

Technical Note

Supplementary Materials: Spatio-Temporal Patterns of Smallholder Irrigated Agriculture in the Horn of Africa Using GEOBIA and Sentinel-2 imagery

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S1: Overview of object variables Random-Forest classification

Table S1. Overview of object variables used in the Random-Forest classification for the cropland classification. For a detailed description of the variables see [1]. Abbreviations: St. Dev. is standard deviation.

Type	Variable	Definition
Shape	Area	The number of pixels within an object. A proxy for size.
	Asymmetry	The more longish an object, the more asymmetric it is.
	Border index	The smallest rectangle enclosing the object.
	Border length	Sum of the edges of the object.
	Compactness	The product of the maximum length and width divided by the number of pixels of the object.
	Length width ratio	The maximum length divided by the maximum width of the object.
	Rectangular fit	How much the object approaches the shape of a rectangle.
	Roundness	Difference between the radius of the largest enclosing ellipse and the radius of the smallest enclosing ellipse.
	Shape index	The border length of an object divided by four times the square root of its area.
Texture	St. Dev. blue reflection dry-season mosaic	
	St. Dev. green reflection dry-season mosaic	
	St. Dev. red reflection dry-season mosaic	
	St. Dev. NIR reflection dry-season mosaic	
Spectral	12x mean monthly NDVI	
	Mean blue reflection dry-season mosaic	
	Mean green reflection dry-season mosaic	
	Mean red reflection dry-season mosaic	
	Mean NIR reflection dry-season mosaic	

S2: Process-based rules for irrigation classification

The process-based rules for irrigation classification are established on a monthly basis, i.e. vegetation differences between the monthly NDVI composites are considered. The following rules apply, which are expressed in three processing steps and exemplified with the months September and October.

Step 1: Each cropland object is labeled as crop growth when the following rules apply:

- The NDVI in October is higher than the NDVI in September. Also, the NDVI in October must have a value of 0.1 or higher to ensure vegetation is present.
- The NDVI in October is lower than the NDVI in September, but in both months the NDVI is consistently high. Here, the NDVI in September is 0.4 or higher and the maximum allowed NDVI decrease between the two months equals 0.1 or less. For example, an NDVI of 0.6 in September and an NDVI of 0.5 in October will be labeled as crop growth. This rule is established to ignore small drops in high NDVI values, as additional water is required to maintain large vegetation activity.

Croplands showing no crop growth are classified as rainfed cropland. For croplands showing crop growth we continue with step 2 followed by step 3.

Step 2: All neighbouring objects (cropland and other LULC) in a radius of 5 km around the object under consideration are labeled for vegetation/crop growth according to the rules in Step 1. If vegetation/crop growth is observed, they are flagged with a 1, else with 0. Non-vegetation objects are not considered (NDVI below 0.1 for the entire year).

Step 3: We now classify the observed crop growth as irrigation- or rainfall-induced growth. The heterogeneity of the now binary neighbours is assessed and the percentage of neighbours showing vegetation growth determined. If this percentage is high, this means that all neighbours (including the cropland object under consideration) experience vegetation/crop growth, i.e. is completely homogeneous in their behaviour, which occurs on a higher level than the field level and implies rainfall-induced NDVI increase (Figure B.9A). If the percentage is lower, not all neighbours show vegetation/crop growth and a more heterogeneous pattern emerges (Figure B.9B), which implies that the crop growth of the cropland object under consideration occurred at field level (independent of its neighbours). Three different spatial-heterogeneity thresholds were set to flag a crop growth as irrigation-induced, namely at least 15%, 25%, and 35% of neighbouring objects show no vegetation growth. For the 15% threshold this means that for at least 15 out of 100 neighbouring objects no crop growth occurs to classify the crop growth of the cropland under consideration to be a result of irrigation. The optimal spatial-heterogeneity threshold distinguishing irrigation- or rainfall-induced crop growth is not known and cannot be calibrated due to the absence of ground truth. Therefore, three thresholds were chosen (15%, 25%, 35%) to give an indication of the spatio-temporal range of irrigated agriculture in the Horn of Africa.

