System Development for Land Cover and Deforestation Area Estimation due to Forest and Land Fires

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Abstract. Forest and land fire is one of the causes of peatlands deforestation. Forest and land fire occurred at the beginning of land clearing activities for land conversion known as Land Use, Land Use Change and Forestry (LULUCF). Spatio-temporal data mining technique can be used for estimation of deforested peatland area and its association with forest and land fire. The previous study has compared two classified Landsat 8 images in order to estimate the land cover change in Rokan Hilir district, Riau Province. This research aims to develop an application to automate peatland deforestation estimation due to the forest and land fire using the Shiny framework in R programming language. The data used are Landsat 8 images in 2014 and 2016 of Riau Province and MODIS burned area data product (MCD64A1) image in 2015 of Riau Province. The system was developed using Adaptive Software Development (ASD) method. The main features of the system are land cover area comparison and land cover changes due to forest and land fire calculation. The testing results show that both of the features are successfully implemented. With the automation system in estimating deforestation of peatlands due to forest and land fire, the proses of estimating deforestation levels in peatlands in relation to forest and land fire can easily be done.

1. Introduction
Peat are water-saturated soils and are composed of organic matter from plant residues that have a thickness of 50 cm or more [3]. Peatland has many functions for humans and the surrounding ecosystem. Peatland function as rainwater uptake, prevent floods and guarantee water supply throughout the year. Indonesia is a country that has extensive peatlands area. According to the Indonesian National Carbon Accounting System (INCAS) [2] data in 2011 Indonesia has a peatland area of 14.8 million hectares. Peatlands found in Indonesia are mostly scattered on the islands of Sumatra, Kalimantan, and Papua. However, the vast peatland is decreasing every year due to peatland deforestation. In the 2009-2013 period, Indonesia lost forests due to deforestation of 1.13 million hectares annually. In other words, Indonesia loses forest area by three football fields every minute.

One of the causes of peatland deforestation is forest and land fires. Almost all of the causes of peatland fires are people who intentionally or not burn vegetation in the forest [7]. One of the goals of intentional burning is to clear land. Land clearing by burning forests is relatively cheaper than land clearing by other methods [4]. In addition to forest and land fires due to human activities, prolonged drought and minimal rainfall are supporting factors for forest and land fires. This condition is common to happen from October to November.
Forest and land fires are very adverse to humans and the environment. Forest and land fires could trouble people health and disturb their activities. According to the National Disaster Management Agency (BNPB) [1], forest fire pollutants contain particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and Ozone (O₃). These pollutants can cause respiratory problems, cause asthma, reduce the function of the lungs, and also trigger infant and fetal death. In 2014, the National Disaster Management Agency (BNPB) recorded the loss suffered by Riau Province due to forest and land fires reaching 15 trillion rupiahs and schools were forced to close for one week. In addition, BNPB noted, the amount of land burned in Riau in 2014 included two thousand hectares of biosphere reserves and two thousand hectares of land burned. Moreover, 58 thousand people were stricken with acute respiratory tract infections.

Study on estimating area of deforestation has been carried out by Sofiana [5]. The research links deforestation to forest and land fires that occur. This study uses Landsat 8 imagery data for the period 2014 to 2016. The classification process was carried out to those images using the C5.0 decision tree algorithm with spectral bands as explanatory variables. The image classification results for the 2014 and 2016 periods were used for land cover change analysis by pixel-based comparisons. Meanwhile, image classification results for 2015 was used for forest and land fires evaluation. The area that was being resettled changed are evaluated for forest and land fires that might occur. Sequences of hotspots that occurred in 2015 were plotted on the results of the 2015 image classification. Estimated area of deforestation was done using Spatio-temporal data mining techniques.

In practice, estimating changes in peatland cover due to forest and land fires involves complex calculations and large data processing. Referring to Sofiana [5] the process of calculating the area of peatland deforestation due to forest and land fires is still done manually. First, the composite image is built from 3 Landsat images with different bands, 7, 5 and 4. Then the image is clipped to determine the area of interest to be studied. Then the digital number of each composite image is extracted and image classification is performed on the dataset of digital number. Classification begins by taking a pixel sample of 10% of the total pixels of the composite image using the help of Quantum GIS program. Before the sample pixel goes through the model creation stage, a separability test is carried out between pixel samples that have different classes so that the model produced in the classification process has good accuracy. Next, the classification model is formed using the C5.0 algorithm. Composite imagery in 2014 and 2016 that have been classified are compared to see changes in class in each pixel. Changes in each class that indicate deforestation are then analyzed with forest and land fires using the 2015 composite image to see the relationship with forest and land fires.

