Water Productivity Analysis: Irrigation Season 2020

APSAN-Vale project

REPORT 218

CLIENT Agência de Desenvolvimento do Vale Zambeze (ADVZ)

AUTHORS Jonna van Opstal
Martijn de Klerk
Alexander Kaune
Corjan Nolet
Jack Beard

DATE January 2021

Water Productivity Analysis: Irrigation Season 2020

APSAN-Vale project

FutureWater Report 218

Client
Agência de Desenvolvimento do Vale Zambeze (ADVZ)

Authors
Jonna van Opstal – Senior Water Productivity Expert (j.vanopstal@futurewater.nl)
Martijn de Klerk – Flying Sensor Expert, Project Manager (m.deklerk@futurewater.nl)
Alexander Kaune – Agro-hydrologist (a.kaune@futurewater.nl)
Corjan Nolet – Remote Sensing and GIS Expert (c.nolet@futurewater.nl)
Jack Beard – Consultant (j.beard@futurewater.nl)

APSAN-Vale project partners
Resilience B.V.
HUB

Date
January 2021

Addendum added on
June 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) in combination with a water productivity simulation model and field observations, and FAO's water productivity data portal WaPOR.

This report shows the water productivity analysis for the irrigation season 2020 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). Water productivity can indicate if the implemented 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 2020 (April to October) 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.

During the irrigation growing season a total of 170 flights were performed monitoring the fields of 42 PPC's (small commercial farmers), covering a total of 840 ha. The number of farmers monitored in this report for the field scale water productivity analysis are 32 in total, with fifteen in Báruè, nine in Moatize, and eight in Nhamatanda. For a total of 67 fields a crop specific water productivity is calculated for the major crop types: tomato, cabbage, potato, onion, beans, and maize. The results of the flying sensor imagery acquired throughout the season are presented in printed field maps and also shared through our online portal (https://www.futurewater.eu/apsanvaleportal/), which enables field technicians, farmers and other stakeholders to access the maps in the field. Canopy cover and water productivity maps created for this report will also be accessible in this online data portal.

The field scale tomato water productivity was found to range from 0.83 to 1.61 kg/m^3 in Nhamatanda, 1.80 to 2.37 kg/m^3 in Moatize, and 0.77 to 1.24 kg/m^3 in Báruè. After normalization for climatic conditions, the increase in water productivity was found to be -7% in Báruè, 19% in Moatize, and 15% in Nhamatanda, resulting in an average 9% increase in comparison to the baseline values. Báruè was noted to be lower due to the sensitivity of waterlogging in clay soils, which were simulated in AquaCrop but are assumed to not have the same effect in reality. The field scale cabbage water productivity indicated an increase of 23%, 31%, and 30% for Báruè, Moatize, and Nhamatanda, respectively. The overall increase in cabbage water productivity was 28%. The field scale water productivity increase calculated for all crops (tomato, cabbage, potato and onion) gave an average of 25% for Báruè, 23% for Moatize, and 61% for Nhamatanda. Overall, the field scale water productivity increased with 33% compared to the baseline.

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 biomass water productivity was compared with baseline values, and indicated an increase ranging from 11% in Báruè to 15% in Nhamatanda, and 44% in Moatize. At basin scale the water productivity was determined using the WaPOR data portal providing values on biomass water productivity, for which the catchment delineation from each district was used as the boundary of the basin. These values are compared with the baseline assessment and determined that an increase of water productivity was achieved of 5%, 50%, and 20% for Báruè, Moatize, and Nhamatanda, respectively. The average increase in biomass water productivity was 25% for all districts together.

Both the field scale water productivity analysis and the basin scale analysis indicate an improvement of water productivity and achieve the set target for 2020 of 15% as stated in the project logframe.

Content

List of Tables

List of Figures

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.

---

[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.

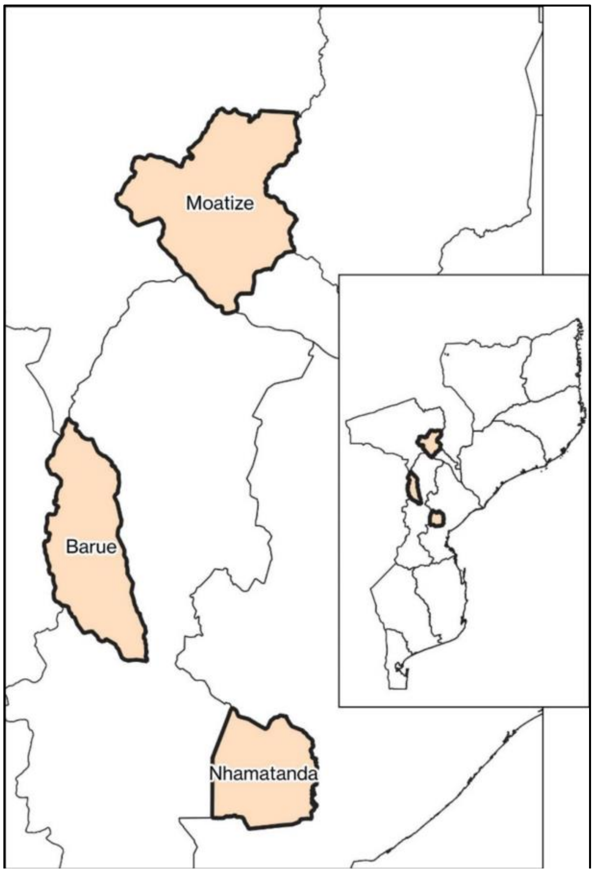

Figure 1 Location districts of APSAN-Vale project activities

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 irrigation season commenced in April 2020 with the planting of the most crops occurring in May. The major crop types that are planted in the irrigation season are tomato, cabbage (Portuguese *repolho* and *couve*), potato, and onions. Some fields also had maize and beans, which are more typically rainfed season crops. The season continues till end of September with the harvest occurring between July and September depending on the time of planting. The rainfall during this season is minimal depending on the location therefore (supplemental) irrigation is required. 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 32 farmers was used.

Table 2 Overview of number of flights made and farmers monitored during the 2020 irrigation season

	Báruè	Moatize	Nhamatanda	Total
Flights taken	66	59	45	170
Farmers monitored	15	13	14	42
Farmers monitored for WP	15	9	8	32
Area covered	300 ha	260 ha	280 ha	840 ha

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, PPC's)

For each district several small commercial farmers (PPC's) were selected for the project to implement numerous innovative practices (boas practicas) for boosting water productivity. Most of the selected PPC's were monitored with flying sensor flights. In Báruè, Moatize, and Nhamatanda, fifteen, thirteen, and fourteen PPC's respectively were monitored with the flying sensors. Figure 2 indicates the locations of the PPC's monitored during the irrigation growing season.

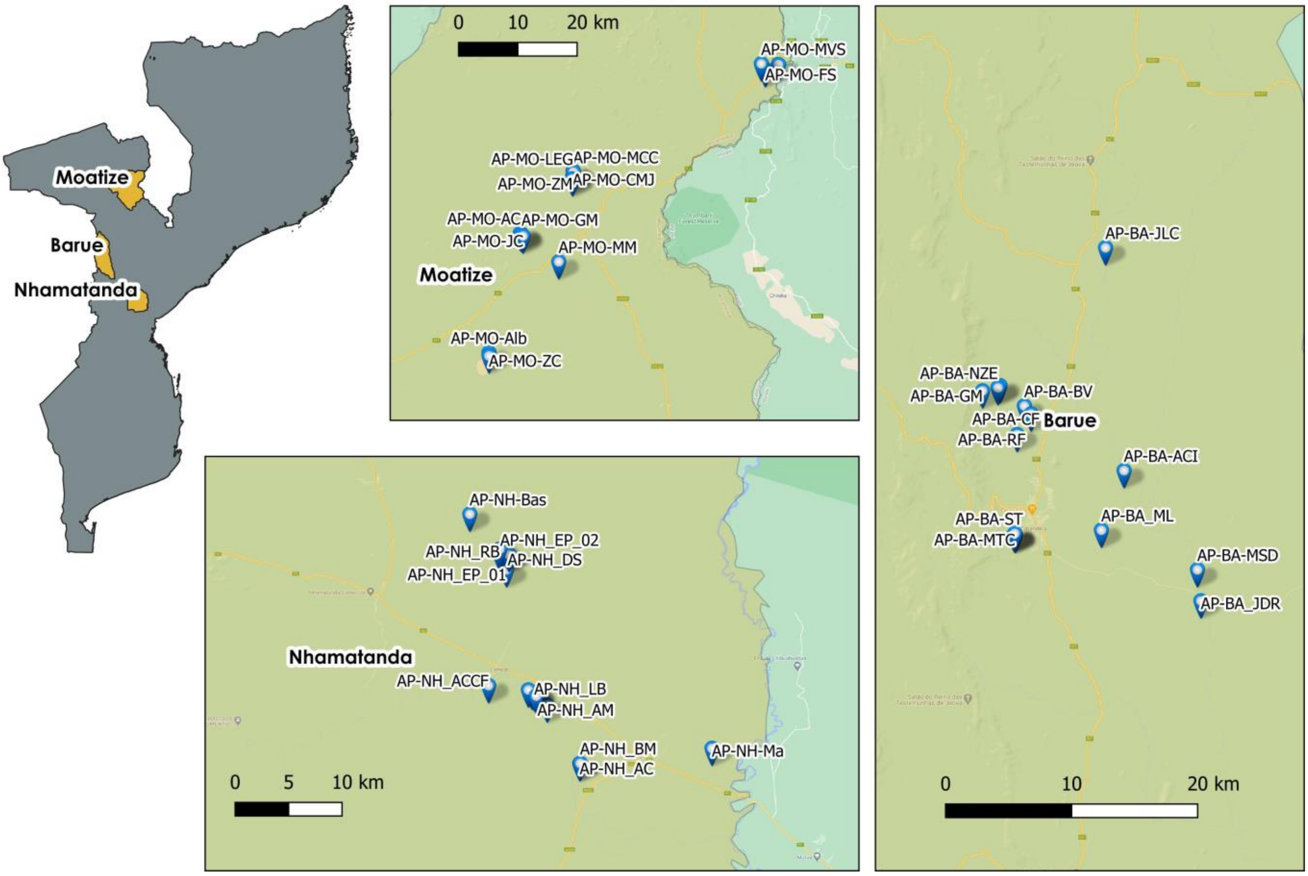

Figure 2 Location of selected PPC's monitored with flying sensor flights during the irrigation season 2020

2.1.2 Sub-basins / local communities

The sub-basin scale is a level between the field scale of the PPC's 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 PPC's. 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 PPC's of 30 ha. The locations of these communities are presented in figures 3, 4, and, 5 for Moatize, Nhamatanda, and Báruè respectively. Each have selected 3 to 4 clusters surrounding the PPC's. For Báruè the PPC's were more widespread, therefore the selection is based on the streamlines with Catandica I and II being upstream communities, and Catandica III and IV being relatively downstream communities.

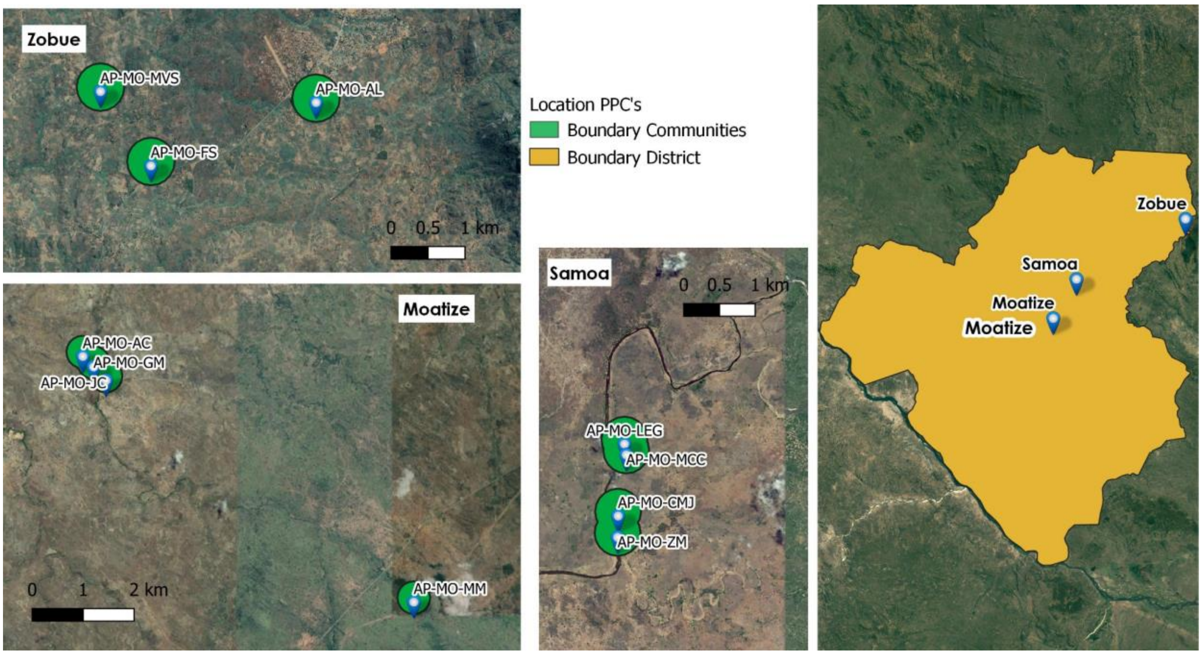

Figure 3 Location and boundaries of local communities (sub-basin level) in Moatize district

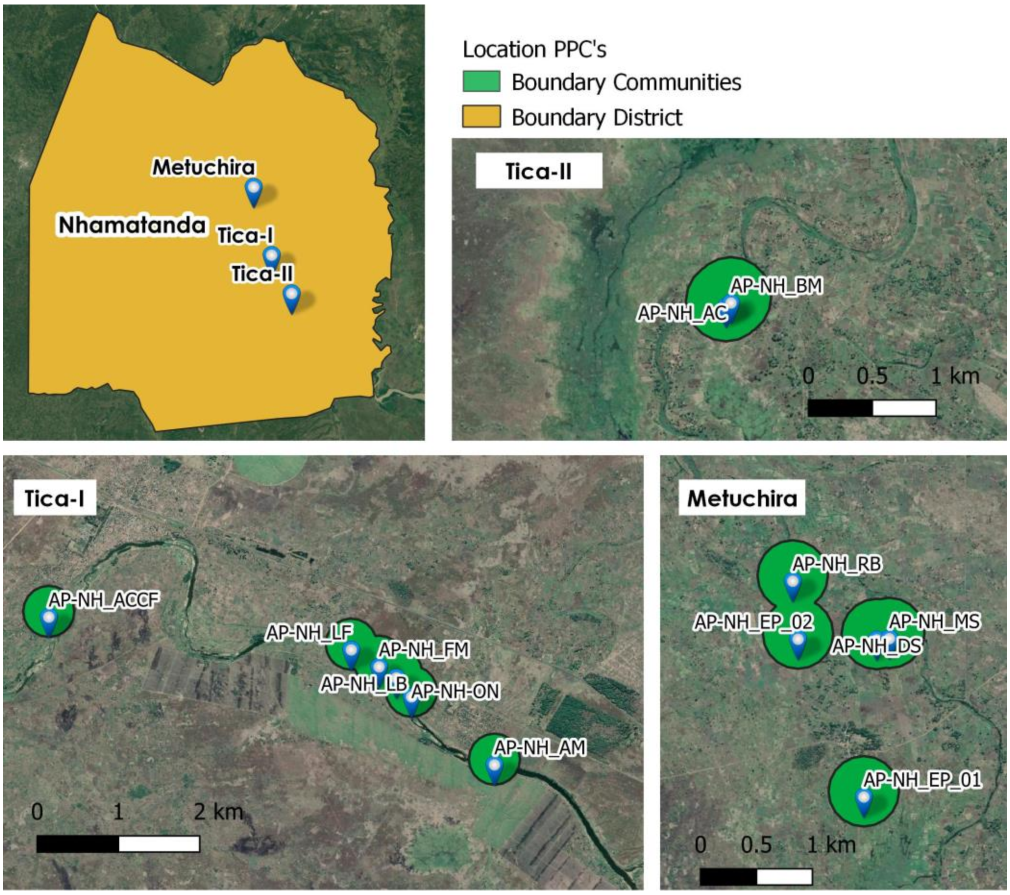

Figure 4 Location and boundaries of local communities (sub-basin level) in Nhamatanda district

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.

