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Estimation of Peatland Fire Carbon Emissions Using Remote Sensing and GIS

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Abstract

Global warming occurs due to too many greenhouse gases in the atmosphere, especially carbon dioxide (CO_2). One of the causes of the increasing amount of CO_2 gas is forest and peatland fires. Peatlands are known to store carbon stocks not only above the ground surface but also below the ground surface which if there is a fire it will turn into carbon emissions. The forest and peatland fires in 2015 were one of the worst fire events in Indonesia (Sumatra and Kalimantan) in recent years. Therefore, many researchers have tried to estimate carbon emissions resulting from fires in several areas. This study estimates the number of carbon emissions (above surface and subsurface carbon emissions) from peatland fires in Banjar Regency in 2015 using remote sensing technology (Landsat 8), imagery data and Geographic Information Systems (GIS). Based on two types of vegetation, namely shrubs and agricultural land (the results of land cover classification), that occupy burned peatlands, the resulting carbon emissions above the surface of 1,718.55 tons. Meanwhile, the amount of subsurface carbon emissions (based on the category of depth and peat maturity) is 1,092.14 tons. So the total carbon emissions resulting from peatland fires in Banjar Regency in 2015 were 2,810.69 tons. Overall, our findings indicate that peat fires in the Banjar district produce significantly higher carbon emissions than currently reported in emission inventories, which has consequences for the predicted impacts of peat burning on air quality.

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Introduction

Global *warming* is an increase in the average temperature in the atmosphere and the earth's surface. Global warming is known to occur due to too many greenhouse gases in the atmosphere which have heat-trapping properties, so these gases envelop the earth and reflect heat radiation (which should be transmitted to outer space) to the earth's surface (Bourgeau-Chavez *et al.,*, 2020). One of the greenhouse gases that play a major role in global warming is carbon dioxide (CO_2). The amount of CO2 gas in the atmosphere is due to the burning of fossil fuels such as coal, gas, and oil, land clearing, and especially the burning of forests or peatlands which in recent years have been a source of large amounts of carbon emissions (Che Azmi *et al.,* 2021).

Peatland fires are becoming increasingly common in Indonesia. The peatland fires in Indonesia that occurred in 2015 were one of the peatland fires with a fairly severe impact, both for the people living around peatland areas and for citizens of other countries, such as citizens of Singapore and Malaysia who also felt the effects of the smoke generated by the fires of the peatland (Lestari *et al.,* 2020). The island of Kalimantan, especially South Kalimantan, which is one of the provinces with the largest peatland area and contains a lot of carbon stocks (according to the results of studies from several studies), also experienced quite severe peatland fires in 2015 (Hayasaka *et al.,* 2014). One of the districts in South Kalimantan that experienced peatland fires in 2015 was Banjar Regency. Of course, the peatland fires produce quite a lot of carbon emissions because the carbon emissions do not only come from above the surface but also from below the surface. Therefore, this study was conducted to estimate the number of carbon emissions produced using remote sensing technology and Geographic Information Systems (GIS).

The objectives of this study are to identify the type of land cover on peatland burned in Banjar Regency in 2015 and to estimate above-ground and sub-surface carbon emissions from peat fires in Banjar Regency 2015.

Materials and methods

Materials

Landsat 8 image 2015 before and after fire, Biomass Field data, Peat depth data, Bulk Density (BD), and C-organic for each type/maturity level of peat in Kalimantan-Indonesia, Administrative Map and Land Map of Banjar Regency South Kalimantan Land System Map RePPProT (Regional Planning Program for Transmigration).

Peatland is land that has a layer of soil rich in organic matter (C-organic > 18%) with a thickness of 50 cm or more. The organic matter that makes up peat soil is formed from plant remains that have not fully decomposed due to water-saturated and nutrient-poor environmental conditions. Therefore, peatlands are often found in *back swamp* areas or basin areas with poor drainage (Agus and Subiksa, 2008).