Our previous study has succeeded in implementing the image classification process that was conducted by Sofiana [5]. However, the system has not been able to do pixel-based comparisons between two images. So the area of deforestation due to forest and land fires cannot be estimated yet. The module of land cover change prediction will be developed in this study. This module will receive input in the form of Landsat 8 image data and MODIS imagery. The classification process in this system uses the land cover classification model proposed by Sofiana [5]. The module was developed using the R programming language and the Shiny framework. This module's output is a table containing the results of a comparative analysis of land cover changes.

The purpose of this research is to develop a module to estimate peatland deforestation due to forest and land fires using classification model. This proposed system is expected to assist users in the process of estimating peatland deforestation due to forest and land fires which is useful in determining future policy by stakeholders.

2. Methodology
2.1. Study Data
Imagery data used to develop this module are Landsat 8 and MODIS MCD64A1 in Riau and Jambi Provinces. The Landsat 8 imagery used includes images of 11 May 2014 and 19 July 2016 which are used in the classification of land cover. While the MODIS MCD64A1 imagery used is an image taken on August 2015 and it is used as a burned area classification image. MODIS MCD64A1 is combined
imagery that taken from Terra and Aqua. Every pixel in MODIS MCD64A1 represents 500m square of land.

2.2. Research Steps
This study implements one of the agile system development methods, namely Adaptive Software Development (ASD) which has three phases: the speculation phase, the collaboration phase, and the learning phase. The speculation phase is started by analysing the land cover classification model developed by Sofiana [5]. Furthermore, the next steps is to analyse the features and functions of existing web-based application that was developed in our previous work. Finally, system requirements were identified for a new module that is useful for estimating area of peatland deforestation due to forest and land fires and also determining system scopes for that module. In the collaboration phase, the system begins to be designed and developed according to the results of the analysis from the previous phase. The steps taken are illustrated in Figure 1.

![Figure 1. System development steps using ADS.](image)

3. System Development
3.1. First Iteration
The main objective of the first iteration is to develop a module for estimate area of peatland deforestation due to forest and land fires based on comparison of pixel images per period through three phases in ASD, namely the speculation phase, the collaboration phase, and the learning phase.

3.1.1. Speculation phase. In the first iteration speculation phase, there are four objectives namely understanding the flow of determining the estimated area of peatland deforestation due to forest and land fires, understanding and testing the classification model, both the land cover classification model and the burned area classification model, analysing features contained in the developed system, as well as designing the use case diagram of the module to be developed. The result of understanding the flow of determining the estimated area of peatland deforestation due to forest and land fires are as follows:

- The estimation of deforestation area involves three images from three different periods. The imagery in the first and third periods will be analyzed using the land cover classification model. While the image in the second period will be analyzed based on hotspots that occur as a representation of forest and land fires using the burned area classification model. The three
images used are composite images derived from Landsat 8 satellite images using band 7, band 5, and band 4.

- Analysis of the image is done by classifying each pixel of the image. After the image is classified, pixel-based comparisons are made using the x and y coordinate systems of the raster. Each pixel classified as a fire in the second period will be observed for land cover change at the corresponding pixels in the first-period one and third-period imagery.

The results of understanding and testing the classification model are as follows:

- Both image classification models for land cover and burned area were built using the C5.0 decision tree algorithm. In the land cover classification model, first-period pixel and third-period pixel will be classified into nine classes. The class includes Overgrown shrubs, Forests, Plantations, Urban, Rice fields, Body of Water, Open land, Clouds, and Unclassified. While the classification model of the burned area will classify the image in period two to six classes including Clouds, Smoke, Before burning, After burning, Burning, and Unclassified.

- The land cover model proposed by Sofiana (2018) was evaluated using land use and land cover digital map in the shapefile format from Ministry of Environment and Forestry Indonesia. Evaluation was done by looking at how many pixels classification results contained in the shapefile with the corresponding class.

