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To cite this article: P K Diem *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **964** 012005

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Assessing the applicability of Fusion Landsat-MODIS data for mapping agricultural land use - A case study in An Giang Province

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Abstract. This study aimed to evaluate the applicability of using time-series data of spatiotemporal fusion Landsat-MODIS imagery for mapping agricultural land use in An Giang province, Vietnam. The Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) was adopted for fusion techniques to integrate the relatively high spatial resolution of Landsat (30 meters) and frequently revisit time of MODIS (MOD09Q1, 8-days). The Maximum Likelihood Classifier (MLC) was then used to classify the land cover categories based on variations of NDVI (Normalized Difference Vegetation Index) time-series over the observation period. The overall accuracy is about 84.9%, and a kappa coefficient of K=0.7, which revealed the effectiveness of using Fusion Landsat-MODIS NDVI data in land cover classification at the provincial scale. The current of the agricultural land use was finally mapped, including seven categories, namely built-up areas (10.49%), double rice crops (4.8%), triple rice crops (68.24%), perennial tree/orchards (4.08%), annual crops (7%), water surfaces (3.07%), and forest (2.32%). The results indicate that the agricultural land use cover can be detected in detail using Fusion Landsat-MODIS imagery. The classification is dramatically higher compared to the map classified by a conventional method of solely Landsat 8 image analysis (overall accuracy of 67.3% and Kappa coefficient K=0.35). The research outcomes will support the detailed information for managers in evaluating the impact of climate change on the rice cropping system toward sustainable agriculture development.

Keywords: Agricultural land use, An Giang province, fusion, Landsat-MODIS, STARFM.

1. Introduction

An Giang is one of the provinces with the main rice production areas of Vietnam's biggest "rice bowl" in the Vietnam Mekong Delta. The rice production area of An Giang province was about 620 thousand hectares, accounting for 8.3% of the country' rice cultivation area in 2019. The rice production in 2019 reached nearly 4 million tons, accounting for 9.2% of rice production in Vietnam [1]. The transformation of farming structure and land-use changes need to be continuously monitored and updated. However,

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the implementation requires much time, cost, human resources, and cooperation between different management levels. The government issued Decree No 03/2019/NDD-CP on 04 January 2019 [2] on the exploitation of remote sensing data, which mentioned the critical role of remote sensing in mapping the current agricultural land use.

Nowadays, remote sensing data have been utilized effectively in monitoring the change of agricultural cultivation in many areas around the world [3, 4, 5]. However, most of these studies used satellite images with moderate spatial resolution such as Landsat (30 m), Sentinel 2 (10 m) at a single time, or low-resolution data of multi-temporal such as MODIS MOD09A1, MOD09Q1, and MOD13A1. Yet, the above studies have limitations of detecting detailed agricultural land use such as triple rice crop, double rice crop, and other crops with seasonal growth characteristics. In addition, the percentages of cloud cover on the optical satellite imagery are very high, which is the cause of the low capacity of mapping seasonal crops. On the other hand, the multi-temporal MODIS images have a spatial resolution of no less than 250 m. One pixel of MODIS data is equivalent to 6.25 hectares in the field, including many mixed land cover types. Therefore, it reduces the detail of classification, and it is only suitable for regional and national studies.

The above analysis has shown the limitations of using single moderate-resolution imagery and low resolution of multi-temporal imagery. Integration of multi-temporal and high spatial resolution is proved more efficient in many studies as it gives better solutions for detecting, mapping the distribution of rice crop seasonality [6], monitoring the current land-use changes [7], vegetation cover changes [8, 9, 10]. The spatial and temporal adaptive reflectance fusion model (STARFM) [11] is the most widely used data fusion algorithms for Landsat and MODIS imagery [12, 13], beneficial for detecting gradual changes over large land areas [11, 14]. Therefore, this study was conducted to evaluate the applicability of using time-series data of fusion Landsat-MODIS imagery based on STARFM algorithms to map agricultural land use in An Giang province. Simultaneously, a comparison with mapping land use using single Landsat imagery was also be conducted to confirm the effectiveness of using fusion Landsat-MODIS imagery.

