THE USE OF REMOTE SENSING AND GIS IN MONITORING TROPICAL RAIN FOREST

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ABSTRACT:

The demand for timely and accurate geographic information has accelerated greatly for a number of earth related fields including natural resource management and exploitation, urban and regional planning, development of industry and agriculture, and geological exploitation. Geographic information can be derived easily from the remotely sensed data. All remote sensing data used the optical portions of the electromagnetic spectrum as its own source of energy has experienced two kinds of limitations. First, if cloud cover is present, data can not be obtained using sensors operating in those wavelength regions. Second, the spectral regions sampled do not always provide sufficient information to differentiate between various forest or other agricultural and cultural cover types. Radar data, which utilizes the active microwave portion of the spectrum, can provide important additional information about terrain surfaces and forest and agricultural plants canopies. Satellite remote sensing often used to obtain information on actual land cover land use and to monitor changes in the regions with often cloudy conditions in the microwave range. The main objective of this research was to monitor tropical rain forest land use changes in two Indonesian test sites using multi-temporal ERS-1 and JERS-1 radar data and optical Landsat TM, MSS and Spot XS data.

1. INTRODUCTION

Forest resources are important socially, economically and environmentally. For many years the problems of deforestation in the tropical rain forest had raised considerable international interest. Degradation is another existing way of tropical rain forest destruction. From 1850-1980 about 15% of the earth's forest cover disappeared as a result of human activities (World Resources Institute 1987), according to this report the tropical rain forest of Asia, Africa, and South America declined by 27 percent. This depletion is very significant, where about 2.5 billion people depend on natural forest resources for many economic and environmental goods and services. According to the Food and Agriculture Organization of the United Nation report of 1988, between 1980 and 1985 the estimated annual rate of tropical forest degradation was 0.6 percent or 11.4 million hectares. The major causes of this degradation in the tropics are agriculture expansion, overgrazing, fuelwood gathering, and logging. Behind all these causes is the population growth. In general, high population pressure has its impacts on the tropical forest land use and its changes. These changes are mostly either because of the urban expansion in the , or the farmers want to change the farming system (e.g. from food crop to market or cash crop). They could also be due to multiple or over use of the land that resulted in soil fertility depletion which reduced crop production. In order to manage and control the hazard land use changes, especially in tropical countries in heavily populated areas, it is essential to monitor these changes.

Given the importance of the tropical forest issue in terms of biodiversity, climate, biochemical cycles and economic development, there is a need of concentrated effort to find the best and effective type of remotely sensed data and then develop effective utilization of this data in an operational forest monitoring program.

In the twentieth century, the demand for timely and accurate geographic information has accelerated greatly for a number of earth related fields including monitoring tropical rain forest conditions. Geographic information can be derived easily from the remotely sensed data such as: aerial photographs, Multispectral Scanner (MSS) using aircraft or spacecraft, Landsat Thematic Mapper (TM), SPOT Panchromatic and MSS, AVHRR NOAA, etc. All remote sensing data used the optical portions of the electromagnetic spectrum as its own source of energy has experienced two kinds of limitations. First, if cloud cover is present, data can not be obtained using sensors operating in those wavelength regions. Second, the spectral regions sampled do not always provide sufficient information to differentiate between various forest or other agricultural and cultural cover types. Radar data, which utilizes the active microwave portion of the spectrum, can provide important additional information about terrain surfaces and forest and agricultural plants canopies. Satellite remote sensing often used to obtain information, on actual land cover/land use and to monitor changes in the regions with often cloudy conditions such as indonesia. However, radar data can be independent of the atmospheric conditions and the time of the day. Therefore, data supplied by Synthetic Aperture Radar (SAR) such as the European Remote Sensing Satellite (ERS-1) has potential for environmental applications. The main objective of this research was to detect changes in the land use of the tropical rain forested area, including the forest land, agricultural land and other land resources near the forest using multi-temporal optical data (e.g., Landsat MSS and TM and Spot XS data) and microwave (e.g. ERS-1 and JERS-1 radar data) satellite images in two Indonesian test site (i.e. Bengkulu, South Sumatra and Jambi, Central Sumatra).

