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Using Sentinel-2 satellite data for detection of trees in the Inner Niger Delta

A&W-report 2555

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Using Sentinel-2 satellite data for detection of trees in the Inner Niger Delta - Final technical report

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Cover photo
Flooded *Acacia seyal* forest in the Inner Niger Delta, Leo Zwarts

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Contents

1 Introduction

BAMGIRE-project

The management of water resources in a land-locked country as Mali is complex and involves a multitude of stakeholders and interest. Through the program of PCA-GIRE (2015-2020), the embassies of Sweden and The Netherlands are supporting and coaching the process of implementation of Integrated Water Resources Management (IWRM) in the Upper Niger Basin. The overarching goal of this program is to: Strengthen the implementation of IWRM at the local, national and international levels by supporting Malian authorities and other stakeholders involved in the implementation of the national IWRM policy.

The BAMGIRE project (2015-2019), led by Wetlands International Mali, is part of the larger PCA-GIRE program. BAMGIRE encompasses the support of the political process and provides the science-based background and content to the process. The project of BAMGIRE is set up in different modules, arranged in a logical framework. Amongst others, this refers to the hydrological modelling of the system including a detailed spatial flooding model of the Inner Niger Delta (IND), the setup of an Observatory for the Upper Basin, an ecosystem services mapping of the IND, an ecological hotspot analysis of the Upper Niger Basin, and a decision support system for IWRM in the basin (figure 1).

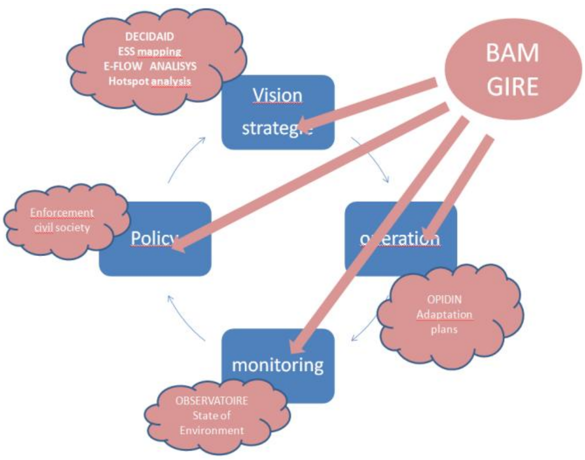


Figure 1: Simplified structure of the BAMGIRE project, projected on a general management and policy cycle

The overall goal of the BAMGIRE project (2015-2019) is *"A living Inner Niger Delta, where livelihoods and biodiversity are secured in a changing environment"*. The specific Project Objective is that "Government, decentralized institutions and community actions sustain the flooding regime and natural resources of the Inner Niger Delta so that livelihoods, biodiversity and the economy can adapt to a changing environment".

Mapping trees in the Inner Niger Delta

Although there are very few forests in the Inner Niger Delta, dispersed trees are present in many areas. *Acacia seyal* forests specifically occur on the highest floodplains in moist areas. On the vegetation map of the Inner Niger Delta (IND) created by Zwarts *et al.* (2005) no forests were indicated because at that time resolution of satellite images was too coarse to distinguish trees. In 2012 the distribution and coverage of forests was mapped for a selected area of 1956 km^2 by manually digitizing areas with trees using high resolution Google Earth imagery (Zwarts 2012). Trees occurred in a small part, 210 km^2 (11%), of the research area and coverage in most areas was less than 5%. Several reasons explain the lack of trees in the IND. Firstly, the

grazing pressure is too high; young trees are eaten before they can settle. Secondly, trees are removed by farmers when they create new rice fields. Thirdly, people cut down trees to use as source of firewood. Nevertheless, in some areas dry woodland may reappear, for example in areas that are no longer inundated, and therefore no longer used for agriculture (Zwarts 2012).
Currently, high resolution Sentinel-2 satellite data are available for free. These images allow semi-automatic detection of vegetation. This technical report describes the technical approach and methods for detecting trees using Sentinel-2 satellite data. The output map showing the distribution of trees and forests can be combined with the flood maps created based on the new flooding model (Davids *et al.* 2018), to assess presence and distribution of flood forests. Flood forests are of high economic value for the population of the IND and are also important with regard to biodiversity of birds (Beintema *et al.* 2005). The method can also be used to monitor forest/tree cover change over the years.

2 Sentinel-2 satellites

In this chapter some background information is given about the Sentinel-2 satellites and image selection. Chapter 3 describes the technical approach that was used for detection of trees.

2.1 The Sentinel-2 mission

The Sentinel-2 mission is part of six Sentinel missions, developed by ESA for the European Copernicus program. Aim of this program is effective environmental monitoring to help respond to the challenges of global change; e.g. to monitor land use change, to provide information for risk mapping and to support relief efforts in case of natural disasters or other humanitarian crises (ESA 2015). Data acquired by the Sentinel missions is made available free of charge and can be downloaded using the Copernicus Open Access Hub (ESA 2018). The Sentinel-2 mission consists of two identical polar-orbiting satellites in the same sun-synchronous orbit phased at 180 degrees to each other at a mean altitude of 786 km. Satellite revisit time is 10 days at the equator for Sentinel-2A data acquisited between 2015 and 2017. From the summer of 2017 onwards, the Sentinel-2B satellite is also operational, which has decreased the revisit time to 5 days.

The Sentinel-2 satellites are designed for multispectral, high-resolution imaging. Data is collected for 13 spectral bands ranging from the visible spectrum to near-infrared and shortwave-infrared (figure 2). Pixel resolution varies from 10x10 m for the blue (band 1), green (band 2), red (band 3) and NIR bands (band 8) and 20x20 m for the red-edge (bands 5, 6, 7, 8A) and SWIR bands (bands 11 & 12). Compared to the Landsat missions, the width of Sentinel-2 spectral bands is more narrow to reduce the influence of atmospheric constituents, such as water vapour (ESA 2015). Another benefit compared to the Landsat missions, is reflectance measurement for four red-edge bands, which allows for better vegetation classification and monitoring. Healthy green vegetation has a characteristic spectral response with a steep increase between maximum absorption of red light and maximum reflection of near-infrared light. The steepest point of this red edge is called the red edge position. This point varies for different types of vegetation (figure 3).

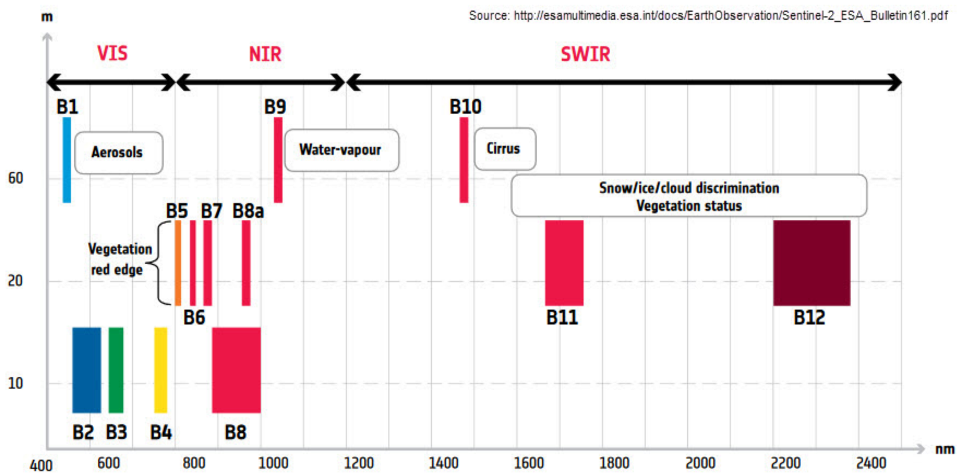


Figure 2: Sentinel-2 Spectral bands.