2. Study Area and Methods

2.1. Study area

An Giang is located in the Southwestern of Vietnam within a latitude of $10^0$10’30” - $10^0$37’50” N and longitude of $104^0$47’20” - $105^0$35’10” E. The Northwest borders with Cambodia, the East and Northeast borders Dong Thap province, the South and Southwest borders Kien Giang province, the Southeast borders Can Tho city (Figure 1).

2.2. Data collection

An Giang province is covered by three separate Landsat scenes. The Landsat 8 data with a low cloud cover rate of less than 10% were collected from the US Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). These scenes were captured on 10/01/2019, 11/02/2019, 27/02/2019, 14/07/2019, and 18/10/2019. This data is used for fusion with MODIS MOD9Q1.

The MODIS MOD09Q1 data (8-day composite product with 250-meter spatial resolution) collected using the GEE platform was captured from January 2019 to December 2019 with 46 images in total. In addition, the other maps were also collected, including the land inventory map of An Giang province in 2019, the administrative map of An Giang province, inventory data, and the provincial statistical yearbook in 2019.

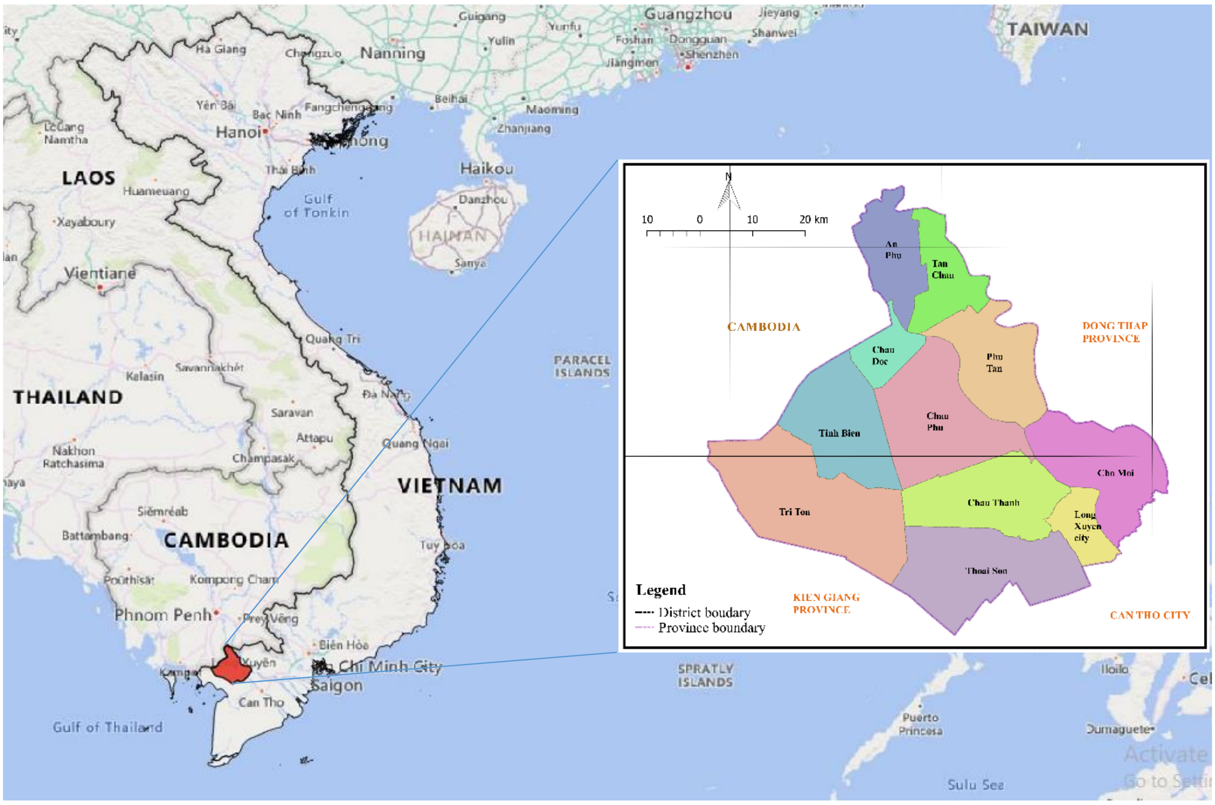

Figure 1. Location map of the study area (An Giang province)

2.3. Methods

2.3.1. Preprocessing and calculating NDVI images

The collected Landsat 8 and MODIS MOD09Q1 imagery were preprocessed using the Google Earth Engine (GEE) platform to optimize performance. These data were adjusted coordinate system, spatial subset, estimating the Normalized Difference Vegetation Index (NDVI) as formula (1) [15]:

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

where NIR and RED are Near Infrared and Red wavelengths, respectively.