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 (explained in 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 (explained in 2.2.2).

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

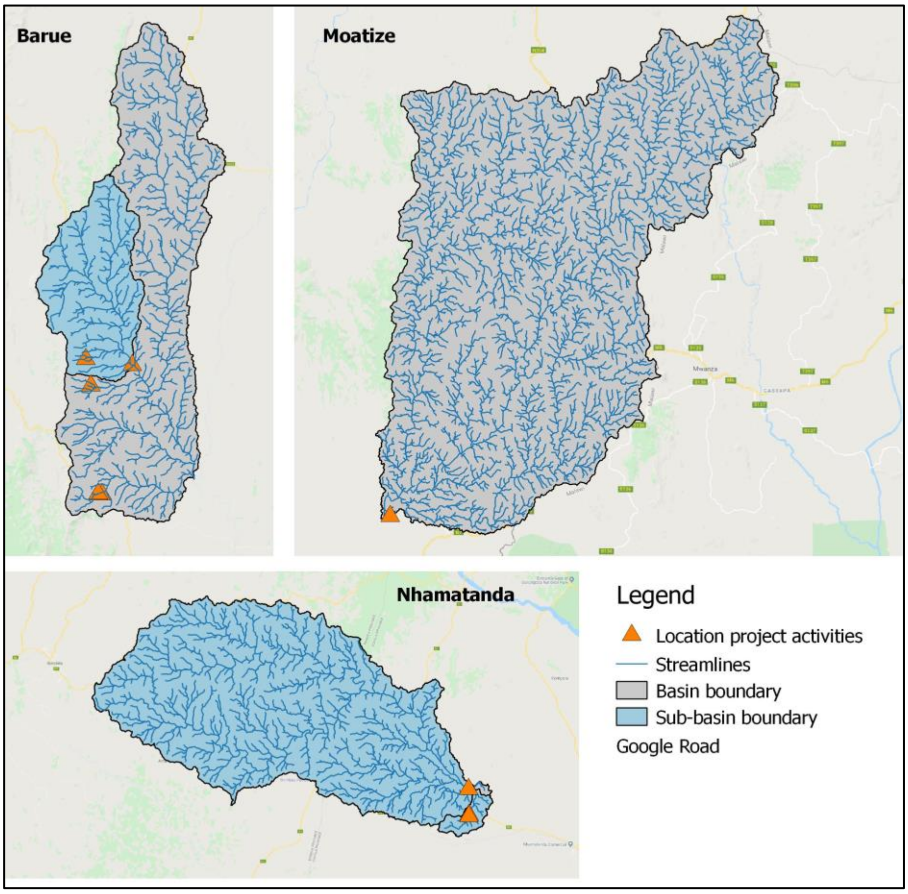

Figure 6 Delineation of basins and streamlines for the three districts

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).

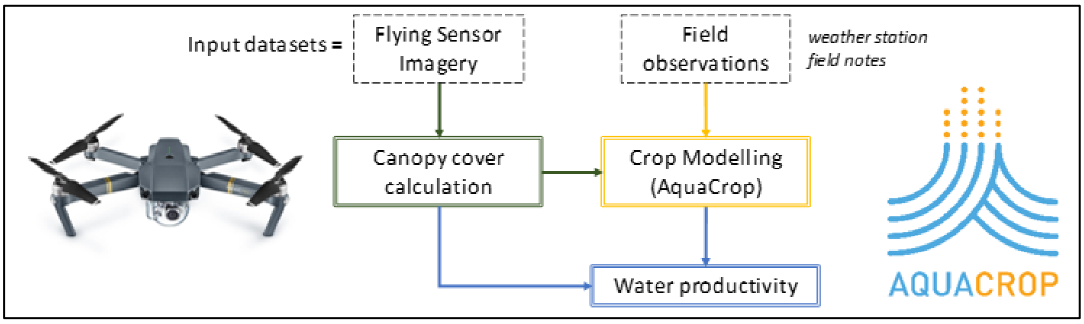

Figure 7 Workflow for calculation of crop specific water productivity analysis

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.

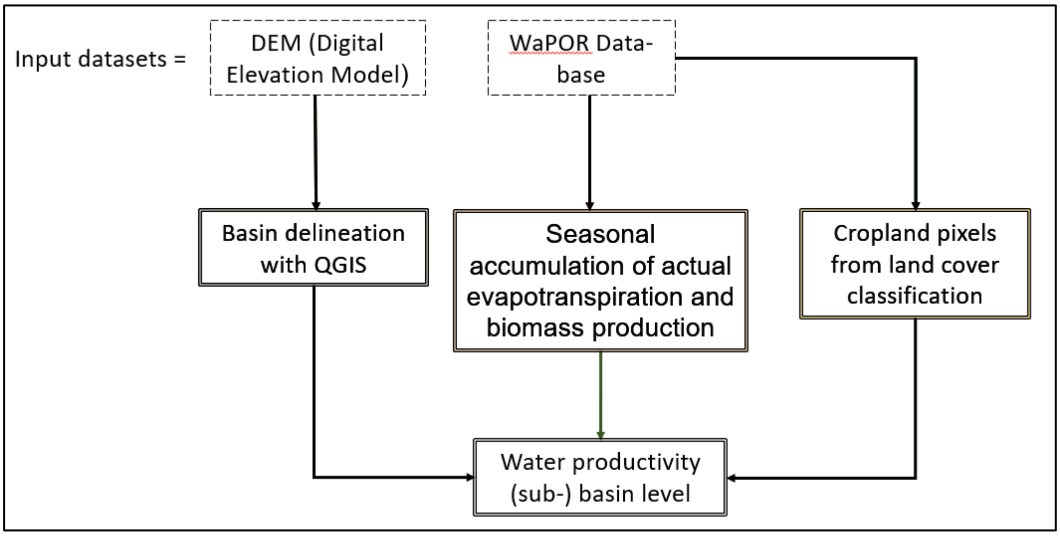

Figure 8. Workflow for biomass water productivity analysis

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.

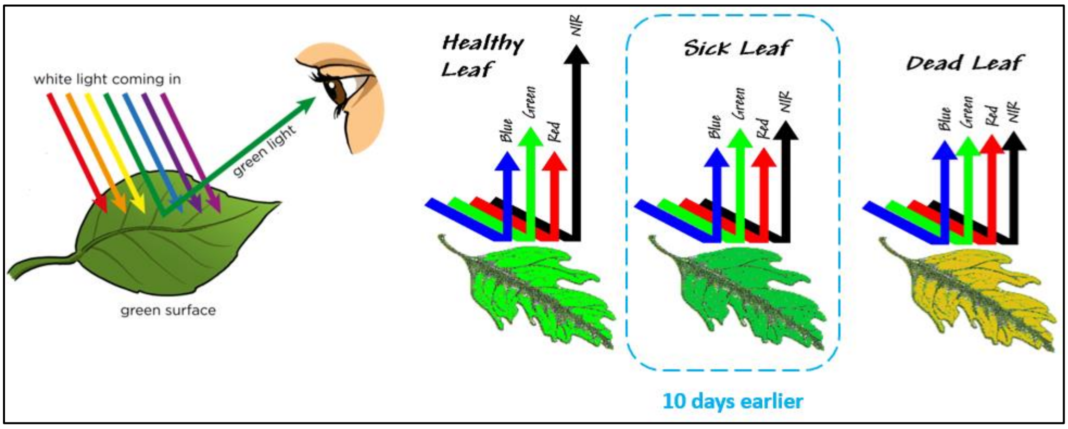

Figure 10 Illustration explaining the response of near infrared (NIR) wavelength to vegetation status

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 39, 32, and 41, respectively. The total area monitored with the flying sensors was 220 ha., 190 ha., and 240 ha. for Báruè, Nhamatanda, and Moatize respectively.

Table 3 Overview of flights and area during the 2020 irrigation season

	Báruè	Moatize	Nhamatanda
May	7 – 8 May 2020	12 – 14 May 2020	5 – 6 May 2020
June	4 – 5 June 2020	9 – 11 June 2020	1 – 3 June 2020
July	9 – 10 July 2020	14 – 15 July 2020	6 – 7 July 2020
August	6 – 8 August 2020	18 – 19 August 2020	3 – 4 August 2020
September	1 – 3 September 2020	15 – 16 September 2020	
October	6 – 8 October 2020		
Flights taken	66	59	45
Area covered	300 ha	260 ha	280 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 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.

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].

[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
[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.

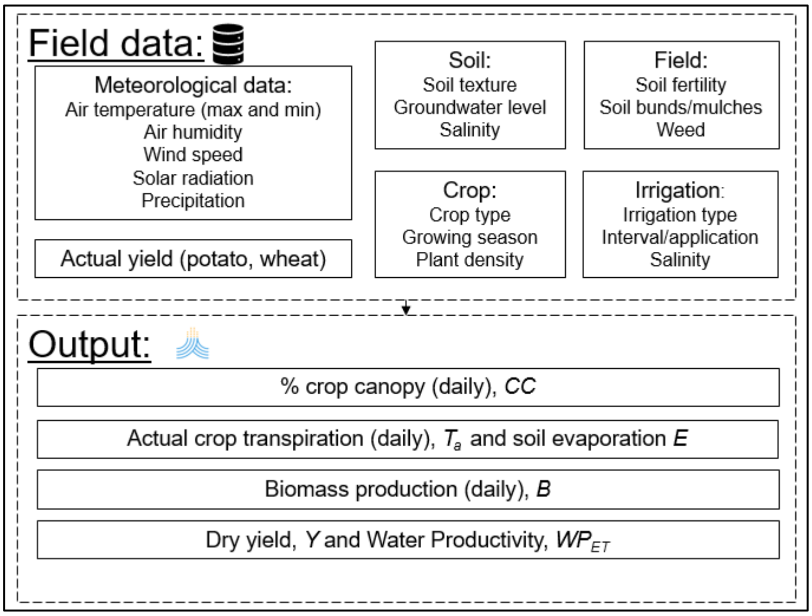

Figure 11. Field data and output simulations of the AquaCrop model.

Field data

The next step is to collect basic crop information from the selected districts (Báruè, Moatize and Nhamatanda). Basic information about planting dates, plant density, total growth length (length of the crop cycle), irrigation interval, 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 field book of the PPC's 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
MC*** [-]	0.26		0.33		0.82	0.80	0.82	0.85
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.

** Harvest Index

*** Moisture Content

Soil and field management information

According to collected field information the soil texture of each district 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 district are shown. 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 district

