Final report

Remote Sensing for Land Suitability Assessment in Angola

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1 Introduction

1.1 Background

The government of Angola considers the agricultural sector as an economic sector that offers great prospects and therefore aims to further develop the agricultural sector in order to diversify its economy. The potential for expanding the area under production is great. The country has fertile soils, a favorable climate, sufficient water resources and abundant unexploited land. Specifically, the province of Huambo is mentioned as one of the most promising areas for a growing agricultural sector.

Currently, the Angolan agricultural sector is characterized by low productivity and low competitiveness. To support the effective planning of interventions that increase production and expand the agricultural sector, reliable information is crucial. The reliability of the existing data on agricultural production in Angola is unclear. Additionally, there is no insight in which regions of unexploited lands would show the highest potential yields if put into production. Therefore, the uncertainty related to investing in new land resources is high.

This pilot project focused on the use of remote sensing for providing relevant data and information to support effective decision making and planning for the expansion of the Angolan agricultural sector.

1.2 Objectives

The general purpose of the project was the development and application of remote-sensing based products that support planning and monitoring of agricultural development, and the assessment of the potential of agricultural areas for three selected crops.

The specific objectives of this pilot project were to provide the Institute for Agricultural Development (IDA) and the Faculty of Agricultural Sciences of the José Eduardo dos Santos University (UJES-FCA) with:

- Information on trends (of the past 10 years) in land use and land development and insight in the reliability of historical statistical data;
- An agro-ecological potential map for the province of Huambo for 3 crops;
- A tentative map showing irrigation potential in the Province of Huambo.

1.3 Study area

The project focused on the Angolan Province of Huambo. As the main agricultural center in the country, Huambo is a priority area for agricultural development and expansion. The central province is landlocked and relatively small with a surface area of just over 34,000 km^2. There are typically three agricultural production cycles in the area.

Figure 1. Location of Huambo Province in the center of Angola.

2 Approach

2.1 General methodology

The objectives of the assignment as stated in Paragraph 1.2 translate to three types of project output. New insights gained over the course of the project to further specification (and, to a certain extent, modification) of the project deliverables, as listed below:

1. A trend analysis of (agricultural) land use and land development:
    a. Historical (10 consecutive years) trend analysis for the province of Huambo based on phenology analysis at 250m resolution;
    b. Historical trend analysis (4 separate years) for a smaller region that falls within 1 Landsat tile covering the south-eastern quarter of Huambo province (at 30m resolution);
2. Crop-specific agro-ecological potential maps for the province of Huambo:
    a. Maize (2 growing seasons);
    b. Potato (3 growing seasons);
    c. Beans (1 growing season).
3. A tentative irrigation potential map for the province of Huambo;
4. Presentation of Agro-Ecological potential and Irrigation potential maps in FieldLook.

Details on the above project deliverables are discussed in Chapter 3 of this report. These spatial data products are the end products of information chains relying heavily on remotely sensed data. The consortium only made use of satellite imagery and spatial data products that are available in the public domain. Specific steps and technical assumptions were discussed with UJES-FCA to ensure their relevance for the Angolan context.

Early in the project, in consultation with RVO, the decision was taken to transfer some of the budget foreseen for technical activities to the travel budget. This allowed for the project team to pay sufficient attention to the cooperation and business development components of the project. The event was organized in conjunction with the other Dutch pilot consortium active in Huambo, the Knowledge-to-Knowledge team of Wageningen UR, as well as with support from the Dutch Embassy and the Netherlands Space Office. This event enhanced the chances of a successful introduction of the developed remote sensing-derived products to the Angolan market (see Chapter 4 for further details). As a result of this budget shift, some of the technical activities as described in the project proposal were somewhat simplified and/or made more efficient. Where relevant, these adjustments are described in this report.

2.2 Trend analysis of agricultural land use

The methodology initially proposed for mapping cropping patterns for a 10-year historical period was updated as a result of challenges encountered early in the project. Because of the presence of persistent cloud cover over Huambo province, it was not feasible to use 30 m Landsat data with a repeat cycle of approximately 16 days over a historical period of 10 years. Since coarser resolution MODIS data (250m) is available on a daily basis for the same historical time period, we were able to utilize the increased temporal resolution of MODIS to extract more cloud-free data. Hence, we processed MODIS-based data to produce maps showing cropping cycles of Huambo province at 250 m spatial resolution (instead of 30m) for the historical period 2007-2017.

In order to compare the level of spatial and temporal detail that can be obtained using higher resolution optical satellite data, we used Landsat (30m) data to produce maps showing the cropping cycles only for the dry season (May to September) of 4 separate calendar years (2008, 2013, 2015, 2017). Since this was a demonstration product, we only processed 1 tile of Landsat data for comparison. As Huambo province is covered by 4 Landsat tiles (see Figure 2), we selected the tile that covers a large portion of the south-eastern section of the province.

The updated methodology described above also considered the transfer of part of the technical budget to travel / cooperation budget, as described in Paragraph 2.1.

Figure 2. Map showing the 4 Landsat tiles that cover Huambo Province in Angola. We downloaded Landsat data for the tile that covers the south-eastern part of the province. It is denoted as Landsat tile path 180 row 69.

The two revised activities described above require acquisition of MODIS (250m) and Landsat (30m) satellite data and processing them as described below:

1. MODIS

- Download: Daily MODS (250m) data for the 10-year historical period 2007-2017.
- Processing:
  1.1. Produce 14-day Normalized Vegetation Index (NDVI) composites starting 1-1-2007 and ending 31-12-2017 (287 composites over the 10-year period). This process minimizes the effect of cloud cover on all pixels. When a pixel is obscured by cloud cover for the entire 14-day period, the NDVI value of the previous composite date was used.
  1.2. A quality layer was produced for each of the NDVI composites. This indicates whether an NDVI value was calculated for the pixel or whether a previous value was used due to persistent cloud cover.
  1.3. Estimate the seasonal trends (phenology) that occurred in the 10 years covered by the historical dataset of MODIS-based 14-day NDVI composites. We appied a similar phenology algorithm[1] that is applied to 100m (Proba-V) and 30m (Landsat) data for the

[1] Based on methodology described in Van Hoolst, R., Eerens, H., Haesen, D., Royer, A., Bydekerke, L., Rojas, O., ... & Racionzer, P. (2016). FAO's AVHRR-based Agricultural Stress Index System (ASIS) for global drought monitoring. *International Journal of Remote Sensing*, *37*(2), 418-439.

FAO WaPOR database. The results were analyzed for the ability of MODIS-based NDVI data (at 250 m resolution) to characterize cropping seasons in the study area.

1.4. Report an annotated description of the observed results for Huambo province for 2007-2017.
1.5. The 14-day NDVI composites for 2007-2012 were transferred to FutureWater for use in the production of agro-ecological potential maps. The NDVI data is used as proxy for current land productivity.
1.6. As a final step, we applied an algorithm[1] that aims to identify high growth vegetation types (including crops) to the long-term time series of MODIS-based NDVI. This step was added in order to compare Landsat-based results produced (see point 2.4 below).

2. Landsat

- Download: Landsat 5, 7, and 8 data for the period May-September for the following calendar years: 2008 (10 images are available), 2013 (9 images), 2015 (15 images), and 2017 (19 images).
- Processing:
  2.1. Pre-process the downloaded raw satellite data by cloud-masking, gap-masking (gaps that occur in Landsat 7 data due to the Scan Line Correction error) and running gap-filling algorithms.
  2.2. Calculate NDVI using the red and near-infrared reflectance bands of Landsat.
  2.3. Calculate dekadal NDVI composite images.
  2.4. For reasons explained in section 3.1.2, we did not run a phenology algorithm on the Landsat data. Instead, we applied an algorithm to the dry season (May-Sept) of the 4 separate calendar years of Landsat-based dekadal NDVI composites that aims to identify high growth vegetation types (including crops). The algorithm[2] was developed to identify crop fields in high intensity cropping areas, where the results can be used to identify crop fields through the presence of high 'crop probability' values. However, the conditions in Huambo are different in that fields are smaller and lower intensity cropping is practiced. Therefore, when the algorithm was applied to Huambo province, pixels with the highest 'crop probability' represent woodland and other high growth vegetation areas including cropland.These results were analysed for further insight in the spatial and temporal patterns of high growth vegetation (including cropland) at 30 m resolution.
  2.5. Report an annotated description of the observed results for Huambo province. A comparison was made with the MODIS-based results.

2.3 Agro-ecological potential maps

Activity 2 concerns the production of an agro-ecological potential map of the province of Huambo. This map can support the government of Angola and the IDA to identify the most promising areas to invest in agricultural expansion. The original intention was to select three crops, where with 3 cropping cycles per year, a maximum of 9 maps would be prepared. After consultation with UJES-FCA, it became clear that in fact not all three seasons are relevant for the main crops. The crops maize, potato and beans were identified as the most interesting crops for Huambo Province. It is possible for potato farmers to take advantage of three growing seasons, whereas maize and beans are grown during two and one growing season(s) respectively. Findings regarding crop cultivation as discussed with UJES-FCA are reported in

[1] Following the methodology described in Yan, L. and Roy, D.P. (2014). Automated crop field extraction from multi-temporal Web Enabled Landsat Data. Remote Sensing of Environment, 144:42-64.

Table 1. Agro-ecological suitability maps will be produced in accordance with this cropping calendar.

Table 1. Cropping seasons in Huambo Province (based on correspondence with UJES-FCA).

Crop	*Sowing month*	*Harvesting month*	*Comments*
Maize	October	May	Season length depending on variety
	July	October - December	Much used for fresh consumption. Season length depending on variety and October rains.
Potato	October	January	Prone to diseases, requires heavy phytosanitary treatment, not cultivated by many farmers
	February	May	The most profitable and most productive season. Rainfed early in the season and can end with irrigation depending on the variety. Cultivated by all potato farmers.
	July	October	Only cultivated by farmers with access to irrigation. Risky due to possible rains in September, which may require harvesting before full maturity.
Beans	February	June	Cannot be sown too early as it can suffer damage to flowers by February precipitation.
Cassava	Cassava can be cultivated throughout the year and is particularly relevant to food security		

The agro-ecological potential maps essentially indicate where the potential crop yield is expected to be highest for each of the crops and each of the seasons, based on long-term natural conditions (unirrigated). *Slope* of the terrain is an important factor to consider, in order to determine whether crop cultivation is feasible at a location. In addition, three stress types commonly assumed to determine crop growth were included: *soil water stress*, *air temperature stress*, and *soil fertility stress.* Finally, as a proxy of all integrated landscape and climate features, *current land productivity* was also included in the final agro-ecological potential maps. The procedure was followed for each of the combinations of crops and seasons listed in Table 1, thus incorporating typical climatological patterns as well as crop-specific properties such as rooting depth and crop factor used in potential evapotranspiration calculations.

The integrated agro-ecological potential maps were expressed in percentages, as an average value of each of the five criteria: slope, land productivity, and the three crop growth stress factors. The input datasets were available with a variety of spatial resolutions. The end products were delivered with a 100x100m resolution (1 ha).

Appropriate input datasets for performing the land suitability mapping procedure were identified based on several criteria, such as availability for Huambo Province, long-term availability for a recent period, and spatial resolution. Given the potential of remote sensing technology to meet these requirements, many of the identified datasets are derived from satellite observations. Table 2 lists all the identified datasets with their key properties. The period of analysis was determined at 2002 – 2012, based on data availability and the required length to draw long-term conclusions.

Table 2. Overview of inputs to the agro-ecological land suitability mapping procedure.

Description	*Source*	*Resolution*	*Satellite-derived?*
Elevation	SRTM[1]	90 m	Y
Daily rainfall	CHIRPS	5 km	Y
Daily temperature (min, mean, max)	Earth2Observe[2], downscaled with DEM	5 km (interpolated with DEM / lapse rate)	Partly
Soil hydraulic properties	HiHydroSoil[3]	250 m	Partly
Soil nutrient content	SoilGrids[4]	250 m	Partly
Land use	Copernicus[5]	100 m	Y
Reference evapotranspiration	Earth2Observe	1 km	N
NDVI	MODIS	250 m	Y

2.4 Tentative irrigation potential map

For reasons described in Paragraph 2.1, as well as the absence of calibration data for the irrigation model, the method for creating the tentative irrigation potential map was somewhat simplified compared to the original project proposal. An adjusted methodology was developed in which the agro-hydrological model Spatial Processes in HYdrology (SPHY)[6] was set up for entire Huambo province, assuming irrigated agriculture all over the province. This results in a map of evapotranspiration deficit per pixel, which is a measure of the volumes of water that would need to be supplied by irrigation (moisture stress of the crop). The model was set up for one year; the driest year in the 2002 – 2012 period.

Another crucial component in assessing the potential for irrigation is the distance from the potential irrigation scheme to the natural course of a river, stream, lake, or to an existing reservoir. GIS data layers on the stream network (WWF Hydrosheds)[7] and lakes and reservoirs (Global Lakes and Wetlands Database)[8] was used to assess the distance from potential water sources, as well as the elevation difference that would need to be overcome by pumping. Combined with the evapotranspiration deficit map and the slope of the terrain, this yielded a tentative irrigation potential map of Huambo Province.

All model input datasets were downloaded and preprocessed / reprojected where necessary. Air temperature from the Earth2Observe dataset was downscaled based on a digital elevation model and a lapse rate of -0.0065 °C/m. Based on the daily CHIRPS rainfall data, annual rainfall was evaluated to select the driest year. The driest year of the considered time series was found to be 2012, with an annual total rainfall of 1,100 mm. The model was set up for this year with a spatial resolution of 100 x 100 m.

[1] https://www2.jpl.nasa.gov/srtm/
[2] http://www.earth2observe.eu/
[3] https://www.futurewater.nl/2015/07/soil-hydraulic-properties-nl/
[4] https://www.isric.org/explore/soilgrids
[5] https://land.copernicus.eu/global/products/lc
[6] www.sphy.nl
[7] https://www.worldwildlife.org/pages/hydrosheds
[8] https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database

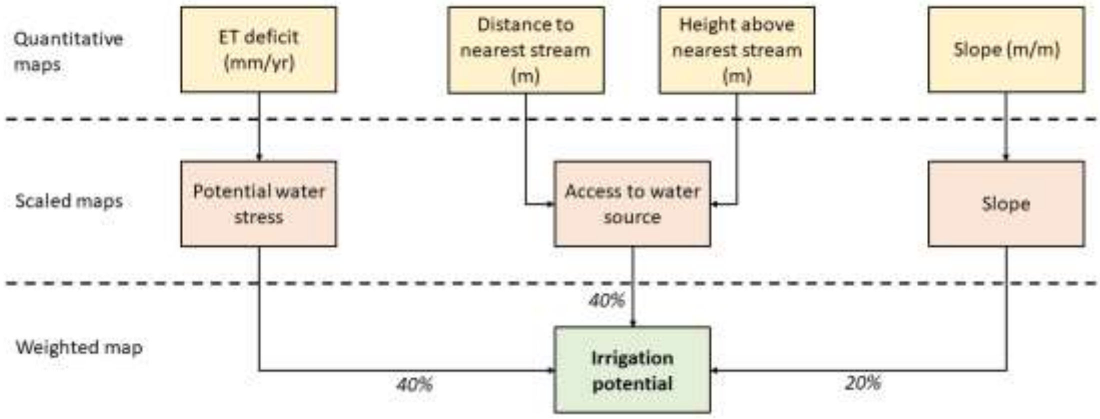

Figure 3 Flowchart of applied methodology for producing the tentative irrigation potential map.

3.1 Trend analysis of agricultural land use

3.1.1 *NDVI*

First processing steps of the MODIS and Landsat satellite data (as set out respectively in points 1.1 and 2.1-2.3 of Section 2.2) produced intermediary datasets in the form of Normalized Difference Vegetation Index (NDVI) composites. The NDVI correlates well with photosynthetically active vegetation and is therefore a measure of the greenness of the earth's surface. As it is calculated using only the red and NIR bands, the NDVI is a commonly used vegetation index that can easily be derived using most multispectral sensors.

In order to minimize the effect of cloud cover, we combined data for several days into 1 dataset – referred to as a *composite*. MODIS-based (250m) 14-day NDVI composites for the period 2007-2017 consisted of 287 data layers for Huambo province. Landsat-based (30m) dekadal[1] NDVI composites were created for the relatively clear-sky period stretching from May to September of four separate years, 2008, 2013, 2015, 2017. Since adding Landsat for these purposes was a test case, we only used data for one Landsat tile. The period that was covered by Landsat for each separate calendar year was made up of 15 dekadal NDVI composites, representing dekad 13 to 27 for each of the 4 calendar years. The reasons for working with a temporal subset are explained in section 2.2.

Figure 4 shows an example of NDVI composite datasets based on MODIS (250m, right) and Landsat (30m, middle) for a similar composite time period. On the NDVI images, darker shades of green respresent higher NDVI values which indicate denser vegetation and/or vigorous vegetation growth. Although the Landsat data shows more detail than the MODIS based NDVI, the 2 NDVI images show similar patterns, which correspond to the patterns of vegetation growth in the area. A very high-resolution satellite image available in Google is shown on the left for context. In this example area in Huambo province, higher NDVI values mainly correspond to areas of woodland and riverine vegetation.

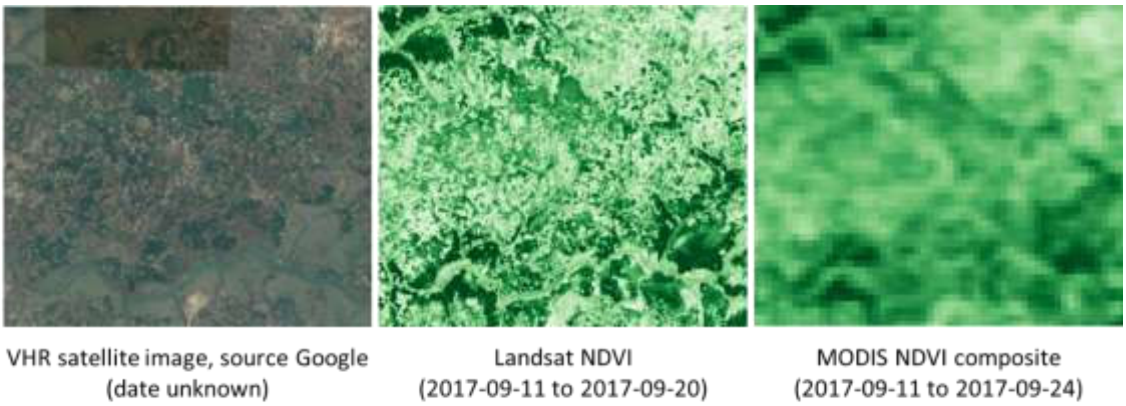

Figure 4. Examples of Landsat and MODIS based NDVI for a subset of the area covered by Landsat. The Landsat and MODIS based NDVI data is shown using the same legend where darker shades of green respresent higher NDVI values. For context, the very high resolution image on the left was obtained from Google.

