FutureWater

Water Productivity Technical Report

Baseline assessment for APSAN Vale project

REPORT 195

CLIENT Agência de desenvolvimento do Vale Zambeze (ADVZ)

AUTHORS Alexander Kaune
Jonna van Opstal

DATE January 2020

Water Productivity Technical Report

Baseline assessment for APSAN Vale project

FutureWater Report 195

Client
Agência de desenvolvimento do Vale Zambeze (ADVZ)

Authors
Alexander Kaune – Agro-hydrologist (a.kaune@futurewater.nl)
Jonna van Opstal – Senior Water Productivity Expert (j.vanopstal@futurewater.nl)

Date
January 2020

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 and WaPOR in combination with a water productivity simulation model and field observations. This report shows the water productivity baseline assessment of eight crops in three different locations in Mozambique. This assessment is crucial to further evaluate the impact of field interventions on water productivity.

Summary

In Mozambique, smallholder farming systems have a huge potential to increase water productivity by improved (irrigated) water management, better access to inputs and agronomical knowledge and improved access to markets. An assessment of the opportunities to boost the water productivity of the various agricultural production systems in Mozambique is a fundamental precondition for informed planning and decision-making processes concerning these issues. To evaluate the added value of improved practices and knowledge in farming systems (e.g. improved water management, better access to inputs and agronomical knowledge) it is necessary to initially develop a baseline assessment of water productivity. In this report, a baseline assessment of water productivity for Maize, Sorghum, Bean, Rice, Tomato, Potato, Cabbage and Onion was developed in three different locations in Mozambique (Nhamatanda, Moatize and Báruè). A crop growth model (FAO AquaCrop model) was calibrated against observed crop yields and simulated water productivity results were obtained for each crop in each location. Each crop has a different response to water stress and to field management conditions (e.g. soil fertility, irrigation) which influences crop yield. In addition, each location has different climate and soil characteristics which influences water productivity results. A time frame of 2001 to 2017 was used for the analysis with the crop growth model. Details of the methods used, and results are explained in the report. At a sub-basin and basin scale the WaPOR FAO Water Productivity database was used to calculate the biomass water productivity baseline values. A time frame of 2009 – 2018 was used for the WaPOR analysis based on the data availability in the database. This baseline study will help to assess the improvement in water productivity through field interventions.

Content

Tables

Figures

1 Introduction

1.1 Water productivity – concept and background

In order to meet the future needs of food and fibre production, developing and developed countries need to focus more on efficient and sustainable use of land and water (Bastiaanssen and Steduto, 2017). 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). Within this project the use 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.

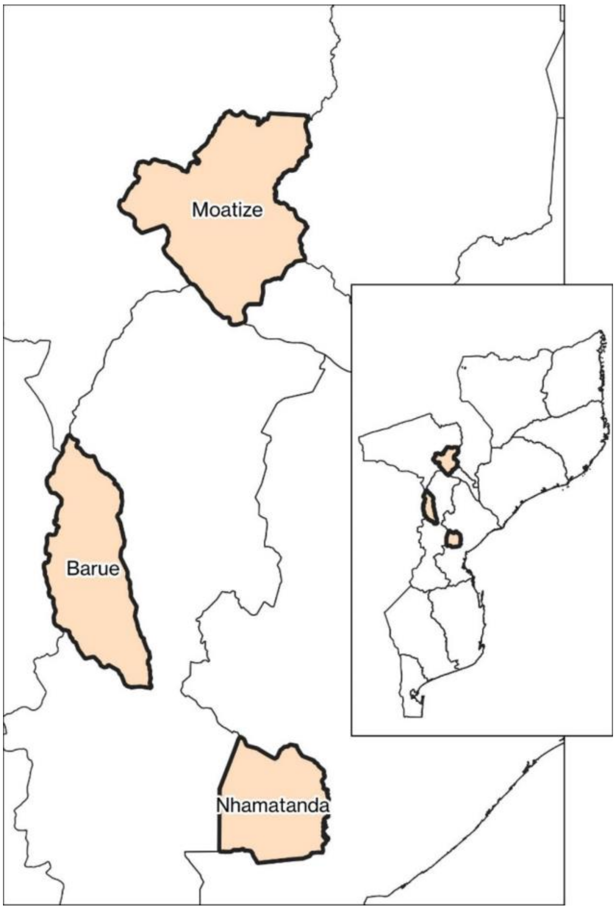


Figure 1. Location districts of APSAN project activities.

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.

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

1.3 Baseline assessment

In the logframe a baseline is stated to be at 0% for the water productivity indicators. However, it is necessary to quantify the value of the 0% to enable assessment of increases in water productivity. This baseline assessment technical report provides the water productivity values for the selected crops and districts as used in the continuation of this project. The underlying methodology, data, and calculations are included for clarification of the values (section 2). The selected crops for the water productivity assessment were selected based on their importance in these districts. They are listed in Table 2 for the different districts and distinguishing between rainfed and irrigation (horticultural) growing seasons.

Table 2. Selected crops in APSAN Vale project for water productivity assessment.

Irrigation / Rainfed Season	Region	Crop type
Rainfed	Moatize, Nhamatanda, Báruè	Maize
	Moatize, Nhamatanda, Báruè	Sorghum
	Nhamatanda	Rice
	Báruè	Beans
Irrigation	Moatize, Nhamatanda, Báruè	Tomato
	Moatize, Nhamatanda, Báruè	Cabbage
	Moatize, Nhamatanda, Báruè	Onion
	Moatize, Nhamatanda, Báruè	Potato

2 Methodology

2.1 Approach

The baseline assessment follows two approaches for the calculation of water productivity:

1. At field scale the most detailed information is available regarding crop type and management strategies. At this scale a crop specific water productivity is calculated for the selected crops at the three different districts using crop simulation modelling (2.1.1).
2. At sub-basin and basin scale limited information is available on the spatial distribution of the crop types. At this scale a biomass water productivity is calculated using data from WaPOR, FAO's Open Access Portal with Water Productivity data (2.1.2).