District	Soil texture
Báruè	Clay
Moatize	Sandy Loam
Nhamatanda	Sandy Clay

```
SandyLoam.SOL
1  deep uniform 'sandy loam' soil profile
2        6.0                 : AquaCrop Version (March 2017)
3       46                   : CN (Curve Number)
4        7                   : Readily evaporable water from top layer (mm)
5        1                   : number of soil horizons
6       -9                   : variable no longer applicable
7   Thickness  Sat   FC    WP     Ksat   Penetrability  Gravel  CRa       CRb          description
8   ---(m)-   ----(vol %)-----  (mm/day)      (%)        (%)    ---------------------------------------
9     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 irrigation 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, irrigation depth, and fertilizer stress. 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 irrigation season: May 2020 to September 2020.

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 irrigation 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

[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

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).

2.5.3 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.

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.

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

---

[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 irrigation season is shown in Figure 13. The TAHMO station in Moatize was not operational in the period April to end of August 2020, therefore the WaPOR reference evapotranspiration was used. The three districts display a similar pattern in the reference ET, with Moatize having a slightly higher ET than the other districts. The reference ET is lower at the start of the season, approximately 3 – 6 mm/day, and higher during the remainder of the season, with peaks occurring in September and October.

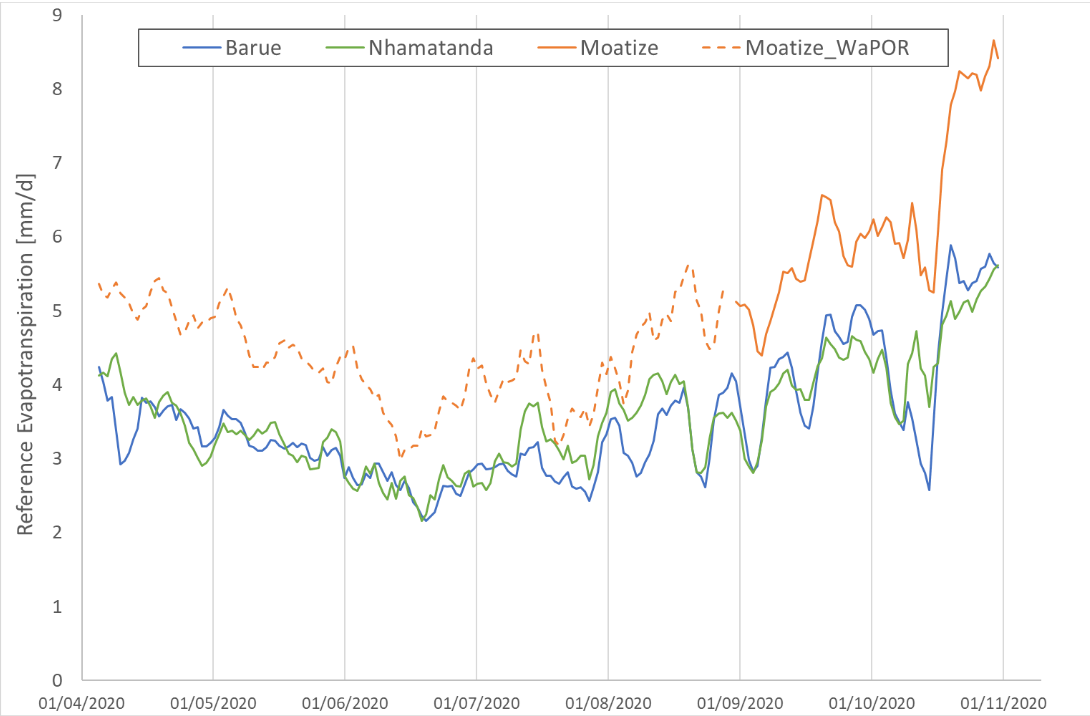

Figure 13 Five day average reference evapotranspiration for the three districts during the irrigation season 2020 from TAHMO stations and supplemental WaPOR data for Moatize

The weather conditions during the 2020 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 2020 monthly values and displayed in Figure 14.

Figure 14 shows that the reference ET for Báruè was similar or lower each month this season compared to the long term average. For Nhamatanda and Moatize the reference ET was higher each month, in particular for Moatize. 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 irrigation season. These values are used in the normalization of the water productivity results as presented in section 2.6 of this report.

[17] https://tahmo.org/

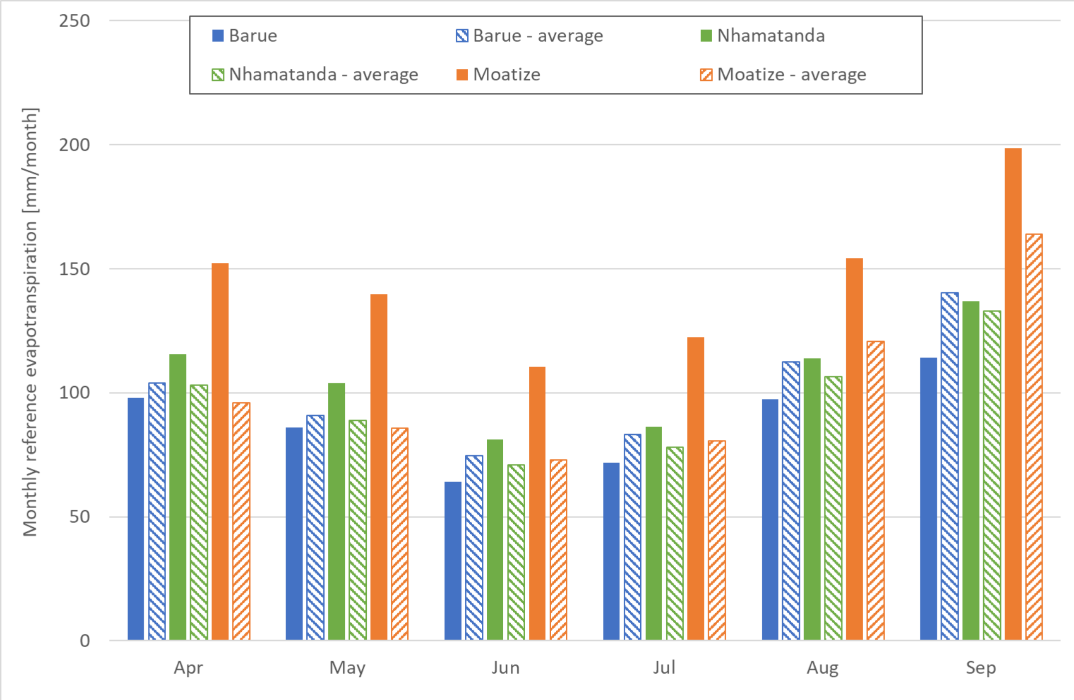

Figure 14 Comparison of 2020 monthly reference evapotranspiration with long-term average (2009-2018) with WaPOR data portal product

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

	Báruè	Moatize	Nhamatanda
Reference ET 2020 [mm]	531	878	638
Reference ET Average [mm]	605	619	580

3.2 Precipitation

The irrigation season is characterized by some rainfall events at the start of the season (April) followed by a long dry period with limited rainfall. 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 40 mm/day at the start of the season, for 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 April the rainfall was above average especially for Báruè. Note that Báruè is located in the vicinity of mountains, therefore the elevation difference can give more rainfall events. However, the satellite data also records coarser pixels (5km), therefore does not capture the variability of rainfall in the district. The rainfall noted for Báruè could have occurred mainly in the mountain area and not affect the agriculture areas in the lower elevation. The rest of the irrigation season the rainfall was low >20mm/month for all districts, indicating the significance of practicing (supplemental) irrigation. The total seasonal precipitation was higher for Báruè, compared to the long-term average, and lower for Nhamatanda and Moatize. This shows a similar trend as with the reference ET data as presented in Figure 14 and Table 6.

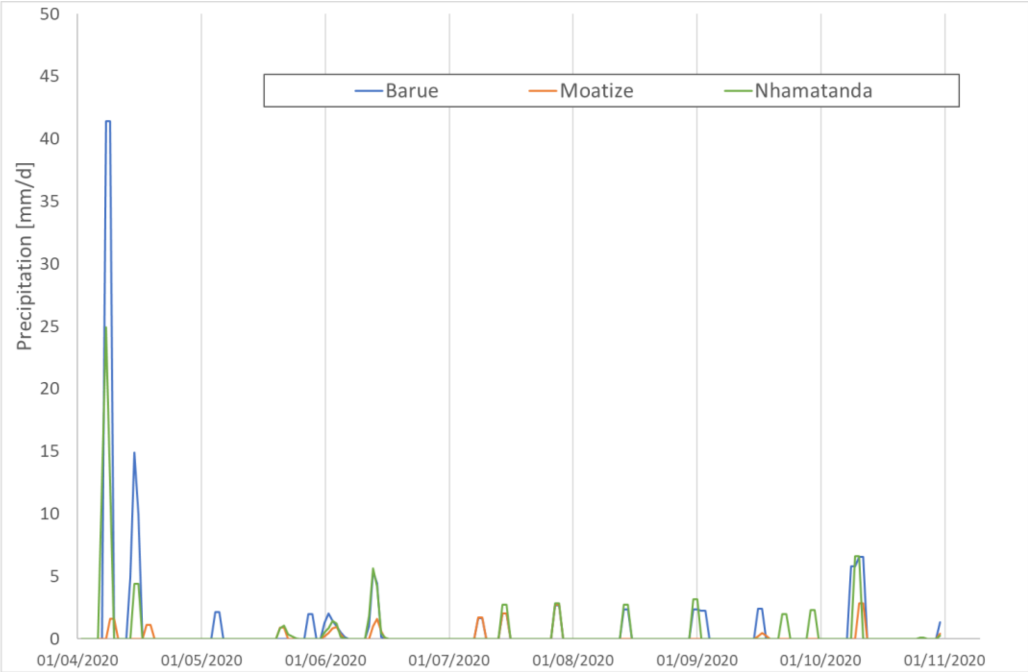

Figure 15 Daily precipitation during the 2020 irrigation season from CHIRPS satellite data product

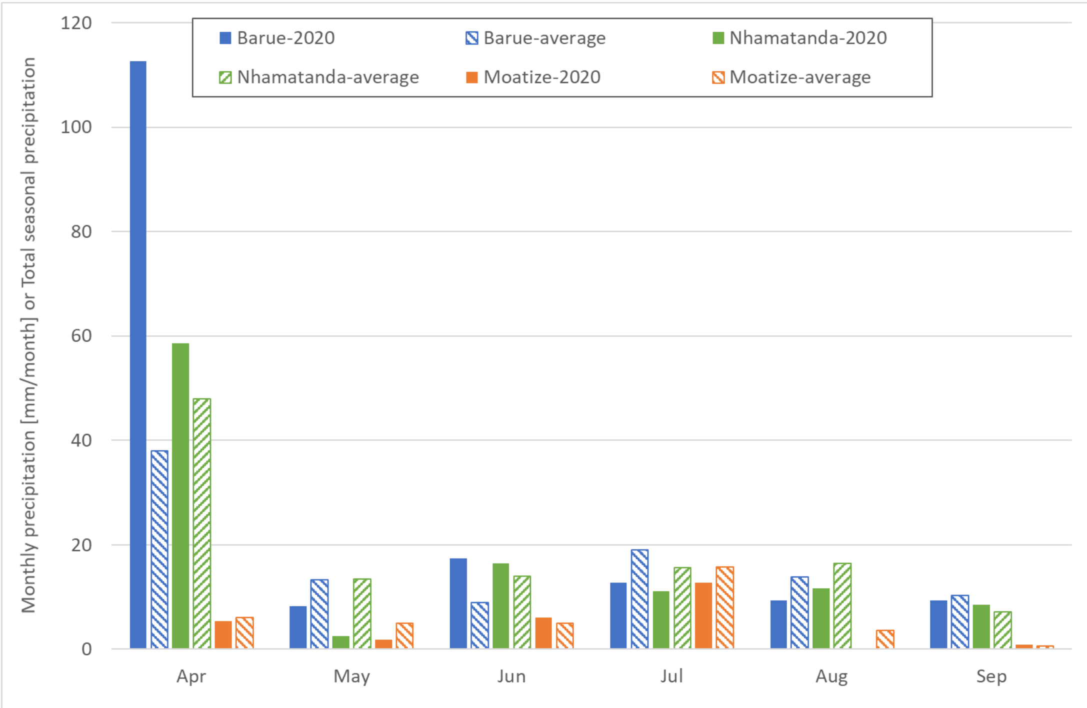

Figure 16 Comparison of 2020 monthly precipitation with long-term average (2001-2018) with CHIRPS

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 PPC's for monitoring. An example of one of these maps from the 2020 irrigation season is 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.

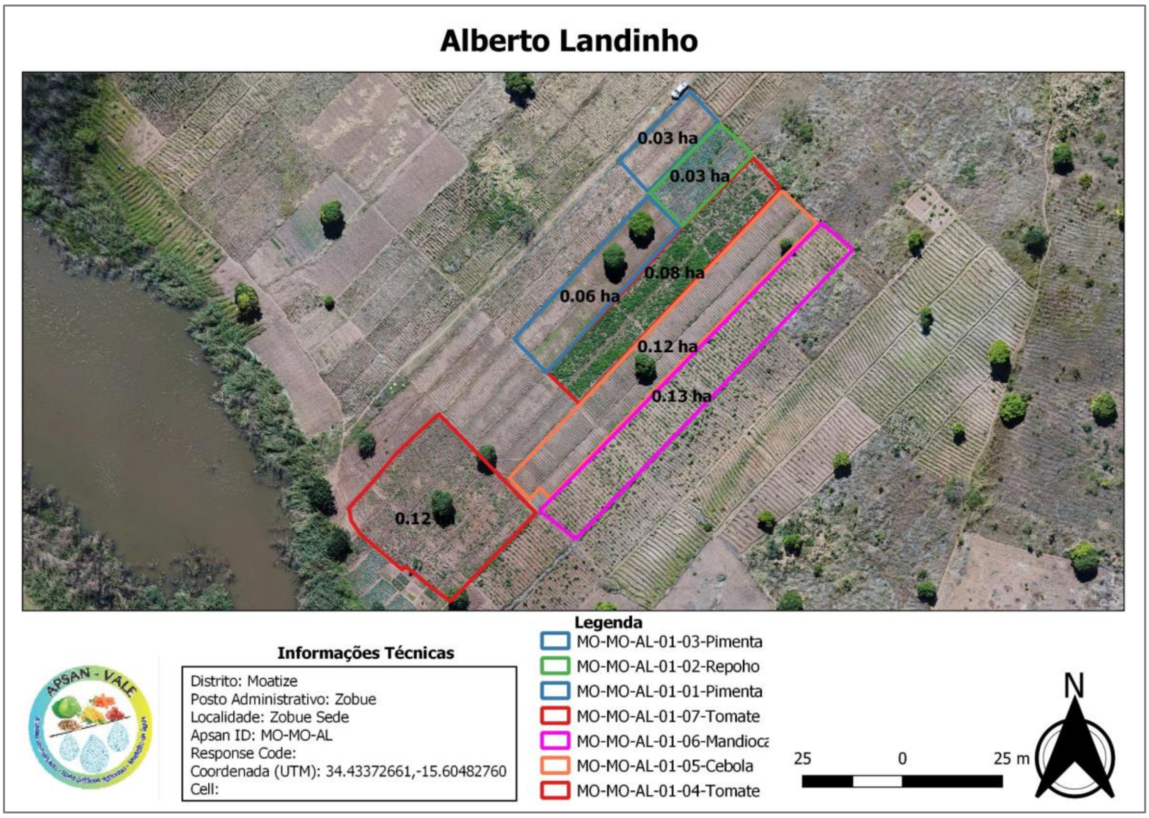

Figure 17 Field registration map of PPC (small commercial farmer) Alberto L. in Moatize district

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 from the 2020 irrigation season 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.

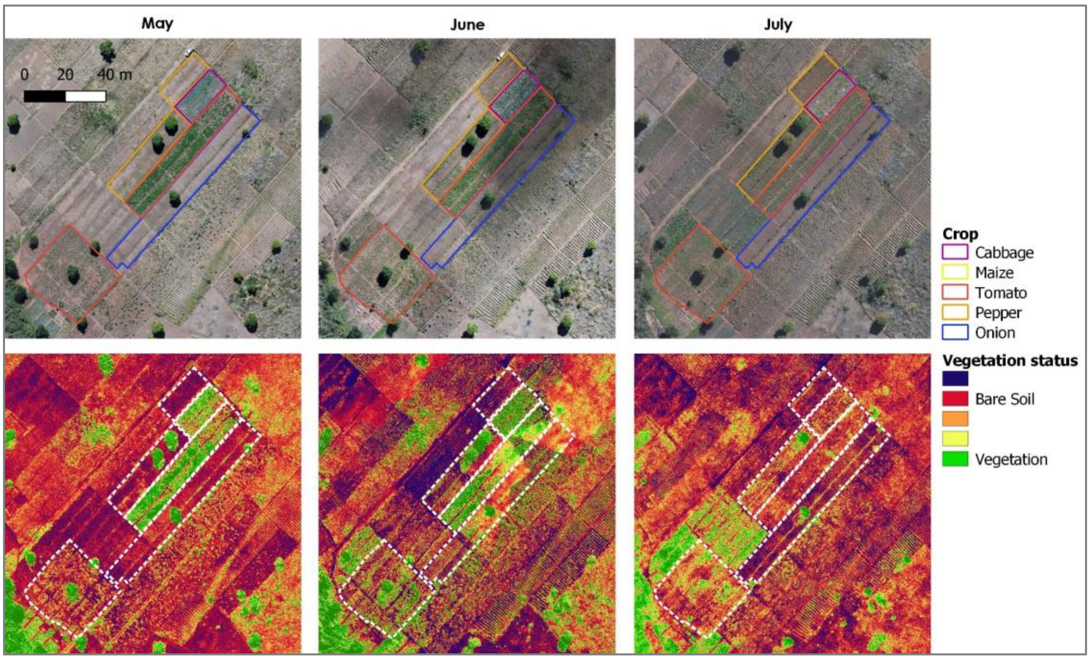

Figure 18 Development of the vegetation status of PPC (small commercial farmer) Alberto L (in Moatize)

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, which can be accessed through https://futurewater.eu/apsanvaleportal/. The flying sensor maps are uploaded to the portal 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 portal is shown in Figure 19. The canopy cover and water productivity maps are also added to the portal, just like other features such as 'Export to pdf', which makes it available to download maps for offline use.

Figure 19 Screenshot of the 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 PPC's. 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 potato field of PPC Naume in Báruè is presented in Figure 20 for four flight dates during the season. The canopy cover development shows that the two potato plots have their peak vegetation at a different time. The bottom (Southern) field displays a full vegetation cover in June, whereas the upper (Northern) field shows a full cover in July. In August most of the field has been harvested.

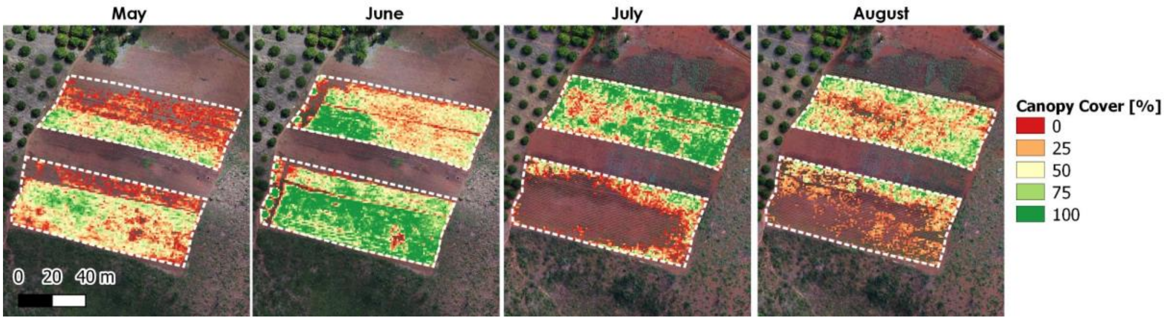

Figure 20 Canopy cover development over two potato fields (PPC Naume in Báruè) for four flight dates

After determining the canopy cover for all fields, a curvilinear relationship is developed, presenting the crop development during the growing season. The same field of Figure 20 is shown as a curvilinear graph in Figure 21. The four flight dates are presented in the graph with the canopy cover being 32%, 49%, 70%, and 43%. At the day of planting (5th May 2020) the canopy cover is 0%. The graph shows that the peak of canopy cover occurs approximately at day 55 to 60 after planting.
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.

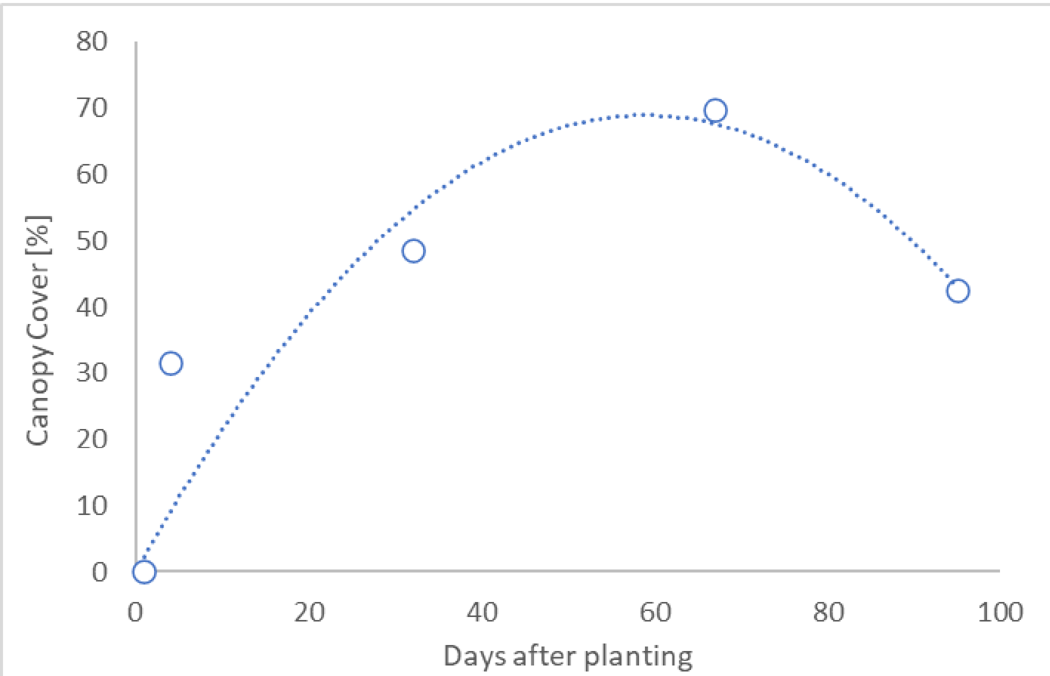

Figure 21 Canopy cover curvilinear of PPC Naume in Báruè using the canopy cover determined from four flying sensor flights (indicated with circles) and the planting date (indicated as first circle at Day 0)