2.3.2. Landsat-MODIS fusion

Fusion of Landsat and MODIS datasets were processed by using the Spatial-temporal adaptive reflectance fusion model (STARFM) [11, 16]. STARFM was used for simulation between multi-temporal MODIS images (250 m spatial and 8-day temporal resolutions) and a Landsat image (30 m resolution) to create new datasets at 30 m spatial and 8-day resolutions directly for NDVI images using equation (2). Images of MODIS and Landsat acquisition on the same day are paired to create the model. MODIS pixels map to their corresponding Landsat pixels and a weighting window is created based on the central Landsat pixel and the surrounding Landsat pixels that affect the MODIS values. The MODIS pixels are weighted based on the values of the pixels they cover, both spatially and in relation to the amount of time from one image to the next.

$$L\left(x_{\omega/2}, y_{\omega/2}, t_0\right) = \sum_{i=1}^{\omega}\sum_{j=1}^{\omega}\sum_{k=1}^{\omega} W_{ijk} \times \left(M\left(x_i, y_j, t_0\right) + L\left(x_i, y_j, t_k\right) - M\left(x_i, y_j, t_k\right)\right) \quad (2)$$

where L and M are Landsat and MODIS surface reflectance, respectively; ω is the searching window size, $(x_{\omega/2}, y_{\omega/2}, t_0)$ is the center pixel of the moving window; (x_i, y_j) is a given pixel location for a Landsat and MODIS image pair; t_k is the acquisition date for the image pair; t_0 is the acquisition date for a simulated date; and W_{ijk} is the weight deciding the influence of each neighboring pixel to the simulated reflectance of central pixel ($x_{\omega/2}$, $y_{\omega/2}$).

2.3.3. Remote sensing interpretation method and reliability assessment

Landsat-MODIS classification: The Maximum Likelihood Classifier (MLC) was used to classify a time series of 46 fused MODIS-Landsat images. The MLC is the most effective method in classifying land use/land cover, whereas the probability of each pixel is calculated and then assigned to the class name with the highest probability [17]. The classification samples are selected based on the characteristics of NDVI variations. In the rice cultivation areas, the NDVI variation graph is sinusoidal, the maximum value of NDVI corresponding to the growth peaks of rice [18].

Landsat 8 classification: The Maximum Likelihood Classification (MLC) was applied on a single Landsat 8 image dated 11/02/2019. The classification aims to evaluate the effectiveness of using a single Landsat image compared to the Fusion Landsat-MODIS time-series in mapping the agricultural land use.

Assessment of reliability: The reliability of classification was assessed by the Kappa coefficient (K) and overall accuracy (T) based on the confusion matrix [19, 20]. The classified by single Landsat 8 and fusion Landsat-MODIS time-series were then reclassed into the same number of classes and class types. The total number of survey points for each land use type was decided depending on the proportion of land use types. There are 450 ground truth points collected through a field trip survey (250 points) and virtual tours on Google Earth (200 points).

3. Results and Discussion

3.1. Analyzing the variations of NDVI time-series for different land use types

Each land use type is characterized by variations of NDVI time-series over a period of time. In general, NDVI values vary from −0.39 to 0.9 throughout the year. The detail of NDVI variations for each land use type in this study is shown in Figure 2.

