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Using Sentinel-2A to identify the change in dry marginal agricultural land occupation

Indarto INDARTO ✉, Bayu T.W. PUTRA, Marga MANDALA

University of Jember, Faculty of Agricultural Technology, Jl kalimantan No. 37 Kampus Tegalboto, 68121, Jember, Jawa Timur, Indonesia

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Abstract

Dry marginal agricultural land (DryMAL) potentially use as an alternative resource for crop production. DryMAL defined as land having low natural fertility due to its intrinsic properties and forming environmental factors. This study uses Sentinel-2A imagery to map the spatial extent, compare the result of the classification, and identify the change in DryMAL occupation. The area of study (461.9 km^2) is part of Situbondo Regency and is located at the eastern part of East Java, Indonesia. Sentinel-2A image captured in dry-season of 2018 use for this study. Then, supervised image classification using a maximum likelihood algorithm use for image treatment and processing. Furthermore, 450 ground control points for training areas collected during the field surveys. Five bands use in the classification process. The maps produced from the classification process were then compared to the land-use map from the year 2000. The change in DryMAL occupation from 2000 to 2018 was calculated by comparing the classified and land-use map. Supervised classification yielded an overall accuracy of 95.8% and a kappa accuracy of 93.2%. The classification produced six (6) classes of land use: (1) forest, (2) pavement or built-up area, (3) irrigated paddy field, (4) non-irrigated rural area, (5) dry marginal land and (6) water body. Globally, during the last two decades, regional development led by the Regency occupied more DryMAL area for developing plantation. The effort reduces the amount of non-irrigated and converting to the plantation, pavement areas, and irrigated paddy-field.

Keywords: *agricultural, change, land, mapping, marginal, Sentinel-2A*

INTRODUCTION

According to ELBERSEN *et al.* [2018] and VON COSSEL *et al.* [2019], Marginal agricultural land defined as limitation lands which are severe for sustained application and sensitive to land degradation. Inappropriate human intervention, contaminated and potentially contaminated sites can cause land degradation. Marginal agricultural land (MAL) exists in many parts of Indonesia. According to MILBRANDT and OVEREND [2008], the Indonesian total land area covering 1,847,033 km^2. The marginal land occupied about 37,123 km^2 (2% of total area). The biomass resource potential on marginal lands estimated at 15,494,000 t·y^{-1}.

These lands are abandoned and rarely used, especially for agricultural activities. However, this land type can be used as an alternative resource for crop production, both food and energy services. MAL use for the production of industrial crops to serve biomass and energy demand [GERWIN *et al.* 2018; LONGATO *et al.* 2019; VON COSSEL *et al.* 2019].

Dry marginal agricultural land (DryMAL) in this study is the specifics form of MAL. DryMAL defined as land having low natural fertility due to its intrinsic properties and forming environmental factors [MULYANI, SARWANI 2013]. An illustration of DryMAL discussed in this study is shown in Photo 1. DryMAL usually has a lower crop-growing capacity than average fertile land. This condition is probably due to the soil's lack of organic content, the limited availability of water, and other intrinsic factors that are constrained by the nature of this environment [MULYANI, SARWANI 2013].

Usually, farmers will often choose to apply more fertilizer, pesticide, and herbicide in a bid to grow their crops. Inappropriate choices of the types of crops plant in their fields have added to the complexity of the problem. The majority of farmers will usually carry out crop planting on a massive scale, as other farmers do. This massive planting

Photo 1. Example of dry marginal agricultural land (phot. *I. Indarto*)

results in over-supply during the peak season and a rapid decrease in crop prices, meaning farmers' total revenues will fall below their expected values. This cycle is repeated every time, with only a few farmers able to escape it and survive [INDARTO, MANDALA 2019].

The limited amounts of land owned by farmers on which to grow their crops is also a constraint factor. The system of smallholder farming [NYAMBO *et al*. 2019] on narrow areas of land tends to increase input-cost and a reduction in net revenue. Besides the issue explained above, many farmers in these marginal areas use their land resources to grow crops solely for their own everyday consumption (i.e. not to sell) [INDARTO, MANDALA 2019]. These typical problems of smallholder farmers as described above, also found in many parts of the world [DONATTI *et al.* 2019].

Various efforts have been initiated by the government of Situbondo, University of Jember and other stakeholders. There have been many activities aimed at strengthening the capacity building of farmer organizations, to increase land productivity, increase farmer revenue, and increase the social welfare of the society. Over the last fifteen years, the government introduced several deep pumping stations to distributing water from groundwater resources for consumptive use and irrigation. However, the pumping of water from deep groundwater sources for agricultural practices continues to be both expensive and inefficient. The operational and high servicing costs of a pump system remain out of reach for farmers [INDARTO, MANDALA 2019].