2. MATERIALS AND METHODS

2.1 Study Areas

Two test sites were used for this research. The first study area is located on the south west coast of Sumatra, Indonesia. It is situated between 3°35'00" and 3°51'00" Latitude South and between 102°12'00" and 102°45'00" Longitude East. The area lies in the Bengkulu province and covers about 2,100 km^2. In general, the topography of this study area can be considered undulating through rolling to mountainous. The altitude varies from 0 to 1800 m asl. The settlements are located along the main and secondary roads. Bengkulu is one of the nine major cities in sumatra and it is the seaport city on the south-western coast of Sumatra. The main river in the area is the Air-Bengkulu river. Most of the irrigation systems are of the conventional gravity type.

The major land use/cover classes exist in the area are: cultivated land which consist of rain fed agriculture land and irrigated agriculture land; agro-forestry, which is a combination of forest trees and crops; forest plantations; shifting cultivation, is characterized by scattered arable plots in the forest area which involves the cutting/burning of the natural vegetation (forest, scrub or grass); natural forest is consist of highland and lowland rain forest; mixed cover of bushes Grass/Scrub/shrubland; and urban or settlements which include villages, towns and cities.

The second area of study lies approximately from latitude 1° 15' to 1° 45' (S) and from longitude 102° 15' to 102° 45' (E). This area is located in the Bungotebo county, northwestern part of Jambi province, Central Sumatra. The river Batang Hari divided the area into two part. The form of topography in this site is relatively flat land with a very small part of mountains. The altitude varies between 25 to 160 m. Verstappen (1973), used the peneplain to refer to this type of terrain. Part of the peneplain are covered with acid volcanic tuff, particularly near the Bukit Barisan mountain. Podzolic red yellow soil type is dominant in the study area. The land cover in this test site is dominated by forests. Plantations of rubber, oil palm are found in the area. Most of rubber plantations were planted by the indigenous people and normally located at the boundary of or inside forest. New settlements that cause by transmigration is located in the south and southeast of the study area. Other agriculture cover types like rice field also found in the area.

2.2. Data Used

For the first test site, the remote sensing data were acquired by both passive and active systems. Landsat-1 MSS data of 13 June 1973 were used to classify land use in 1973 and to compare with land use data of 1990. The spatial resolution was 80 x 80 m square and spectral bands were representing the green, red, and two in infrared part of the spectrum. The Landsat-5 TM data, acquired on 29 December 1990 were used to study recent land use. The spectral bands used were blue, green, red, NIR, two MIR, and one thermal IR. The spatial resolution was 30 x 30 m square.

ERS-1 Synthetic Aperture Radar (SAR) data acquired on 20 July 1993 in C-Band (5.6 cm wavelength) and VV polarization were used. The spatial resolution was 12.5 m with a swath width of 100 km. The incidence angle was 23°. During 1994, two other images were acquired of the study area. Unfortunately, because the new images were obtained in a different acquisition mode, there was a significant shift from the image acquired in the preceding year. Two JERS-1 Synthetic Aperture Radar data sets acquired on 6 March 1993 and 20 May 1994 were also used for the study. The data were obtained in the L-Band (23 cm wavelength), HH polarization and an incidence angle of 35°. The spatial resolution was 12.5 m and the swath width was 75 km.

For the second study area the following data were available: Landsat-5 TM data of September 15, 1993, Spot XS data of March 21, 1993, ERS-1 images of October 17, 1993, June 6, 1994, and July 7, 1994, and JERS-1 of August 16, 1993.

2.3 Method Used

For the first test site, our methods included the classification and interpretation of the microwave and optical remote sensing data, field checks, change detection analysis, and comparison of the results of different types of data.