2.1.1 Crop specific water productivity at field scale

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; Hunink and Droogers, 2010, 2011). In addition, AquaCrop has been applied to predict water productivity and crop yield based on flying sensor information (den Besten et al., 2017) and to assess irrigation scheduling scenarios (Goosheh et al., 2018). 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 preestablished 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 2). In this work, selected model parameters were tuned based on observations. Tuned model parameters included plant density, length of the growth period, increase in canopy cover, decrease in canopy cover, harvest index, fertility stress and cover of weeds.

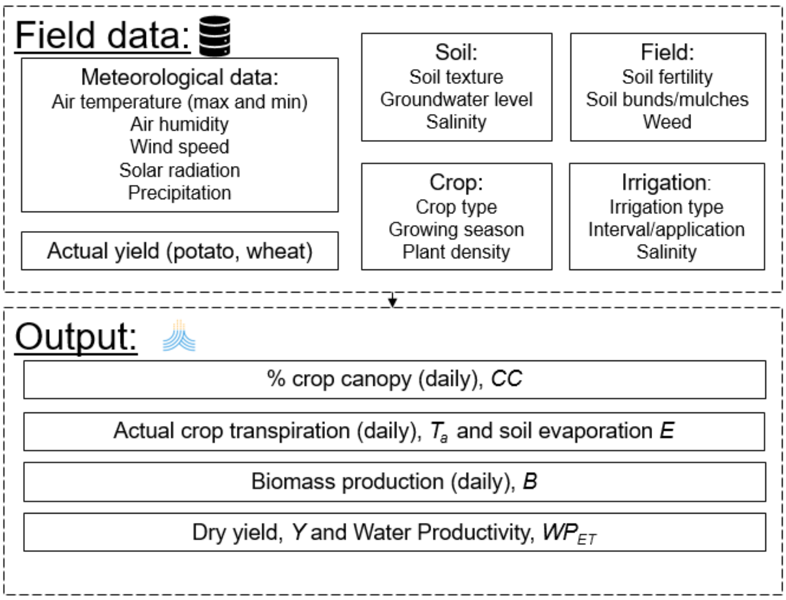


Figure 2. Field data and output simulations of the AquaCrop model.

2.1.2 Biomass water productivity at (sub-) basin scale

WaPOR is FAO's water productivity data portal containing information on evapotranspiration, biomass productiction, 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 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 3.

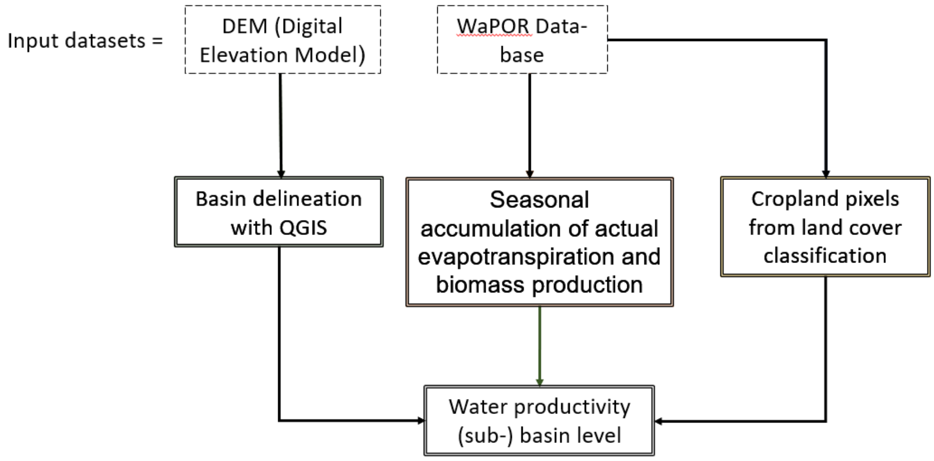


Figure 3. Workflow for (sub-) basin level water productivity assessment.

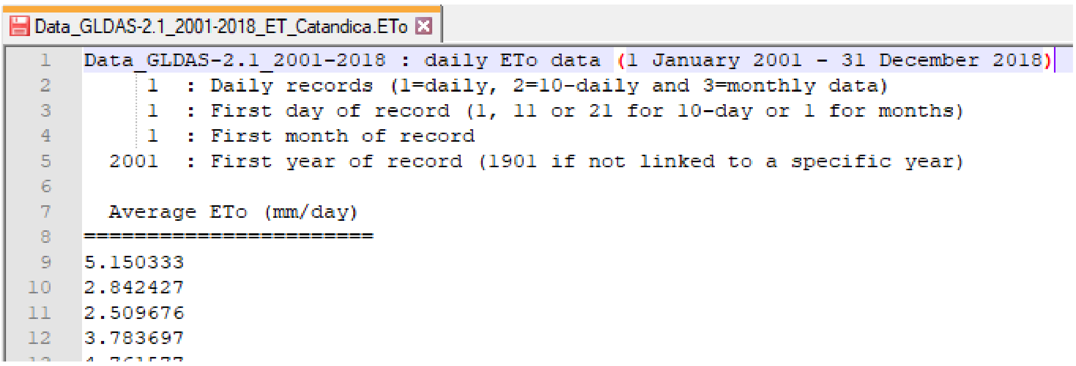
2.2 Obtaining water productivity with the AquaCrop model

2.2.1 Meteorological datasets

The water productivity simulations with the AquaCrop model were developed in three different sites in Mozambique (Báruè, Nhamatanda, and Moatize). For each of these sites the required meteorological datasets were obtained for the period 2001-2017. Meteorological datasets from ground stations normally are not available for a long period of historical record. The weather stations installed for this project in the three districts commenced recordings in 2019. Hence, we obtained meteorological datasets from available state-of-the-art global products. Daily precipitation data was obtained from CHIRPS product. CHIRPS precipitation is a remotely sensed and ground-corrected dataset available globally at 0.05º resolution (Funk et al., 2015). Daily air temperature (maximum and minimum), solar radiation and wind speed were obtained from GLDAS-2.1 to determine the daily reference evapotranspiration with the FAO Penman-Monteith equation. GLDAS-2.1 is a land surface modeling system that drives multiple models, integrates a huge quantity of observation-based data, and runs globally at 0.25° resolution (Rodell et al., 2004). A summary of the climatic data used in the AquaCrop model is shown in Table 3. In Figure 4 an example of an input file used in AquaCrop for daily reference evapotranspiration in Báruè is shown.