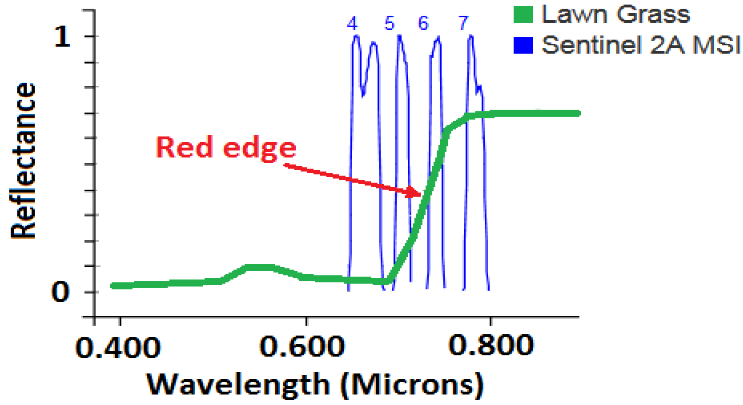


Figure 3: Sentinel-2 Red edge bands and spectral signature for lawn grass.

2.2 Selection of images

A comparison between Bing maps aerial footage and a Sentinel-2 false colour infrared composite for the Akkagoun forest, shows that trees are clearly visible on Sentinel-2 imagery (figure 4).

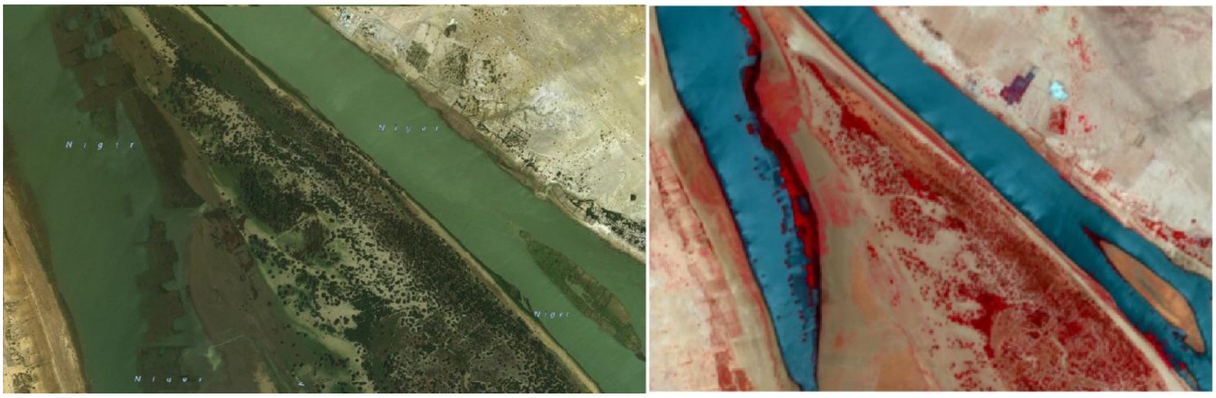
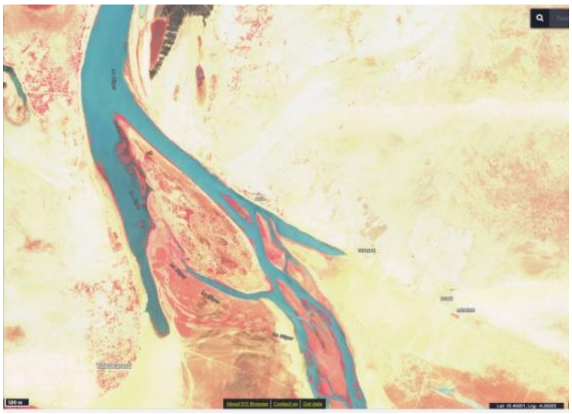
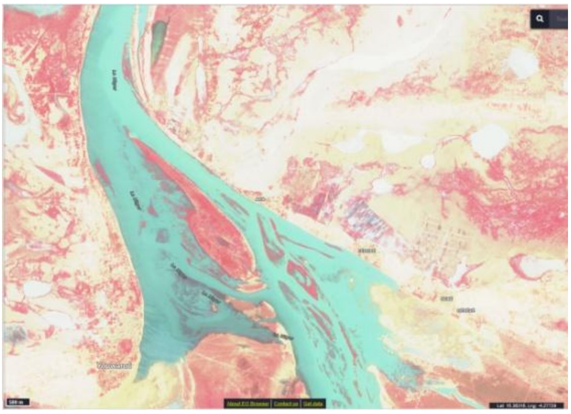


Figure 4: Detail of the Akkagoun forest on Bing maps (left) en Sentinel-2 false colour infrared composite for June 12th 2018 (right).

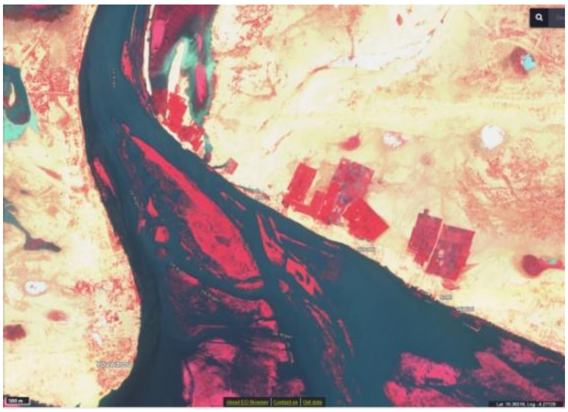
Imagery for different dates was compared to select the optimal date for detection of trees. It was found that specifically Sentinel-2 data acquisited during the dry season, between the end of March and beginning of June, can be used to map trees because little other vegetation is present during that period (figure 5). Cloud free Level 1C images were downloaded for Sentinel tiles PUC (Akka, and north of Akka) and PUB (Mopti area) for April 18th and June 12th (table 1)(figure 6).



18-04-2016



6-08-2016



5-10-2016

Figure 5: False colour infrared composites for Akka for three different dates in 2016; vegetation is displayed in red (ESA 2018b).

Table 1: Sentinel-2 Level 1C datasets that were used (ESA 2018).