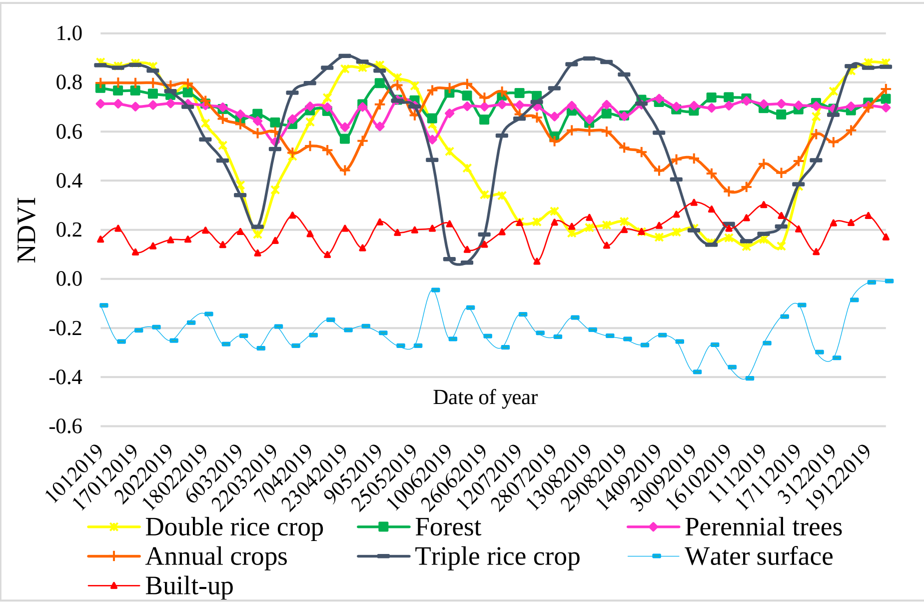

Figure 2. The variations of NDVI time-series extracted from fused Landsat-MODIS imagery for different land use types.

NDVI Landsat-MODIS time-series provides the information for monitoring the changes of vegetation cover over time. In the rice crop systems, the pixel has the curve of NDVI value following a sinusoidal pattern with two times reaching maximum value corresponding to double rice crop, and the curve with sinusoidal pattern with three times reaching the maximum value (maximum value of NDVI about 0.9) presented for triple rice crop. The NDVI time-series of forest is quite stable at high range values (about 0.61 - 0.8) during the year. The forest in An Giang is classified as the mixed forest, and melaleuca forest (based on the field survey). These forest types are general evergreen forests with no dry season defoliation. Therefore, there is no significant change in NDVI value over different seasons in one year. For the perennial trees, NDVI is also stable at a high-value range, while the NDVI time-series of annual crops are seasonally variable depending on characteristics of growing length and specific species such as corn, bean, and other upland vegetables. As the curve of the perennial trees and forest above (pink line and green lines) show a quite similar pattern, the classification of these classes, therefore, was differentiated by combining with the distribution sites in An Giang inventory map. In a different way, the NDVI values of the water surfaces are always lower than zero due to the passing through water of incident energy. Built-up areas, including residential land, headquarters, offices, and roads, are generally identified with NDVI values between 0.13 and 0.26 during the year.

3.2. Assessing of fusion imagery applicability for mapping agricultural land use

There are 450 ground truth points collected in total for assessing the classification accuracy. It was split into small subsets, including 20 perennial trees points, 64 annual crops points, 32 forest points, 33 built-up points, 32 double rice crop points, 247 triple rice crop points, and 22 water surface points. The survey locations for each land use type were randomly selected and which is shown in Figure 3.