Table 3. Climatic daily input data used in the AquaCrop model for the period 2001-2017.

Data	Source
Precipitation	CHIRPS
Maximum temperature	GLDAS-2.1
Minimum temperature	GLDAS-2.1
Reference Evapotranspiration	Input data from GLDAS-2.1 using FAO Penman-Monteith equation


Data_GLDAS-2.1_2001-2018_ET_Catandica.ETo

```
Data_GLDAS-2.1_2001-2018 : daily ETo data (1 January 2001 - 31 December 2018)
      1  : Daily records (1=daily, 2=10-daily and 3=monthly data)
      1  : First day of record (1, 11 or 21 for 10-day or 1 for months)
      1  : First month of record
   2001  : First year of record (1901 if not linked to a specific year)

  Average ETo (mm/day)
=======================
5.150333
2.842427
2.509676
3.783697
```

Figure 4. Example input file in AquaCrop model for reference evapotranspiration ETo in Báruè.

2.2.2 Crop information

The next step is to collect basic crop information from the selected sites (Báruè, Moatize and Nhamatanda). Basic information about planting dates, plant density, total growth length (length of the crop cycle), and crop yield is key to obtain reliable AquaCrop simulations (Table 4). The planting date is similar between sites. The harvest occurs during specific months. The exact harvest date depends on the meteorological and management conditions. Plant density and crop yields may vary. Crop yields in the selected field sites are low compared to average global crop yields (FAO, 2012). Values from Table 4 were based on information from the region as listed in Annex 1.

Table 4. Crop information collected from Báruè, Moatize and Nhamatanda.

	Maize	Sorghum	Bean*	Rice**	Tomato	Potato	Cabbage	Onion
Planting date	15/11	1/12	15/11	1/02	1/03	1/03	1/03	1/03
Harvest	May	June	March	May	July	July	July	July
Plant density (plants/ha)	27,000-44,000	40,000-80,000	43,000-83,000	500,000-1,000,000	25,000-33,000	30,000-60,000	30,000-40,000	100,000-200,000
Crop yield (t/ha)	0.89-2.58	0.49-1.00	0.8-1.00	4.00	7.00-13.83	5.00-13.88	4.00	1.50-7.66

*only in Báruè, **only in Nhamatanda

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 5 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 Table 4).

Table 5. Calibrated parameters for selected crops in Báruè, Moatize and Nhamatanda.

	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage*	Onion*
HI (%)	20	10	30	50	60	80	50	40
CGC (-)	0.0050	0.0048	0.0049	0.0084	0.0075	0.0162	0.1190	0.1190
CDC (-)	0.0040	0.0039	0.0044	0.0060	0.0040	0.0020	0.1000	0.1000
From sowing to emergence (°C days)	132	210	88	40	43	310	2	6
From sowing to maximum rooting depth (°C days)	2324	2453	1332	296	891	1672	40	77
From sowing to start senescence (°C days)	2310	2447	1354	1040	1553	1525	86	45
From sowing to maturity (length of crop cycle) (°C days)	2805	2728	1947	1520	1933	1977	100	85
From sowing to flowering (°C days)	1452	1613	834	920	525	852	28	67
Length of the flowering stage (°C days)	297	474	349	280	750	1	40	18

*Growing stages in calendar days.

2.2.3 Soil and field management information

According to collected field information the soil texture of each site was determined. The hydraulic properties of the soil are correlated with the soil texture. The AquaCrop model includes pre-established hydraulic properties such as Field Capacity (FC) and Wilting Point (WP) for each soil texture. Field Capacity and Wilting Point values are key to determine the soil water storage capacity and determine the water stress thresholds. In Table 6 the soil textures obtained for each site are shown. In Figure 5, an example of FC and WP values (FC=22%, WP=10%) used in the AquaCrop model are shown for sandy loam.

Table 6. Soil texture in each site.

Site	Soil texture
Báruè	Clay
Moatize	Sandy Loam
Nhamatanda	Sandy Clay

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

Figure 5. Soil characteristic in Moatize.

For the AquaCrop model, field management information is required from each site. Field management information includes the irrigation schedule (only for irrigated crops), soil fertility conditions, and weed cover. Maize, Sorghum, Bean and Rice are rainfed crops. For Maize, Sorghum and Bean the low crop yields are driven by low soil fertility conditions. Hence, we used a range of fertility stress values in the model from 70% to 90% (Table 7). Also, according to observations weed is present in the fields, so we included a weed parameter of 50%. For Rice the observed crop yield is not too low, thus the fertility stress was set between 1% and 20% and the weed parameter at 5%. Tomato, Potato, Cabbage and Onion are irrigated crops with a known irrigation interval of 7 days. Information about the irrigation application volume is uncertain. Hence, we used a range of possible irrigation application volumes between 1mm and 10mm for a known interval of 7 days (Table 7). These are low irrigation application volumes according to the low crop yields found in the sites.

Table 7. Field management parameters for AquaCrop for rainfed and irrigated crops.

	Rainfed crops				Irrigated crops			
	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage	Onion
Irrigation application (mm)	-	-	-	-	1, 5, 10	1, 5, 10	1, 5, 10	1, 5, 10
Irrigation interval (days)	-	-	-	-	7	7	7	7
Fertility stress (%)	70, 80, 90	70, 80, 90	70, 80, 90	1, 10, 20	70	50	10	10
Relative cover of weeds (%)	50	50	50	5	5	5	5	5

2.3 (Sub-) basin water productivity

2.3.1 Basin delineation

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). The outflow points for the sub-basins and basins are determined by evaluating the location of the project activities in the fields. The sub-basins should be representative for the streamflow that has influence on 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.

