Barue	AP_BA_FLM-01-02	-17.837	33.139	sandy clay	low	Soya bean	Soja	08/Dec	114	13.3	Low	no	Low	no	no
2020-2021	Rainfed	Barue	AP_BA_LSM-01-01	-18.123	33.189	sandy clay	low	Maize	Milho	24/Nov	142	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_LSM-01-02	-18.123	33.189	sandy clay	low	Beans		20/Jan	85	13.3	Optimal	no	Moderate		
2020-2021	Rainfed	Barue	AP_BA_OJ-01-01	-17.930	33.254	sandy clay	moderate	Maize	Milho	07/Dec	129	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_OJ-01-02	-17.930	33.254	sandy clay	moderate	Soya bean	Soja	01/Dec	66	13.3	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_RET-01-01	-18.158	33.187	sandy clay	low	Maize	Milho	22/Nov	139	2.5	Low	no	Low	no	no
2020-2021	Rainfed	Barue	AP_BA_JLC-01-01	-17.856	33.219	sandy clay	low	Maize	Milho	09/Dec	122	2.5	optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_JLC-01-02	-17.856	33.219	sandy clay	low	Soya bean	Soja	01/Jan	90	13.3	Low	no	Low	no	no
2020-2021	Rainfed	Barue	AP_BA_VT-01-01	-17.366	33.203	sandy clay	low	Maize	Milho	12/Dec	129	2.5	optimal	no	Low	no	no
2020-2021	Rainfed	Barue	AP_BA_ACI-01-01	-18.017	33.241	sandy clay	low	Maize	Milho	05/Jan	143	2.5	Optimal	no	Moderate	no	no
2020-2021	Rainfed	Barue	AP_BA_ML-01-01	-18.461	33.212	sandy clay	low	Maize	Milho	02/Dec	129	2.5	low	no	high	no	no
2020-2021	Rainfed	Barue	AP_BA_JDR-01-01	-18.012	33.299	sandy clay	low	Maize	Milho	04/Dec	142	2.5	moderate	no	moderate	no	no