From the additional information acquired in the field, a supervised classification was performed on the available Landsat MSS (all bands) as well as TM data (bands 2, 3, 4 and 5). Training samples were first selected from various land cover types: wetland rice field; shifting cultivation and secondary forest; bush and scrub; lowland forest (primary forest); settlement; sea beaches and bare soil; sea and lake. After selecting the training samples, a classification was run using a maximum likelihood algorithm. A quantitative evaluation of both classification results was done by testing the accuracy using a confusion matrix which showed the overall and average accuracies by class.

An attempt was also made to incorporate radar data (ERS-1 and JERS-1 data) in multispectral classification by combining ERS-1 with Landsat TM3, TM4 and TM5. Similar combinations of JERS-1, TM3, TM4 and TM5 bands were also classified.

Because ERS and JERS radar data are acquired in single bands (e.g. wavelength, polarization, incidence angle), digital image processing techniques are limited. It was therefore decided to print the radar images in hard-copies for visual interpretation. In this case, other information (e.g. contextual or spatial) can be used as key interpretation elements to delineate the boundaries of different land covers. The visual interpretation maps of the ERS-1 and JERS-1 images were digitized, polygonized and rasterized for comparison to see how many classes could be recognized in each of them. Later, both interpretation maps were rasterized to 30 m pixel size and registered to the 30 m spatial resolution of TM, MSS and other materials.

The Landsat MSS classification map of 1973 and TM classification map of 1990 were compared to calculate the land use changes (e.g. decreases or increases in the areas of different land use classes) during 17 years. Another comparison of a 1988 Landsat MSS classification map, land use/land cover map and Landsat TM classification map of 1990 was made to detect the changes in land uses during that period. Emphasis was put on certain classes that were expected to have significant changes (e.g. forest, agriculture, and settlement cover types).

Because urban areas can be detected best on ERS-1 radar images, a change detection analysis was performed by overlaying the settlement area from the ERS-1 image on the TM classification. The same step was repeated by overlaying the settlement maps from the 1973 MSS and 1990 TM classifications to show urban development during 17 years.

Methods used with the data of the second test site included: image pre-processing (e.g. radiometric and geometric correction and filtering), object identification and detection, image classification, optical and radar satellite image fusion and comparison to detect forest and deforested areas.

3. RESULTS AND DISCUSSIONS

Using the MSS data it was not possible to have more than eight classes because of the overlap between the clusters. It was especially difficult to separate different forest types (swamp forest, tidal forest, natural forest and rubber plantation) because the forest types are not homogeneous in terms of the tree species. Each forest type consists of many tree species, resulting in mixed spectral reflectance characteristics. Thus it was decided to combine some of these classes.

Shifting cultivation and secondary forest were placed in one class because the farmers cultivate several crops (such as coffee, rubber, cereals, etc.) which makes it spectrally confusing with other cover types. In addition, the farmers do not clear the area completely. It was difficult to distinguish between the river and wetland rice fields because the river is narrow in some locations and surrounded by bushes and other vegetation. Also in some places the wetland rice is located next to the river. This causes a mixed signature of water and vegetation. Therefore, both were classified together.

Different types of soils (such as red soil, brown soil etc.) did not show distinct spectral signatures. As a result, they were not separated into different classes. The same situation occurred with the settlement and homestead gardens. The homestead gardens consist of agricultural crops, fruit trees and bare soil. The settlements and homestead gardens were also classified as one.

However, it was possible to distinguish between natural forest (lowland forest), shifting cultivation and secondary forest, wetland rice, settlement, sea and lake. The bare soil and beach were classified together because both classes have almost the same spectral signatures.

A quantitative evaluation of the supervised classification results indicated an overall classification performance of the MSS data of 88.9%, which is relatively good. Most of the individual classes had classification accuracies exceeding 80 %, except for the bush and grass which had an accuracy of 77.9%. About 5% of the grass test fields were confused with the lowland forest and 18% with the shifting cultivation.

