USING SENTINEL IMAGES FOR THE ESTIMATION OF RICE BIOMASS IN QUOC OAI DISTRICT (HANOI)

Dang Vu Khac[*] and Doan Hoai Trang

Faculty of Geography, Hanoi National University of Education
Master student of Faculty of Geography, Hanoi National University of Education

Abstract. During the rice production process, the rice straw - one of the residual products becomes an environmental pollutant due to the open burning giving rise to greenhouse gases emission. That's why the identification of gas emissions needs to estimate the amount of rice biomass. Remote sensing data has been exploited to determine the area of rice cultivation and to estimate the dry rice biomass in Quoc Oai district, Hanoi city. On the one hand, the Sentinel-2 image was used to classify the land cover categories, thereby identifying the spatial distribution of the rice to delimit the extent of rice biomass, which was obtained from regression analysis. On the other hand, the Sentinel-1 radar image was used to calculate the rice biomass during the summer season when Sentinel-2 images have constraints due to clouds, fog, and mist. The validation of image classification has provided an overall accuracy of 86.31% with a Kappa index of 0.81. Meanwhile, the regression analysis shows a high correlation between the backscattering values of VV and VH in the radar image and the dry rice biomass measured on the ground (R = 0.923 and R^2 = 0.852), with a relatively low average error (RMSE = 6.58 kg/100 m^2). By linear regression method, the study has found the total dry rice biomass of 28728.5 tons, which was revealed after the Summer-Autumn rice crop 2021 for the whole Quoc Oai district. The results from this study have proved the effectiveness of the method and they have contributed to supporting managers in proposing the appropriate policies to monitor and protect the environment in the future.
Keywords: rice straw, rice biomass, regression, classification, Sentinel-1/2.

1. Introduction

Rice is one of the grains that plays a particularly important role in ensuring food security and it is the main ration plant of many countries, including Vietnam. The demand for rice is strongly increasing along due to the growth in world population in general, and in Vietnam in particular. The analysis by the International Food Policy Research Institute (IFPRI) shows that the world demand for rice is rising by about 1.8%

per year [1]. The achievements in rice production have helped Vietnam to ensure domestic consumption demand also to spend a considerable amount on export. However, together with the increase in rice production in Vietnam, many residual products generated during this process have not been properly treated, especially rice straw. They are usually abolished by burning in the field after harvest [2, 3]. Moreover, the rice straw is often not completely dry, so when burned, it will form smoke that covers a large area in the suburbs and is sometimes carried away by the wind, penetrating the residential areas of inner districts. Although the burning of rice straw creates many such consequences, this issue has not been considered in air quality management programs in many countries.

Currently, research on the inventory of rice biomass is still facing many difficulties, especially in collecting data on the fields because of several reasons such as the large surveying area, the limitation of budget, the lack of human resources, or the lack of observation equipment, etc. Therefore, it is necessary to find an effective method to timely collect data with reasonable cost and high reliability. In the main rice-growing countries of the world, there have been several studies applying the experimental formula to remote sensing images to investigate the rice growth process [4, 5]. Specifically, the regression analysis method by correlating the rice biomass with the backscattering values from radar images was commonly considered because this approach reduces costs, time duration, and less impact on vegetation [1, 6, 7]. For instance, Harsimran Singh Sodhi has compared the methods of estimating above-ground biomass (AGB) using optical data, radar data, and lidar data [7]. The results show that radar images are adequate for this purpose because of their ability to capture longitudinal structural features and they can overcome weather constraints. However, radar data is not a reasonable choice for discriminating vegetation categories likely optical data, which may affect the accuracy of AGB. Therefore, it is possible to combine radar and optical images to improve the accuracy of biomass estimates [7].

In Vietnam, there were also several researches on rice biomass such as the one by Hoang Anh Le (2020) [8]. In this study, the radar images have been handled to estimate the rice cultivation area and its yield for each locality. From the obtained data, the author applies the formula to calculate total gas emissions. The results show that backscattering values from radar images are strongly correlated with rice yield and biomass [8]. However, the authors based on the percentage of residual products and combustion efficiency from published works in some Asian countries such as Thailand and China to calculate the amount of rice biomass, but this approach also has several limitations due to the diversity in agricultural practical methods between different countries.