[1] Dekadal refers to a period of approximately 10 days. It splits the month in 3 parts, where the first and second dekads consist of 10 days each and the duration of the last dekad ranges between 8 and 11 days.

3.1.2 *Phenology*

Phenology indicates the cycle or season of a crop and can be characterized by the moment that a growing season starts and when it ends. Phenology can be derived from satellite-based NDVI time series. The graph in Figure 5 shows how NDVI values increase and decrease over the course of a growing season. By identifying the seasonal maximum NDVI, the phenology algorithm identifies the start of the season (SOS) by identifying a 75^{th} percentile NDVI value earlier along the time line, and similar for the end of season (EOS).

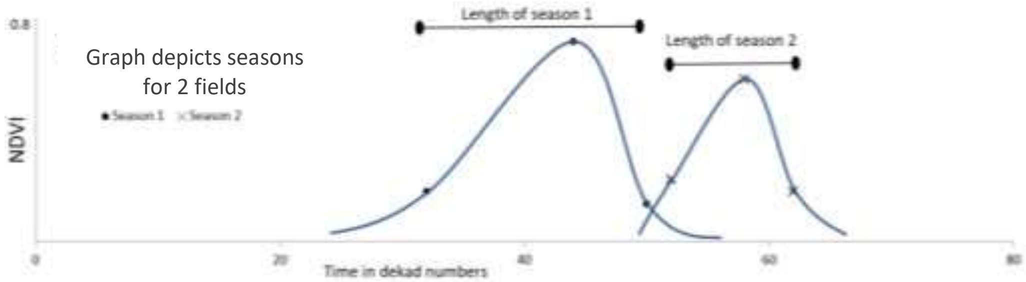

Figure 5 Graph showing how the start and end of a growing season can be determined from an NDVI time series. This example shows the NDVI curves for 2 separate fields, containing a crop in season 1 and in season 2 respectively.

Since growing seasons can span across different calendar years, a growing season is assigned to a calendar year if the EOS occurs in it. However, when the EOS occurs very early in a calendar year, applying this rule will give an incorrect representation of when the season took place. Therefore, if the EOS occurs within January, the season is attributed to the previous calendar year.

Through phenology analysis, we can potentially find areas where changes in temporal and spatial trends or patterns in growing seasons have taken place, for example it should become clear if growing seasons start earlier or end later, or become longer or shorter over time.

Note that the phenology analysis will also include natural vegetation that has a seasonal pattern. For example deciduous natural woodland types will show seasonal trends. For some land cover types the NDVI values do not fluctuate strongly enough to identify a clear start and end of season, thereby being left out of the estimation of cropping areas, e.g. urban areas with very little vegetataion. If no growing season can be distinguished, a 'no season' label is applied.

The accuracy of phenology analyses can be affected by various additional factors. Outcomes of phenology analyses depend on the definitions of the start/end of growing season as applied in the phenology algorithm. The quality of the NDVI time series plays a determining role in the phenology outcome. For example, noise in the NDVI time series can cause the incorrect identification of different seasons. Furthermore, the pixel size of the input data will determine the detail and usefulness of the outcome. Lower resolution pixels such as MODIS-based NDVI will not be able to identify field-level growth trends, but should be interpreted with a focus on regional trends of general vegetation growth cycles.

The results of the phenology analysis applied to 250m MODIS-based NDVI data are shown in Figure 6.to **Figure 9**. The maps in the left column indicate the date of the Start of Season (SOS) and the maps in the middle column represents the date of the End of Season (EOS) whilst the map in the column on the right indicates the length of the season in number of days (between the SOS and EOS). The colour bar for each map column can be found at the bottom of the column. The SOS and EOS legends represent a range of calendar dates, with dark blue representing early dates in the given date range and yellow representing later dates in the given date range. It is important to check the date range given on the legend as in Figure 6, for example, dark blue on the SOS map represents a start of season around July of the previous calendar year, whilst dark blue in the EOS map represents an end of season around January of the target year.

Furthermore, dark blue in the maps on the right represents areas where only a short season of approximately 10-13 days was detected. Since it is unlikely that such short cropping seasons exist in Huambo, we assume that these areas probably do not represent cropland - these results may be erroneous, but they were probably obtained because another vegetation type has presented an NDVI curve that was identified by the algorithm as a short season. Season 1 of calendar years 2010, 2011 and 2013 show particularly high percentages of very short seasons and 2016 has a particular patch of short season 1 and 2 in the north of the province.

MODIS-based phenology results were also produced for a third season, but only scattered pixels were detected as having a third growing season, and most very short (10-15 days), we therefore did not include these results in the report. Note that phenology results were not produced for 2007 as the NDVI values in this year do not form a complete first season. This is also true for the last season of 2017.

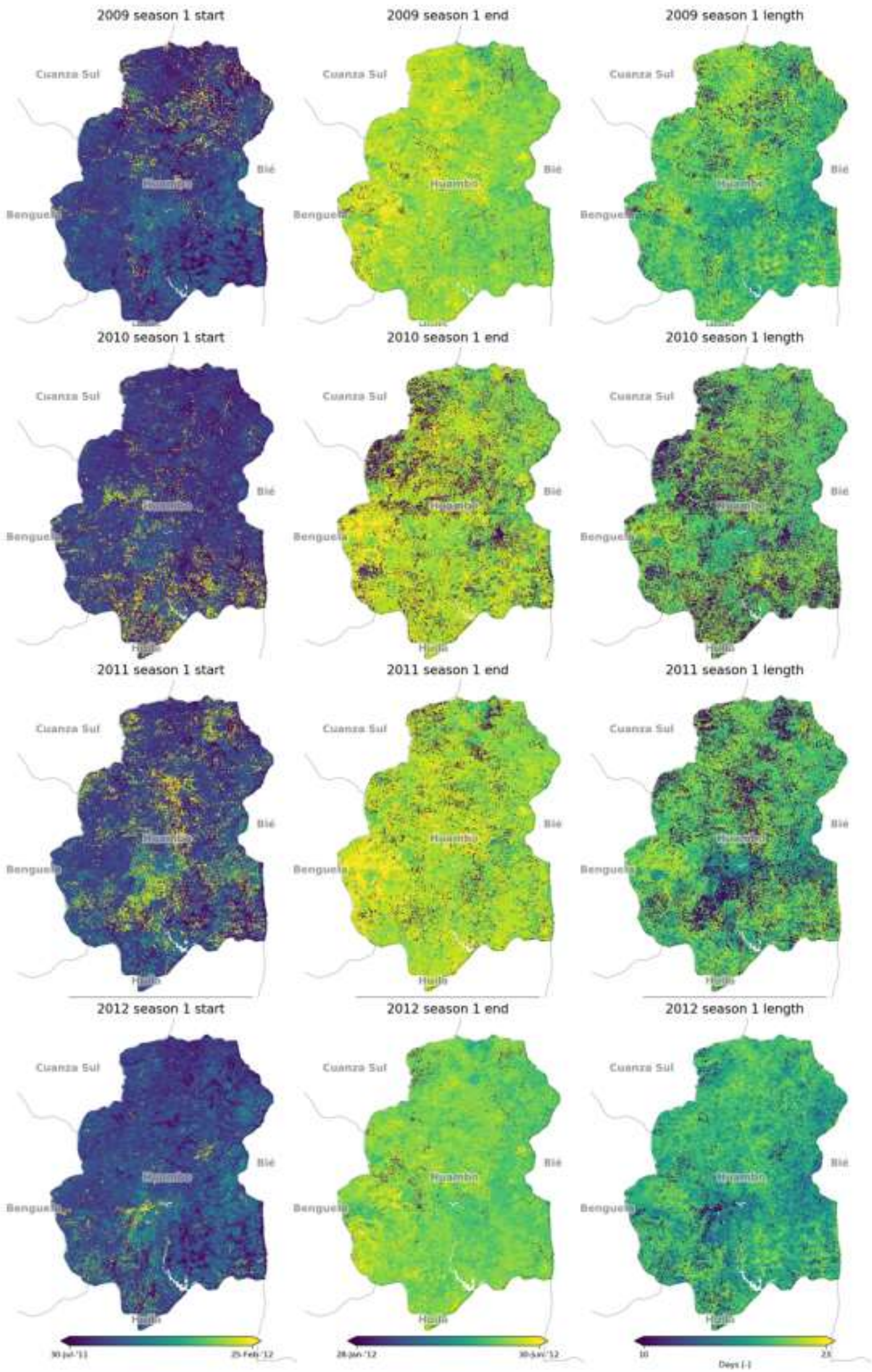

Figure 6. MODIS-based phenology results for Season 1 showing the regional spread of the start of Season (SOS) and end of season (EOS) as well as the observed length of the growing season for Huambo province for years 2009-2012. The calculate the length of the growing season in days, the scale reading should be multiplied by 14.

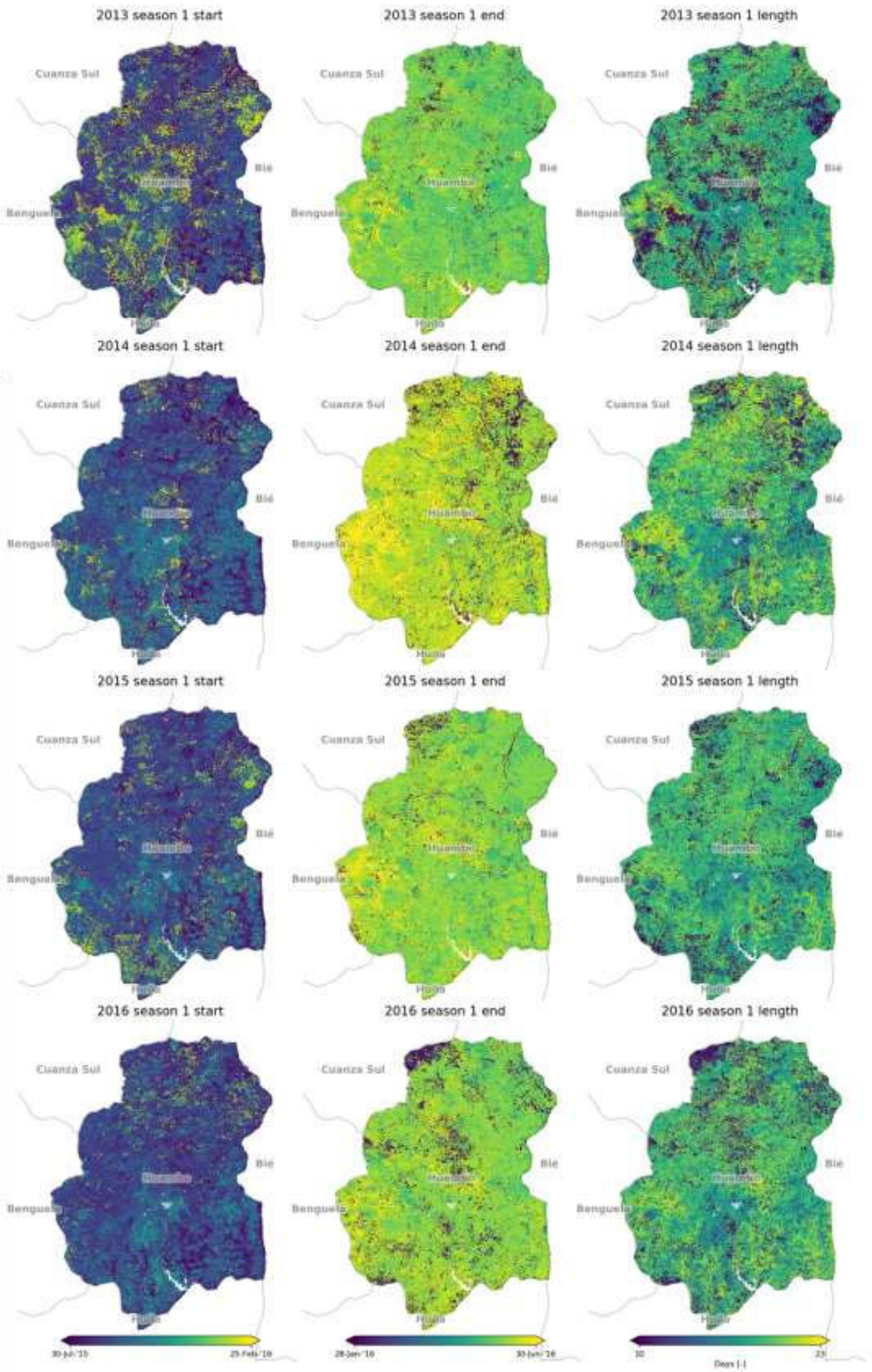

Figure 7. MODIS-based phenology results for Season 1 showing the regional spread of the start of Season (SOS) and end of season (EOS) as well as the observed length of the growing season for Huambo province for years 2013-2016. The calculate the length of the growing season in days, the scale reading should be multiplied by 14.

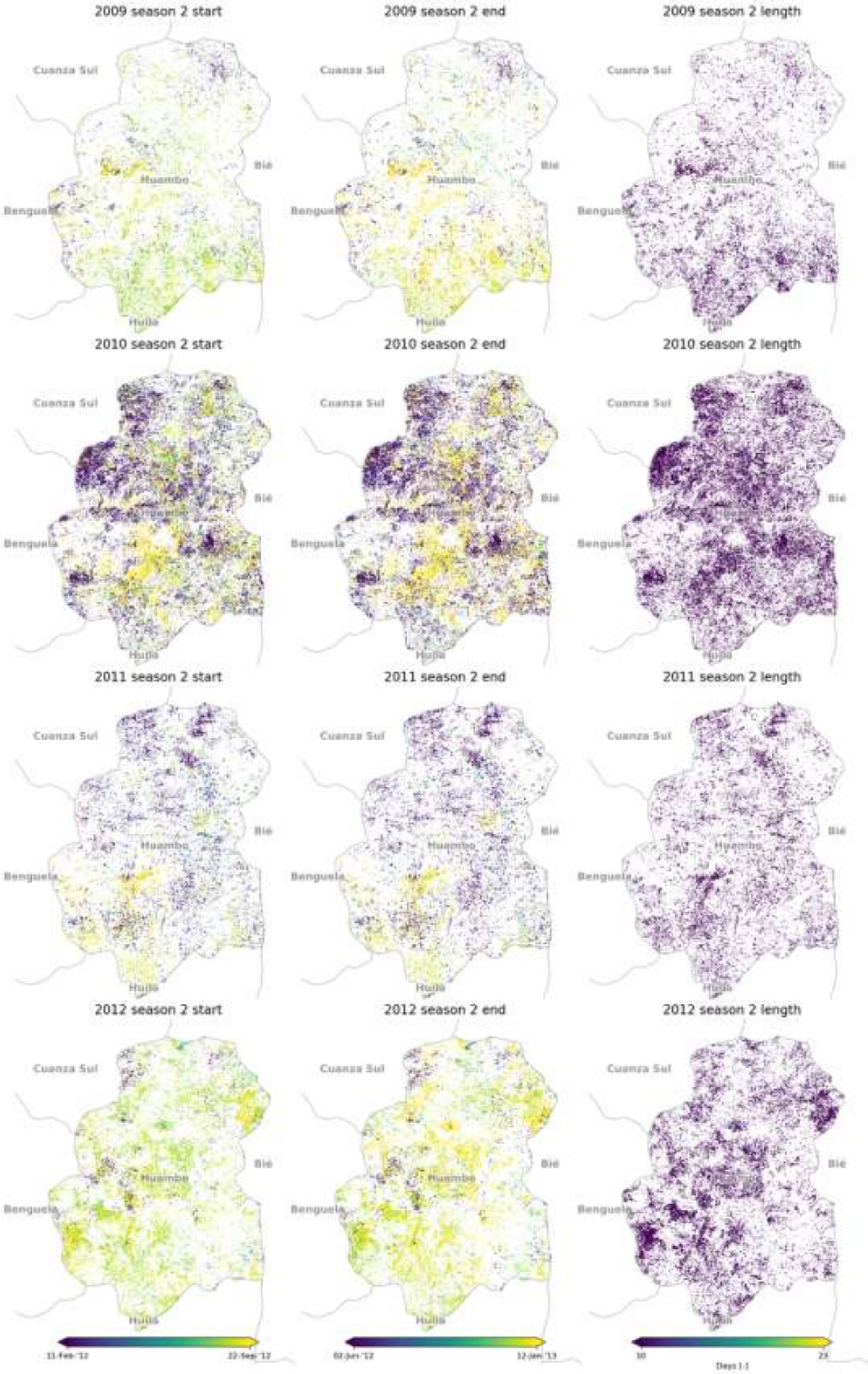

Figure 8. MODIS-based phenology results for Season 2 showing the regional spread of the start of Season (SOS) and end of season (EOS) as well as the observed length of the growing season for Huambo province for years 2009-2012. . The calculate the length of the growing season in days, the scale reading should be multiplied by 14.