Productname	Date	Tile
S2A_MSIL1C_20180418T104021_N0206_R008_T30PUB_20180418T141211	18-04-2018	PUB
S2A_MSIL1C_20180418T104021_N0206_R008_T30PUC_20180418T141211	18-04-2018	PUC
S2B_MSIL1C_20180612T104019_N0206_R008_T30PUB_20180612T124732	12-06-2018	PUB
S2B_MSIL1C_20180612T104019_N0206_R008_T30PUC_20180612T124732	12-06-2018	PUC

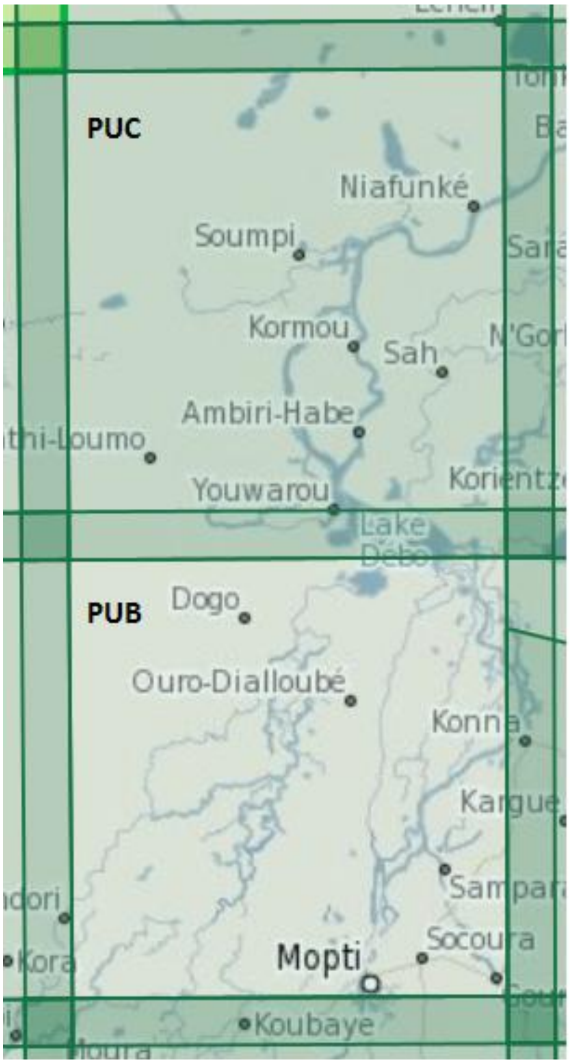


Figure 6: Footprints for Sentinel-2 tiles PUC and PUB (ESA 2018).

3 Methods

3.1 Data preprocessing

Sentinel Level 1C granules/tiles are 100 km x 100 km squared ortho-images in the UTM-WGS84 projected coordinate system. Digital numbers for Level 1C images represent top-of-atmosphere (TOA) reflectance values. Level 2A products can be generated on the user side by applying atmospheric correction using the Sen2Cor algorithm implemented in ESA's Sentinel Application Platform software (SNAP)(ESA 2018c). This algorithm converts TOA to bottom-of-atmosphere (BOA) reflectance values (ESA 2015b). To be able to compare Sentinel-2 images from different acquisition dates, atmospheric correction is necessary. This compensates for effects of atmospheric scattering and absorption and takes into account differences in atmospheric conditions and solar geometry. The Sen2Cor processor implemented in SNAP performs atmospheric, terrain (optional) and cirrus correction (Mueller-Wilm 2016).

3.2 Calculating Fractional Vegetation Cover

Also implemented in SNAP is a biophysical processor that can be used to calculate biophysical variables such as: Leaf Area Index (LAI), the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and the Fractional Vegetation Cover (FVC) (Weiss & Baret 2016). Researchers have used the FVC to map vegetation quality as well as changes in ecosystems; in dry areas it is also an indicator for soil degradation and desertification (Song et al. 2017). The FVC is considered a good alternative for vegetation indices (e.g. NDVI) for monitoring green vegetation (Weiss & Baret 2016). On the Eumetsat website the FVC is described as:

"Fractional Vegetation Cover (FVC) defines an important structural property of a plant canopy, which corresponds to the complement to unity of the gap fraction at nadir direction, accounting for the amount of vegetation distributed in a horizontal perspective. FVC is related with the partition between soil and vegetation contribution for emissivity and temperature. This property is necessary for describing land surface processes and surface parameterisation schemes used for climate and weather forecasting. Besides, the FVC is relevant for a wide range of Land Biosphere Applications such as agriculture and forestry, environmental management and land use, hydrology, natural hazards monitoring and management, vegetation-soil dynamics monitoring, drought conditions and fire scar extent." - (Eumetsat LA SAF 2018)

The FVC algorithm implemented in SNAP uses machine learning based on neural networks. The neural networks are trained based on a training database consisting of a large number of PROSAIL (this is a radiative transfer model) input variables, including canopy, leaf and soil variables. The PROSAIL algorithm also takes into account differences in observation geometry, such as different viewing angles and sun zenith angles. FVC values vary between 0 and 1 and are calculated at 10 meter pixel resolution. In its calculation only green elements are considered (with a leaf chlorophyll content higher than 15 migrograms.cm^{-2})(Weiss & Baret 2016). FVC was calculated for the PUB and PUC tiles for June 12th 2018 (figure 7).

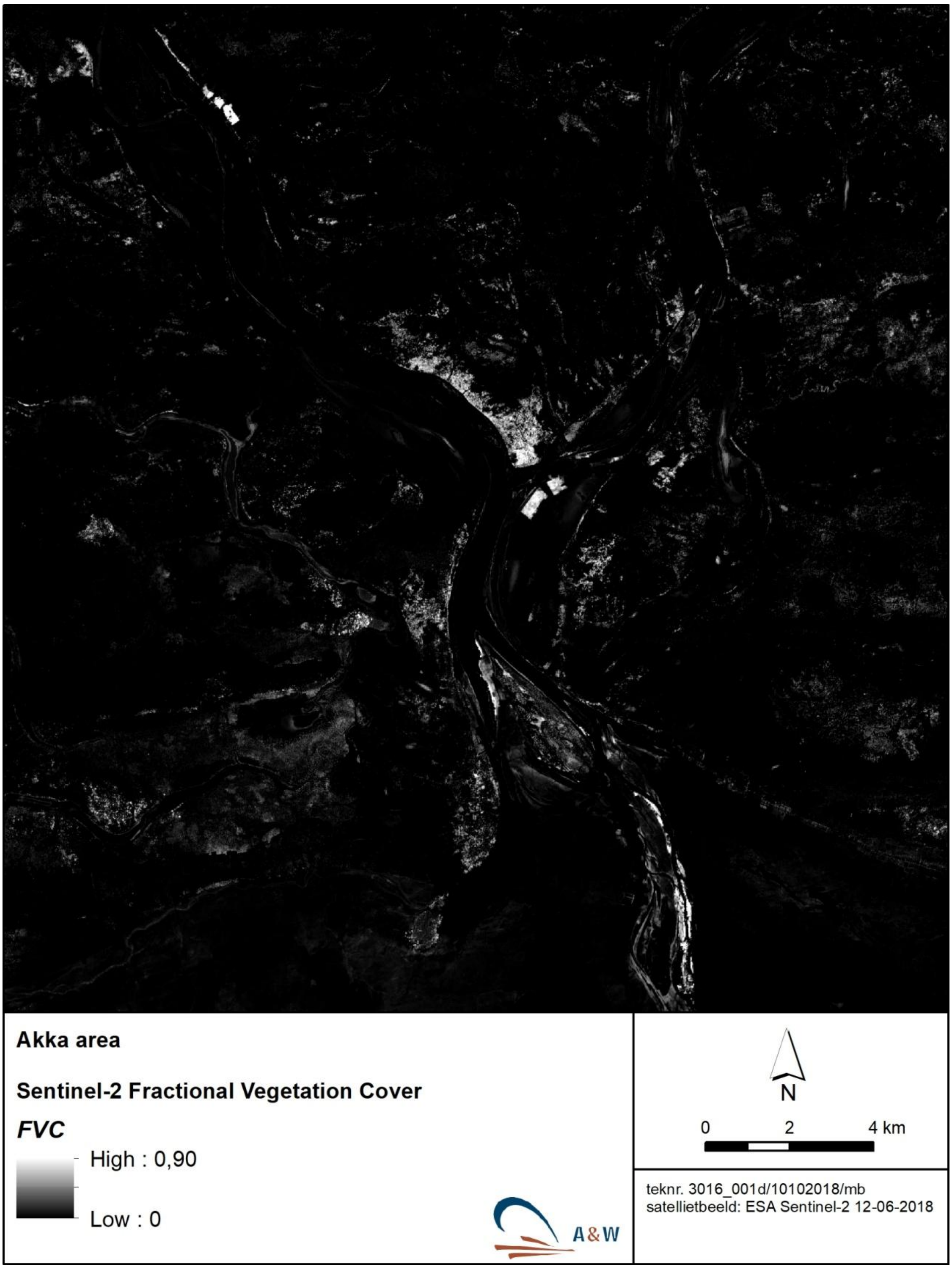


Figure 7: Fractional Vegetation Cover on June 12th 2018 for the Akka area.