Since 2015, the Sentinel-1 and Sentinel-2 satellites were launched into orbit to acquire images of the Earth's surface, which have been widely promoted to use in resource and environmental monitoring [9]. In this research, Sentinel-2 satellite images can be exploited to determine the rice cultivation area. Meanwhile, Sentinel-1 satellite images have also become a common choice in estimating rice biomass as they have overcome weather limitations that multispectral satellite images have often encountered [1, 8, 9]. The simultaneous use of the Sentinel-2 images and the Sentinel-1 images, together with field measurement data in this study allows us to assess dry rice biomass.

The obtained rice biomass will contribute to calculate the volume of gas emission and propose the appropriate policy for the effective control of gas emissions due to the burning of dry rice biomass from the rice production process to respond to the purpose of sustainable development in Hanoi city in general and the district of Quoc Oai in particular.

2. Content

2.1. Method and used data

2.1.1. Used data

* Satellite images

Satellite image data used in this study includes 2 types which are optical image and radar image which are described in Table 1.

Table 1. Sentinel image parameters

Satellite	Sentinel 1A	Sentinel 2A
Sensor	C-SAR	MSI
Processing level	Level 1	Level 2
Date	28 September 2021	26 August 2020
Resolution	10 m	10 m, 20 m, 60 m

- *Radar image:* the Sentinel-1 satellite can provide radar data with a temporal resolution of 12 days and a spatial resolution of 10 m in all weather conditions [10]. Microwaves are highly sensitive to some parameters such as the roughness of the ground surface, the structure, and orientation of vegetation, as well as the moisture content [11]. In addition, VV and VH polarization allow us to detect a site with bare soil or vegetation [12]. For monitoring crops in general, radar images are useful material in tropical areas with specific climate conditions. The study uses the Sentinel-1 image captured on September 28, 2021, to estimate dry rice biomass. The collected data has been processed at level 1 with orbital coordinates but it has not been georeferenced. The phase value was replaced by intensity and amplitude components, but the speckle noise has not been filtered yet.

- *Optical images:* Sentinel-2 can offer multispectral images, which allow us to determine the land covers categories through the reflectance of spectral bands. In this study, a multispectral image, taken on August 26, 2020, was used to identify the spatial distribution of rice cultivation for the Summer-Autumn rice crop of the Quoc Oai district. This image has been pre-processed at level 2A by NASA with a transformation from DN values to reflectance ones, and it has been georeferenced in the UTM coordinate system. The Sentinel-2's bands have different spatial resolutions, but raster-based analysis demands bands at identical dimensions. That is the reason, we have applied an up-sample for all existing spectral bands with the dimensions of 20 m and 60 m to the higher resolution of 10 m using the convolution neural network method [13].

*** In-situ measurement**

There are two rice crops in the study area: the Winter-Spring crop lasts from February to June and Summer-Autumn crop expands from July to November of each year. The dry biomass data (rice straw) has been collected at 15 quadrats (OTC) in the Quoc Oai district (each OTC has an area of 100 m^2). The in-situ measurement was carried out during the harvesting of the Summer-Autumn rice crop in October 2021 (Figure 1). The entire rice plants in each OTC have been cut from bottom to top, and rice grains have been removed. The weight of rice straw (kg) has been measured after its plant has been conventionally dried under sunlight.

Figure 1. Harvesting rice in the quadrat (OTC) at Can Huu commune

2.1.2. Method for identifying the amount of dry rice biomass

*** Identifying the area of rice cultivation**

To determine the area of Summer-Autumn rice cultivation in the Quoc Oai district, the Maximum Likelihood classification method has been applied to Sentinel-2 images. A set of samples (ROIs) for each category of land cover has been selected based on visual interpretation factors. Then, the separability between different category pairs was calculated, providing a good result in which the values ranged from 1.9 to 2.0.
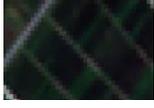
The major land covers include water bodies, residences, forests, rice fields, grassland, and bare soil (Table 1).