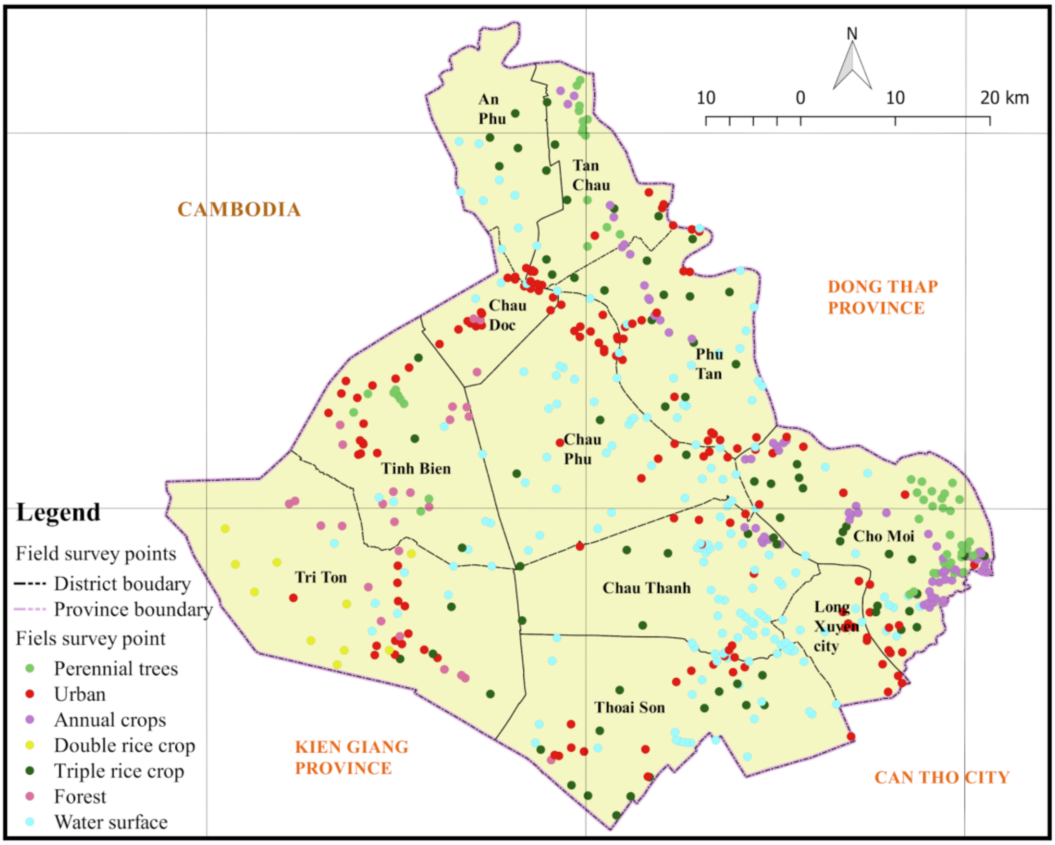

Figure 3. The location of the ground truth points for accuracy assessment.

The results of reliability assessment for the fused Landsat-MODIS multi-time-series and the single Landsat 8 image are shown in the confusion matrix Table 1, respectively.

Table 1: The classification error matrix using fused Landsat-MODIS time series and single Landsat 8 image.

Fused Landsat-MODIS									
		Predicted classes							Accuracy (%)
	Land use types	Triple rice crop	Double rice crop	Perennial trees	Annual crops	Forest	Built-up	Water surface	
Actual classes from survey	Triple rice crop	220	4	2	15	0	4	2	89.1
	Double rice crop	4	23	2	2	1	0	0	71.9
	Perennial trees	2	0	15	3	1	0	0	71.4
	Annual crops	5	0	2	50	6	1	0	78.1
	Forest	0	1	2	0	25	4	0	78.1
	Built-up	1	0	1	1	0	30	0	90.9
	Water surface	2	0	0	0	0	0	20	90.9
	Reliability (%)	94.0	82.1	62.5	70.4	75.8	76.9	90.9	84.9
	Kappa index	0.7							

Landsat 8 data								
		Predicted classes						
		Rice crops	Perennial trees	Annual crops	Forest	Built-up	Water surface	Accuracy (%)
Actual class from survey	Rice crops	188	2	10	2	4	1	90.8
	Perennial trees	23	14	8	0	0	0	31.1
	Annual crops	51	2	41	4	1	0	41.4
	Forest	3	2	1	13	4	0	56.5
	Built-up	20	0	4	1	34	4	54.0
	Water surface	0	0	0	0	0	13	100.0
	Reliability (%)	65.5	63.6	64.1	75.0	79.1	72.2	67.3
	Kappa index	0.35						