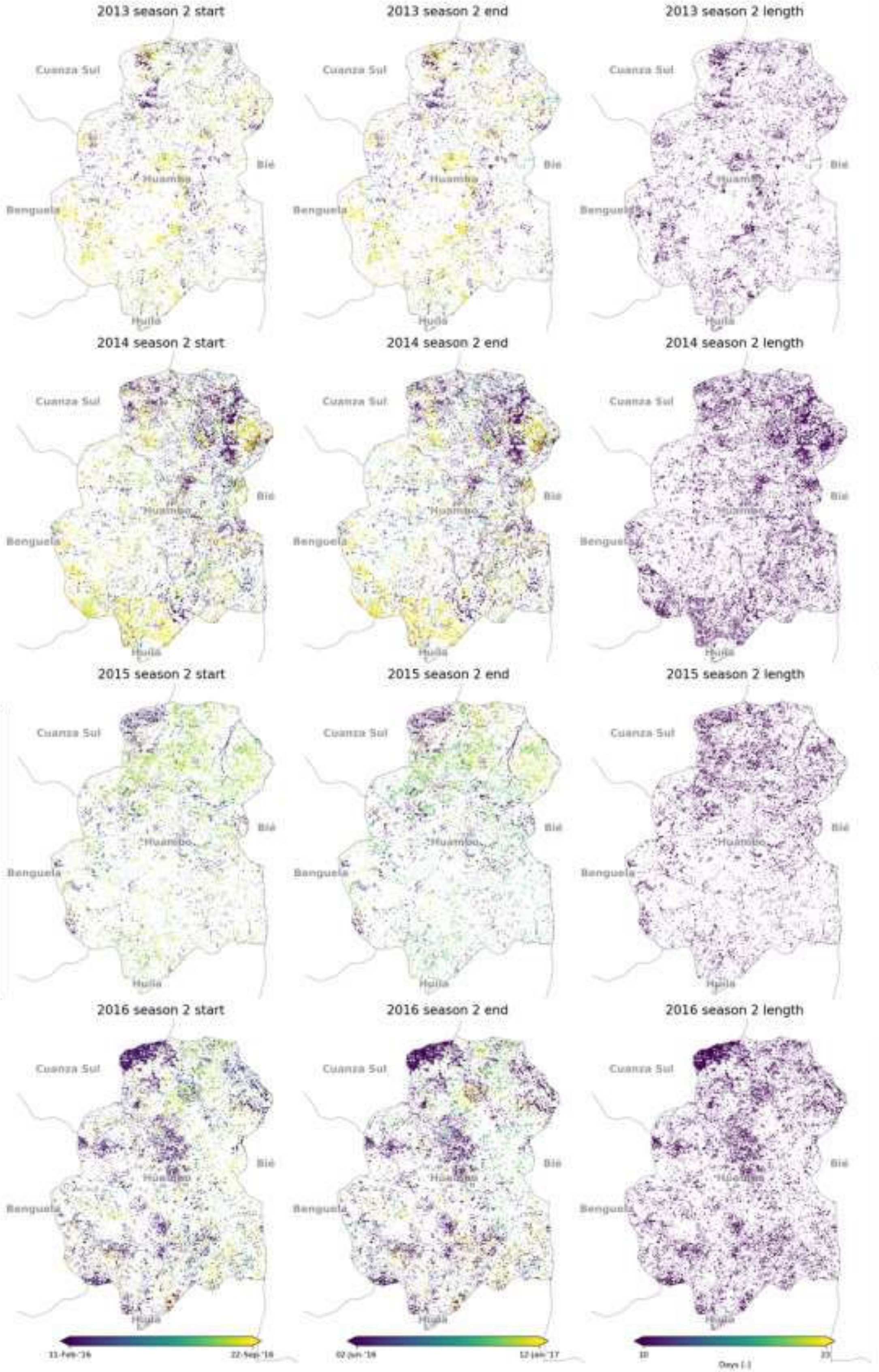

Figure 9. MODIS-based phenology results for Season 2 showing the regional spread of the start of Season (SOS) and end of season (EOS) as well as the observed length of the growing season for Huambo province for years 2013-2016. . The calculate the length of the growing season in days, the scale reading should be multiplied by 14.

Figure 6 and Figure 7 show that the first season detected in large areas of Huambo province seem to start around September/October (blue/green) shades on the map and end around April/May of the next year (dark/light green). This timing coincides with the growing season for maize, shown in Table 1. In some years (e.g. 2009, 2010, 2011 and 2014), the end of season 1 is detected in June (yellow). For some areas the start of the season is detected much later, around January/February, but there is no correlation between a late start of season and a late end of season. Rather, areas that had a late start of season seem to correlate with a shorter season. The start and end dates of these shorter seasons match the growing seasons of potatoes and beans, indicating that these may have been planted in these areas although the MODIS pixels are too large to detect separate fields, this would be possible using the higher resolution Landsat data.

Unfortunately, it was not possible to obtain results from phenology analyses on the 30 m Landsat data available. The reason for this was that the period for which Landsat data was available for this case study (the dry season from May to September for 4 separate years) would not include a full season's NDVI growth curve for agricultural crops, showing a clear SOS and EOS, with a maximum in between. In fact, as shown in Table 1, both maize and potatoes are harvested in May, with the next growing season starting in July of the calendar year, so that a typical NDVI curve observed on the Landsat data shows a 'dip' (see Figure 10). We therefore did not run the phenology algorithm on the Landsat data[1].

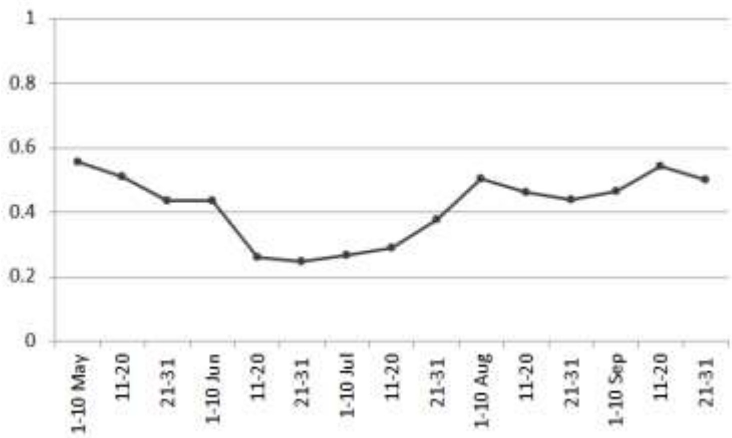

Figure 10. Graph showing a typical Landsat-based NDVI curve extracted for a cropland in the period May to September in Huambo province. The end of May shows decreasing NDVI values associated with the end of the production period. The NDVI curve then increases from mid-July which is associated with the start of the next growing season.

The production of Landsat-based phenology will be made possible if more Landsat scenes are added, preferably covering the full calendar year. This would require a lot more time-consuming input (e.g. cloud masking and gap filling of the data in the non-dry periods), which did not fall within the scope of this case study. Examples of Landsat-based phenology results can be viewed and downloaded from the FAO WaPOR data portal[2]. Unfortunately, 30m phenology data for Angola are not available on the FAO WaPOR data portal[3].

[1] It should be noted that the mismatch between the dates of the Landsat data acquired and the growing seasons came about through a combination of factors. The main factor that determined the dates of Landsat data obtained was the period in which non-cloudy Landsat data could be easily acquired for this case study. Information on the growing seasons for the various main crops (Table 1) was obtained later.

[2] https://wapor.apps.fao.org/home/1

[3] Select the *Sub-national (30 m)* Tab, pick an area, and select the Phenology layer from the *Layers* button on the left of the screen.

3.1.3 *Vigorous vegetation growth*

In order to make use of the added detail that the 30m Landsat data offers, we processed the Landsat data using an algorithm that identifies areas of vigorous vegetation growth based on a time series of NDVI datasets. As a comparison we analysed the MODIS-based NDVI data in the same way. From the maps shown in Figure 11, areas of vigorous vegetation growth can be distinguished from areas of no or low vegetation growth by means of the ‘probability’ values, where a high probability value indicates areas of vigorous vegetation growth and pixels with a low probability value indicate areas of no or low vegetation growth. The maps based on the Landsat data (Figure 11) represent vegetation growth for the period May to September of the 4 separate calendar years, 2008, 2013, 2015 and 2017.

The maps in Figure 11 don’t show major changes in vegetation patterns in this part of Huambo province within the period May to September of 2008, 2013, 2015 and 2017. The most notable difference across the entire area is apparent between the 2008 and 2013 images where it seems that vegetation vigor generally diminished between 2008 and 2013. The vegetation patterns do not seem to change much between 2013 and 2015 and the map for 2017 suggests a slight further decrease in vegetation growth over the time period 2015-2017.

When long term annual rainfall anomalies (see Figure 12) are compared with these results, it seems that 2017 was a particularly dry period for Huambo province. A breakdown of the monthly rainfall for Huambo province shows that January to April 2017 received particularly low rainfall within the period preceding May-Sept 2017 (see Figure 13), which most likely explains the lower levels of vegetation vigor observed for 2017 compared to 2015.

On the other hand, the more vigorous vegetation growth patterns seen in the map for 2008 compared to 2013 cannot be directly linked to particularly higher rainfall preceding May-Sept 2008 or lower rainfall preceding May-Sept 2013. There does not seem to be a correlation between rainfall and diminished levels of vegetation vigor observed between 2008 and 2013. In fact, the months preceding May-Sept 2013 received more rainfall than the same period in 2008. The diminished vegetation vigor seen in 2013 is probably attributed to the effect of human activities related to the removal of woodland vegetation cover, such as the examples shown in Figure 14.

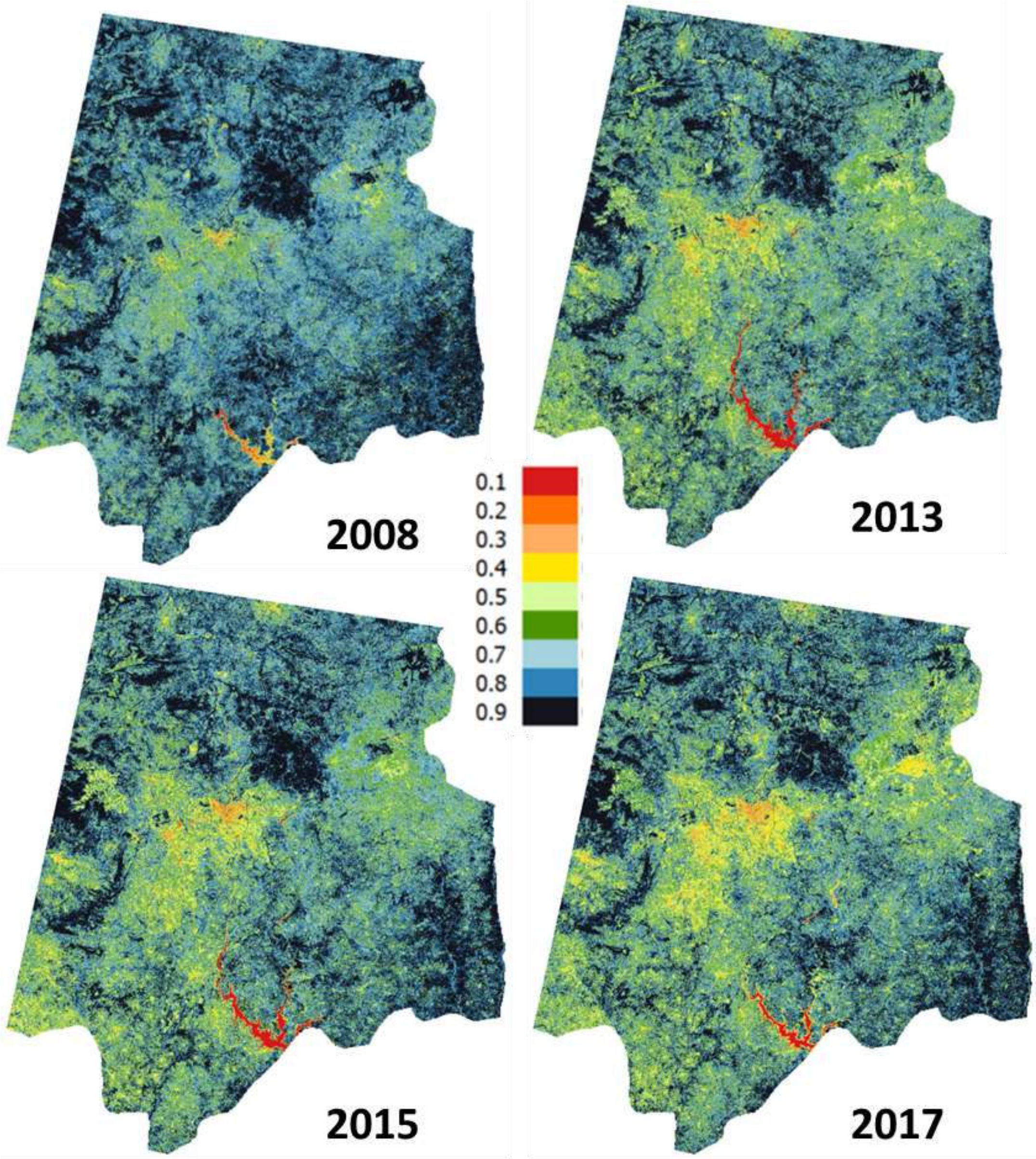

Figure 11. Maps derived from Landsat NDVI time series data showing patterns in vigorous vegetation growth (including croplands and woodland) for a part of Huambo province for the period May-September of the years 2008, 2013, 2015 and 2017. Dark to light blue areas correspond mainly to woodland and other vegetation with vigorous growth (such as cropland) in the period May-Sept of the calendar year. Areas in red represent non-vegetation such as water and areas of bare soil, whilst orange areas correspond mostly to areas of very low vegetation, such as urban areas.

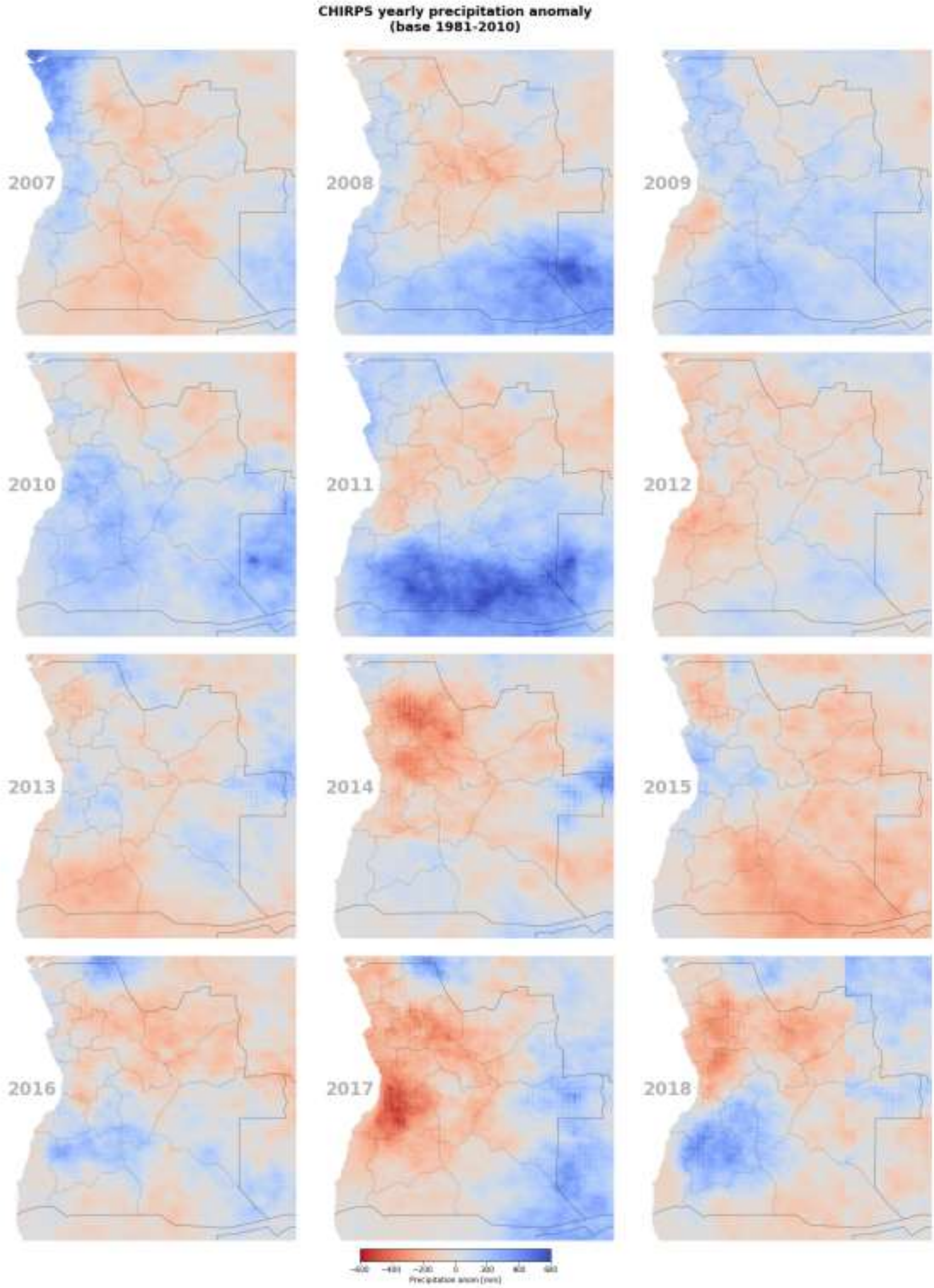

Figure 12. Maps showing annual precipitation anomalies for 2007 to 2018 based on CHIRPS rainfall data[1]. Red areas have received significantly less rainfall than normal, whilst blue indicates significantly lower annual rainfall than normal (where 'normal' refers to the base period 1981-2010). A figure showing annual rainfall anomalies from 1981 to 2018 is included for additional information in Appendix 1.