- Residence includes all surfaces of buildings such as houses, roads, factories, and other human constructions.

- Bare soil includes all surfaces without vegetative such as abandoned agricultural areas, mining areas, etc.

- Grassland includes bare land areas, that have been covered with weeds, or other crops are grown, etc.

Table 2. The characteristics for visual interpretation of main land cover categories in the study area

No.	Land cover categories	Description of Sentinel-2 image	Natural color of the S-2 image	Natural color of the GE image
1	Water bodies	Light blue or purple color. The texture is relatively smooth. They have clear shapes.		
2	Residence	Deep pink color, with a patchy texture. They distribute along routes and often intersperse with vegetation.		
3	Forest	Dark green color, and a very rough texture. They include natural forests, plantations, and orchards.		
4	Grassland	Light green color, smooth texture. They concentrate around the waterbodies, where rice fields transfer to forest land		
5	Rice field	Very dark green or black color. The texture is relatively homogeneous, the boundaries are quite clear.		
6	Bare soil	Brown, light yellow color. Distributed mainly along roadsides, where there are construction works,		

* Identifying rice biomass

The purpose of regression analysis is to find out the dependent relationship of one variable (often called the dependent variable) on one or several other variables (often called the independent variable) for estimating or predicting the expected value of the dependent variable when the value of the independent variables are known in advance. Thereby a model allows to estimate the amount of dry rice biomass as the following equation [14]:

$$B = X_0 + X_1.R_{VV} + X_2.R_{VH} \tag{1}$$

Where, B is dry rice biomass;

R_{VV} and R_{VH} are backscatter coefficients in decibels;

X_0, X_1, and X_2 are coefficients determined by correlation analysis based on ground measurement data and satellite image data at the same position.

In this study, the method of multivariable linear regression analysis was used for identifying the correlation between dry rice biomass with the backscattering values at VV and VH polarization of Sentinel-1 images. R_{VV} and R_{VH} are considered independent variables, and dry rice biomass measured is considered the dependent variable. The weight of

dry rice biomass in 10 OTCs among 15 OTCs was used for linear regression analysis, and the remaining data of 5 OTCs were considered to test the model. The model is chosen based on the correlation coefficient (R) and the square root of the mean error (RMSE) between the measured data and the calculated data. By analysis of regression models, it was found that dry rice biomass and backscattering values VV and VH of radar image had the highest correlation coefficient (R=0.923 or R^2=0.852) and low RMSE (6.58 kg/100 m^3). Therefore, the regression equation for the best fit has the following form:

$$B = 2.460 + 36.175R_{VV} + 121.054R_{VH} \qquad (2)$$

2.2. Results

2.2.1. Area of rice cultivation

The Sentinel-2 image captured on August 26, 2020 were classified using the supervised classification method with the Maximum Likelihood operator, and the area of rice cultivation in Quoc Oai during the Summer-Autumn crop has been mapped (Figure 2). The Kappa coefficient and overall accuracy have been considered to evaluate the accuracy of classification results during the determination of area and the spatial distribution of rice fields [11]. The validation has provided an overall accuracy of 86.31% (3338374/3867696) with a Kappa index of 0.81. The above results show that the overall accuracy and the Kappa index are adequate, respectively (> 80% and k > 0.8) for reliable results.
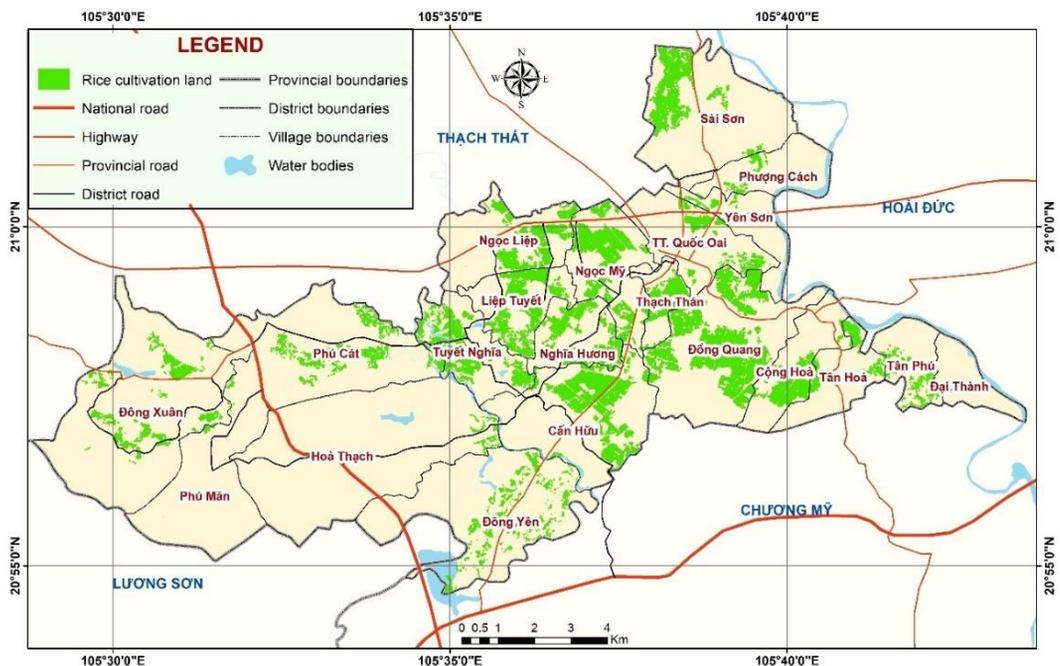

Figure 2. Area of rice cultivation for Summer-Autumn rice crop in 2021

Using statistical analysis from the classification results by extracting data on the area of rice fields have been obtained by the commune administrative unit. The analysis shows that the Dong Quang commune has the largest area of rice cultivation (410 ha), followed by the Can Huu commune (236.3 ha) and the Sai Son commune (218.6 ha). Some communes have a relatively small area of rice cultivation such as Dai Thanh (0.9 ha), Phu Man (7.5 ha); Phuong Cach (33.6 ha); Yen Son (30 ha).
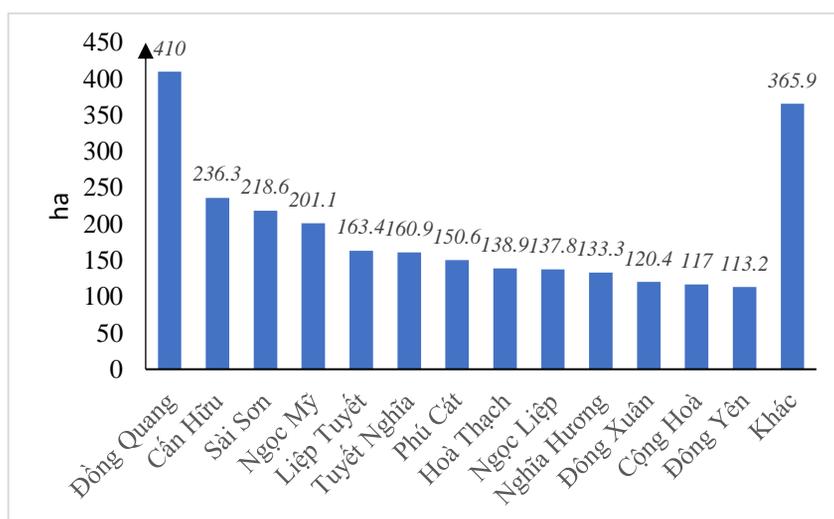

Figure 3 Area of rice cultivation by administrative unit
for Summer-Autumn rice crop in 2021

2.2.2. Rice biomass

The analysis of the regression model was realized between dry rice biomass with backscattering values on radar images. The amount of dry rice biomass was calculated based on dual-polarization VV and VH shows a high correlation coefficient (R = 0.923 and R2 = 0.852) and relatively low mean error (RMSE = 6.58 kg/100 m^2). It can be seen that dry rice biomass and backscattering values VV and VH of Sentinel-1 image are highly correlated. The regression equation to calculate the weight of dry rice biomass has the following form:

$$B = 24.60 + 361.75R_{VV} + 1210.54R_{VH} \qquad (2)$$

Applying correlation model (2) to calculate dry rice biomass for each pixel of Sentinel-1 image (100 m^2). The area of rice land cultivation was then used to delimit the rice biomass values from the ones of other land cover categories. The obtained results are shown in Figure 4.