These results show that there are 07 types of agricultural land use, including double rice crop, triple rice crop, perennial trees, annual crops, forest, built-up, and water surface. The classified map using the fused Landsat-MODIS time-series achieved an overall accuracy of 84.9% and a kappa coefficient of 0.7. Meanwhile, only 06 land use types have been recognized using the single Landsat 8 image, including rice crops, perennial trees, annual crops, forest, built-up, and water surface, with an overall accuracy of 67.3% and kappa coefficient of 0.3. In order to compare the accuracy scientifically between the fusion Landsat-MODIS time-series and the single Landsat 8, the double rice crop and triple rice crop were grouped into rice crops type to ensure consistency with Landsat 8 classified map. The result indicates that the grouped classified overall accuracy of 86.9% and Kappa coefficient of 0.74. The above results show that the achievement of current agricultural land use maps in An Giang province using Landsat-MODIS multi-time-series is higher reliability than single Landsat imagery. However, the misclassification of the perennial trees and annual crops remains (Table 1) due to small areas of cultivation in reality that could not be detected with the use of 30 m spatial resolution imagery. In addition, the remaining thin cloud pixels in the Landsat 8 input senses (Scenes dated 14/7/2019, 27/02/2019) lead to a sudden drop in NDVI value of perennial trees in the fused Landsat-MODIS time-series compared to the other period in this year. However, this research has shown the feasibility of fusion Landsat-MODIS images in mapping agricultural land use. Further studies on the fusion of higher temporal and spatial resolution satellite images need to be taken into consideration for highly applicable monitoring and management of agriculture at the provincial level.

3.3. The current agricultural land use map

The agricultural land use in An Giang province in 2019 was mapped with high reliability, which included 07 land use types as perennial trees, annual crops, forest, double rice crop, triple rice crop, water surface, and built-up (Figure 4).

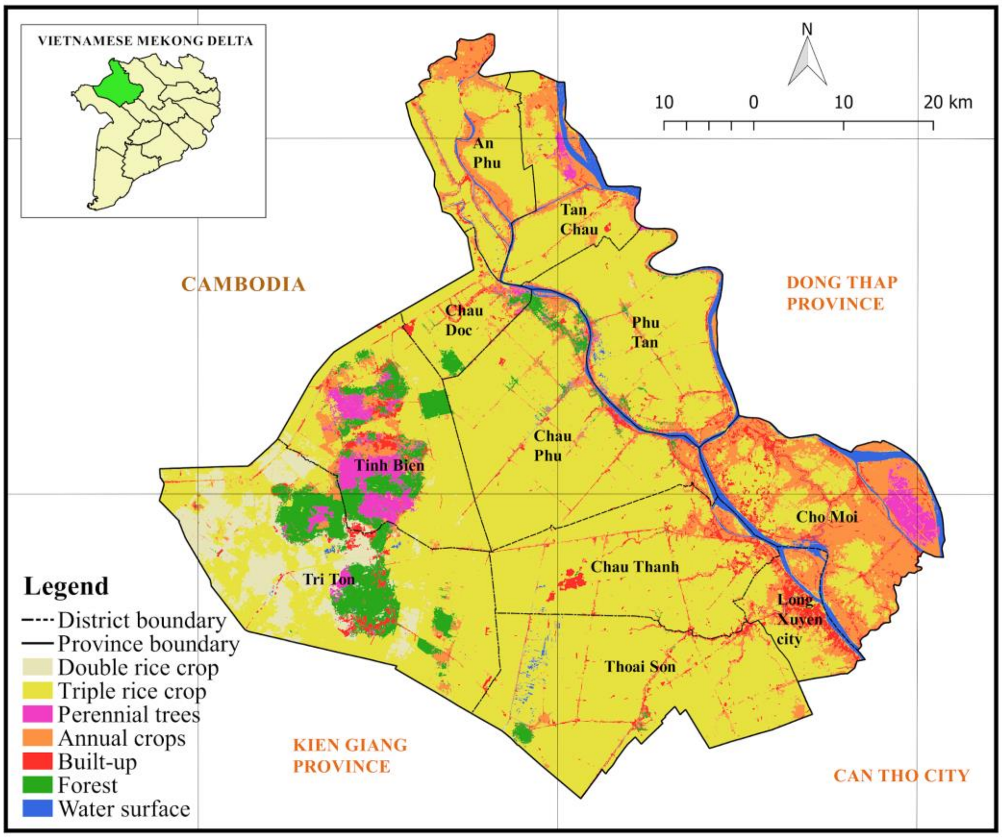

Figure 4. The current agricultural land use map classified by fusion data in An Giang in 2019**.**

In 2019, the agricultural land area in An Giang was about 299,679.20 ha, accounting for 84.30% of the total area. In which, the rice cultivation area accounts for the largest proportion, mainly triple rice crop with an area of 236,582.71 ha (68.24%), double rice crop with 16,647.08 ha (4.80%). The perennial trees take up only 14,128.09 ha (4.08%). Annual crops such as watermelon, corn, sweet potato distributed in alluvial soil located along the coastal river occupy about 24,263.04 ha (7.00%). A small area is occupied by mixed and melaleuca forests, about 8,058.12 ha (2.32%). The rest area is built-up, and the water surfaces jointly account for 13.56% of the total land area (Figure 5).