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 crop specific 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 crop water productivity as presented in FutureWater Report 195[18]. A comparison with baseline values is not provided for the typical rainfed crops i.e. beans and maize. The results from the irrigation season are higher than the baseline, which is calculated for a rainfed season. In the results the crop yield is also presented, which is the fresh harvestable crop yield as computed by AquaCrop and using the harvest index and moisture content, which are specific for each crop type and listed in Table 4.

In Table 7 the water productivity and crop yield results for Nhamatanda are presented for the main crop types cultivated cabbage, maize, onion, potato, and tomato. The values for cabbage water productivity indicate an increase in water productivity compared to the baseline of 13 up to 40%. For onion the water productivity also indicated a major increase, however the baseline values for onion crop were relatively low. Tomato was grown at most fields and indicates a range of water productivity values from 0.75 to 1.46 kg/m^3 and fresh yield of 4.9 to 12.5 ton/ha. The range in water productivity values indicates the variability between farmers and their practices. Even within the fields of the same farmer (e.g. AP_NH_FM_01) some variability exists between water productivity values, whilst yield values are similar. This likely indicates the differences in the water management, where increases can be achieved.

Table 7 Results of AquaCrop water productivity and crop yield, and percent change of water productivity compared to baseline for Nhamatanda farmers

Plot ID (location and farmer)	Crop	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with Baseline	Fresh crop yield [ton/ha]
AP_NH_LB-01-04	Cabbage	1.24	1.36	13%	11.8
AP_NH_EP-01-02	Cabbage	1.54	1.69	40%	16.5
AP_NH_RB-01-02	Cabbage	1.49	1.64	35%	15.0
AP_NH_RB-01-03	Cabbage	1.47	1.62	34%	12.6
AP_NH_LF-01-03	Maize	1.02	1.12	Baseline is rainfed season	3.5
AP_NH_ASC-01-02	Maize	0.80	0.88		2.2
AP_NH_RB-01-01	Maize	0.96	1.06		2.7
AP_NH_AL-01-02	Maize	0.89	0.98		2.7
AP_NH_LF-01-01	Onion	0.66	0.73	458%	5.7
AP_NH_LB-01-01	Onion	0.33	0.36	179%	3.2
AP_NH_LF-01-04	Potato	2.74	3.01	32%	28.1
AP_NH_AM-01-04	Tomato	1.29	1.42	23%	10.5
AP_NH_FM-01-01	Tomato	1.23	1.35	18%	12.5
AP_NH_FM-01-02	Tomato	1.40	1.54	34%	12.0
AP_NH_FM-01-05	Tomato	1.46	1.61	40%	11.8
AP_NH_LF-01-02	Tomato	1.12	1.23	7%	8.2
AP_NH_EP-01-04	Tomato	1.16	1.28	11%	10.8
AP_NH_AL-01-03	Tomato	0.75	0.83	-28%	4.9
AP_NH_EP-02-01	Tomato	1.18	1.30	13%	9.2

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

Table 8 presents the results of water productivity for Moatize selected PPC's, for the main crop types cabbage, maize, and tomato. For cabbage the water productivity values indicated an increase with the baseline from 23% to 42%. The tomato fields showed some variability in water productivity from 1.27 to 1.67 kg/m^3 and an increase from 1 to 32% compared to the baseline values. The fresh yield from cabbage and tomato fields are comparable with field reports. Interestingly the lowest tomato yields, 15 ton/ha, had large difference in water productivity namely 1.27 kg/m^3 compared to 1.46 kg/m^3. This is likely due to the irrigation management (interval and application rate) and other practices implemented by the farmers.

Table 8 Results of AquaCrop water productivity and crop yield, and percent change of water productivity compared to baseline for Moatize farmers

Plot ID (location and farmer)	Crop	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with Baseline	Fresh crop yield [ton/ha]
AP_MO_GF-01-02	Cabbage	1.00	1.42	23%	9.1
AP_MO_AL-01-02	Cabbage	1.10	1.56	36%	11.8
AP_MO_LG-01-02	Cabbage	1.01	1.43	25%	13.6
AP_MO_FS-01-03	Cabbage	1.15	1.63	42%	13.9
AP_MO_FS-01-01	Maize	1.19	1.69		5.2
AP_MO_AJE-01-01	Tomato	1.59	2.26	26%	17.0
AP_MO_GF-01-01	Tomato	1.55	2.20	23%	19.4
AP_MO_MM	Tomato	1.43	2.03	13%	20.1
AP_MO_CM-01-01	Tomato	1.47	2.09	16%	19.7
AP_MO_AL-01-04	Tomato	1.59	2.26	26%	20.6
AP_MO_AL-01-07	Tomato	1.27	1.80	1%	15.0
AP_MO_MC-01-01	Tomato	1.46	2.07	16%	15.0
AP_MO_LG-01-01	Tomato	1.45	2.06	15%	19.5
AP_MO_MVS-01-01	Tomato	1.57	2.23	24%	17.1
AP_MO_FS-01-02	Tomato	1.67	2.37	32%	22.8

Table 9 presents the water productivity results of the selected PPC's in Báruè. The major crop types are presented, which are bean, cabbage, maize, onion, potato, and tomato. For bean and maize, the comparison with baseline is omitted due to the baseline values being representative for the rainfed season and not irrigation season. The values for increase in water productivity compared to the baseline are lower (or negative) for potato and tomato fields. These crops are more sensitive to water logging, which in AquaCrop results in yield loss. This especially occurred in the simulations of Báruè due to the soil type being Clay. This is even more accentuated due to the higher rainfall occurring in Báruè (as shown in Chapter 3). However, in practice with rain events, it is expected that farmers adjust their irrigation events accordingly to avoid water logging. This response was in current AquaCrop simulations not incorporated, resulting in lower yield (and water productivity) values than expected.
Overall the increase in water productivity for cabbage was -4 to 53% compared to baseline values. For tomato the increase in water productivity was -26 to 12%.

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 22, 23, and 24, 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 low (red) to high (green), however comparison between fields with different crop types is not relevant. For instance, the water productivity of onion is low compared to those of cabbage or tomato, due to the difference in harvested crop and vegetation cover. Overall, the majority of the PPC's show a positive increase in water productivity compared to baseline values.

Table 9 Results of AquaCrop water productivity and crop yield, and percent change of water productivity compared to baseline for Báruè farmers*

Plot ID (location and farmer)	Crop	Water Productivity [kg/m³]	Normalized Water Productivity [kg/m³]	% change with Baseline	Fresh crop yield [ton/ha]
AP_BA_DVS-01-01	Bean	0.55	0.48		1.7
AP_BA_RF-01-02	Bean	0.68	0.60		2.6
AP_BA_ST-01-03	Bean	0.58	0.51		1.9
AP_BA_CF-01-01	Bean	0.65	0.57		1.8
AP_BA_DN-01-01	Bean	0.55	0.48		1.7
AP_BA_MTC-01-01	Bean	0.75	0.66		2.4
AP_BA_AJ-01-01	Cabbage	1.58	1.39	22%	17.8
AP_BA_AJ-01-02	Cabbage	1.25	1.10	-4%	10.0
AP_BA_GM-01-03	Cabbage	1.58	1.39	22%	17.8
AP_BA_JLC-01-01	Cabbage	1.66	1.46	28%	12.1
AP_BA_JLC-01-02	Cabbage	1.57	1.38	21%	11.3
AP_BA_ACI-01-02	Cabbage	1.41	1.24	9%	15.6
AP_BA_ACI-01-04	Cabbage	1.59	1.40	22%	17.0
AP_BA_ML-01-01	Cabbage	1.60	1.40	23%	11.5
AP_BA_DVS-01-02	Cabbage	1.58	1.39	22%	17.8
AP_BA_ST-01-01	Cabbage	1.58	1.39	22%	17.8
AP_BA_CF-01-02	Cabbage	1.87	1.64	44%	13.2
AP_BA_CF-01-03	Cabbage	1.99	1.75	53%	14.2
AP_BA_JDR-01-01	Cabbage	1.57	1.38	21%	11.3
AP_BA_JDR-01-02	Cabbage	1.45	1.27	12%	10.4
AP_BA_MFD-01-01	Cabbage	1.57	1.38	21%	11.3
AP_BA_MFD-01-02	Cabbage	1.64	1.44	26%	11.9
AP_BA_MFD-01-03	Cabbage	1.66	1.46	28%	12.1
AP_BA_BV-01-03	Cabbage	1.68	1.47	29%	12.2
AP_BA_MTC-01-02	Cabbage	1.58	1.39	22%	17.8
AP_BA_ST-01-02	Maize	1.13	0.99		3.8
AP_BA_DN-01-02	Maize	0.51	0.45		1.3
AP_BA_CF-01-01	Onion	0.38	0.33	157%	4.6
AP_BA_ST-01-01	Onion	0.31	0.27	109%	3.8
AP_BA_JDR-01-03	Onion	0.41	0.36	177%	4.6
AP_BA_MFD-01-03	Onion	0.35	0.31	136%	4.2