3.3 Spectral response

In June, most of the land in the IND is bare because vegetation has been either eaten by cattle or dried-out. The only remaining vegetation consists of trees of the flood forests, patches of dense green meadow vegetation on low lying floodplains and actively irrigated areas (figure 8).

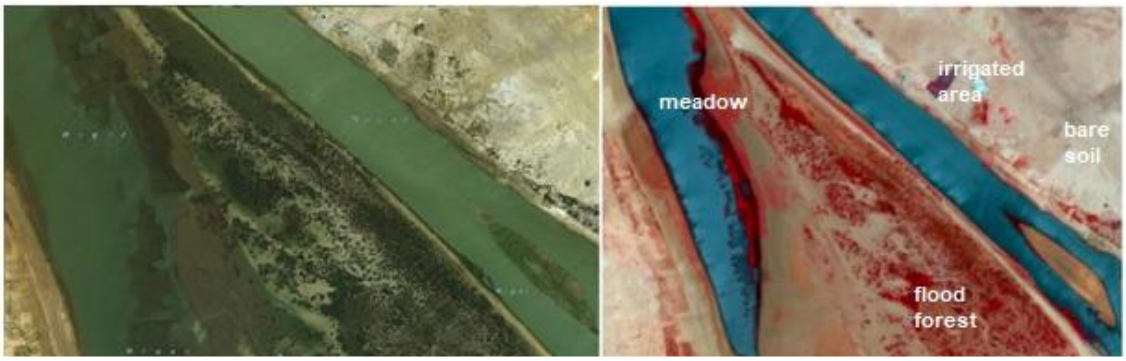


Figure 8: Examples for flood forests, meadow vegetation, irrigated areas and bare soil land cover types in the Akkagoun area on June 12th 2018 (left: Bing maps)(right: Sentinel-2 false colour infrared composite).

To assess spectral separability for different land cover categories, sample points were generated for areas with forest/single trees (N=900), dense green meadow vegetation of low grasses and rushes (*Juncus* spec.)(N=300) and bare soil (N=300)(figure 10). Forest sample points include *Diospyros*, *Acacia* and *Eucalyptus* species. These categories were distinguished based on field knowledge in combination with visual interpretation of high resolution Bing maps imagery.

Spectral response on June 12th 2018 was assessed for these sample points (figure 9). This graph shows that reflectance values for meadow vegetation and forest are quite similar for most bands except for the short wave infrared bands 11 and 12. Therefore, it may be difficult to distinguish between forest and meadow vegetation using only spectral characteristics.

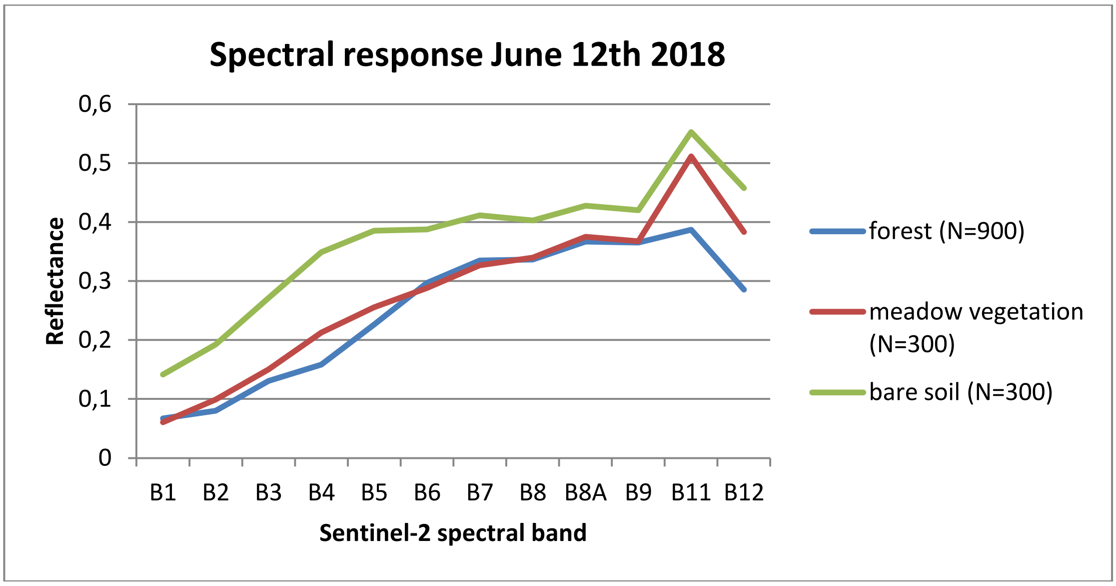


Figure 9: Spectral response curve showing reflectance for forest, meadow vegetation and bare soil on June 12th 2018.