The map shows that the dry rice biomass of Quoc Oai district mainly ranges from 50 to 200 kg/100 m^2 because the amount of dry rice biomass depends on the rice variety, level of fertilization, soil type, climate, irrigation conditions, and season [15].

After obtaining the amount of rice biomass per pixel, the data from the remaining 5 OTCs were analyzed to validate the model, the results are shown in Table 3. The comparison

shows that there is a high correlation between dry rice biomass collected from the field and dry rice biomass calculated from satellite images. The mean error of 2.18% is acceptable with the root mean square error (RMSE) of 11.1 kg/100m^2.
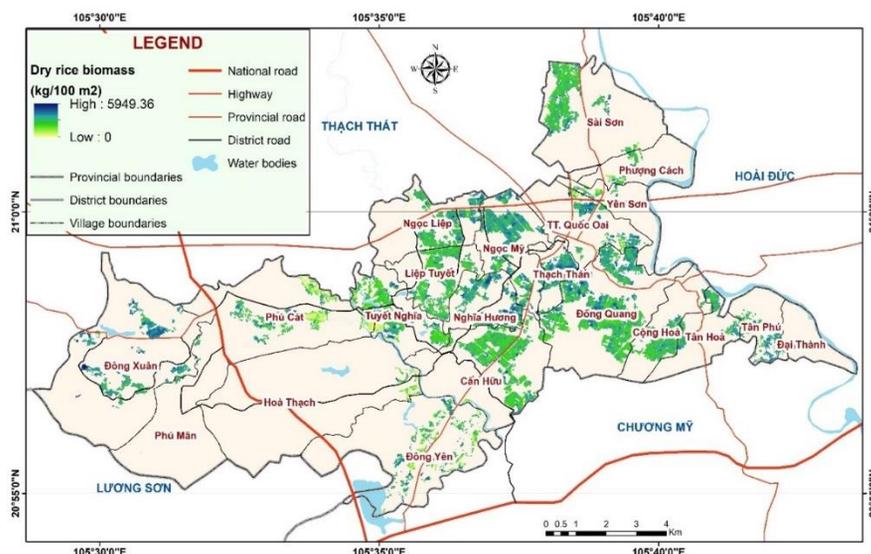

Figure 4. Rice biomass of each pixel for Summer-Autumn rice crop in 2021 (kg/100m^2)

Table 3. Comparison of rice biomass issued from different data sources

No.	Dry rice biomass issued from in-situ measurement (kg/100m^2)	Dry rice biomass issued from radar image (kg/100m^2)	Error (kg/100m^2)
1	107.0	104.4	-2.6
2	113.0	99.8	-13.2
3	116.0	107.0	-9.0
4	89.0	92.8	3.8
5	83.0	92.9	9.9

The total rice biomass per pixel was calculated and thereby the total dry rice biomass of Quoc Oai district for the Summer-Autumn rice crop 2021 was 28728.53 tons, with an average of 112.63 kg/100m^2. This amount is equivalent to 11.26 tons/ha.