AP_BA_BV-01-02	Onion	0.35	0.31	136%	3.9
AP_BA_NZ-01-01	Potato	2.16	1.90	-44%	17.3
AP_BA_NZ-01-02	Potato	1.69	1.48	-56%	8.7
AP_BA_GM-01-02	Potato	2.15	1.89	-44%	17.9
AP_BA_GM-01-01	Tomato	1.06	0.93	-16%	10.0
AP_BA_JLC-01-03	Tomato	1.29	1.13	2%	10.5
AP_BA_ACI-01-01	Tomato	1.41	1.24	12%	13.0
AP_BA_ML-01-02	Tomato	1.17	1.03	-7%	9.8
AP_BA_RF-01-01	Tomato	1.01	0.89	-20%	9.8
AP_BA_CF-01-01	Tomato	1.19	1.04	-5%	7.9
AP_BA_CF-01-01	Tomato	1.24	1.09	-2%	8.5
AP_BA_JDR-01-04	Tomato	1.33	1.17	6%	11.2
AP_BA_MFD-01-02	Tomato	1.37	1.20	9%	11.9
AP_BA_MFD-01-03	Tomato	0.93	0.82	-26%	11.7

*For Báruè see the updated values in Table 24 in Addendum.

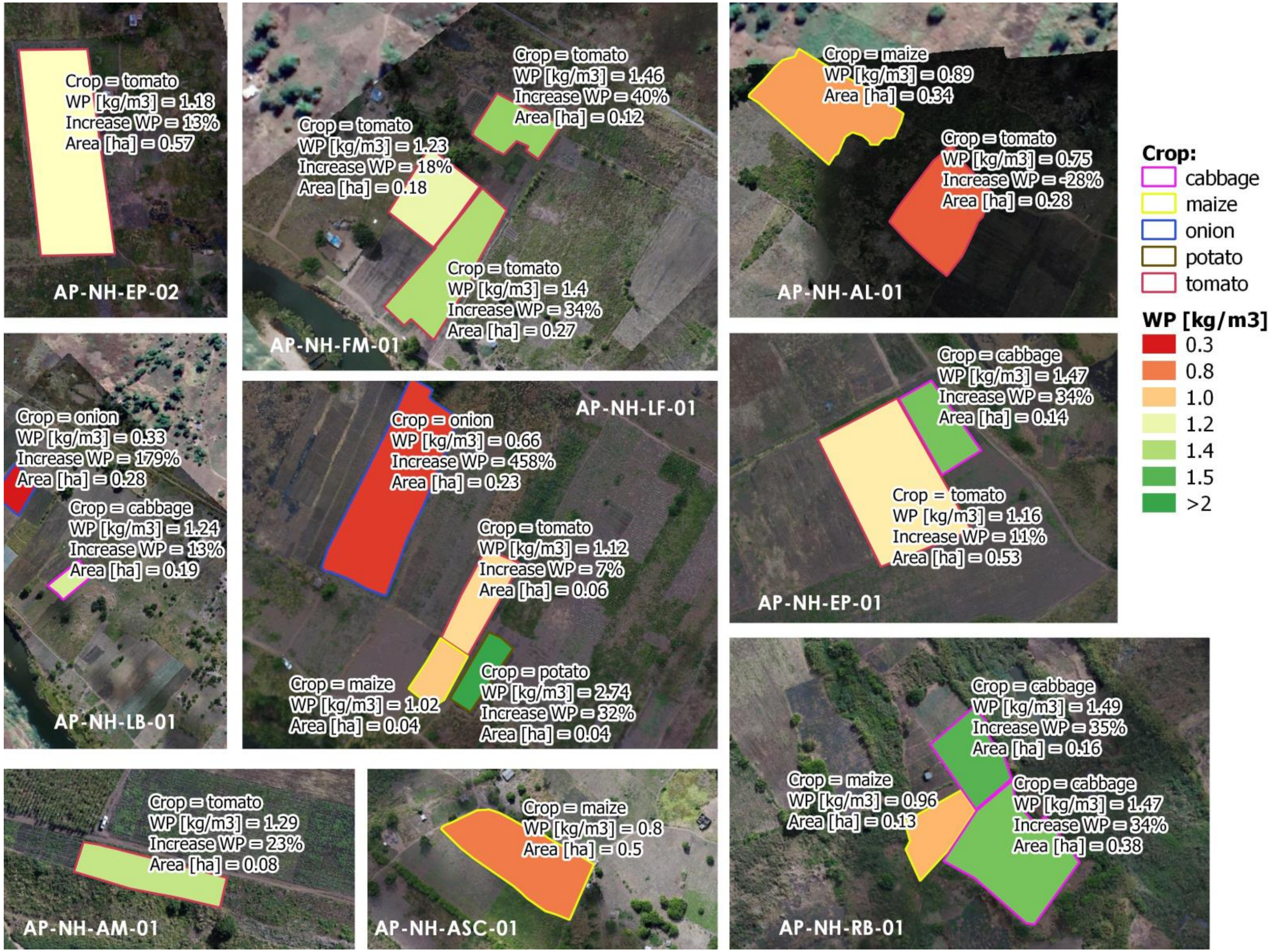

Figure 22 Field water productivity maps of Nhamatanda for selected PPC's for major crop types

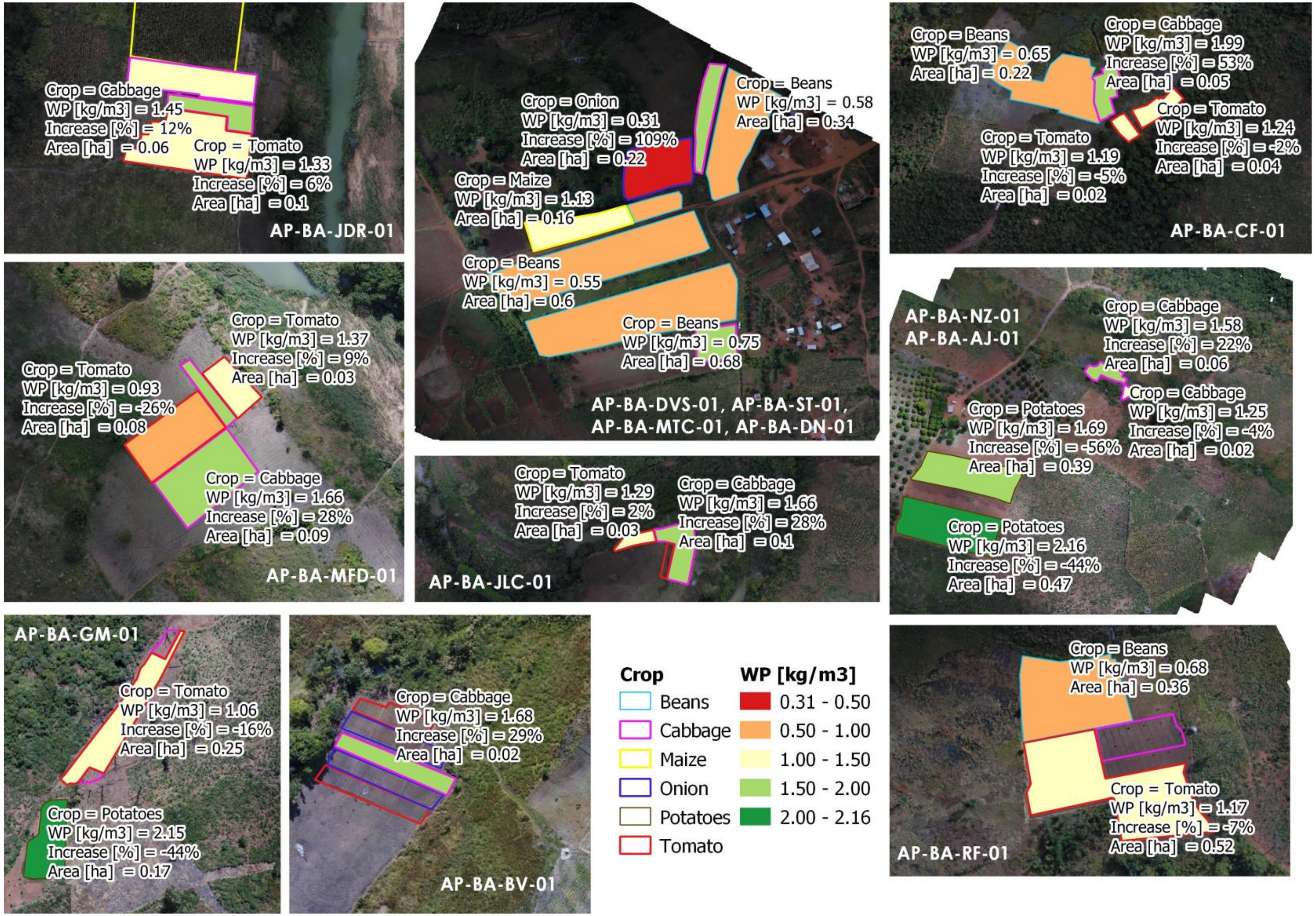

Figure 23 Field water productivity maps of Báruè for selected PPC's for the main crop types

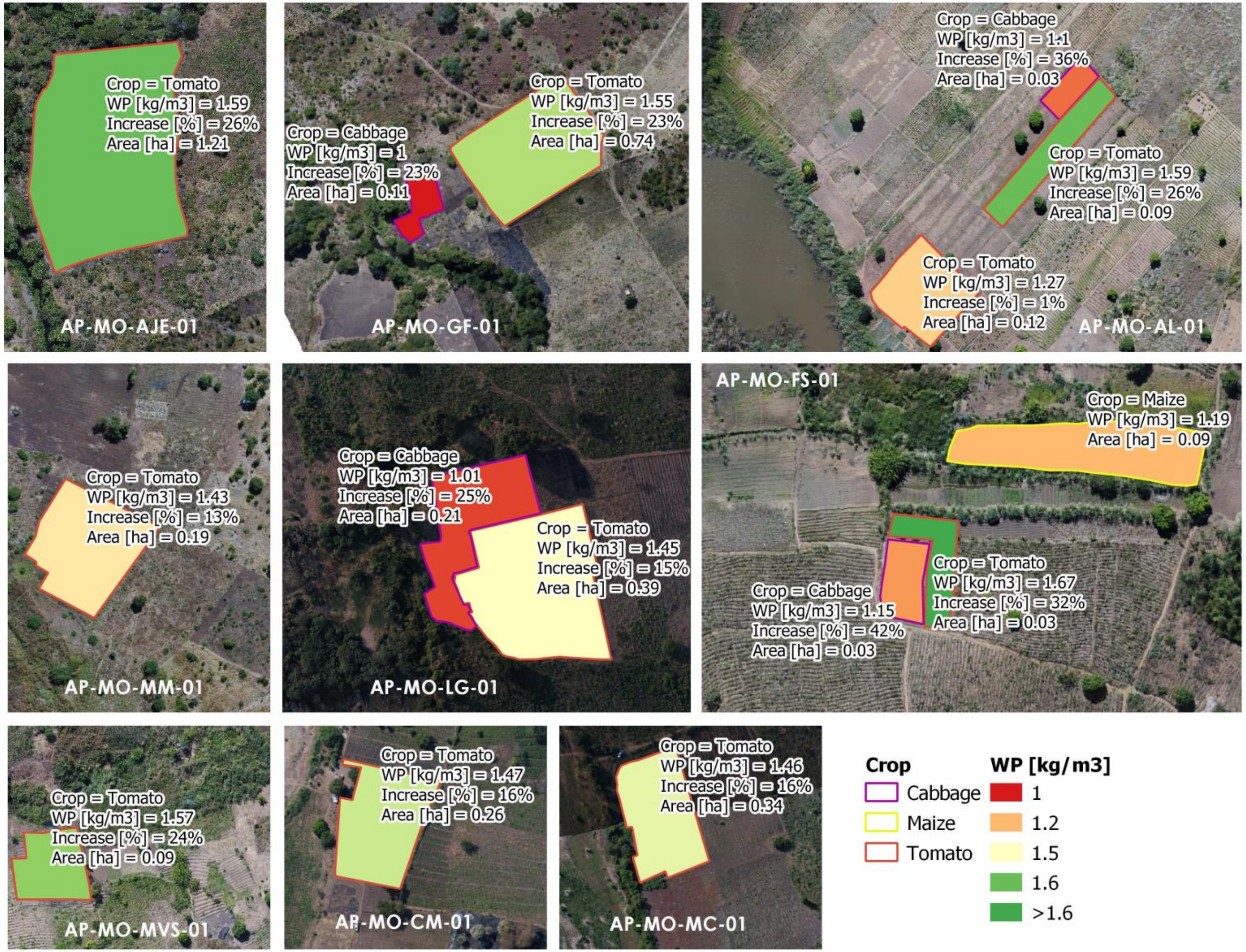

Figure 24 Field water productivity maps of Moatize selected PPC's for main crop types

5 Sub-basin scale Water Productivity results

The sub-basin scale is described as the level between the field scale of the selected PPC's and the basin scale delineated for each district. The sub-basin scale was determined to be a 30 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 irrigation season 2020: May 2020 to September 2020. 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 favorable climate in this region. The lowest values for water productivity are found in Nhamatanda. In Moatize the highest water productivity is found in Zobue, which is closer to the mountain range and probably has more favorable conditions.

The maps of the sub-basin water productivity results are presented in Annex 2 of this document.

Table 10 Average 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	308	6.08	1.97
	Catandica II	292	5.84	2.00
	Catandica III	254	4.89	1.93
	Catandica IV	253	4.49	1.78
Moatize	Moatize	187	2.84	1.52
	Samoa	258	3.78	1.46
	Zobue	273	4.48	1.64
Nhamatanda	Metuchira	316	4.42	1.40
	Tica I	299	4.00	1.34
	Tica II	371	5.15	1.39

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. The lower water productivity can be attributed to the higher values of evapotranspiration reported in WaPOR during the growing season. 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	337	316	366
	10th percentile	261	239	300
	90th percentile	408	393	437
Biomass production [ton/ha]	Average mean	6.2	5.1	5.3
	10th percentile	4.6	3.6	4.0
	90th percentile	7.7	6.5	6.7
Water productivity [kg/m^3]	Average mean	1.83	1.60	1.44
	10th percentile	1.69	1.41	1.30
	90th percentile	1.98	1.81	1.57

Figure 25 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.

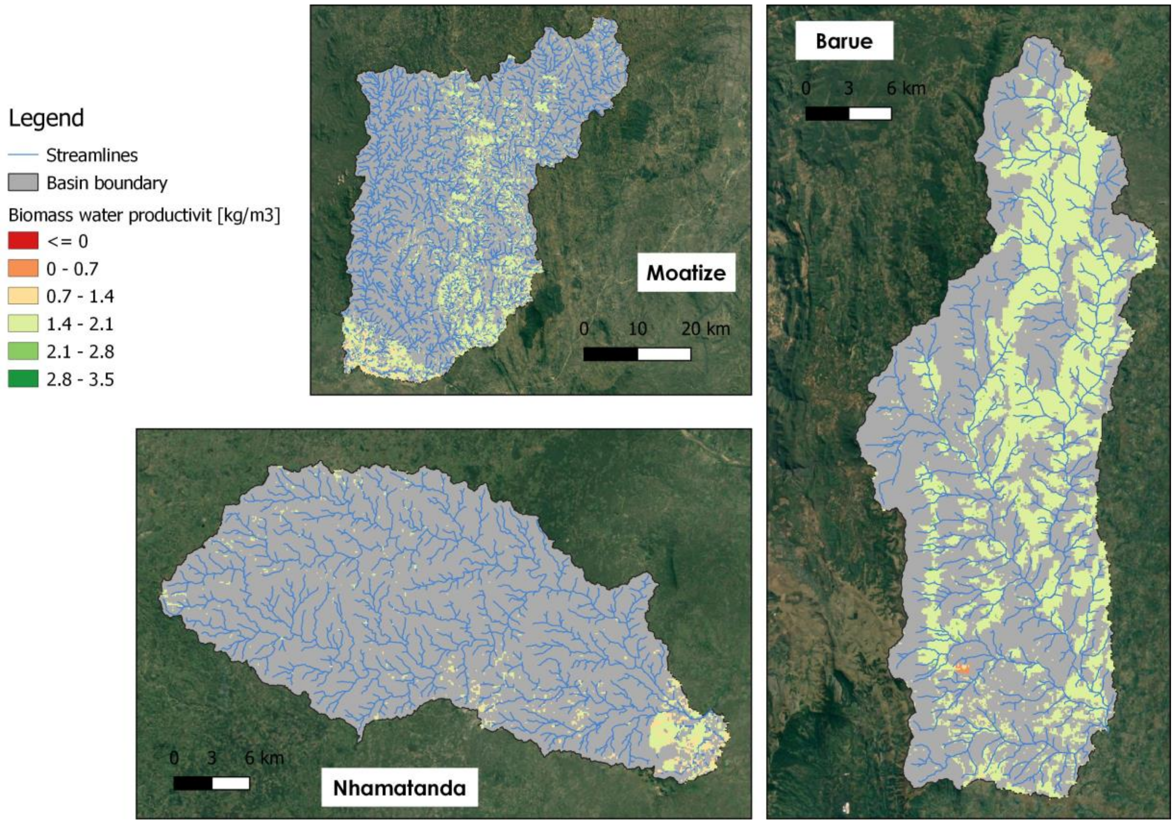

Figure 25 Seasonal biomass water productivity for cropland pixels in Moatize, Báruè and Nhamatanda at basin scale using WaPOR data portal

7 Seasonal Water Productivity assessment

The baseline assessment water productivity report[19] 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 PPC's 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 three levels. Firstly, the change of water productivity due to specific interventions at the field of the PPC's 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 neighboring PPE's and communities adopting the interventions. Lastly, the basin level, which is considered to display the increase of the overall water productivity of the region or basin scale. During this season the activities were focused on a selection of PPC's 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 (communities or sub-basin and basin scale). 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 sub-basin and 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, 13, and 14. Table 12 elaborates on the water productivity of tomato fields. Table 13 displays the water productivity of cabbage fields. Table 14 provides an overview of each district and all major crop types evaluated in the irrigation season. Water productivity is normalized for climate influences using the reference evapotranspiration. This is compared with the median of the baseline.

Table 12 indicates that tomato productivity showed largest improved in water productivity in Moatize, then followed by Nhamatanda, and lastly Báruè with 19, 15, and -7% respectively. The overall increase in tomato water productivity was 9%

As mentioned in chapter 4, the lower values in water productivity for Báruè can be attributed to the precipitation and the adjustment in water management, which is not fully reflected in the AquaCrop simulations. Additionally, the correction to normalized water productivity decreased the water productivity due to the lower than average reference evapotranspiration. However, due to the large elevation differences in the district of Báruè, local variation in weather is expected, which is not possible to capture with the weather station or satellite data.

Results on fresh yield showed the highest values for Moatize. Nhamatanda and Báruè displayed similar values in fresh yield.

Table 13 shows a similar analysis but then for the cabbage fields. The increase in water productivity was similar for all districts being 23%, 31%, and 30% for Báruè, Moatize, and Nhamatanda respectively. The overall increase in cabbage water productivity was 28%. The fresh yield also shows similar values with Nhamatanda being slightly higher with 14 ton/ha, followed by Báruè with 13.8 ton/ha and Moatize with 12.1 ton/ha.

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

Table 12 Normalized tomato water productivity (in kg/m³) and fresh yield (in ton/ha) for irrigation season 2020 compared to the baseline

	Báruè*	Moatize	Nhamatanda	Overall
Baseline water productivity				
Range [kg/m³]	0.69 – 1.45	1.50 – 2.25	1.02 – 1.35	
Median [kg/m³]	1.11	1.79	1.15	
Irrigation season 2020 water productivity				
Range [kg/m³]	0.77 – 1.24	1.80 – 2.37	0.83 – 1.61	
Average (mean) [kg/m³]	1.03	2.13	1.32	
Relative change (%)	-7%	+19%	+15%	9%
Irrigation season 2020 fresh yield				
Range [ton/ha]	7.5 – 13.0	15.0 – 22.8	4.9 – 12.5	
Average (mean) [ton/ha]	10.2	18.6	10.0	

*For Báruè see the updated values in Table 21 in Addendum.

Table 13 Normalized cabbage water productivity (in kg/m³) and fresh yield (in ton/ha) for irrigation season 2020 compared to the baseline

	Báruè*	Moatize	Nhamatanda	Overall
Baseline water productivity				
Range [kg/m³]	0.73 – 1.44	0.81 – 1.54	0.78 – 1.55	
Median [kg/m³]	1.14	1.15	1.21	
Irrigation season 2020 water productivity				
Range [kg/m³]	1.10 – 1.75	1.42 – 1.63	1.36 – 1.69	
Average (mean) [kg/m³]	1.40	1.51	1.58	
Relative change (%)	+23%	+31%	+30%	+28%
Irrigation season 2020 fresh yield				
Range [ton/ha]	10.0 – 17.8	9.1 – 13.9	11.8 – 16.5	
Average (mean) [ton/ha]	13.8	12.1	14.0	

*For Báruè see the updated values in Table 22 in Addendum.

Table 14 indicates the overall assessment of water productivity for the irrigation season at field level. The values are weighted by number of fields for each value, assuming that fields are similar in size. The overall increase in water productivity was 25% for Báruè, 23% for Moatize, and 61% for Nhamatanda. The higher changes in water productivity are mostly attributed to the onion crops, which had a low baseline value. Overall, the increase in water productivity is 33%, which is reported as such in the logframe and progress reports.