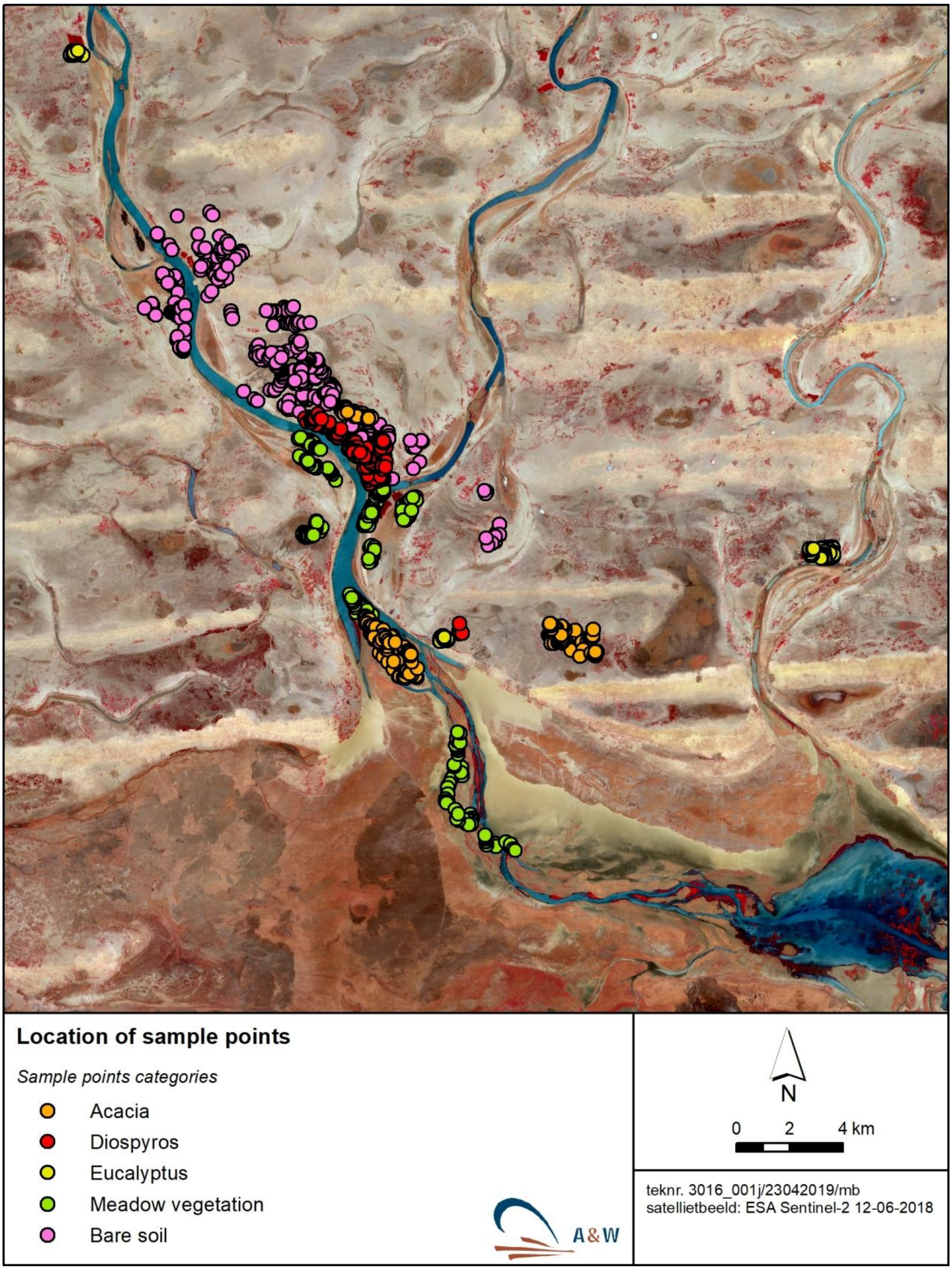


Figure 10: Location of sample points for forest (Acacia, Diospyros and Eucalyptus), meadow vegetation and bare soil.

3.4 Filtering of FVC

To assess the FVC value for forests, FVC values were extracted for June 12th 2018 for 900 sample points that were generated for known forested areas (for *Acacia sp*., *Diospyros* and *Eucalyptus*), based on the forest outlines digitized by Zwarts (2012)(figure 10). Based on analysis of the FVC values, it was found that a threshold value of 0.0415 can be used to distinguish between trees and areas with sparse vegetation other than trees.

However, actively irrigated areas also have high FVC values; these areas should not be classified as forests. They were filtered out by calculating the change in Green NDVI between April 18th 2018 and June 12th 2018. In irrigated areas the Green NDVI strongly increases between these dates. Pixels where change in Green NDVI is higher than 0.1 are classified as irrigated areas (figure 11). The threshold of 0.1 is based on inspection of pixel values for known irrigated areas.

Unfortunately, in some bare soil areas, artefacts with high FVC values occur; neither trees nor irrigated crops are present here (figure 12). These artefacts specifically occur in lower areas with moist soil. These artefacts are probably caused by errors in the neural network training database for LAI calculation. Research has shown that LAI values derived from SNAP can be overestimated for bare soil areas (Visús & Oliver-Villanueva 2018). Because the FVC is calculated based on the LAI, these errors may also affect the FVC values.

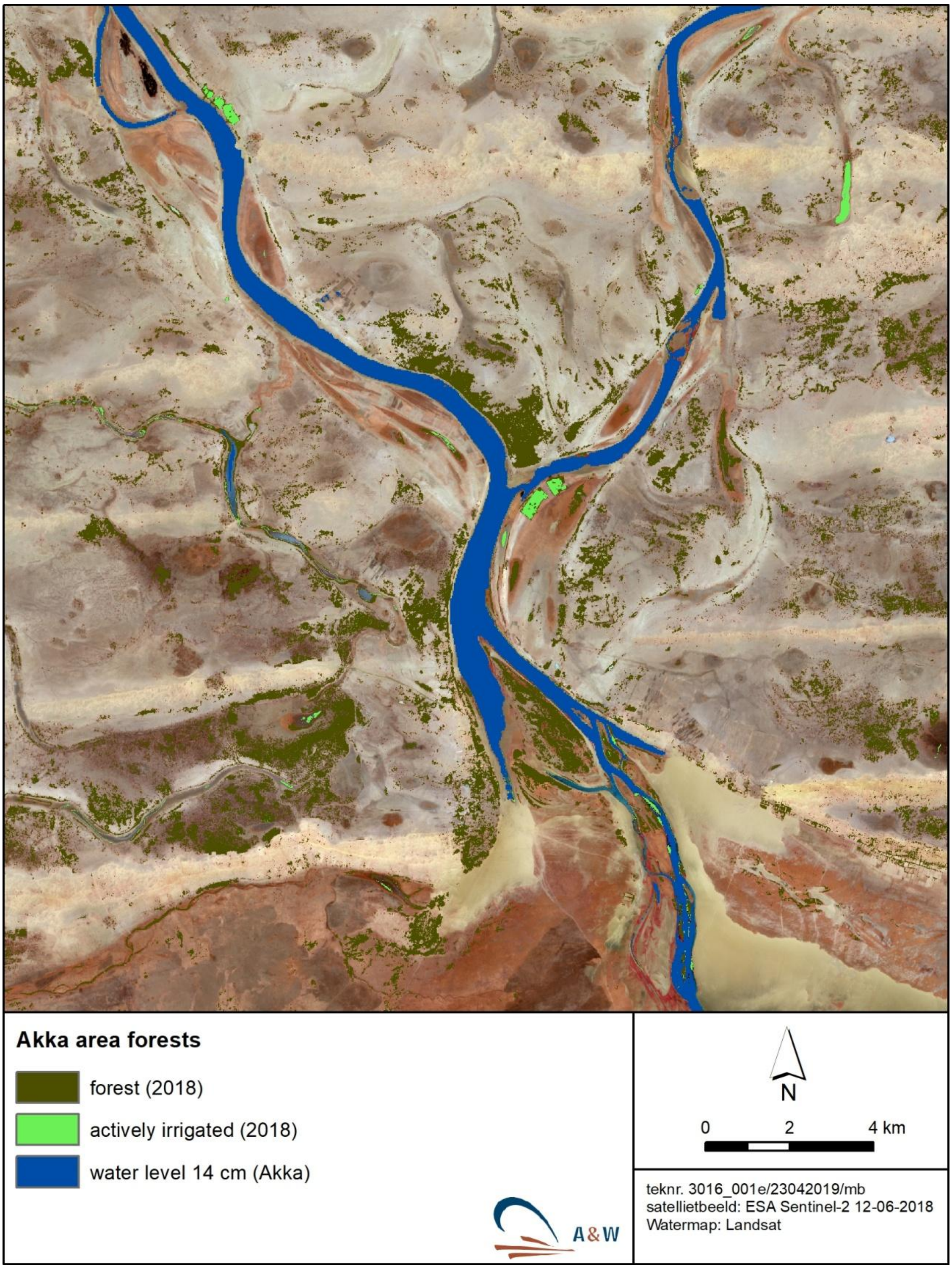


Figure 11: Map of the Akka area in June 2018, showing forest and actively irrigated areas. Water level 14 cm refers to the area being covered by water at a water level of 14 cm measured at the hydrological station of Akka. This water map is based on a separate analysis for extracting water from satellite imagery (Davids et al. 2018).