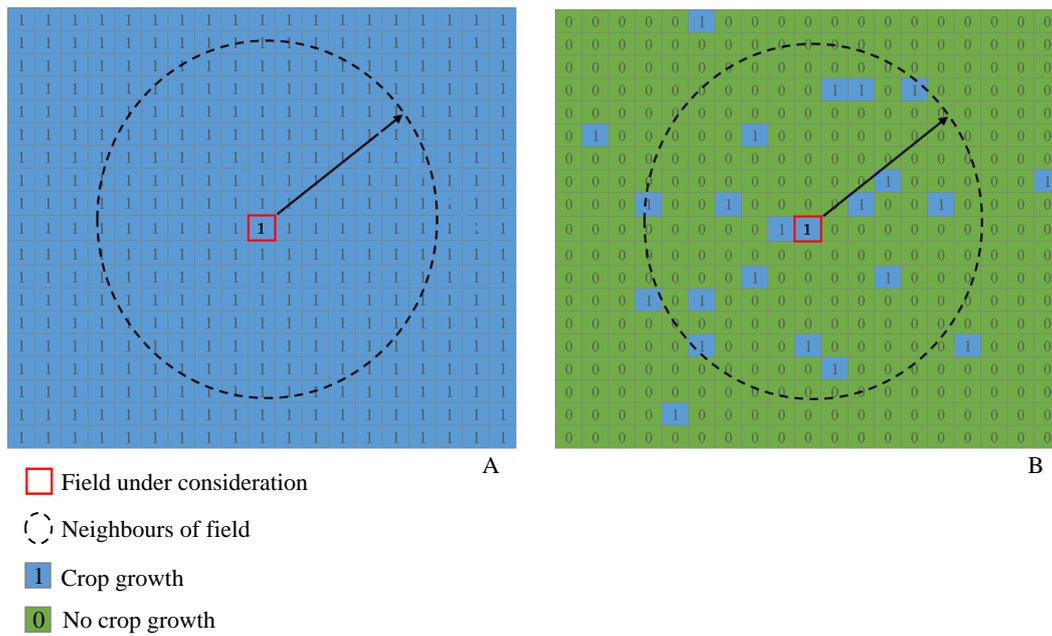


Figure S2. Illustration of vegetation development of neighbouring objects of the field under consideration. A represents a rainfall-induced crop growth for the field as 100% of the neighbours show vegetation growth (spatial homogenous vegetation development of neighbours), and B represents an irrigation-induced crop growth for the field as only 18 out of 170 neighbours (~10%) show vegetation growth (spatial heterogeneous vegetation development of neighbours). Here, the percentage of neighbours showing no growth (~90%) is well above all three thresholds (15%, 25%, and 35%) of this study, and hence this object is classified as irrigated cropland for the studied month.