Table 14 Overall change in water productivity for irrigation season 2020 compared to the baseline for all major irrigation season crop types (tomato, cabbage, potato, and onion) weighted by number of plots as indicated in brackets

	Báruè*	Moatize	Nhamatanda	Overall
Tomato	-7% (11)	+19% (10)	+15% (8)	
Cabbage	+23% (19)	+31% (4)	+30% (4)	
Potato	-48% (3)		+32% (1)	
Onion	+143% (5)		+319% (2)	
Overall	+25%	+23%	+61%	+33%

*For Báruè see the updated values in Table 23 in Addendum.

7.2 Water productivity assessment at sub-basin scale

Chapter 5 elaborates on the analysis performed at sub-basin scale using the communities or surrounding fields around each PPC. Table 15 presents the assessment at sub-basin scale using the normalized water productivity. The values are compared with the baseline values for the basin scale analysis, which are deemed representative for cropland areas in the district. The average increase in water productivity was 11% in Báruè, 44% in Moatize, and 15% in Nhamatanda. The overall average is 22% increase in biomass water productivity.

Table 15 Biomass normalized water productivity for sub-basins and the change with the baseline values

	Normalized water productivity [kg/m^3]	Relative change with baseline [%]	Overall
Báruè			+11%
Catandical	1.71	+14%	
CatandicalI	1.73	+15%	
CatandicalII	1.66	+11%	
CatandicalV	1.54	+2%	
Moatize			+44%
Moatize	2.11	+42%	
Samoa	2.03	+37%	
Zobue	2.28	+54%	
Nhamatanda			+15%
Metuchira	1.53	+17%	
Tical	1.46	+12%	
TicalI	1.52	+16%	
Overall			+22%

7.3 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 irrigation season. Table 16 presents the values of biomass water productivity after normalizing for the 2020 weather conditions and comparing with the baseline values. An increase of biomass water productivity was perceived for all selected basins ranging from 5% to 50%. The average increase for all districts of biomass water productivity is 25%. 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. However, it is similar to the sub-basin analysis as represented in Table 15, thus indicating that improvements in water productivity are observed also in the community and regional scale.

Table 16 Biomass water productivity (kg/m^3) for irrigation season 2020 at basin scale compared to the baseline

	Báruè	Moatize	Nhamatanda	Overall
Irrigation season 2020	1.83	1.60	1.44	
Irrigation season 2020 (Normalized)	1.58	2.22	1.57	
Baseline	1.50	1.48	1.31	
Relative change (%)	+5%	+50%	+20%	+25%

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 32 farmers which were monitored throughout the irrigation season as part of the APSAN-Vale project. A total of 67 fields provided field scale water productivity results for the major crop types: tomato, cabbage, potato, onion, beans, and maize. Results on flying sensor imagery, AquaCrop simulations and field water productivity maps were presented in Chapter 4. After normalization for climatic conditions, the increase in water productivity on average for all crop types was found to be 25% in Báruè, 23% in Moatize, and 61% in Nhamatanda, resulting in an average 33% increase in comparison with the baseline values.
The results of field water productivity of 32 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. This analysis will be presented at meetings for the project and reported on after the next irrigation season.

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 PPC's. 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, followed by Moatize, and lastly Nhamatanda. These values were normalized and assessed with the baseline values for basin biomass water productivity. This indicated an overall increase in water productivity of 22%.
In the next season, areas that are omitted from APSAN Vale activities can also be compared to determine if the increase in biomass water productivity is due to the promoted activities piloted in APSAN Vale. In addition, field data from the APSAN Vale fields can indicate if the increase in biomass is also converted to increase of harvestable product.

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 5%, 50%, and 20% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was 25% for all districts together.

Both the improvements perceived at field scale and basin scale indicate promising results and achieve the targets set in the 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

This table provides an overview of the data collected by local observations and field books. Based on this information the AquaCrop runs were set-up.

Table 17 Field input data from Báruè

	Crop				Field mgt				Irrigation		
ID plot	**Crop type (EN)**	**Crop type (PT)**	**Planting date**	**Planting density [plnts/m2]**	**Fertilizer use (low, moderate, optimal)**	**Mulching yes/no**	**Weed mgt (low, moderate, high)**	**Runoff mgt (yes/no)**	**Irrigation (yes/no)**	**Irrigation method**	**Irrigation interval (days)**
AP_BA_NZ-01-01	Potato	Batata	02/04/2020	4.2	Optimal	no	Low	no	yes	sprinkler	3
AP_BA_NZ-01-02	Potato	Batata	*05/05/2020*	3.3	Optimal	no	Low	no	yes	sprinkler	3
AP_BA_AJ-01-01	Cabbage	Repolho	18/Apr	3.3	low	no	Low	no	yes	sprinkler	3
AP_BA_AJ-01-02	Cabbage	Couve	28/May	5.6	low	no	Low	no	yes	sprinkler	3
AP_BA_GM-01-01	Tomato	Tomate	25/05/2020	2.5	Optimal	no	Low	no	yes	sprinkler	3
AP_BA_GM-01-02	Potato	Batata	04/04/2020	4.2	Optimal	no	Low	no	yes	sprinkler	3
AP_BA_GM-01-03	Cbbage	Repolho	22/05/2020	3.3	Optimal	no	Low	no	yes	sprinkler	3
AP_BA_JLC-01-01	Cabbage	Couve	29/04/2020	5.6	low	no	Low	yes	yes	surface	3
AP_BA_JLC-01-02	Cabbage	Repolho	02/05/2020	3.3	low	no	Low	yes	yes	surface	3
AP_BA_JLC-01-03	Tomato	Tomate	01/05/2020	2.5	low	no	Low	yes	yes	surface	3
AP_BA_ACI-01-01	Tomato	Tomate	17/Apr	3.0	Optimal	no	Low	yes	yes	sprinkler	3
AP_BA_ACI-01-02	Cabbage	Couve	02/May	5.6	Optimal	no	Low	yes	yes	sprinkler	3
AP_BA_ACI-01-04	Cabbage	Repolho	28/Apr	3.3	Optimal	no	Low	yes	yes	sprinkler	3
AP_BA_ML-01-01	Cabbage	Repolho	18/May	4.0	Optimal	no	low	yes	yes	surface	3
AP_BA_ML-01-02	Tomato	Tomate	12/May	2.5	Optimal	no	low	yes	yes	surface	3
AP_BA_DVS-01-01	Bean	Feijao		20.0	low	no	Moderate	no	yes	sprinkler	3
AP_BA_DVS-01-02	Cabbage	Repolho	02/May	3.3	low	no	Moderate	no	yes	sprinkler	3
AP_BA_RF-01-01	Tomato	Tomate	21/Jun	2.5	Optimal	no	low	yes	yes	surface	3
AP_BA_RF-01-02	Cabbage	Repolho	12/May	3.3	Optimal	no	low	yes	yes	surface	3
AP_BA_RF-01-02	Bean	Feijao	23/Mar	20	Optimal	no	low	yes	yes	surface	3
AP_BA_ST-01-01	Onion	Cebola	15/May	33.3	Optimal	no	low	no	yes	sprinkler	3
AP_BA_ST-01-01	Cabbage	Repolho	12/May	3.3	Optimal	no	low	no	yes	sprinkler	3
AP_BA_ST-01-02	Maize	Milho	10/May	4.2	Optimal	no	low	no	yes	sprinkler	3
AP_BA_ST-01-03	Bean	Feijao	25/Apr	20.0	Optimal	no	low	no	yes	sprinkler	3
AP_BA_CF-01-01	Tomato	Tomate	11/May	2.5	low	no	low	yes	yes	Drip	3
AP_BA_CF-01-01	Oniom	Cebola	02/Aug	33.3	low	no	low	yes	yes	Drip	3
AP_BA_CF-01-01	Tomato	Tomato	02/Jul	2.5	low	no	low	yes	yes	Drip	3
AP_BA_CF-01-01	Bean	Feijao		20	low	no	low	yes	yes	Drip	3
AP_BA_CF-01-02	Cabbage	Repolho	25/Apr	3.3	low	no	low	yes	yes	Drip	3
AP_BA_CF-01-03	Cabbage	Couve	24/Jul	5.6	low	no	low	yes	yes	Drip	3
