Monitoring Land Use Change on Tropical Peatland using REMOTE SENSING

presented
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Abstract:
The overall aim of this **Kalteng Consultants** research programme is to investigate the evolution and the economic potential of the **peat swamp forest** (PSF) resource in Kalimantan by **remote sensing** techniques. A **multispectral and multitemporal image analysis** will evaluate the environmental importance and agricultural potential as well as wildlife conservation aspects.

A land-use conversion project for **rice cultivation** (including transmigration) started by the Indonesian government in January 1996. It is planned to develop an area of one million hectares in Central Kalimantan, situated between River Kahayan in the west and River Kapuas or River Barito in the east and Java Sea in the South. The total area of impact may be as much as 1 million hectares. It is proposed to use the **remote sensing technology** for all survey and planning tasks. The paper presents some results from LANDSAT and ERS1 image processing activities.

In order to undertake a global monitoring and survey in a short time it will be essential to use LANDSAT Thematic Mapper and ERS1/2 Radar images, linked to a programme of field checking of forest, peatland development and **peat condition (including depth).** A comprehensive literature survey must be carried out in order to assemble all published information, proceedings and institutional internal reports. All the data will be evaluated to prepare a detailed peatland analysis which will be stored in a **Geographical Information System (GIS).**

The poposer has been established specifically to address the problems of tropical peatland survey, analysis and evaluation in Kalimantan and combines international experts in the required fields of expertise. They will use a test area of approx. 150km x 150km in the south of Palangkaraya.

Key words:
Central Kalimantan, Kalteng Consultants, Remote Sensing, LANDSAT, ERS 1+2, PSF-types and -depth, soil-tips, research area near Sungai Sebangau, 1 Mio. ha rice project, Soft-Ware: ENVI-IDL,
Multitemporal and Multispectral Image Analysis:Image statistic (greylevels, histograms, variance, co-variance), RGB, NDVI (Vegetation Index), Hyperspectral Analysis with Z-Profiles
Image enhancement: filtering, contrast stretching: linear, 2%, equalisation, Gaussian, Square Root Min,
Image Classification: Supervised (Maximum Likelihood Class, Minimum Distance Class., Spectral Angle Mapper, Mahalanobis Distance Class., Neural Net Class.) Unsupervised (IsoData Class.)
Image Fusion, Change Detection, GCP, Warping, RST, Mosaicking, Geocoded Mappings, UTM and Printing.
Grids, Annotation, GIS, Remote Sensing Technology Transfer to Indonesia.

1. Introduction

The aim of the Remote Sensing is twofold. It is planned to produce

- a basic ecological and land use map for the whole area covered by **peat** in Kalteng using LANDSAT TM and ERS-1/2 SAR images. From this map it will become evident where the **peat depth** is small and agriculture will be feasible and where the peat is to deep for such activities.
- a **change detection map** and a fire monitoring system from multitemporal ERS-1 image series, which allow to analyse the loss of forest due to shifting cultivation and uncontrolled forest fires. This knowledge will lead to improved land use planning measures and fire prevention.

Two sources of remote sensing data will be used:

1. **LANDSAT TM images**. Two neighbouring nearly cloud free scenes acquired in 1991 and 1994, which cover 65000 km^2, are available to the Kalteng Consultants team. Furthermore other LANDSAT TM images are also available to the Kalteng Consultants team. Some areas covered by these images are evaluated and classified during an ongoing project. LANDSAT TM images offer the highest quality available in terms of vegetation classification and land use mapping. The images have a ground resolution of 30 m and 7 different spectral channels covering the whole range from the visible light to infrared and a thermal channel. Since the data is stored in a digital format it can be analysed by computer techniques. All LANDSAT TM scenes are partly evaluated and classified.

2. **ERS-1 and ERS-2 SAR images**. Major disadvantage of optical LANDSAT TM images for operational planning and monitoring is the frequent cloud coverage in tropical regions. The all-weather-capacity of SAR allows land surface mapping and monitoring under these conditions. ERS SAR images have the same spatial resolution as LANDSAT images (30m), however only one spectral channel. This limits the number of land use classes, which can be detected by this system to 8-12 classes. The ERS-1/2 receiving stations in Indonesia (Pare-Pare) and Thailand have recorded a set of ERS-1 images covering the whole province of Kalteng, which allows mapping of regions about which no recent optical information is available. Approximately 12 ERS SAR images are necessary to cover the whole peat area of Kalteng.