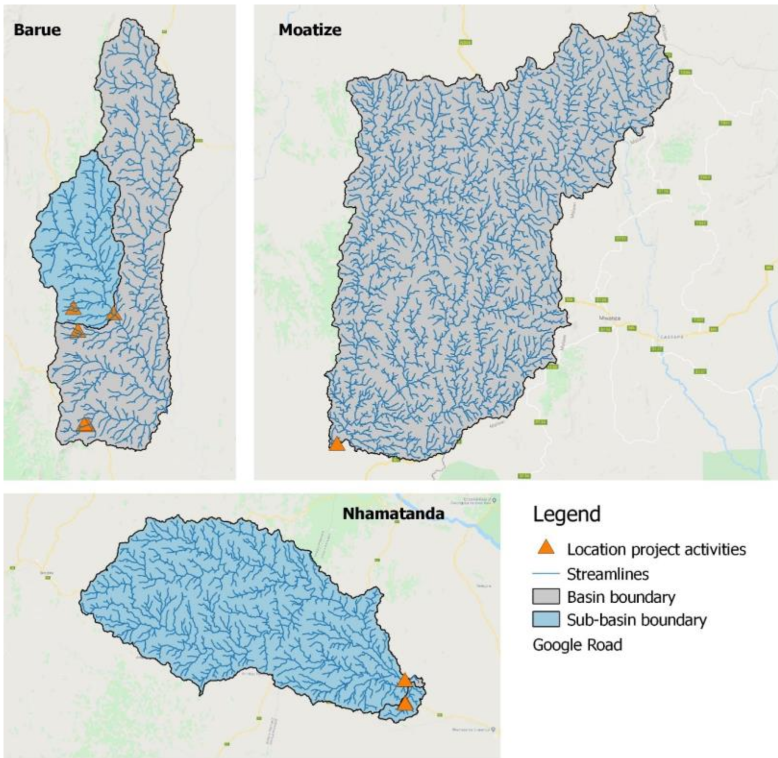


Figure 6. Streamlines and basin delineation for the three districts.

2.3.2 WaPOR

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 evapotranspiration (ET), biomass production, and land cover. Detailed information on the methodology is found in the reference documents of WaPOR (FAO, 2018). The quality of the WaPOR data is reported in the quality assessment report (FAO and IHE Delft, 2019). The data layers were downloaded for Mozambique and aggregated to find seasonal values for the rainfed season (December to April) and irrigation season (June to October). Seasonal values are calculated by using the python scripts as provided by WaterPIP, which were developed for the reporting of water productivity with WaPOR.

<u>Actual Evapotranspiration</u>

The actual evapotranspiration is calculated using a surface energy balance algorithm based on the equations of the ETLook model (Bastiaanssen et al, 2012). 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).

<u>Biomass production</u>

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 (Hilker et al 2008). This model determines the amount of photosynthetic radiation that arrives at a surface and the amount that is absorbed by vegetation depending on the amount of vegetational cover and (non-)stress conditions. This indicates the result of the photosyntheis process in NPP or dry matter biomass production. The biomass production from WaPOR is summed for the rainfed season. Note that WaPOR calculates biomass production for C3 crops, which are the majority of the crops grown globally. However, determining biomasss 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 and moisture content, which is specific for each crop type and crop variety (cultivar).

Land cover classification

WaPOR provides a land cover classification at 100m resolution indicating various vegetation classes such as shrubland, grasses, croplands, trees, etc. This layer was used to determine the location of croplands (rainfed and irrigated) in the basins. This information was used to calculated water productivity for the basins, thus excluding the water productivity of natural areas (shrublands, trees, etc.).

3 Results

3.1 Annual precipitation and reference evapotranspiration

In Figure 7 the annual precipitation and annual reference evapotranspiration is shown for the historical record of 2001-2017 in Nhamatanda, Báruè and Moatize. The period includes dry and wet years which influences the water productivity results shown in section 3.2. In 2015, relatively low precipitation (Moatize: 726mm, Báruè: 619mm, Nhamatanda: 592mm) and high evapotranspiration (Moatize: 1661mm, Báruè: 1639mm, Nhamatanda: 1598mm) is shown for the three sites (dry year). In 2001, relatively high precipitation (Moatize: 1138mm, Báruè: 1765mm, Nhamatanda: 1418mm), and low evapotranspiration (Moatize: 1376mm, Báruè: 1338mm, Nhamatanda: 1307mm) is found (wet year). Overall the precipitation in Moatize is relatively lower than the other two districts, whilst reference evapotranspiration shows a similar trend in all districts.