Figure 12: Misclassification occurs in low lying, bare areas with moist soil (red circles).

3.5 Suggestions for improvement

The method may be improved by combining Sentinel-2 with Sentinel-1 radar data. Sentinel-1 is a twin satellite constellation which provides Synthetic Aperture Radar (SAR) data; the satellites actively transmit microwave signals and measure the energy that is scattered back by the ground surface; presence of clouds will not affect data collection (ESA 2019). The signal is affected by the dielectric constant of materials on the ground, as well as by soil moisture and ground surface roughness. Leafs of trees also strongly scatter the signal. Data is collected for two polarisations, Vertical transmit, Vertical receive (VV) and Vertical transmit, Horizontal receive (VH).

Sentinel-1 data for June 18th 2017 was downloaded and explored. VH pixel values for known forested areas were sampled for different tree species. Canopy cover % for these pixels may vary. In dense forests, canopy cover for a single pixel will be almost 100%, in areas with dispersed trees, mixed pixels (bare soil/trees) occur with lower canopy cover %. Therefore, difference in woody cover % also attributes to the VH value. Boxplots showing values for the VH signal were generated (figure 13). It may be possible to use this data to distinguish between different types of trees. In figure 13, Acacia refers to *A. nilotica* and *A. seyal* (isolated trees); kirkii refers to *Acacia kirkii* (closed forest); seyal refers to *Acacia seyal* (isolated trees); Diospyros refers to mixed forest with *Diospyros mespiliformis*, but also *Balanites aegyptica*, *Boscia senegalensis* etc.; Eucalyptus refers to *Eucalyptus camaldulensis* (forest); Faidherbia refers to *Faidherbia albida* (large, isolated trees). Also a Sentinel-1 composite image was generated, showing strong backscattering in bright green-yellow and low backscattering in dark green-purple (figure 14).

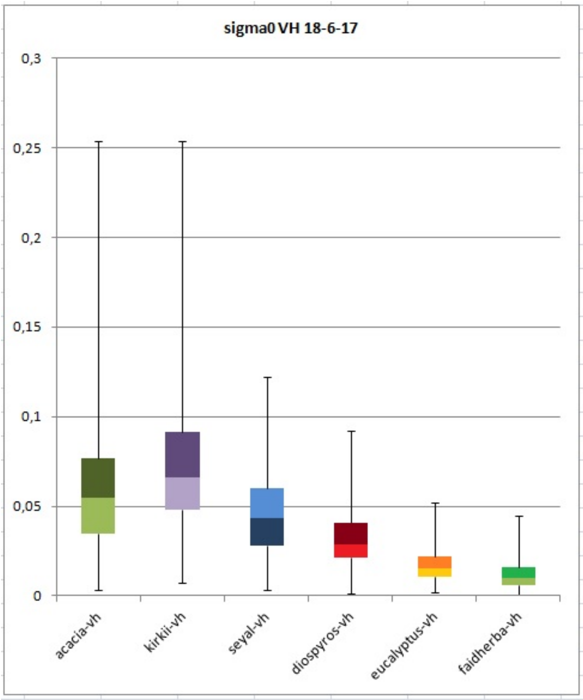


Figure 13: Boxplots showing values for the VH signal (Sentinel-1) on June 18th 2017 for different tree species; boxes display first to third quantile and median. Whiskers show minimum and maximum VH values. When boxes show little overlap it may be possible to distinguish these species of trees.

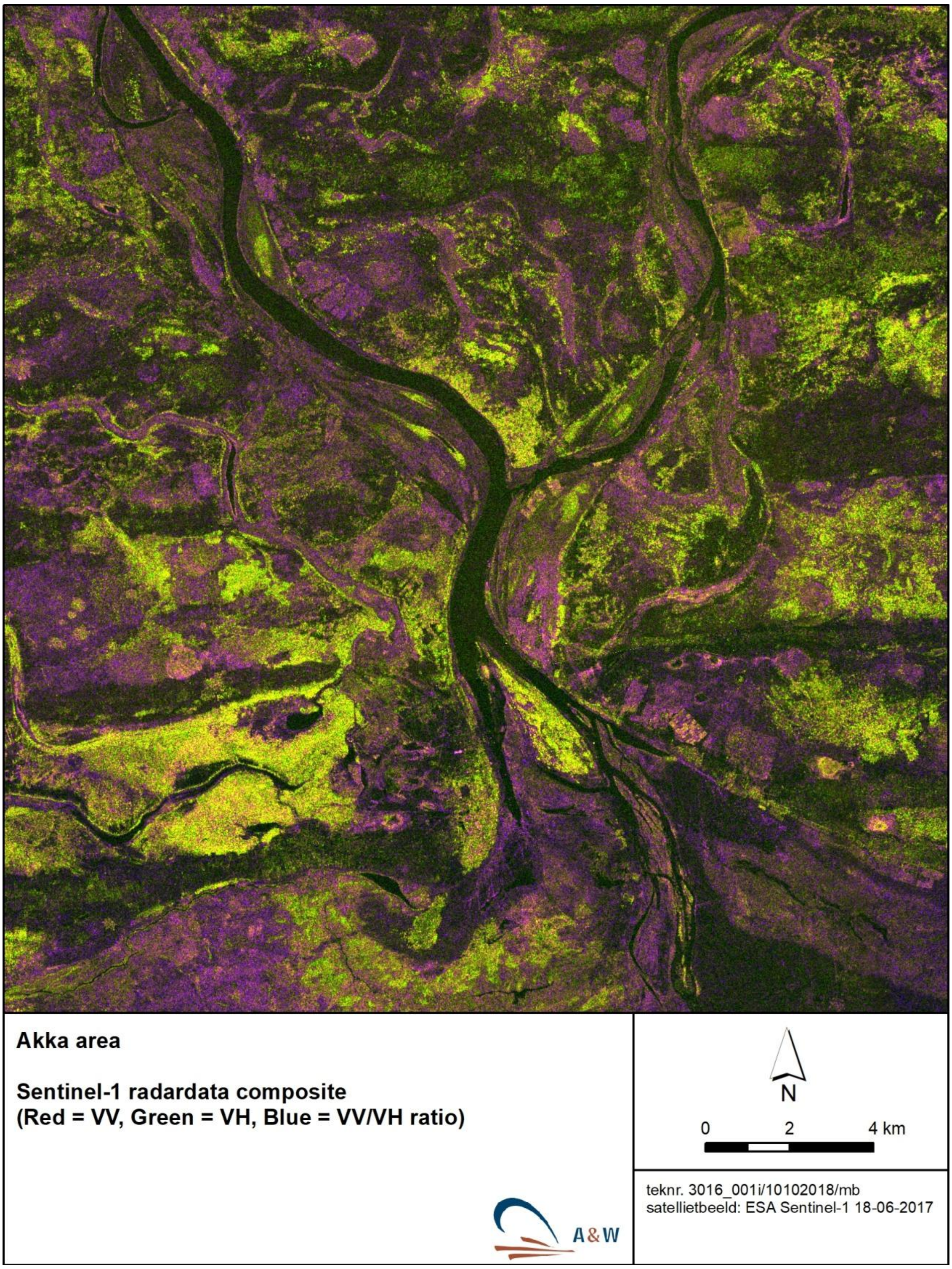


Figure 14: Sentinel-1 radar composite: vegetation is displayed in green colours, representing strong reflection of the radar signal.