Maximum likelihood classification

Maximum likelihood classification is used to transform multispectral images into thematic information on land cover classes. The results of the classification are spectral classes whose identity is not yet known because they are based only on natural groupings. Users should compare with reference data, for example, with land-use data. Thus the spectral classes can be given their identity (Rimal *et al.,*, 2020; Nurlina *et al.,*, 2021).

Test accuracy

The accuracy test, which aims to assess the accuracy of maps generated from remote sensing data, has become universal and recognized as an integral component of the project. The error matrix method or *Confusion Matrix* is a category (nominal) accuracy test of classification results.

The classification accuracy assessment matrix compares category per category (class per class) and the relationship between actual data (*ground truth*) or field data with data from automatic classification results. (Lillesand *et al,* 2004; Rossiter, 2004).

Normalized burn ratio (NBR)

The normalized burn ratio (NBR) is calculated using the calculation of the reflectance value on channels 5 (Near Infrared) and 7 (Midinfrared) which is multiplied by 1000 to change the scale (Key and Benson, 2006).

$$\text{NBR} = 1000x\left[\frac{(R_5 - R_7)}{(R_5 + R_7)}\right]$$

R is the reflection value of each pixel for channels 5 and 7, respectively. Differenced Normalized burn Ratio (dNBR), which measures the change between before burning and after burning response in the near-infrared region (0.76 - 0.90 mm) and the mid-infrared region (2.08 - 2.35mm). Differenced Normalized burn Ratio (dNBR) is calculated by subtracting the NBR after the fire and the NBR before the fire as follows:

$$\text{dNBR} = \text{NBR}_{pre} - \text{NBR}_{post}$$

dNBR is the change of normalized ratio fire, NBR_{pre} is Normalized ratio before fire, and NBR_{post} is Normalized ratio after fire (Key and Benson, 2005).

Research procedure

This research was conducted in two stages of research, namely: the preparation stage and the data implementation stage. At the data preparation stage, what was carried out included library research and image data collection that could be downloaded from the internet. For the implementation phase, the data is divided into three, namely land cover classification, dNBR data processing, and estimation of carbon emissions above and below the surface on burned peatlands in Banjar Regency in 2015. The general research procedure is shown in the following chart that show in Fig. 1.

The formula for calculating above-ground carbon emissions is as follows:

$$C_{aboveground} = \sum_{i=1}^{n}\sum_{j=1}^{3} A_{ij} x B_{ai} x Cf_a x \beta_{aj}$$

With $C_{aboveground}$ is Carbon Emissions Surface, I is type of vegetation, j is Burn Severity Class, A is burned area, B_a is Biomass value per vegetation, Cf_a is Percentage of carbon from above-ground biomass, a is Above-ground combustion fraction (% consumption) (Poulter *et al.*,, 2006). For the subsurface carbon emissions, use the following formula:

$$KC = B \times A \times D \times C$$

With KC is Carbon Content, B is *Bulk Density* (BD) peat, A is Area of peat, D is Thickness of peat, C is Soil organic carbon content (C-organic) (Wahyunto *et al.*,, 2004).

Results and discussion

Land cover classification

Landsat images of April 8, 2015, were classified using the Maximum Likelihood classification method or classification by looking for the maximum similarity of pixel values; this classification is used to transform multispectral images into thematic information on land cover classes. The results of the land cover classification can be seen in Table 1.

Table 1. Distribution of Peatland Cover in Banjar Regency in 2015

No	Land Cover	Area (ha)	Percentage (%)
1	Open field	4.095.64	7.06
2	Settlement	2.153.52	3.71
3	Plantation	5.333.11	9.19
4	Agriculture	13.345.27	22.99
5	Shrubs	32.413.81	55.84
6	body of water	707.31	1.22
	Total	58.048.80	100.00

The condition of peatland cover in 2015 showed in Fig. 2 was dominated by shrubs, around 55.84 percent and agriculture, around 22.99 percent. The water body class land cover is the least, which is around 1.22 percent. The results of the overall accuracy of the land cover classification accuracy test using the confusion matrix method, which is about 92.69 percent.

Identification of burned land

The identification of burned land in this study used dNBR and NDVI data in 2015.