The supervised classification of Landsat TM 1990 data resulted in 12 spectral classes. Some were merged to obtain the final nine classes because the low frequency of pixels in some classes. The nine classes were: lowland forest (primary forest); shifting cultivation with secondary forest; beach with bare soil; wetland rice field; bush with grass; settlement with homestead garden; lake; sea and cloud.

It was difficult to distinguish between different forest types such as swamp forest, tidal forest and rubber plantation. As in the Landsat MSS classification, the TM classification result also did not show the difference between wetland rice and river. The overall classification performance of the TM data was 91%, which is even better than the results from MSS data.

A multisensor spectral classification of TM with ERS-1 and TM with JERS-1 data was attempted. Because of the high speckle noise of the radar data, the classification result was not as good, and resulted in a small number of classes. These classes were lake, sea, vegetation, settlement and the wetland rice. The settlements were significantly clearer on the radar image compared with the Landsat TM image because of the radar corner reflection phenomenon. The wetland rice fields, lake and sea appeared very dark on the radar image because of the specular reflectance from the water.

The following classes were obtained from the visual interpretation of the ERS-1 image of 1993: lowland forest; shifting cultivation and secondary forest; clearcut with bush; wetland rice; rubber with bushes; swamp forest; beach with coconut trees; settlement; lake; river and sea. The visual interpretation of the JERS-1 image resulted in the same number of classes as with ERS-1, but tidal forest was clear in the JERS-1 image. A comparison of these two interpretations shows that it was easier to delineate the boundaries of wetland rice fields and water bodies (such as river, lake and sea) on the JERS-1 image than the ERS-1 image because JERS-1 has a longer wavelength. However, the settlements in the ERS-1 data were very clearly delineated because the original spatial resolution of the ERS-1 image is much higher than the JERS-1 image and also the effect of VV polarization. The ability to recognize lowland forest, swamp forest, rubber plantations, and coastal coconut plantations using the JERS-1 image were better than ERS-1 because the L-band energy penetrates through vegetation canopies better than C-band. Both maps showed differences in the location of shifting cultivation with secondary forest and bushes classes.

In general, comparing the ERS-1 and JERS-1 interpretations and TM classification, the radar images provided four more classes than the optical image. These classes were swamp forest, tidal forest, rubber plantations and coastal coconut plantations.

Figure 1 shows the changes for different classes between 1973 and 1990. To analyze land use changes, the classification result of 1990 was overlaid on the result of 1973. The major change took place in the lowland forest area. The reduction in lowland forest was replaced mainly by shifting cultivation with secondary forest (10595.5 ha or 13.1%), followed by bush and clearcut (3657 ha or 4.5%), settlement (2603.4 ha or 3.2%), wetland rice (1007.8 ha or 1.2%) and bare land (0.27%). Shifting cultivation increased from 19.1 % in 1973 to 38% in 1990; 13.1 % of this increase came from lowland forest while 12.9% came from bush and 11.1% remained as it was in 1973. The main factors effecting shifting cultivation expansion are the population pressure and socio-economic aspects. High population growth, both natural and immigration, in a limited area puts pressure on the environment, which will finally reduce the sustaining capacity of the land. So we can say that the increase of population results in the increase of shifting cultivation. Figure 2 shows the relationship between the population, shifting cultivation and lowland forest in Bengkulu province. The high positive relationship shows that the increase of shifting cultivation area is related mainly to the population increase. Conversely, the relationship between the population and lowland forest area is negative, which indicates that the increase of population results in a decrease in lowland forest.

The results from data analysis of the second data set were consistent with the results from the first test site. The classification result of Spot data shows that 11 classes were able to be recognized, while Landsat TM recognized 9 classes. Multi-temporal ERS-1 image recognized 8 classes, while single JERS-1 image shows only 5 classes. JERS-1 image was able to recognize the forest cover type classes better than ERS-1 images because the first used longer wavelength. The classification accuracy of all four optical and radar data clearly shown on Figures 3, 4, 5, and 6.

