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Automated Near-Real-Time Mapping and Monitoring of Rice Extent, Cropping Patterns, and Growth Stages in Southeast Asia Using Sentinel-1 Time Series on a Google Earth Engine Platform

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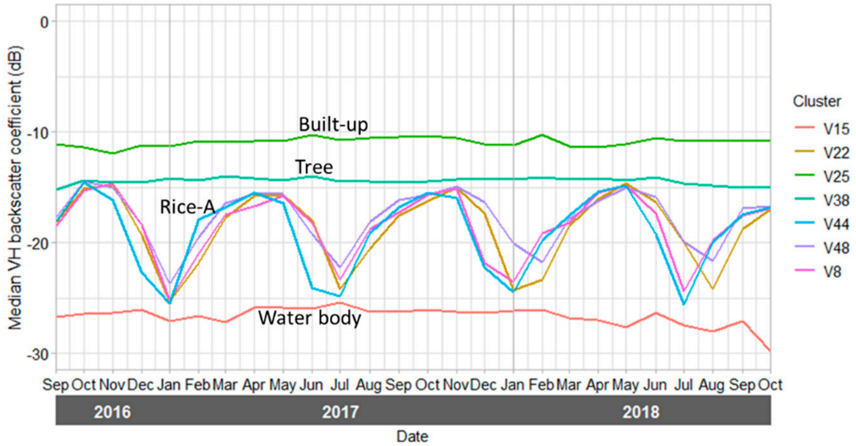
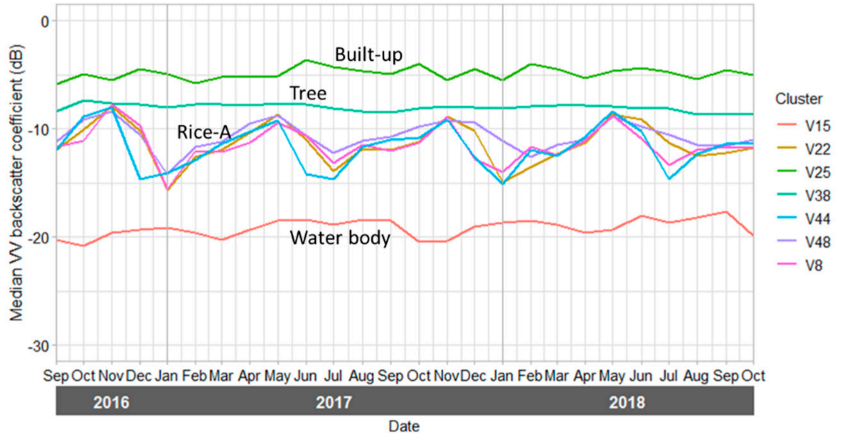
Abstract: More than 50% of the world's population consumes rice. Accurate and up-to-date information on rice field extent is important to help manage food and water security. Currently, field surveys or MODIS satellite data are used to estimate rice growing areas. This study presents a cost-effective methodology for near-real-time mapping and monitoring of rice growth extent and cropping patterns over a large area. This novel method produces high-resolution monthly maps (10 m resolution) of rice growing areas, as well as rice growth stages. The method integrates temporal Sentinel-1 data and rice phenological parameters with the Google Earth Engine (GEE) cloud-based platform. It uses monthly median time series of Sentinel-1 at VH polarization from September 2016 to October 2018. The two study areas are the northern region of West Java, Indonesia (0.75 million ha), and the Kedah and Perlis states in Malaysia (over 1 million ha). K-means clustering, hierarchical cluster analysis (HCA), and a visual interpretation of VH polarization time series profiles are used to generate rice extent, cropping patterns, and spatiotemporal distribution of growth stages. To automate the process, four supervised classification methods (support vector machine (SVM), artificial neural networks (ANN), random forests, and C5.0 classification models) are independently used to automatically identify cluster labels. The results from each classification method were compared. The method can also forecast rice extent for up to two months. The VH polarization data can identify four growth stages of rice—T&P: tillage and planting (30 days); V: vegetative-1 and 2 (60 days); R: reproductive (30 days); M: maturity (30 days). Compared to field survey data, this method measures overall rice extent with an accuracy of 96.5% and a kappa coefficient of 0.92. SVM and ANN show better performance than random forest and C5.0 models. This simple method could be rolled out across Southeast Asia, and could be used as an alternative to time-consuming, expensive field surveys.

Keywords: rice fields; rice phenology; automated near-real-time mapping and monitoring; Sentinel-1; Google Earth Engine

Supplementary Materials



(**a**)



(**b**)

Figure S1. Comparison between representative (a) VH and (b) VV polarization cluster profiles for clusters related to rice field-A, water body, built-up and tree from September 2016 to October 2018 at site 1, the northern regions of West Java, Indonesia.