AP_BA_JDR-01-01	Cabbage	Repolho	25/May	3.3	Optimal	no	low	yes	Yes	surface	3
AP_BA_JDR-01-02	Cabbage	Couve	05/May	5.6	Optimal	no	low	yes	Yes	surface	3
AP_BA_JDR-01-03	Onion	Cebola	01/Jun	33.3	Optimal	no	low	yes	Yes	surface	3
AP_BA_JDR-01-04	Tomato	Tomate	24/Apr	2.5	Optimal	no	low	yes	Yes	surface	3
AP_BA_MFD-01-01	Cabbage	Repolho	20/Apr	3.3	Optimal	no	low	yes	yes	surface	3
AP_BA_MFD-01-02	Tomato	Tomate	21/Apr	2.5	Optimal	no	low	yes	yes	surface	3
AP_BA_MFD-01-02	Cabbage	Couve	22/Apr	5.6	Optimal	no	low	yes	yes	surface	3
AP_BA_MFD-01-03	Onion	Cebola	20/Apr	33.3	Optimal	no	low	yes	yes	surface	3
AP_BA_MFD-01-03	Cabbage	Couve	03/Aug	5.6	Optimal	no	low	yes	yes	surface	3
AP_BA_MFD-01-03	Tomato	Tomate	29/Jul	2.5	Optimal	no	low	yes	yes	surface	3
AP_BA_BV-01-01	Tomato	Tomate	15/Jun	2.5	low	no	low	yes	yes	surface	3
AP_BA_BV-01-02	Onion	Cebola	24/Jun	33.3	low	no	low	yes	yes	surface	3
AP_BA_BV-01-03	Cabbage	Couve	03/Jun	5.6	low	no	low	yes	yes	surface	3
AP_BA_DN-01-01	Bean	Feijao	02/May	20.0	low	no	low	no	yes	sprinkler	3
AP_BA_DN-01-02	Maize	Milho	09/Jun	4.2	low	no	low	no	yes	sprinkler	3
AP_BA_MTC-01-01	Bean	Feijao	03/Apr	20.0	Optimal	no	low	no	yes	sprinkler	3
AP_BA_MTC-01-02	Cabbage	Repolho	28/Jul	3.3	Optimal	no	low	no	yes	sprinkler	3

Table 18 Field input data from Moatize

	Crop			Field mgt				Irrigation		
ID plot	Crop type (PT)	Planting date	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)	Irrigation method	Irrigation interval (days)
AP_MO_AJE-01-01	Tomate	12.04.2020	80x60	Moderate	no	High	yes	yes	Sulcos (Gravidade)	5 dias
AP_MO_GF-01-01	Tomate	02.04.2020	80x60	Low	no	Moderate	yes	yes	Sulcos (Gravidade)	6 dias
AP_MO_GF-01-02	Couve	28.04.2020	50x50	Low	no	Moderate	yes	yes	Sulcos (Gravidade)	6 dias
AP_MO_MM	Tomate	15.04.2020	80x60	Optimal	no	Moderate	yes	yes	Sulcos (Gravidade)	6 dias
AP_MO_CM-01-01	Tomate	15.04.2020	80x60	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	7 dias
AP_MO_CM-01-02	Pimenta	16.04.2020	50x50	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	7 dias
AP_MO_ZM	Tomate	20.04.2020	80x60	Low	no	Low	yes	yes	Sulcos (Gravidade)	8 dias
AP_MO_AL-01-02	Repolho	15.04.2020	50x50	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	8 dias
AP_MO_AL-01-04	Tomate	12.04.2020	80x60	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	8 dias
AP_MO_AL-01-05	Cebola	15.05.2020	15x15	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	8 dias
AP_MO_AL-01-07	Tomate	02.05.2020	80x60	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	8 dias
AP_MO_MC-01-01	Tomate	25.04.2020	80x60	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	05 dias
AP_MO_MC-01-02	Feijao	30.04.2020	40x50	Low	no	Low	yes	yes	Sulcos (Gravidade)	05 dias
AP_MO_LG-01-01	Tomate	5.04.2020	80x60	Low	no	Low	yes	yes	Sulcos (Gravidade)	05 dias
AP_MO_LG-01-02	Repolho	3.04.2020	50x50	Low	no	Low	yes	yes	Sulcos (Gravidade)	05 dias
AP_MO_MVS-01-01	Tomate	25.04.2020	80x60	Low	no	Moderate	yes	yes	Sulcos (Gravidade)	7 dias
AP_MO_FS-01-01	Milho	15.03.2020	90x40	Low	no	Moderate	yes	yes	Sulcos (Gravidade)	06 dias
AP_MO_FS-01-02	Tomate	20.03.2020	80x60	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	06 dias
AP_MO_FS-01-03	Repolho	25.03.2020	50x50	Moderate	no	Moderate	yes	yes	Sulcos (Gravidade)	06 dias

Table 19 Field input data from Nhamatanda

	Crop				Field mgt				Irrigation		
ID plot	Crop type (PT)	Planting date	Harvest date (optional) Data de Colheita	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Irrigation (yes/no)	Irrigation method	Irrigation interval (days)
AP_NH_AM-01-04	Tomate	15.04.2020	29.06.2020	2.1	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_FM-01-01	Tomate	01.04.2020	28.06.2020	2.1	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_FM-01-02	Tomate	01.04.2020	28.06.2020	2.1	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_FM-01-05	Tomate	15.04.2020	04.07.2020	2.1	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_LF-01-01	Cebola	01.05.2020	07.07.2020	44.44	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_LF-01-02	Tomate	18.04.2020	29.06.2020	2.08	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_LF-01-03	Milho	28.04.2020	16.08.2020	2.78	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_LF-01-04	Batata doce	02.04.2020	30.08.2020	13.33	Moderate	no	Low	yes	yes	Sulcos	8 dias
AP_NH_ASC-01-02	Milho	25.04.2020	14.08.2020	2.8	Low	no	Low	yes	yes	Sulcos	7 dias
AP_NH_LB-01-01	Cebola	28.04.2020	28.06.2020	44.44	Moderate	no	Low	yes	yes	sulcos	7 dias
AP_NH_LB-01-03	Cebola	27.04.2020	27.06.2020	44.44	Moderate	no	Low	yes	yes	sulcos	7 dias
AP_NH_LB-01-04	Repolho	20.04.2020	02.07.2020	2.78	Moderate	no	Low	yes	yes	sulcos	7 dias
AP_NH_EP-01-02	Couve	28.04.2020	22.06.2020	4.0	Moderate	No	Moderate	yes	yes	sulcos	7 dias
AP_NH_EP-01-04	Tomate	03.04.2020	15.06.2020	2.1	Moderate	No	Moderate	yes	yes	sulcos	7 dias
AP_NH_RB-01-01	Milho	15.04.2020	28.08.2020	2.8	Low	No	Moderate	no	yes	sulcos	7 dias
AP_NH_RB-01-02	Couve	25.04.2020	15.06.2020	4.0	Low	No	Moderate	no	yes	sulcos	7 dias
AP_NH_RB-01-03	Repolho	20.04.2020	25.07.2020	2.8	Low	No	Moderate	no	yes	sulcos	7 dias
AP_NH_AL-01-01	Feijao	02.05.2020	28.06.2020	5	Low	No	Moderate	yes	yes	sulcos	5 days
AP_NH_AL-01-02	Milho	22.04.2020	25.08.20	2.8	Low	No	Moderate	yes	yes	sulcos	5 days
AP_NH_AL-01-03	Tomate	25.04.2020	01.07.2020	2.1	Low	No	Moderate	yes	yes	sulcos	5 days
AP_NH_EP-02-01	Tomate	15.03.2020	27.06.2020	2.1	Moderate	No	Moderate	yes	yes	sulcos	7 dias

Annex 2 – Sub-basin water productivity maps

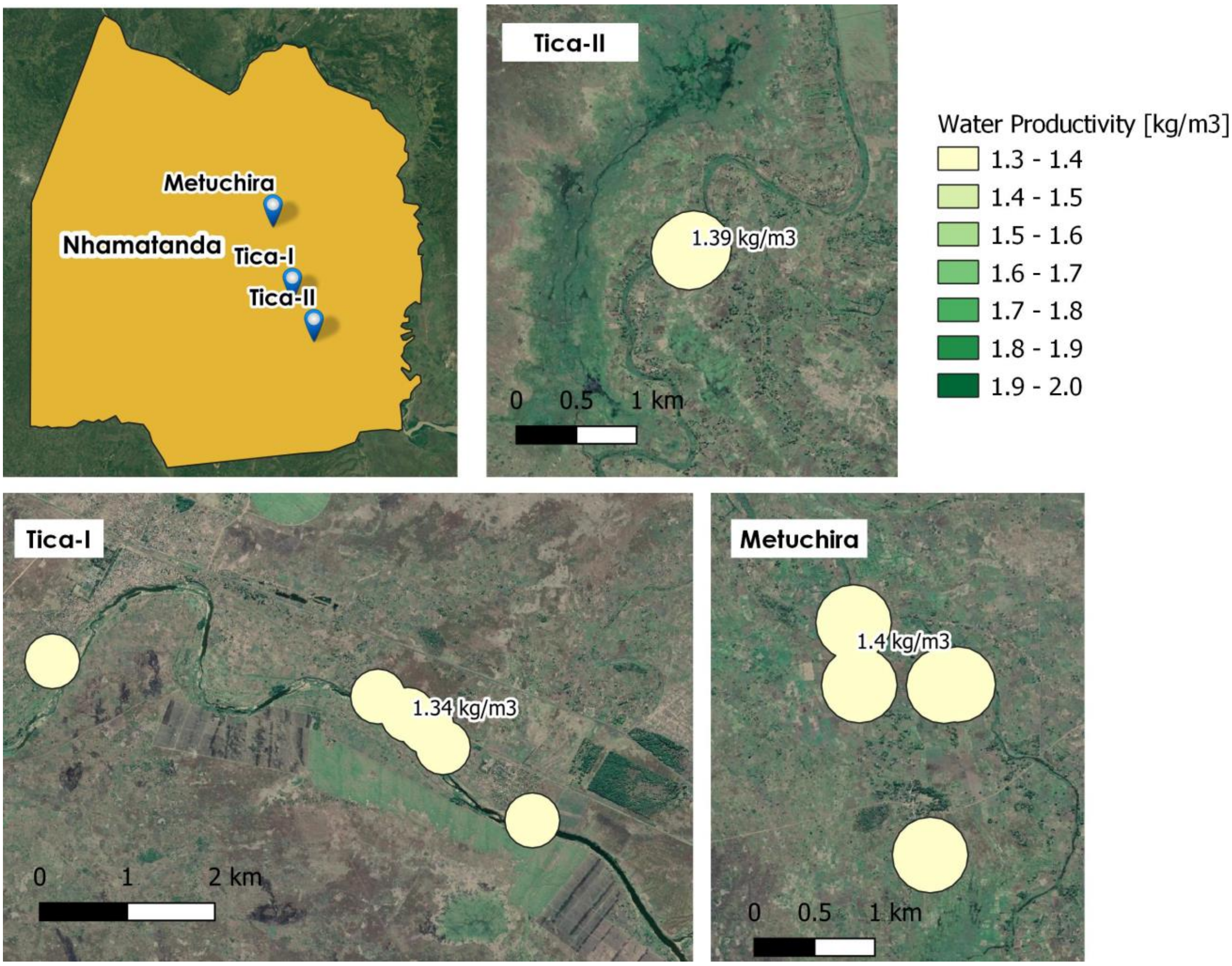

Figure 26 Sub-basin scale map of biomass water productivity in Nhamatanda using data from the WaPOR portal

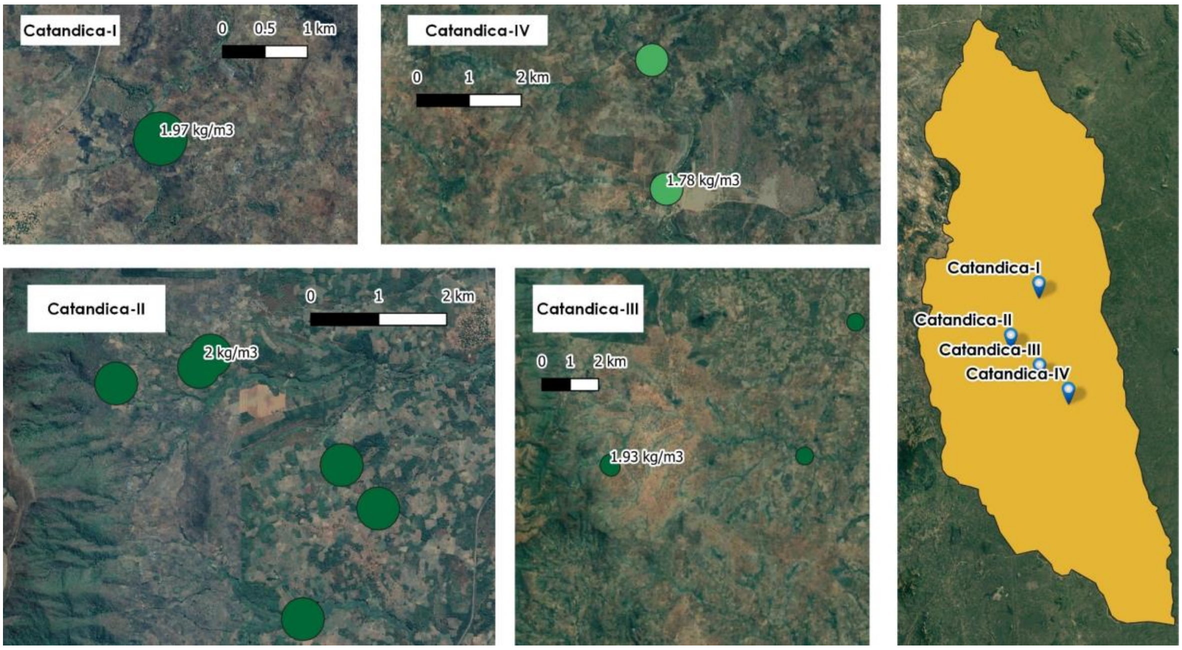

Figure 27 Sub-basin scale map of biomass water productivity in Báruè using data from the WaPOR portal

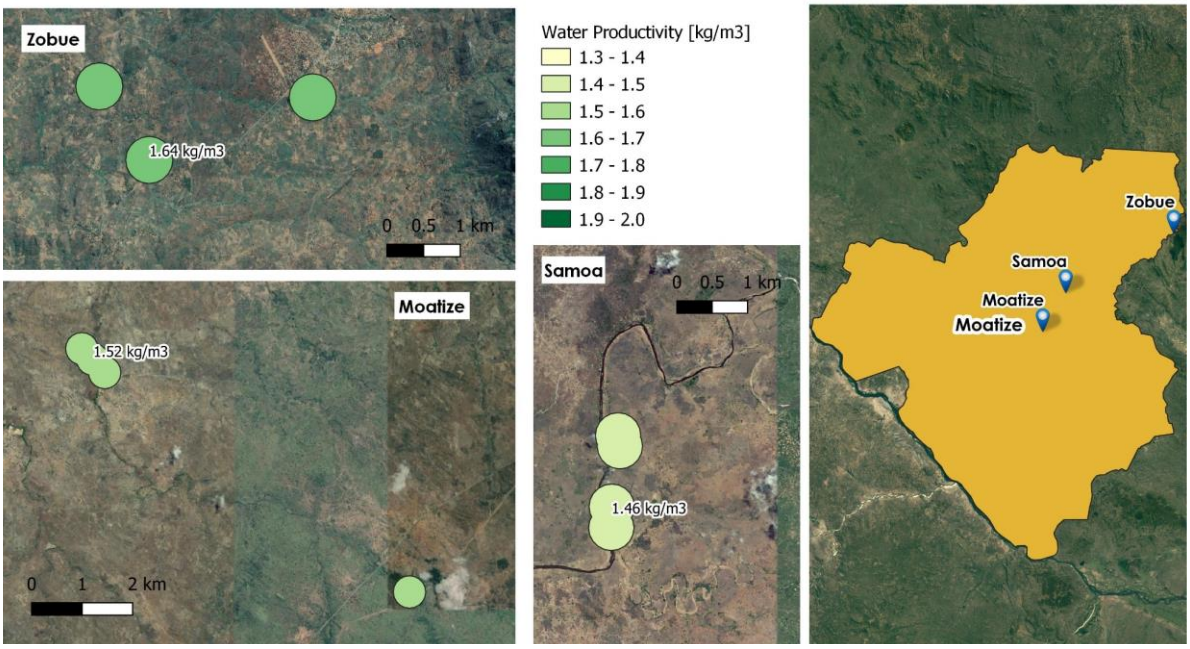

Figure 28 Sub-basin scale map of biomass water productivity in Moatize using data from the WaPOR portal

Addendum June 2021 - Updated water productivity analysis values for Báruè

Introduction

Based on new field information, updates on the water productivity analysis of irrigation season crops (tomato, potato, cabbage, and onion) were determined in Báruè. The field information gave new insight on the soil type, planting dates, and growth lengths of the crops. The baseline values of Báruè were updated for these crops with the new information. This addendum provides an update of the water productivity analysis of the irrigation season 2020. Information from Nhamatanda and Moatize did not lead to a necessity to update the water productivity analysis for those districts.

Update to input parameters

The adjustments made for the input parameters in the baseline assessment addendum, are also implemented in the water productivity analysis of the irrigation season 2020 for Báruè. Soils in Báruè turn out to be of type sandy clay loam instead of heavy clay (Table 20). The change in soil type impacted mostly the irrigation season analysis due to frequent irrigation events causing waterlogging in the clay soil. Effects of soil type were limited in the rain season water productivity analysis.

Table 20. Updated soil texture for Báruè.

Site	Soil texture (updated)	Soil texture (original)
Báruè	Sandy Clay Loam	Clay