Table 2. Area burned.

Vegetation Type	Area Based on Fire Level (Ha)				Total Area (Ha)
	Low-severity burn	*Moderate- to low-severity burn*	*Moderate- to high-severity burn*	*High-severity burn*	
Agriculture	220,61	754,91	187,61	1.70	1.164,84
Shrubs	391,89	2.379,19	593,13	23.43	3,387,65
		Amount			4,552.50

Table 3. Carbon emissions on peatland surface.

Vegetation Type	Carbon Emissions (tons)
Agriculture	568,26
Shrubs	1.150,29
Total Emissions	1.718,55

The dNBR data can be seen from the pixel values to determine which areas were burned. According to The US Geological Survey FIREMON Program, the burn severity class is based on the pixel value of the dNBR data (Smith *et al.,* 2014; Bourgeau-Chavez *et al.,* 2020). dNBR and NDVI data are overlaid with data from land cover classification to determine the type of vegetation/ land cover occupying burned peatlands. The results of data analysis and processing for the identification of burned land can be seen in Table 2.

Table 4. Emissions of subsurface peatland carbon.

Peat Depth	Carbon Emissions (tons)
Shallow/Thin	20,72
Currently	15,93
Deep/Thick	1.055,49
Total Emissions	1.092,14

From Table 2, it is known that the type of land cover/vegetation that burned the most was shrubs with a total area of 3,387.65 ha that burned with a percentage of 76% of the total area burned, while agriculture with an area that burned was 1,164.84 ha and the percentage by 26%. Shrubs are the vegetation that burns the most because they have the characteristics of smooth fuel and low water content, so they are very susceptible to fire. The map of the burned peatland area and its land cover can be seen in Fig. 3 and Fig. 4.

Estimated carbon emissions

Top Surface Carbon Emissions: To calculate carbon emissions from above the surface, the Carbon Emissions Model formula from Poulter *et al.,* 2006. The result of the calculation of carbon emissions above the surface based on the type of vegetation can be seen in Table 3 as follows. Fires in bush vegetation produce more carbon emissions than agriculture. This is because, in the type of shrub vegetation, the burned area is larger than the agricultural area (Nurlina *et al.,* 2018).

Subsurface carbon emissions: To calculate subsurface carbon emissions, the Carbon Content formula from the book Wahyunto *et al.,* (2004). The following is the result of the calculation of subsurface carbon emissions based on the level of peat depth (Table 4). The amount of subsurface carbon emissions is 1,092.14 tons with the category of deep/thick peat (3 meters) producing the most carbon emissions. This may be because fires at depths of 3 meters or more are very difficult to extinguish and therefore fires last longer and produce more carbon emissions (Luta *et al.,* 2017).