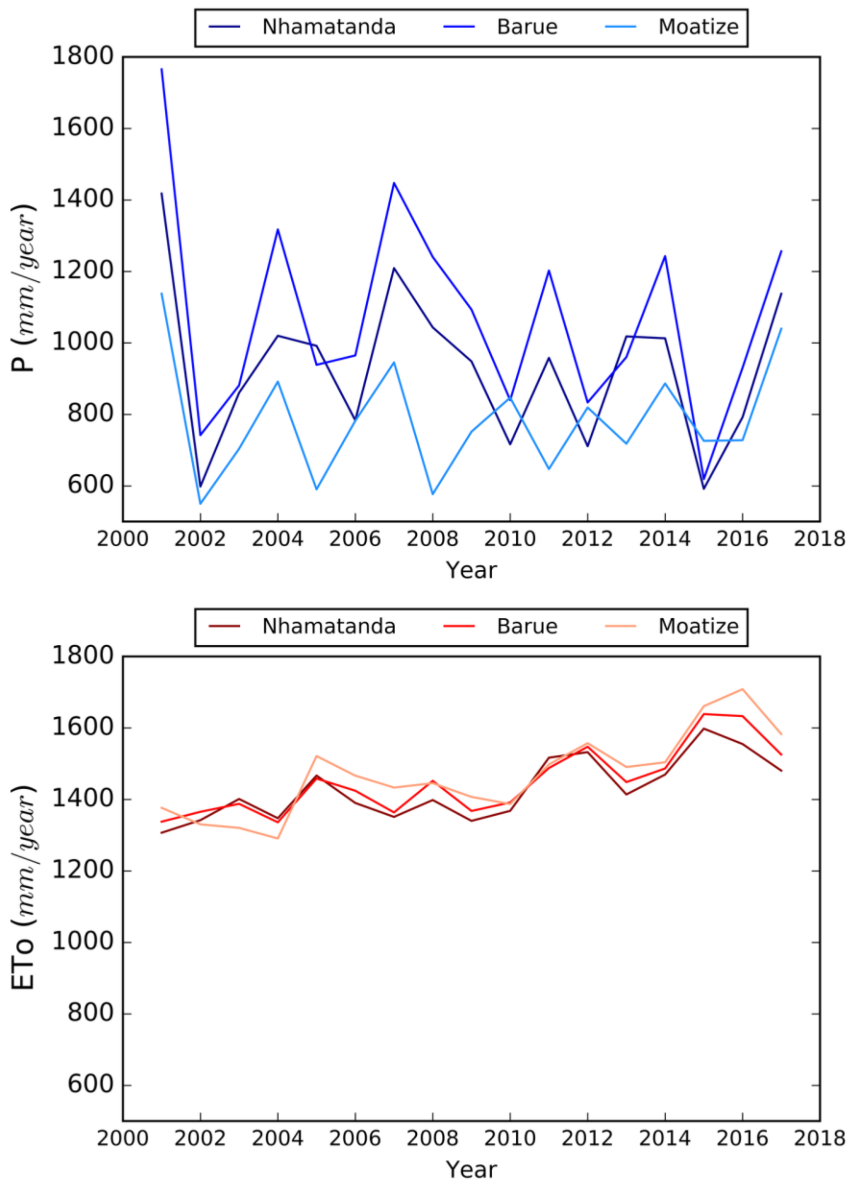


Figure 7. Annual precipitation, P (mm/year) and annual reference evapotranspiration, ETo (mm/year) for historical period 2001-2017 in Nhamatanda, Báruè and Moatize (Mozambique).

3.2 Baseline water productivity of main crops

In Table 8, Table 9, and Table 10 the baseline water productivity for rainfed and irrigated crops in Nhamatanda, Moatize and Báruè is shown for different percentiles. The water productivity results are obtained from a sample of AquaCrop simulations for the historical period 2001-2017 with a combination of model parameters. For irrigated crops the sample consists of three different irrigation applications (Table 7) and two different plant densities (Table 4). For rainfed crops the sample consists of three different fertility stress levels (Table 7) and two different plant densities (Table 4). Hence, the water productivity results include the climate variability and the variability in field management in each site. This provides a complete assessment of the baseline as the possible range of water productivity values is determined. For example, for rainfed Maize in Nhamatanda, the baseline water productivity is between 0.210 kg/m³ and 0.370 kg/m³ for a confidence interval of 80%. In Báruè, the baseline water productivity for Maize is the highest with values between 0.250 kg/m³ and 0.440 kg/m³. The highest water productivity is obtained for irrigated potato (between 3.282 kg/m³ and 4.267 kg/m³ in Moatize), which in part occurs due to relatively high crop yields. The results for rainfed rice show a high variability from 0.020 kg/m³ to 1.330 kg/m³, which in part is influenced by the high crop sensitivity due to water deficit in dry years. Results for Onion also show high variability with water productivity values equal to zero due to total yield loss in dry years, and values up to 1.060 kg/m³ in Moatize when the crop yield increases.

Table 8. Baseline water productivity (kg/m³) for rainfed and irrigated crops in Nhamatanda.

	Rainfed crops				Irrigated crops			
Percentile	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage	Onion
10th	0.210	0.221	-	0.020	1.020	2.061	0.781	0.000
25th	0.233	0.263	-	0.160	1.060	2.170	0.923	0.000
50th (median)	0.300	0.335	-	0.875	1.150	2.290	1.210	0.130
75th	0.328	0.388	-	1.165	1.265	2.428	1.370	0.415
90th	0.370	0.428	-	1.330	1.350	2.608	1.549	0.590

Table 9. Baseline water productivity (kg/m³) for rainfed and irrigated crops in Moatize.

	Rainfed crops				Irrigated crops			
Percentile	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage	Onion
10th	0.230	0.120	-	-	1.501	3.282	0.812	0.000
25th	0.260	0.140	-	-	1.630	3.515	0.950	0.120
50th (median)	0.325	0.180	-	-	1.790	3.810	1.150	0.560
75th	0.370	0.208	-	-	1.948	4.110	1.340	0.818
90th	0.409	0.220	-	-	2.247	4.267	1.540	1.060

Table 10. Baseline water productivity (kg/m³) for rainfed and irrigated crops in Báruè*

	Rainfed crops				Irrigated crops			
Percentile	Maize	Sorghum	Bean	Rice	Tomato	Potato	Cabbage	Onion
10th	0.250	0.110	0.070	-	0.692	1.552	0.731	0.000
25th	0.280	0.130	0.080	-	0.840	2.605	0.910	0.000
50th (median)	0.370	0.140	0.110	-	1.105	3.365	1.140	0.130
75th	0.410	0.160	0.138	-	1.330	3.560	1.300	0.528
90th	0.440	0.189	0.160	-	1.446	3.810	1.439	0.698

*For Báruè use the updated water productivity values for irrigated crops in Table 14 in Addendum.

3.3 (Sub-) basin biomass water productivity baseline

The results for actual evapotranspiration, biomass production, and biomass water productivity using WaPOR, are shown for each district and growing season in Table 11. The evapotranspiration is lower in Moatize during the rainfed season because there is lower rainfall in this area as was noted in the precipitation data (Figure 7). The biomass production was highest in Báruè for both the rainfed and irrigation season. This area is also observed as more fertile due to its location to the mountains (receiving more humidity) resulting in higher biomass water productivity values for Báruè than Moatize and Nhamatanda, with the latter having the lowest water productivity. Similar conclusions were drawn for the crop specific water productivity values (3.2) for selected crop types.