S3: Variable importance of the Random Forest

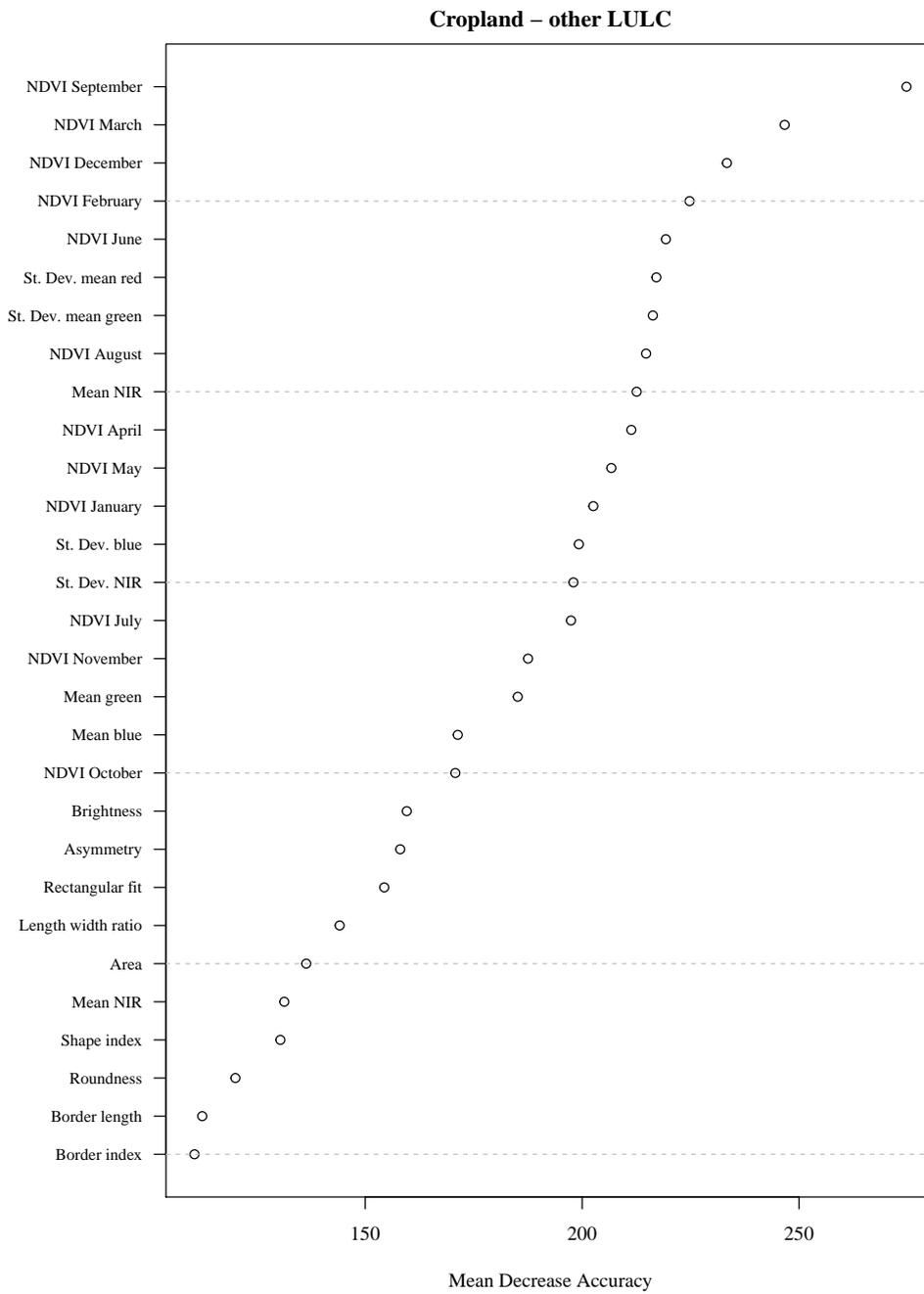


Figure S3. Variable importance as expressed by the Mean Decrease Accuracy in the Random-Forest classification of cropland and other LULC. Abbreviations: St. Dev. is standard deviation.

S4: Overview of availability monthly NDVI information**Table S4.** Cumulative availability of monthly NDVI for the objects in the validation set with incomplete NDVI timeseries (%) and all objects in the Horn of Africa (% and Mha).

Number of months NDVI is available	Availability validation set incomplete NDVI time series (%)	Availability Horn of Africa (%)	Availability Horn of Africa (Mha)
12	-	69.9	173.1
11	73.7	89.8	222.6
10	92.0	96.1	238.2
9	97.2	98.3	243.6
8	98.9	99.1	245.5
7	99.5	99.5	246.5
6	99.7	99.7	246.9
5	99.9	99.8	247.4
4	99.9	99.9	247.6
3	100.0	100.0	247.7
2	100.0	100.0	247.7
1	100.0	100.0	247.7
0	100.0	100.0	247.8