3. Conclusions

For monitoring the gas emissions due to the burning of rice straw, the estimation of dry rice biomass after each harvest will be necessary, which could help authorities to propose adequate policies for avoiding the wastage of biological resources and for minimizing environmental pollution. This study shows that the regression analysis in association with the supervised image classification methods can be applied to Sentinel 1 and Sentinel 2 images for providing a reliable result, especially when the survey must be

carried out on a broad territory. Optical satellite images and radar images, each of them separately has advantages and disadvantages in rice crop monitoring. However, the combination of these two data sources has been realized in this study to overcome their limitations and promote their advantages. With coefficient R = 0.923 corresponding to $R^2 = 0.852$, and relatively low root mean square error (RMSE = 6.58 kg/100 m^2), it shows that the weight of dry rice biomass and the values of VV and VH backscattering in Sentinel-1 image is strongly correlated. Quoc Oai is a rural district of Hanoi city, located in the transitional region between the mountains and the plain with about 90% of the population living in rural areas. Quoc Oai has a large area of agricultural land and the obtained results show that after the Summer-Autumn rice crop of 2021, Quoc Oai district can yield 28 728.53 tons of rice straw.

REFERENCES

[1] Ndikumana, Emile, et al., 2018. Estimation of Rice Height and Biomass Using Multitemporal SAR Sentinel-1 for Camargue, Southern France. *Remote Sensing*, 10(9).

[2] Minh Hieu, 2021. *Hanoi is full of pollution due to burning rice straw*, Tien Phong Newspaper, accessed 26/1-2022, from https://tienphong.vn/ha-noi-mit-mu-o-nhiem-do-dot-rom-ra-post1343910.tpo.

[3] Minh Ngọc, 2020. *Warning about environmental pollution from burning straw*, Vietnam Law Newspaper, accessed 26/1-2022, from https://baophapluat.vn/canh-bao-o-nhiem-moi-truong-do-dot-rom-ra-post350503.html.

[4] Chang, Chih-Hua, Liu, Cheng-Chien, and Tseng, Ping-Yu, 2012. Emissions Inventory for Rice Straw Open Burning in Taiwan Based on Burned Area Classification and Mapping Using Formosat-2 Satellite Imagery. *Aerosol and Air Quality Research*, 13(2), pp. 474-487.

[5] Kanabkaew Thongchai and Nguyen Thi Kim Oanh, 2011. Development of spatial and temporal emission inventory for crop residue field burning. *Environmental Modeling & Assessment*, 16, pp. 453-464.

[6] Kumar, Lalit, et al., 2015. Review of the use of remote sensing for biomass estimation to support renewable energy generation. *Journal of Applied Remote Sensing*, 9(1).

[7] Sodhi, Harsimran Singh, 2019. Application of Remote Sensing for Above-Ground Biomass Estimation. *International Journal of Science and Research*, 10(4), pp. 182-187.

[8] Le Hoang Anh, et al., 2020. Inventory of gas generated by burning rice straw on the field at Hanoi city using Sentinel-1 satellite. *VNU Journal of Science: Earth and Environmental Sciences*, 37(1), pp. 81-92 (in Vietnamese).

[9] Nguyen Van Thi, Nguyen Dinh Huong, and Tran Quang Bao, 2018. Relationship between backscattering of Sentinel-1 radar image and NDVI index of Sentinel-2 optical image: a case study for dipterocarp forest in Dak Lak province. *Journal of Forestry Science and Technology*, 3, pp. 167-176 (in Vietnamese).

[10] *Sentinel-1*, Wikipedia, accessed 03/06-2022, from https://en.wikipedia.org/wiki/Sentinel-1.

[11] Le Van Trung, 2005. *Remote Sensing*, Ho Chi Minh City National University Publishing House, 419.

[12] Nguyen Van Khanh, 2021. *Modeling the change of land covers due to flooding in the Mekong Delta using remote sensing and GIS data*. Cartography and Remote Sensing, University of Mining and Geology, Ha Noi.

[13] Galar, Mikel, et al., 2020. Super-Resolution of Sentinel-2 Images Using Convolutional Neural Networks and Real Ground Truth Data. *Remote Sensing*. 12(18), pp. 2941.

[14] Pham Thi Huong, 2015. *Multiple Linear Regression, Nonlinear Regression, and Applications*. University of Natural Science, Hanoi National University, Hanoi (in Vietnamese).

[15] Pham Thi Mai Thao, 2019. Research on emissions inventory for rice straw open burning in An Giang province. *Journal of Science and Technology in Civil Engineering* 13 (1), pp. 100-108.