The results of system analysis built in the previous work found that the system only provides functions namely generating a model of land cover classification, implementing the model to an image and storing the classified image in TIF format. The system has not been able to compare changes in two land cover from two Landsat 8 images in two different time periods. In addition, this system has not been able to analyse changes in land cover and look for a relation with forest and land fires. So these features need to be added to the system.

Use case diagram in Figure 2 explains the interaction between users with the new module in the application. The interactions include comparing the of the land cover area change between two Landsat 8 images with different periods, observing land cover changes that occur due to fire and viewing at land cover change in graphs.

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**Figure 2. Use case diagram of Land Use and Land Cover Change Module**
3.1.2. **Collaboration Phase.** In this phase, the land use and land cover change module was developed and integrated into the application. In addition, this phase also attempts to increase accuracy in classification model [5]. The results of this phase are as follows:

- There are some attempts to improve accuracy of the classification model. The attempt begins by examining the training data used in generating the model. This attempt was carried out by observing whether each pixel taken manually from a Landsat 8 composite image has been correctly labelled. Every pixel sample was overlapped to shapefile data from Ministry of Environment and Forestry. Illustration of overlapping sample points and shapefile data can be seen in Figure 3.

![Sample points](image)

**Figure 3.** Illustration of overlapping sample points on Land use and land cover shapefile

From the results of this evaluation, several samples were not labeled correctly. The class that has the largest labeling error rate is the Rice Field class with a percentage of labeling errors of 91.36%. The overall results of evaluation can be seen in Table 1. True sample means that the sample as the same class as those in the land use and land cover digital map, otherwise the sample is denoted as false sample.

**Table 1.** The results of overlapping sample points with land use and land cover.

| No | Class          | Number of samples | Number of true samples | Number of false samples | Percentage of true sample |
|----|----------------|-------------------|------------------------|-------------------------|--------------------------|
| 1  | Water          | 29,780            | 28,504                 | 1,276                   | 95.72                    |
| 2  | Forests        | 153,142           | 117,173                | 35,969                  | 76.51                    |
| 3  | Plantation     | 130,152           | 79,186                 | 50,966                  | 60.84                    |
| 4  | Open field     | 104,327           | 43,443                 | 60,884                  | 41.64                    |
| 5  | Rice paddy field | 5,152         | 445                    | 4,707                   | 8.64                     |
| 6  | Brushes        | 169,197           | 49,726                 | 119,471                 | 29.39                    |
| 7  | Urban          | 4,314             | 3,413                  | 901                     | 79.11                    |

The accuracy of land use and land cover model proposed by Sofiana [5] is a quite low. The model cannot identify properly land use and land cover class with same colour, such as Open field class and Rice paddy class. Future improvements are needed to make estimation result more accurate.
The new module that was developed consists of two main features, namely the comparison of land cover area and calculation of land cover change due to forest and land fires. The function of uploading images and on the land cover change area comparison module can be seen in Figure 4. This feature accepts the TIF format image input and the decision tree model in RDS file type. The results of the calculation of land cover change can be seen in Figure 5. The visualization of the calculation results is represented in the form of tables and bar graphs. Both types of data presentation show changes in land cover that occur from year to year.

The second function is the calculation of land cover change due to forest and land fires. This function performs the process of selecting pixels in the first and third-period images that correspond to the second-pixel image which is indicated as a burned area. The results of the calculation of this module are represented in tabular form and it can be seen in Figure 6. On each pixel that is indicated to be burned pixel in 2015, the change in land used and land cover class is identified at the corresponding pixel and then its land area is calculated.

3.1.3. Learning Phase. Testing of each feature was carried out in this phase. All functions that were created during the first iteration collaboration phase were evaluated using the black box testing method. The test results and test scenarios can be seen in Table 2. The test results show that all the functions were successfully tested and produced the results as expected.
Table 2. A System testing in the first iteration.

| Module Function                        | Expected Result                                                                 | Test Result |
|----------------------------------------|---------------------------------------------------------------------------------|-------------|
| Comparing land cover change            | The application displays tables and graphs of land cover change                 | Success     |
| observing land and forest fire effect on land cover change | The application displays a comparison table of changes in land cover affected by land and forest fire | Success     |
| clearing system memory                 | The calculation results that were previously saved are cleared                  | Success     |

3.2. Second Iteration

The main purpose of the second iteration is to replace the use of Landsat 8 composite imagery with MODIS MCD64A1 imagery to identify burned area. This step was conducted through three phases in ASD, namely the speculation phase, collaboration phase, and learning phase.