S5: Illustrations classification irrigation schemes

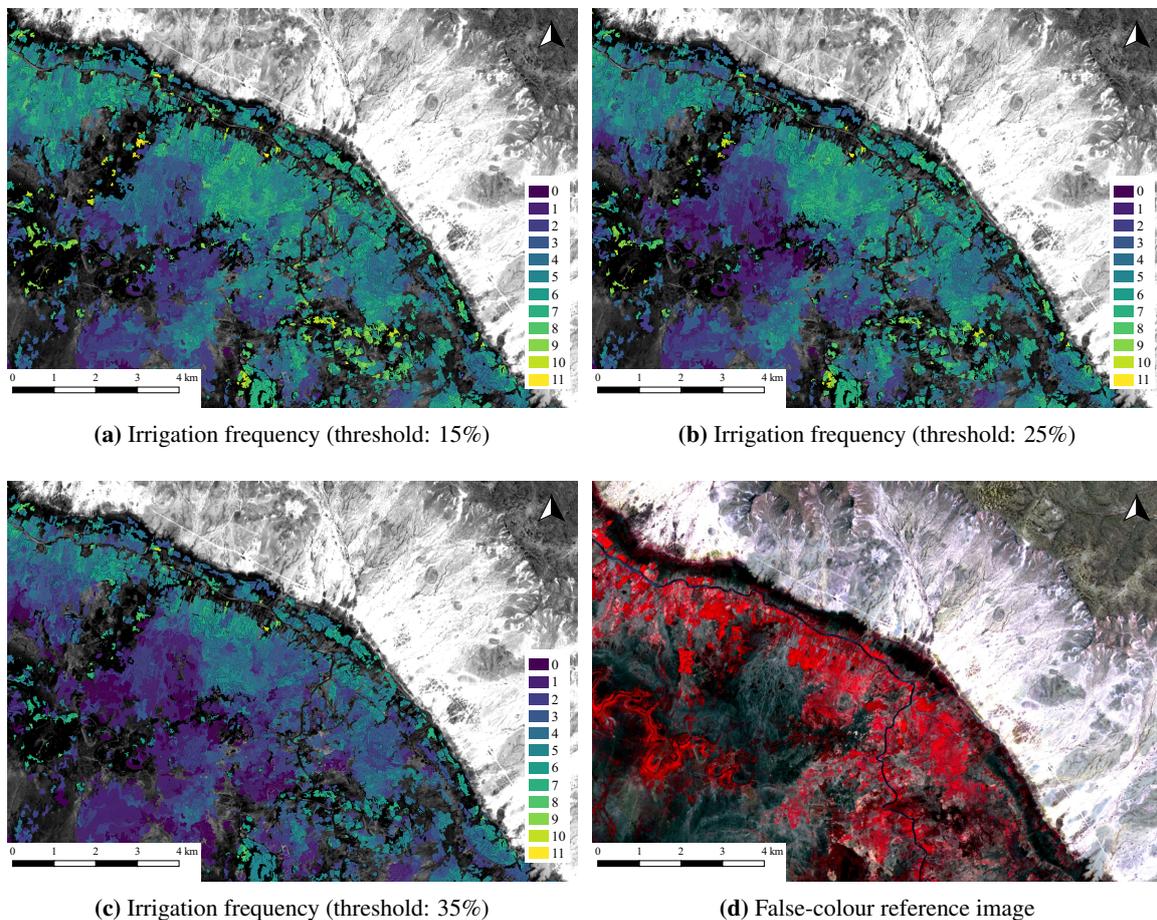


Figure S5.1. Illustration of irrigation classification result (a–c) for a smallholder irrigation scheme near Mustahil (Ethiopia, close to Somalian border) in which the monthly maps are summed to give the frequency of irrigation events at field level for one year for the four spatial-heterogeneity thresholds (min: 0, max: 11). A false-colour image (d) derived from the dry-season mosaic (RGB: NIR, red, green) is shown as a reference image of the area and serves as black-and-white background in (a–c). Center coordinates: 5°25.089' N 44°33.150' E.