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[1] Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. and Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data* 2, 150066. doi:10.1038/sdata.2015.66. Data obtained from: http://chg.geog.ucsb.edu/data/chirps/

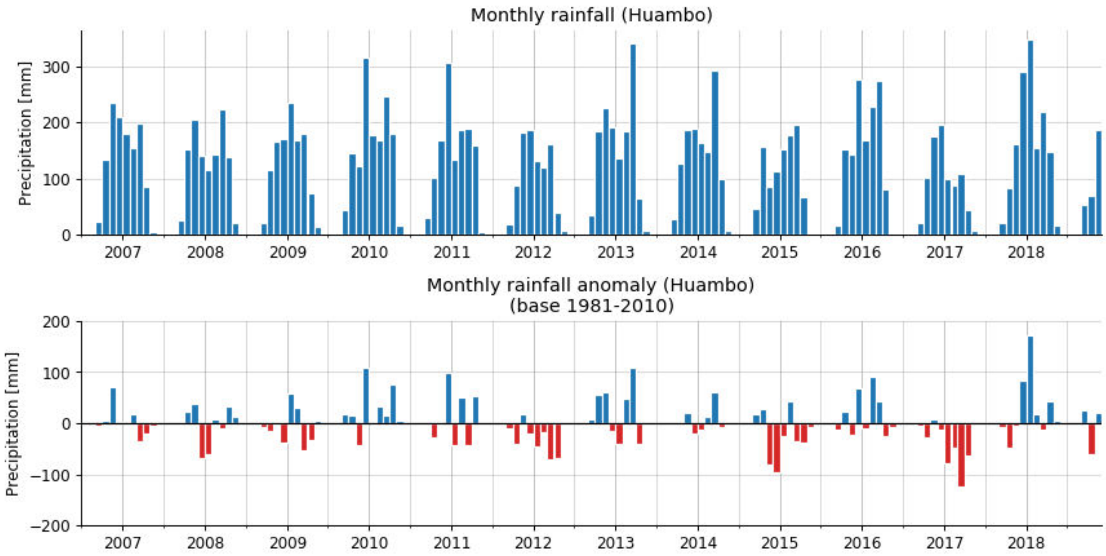


Figure 13. Graph showing monthly rainfall figures (top) and monthly rainfall anomalies (bottom) for Huambo for the period Jan 2006 to Dec 2018. Data obtained from CHIRPS.

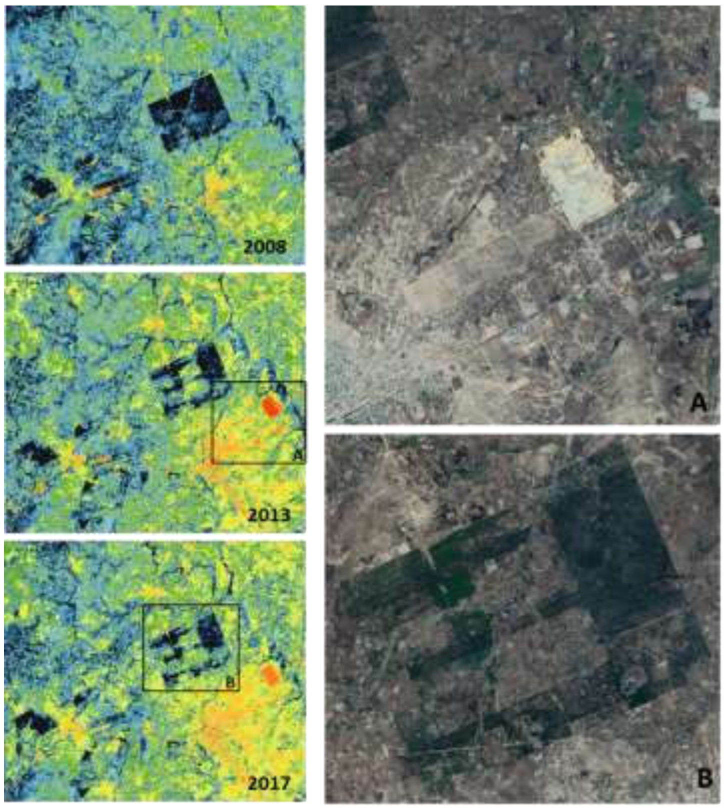


Figure 14. Maps showing zoomed in sections of the Landsat-based maps of vigorous vegetation growth for 2008, 2013 and 2017. There is very little difference between the images for 2013 and 2017, but changes that occurred between 2008 and 2013 are clearly visible in the 2 examples shown: Subset A shows the expansion of urban area around Caala, whilst Subset B shows that large areas of tree cover have been removed in the Ussombo forest to be replaced by crop fields. Dark blue represents vegetation with high growth whilst light blue and shades of green correspond mainly to other vegetation with vigorous growth (such as cropland) whereas yellow and orange correspond mostly to areas of very low vegetation, such as urban areas and bare soil.

Whilst the maps of vigorous vegetation growth derived from MODIS data do not show detailed instances of changes in vegetation cover, overall patterns of vegetation cover change can be studied by comparing maps representing vegetation vigor across time. Figure 15 shows 2 maps of vegetation vigor for 2 groupings of 5 years each, i.e. 2007-2011 and 2013-2017. Comparison of these maps does not show any big changes over the longer-term period, but the trend seems to have been a general decrease in vegetation vigor, especially in the southern half of Huambo province. This trend is also seen in the Landsat-based vegetation vigor maps (Figure 14) and is probably attributable to human activities such as expansion of urban areas and removal of woodland vegetation across the region during this time period. Combined with these processes, agricultural land was probably expanded.

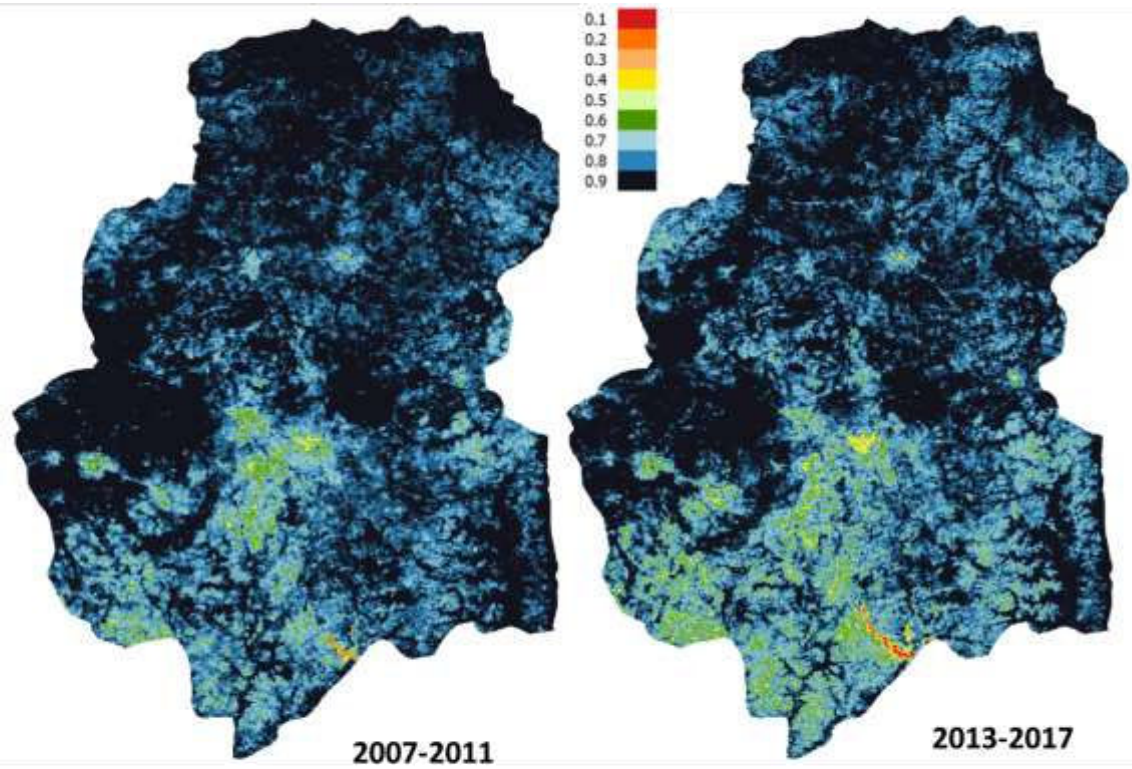


Figure 15. Maps derived from MODIS NDVI time series data showing patterns in vigorous vegetation growth (including croplands and woodland) for a part of Huambo province for two 5-year periods: 2007-2011 and 2013-2017. Dark to light blue areas correspond mainly to woodland and other vegetation with vigorous growth (such as cropland) whereas areas in red represent non-vegetation such as water and areas of bare soil, whilst yellow and orange correspond mostly to areas of very low vegetation, such as urban areas.

3.2 Agro-ecological potential maps

The required datasets were obtained from the various sources as indicated in Table 2. All necessary pre-processing was performed to extract datasets for Huambo Province and, where required, reprojected to the necessary geographic projections and spatial resolution. Example inputs into the procedure are given in Figure 16

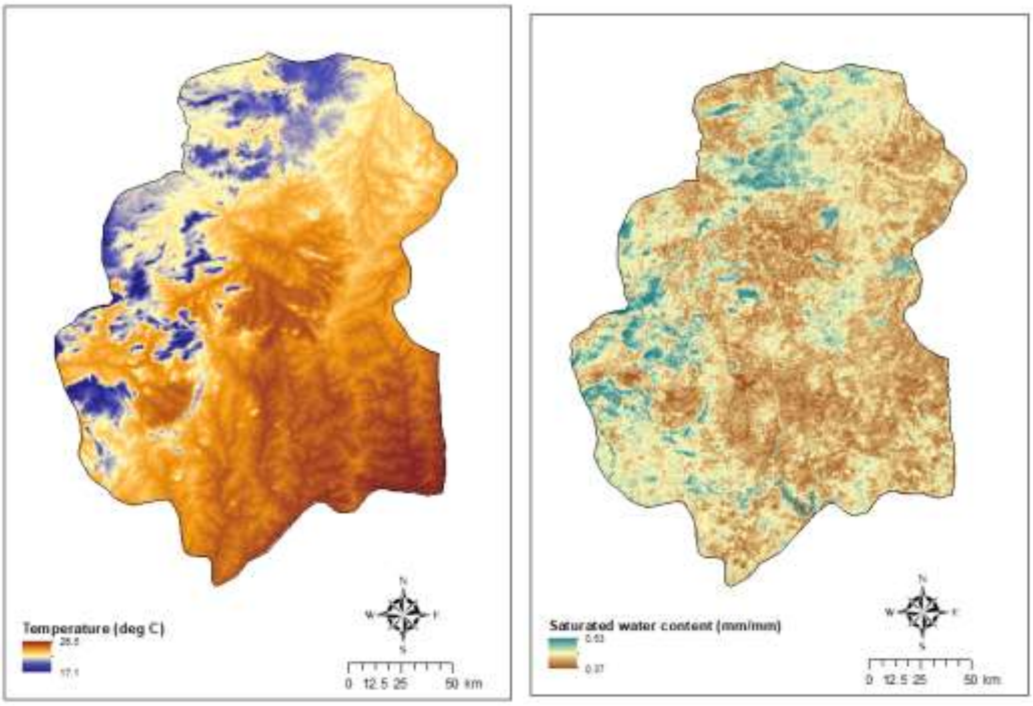


Figure 16. Maximum of daily average temperature in 2012 (left) and saturated topsoil water content (right).

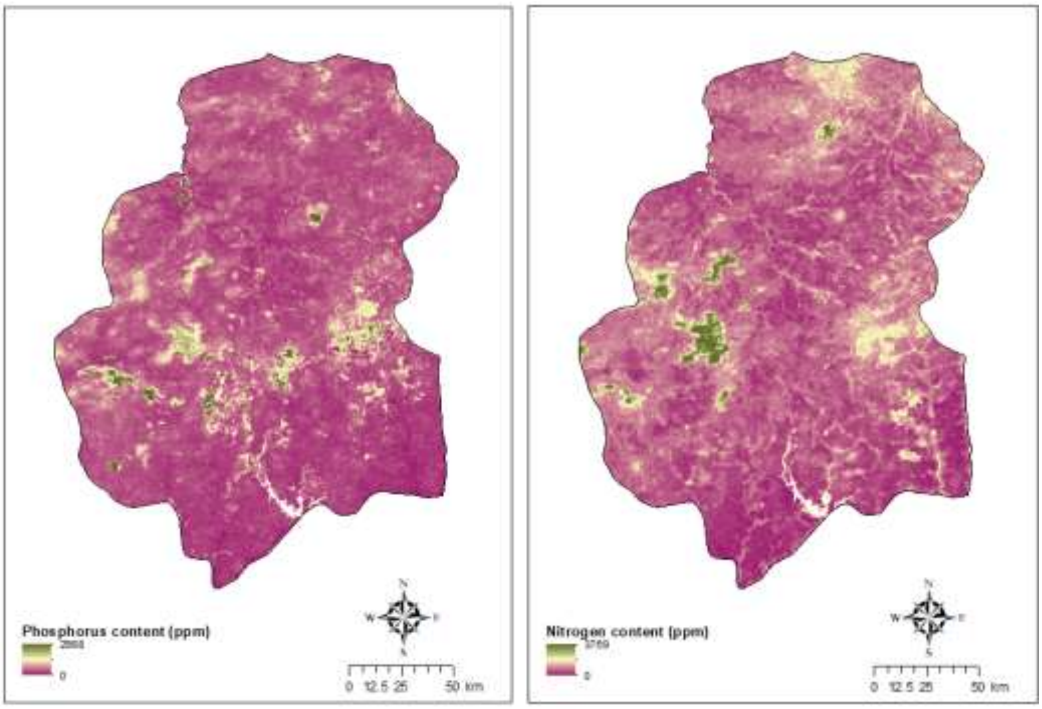


Figure 17. Topsoil nutrient content in Huambo Province: phosphorus (left) and nitrate (right). Data source: ISRIC SoilGrids.

3.2.1 *Soil water*

Daily precipitation and the potential evapotranspiration for each crop was obtained for the Huambo province. The crop evapotranspiration was determined by using the Hargreaves method and crop coefficients (K_c) for each development stage. Each development stage was assumed to be one month. A ratio between precipitation and the crop evapotranspiration was obtained for each cropping period (Feb-May, Jul-Oct, Oct-Jan). A ratio lower than 1 corresponds to a potential water deficit for that period. A ratio value higher than 1 corresponds to a potential water excess for that period. The degree of each condition was also established (Table 1). For the cropping periods February-May and October-January a potential water excess was obtained for the entire Huambo province. Conversely, for the cropping period July-October a potential water deficit was obtained for the entire Huambo province. The degree of water deficit and degree of water excess vary spatially depending which crop is planted. Figure 18 - Figure 20 present results regarding potato cultivation in the three respective seasons.

Table 3. Ranges of precipitation and crop evapotranspiration ratio (P/ETc) for potential water deficit and potential water excess used in Huambo province, Angola.

No.	P/ETc	Water condition	Degree of water condition
1	0-0.50	Potential water deficit	Very High
2	0.50-0.60		High
3	0.60-0.75		Mid
4	0.75-1.00		Low
5	1.00-1.33	Potential water excess	Low
6	1.33-1.66		Mid
7	1.66-2.00		High
8	>2.00		Very High

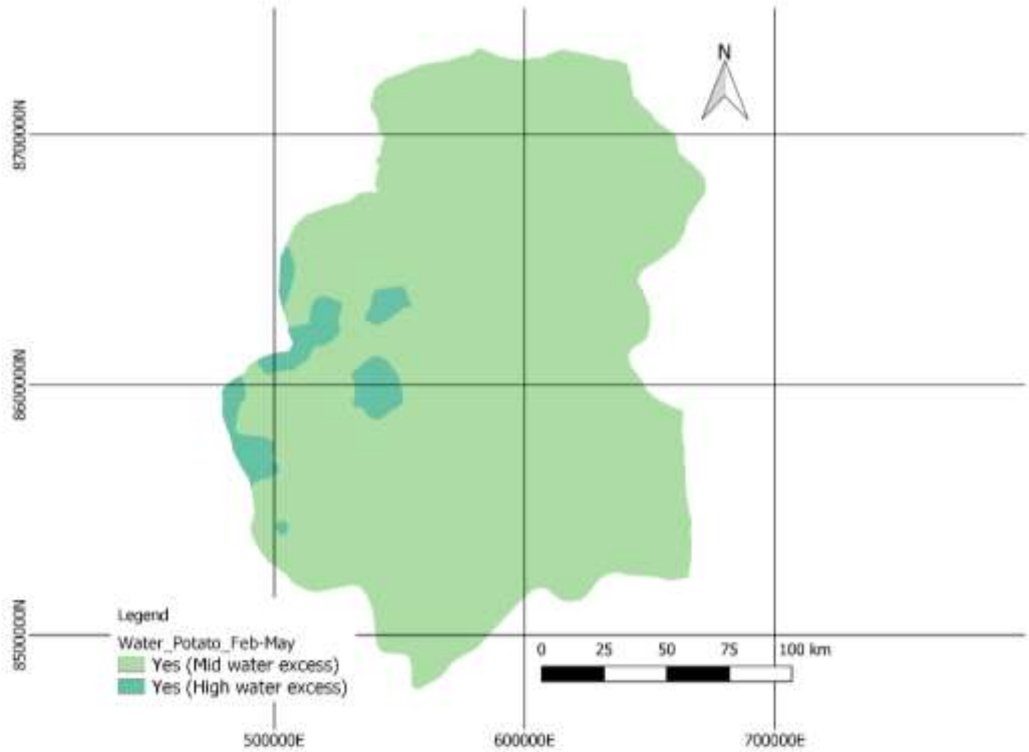


Figure 18. Land suitability for potato production between February and May considering water balance between precipitation and crop evapotranspiration, Huambo Province.