The maps in Figures 8 and 9 display the spatial distribution of biomass water productivity for cropland areas in the basins. Note that the areas classified as croplands are limited in the Nhamatanda basin (Figure 10). This requires further evaluation to determine if the land cover data provided by WaPOR for this area was accurate or requires further improvement. For Báruè the water productivity values are well distributed, whilst in Moatize the high water productivity values are found in upstream areas (in the mountains). The downstream areas of Moatize display lower water productivity values. These are also the areas that were selected for project activities, thus there is potential for improvement to be made.

Table 11. Evapotranspiration, Production, and Biomass Water Productivity average for the cropland areas of each basin and growing season.

	Rainfed season			Irrigation season		
	Nhamatanda	Moatize	Báruè	Nhamatanda	Moatize	Báruè
Actual Evapotranspiration [mm]	620	546	641	373	325	392
Above-ground biomass production [ton/ha]	7.1	8.3	10.2	4.8	4.7	5.8
Biomass Water Productivity [kg/m3]	1.18	1.57	1.61	1.31	1.48	1.50

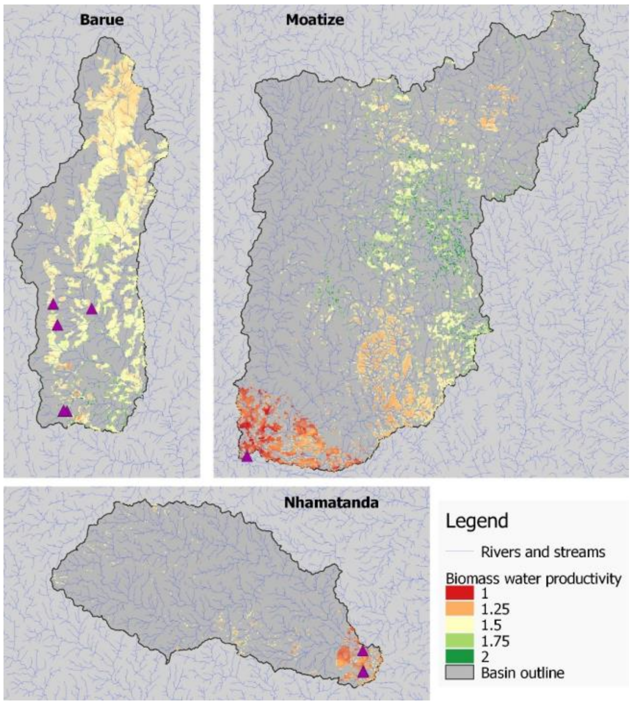


Figure 8. Irrigation season biomass water productivity average for 2009-2018.

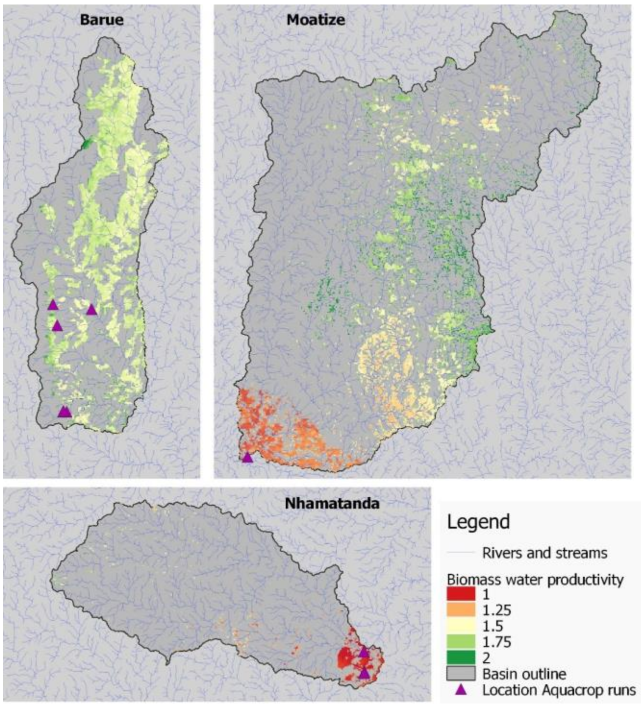


Figure 9. Rainfed season biomass water productivity average for 2009-2017.

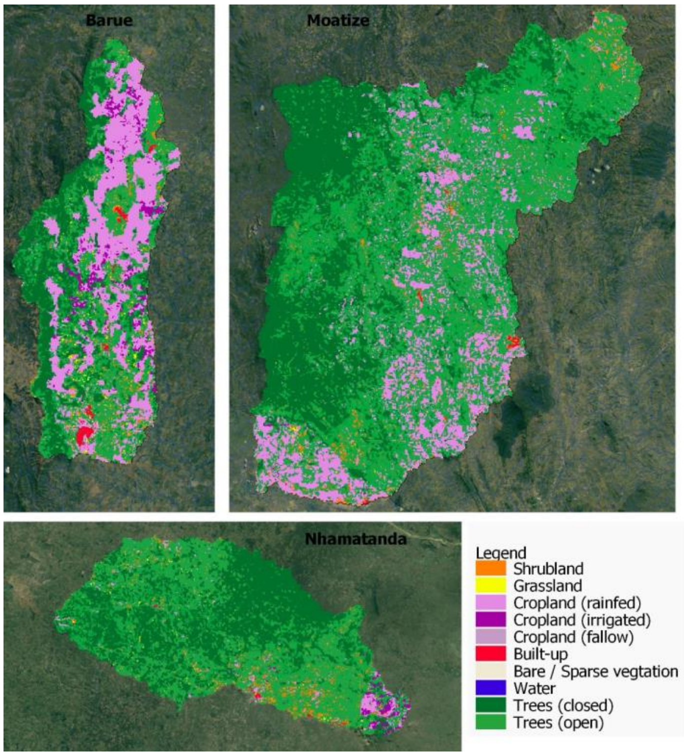


Figure 10. Land cover classification from WaPOR.