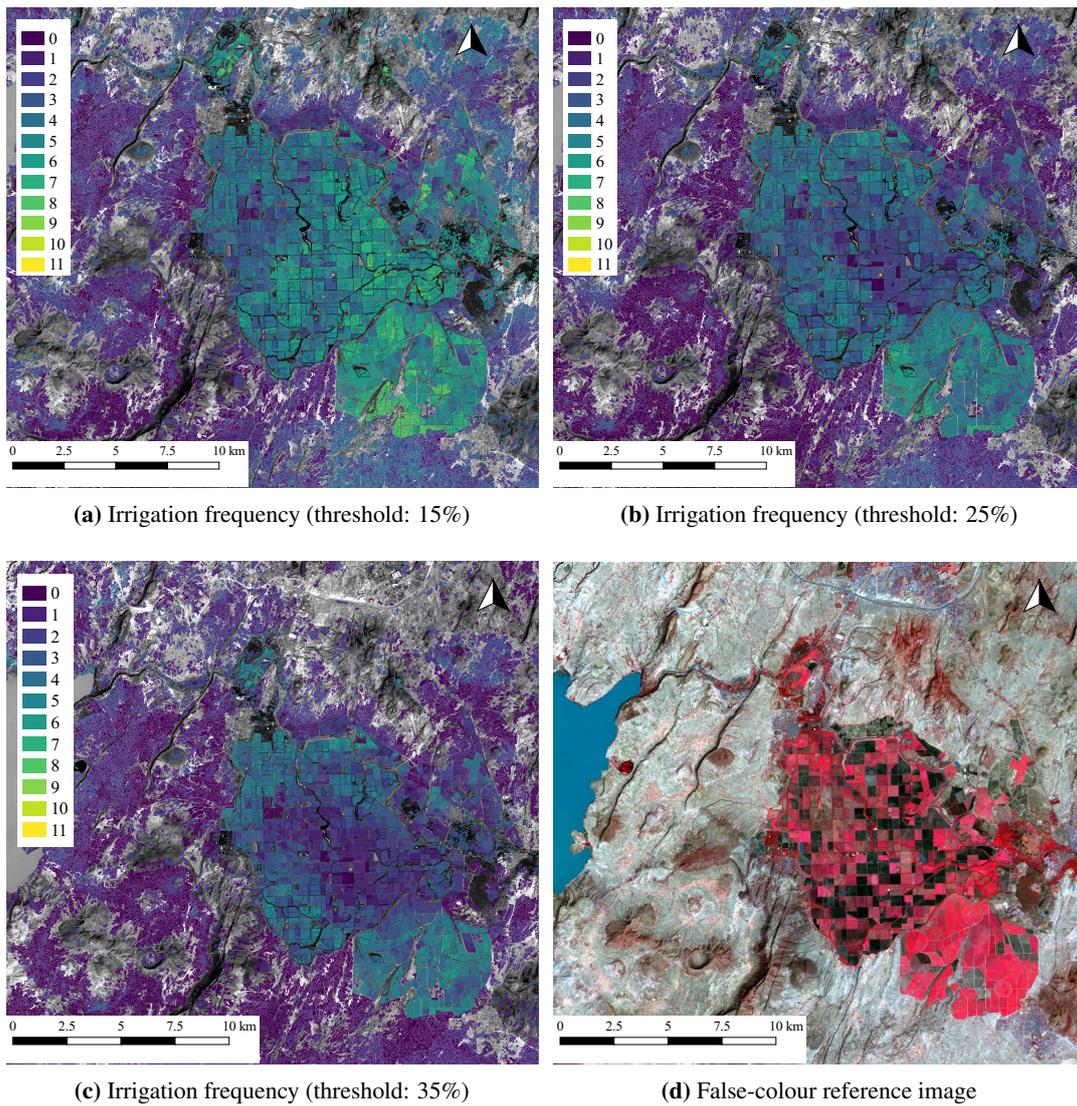


Figure S5.2. Illustration of irrigation classification result (a–c) for the Wonji-Shoa irrigation scheme near Koka Lake (Awash basin, Rift Valley, Ethiopia) in which the monthly maps are summed to give the frequency of irrigation events at field level for one year for the four spatial-heterogeneity thresholds (min: 0, max: 11). A false-colour image (d) derived from the dry-season mosaic (RGB: NIR, red, green) is shown as a reference image of the area and serves as black-and-white background in (a–c). Center coordinates: 8°24.622' N 39°13.981' E.