Photo 2. Example of mango trees planted in dry marginal agricultural land on the area of study (phot. *I. Indarto*)

The government has made other efforts, however, through the introduction of certain varieties of mango. Some farmers in these areas have opted to plant mango trees as an alternative to a secondary income (Photo 2). Mango trees favour the long dry period and lower rainfall. To this end, mangoes have been successfully planted and developed in the region, and today, more investors are planting mango in these regions. However, the added value from mango circulation is captured mostly by distributors, investors, buyers and re-sellers. Again, the farmer remains stuck in a poverty cycle [PAYNE 2005].

Despite this, however, there are mango plantations on only a few areas of this marginal land. The abundant DryMAL resources are still unusable during the peak dry season, which means limitations on the usability of these land resources for agricultural practice remain a barrier. Contrary to the view of sustainable development goals, this type of farming practice will create more marginal populations [INDARTO, MANDALA 2019].

The duration of the dry season in this area most likely benefits the production of grain seed. There have been many efforts initiated to increase productivity and reduce barriers. One such measure has involved the introduction of a public-private partnership (PPP), and the region is now positively supporting grain seed production. The advantage for grain seed posed by the length of the dry season in the region has enabled it to become established as a grain seed production area by leveraging the existing DryMAL resources [INDARTO, MANDALA 2019].

Optimizing the productivity of these land resources will benefit the society through the addition of marginal income from seed production and therefore bolster the incomes of the farmers. At the initial stage of its implementation, the PPP involved focus group discussions, field surveys, mapping, and setting-up of demo-plots. There is an urgent need to conduct mapping to calculate the spatial extent of these marginal lands [INDARTO, MANDALA 2019].

This study aims to employ Sentinel-2A image to map the spatial extent of DryMAL, to compare the classification result and to detect the change in DryMAL occupation over the last two decades.

Sentinel-2A has provided fine-resolution imagery that is available for free download. The data can be downloaded from the United States Geological Survey website [USGS 2019] or by using the Sentinel hub [ESA 2013; Sentinel Hub undated]. This remote sensing satellite system has global coverage and provides imagery at a global level. Furthermore, Sentinel-2A provide the spatial, spectral and temporal resolution that may appropriate for the identification and mapping of DryMAL in this study.

The use of satellite imagery for mapping agricultural areas is a widely known method and employed by many researchers around the world. There are many studies containing examples of the use of Sentinel-2 imagery for the identification and mapping of agricultural-related issues [ABDI 2019; FORKUOR *et al.* 2018; GOGA *et al.* 2019; MANSARAY *et al.* 2019; RUJOIU-MARE *et al.* 2017]. These studies illustrate the potential applicability of Sentinel-2A for mapping land use and land cover or other phenomena related to the agriculture field.

Pixel-based image classification is a widely known method to recognize and to map objects based on the digital number contained in the pixel. There are two well-known types of classification methods, i.e., supervised and unsupervised [SCHOWENGERDT 2007]. Supervised classification explores any available algorithms, and the critical thing to be considered is the type and number of training areas and selected band combinations used. Unsupervised classification uses any clustering algorithms to classify the pixels based solely on the similarity of their DN values [RICHARDS 2013].

METHODS

STUDY AREA AND INPUT DATA

Situbondo Regency (Fig. 1) is located in the eastern part of East Java and covers a total area of 1649.80 km^2. The region has a tropical climate, yet is relatively dry compared with other sub-areas. Its annual rainfall ranges from 500 to 1500 mm·y^{-1}, which is less than the average annual rainfall amounts received in other regions of East Java (1500–3500 mm·y^{-1}) [INDARTO 2013].