Another option for improvement may be to use object-based feature extraction techniques in combination with spectral characteristics. Downside of using FVC is that the algorithm is developed for detection of vegetation cover and not specifically trees. Although imagery was used for the dry season, still patches of vegetation other than trees were present which lead to misclassification when only the FVC is used. Using change analysis between imagery from April and June did not solve this problem.

Spiekermann *et al.* (2015) have successfully mapped sparsely and densely vegetated areas on the Dogon Plateau and Seno Plain in Mali using object-based image classification of RapidEye satellite data; pixel resolution of RapidEye is 5 m. However, this method will require proprietary Erdas IMAGINE or Trimble eCognition software, since no open source tools are yet available that allow satisfactory object based classification.

4 Products

4.1 Product description

Two final products were derived:

1: IND_forests_20180612.tif
This is a raster file with a 10x10 m pixel resolution. Raster values are either 0 for no forest or 1 for forest pixels. The tif is projected in the WGS84 UTM zone 30 N coordinate system. Included with the tif is an ESRI symbology layer file. The raster shows the pixels classified on forests using the Sentinel-2 image for June 12th 2018. Extent of the map is limited to Sentinel tiles PUB and PUC.

2: IND_forestdensity_20180612.tif
This is a raster file with a 10x10 m pixel resolution. The tif is projected in the WGS84 UTM zone 30 N coordinate system. Raster values represent vegetation cover % per pixel. FVC has been reclassified into 4 classes. Values between 0.35 - 0.9 represent high density; 0.2 - 0.35 medium density; 0.1 - 0.2 low density; 0.0415 - 0.1 very low density (figure 15). Included with the tif is an ESRI symbology layer file. The raster shows the pixels classified on forests using the Sentinel-2 image for June 12th 2018. Extent of the map is limited to Sentinel tiles PUB and PUC.

4.2 Forest compared to water depth

In figure 16 the forest density layer has been combined with the flooding model for Akka (Davids *et al.* 2018). Waterdepth is shown for a water level of 600 cm measured at the hydrological station of Akka. The Akkagoun flood forest (*A. kirkii*) is found in an area with deep water (dark blue) but all other flood forests (*A. nilotica*, but mainly *A. seyal*) occur in areas with shallow water (light blue). Dry forest types (*Diospyros*, etc.) are found at a still higher level being hardly or not flooded (very light blue).

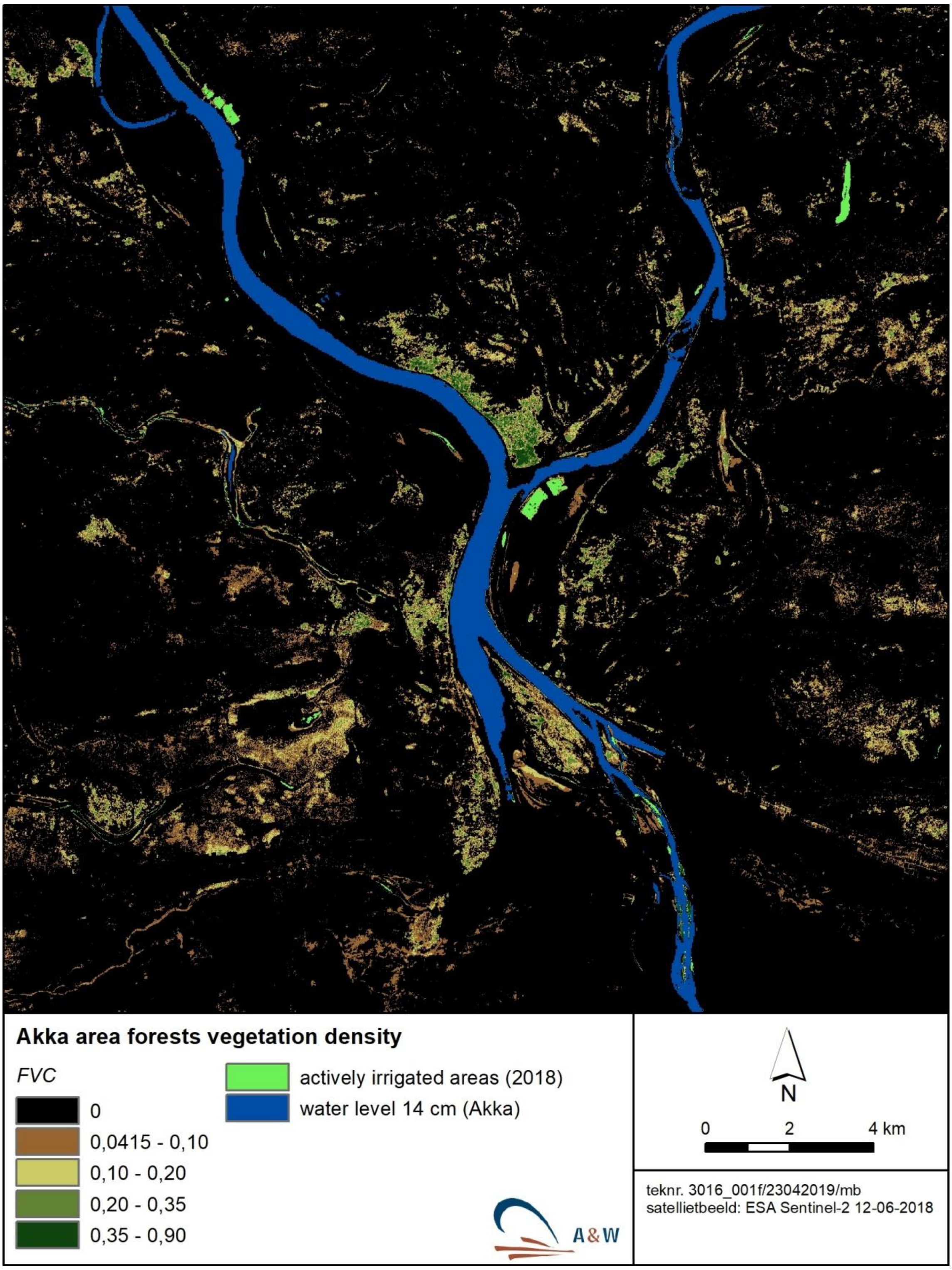


Figure 15: Map showing the forest vegetation density based on the FVC (% vegetation cover per pixel).