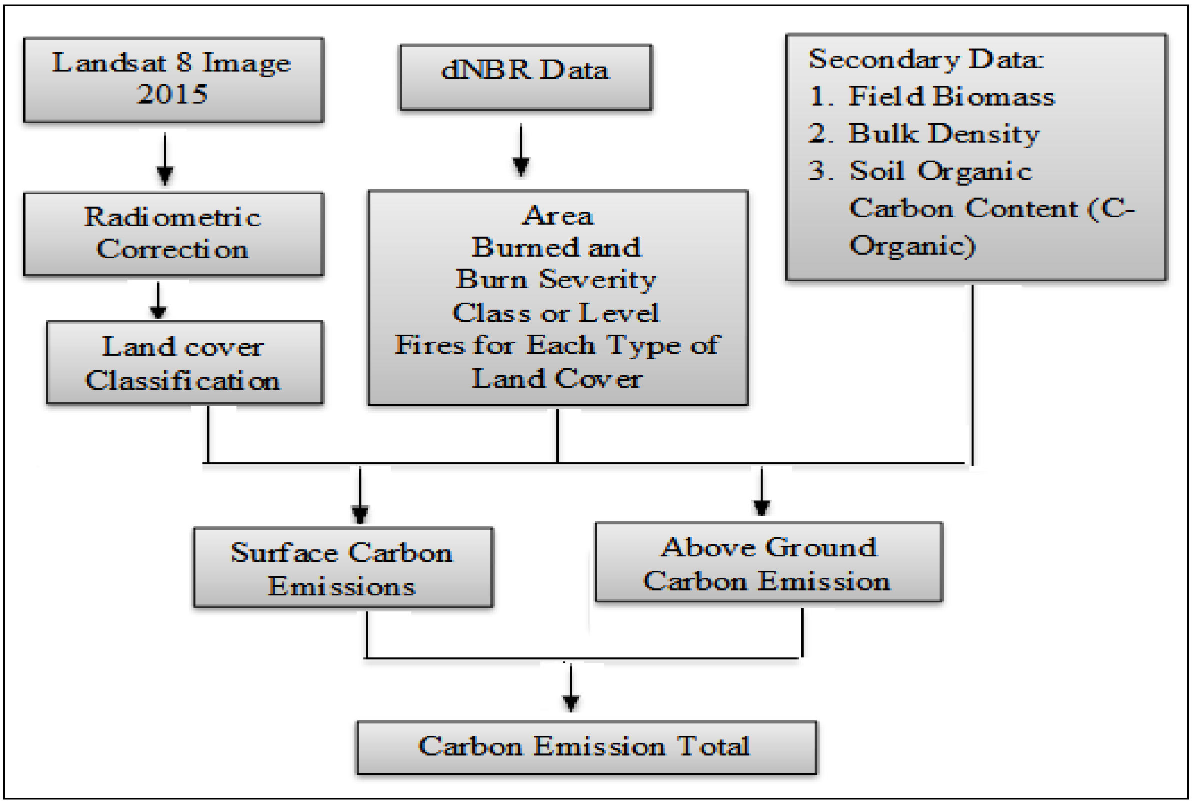

Fig. 1. Research flow chart.