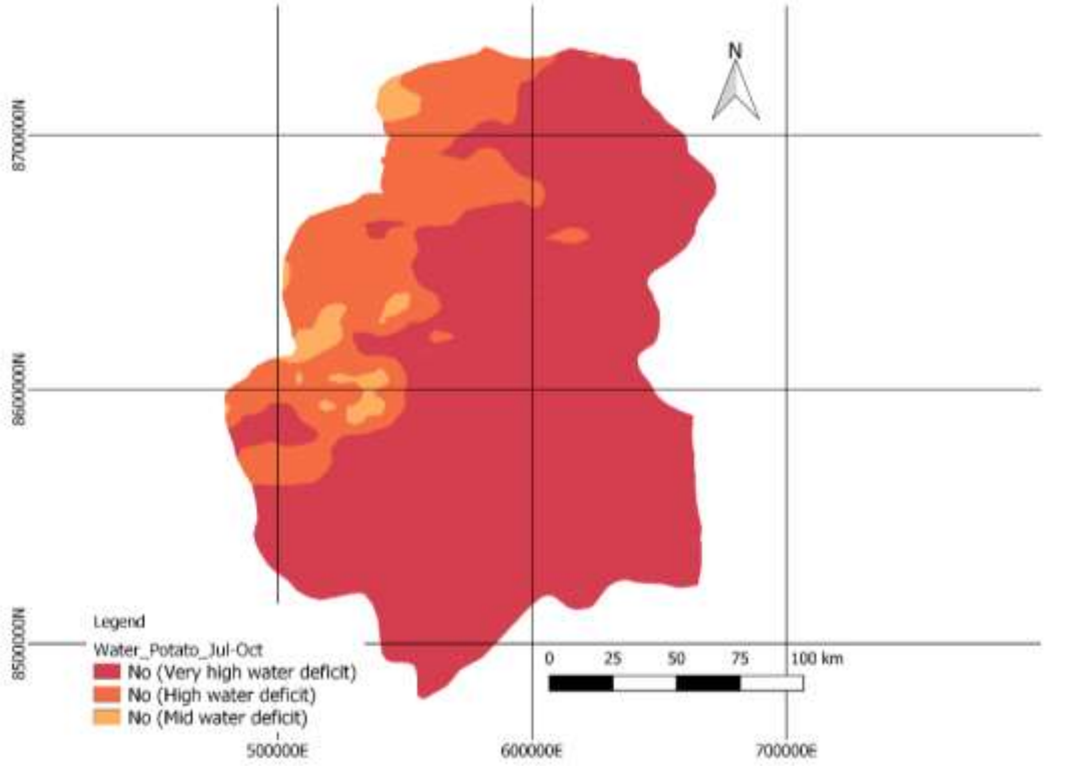


Figure 19. Land suitability for potato production between July and October considering water balance between precipitation and crop evapotranspiration, Huambo Province.

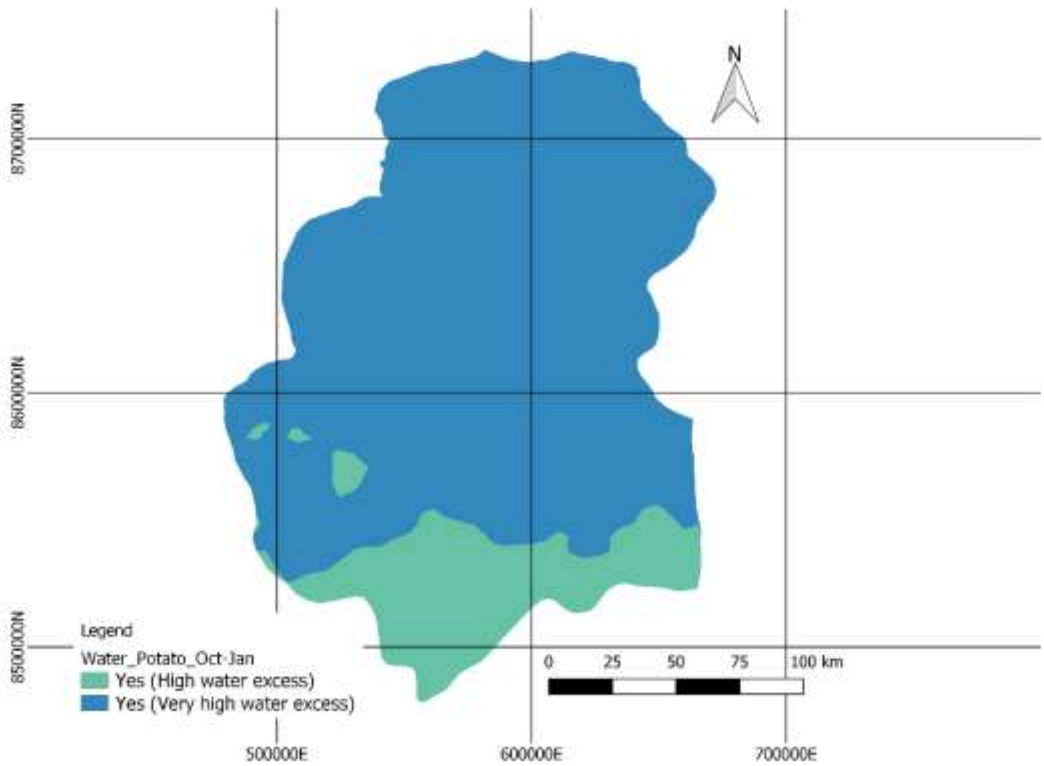


Figure 20. Land suitability for potato production between October and January considering water balance between precipitation and crop evapotranspiration, Huambo Province.

Information about the soil water storage capacity is available for the Huambo province from the HiHydroSoil dataset. A classification of the soil water storage capacity was developed using the FAO method[1] to determine the degree of suitability for agricultural production (Table 4). The logic behind this is that with higher storage capacity of the soil, buffering of excess precipitation in the soil profile is higher and more water will be available to the crop during dry periods.

Table 4 Soil water storage classification used in Huambo province, Angola.

No.	Soil water storage capacity (mm/m)	Degree of suitability
1	25 – 100	Low
2	100 – 175	Medium
3	175 – 250	High
4	>250	Very High

The soil water storage capacity in entire Huambo province is higher than 100mm/m (Figure 8). This means that in the Huambo province the soil water storage capacity is appropriate for agricultural activities. Soil water storage capacities higher than 100mm/m are associated to loam and clay soil textures which are suitable for agricultural production.

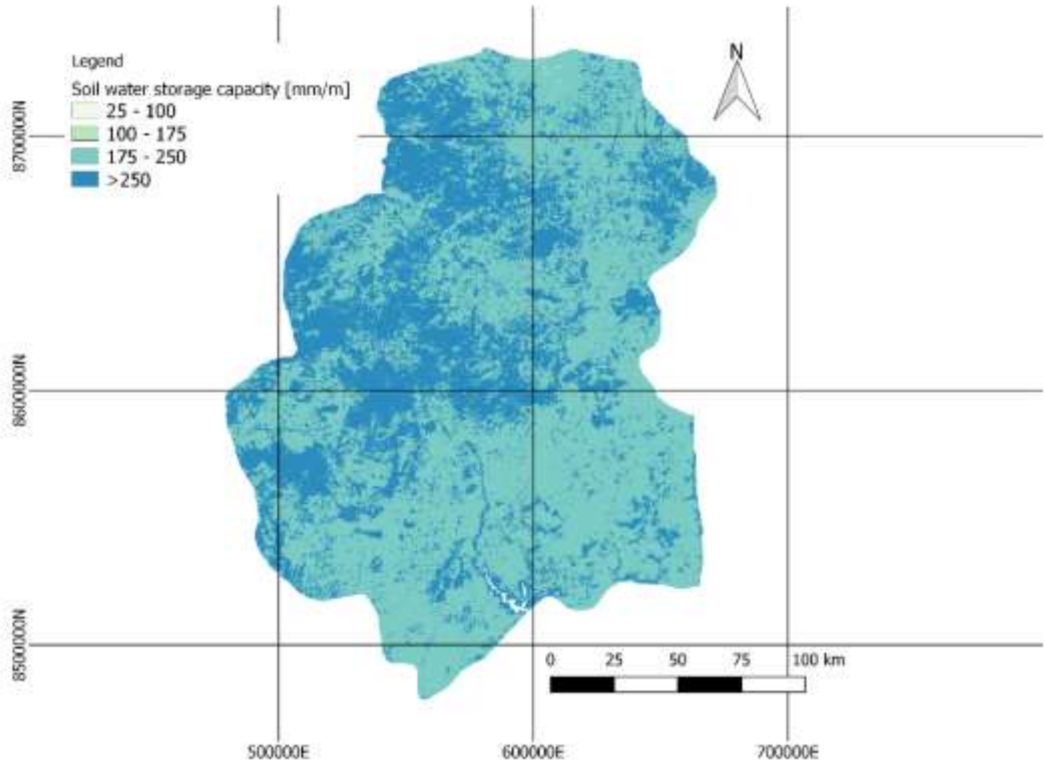


Figure 8. Soil water storage capacity in Huambo Province.

[1] FAO: Crop yield response to water, 2012. *http://www.fao.org/3/i2800e/i2800e.pdf*

3.2.2 *Air temperature*

Similar temperature conditions are required for adequate potato, maize and bean production. Potato, maize and bean yields are affected by low temperatures (5-10°C). The optimum mean daily temperature for potato is between 18°C and 20°C and a night temperature around 15°C is required for tuber initiation. For maize and beans production temperatures should be above 15°C. These threshold values[1] were used to develop land suitability maps based on average daily temperatures between selected cropping periods (Feb-May, Oct-Jan and Jul-Oct). Most of the area in the Huambo province is suitable for this temperature condition. No high temperatures are registered which could damage crop development. Figure 21 shows an example result for potato cultivation in the July – October season.

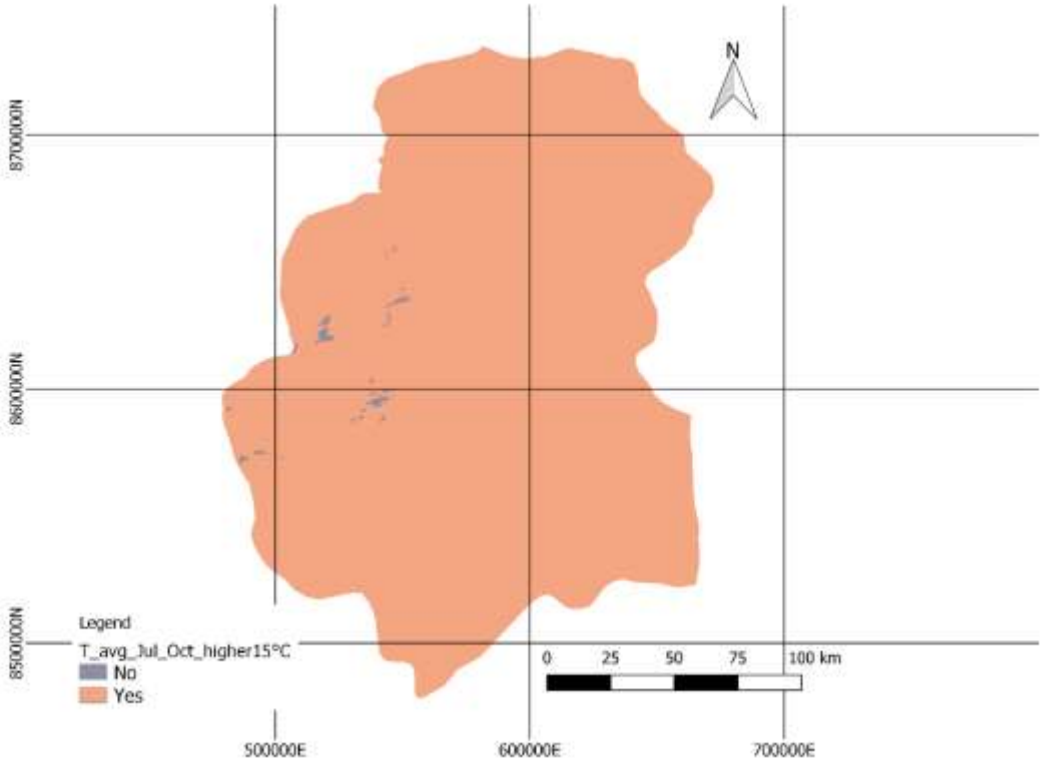


Figure 21. Land suitability for potato between July and October considering average temperature higher than 15°C, Huambo Province.

3.2.3 *Slope*

A terrain slope map was obtained from the available digital elevation map. A classification of the slopes was developed using the methodology of the US Soil Conservation Service (SCS) as presented in Table 5. For land suitability maps only slopes lower than 15% were defined as suitable for intensive potato, maize and bean production. These crops are annual crops, which ideally should be cultivated in low slopes between 0 and 8% to avoid soil erosion. In terrain slopes between 8% and 15% agricultural areas with potato, maize and bean are allowed with soil conservation practices. Terrain slopes higher than 30% are restricted for annual crops. The slope distribution in the Huambo province is shown in Figure 22.

[1] FAO: Crop yield response to water, 2012. *http://www.fao.org/3/i2800e/i2800e.pdf*

Table 5. Terrain slope classification used in the Huambo province, Angola.

No.	Terrain slope (%)	Classification
1	0-3	Annual crops allowed
2	3-8	Annual crops allowed, low soil erosion
3	8-15	Annual crops are allowed, but soil conservation practices are required
4	15-30	Occasional annual crops allowed, only with intensive soil conservation practices
5	30-50	Severe restriction. Only permanent crops with soil conservation practices allowed
6	50-75	Only primary and secondary forests allowed
7	>75	No productive activity allowed

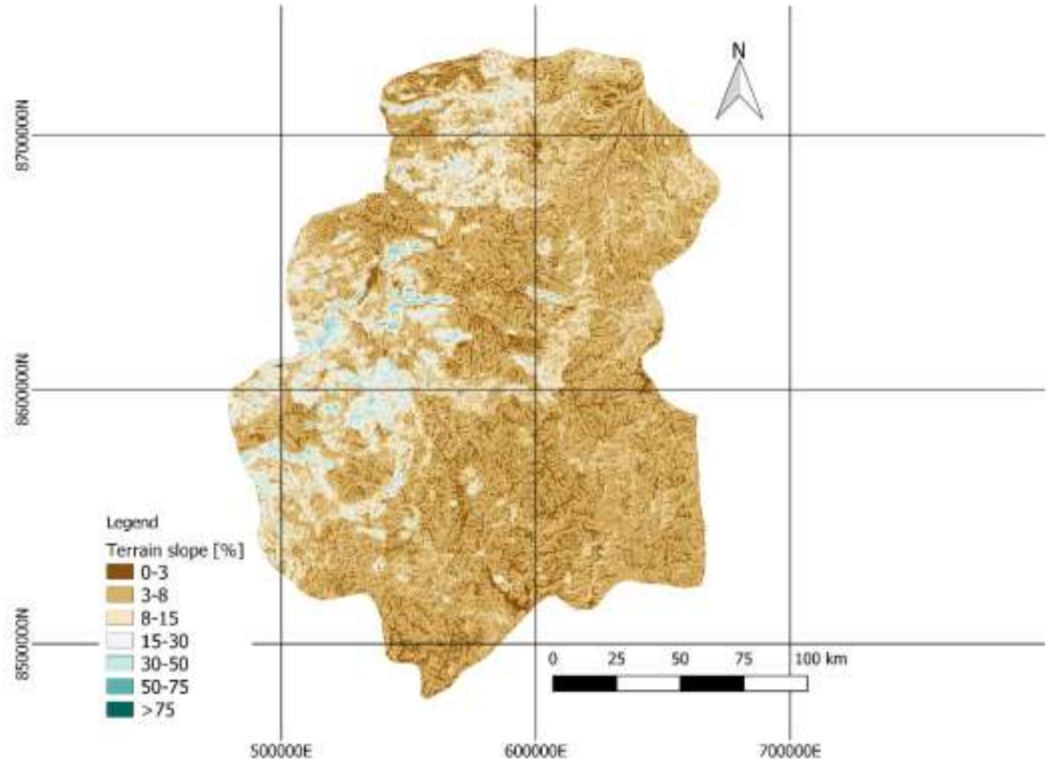


Figure 22 Terrain slopes in Huambo Province.

3.2.4 *Soil fertility*

Nutrient concentration values in the soil for phosphorous and nitrogen are available in the Huambo province. A threshold of 1000 mg/kg for nitrogen and a threshold of 500 mg/kg for phosphorous were used to separate between suitable and non-suitable soil for agricultural crop production (Figure 23 - 24). These thresholds were selected based on recommended critical values from state-of-the-art research on soil nutrients (Bai et al., 2013[1]; Zhang, Wang, Wang, & Wang, 2014[2]).

[1] The critical soil P levels for crop yield, soil fertility and environmental safety in different soil types, Z. Bai et al., 2013. Plant and Soil, Volume 372, Issue 1-2, pp 27-37

[2] Carbon and Nitrogen Contents in Typical Plants and Soil Profiles in Yanqi Basin of Northwest China, J. Zhang et al., 2024, Journal of Integrative Agriculture, Volume 13, Issue 3, pp 648-656

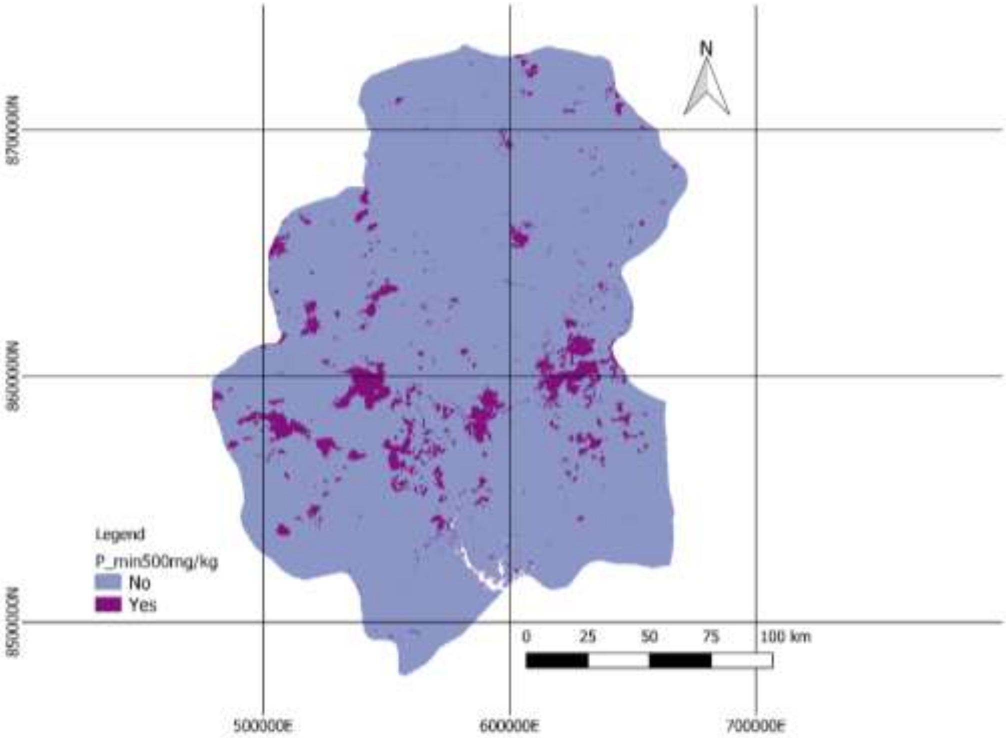


Figure 23 Phosphorous concentration in the soil, higher than 500mg/kg, Huambo Province.