4 Conclusions and continuation

The baseline values provided for crop specific water productivity and baseline water productivity display the variability between and within districts. In additional, the selected time frame for the baseline assessment gives a representation of the temporal variability thereby incorporating both dry and wet years. The crop specific water productivity values will be used in the analysis of logframe indicators 1.2 and 1.3 to calculate the percentage increase during the project duration. The biomass water productivity values will be used in the analysis of logframe indicator 1.4. The overall impact on water productivity as presented in the project goal (0.3) will be a combination of the results in crop specific and biomass water productivity. The indicators will calculate the improvement of the water productivity in percentage. The water productivity values calculated for the growing seasons during the APSAN Vale project will be normalized for the influence of climatic conditions specific for that year. Thus the variability of climatic conditions (dry and wet years) will be reduced and the percentage of increase in water productivity represents improvement due to management strategies.

Spatial maps as presented in project outputs (1.1.1, 1.1.2, and 1.1.3) will be used to provide information to the project team, farmers (small commercial farmers), and extensionists. The sub-basin and basin maps will be used for the hydrology activities to determine the water consumption upstream of the project activities. In addition, the WaPOR data will be used to determine the potential for upscaling of project activities.

References

Agbemabiese, Y. K., Shaibu, A. and Gbedzi, V. D.: Validation of Aquacrop for Different Irrigation Regimes of Onion (Allium Cepa) in Bontanga Irrigation Scheme., 2017.

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.

Bastiaanssen, W. G. M., Cheema, M. J. M., Immerzeel, W. W., Miltenburg, I. J., & Pelgrum, H. (2012). Surface energy balance and actual evapotranspiration of the transboundary Indus Basin estimated from satellite measurements and the ETLook model. Water Resources Research, 48(11), 1–16. https://doi.org/10.1029/2011WR010482

den Besten, N., Simons, G. and Hunink, J.: Water Productivity assessment using Flying Sensors and Crop Modelling. Pilot study for Maize in Mozambique, 2017.

FAO: Crop yield response to water, FAO Irrigation and Drainage Paper, Food and Agriculture Organization of the United Nations, Rome., 2012.

FAO 2018. WaPOR Database Methodology: Level 2. Remote Sensing for Water Productivity Technical Report: Methodology Series. Rome, FAO. 63 pages. Licence: CC BY-NC-SA 3.0 IGO.

FAO and IHE Delft. 2019. WaPOR quality assessment. Technical report on the data quality of the WaPOR FAO database version 1.0. Rome. 134 pp.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelsen, J.: The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes, Sci. Data, 2, sdata201566, doi:10.1038/sdata.2015.66, 2015.

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.

Hilker, T., Coops, N. C., Wulder, M. A., Black, T. A., & Guy, R. D. (2008). The use of remote sensing in light use efficiency based models of gross primary production: A review of current status and future requirements. Science of the Total Environment, 404(2–3), 411–423. https://doi.org/10.1016/j.scitotenv.2007.11.007

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.

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.

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.

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

Pawar, G. S., Kale, M. U. and Lokhande, J. N.: Response of AquaCrop Model to Different Irrigation Schedules for Irrigated Cabbage, Agric. Res., 6(1), 73–81, doi:10.1007/s40003-016-0238-2, 2017.

Pérez-Ortolá, M., Daccache, A., Hess, T. M. and Knox, J. W.: Simulating impacts of irrigation heterogeneity on onion (Allium cepa L.) yield in a humid climate, Irrig. Sci., 33(1), 1–14, doi:10.1007/s00271-014-0444-2, 2015.

Rodell, M., Houser, P. R., Jambor, U., Gottschalck, J., Mitchell, K., Meng, C.-J., Arsenault, K., Cosgrove, B., Radakovich, J., Bosilovich, M., Entin, J. K., Walker, J. P., Lohmann, D. and Toll, D.: The Global Land Data Assimilation System, Bull. Am. Meteorol. Soc., 85(3), 381–394, doi:10.1175/BAMS-85-3-381, 2004.

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, £60.00. ISBN 0-85199-669-8, Exp. Agric., 40(3), 395–395, doi:10.1017/S0014479704372054, 2004.

Wellens, J., Raes, D., Traore, F., Denis, A., Djaby, B. and Tychon, B.: Performance assessment of the FAO AquaCrop model for irrigated cabbage on farmer plots in a semi-arid environment, Agric. Water Manag., 127, 40–47, doi:10.1016/j.agwat.2013.05.012, 2013.

Annex 1 – Overview of input data

This table provides an overview of the data collected by local observations, information from local extensionist, past reports, and other data sources. Based on this information the AquaCrop runs were set-up. For yield reports, the green highlights indicate values from local extensionists whilst yellow highlights indicate values from the FAOSTAT database (national statistics).