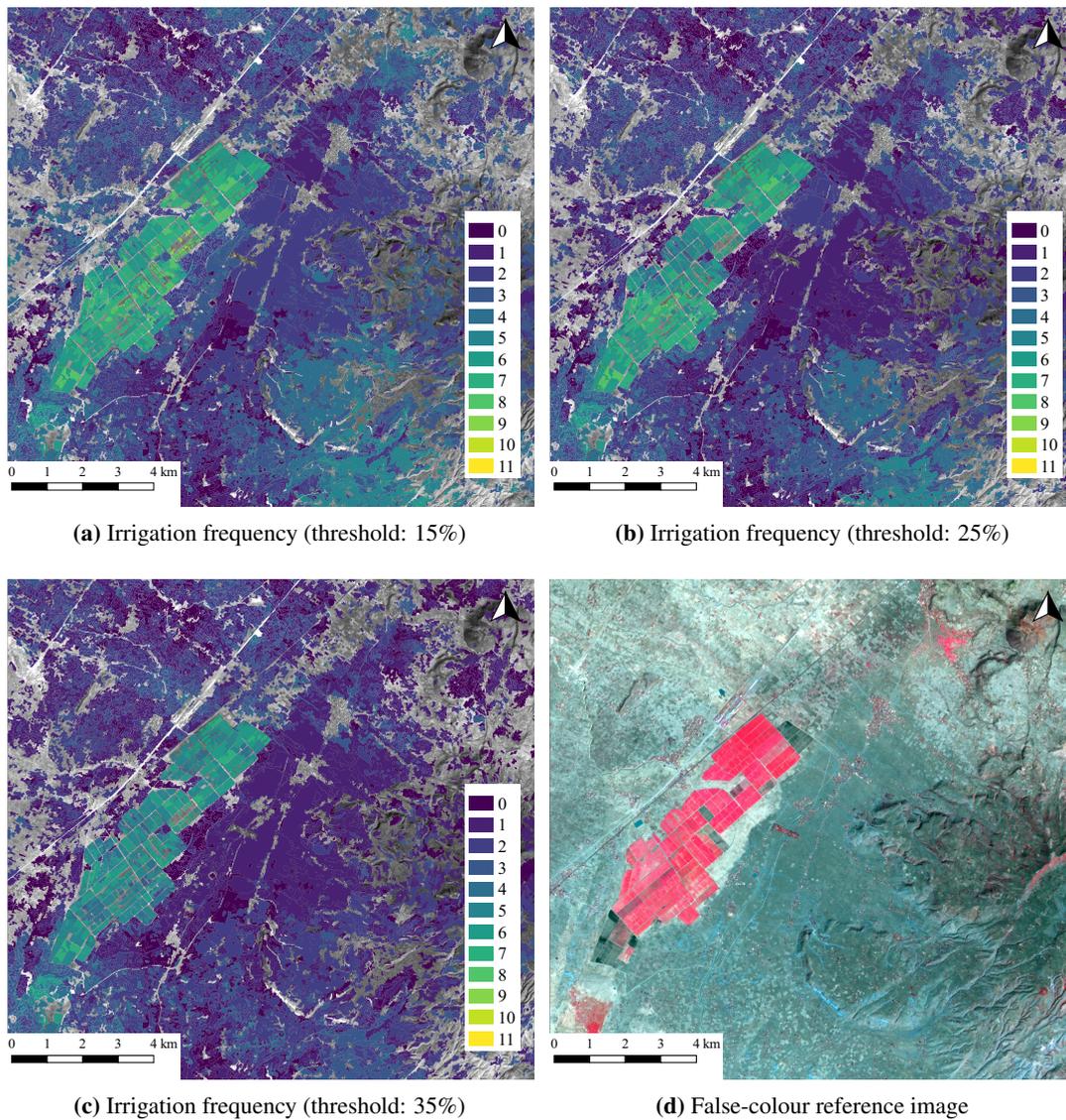


Figure S5.3. Illustration of irrigation classification result (a–c) for an irrigation scheme near Adama (Rift Valley, Ethiopia) in which the monthly maps are summed to give the frequency of irrigation events at field level for one year for the four spatial-heterogeneity thresholds (min: 0, max: 11). A false-colour image (d) derived from the dry-season mosaic (RGB: NIR, red, green) is shown as a reference image of the area and serves as black-and-white background in (a–c). Center coordinates: 8°35.986' N 39°24.543' E.