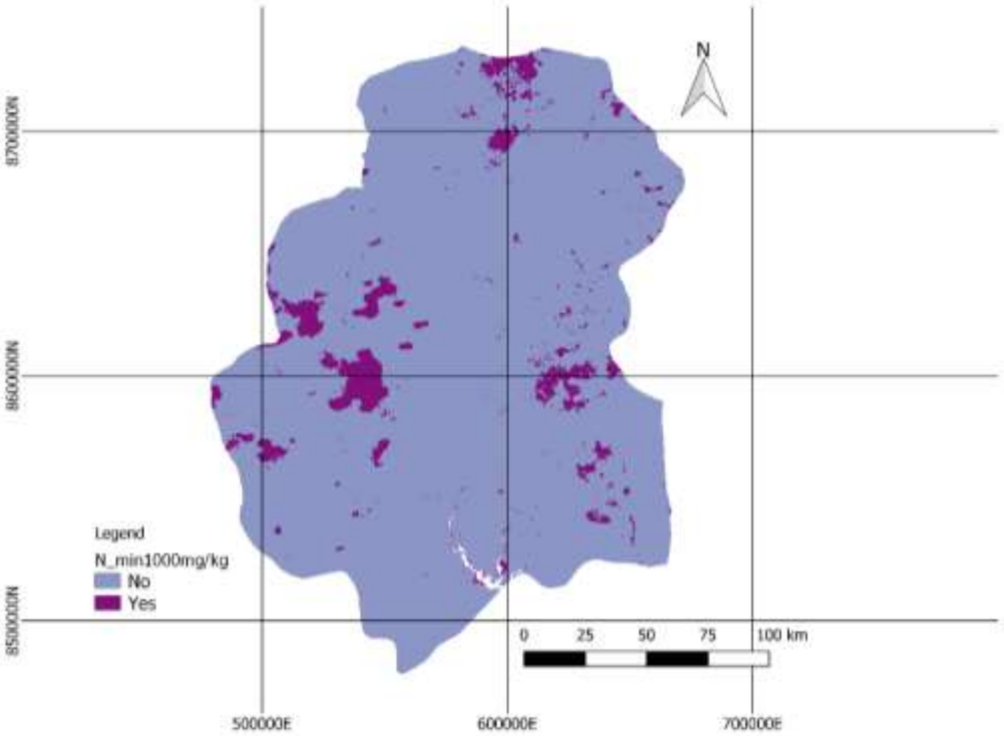


Figure 24 Nitrogen concentration in the soil, higher than 1000mg/kg, Huambo province.

3.2.5 *Current land productivity*

MODIS-based NDVI data is used as a proxy for current land productivity. Higher NDVI values represent a higher potential for land productivity. A threshold for NDVI values was obtained for each cropping period based on the 80% of the maximum NDVI value occurring in the Huambo province. Values higher than this threshold were assigned as the most optimal areas for crop productivity. Figure 25 shows the result for the February – May growing season

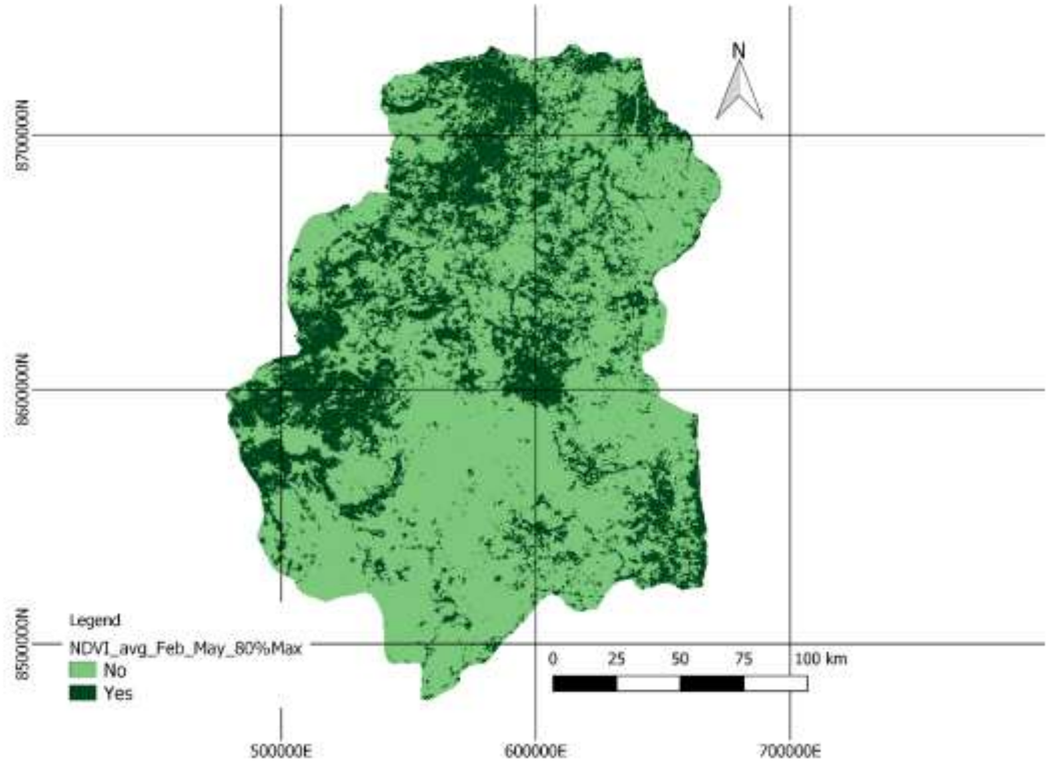


Figure 25 NDVI higher than the 80% maximum value in the cropping period February-May, Huambo Province.

3.2.6 *Integrated acro-ecological suitability maps*

A weighted map including all the environmental characteristics for land suitability was obtained for each cropping period (Feb-May, Jul-Oct, and Oct-Jan). The maps obtained for water, temperature, soil, slope, NDVI, nitrogen and phosphorus were used for this purpose. The weighted map was obtained by multiplying each input map with a weighting factor. In Table 4 the weight for each characteristic is shown. Results show how the agro-ecological suitability is generally high to optimal for cropping periods February-May and October-January (Figure 26 and Figure 28). Regions with optimal suitability are found in the east, west and far north of the province. For the less attractive cropping period of July-October, the suitability map helps to identify areas for potential crop production, which are particularly located in the eastern part of the province (Figure 27).

Table 6 Weighting factor used for each environmental characteristic to determine the land suitability for crop production in the Huambo province.

Environmental characteristic	Weight (%)
Water	20
Temperature	15
Soil	15
Slope	15
NDVI	15
Nitrogen	10
Phosphorus	10

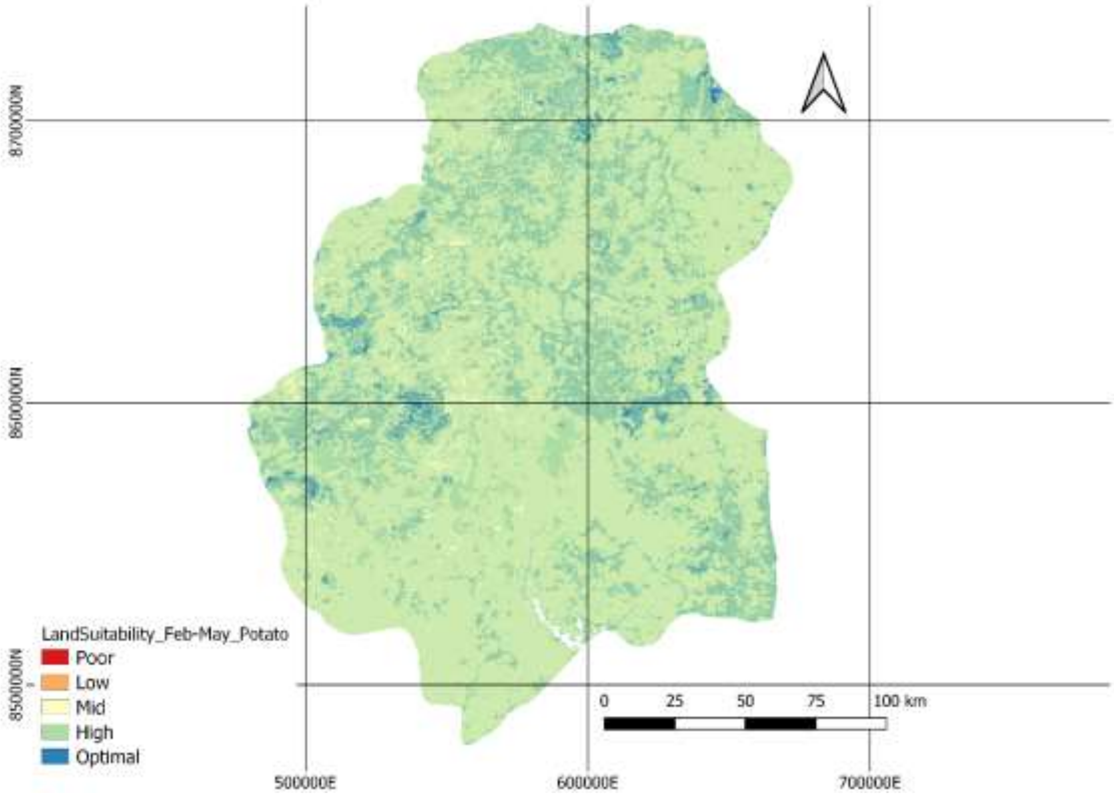


Figure 26 Land suitability for potato, maize and bean production in the cropping period February-May.

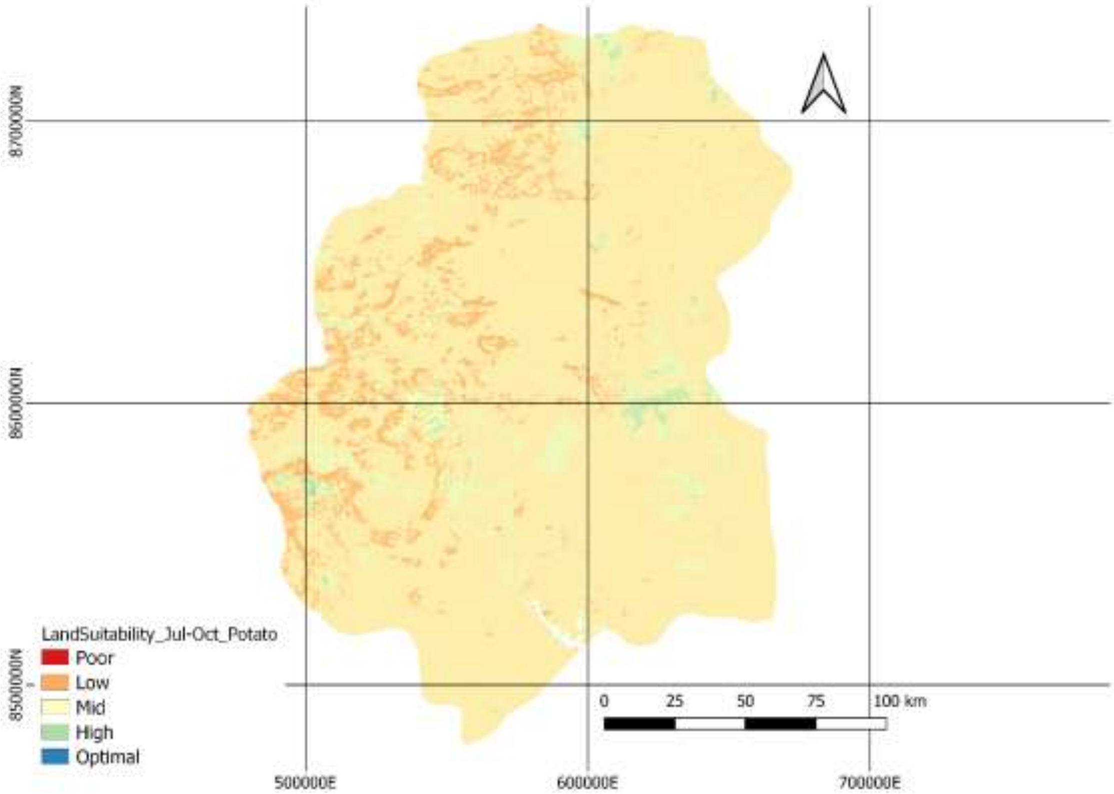


Figure 27 Land suitability for potato, maize and bean production in the cropping period July-October.

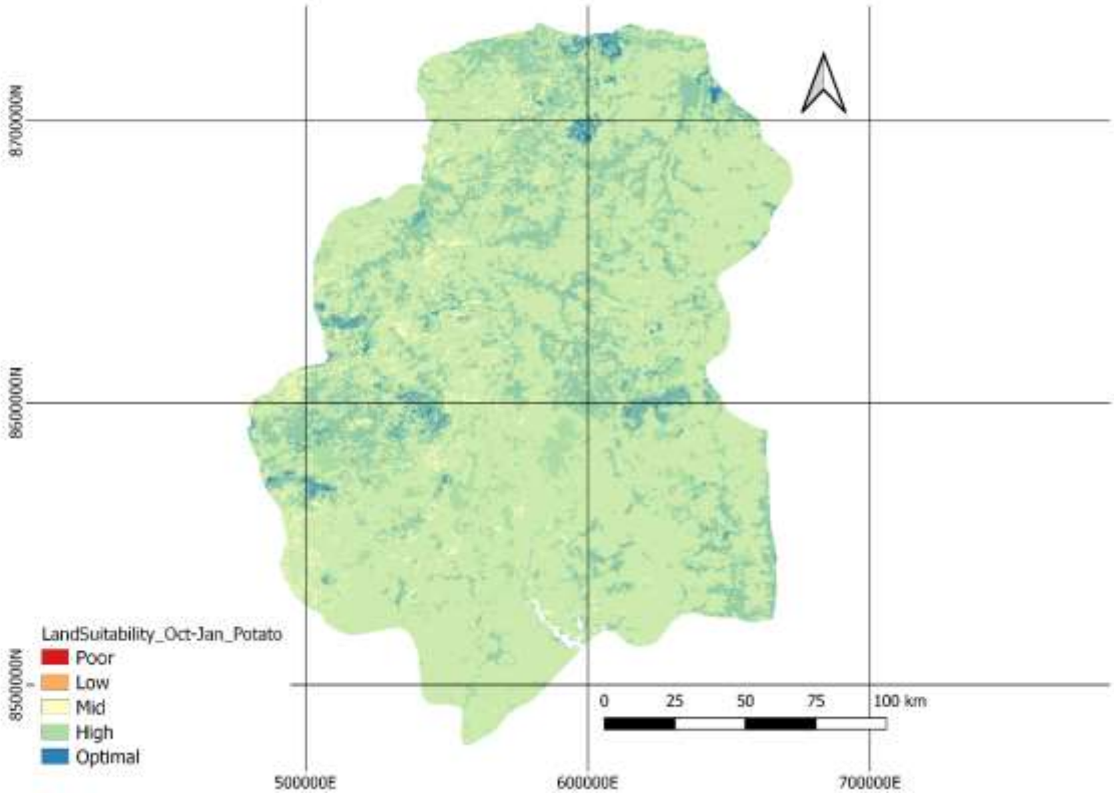


Figure 28. Land suitability for potato, maize and bean production in the cropping period October-January.

3.3 Tentative irrigation potential map

3.3.1 *Crop water stress*

The SPHY model was run with a daily timestep for the dry year 2012, simulating a scenario assuming agricultural development all over Huambo Province. The objective of this exercise was to quantify water stress, or evapotranspiration (ET) deficit, experienced by the crop across the province. This ET deficit can be regarded as an indication of the amount of water that needs to be compensated by irrigation. Due to the occurrence of loss factors in the irrigation process, absolute values of irrigation water needed to be supplied would be even higher, but spatial patterns can be assumed to be representative of crop water stress. The assumption is that, in areas where higher amounts of water need to be supplied in addition to rain water for optimal crop growth, potential for irrigation development is lower.

Figure 29 shows the resulting map produced by the model, were values indicate the ET deficit in mm/year. Temporal dynamics are presented in Figure 30, which clearly shows that water shortages only occur during the dry months May – October.
Figure 31 shows the resulting map of relative crop water stress, one of the three scaled maps on which irrigation potential is based (see Figure 3). Generally, crop water availability in the northern half of the province seems more beneficial to irrigation development. All surface covered by built-up area or water bodies was assumed to be unavailable to irrigation development and was assigned a value of 0 in the map, or “no potential”.

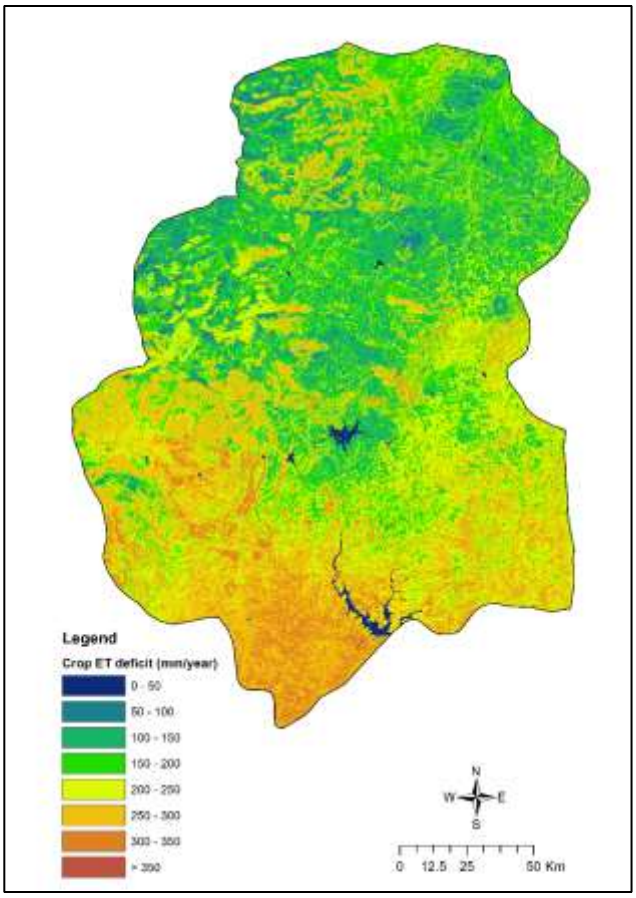


Figure 29. Annual evapotranspiration deficit in Huambo province during a dry year, assuming agricultural development across the province. High values indicate likelihood of high water stress for crops in case of agricultural development.