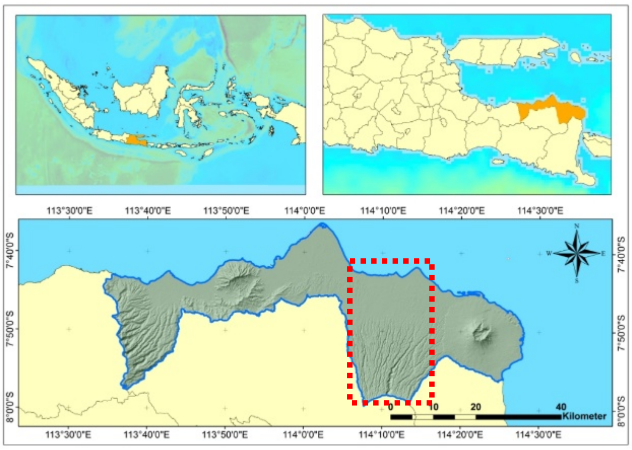

Fig. 1. Situbondo Regency and a subset of the study area; source: BIG 2019

DryMAL makes up around 60% of the total agricultural areas in Situbondo Regency. The area of study covers three districts in the eastern part of Situbondo (Fig. 1). The total area of around 461.69 km^2. The dry season in this region varies in length, from between seven to nine months per year. The dry season begins in May/June and lasts until November/December. There is also very less monthly rainfall. Rainfall amounts greater than 100 mm per month fall only from January to April (four months) [INDARTO 2013].

The ground in the region is characterized by a thin layer of soil comprising only shallow solum and relatively small amounts of organic matter. Many places in the study area have gravel in the upper soil layers (Photo 3). This stony soil layer is typical of the study area and tends to have a slight to moderate slope.

Moreover, the soil layer contains macropores that increase the rate at which runoff infiltrates and percolates to the deep soil layer. As such, only a few intermittent rivers flow in this region. The shallow soil layer in stepped terrain drainage combined with the presence of macropores and intermittent rivers means the groundwater resources are continuously recharged. Groundwater is the primary water source in this region. Similar DryMAL areas also found in central and western areas of the Regency [INDARTO, MANDALA 2019].

Photo 3. Example of the soil in the region (phot. *I. Indarto*)

The input data for this study is Sentinel Image of the location of interest. The image was selected based on the minimum of cloud coverage. The image capture on 20 July 2018, cloud cover 0.68%, tile number = T49MHM, orbit number 46, and orbit direction = descending (Fig. 2).

Fig. 2. Raw image input data; source: USGS EarthExplorer

The existing map is known as RBI (Rupa Bumi Indonesia) digital map. This map is called "RBI (Rupa Bumi Indonesia) format shp" in vector layer format and can be downloaded free of charge from the Indonesian Geospatial Agency (Ind. the Badan Informasi Geospatial – BIG) official site [BIG 2019]. RBI map presents the land use and land cover map of all Indonesian region. The map of this area was created between the years 1999 and 2000. The change in DryMAL occupation interpreted by comparing the map created from sentinel and this RBI map.

TOOL USED

In this study, a Multispec© package [BIEHL 2018] use as a tool for an image processing task. In this study, the QGIS [QGIS 2019] serve for atmospheric correction and visualisation. The Global Positioning System (GPS) and camera used to obtain and to capture the Ground Control Points (GCPs).

PROCEDURE

The image treatment consists of atmospheric correction, image composite, supervised classification, accuracy assessment, and image interpretation (Fig. 3).

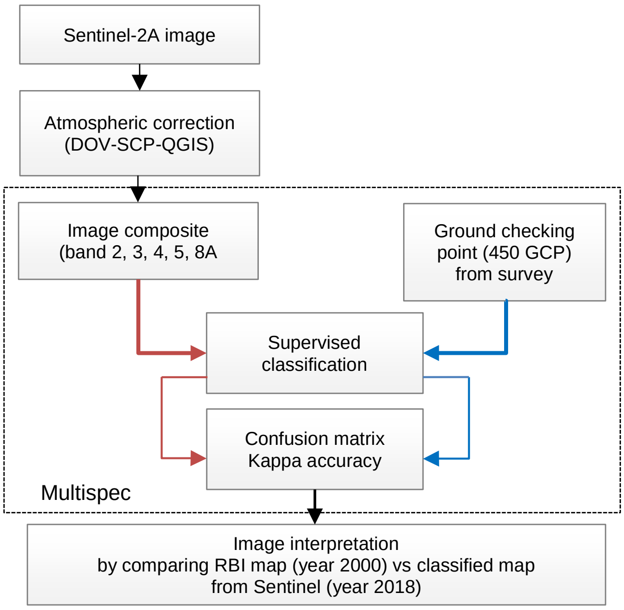

Fig. 3. Procedure of image treatment; source: own elaboration

A Dark Object Subtraction (DOS) algorithm was employed to conduct atmospheric correction by using the Semi-automatic classification (SCP) plug-in on the QGIS platform [CONGEDO 2017]. Five bands of Sentinel-2A (i.e. bands 2, 3, 4, 5 and 8A) are explored to produce image composite.