Table S1. Growth stages from generalized phenological parameters for rice clusters in rice fields in the northern districts of West Java, Indonesia. Table S1 corresponds to Figure 5, 6, 8, and 9. T = Tillage, V1 = Vegetataive-1, V2 = Vegetative-2, R = reproduction, M = Maturity, C = Cash crop and F (blank) = Fallow.

Map unit	Cluster	Area (x 1000 ha)	2016				2017												2018											
			Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	V22	13.330	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M	
	V48	9.624	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M	
	V8	9.725	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M	
	V44	10.107	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M	
B	V11	10.044	T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R
	V10	7.907	C	C	C	C		T	V1	V2	R	M			C	C	C	C		T	V1	V2	R	M			C	C	C	C
	V46	7.993	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M
	V5	12.369	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M
	V12	16.185	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M
C	V32	11.699	T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R
	V13	13.976	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M
	V35	12.207	C	C	C	C			T	V1	V2	R	M		C	C	C	C			T	V1	V2	R	M		C	C	C	C
	V37	11.871	C	C			T	V1	V2	R	M		C	C	C	C			T	V1	V2	R	M		C	C	C	C		
D	V0	6.606			T & V1	V2	R	M	T	V1	V2	R	M	C	C	C	C		T	V1	V2	R	M	C	C	C	C		T & V1	V2
	V2	12.718			T & V1	V2	R	M	T	V1	V2	R	M				T	V1	V2	R	M	T	V1	V2	R	M			T & V1	V2
	V39	13.323			T & V1	V2	R	M	T	V1	V2	R	M	C	C	C	C	T	V1	V2	R	M	C	C	C				T & V1	V2
E	V17	9.175			T	V1	V2	R	M	T	V1	V2	R	M			T & V1	V2	R	M	T	V1	V2	R	M				T	V1
	V42	13.832			T	V1	V2	R	M	T	V1	V2	R	M	C	C	C	T	V1	V2	R	M	T	V1	V2	R	M		T	V1
	V28	10.631	M			T	V1	V2	R	M	T	V1	V2	R	M			T	V1	V2	R	M		T	V1	V2	R	M		T
	V41	13.909	M			T	V1	V2	R	M	T	V1	V2	R	M	C	C	C	T	V1	V2	R	M	T	V1	V2	R	M		T
F	V14	12.444	M		T	V1	V2	R	M	T	V1	V2	R	M	C	C	C	T	V1	V2	R	M	T	V1	V2	R	M	C	T	V1
	V23	11.989	M		T	V1	V2	R	M	T	V1	V2	R	M	C	C	C	T	V1	V2	R	M	T	V1	V2	R	M	C	T	V1
	V40	11.025	R	M		T	V1	V2	R	M	T	V1	V2	R	M			T	V1	V2	R	M		T	V1	V2	R	M		T

Map unit	Cluster	Area (x 1000 ha)	2016				2017												2018											
			Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
G	V21	9.433	M			T	V1	V2	R	M	T & V1	V2	R	M	C	C	C	T	V1	V2	R	M		T	V1	V2	R	M		T
	V24	8.507	M			T	V1	V2	R	M	T & V1	V2	R	M	C	C	C		T	V1	V2	R	M	T	V1	V2	R	M		T
	V16	11.634	M			T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T
	V49	9.845	M			T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M		T

Table S2. Growth stages from generalized phenological parameters for rice clusters in rice fields in Kedah and Perlis states, Malaysia. Table S2 corresponds to Figure 5, 7, 8, and 10. T = Tillage, V1 = Vegetataive-1, V2 = Vegetative-2, R = reproduction, M = Maturity, C = Cash crop and F (blank) = Fallow.

Map unit	Cluster	Area (x 1000 ha)	2016				2017												2018											
			Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
X	V46	23.771		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M			T	V1	V2	R	M	T	V1	V2
X	V47	26.255		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M			T	V1	V2	R	M	T	V1	V2
Y	V6	14.574	M		T	V1	V2	R	M		T	V1	V2	R	M	T	V1	V2	R	M				T	V1	V2	R	M	T	V1
Y	V9	25.313	M		T	V1	V2	R	M		T	V1	V2	R	M		T	V1	V2	R	M			T	V1	V2	R	M	T	V1
Y	V45	29.724		T	V1	V2	R	M			T	V1	V2	R	M	T	V1	V2	R	M			T	V1	V2	R	M		T	V1