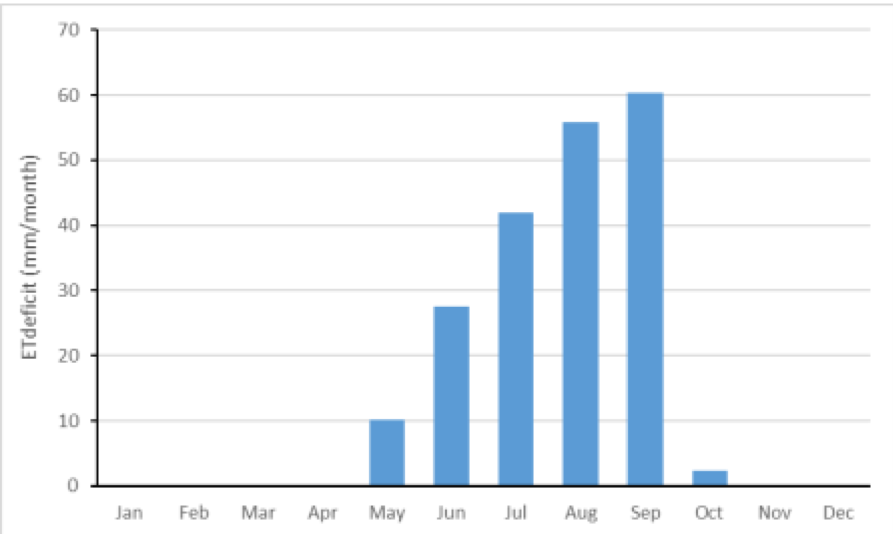


Figure 30. Monthly evapotranspiration deficit averaged for entire province, assuming agricultural development across the province.

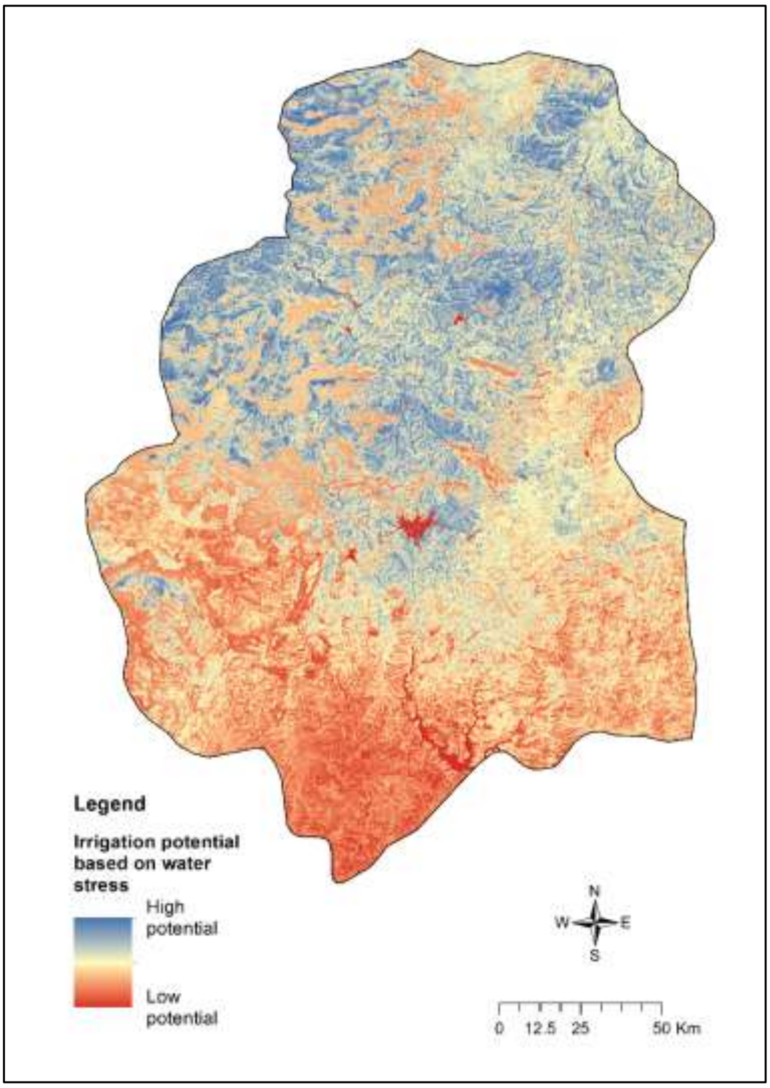


Figure 31. Map of irrigation potential based on crop water stress.

3.3.2 *Access to water source*

Next to the amount of water required by the crop, the accessibility of the nearest water source is an important indicator of irrigation potential. The distance to the nearest stream, as well as the height above nearest stream, were taken into account to estimate this factor. Both aspects are crucial in irrigation development and determine e.g. the length of supply pipelines and drains needed, as well as pumping capacity.

Figure 32 shows the distance to nearest stream and elevation above nearest stream across Huambo Province. The distance to nearest stream was scaled between 0 and 1, were a distance of 0 m indicates highest potential and the maximum occurring value of 7900 m was assigned lowest potential. The height above nearest stream was scaled similarly, using an upper threshold of 200 m above which potential for irrigation development was assumed zero. Figure 33 shows the integrated map of access to a water source, where both distance to and height above nearest stream have equal weight. In case one of the two has zero potential, the integrated map also has value zero.

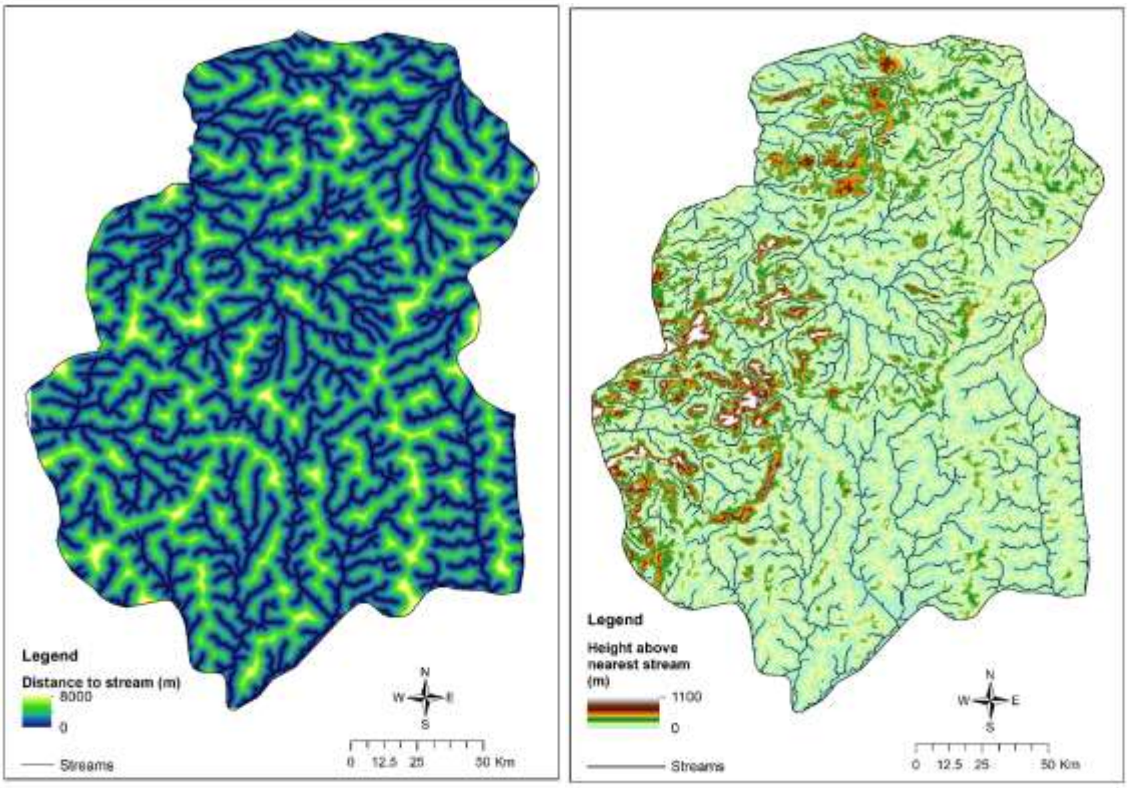


Figure 32. Map of distance to (left) and height above (right) nearest stream.

3.3.3 *Slope*

The final factor determining potential for irrigation development, is the slope of the terrain. Figure 34 shows the map of irrigation potential based on slope, where high potential corresponds with a completely flat surface. Values were scaled between 0% and 15% of slope, where values of 15% were assumed to be entirely unsuitable for irrigation development.

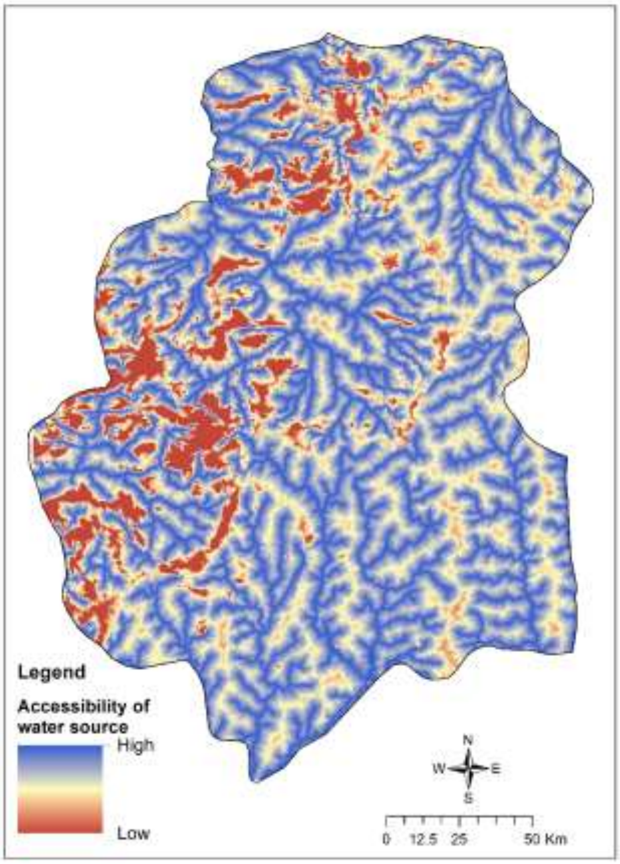


Figure 33. Map of accessibility of surface water source, based on distance to and height above nearest stream.

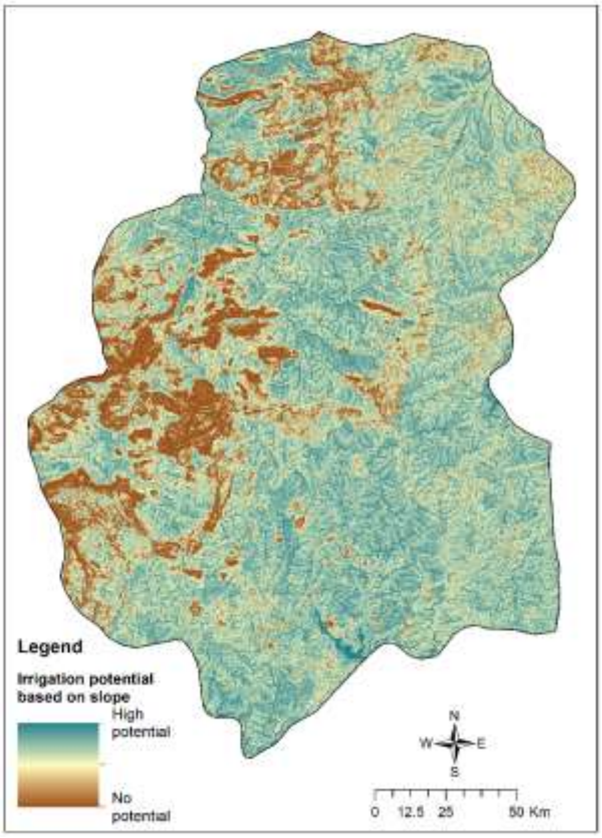


Figure 34. Irrigation potential in Huambo Province based on slope.

3.3.4 *Final irrigation potential map*

Integration of all relative maps was performed according to the steps outlined in Figure 3. Weights applied to the individual maps were 40%, 40% and 20% respectively for crop water stress, access to water sources, and slope. In case one of the underlying maps has zero irrigation potential, the final irrigation potential map also was assigned value zero.

Figure 35 shows the resulting tentative map of irrigation potential in Huambo Province. Although regions of high and very high potential can be found throughout the province, particularly in the west there are substantial areas with low potential. This is mainly related to topography, with steep slopes and high elevations above water sources limiting opportunities for irrigation development. Based on crop water availability (see also Figure 31), particularly patches in the center and northwest of the province jump out as suitable locations for irrigation development.

It should be noted that this map should be regarded as a tentative, first indication of irrigation potential, based largely on satellite-derived public domain data sources available on the global or continental scale. Further tailoring to the local context, e.g. through ground-based data collection, could enhance the results. High-resolution remote sensing, either drone- or satellite-based, can be used to produce more detailed maps of specific parts of the province that are targeted for agricultural development. Also, the use of agro-hydrological models could support a more quantitative assessment (e.g. based on potential yields and expected yield gaps) than the largely qualitative map shown in Figure 35.

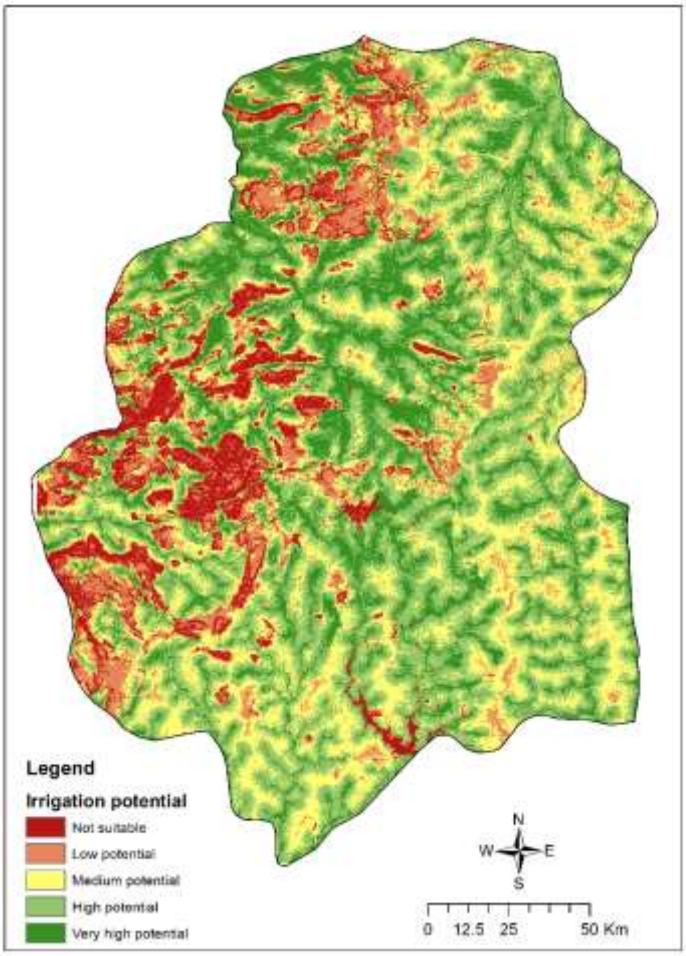


Figure 35. Tentative irrigation potential map for the province of Huambo, based on crop water stress, access to water source and terrain slope.

3.4 Integration into Fieldlook

Fieldlook is a state of the art online field monitoring platform for farmers and farmer collectives. It allows easy comparison of fields and sites by monitoring crop development, production and a range of other datasets such as irrigation potential and water consumption. The platform provides the flexibility to present different levels of analysis and to summarize field information into graphs (see Figure 37), tables and maps.

The Fieldlook platform has been successfully used amongst a growing number of farmers in the Western Cape region in South Africa for the past eight years. This region is of international importance for its production of stone-fruits, citrus, table grapes and wine. Fieldlook has achieved significant savings in water use and has changed the way farmers approach their production. FieldLook is designed and managed by eLEAF.

Figure 36 shows an example of potential of irrigation development of existing agricultural fields, integrated in Fieldlook. This image gives an impression of how the results of the agro-ecological suitability maps and irrigation potential map can be presented in the FieldLook interface, targeted e.g. at farmers or government decision makers.