The classification procedure followed the existing tutorials [BIEHL 2018]. Supervised classification conducted using maximum-likelihood algorithms and collected GCP for training areas. Field surveys conducted between May and October 2019 to collect the 450 GCPs, identify the real conditions in the field and take photographs from the region of interest. Table 1 summarized the statistics of GCPs for each class.

Table 1. Statistics of collected Ground Control Points (GCPs)

Class	Number of the training area	Area (ha)			
		total	min	max	median
Forest-plantation	90	1 238	1.7	41.7	14.0
Built-up area	104	1 067	1.2	44.3	7.3
Irrigated paddy field	86	2 394	16.7	71.4	27.6
Non-irrigated rural area	70	1 648	2.6	39.0	24.9
DryMAL	75	1 423	3.0	37.6	19.2
Waterbody	25	309	11.3	29.4	13.4
Total	450	8 079			

Explanation: DryMAL = dry marginal agricultural land.
Source: own elaboration.

Then, the image clipped with a polygon covering the boundary of the three districts (Arjasa, Asembagus and Jangkar). Figure 4 shows the study area, collected GCPs and photos taken during the field survey. Interpretation conducted by comparing and analysing the change visualised on the Sentinel and existing digital maps.

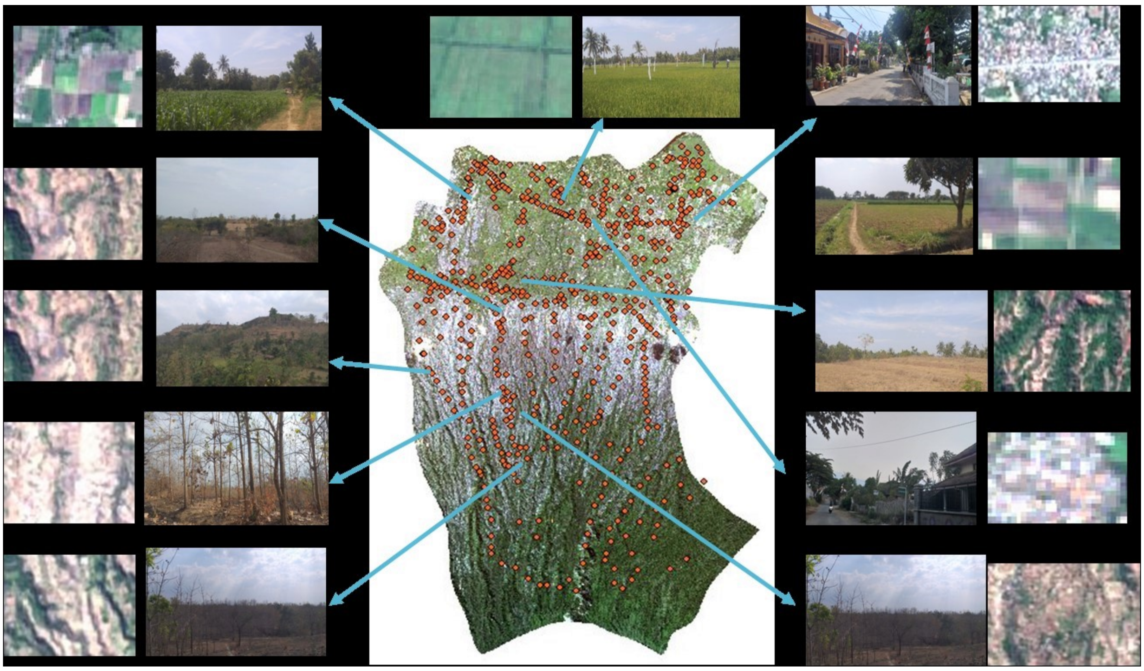

Fig. 4. Collected ground control points; source: own elaboration

Table 2. Confusion matrix

Class type	Irrigated	Dryland	Waterbody	Non-irrigated	Forest	Pavement	Total
Irrigated	13 521	476	5	149	72	252	14 475
DryMAL	500	25 270	38	118	34	218	26 178
Water body	7	3	1 802	6	0	56	1 874
Non-irrigated	441	133	3	7 017	1	66	7 661
Forest	1 608	354	4	9	67 668	251	69 894
Pavement	111	129	33	62	0	2 258	2 593
Total	16 188	26 365	1 885	7 361	67 775	3 101	122 675

Source: own study.