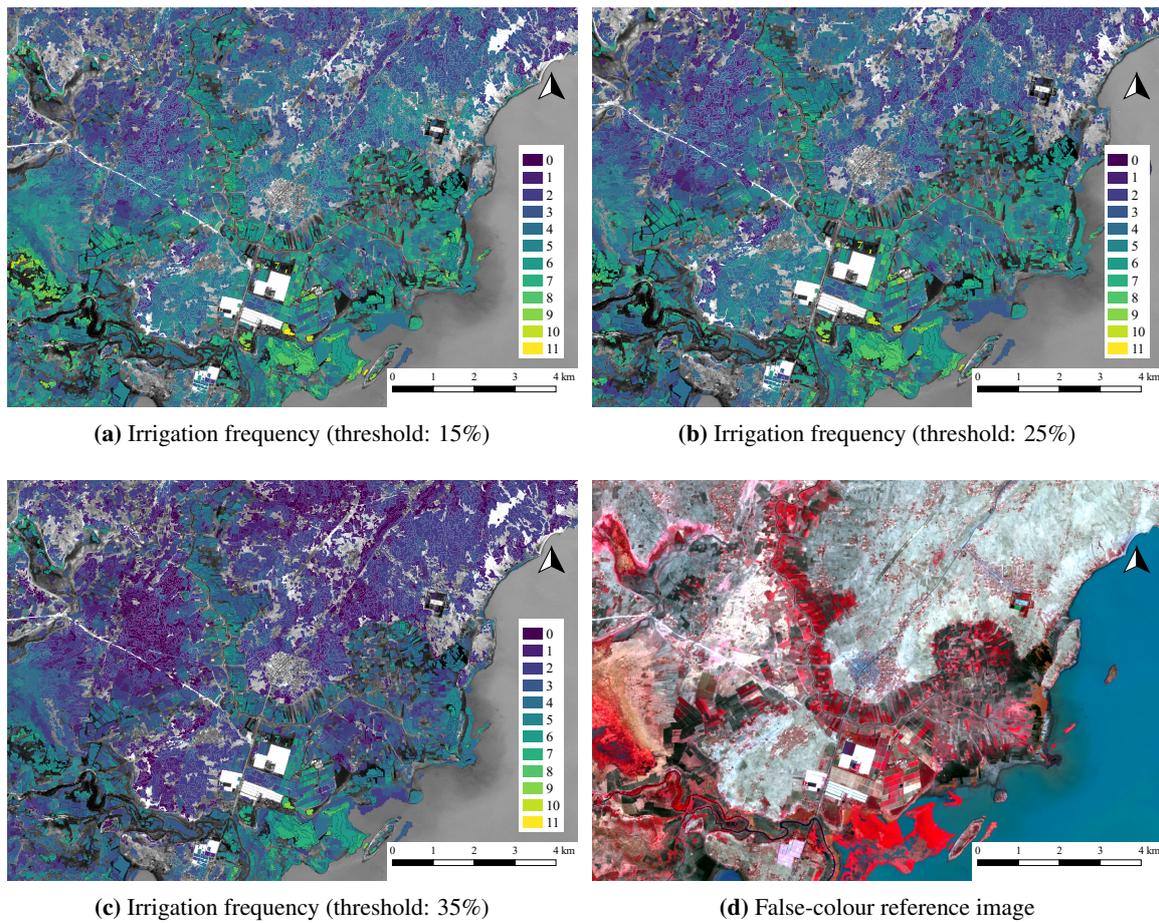


Figure S5.4. Illustration of irrigation classification result (a–c) for a smallholder irrigation scheme near Koka Lake (Awash basin, Rift Valley, Ethiopia) in which the monthly maps are summed to give the frequency of irrigation events at field level for one year for the four spatial-heterogeneity thresholds (min: 0, max: 11). A false-colour image (d) derived from the dry-season mosaic (RGB: NIR, red, green) is shown as a reference image of the area and serves as black-and-white background in (a–c). Center coordinates: 8°26.200' N 39°2.257' E.