4. CONCLUSIONS

The following conclusions can be drawn from the results of the first test site:

- The classification of radar data (ERS-1 and JERS-1) did not give decent results because of the rugged terrain, high moisture content of the whole scene, short wavelengths and low incidence angle, single polarization of both images, and the quality of the images.

- Visual interpretation of radar data gave good results. It was possible to recognize four more classes on radar images than on the optical image. These classes were: swamp forest, tidal forest, rubber plantation and coastal coconut plantations.

- It was possible to detect more classes from a combined image of optical and microwave, which would have been difficult using TM or radar data alone.

- A comparison of the results obtained by supervised classification of 1973 Landsat MSS and 1990 TM images shows that the latter gave more land cover classes and better overall accuracy because of its improved spectral and spatial resolution. However, it was difficult to distinguish between different forest types such as swamp forest, tidal forest and rubber plantations. It was also difficult to differentiate between wetland rice fields and rivers.

- For detecting settlements, ERS-1 was found to be better than JERS-1 and optical data (TM and MSS). In the present study, the settlement information was thus incorporated in the classification result obtained using TM data. This was a good example of improving the results of the multispectral classification of optical data by overlaying the settlement information from radar data.

- Using remotely sensed data, it was possible to detect changes in land use. The major change took place in the lowland forest area. The reduction in lowland forest was replaced mainly by shifting cultivation, with secondary forest followed by bush and clearcut and settlement.

- The main factors which effect land use changes in the study area are the increasing population (both natural and immigration), social and economic aspects and cultivation management practices.

The following conclusions can be drawn from the results of the second test site:

- Spot image was able to recognize more classes (11 to 9) and in higher accuracy (95.41% to 91,5%) comparing to Landsat TM image.

- ERS-1 multi-temporal images was able to detect dynamic object (e.g. three cycle of rice field).

- ERS-1 multi-temporal images detect more land cover type classes than single JERS-1 image (e.g. 8 to 5).

- JERS-1 image was better in classifying forest cover types comparing to JERS-1.

- Combining optical and radar images can enhance the ability of each one of them alone to detect more land and forest cover types in the tropics.

5. REFERENCES

Verstappen, H. Th, 1973. "A Geomorphological Reconnaissance of Sumatra and Adjacent Islands (Indonesia), Groningen: Wolters-Noorhoff Publishing. 182 p.

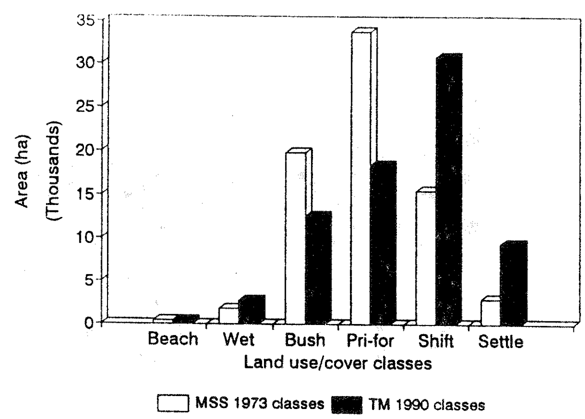

Figure 1. Comparison between Landsat MSS and TM Classes period (1973-1990).