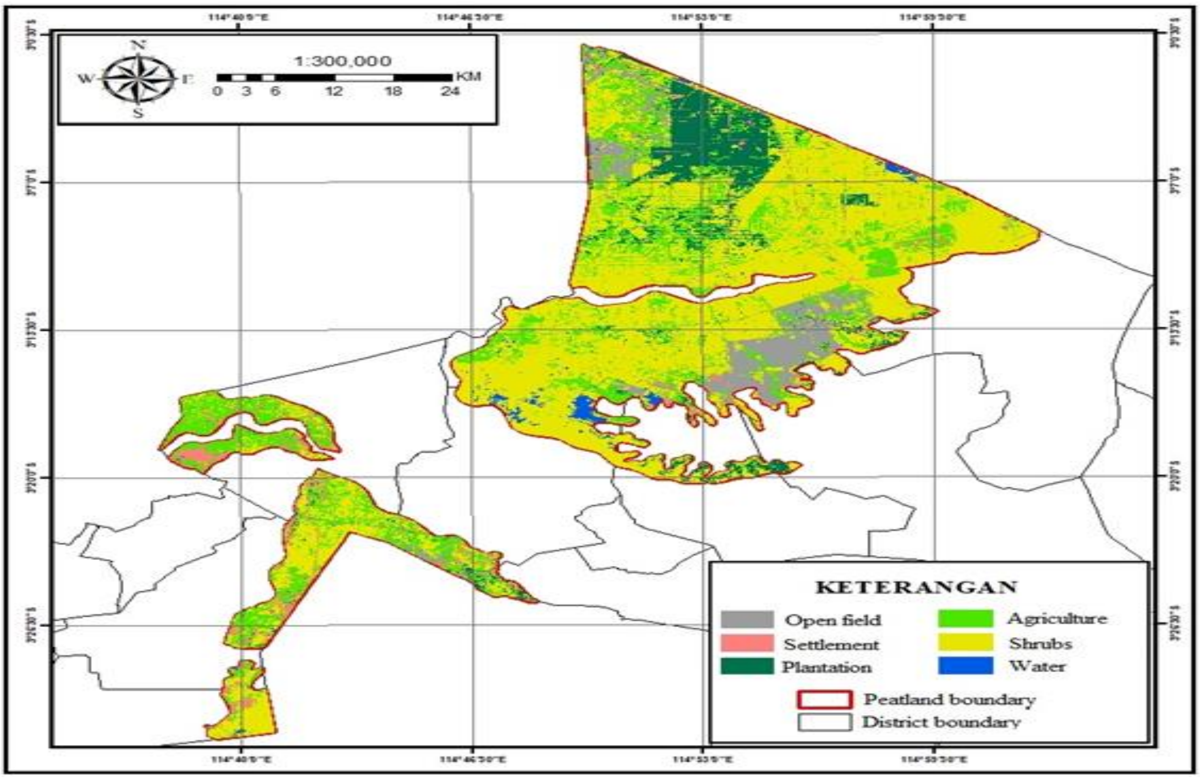

Fig. 2. Peat land cover map of Banjar Regency in 2015.

From the estimated carbon emissions above and below the surface, the total carbon emissions from peatland fires in Banjar Regency in 2015 were 2,810.69 tons. The percentage of carbon emissions above the surface is 61% and carbon emissions below the surface are 39%.

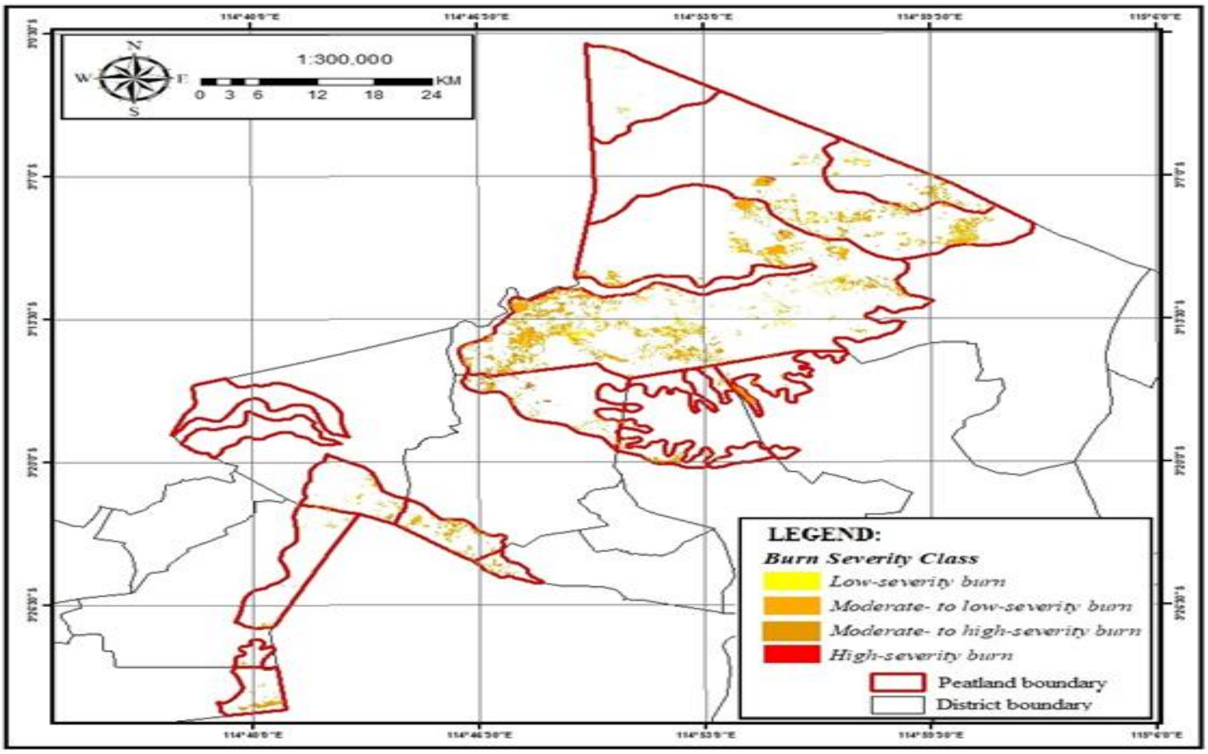

Fig. 3. Peatland cover map of Banjar Regency in 2015.