					Soil		Crop		Field mgt				Irrigation				Yield
Year	**Irrigation / rainfed**	**Region**	**Lat**	**Lon**	**Soil texture**	**Stoniness**	**Crop type**	**Planting date**	**Fertilizer use**	**Mulching**	**Weed managem ent**	**Runoff manage ment**	**Irrigatio n (yes/no)**	**Irrigation method**	**Irrigatio n interval (days)**	**Irrigatio n depth (m3/ha)**	**Crop yield end of this season [ton/ha]**
2001-2018	Rainfed	Moatize	-15.77	34.11	sandyloam	moderate	Maize	15/Nov	low	no	moderate	no	no	N/A	N/A	N/A	0.89
2001-2018	Rainfed	Moatize	-15.77	34.11	sandyloam	moderate	Sorghum	01/Dec	low	no	moderate	no	no	N/A	N/A	N/A	0.49
2001-2018	Rainfed	Nhamatanda	-19.22	34.09	sandy clay	moderate	Maize	15/Nov	low	no	moderate	no	no	N/A	N/A	N/A	2.58
2001-2018	Rainfed	Nhamatanda	-19.22	34.09	sandy clay	moderate	Sorghum	01/Dec	low	no	moderate	no	no	N/A	N/A	N/A	1.00
2001-2018	Rainfed	Nhamatanda	-19.22	34.09	sandy clay	moderate	Rice	01/Feb	low	no	moderate	no	no	N/A	N/A	N/A	4.00
2001-2018	Rainfed	Barue	-17.94	33.15	clay	moderate	Maize	15/Nov	low	no	moderate	no	no	N/A	N/A	N/A	0.89
2001-2018	Rainfed	Barue	-17.94	33.15	clay	moderate	Sorghum	01/Dec	low	no	moderate	no	no	N/A	N/A	N/A	0.49
2001-2018	Rainfed	Barue	-17.94	33.15	clay	moderate	Beans	15/Nov	low	no	moderate	no	no	N/A	N/A	N/A	
2001-2018	Irrigation	Moatize	-15.77	34.11	sandyloam	moderate	Tomato	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		13.83
2001-2018	Irrigation	Moatize	-15.77	34.11	sandyloam	moderate	Cabbage	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		
2001-2018	Irrigation	Moatize	-15.77	34.11	sandyloam	moderate	Onion	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		7.66
2001-2018	Irrigation	Moatize	-15.77	34.11	sandyloam	moderate	Potato	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		13.88
2001-2018	Irrigation	Nhamatanda	-19.22	34.09	sandy clay	moderate	Tomato	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		7.00
2001-2018	Irrigation	Nhamatanda	-19.22	34.09	sandy clay	moderate	Cabbage	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		4.00
2001-2018	Irrigation	Nhamatanda	-19.22	34.09	sandy clay	moderate	Onion	01/Mar	moderate	no	moderate	no	yes	buckets/furrows	7		1.50
2001-2018	Irrigation	Nhamatanda	-19.22	34.09	sandy clay	moderate	Potato	01/Mar	moderate	no	moderate	no	yes	furrows	7		5.00
2001-2018	Irrigation	Barue	-17.94	33.15	clay	moderate	Tomato	01/Mar	moderate	no	moderate	no	yes	furrows/sprinklers	7		13.83
2001-2018	Irrigation	Barue	-17.94	33.15	clay	moderate	Cabbage	01/Mar	moderate	no	moderate	no	yes	furrows/sprinklers	7		
2001-2018	Irrigation	Barue	-17.94	33.15	clay	moderate	Onion	01/Mar	moderate	no	moderate	no	yes	furrows/sprinklers	7		7.66
2001-2018	Irrigation	Barue	-17.94	33.15	clay	moderate	Potato	01/Mar	moderate	no	moderate	no	yes	furrows/sprinklers	7		13.88

Addendum June 2021 - Constraining uncertainties for baseline water productivity results

Introduction

Based on new field information, updated baseline water productivity results were determined for tomato, potato, cabbage and onion in Báruè after constraining uncertainties about the soil type, planting dates, and growth lengths. New field information from Nhamatanda and Moatize did not lead to a necessity to update the baseline water productivity analysis for those districts.

Update to input parameters

Soils in Báruè turn out to actually be of type sandy clay loam instead of heavy clay (Table 12).

Table 12. Updated soil texture for Báruè.

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

Planting dates can actually vary over April to July. Hence, we categorized four planting dates (instead of only one): A) 15 April, B) 15 May, C) 15 June, and D) 15 July. Also, the growth length for each crop is on average approximately only 3 months (instead of 5 months). So for example, if the planting date for tomato is 15 May, then the harvest date is 12 August (Table 13). Some additional minor adjustments were made in the crop growth cycle parameters (growth-degree-days GDD, or growth days) for fine tuning the calibration results.

Table 13. Updated vs original planting and harvesting dates for Báruè.

Crop	Growing period (updated)			Growing period (original)	
	Period	Planting date	Harvesting date	Planting date	Harvesting date
Tomato	A	15 April	13 July	1 March	1 July
	B	15 May	12 August		
	C	15 June	12 September		
	D	15 July	12 October		
Potato	A	15 April	19 July	1 March	1 July
	B	15 May	18 August		
	C	15 June	18 September		
	D	15 July	18 October		
Cabbage	A	15 April	19 July	1 March	1 July
	B	15 May	18 August		
	C	15 June	18 September		
	D	15 July	18 October		
Onion	A	15 April	16 July	1 March	1 July
	B	15 May	15 August		
	C	15 June	15 September		
	D	15 July	15 October		

Updated results

Table 14 shows the updated baseline water productivity results after constraining the uncertainties. The range of water productivity results for a given planting date occurs due to the variability in climate (2001-2017) and irrigation application (1, 5 and 10 mm), just like in the original analysis. Results in Table 14 are more accurate than the initial results obtained in Table 10 as updated information about soils, planting dates and growth lengths were used.

Table 14. Updated baseline water productivity (kg/m³) for irrigated tomato, potato, cabbage and onion in Báruè, based on the new input parameters, for the different growing periods (A to D).

Percentile	Cabbage				Onion			
	A	B	C	D	A	B	C	D
10th	1.02	1.36	1.03	0.65	0.00	0.03	0.11	0.00
25th	1.27	1.52	1.09	0.72	0.10	0.15	0.27	0.02
50th	1.55	1.59	1.17	0.78	0.29	0.48	0.54	0.20
75th	1.68	1.68	1.30	0.85	0.57	0.78	0.81	0.38
90th	1.82	1.75	1.38	0.96	0.93	1.21	1.23	0.62

Percentile	Potato				Tomato			
	A	B	C	D	A	B	C	D
10th	1.82	1.89	1.62	1.39	0.65	0.52	0.50	0.62
25th	1.94	1.96	1.68	1.48	0.77	0.58	0.55	0.67
50th	2.09	2.16	1.83	1.58	0.88	0.68	0.64	0.78
75th	2.38	2.45	2.09	1.78	1.07	0.83	0.77	0.89
90th	2.57	2.66	2.21	1.98	1.19	0.90	0.85	0.99

Results in Table 14 should be used to compare against water productivity field interventions in Báruè and will therefore be used retroactively in the following report:

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