The distribution of agricultural land use is summarised as follows: the triple rice crop accounts for the highest proportion of An Giang province. It is distributed in almost all districts. The double rice crop is distributed in the high terrain of Tri Ton district within a small area, mostly around the foothills with a limited water supply for farming systems than the lowland areas. The perennial trees and annual crops are concentrated in the islets in Cho Moi, Tan Phu district, Tan Chau Township, where the presence of alluvial soil is suitable for most cultivation models. Most of the forest is distributed in mountainous areas in Chau Doc, Tinh Bien, Tri Ton, and Thoai Son districts.

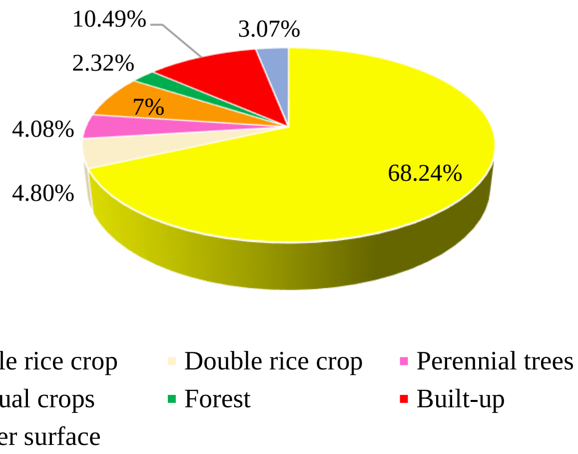

Figure 5. Proportion of land use types classified by fused Landsat-MODIS imagery in An Giang province in 2019.

3.4. Research limitations and outlook

This study improved agricultural mapping at relatively high resolution compared to previous studies toward monitoring modest dynamics related to agricultural transformation. It has become a special matter of concern in the past few years in the Mekong Delta when many spontaneous conversion models have been emerged purely based on the subjective opinions of the farmers. Brackish aquaculture and lotus fields in the ineffective rice cultivation areas of upstream Mekong River are typical examples. These models might disrupt the general plan as well as the local ecological balance. Therefore, we attempt to support the local agricultural managers in this work more precisely. Yet, technology transfer for this fusion technique is currently challengeable. Even though we tried to optimize performance using the start-of-the-art platforms (GEE, R), cross-platform is still the main barrier, especially for data preparation. In this study, we only verified the applicability of fusion data compared to standard data of Landsat 8. In further research, a study on the sensitivity of small changes in land use/land cover in a small region during a short period regarding the above-mentioned agricultural transformations may be a worthy work expected to perform.

Additionally, we conducted Landsat-MODIS fusion to obtain time-series data at 30 meters resolution. Nevertheless, it should be noted that there are free-of-charge data of Sentinel-2 presently data being comparatively similar in terms of characteristics and covering wavelengths with three-time better in spatial resolution (10 meters). Hence, fusion data between Sentinel-2 and MODIS is a reasonable expectation that might be fulfilled, yet we might need adjustments in parameters while processing these two data. It will be meaningful for monitoring and management, especially for local dynamics in land use/land cover changes.

4. Conclusion

The current agricultural land use in An Giang province in 2019 was mapped with an overall accuracy of 84.9% and a kappa coefficient of 0.7 using fused time-series imagery. In particular, the STARFM technique was successfully executed for creating Landsat-MODIS multi time-series (30 m spatial resolution, 8-day temporal resolution). The results revealed that the fused Landsat-MODIS data is more effective in classifying and mapping the agricultural land use in comparison to using a single Landsat image. The research findings provide a ground for further research in assessing and monitoring long-term changes in land use and rice cropping patterns under the condition of climate change.

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