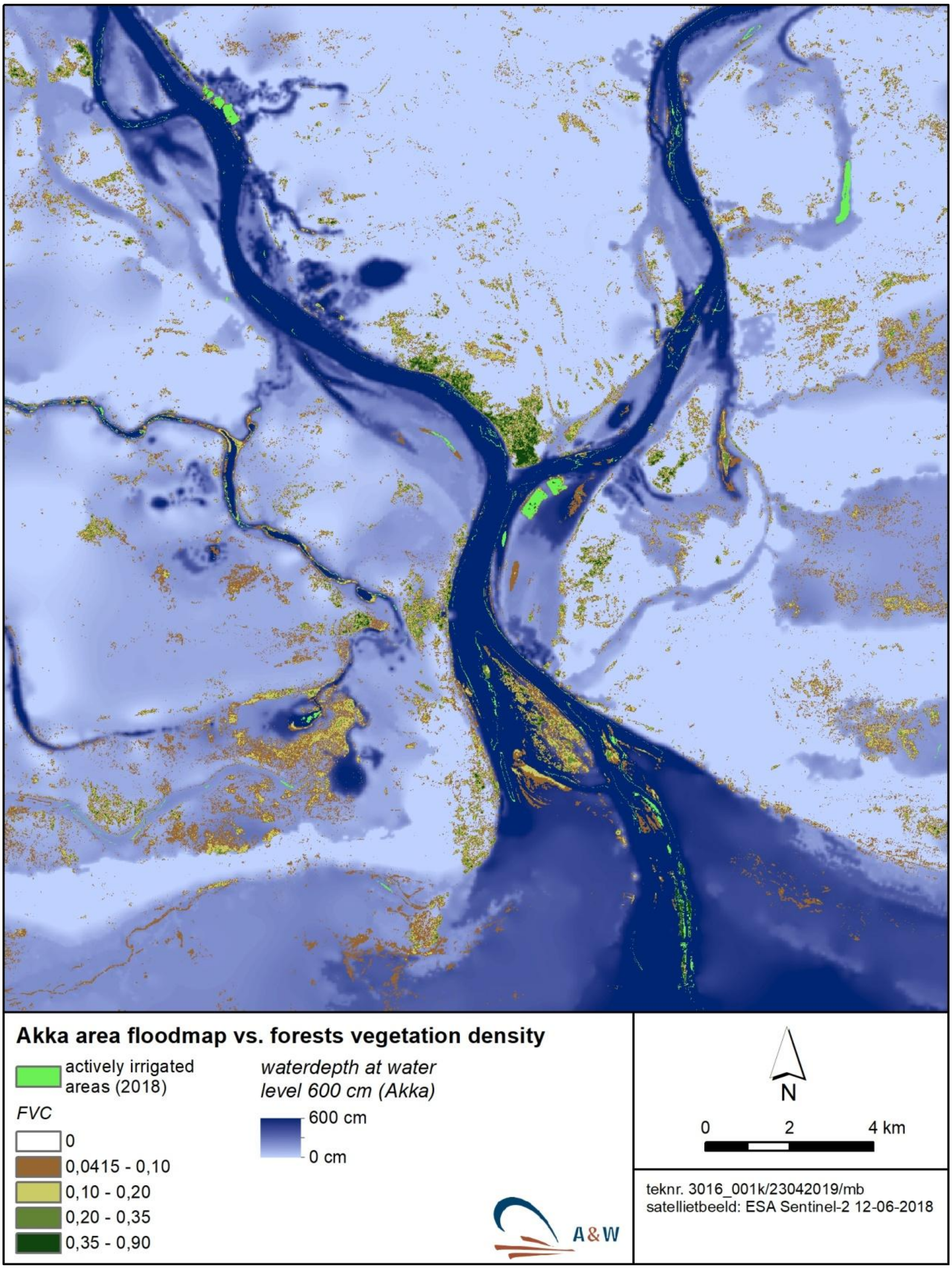


Figure 16: Forest vegetation density in combination with waterdepth for a water level of 600 cm measured at Akka.

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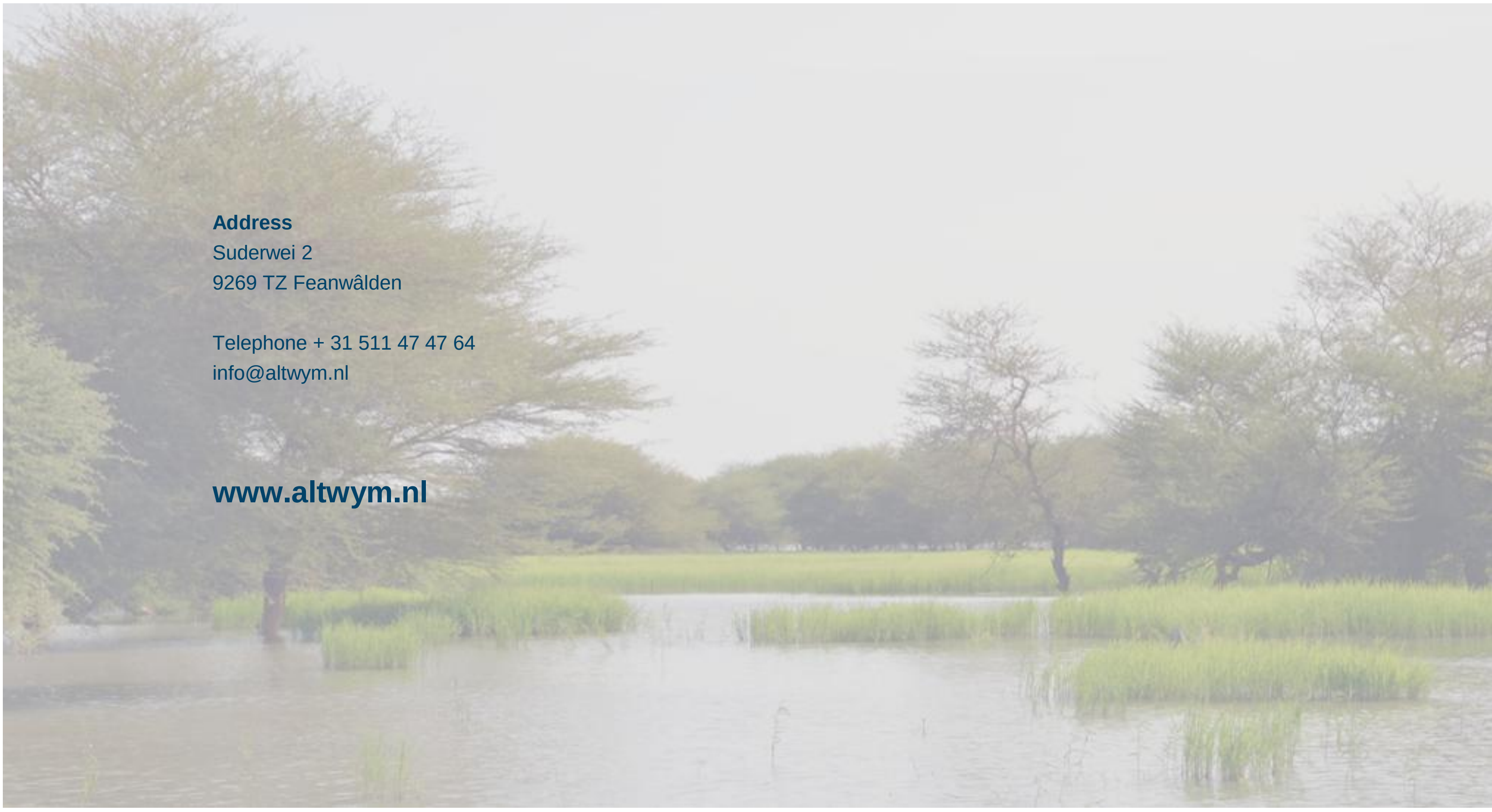

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