3.2.1. Speculation Phase. The examining of the MODIS MCD64A1 imagery was carried out in the speculation phase. The characteristics of the image were studied in order to avoid calculation errors due to differences in the characteristics between the Landsat 8 imagery and the MODIS imagery when making pixel-based comparisons. The characteristics to be considered include the composition of the band, the projection system and the coordinate system used, pixel density and the resolution value possessed by the MODIS MCD64A1 imagery. The replacement of Landsat 8 imagery to MODIS MCD64A1 imagery is expected to improve the accuracy of land cover change calculations due to forest and land fires. In addition, image replacement can increase the speed of the calculation process because the second-period image does not need to go through a classification process. The use of MODIS MCD64A1 imagery in general is to observe the fires that occurred in a certain area.

The results of this phase found that the features on the MCD64A1 MODIS imagery included coordinate values and a band that represented the fire incident. Features of MODIS MCD64A1 imagery data can be seen in Table 3. In addition, there are underlying differences between Landsat 8 images and MODIS MCD64A1. These differences consist of the dimensions of the image, image resolution and the projection and coordinate system used. So that the MODIS MCD64A1 image must go through a resampling process based on Landsat 8 image resolution so that the two images can be compared using pixel-based comparison.

Table 3. Data of MODIS MCD64A1 imagery

| No | Attribute | Description                     |
|----|-----------|---------------------------------|
| 1  | x         | Pixel x coordinate              |
| 2  | y         | Pixel y coordinate              |
| 3  | Band 1    | -2 = Water body                 |
|    |           | -1 = Unclassified               |
|    |           | 0 = Unburn                      |
|    |           | n = burned for n days           |

3.2.2. Collaboration Phase. The forest and land fires and deforestation module has corrected to match the input of new image types. The MCD64A1 image must undergo a resampling process before a pixel-based comparison process can be performed with Landsat 8. Then, this function does not require input
in the form of a burned area classification model [5]. In addition, the application flow is slightly changed by overlaying the first and third-period images with the second-period image. Only pixels that correspond to fire pixels in the second image will be included in the classification process so that the time required is shorter. The burn area classification model proposed by Sofiana [5] is no longer need to be uploaded because the MODIS MCD64A1 already have the information about the wildfire that occurs. Furthermore, the calculation results are still displayed in tabular form which can be seen in Figure 9.

3.2.3. Learning Phase. Testing of each feature was carried out in this phase. All functions that have been developed in the second iteration were evaluated using the black box testing method. Scenarios and test results can be seen in Table 4. The test results show all the functions are working properly.

| Module                                         | Expected Result                                                                 | Test Result |
|------------------------------------------------|--------------------------------------------------------------------------------|-------------|
| Comparing land cover change                    | The application displays tables and graphs of land use and land cover change    | Success     |
| Observing forest and land fires effect on land use and land cover change | The application displays a comparison table of changes in land use and land cover affected by fire | Success     |
| Clearing system memory                         | The calculation results that were previously stored are cleared                 | Success     |

The advantage of this system is its ability to calculate automatically the land cover change because of forest and land fires from Landsat 8 images. GIS software such as Quantum GIS does not provide the feature in automatically detection of land cover change on forest and land fires area. The disadvantage of the system is that the output of the system should be verified by comparing the output to the real deforestation due to forest and land fire.

4. Conclusion
This study has successfully implemented the module for estimating land use and land cover changes and deforestation due to forest and land fires in a web-based application. The module has two main features,
namely the comparison of land use and land cover changes area and calculation of changes in land use and land cover due to forest and land fires. The results of the testing scenario using the black box method show that all the functions in the module are working properly. The system provides advantages that can help users in automatically classifying land use and land cover and estimating the area of land use and land cover changes and deforestation due to forest and land fires.

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