The newly calibrated crop growth parameters are used, that were adjusted for shorter growing lengths and planting dates. Water productivity values are compared with the baseline values specific for the planting date of each field.

Updated results

The re-analysis of the water productivity values using the updated input parameters gave the results as presented in the tables below, Table 21 and Table 22 for tomato and cabbage water productivity respectively. These are updated tables from chapter 7 in the report (tables 12 and 13).

Table 21 Normalized tomato water productivity (in kg/m^3) and fresh yield (in ton/ha) for irrigation season 2020 compared to the baseline

	Báruè (Original)	Báruè (Updated)
Baseline water productivity		
Range [kg/m^3]	0.69 – 1.45	0.50 – 1.19
Median [kg/m^3]	1.11	0.75
Irrigation season 2020 water productivity		
Range [kg/m^3]	0.77 – 1.24	0.82 – 1.21
Average (mean) [kg/m^3]	1.03	1.06
Relative change (%)	-7%	+38%
Irrigation season 2020 fresh yield		
Range [ton/ha]	7.5 – 13.0	9.5 – 14.2
Average (mean) [ton/ha]	10.2	11.8

Table 22 Normalized cabbage water productivity (in kg/m^3) and fresh yield (in ton/ha) for irrigation season 2020 compared to the baseline

	Báruè (Original)	Báruè (Updated)
Baseline water productivity		
Range [kg/m^3]	0.73 – 1.44	0.65 – 1.82
Median [kg/m^3]	1.14	1.27
Irrigation season 2020 water productivity		
Range [kg/m^3]	1.10 – 1.75	0.86 – 1.97
Average (mean) [kg/m^3]	1.40	1.61
Relative change (%)	+23%	+14%
Irrigation season 2020 fresh yield		
Range [ton/ha]	10.0 – 17.8	11.4 – 19.5
Average (mean) [ton/ha]	13.8	17.5

The values for tomato water productivity increased with the updated soil type. The tomato and potato crop were also most sensitive to the effect of waterlogging, and both crops showed an improvement in water productivity values after the re-analysis, as presented in Table 23. In addition, the comparison of water productivity values by categorizing the planting dates, improved the analysis. The results in the baseline addendum showed that water productivity values differ depending on the planting date. For this reason, it is practical to compare the water productivity values with the applicable values.

The results for cabbage water productivity showed an increase in average water productivity due to the change in soil type. Overall, the increase in water productivity compared to the baseline was lower compared to the original value. This is explained by the baseline values also increasing due to the soil type change.

The summary of all four irrigation season crops is shown in Table 23 concluding that all four crops have a positive increase in water productivity and the average water productivity increase for Báruè remained at 25%, with the overall increase in water productivity remaining at 33% for all three districts.

Table 23 Overall change in water productivity for irrigation season 2020 compared to the baseline for all major irrigation season crop types (tomato, cabbage, potato, and onion) weighted by number of plots as indicated in brackets

	Báruè (Original)	Báruè (Updated)	Moatize	Nhamatanda	Overall
Tomato	-7% (11)	+38% (11)	+19% (10)	+15% (8)	
Cabbage	+23% (19)	+14% (19)	+31% (4)	+30% (4)	
Potato	-48% (3)	+32% (3)		+32% (1)	
Onion	+143% (5)	+31% (5)		+319% (2)	
Overall	+25%	+25%	+23%	+61%	+33%

Table 24 (on the next page) lists the detailed results of the water productivity analysis as presented in chapter 4 of the report and is an update of Table 9 in the report. In addition to the irrigation season crop types (tomato, potato, onion, and cabbage), beans and maize that were grown during the irrigation season were also re-analyzed with the updated soil type. The results show that the effect of soil type was limited for these crops with minor changes in the water productivity results. This confirms the assumption that the rain season water productivity results were less impacted by the soil type.

Table 24 Results of AquaCrop water productivity and crop yield, and percent change of water productivity compared to baseline for Báruè farmers

		Original				Updated			
Plot ID (location and farmer)	Crop	Water Productivity [kg/m³]	Normalized Water Productivity [kg/m³]	% change with Baseline	Fresh crop yield [ton/ha]	Water Productivity [kg/m³]	Normalized Water Productivity [kg/m³]	% change with Baseline	Fresh crop yield [ton/ha]
AP_BA_DVS-01-01	Bean	0.55	0.48		1.7	0.54	0.47		1.7
AP_BA_RF-01-02	Bean	0.68	0.60		2.6	0.63	0.55		2.7
AP_BA_ST-01-03	Bean	0.58	0.51		1.9	0.63	0.55		1.9
AP_BA_CF-01-01	Bean	0.65	0.57		1.8	0.66	0.58		2.2
AP_BA_DN-01-01	Bean	0.55	0.48		1.7	0.68	0.60		2.1
AP_BA_MTC-01-01	Bean	0.75	0.66		2.4	0.83	0.73		3.0
AP_BA_AJ-01-01	Cabbage	1.58	1.39	22%	17.8	1.94	1.70	10%	17.5
AP_BA_AJ-01-02	Cabbage	1.25	1.10	-4%	10.0	1.80	1.58	-0.6%	17.1
AP_BA_GM-01-03	Cabbage	1.58	1.39	22%	17.8	1.82	1.60	0%	18.8
AP_BA_JLC-01-01	Cabbage	1.66	1.46	28%	12.1	2.05	1.80	16%	17.6
AP_BA_JLC-01-02	Cabbage	1.57	1.38	21%	11.3	2.02	1.77	14%	19.5
AP_BA_ACI-01-02	Cabbage	1.41	1.24	9%	15.6	1.97	1.73	12%	17.6
AP_BA_ACI-01-04	Cabbage	1.59	1.40	22%	17.0	2.00	1.76	13%	19.5
AP_BA_ML-01-01	Cabbage	1.60	1.40	23%	11.5	1.85	1.62	2%	16.5
AP_BA_DVS-01-02	Cabbage	1.58	1.39	22%	17.8	1.96	1.72	11%	19.5
AP_BA_ST-01-01	Cabbage	1.58	1.39	22%	17.8	1.91	1.68	5%	19.3
AP_BA_CF-01-02	Cabbage	1.87	1.64	44%	13.2	2.24	1.97	27%	19.0
AP_BA_CF-01-03	Cabbage	1.99	1.75	53%	14.2	1.51	1.33	70%	17.6
AP_BA_JDR-01-01	Cabbage	1.57	1.38	21%	11.3	1.82	1.60	0.5%	18.9
AP_BA_JDR-01-02	Cabbage	1.45	1.27	12%	10.4	1.97	1.73	12%	17.6
AP_BA_MFD-01-01	Cabbage	1.57	1.38	21%	11.3	2.07	1.82	17%	19.5
AP_BA_MFD-01-02	Cabbage	1.64	1.44	26%	11.9	2.04	1.79	16%	17.6
AP_BA_MFD-01-03	Cabbage	1.66	1.46	28%	12.1	1.13	0.99	27%	11.7
AP_BA_BV-01-03	Cabbage	1.68	1.47	29%	12.2	1.81	1.59	0%	16.8
AP_BA_MTC-01-02	Cabbage	1.58	1.39	22%	17.8	0.98	0.86	10%	11.1
AP_BA_ST-01-02	Maize	1.13	0.99		3.8	1.02	0.90		3.8
AP_BA_DN-01-02	Maize	0.51	0.45		1.3	0.89	0.78		4.0

		Original				Updated			
Plot ID (location and farmer)	Crop	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with Baseline	Fresh crop yield [ton/ha]	Water Productivity [kg/m^3]	Normalized Water Productivity [kg/m^3]	% change with Baseline	Fresh crop yield [ton/ha]
AP_BA_CF-01-01	Onion	0.38	0.33	157%	4.6	0.80	0.70	46%	8.6
AP_BA_ST-01-01	Onion	0.31	0.27	109%	3.8	0.48	0.42	45%	5.5
AP_BA_JDR-01-03	Onion	0.41	0.36	177%	4.6	0.59	0.52	8%	5.5
AP_BA_MFD-01-03	Onion	0.35	0.31	136%	4.2	0.43	0.38	30%	4.3
AP_BA_BV-01-02	Onion	0.35	0.31	136%	3.9	0.78	0.68	27%	8.4
AP_BA_NZ-01-01	Potato	2.16	1.90	-44%	17.3	2.98	2.62	25%	26.1
AP_BA_NZ-01-02	Potato	1.69	1.48	-56%	8.7	3.69	3.24	55%	28.0
AP_BA_GM-01-02	Potato	2.15	1.89	-44%	17.9	2.87	2.52	16%	20.9
AP_BA_GM-01-01	Tomato	1.06	0.93	-16%	10.0	1.24	1.09	60%	9.5
AP_BA_JLC-01-03	Tomato	1.29	1.13	2%	10.5	1.27	1.11	27%	12.1
AP_BA_ACI-01-01	Tomato	1.41	1.24	12%	13.0	1.36	1.19	36%	14.2
AP_BA_ML-01-02	Tomato	1.17	1.03	-7%	9.8	1.14	1.00	47%	11.2
AP_BA_RF-01-01	Tomato	1.01	0.89	-20%	9.8	0.93	0.82	28%	10.8
AP_BA_CF-01-01	Tomato	1.19	1.04	-5%	7.9	1.38	1.21	38%	11.1
AP_BA_CF-01-01	Tomato	1.24	1.09	-2%	8.5	1.16	1.02	59%	12.7
AP_BA_JDR-01-04	Tomato	1.33	1.17	6%	11.2	1.30	1.14	30%	12.5
AP_BA_MFD-01-02	Tomato	1.37	1.20	9%	11.9	1.36	1.19	36%	13.2
AP_BA_MFD-01-03	Tomato	0.93	0.82	-26%	11.7	1.14	1.00	28%	12.1
AP_BA_BV-01-01	Tomato					0.95	0.83	30%	10.6