RESULTS AND DISCUSSION

CLASSIFICATION RESULT

The supervised classification enabled separation of six types of land use, i.e. irrigated paddy (24.78%), DryMAL (26.22%), waterbody (0.89%), non-irrigated area (4.98%), forest (35.51%) and pavement area (7.62%). The classification achieved an overall accuracy = 95.8% and a kappa accuracy = 93.2%. The confusion matrix is presented in Table 2. The map (Fig. 5) shows the result obtained from the supervised classification.

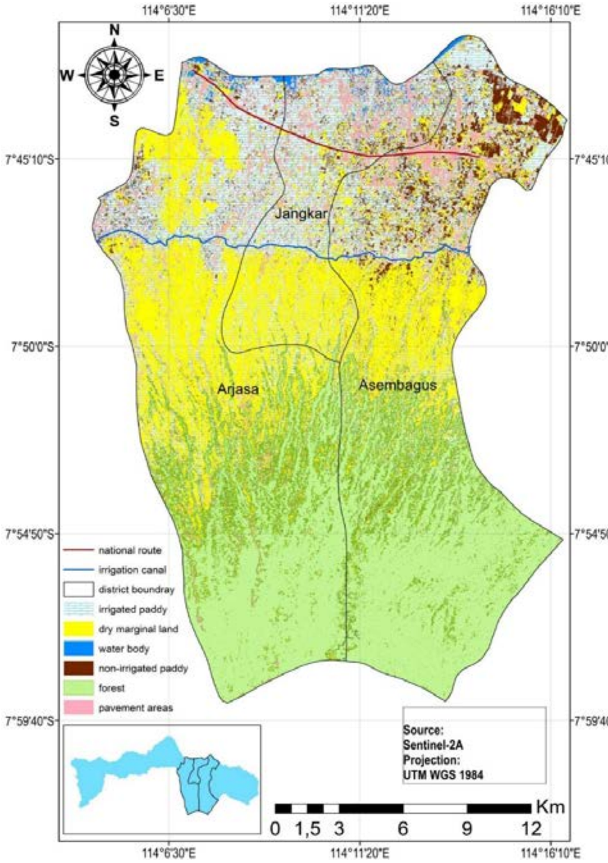

Fig. 5. Classification result; source: own study

The DryMAL, as investigated in this study, appears mostly in the middle area of Figure 5. Moreover, an area of DryMAL also located in the upper-left of the study areas (in the district Arjasa). The upland area of this map composed of forest and plantation, which confirms the existing reality.

Additionally, according to this map, the total area of the three districts is 461.69 km^2. The land in this region is composed of DryMAL (34.3%), irrigated paddy fields (22.0%), non-irrigated areas (13.8%), pavement (3.5%), forests and plantations (26.30%) and water bodies (0.10%). It is confirmed with the reality on the terrain. Figure 6 presents the clipped RBI map of the region of interest. This official digital map uses to compare the classification result.

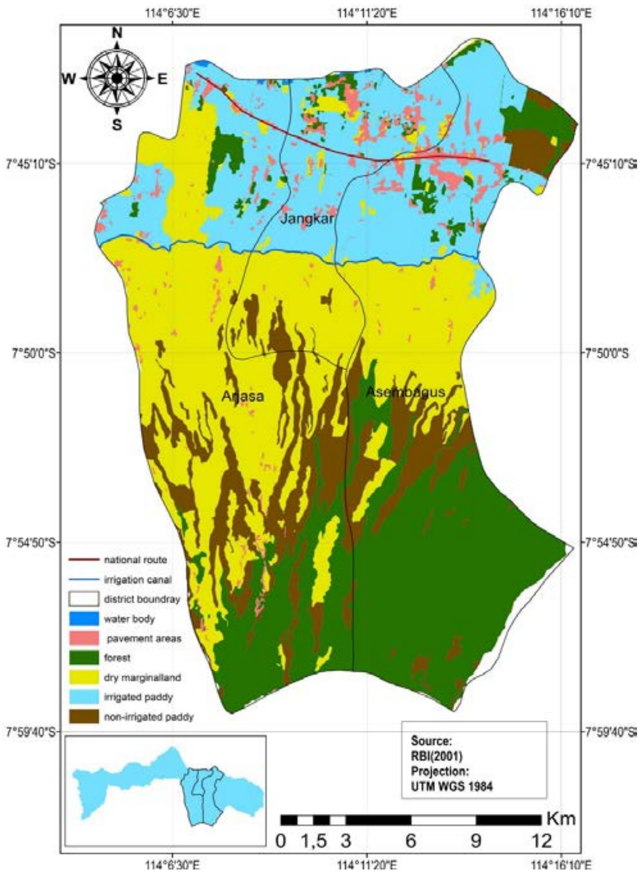

Fig. 6. RBI map; source: own study

INTERPRETATION

Table 3 presents the class type in (km^2) and (%) of the total area mapped using supervised classification method and compared to the RBI digital maps. In the RBI map (Tab. 3, Fig. 6), the pavement area covers only 3.5% of the total area, while between 2000 and 2018, this appears to have increased to 7.62% of the total area mapped. The increase is due to population increase and development in the villages.