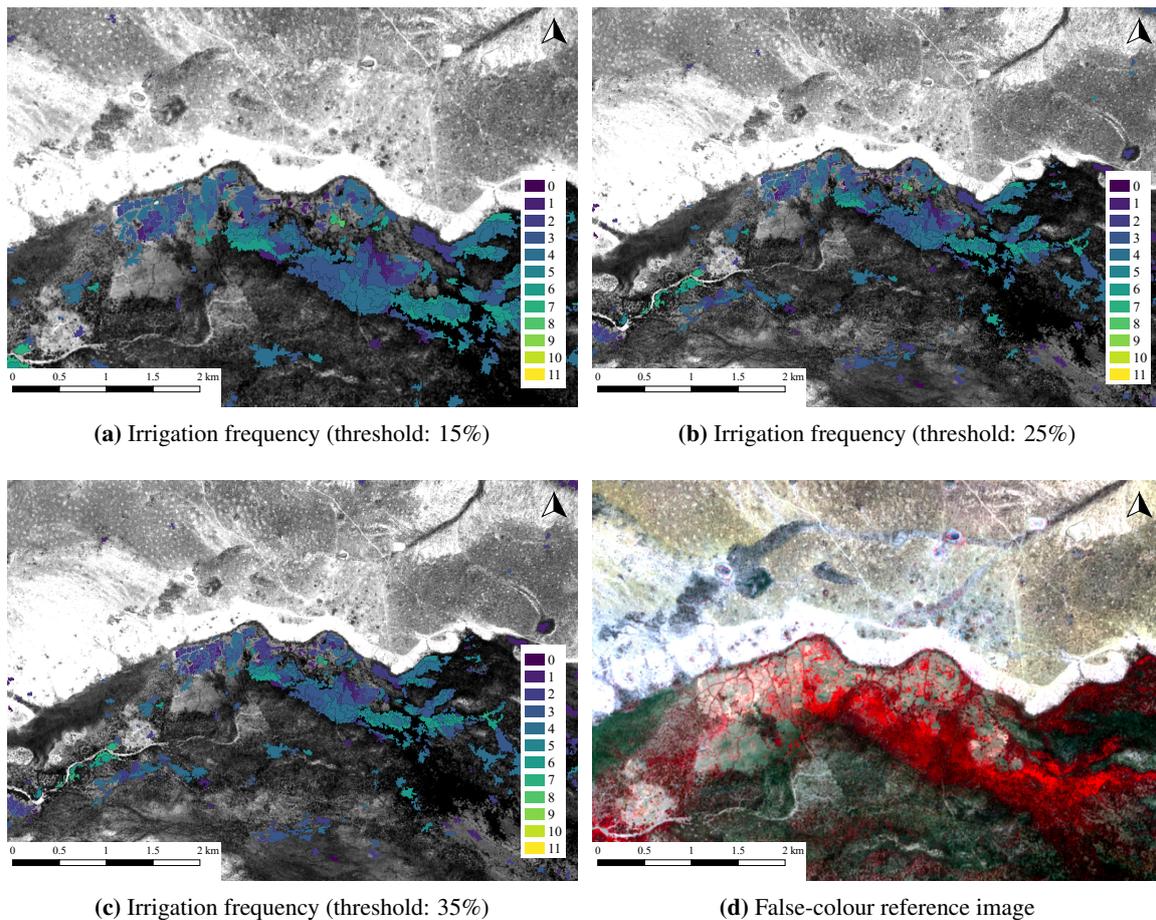


Figure S5.5. Illustration of irrigation classification result (a–c) for a smallholder irrigation scheme near Wayu (Tana River, Kenya) in which the monthly maps are summed to give the frequency of irrigation events at field level for one year for the four spatial-heterogeneity thresholds (min: 0, max: 11). A false-colour image (d) derived from the dry-season mosaic (RGB: NIR, red, green) is shown as a reference image of the area and serves as black-and-white background in (a–c). Center coordinates: 1°31.866' N 39°32.292' E.

Reference

1. Trimble. eCognition Developer 9.3 Reference Book, Trimble Germany Documentation, Munchen, Germany 2017.



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