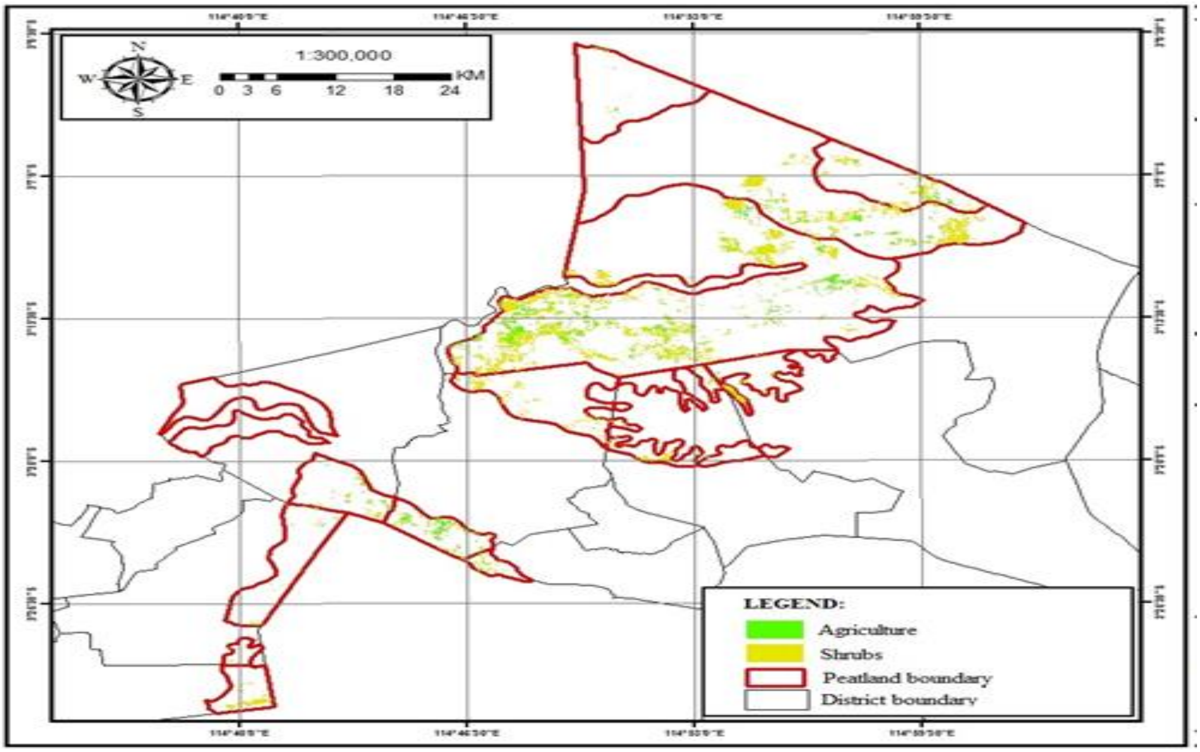

Fig. 4. Map of burned peatland cover.

The percentage of carbon emissions above the surface that is greater than carbon emissions below the surface indicates that burning vegetation has a large role in the number of carbon emissions into the atmosphere which in turn causes global warming. In the event that similar smouldering fires are not observed in other temperate, boreal, and tropical peatland locations, emissions from peatland burning may potentially be a significantly greater problem than is now anticipated.

Conclusion

From the results of data analysis and processing, the following conclusions are obtained the type of land cover on peatland that burned in Banjar Regency in 2015 was shrubs with a percentage of the area burned by 74% and agricultural land by 26%.

The total carbon emissions resulting from peatland fires in Banjar Regency in 2015 were 2,810.69 tons resulting from carbon emissions above the surface of 1,718.55 tonnes and subsurface carbon emissions of 1,092.14 tons. The results indicated that carbon emissions from fires above the peat soil surface were estimated to be greater than those from the peat soil itself.

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