Table 3. Comparison of maps

Class	Supervised		RBI map	
	km^2	%	km^2	%
Pavement area	35.17	**7.62**	16.0	**3.5**
DryMAL	121.04	**26.22**	158.4	**34.3**
Irrigated paddy	114.41	**24.78**	101.4	**22.0**
Forest and plantation	163.94	**35.51**	121.4	**26.3**
Non-irrigated paddy	23.01	**4.98**	63.9	**13.8**
Water body	4.12	**0.89**	0.6	**0.1**
Total	461.69	100	461.7	100

Source: own study.

The supervised classification enables better identification of water bodies. The waterbody area increased by 0.79%. The increase is due to the development of aquaculture sites to culture shrimp and harvest salt, located along the region's coastline (the northern part of the map). The Sentinel-2A band enables better identification of these sites. Part of the economic development in the regions supported by this type of industry. It noted that parallel to the coastal area, we see the national route (appearing as a continuous red line) that links Sumatra, Java and Bali Islands.

The irrigated-paddy-field class is a land-use type that mapped consistently using both the supervised and RBI. This region characterized by the constant development of irrigated areas over the past twenty years. The primary irrigation canal passes across the maps and noticeably divides the region into two distinct land-use types. The RBI map (Fig. 6) shows that below the irrigation canal, we find the irrigated area (irrigated paddy denoted as a light-blue colour). This area accounts for around 22% of the total area on the map. The government built the canal between 1980 and 1985. The region of interest is the driest area in East Java. Water flows to this area through an irrigation canal from the Sampean Reservoir located ±40 km from the region. This region is the last downstream area covered by the canal; as such, there is only minimal water available for irrigation. In the two maps above, we see slightly different totals calculated for irrigated paddy, i.e. 24.78% (in the supervised map) and 22% (in the RBI map). The difference is 2.78%. It noted that the region received more rainfall in the year 2018, and therefore more agricultural areas (in both irrigated and non-irrigated areas) were planted with paddy. These were monitored via the Sentinel imagery and classified using the supervised method as additions to the irrigated area. Agricultural fields have also been converted to pavement areas in the area below the canal.

The shift in land occupation in the region observed using three classes of land-use type, i.e., DryMAL, forest and plantation (forest), and non-irrigated area. The original land resources for these three classes in this region were similar, i.e. DryMAL. The total area occupied by these three classes in the RBI map = (34.30 + 26.30 + 13.80) = 74.40%, while on the supervised map, the total area = (26.22 + 35.51 + 4.98) = 66.71%. The illustration above demonstrates the potential for DryMAL resources in this region.

Globally, regional development led by local government during the last two decades has changed the land use by reducing the amount of DryMAL area, increasing forest plantation and reducing the amount of non-irrigated areas. DryMAL and non-irrigated areas are the land resources should be optimised for further agricultural activities. In summary, the Sentinel-2A sufficiently appropriate for the identification and mapping of principal DryMAL occupation in this region.

CONCLUSIONS

This study demonstrates the application of Sentinel-2A imagery to map the change of DryMAL occupation from periods of 2000 to 2018. Three districts in the eastern part of Situbondo Regency (i.e. Arjasa, Jangkar, and Asembagus, that cover an area of 461 km^2) used as a sample of DryMAL region investigated. Supervised classification using a maximum likelihood algorithm and conducted on the platform of Multispec can successfully classify Sentinel-2A pixels into six classes of land-occupations. The pavement or build area occupied only 7.62% of the total area mapped. Then, the DryMAL cover about 26.22%, followed by irrigated paddy-field (24.78%), forest and plantation (35.51%), non-irrigated area (4.98%) and water body (0.89%). The comparison of the classified and RBI maps shows how DryMAL occupation has changed. The spatial, spectral and temporal resolution of the imagery obtained by Sentinel-2A sufficiently appropriate for the identification and mapping of primary DryMAL occupation in this region. The map will benefit for the government agency, local stakeholders and the university for further action related to DryMAL optimization and development.

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