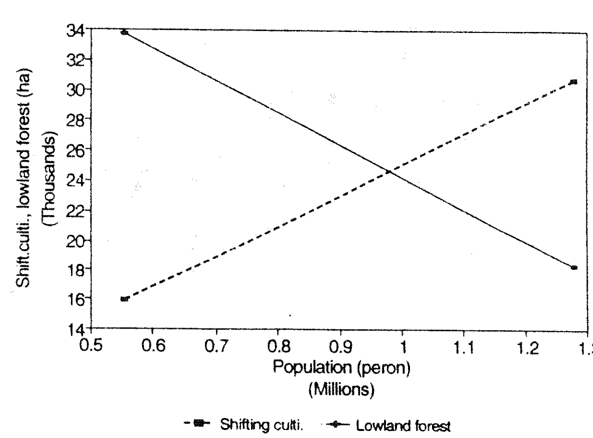

Figure 2. Relationship between population, shifting cultivation and primary (lowland) forest.

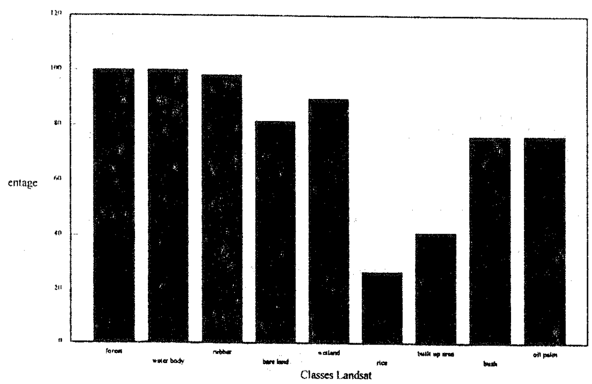

Figure 3. Classification Accuracy Assessment of Landsat TM data.

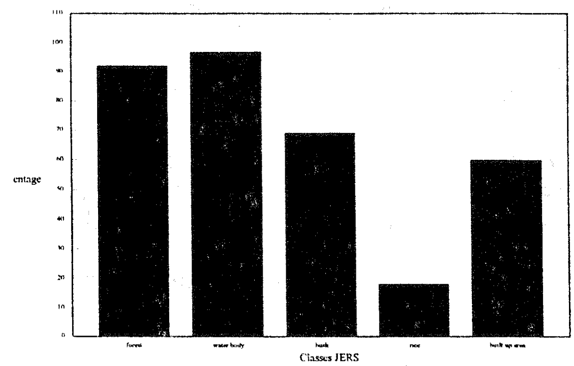

Figure 6. Classification accuracy assessment of single JERS-1 data.

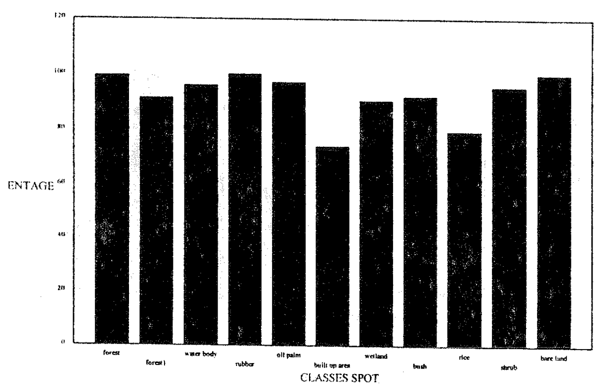

Figure 4. Classification accuracy assessment of Spot XS data.

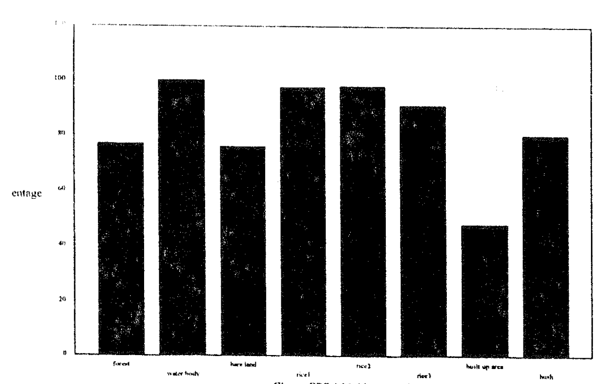

Figure 5. Classification accuracy assessment of multi-temporal ERS-1 data.