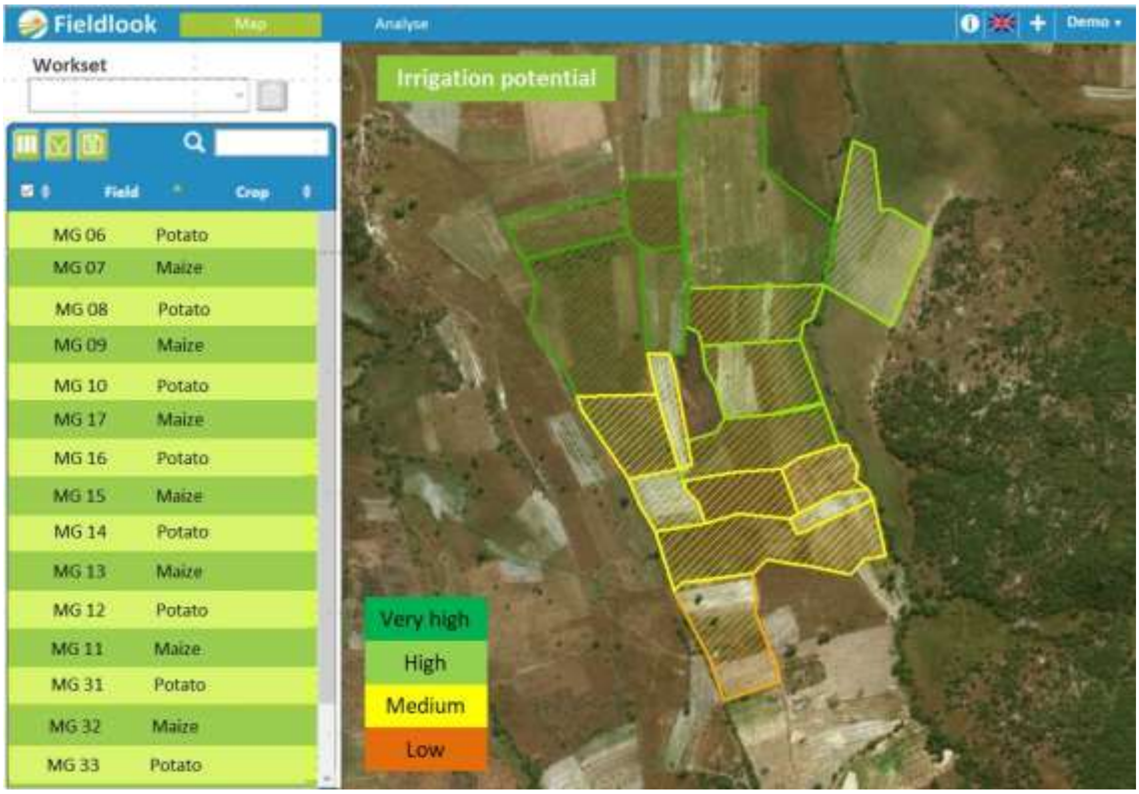


Figure 36 Example of integration of remote sensing-based data products into Fieldlook: the irrigation potential for a set of fields in Huambo Province (coordinates of midpoint: lat -12.966, long 15.402).

Figure 37. Example of field graphs showing actual evapotranspiration of 3 specific fields (coloured lines), compared to the other fields (light grey). These graphs provide crop statistics from the date of the crop emergence throughout the growing cycle. This allows the user to track crop status and identify fields that might need extra attention.

4 Cooperation with Angolan and Dutch counterparts

4.1 General cooperation

4.1.1 *Introduction*

The land suitability pilot has been strongly linked to the other RVO-supported private sector pilot on remote sensing in Huambo, as well as the Knowledge to Knowledge (K2K) project led by WEnR. Throughout the pilot, the project team cooperated closely with the consortia executing these other projects. Information was shared where relevant, and events such as progress meetings, the visit of Angolese counterpart to the Netherlands, and the visit of the Dutch delegation to Angola, were organized in good collaboration. Synergies between the projects were ensured, among others, by eLEAF's participation in both pilot projects, and FutureWater's involvement in capacity building within the K2K framework. Correspondence with the Dutch Embassy in Luanda was also regularly maintained, to report project progress and identify opportunities for showcasing (intermediate) results.

During the project, contacts were established with Angolan stakeholders from the private, public, as well as the academic sector. As this pilot constituted the first activity in Angola for the consortium, it provided a unique opportunity to enter a new market and successfully showcase satellite-based information services. It is foreseen that these initial contacts will further materialize into longer-term partnerships, such as under the Mavo Diami initiative described below. Paragraph 4.1 highlights some key aspects of the Angolan-Dutch cooperation realized over the course of the project. The closing event that took place in Huambo on the 6th of February 2019 is described in Paragraph 4.2.

4.1.2 *University Jose Eduardo dos Santos*

Early in the project, contact with UJES-FCA (Faculty of Agricultural Sciences) was established to initiate a working relationship between the project team and the university. In addition, the project approach was discussed in the context of the reality of the Angolan agriculture sector and the needs of UJES-FCA. This was instrumental in further specification of the approach, e.g. by determining relevant crop types and growing seasons to be included in the project work.

In June 2018, a FutureWater staff member traveled to Angola for further expanding the link between the project team and UJES-FCA. During this mission FutureWater cooperated with WEnR on the provision of a two-week capacity building workshop on remote sensing for agricultural applications (Figure 38). In addition, the Embassy was visited, and discussions were held to explore possible links between the Land Suitability pilot (and general expertise of the project team) with the needs of the agricultural sector in Angola.

Figure 38 Working session organized by FutureWater and WEnR with UJES-FCA staff in Huambo, Angola, June 2018.

Two UJES-FCA staff members visited Wageningen during the month of September 2018. The representatives, Mr. Issau Quissindo, Forestry researcher and Mr. Ngoma Fortuna, IT expert, are responsible for the development of technical components with regards to the establishment of a Remote Sensing and GIS lab at the university. The approach and progress of the land suitability pilot was discussed with them at Wageningen University on September 6th, 2018. In addition to this discussion, a full day program was organized by project partners FutureWater and eLEAF on September 19, 2018. During this day, several sessions were organized to exchange knowledge with regards to remote sensing opportunities for the Angolan agricultural sector (see the program of the visit in Appendix 2). In particular, the ambition of the university to host a database of relevant satellite-derived data layers at the lab was discussed and experiences and data were shared.

4.1.3 *Mavo Diami*

FutureWater and eLEAF are both involved in the development of Mavo Diami, an initiative to be proposed under the G4AW program. Several developments with regards to market analyses and connections with local partners took place within Mavo Diami in parallel to the land suitability pilot, and close links between both trajectories were maintained to ensure effective and efficient market introduction of Dutch geodata solutions for agriculture in Angola. The successful completion of the land suitability pilot is expected to catalyze future uptake of Mavo Diami services in Angola, as first versions of agro-ecological suitability and irrigation potential maps can be included as early deliverables to Mavo Diami end users.

4.2 Closing event

The closing event of both private sector pilots was organized in Huambo jointly with a K2K event on February 6th, 2019, supported among others by the Dutch Embassy. A total of over 100 participants from public, private and academic sector were present (Appendix 4). Following the event, an article was published by the Dutch Ministry of Agriculture.[1]

[1] https://www.agroberichtenbuitenland.nl/landeninformatie/angola/nieuws/2019/02/11/angola---agricultural-stronghold

The program for the day is included in Appendix 3. Next to presentations of the pilot results (Figure 39), interactive sessions comprised the core of the agenda. Key Angolan stakeholders with which links were established / strengthened during the event and the subsequent days were, among others:

- Agrolider (http://www.grupolider-ao.com/en/agrolider)
- Tchissolatec (http://tchissolatec.com/)
- LMRI (Syngenta representative in Angola)

Contacts with these potential partners are currently being followed up in the framework of the Mavo Dlami initiative.

Figure 39 Presentation of the results of the land suitability pilot project in Huambo, February 2019.

5 Conclusions and recommendations

5.1 Trend analysis of agricultural land use

- Remote sensing data from different sensors have been successfully applied to perform a spatiotemporal agricultural trend analysis for Huambo Province, Angola;
- Trend analysis of (agricultural) land use shows a general decline in vegetation vigor, which is probably attributable to removal of tree cover. The most notable changes in land cover linked with removal of tree cover and urban expansion were detected between 2008 and 2013. These changes were clearly visible on Landsat data at 30 m resolution;
- MODIS data at 250m resolution can be used to assess general trends in land cover and phenology (seasons) over time, but the spatial resolution is too low to make any deductions specifically on changes in agricultural land cover. This is partly due to the nature of the agricultural croplands (e.g. small field sizes and in some areas scattered locations);
- MODIS data showed general trends in growing seasons for Huambo over time. Landsat-based phenology can add more detailed information on phenology (i.e. start and end of the growing season), but this would require Landsat data for the entire year (and preferably at least 3 years) and without large data gaps. This requires a significant additional input for masking cloud and cloud shadow, and filling data gaps using peer reviewed interpolation methods.
- Sentinel-2 optical data at 10m spatial resolution is a good potential source of high resolution optical satellite data, to be used instead of, or with Landsat data for more detailed mapping and monitoring purposes.

5.2 Agro-ecological suitability mapping

- Smart integration of different satellite-derived information and other GIS data have successfully yielded season-specific agro-ecological suitability maps of Huambo Province for potato, maize and bean;
- Suitability for cultivation of these crops largely depend on the season. Where several highly suitable areas have been identified across the province for the February-May and October-January seasons, only a few patches of land allow for productive crop cultivation in the dry May-October period. These are mainly located in the east of the province.
- The suitability maps provide a preliminary indication of areas that are interesting to focus on in future agricultural development. Next to use of higher-resolution data sources, future improvements should focus on the further tailoring of the approach to the local context of Huambo. Threshold values specific to e.g. crop, climate and soil should be adjusted further based on on-the-ground-knowledge, and agro-hydrological models can be applied to quantify likely yield gaps and water productivity. This will enable the production of quantitative rather than qualitative (high-low) maps, and allow for translation to economical parameters.

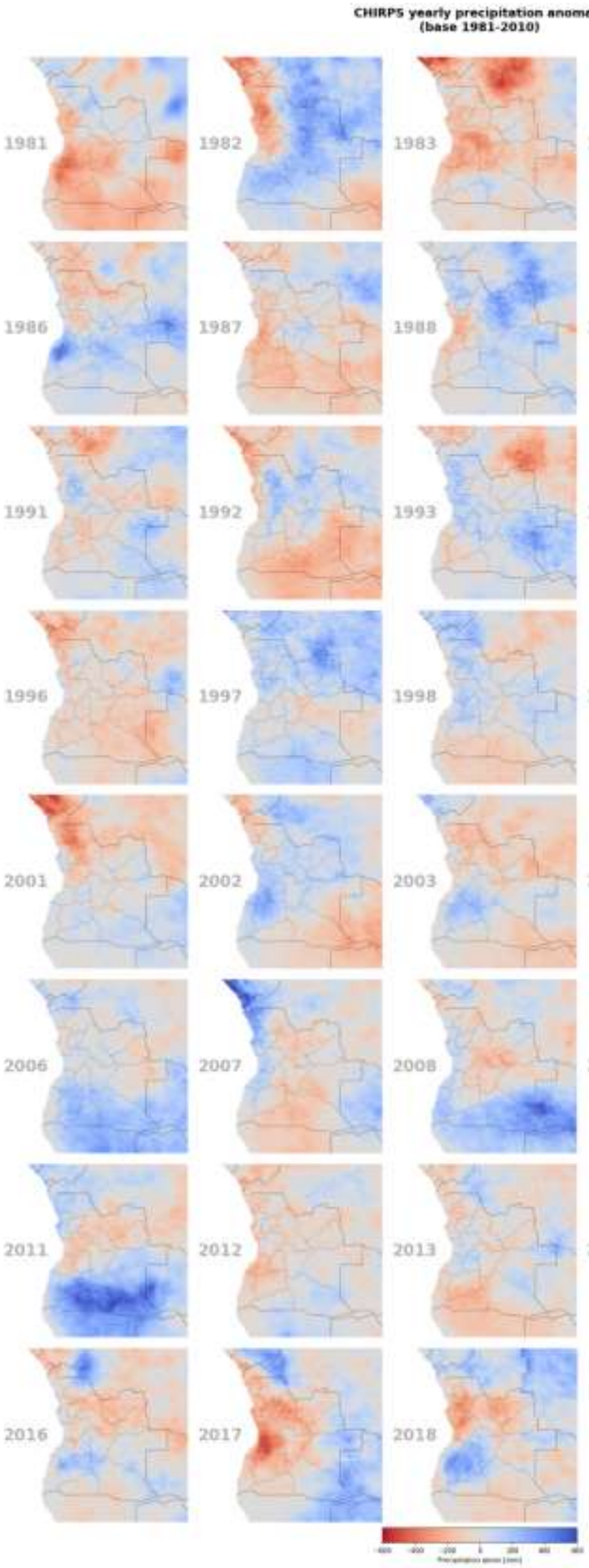
5.3 Irrigation potential mapping

- Based on remotely sensed datasets and a hydrological model, a tentative map of potential for irrigation development was successfully constructed for Huambo Province. This map is especially useful for gaining first insight in key regions to focus on in irrigation development, accounting for local water availability, topography, soil characteristics and other relevant factors;
- Key regions for irrigation development were identified, among others, in the mid-north and northwest parts of the province;
- The tentative map created in this pilot project still holds great potential for further improvement. High-resolution satellite and drone data can further improve the level of detail to that of smallholder field size. Ground data on soils, improved local weather data and the use of agro-hydrological models are just some of the ways to further enhance the current product, which is largely qualitative and based on global public-domain datasets.

5.4 Opportunities for remote sensing in Angolan agriculture

- Angola currently strongly focuses on agricultural development. Huambo is the number one province in terms of agricultural activity;
- Because of large distances, long travel times and suitable climate, Angola is a country where remote sensing-based services hold great potential for the agricultural sector. This pilot has demonstrated various applications related to land suiability, but a wide range of different services can be thought of (e.g. in-season irrigation support, identification of weakly and strongly performing fields, and advice on farm management practices);
- It is highly recommended to further explore opportunities with Angolan stakeholders in the agricultural sector. Large farming enterprises and key government agencies have shown their interest in services based on remote sensing, and the current momentum is illustrated by the development of the Remote Sensing and GIS lab at UJES-FCA. Further steps should be taken to mapping out the user needs of these stakeholders, and towards joint piloting of applications. The Mavo Diami iniative could achieve a great leap forward towards operational, self-sustaining services, incorporating the technical recommendations following from this pilot project.

Appendix 1: Annual rainfall anomalies for Angola, 1981-2018



Appendix 2: Agenda of visit of UJES-FCA staff to FutureWater and eLEAF

September 19, 2018

Morning (@FutureWater):

9:00h - 9:30h	Welcome / company introduction FutureWater
9:30h - 10:45h	Session on Agro-ecological suitability mapping and irrigation potential mapping: presentation and discussion
10:45h - 11:00h	Coffee break
11:00h - 12:15h	Session on RS/GIS Database constructed by UJES-FCA
12:30h - 13:15h	**Lunch (in town)**

Afternoon (@eLEAF)

13:30h - 14:00h	Welcome / company introduction eLEAF
14:00h - 15:00h	Session on agricultural trend analysis / phenology / WAPOR: presentation and discussion
15:00h - 15:15h	Coffee break
15:15h - 16:00h	Session on data infrastructure with eLEAF IT team
16:00h - 16:30h	Fieldlook and Irrigation planner

Locations: FutureWater, Costerweg 1V, 6702 AA, Wageningen
eLEAF, Hesselink van Suchtelenweg 6, 6703 CT, Wageningen

Contact person: Gijs Simons (FutureWater)
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Appendix 3: Agenda of closing event, Huambo

UNIVERSIDADE JOSÉ EDUARDO DOS SANTOS

FACULDADE DE CIÊNCIAS AGRÁRIAS

"O Uso da Detecção Remota para Impulsionar a Agricultura de Precisão em Angola"

Data: 06 de Fevereiro de 2019

Local: Faculdade De Ciências Agrárias, Chianga– Huambo

Mestre de Cerimónia: MSc Daniel Lucas

PROGRAMA		
SESSÃO DE ABERTURA		
HORAS	**ACTIVIDADE**	**RESPONSÁVEL**
08:30 - 09:00	Recepção dos participantes e convidados	Protocolo
09:00 – 09:35	Hino Nacional (cantado)	Participantes
	Apresentação da mesa do *Presidium*	Mestre de Cerimónia
	Palavras de boas vindas	Sua Excelência Governadora da Província do Huambo, Dra. Joana Lina
	Intervenção da Embaixada da	Chefe Adjunto de Missão da Embaixada

	Holanda	do Reino dos Paises Baixos em Angola, Alex Oosterwijk
09:35 – 09:45	Momento cultural	Grupo FCA
09:35 – 10:00	O Projecto K2K – A trajectória das tecnologías inovativas na UJES e próximos desafios	Vice Reitora Área Científica e Pós-Graduação da UJES, Prof. Doutora Virgínia Quartim
10:00 – 10:15	Importância da Detecção Remota para o desenvolvimento da agricultura em Angola	WUR ou NSO
10:15 – 10:45	**PAUSA PARA CAFÉ**	
SESSÃO 1: RESULTADO DO PROJECTO K2K E ESTUDOS DE CASO		
10:45 – 11:00	Projecto K2K: resultados da relação bilateral entre WUR e UJES	Decana da FCA, Prof. Doutora Imaculada Matias
11:00 – 11:45	Aplicação de detecção remota ao desenvolvimento agrícola em Angola: projectos-piloto ✓ Detecção remota e cultivo de batata na província do Huambo, Angola. ✓ Detecção remota para mapear as terras agricultáveis na Província do Huambo, Angola.	Coordenação K2K
SESSÃO 2: AUMENTAR A CAPACIDADE DOS AGRICULTORES ANGOLANOS - O LABORATÓRIO DE DETECÇÃO REMOTA DA FCA/UJES		
11:45 – 12:00	Apresentação do LABSIGDER da FCA / UJES: exemplo de trabalho prático	MSc Isaú Quissindo
12:00 – 12:30	Inauguração do LABSIGDER e visita às instalações	Prof. Doutora Maria do Rosário Sambo e Chefe Adjunto de Missão da Embaixada do Reino dos Paises

		Baixos em Angola
12:30 – 12:45	**Pausa para café e interacção dos participantes**	
SESSÃO 3: O FUTURO DA DETECÇÃO REMOTA PARA O DESENVOLVIMENTO DA AGRICULTURA EM ANGOLA		
12:45 – 13:00	Programa G4AW: usando dados de satélite e móveis para apoiar a segurança alimentar	Representante NSO
13:00 – 14:00	Lançamento do MAVO DIAMI (G4AW)	Representante MAVO DIAMI
SESSÃO DE ENCERRAMENTO		
14:00 – 14:10	Palavras de Circunstância	Sua Excelência Ministra do ESCTI, Prof. Doutora Maria do Rosário Sambo

Appendix 4: List of participants of closing event, Huambo

UNIVERSIDADE JOSÉ EDUARDO DOS SANTOS
FACULDADE DE CIÊNCIAS AGRÁRIAS
HUAMBO

PROJECTO DE REFORÇO DE CAPACIDADES EM DETECÇÃO REMOTA PARA O DESENVOLVIMENTO AGRÍCOLA EM ANGOLA (K2K)

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