A two stage monitoring system will be established, in which ERS-SAR images are used for basic mapping, planning and monitoring purposes in the highly inaccessible **peat swamp** regions of Kalteng. The most important advantage of ERS-SAR satellites, compared to optical remote sensing systems, is the all weather capability. This opens up the possibility to receive a set of new images of e.g. the whole island of Kalimantan every month. Areas of interest can then be examined in more detail using conventional survey methodology, like high resolution LANDSAT TM images, aerial photography and ground survey. This procedure reduces time and money for survey, looking only on regions where unwanted changes could be detected.

Throughout the project the software package ENVI - IDL will be used for all image processing (installed on 586-Pentium computers with 133 MHz using WINDOWS NT or WINDOWS 95).

Main emphasis will be put on the applicability of all evaluation methods to the needs of the Indonesian partners. Thus the project will rely on software and computer equipment, which is already available at BPPT, BAPPEDA and BPN. In the framework of bilateral German-Indonesian projects officials in different authorities were already trained in analysing optical satellite data using the ERDAS IMAGINE and ENVI - IDL software package. Complete technology transfer will be achieved by close co-operation.

2. Remote Sensing in Kalteng

2.1 Image processing

a.) Processing of LANDSAT TM images:
For LANDSAT TM image processing well established methods are used. The following tasks are performed:

1. Image preparation (tape reading, file format conversion, basic enhancement)
2. Geometric correction according to BAKOSURTANAL maps (Peta Rupabumi Indonesia) and GPS measurements
3. Image enhancement, analysis of different TM band combinations
4. Identification of training areas (Sungai Sebangau)
5. Supervised classification
6. Final editing of classified images after ground truth evaluation
7. Map production
8. Plotting of maps
9. Photographic reproduction of LANDSAT image with CIRRUS Printer

b.) ERS SAR processing:
ERS-1 SAR PRI (GEC) data has been used. The data are read from Exabyte tapes using a public domain software tool provided by DLR Oberpfaffenhofen. This software allows calibration of the raw data towards $\sigma°$-values directly during data input from the tapes. Image processing are done in several steps:

1. Reading Exabyte tapes of ERS-1 GEC data
2. Calibration (and Geocoding) according to BAKOSURTANAL maps (Peta Rupabumi Indonesia) and GPS measurements
3. Reduction of the 16 bit data to 8-bit data in order to increase processing speed and data handling.
4. Mosaicking of 10 adjacent ERS SAR scenes will be done covering more than 100 000 km^2
5. Speckle reduction
6. Filtering and RGB image production
7. Principal component transform in order to identify temporal changes

8. Digital delineation of principal land use classes in two ERS-1 image sets (1994 and 1996)
9. Map production
10. Plotting of maps

All image processing steps and RGB image production are described in detail in several papers. In short enhanced mono-temporal images are produced by applying different texture filters to one ERS-1 scene. The results of three different filter operations are then combined into a single RGB colour image by assigning each texture feature to a different colour channel. From these RGB images land use maps will be produced in which each class is assigned a different colour in the GIS overlay.

2.2 Image classification

a.) LANDSAT TM images
LANDSAT TM images are interpreted be visual inspection as well as by semi-automatic classification schemes as the supervised classification. Preliminary results show that at least 15 vegetation types and land use classes can be discriminated in the available LANDSAT TM scenes as:

1. Peat swamp forests of several different types which differ in species composition, canopy structure, leaf colour, tree height etc.
2. Flooded swamp forest
3. Lowland *Dipterocarp* forest
4. Heath forest
5. Mangrove forest
6. Water hyacinths and floating grass
7. Alang-Alang grassland
8. Burnt forest
9. Shifting cultivation
10. Transmigrate areas
11. Bushland
12. Bare soil
13. Plantations
14. Water bodies
15. Settlements and roads
16. Selectively logged forest
17. Different intensities of logging

b.) ERS SAR images:
The proposed project relies on visual interpretation of optimised SAR-images, since until now no operational automatic classification procedure for SAR-images is known, which achieves the same accuracy as a skilled human interpreter. It is anticipated that the following vegetation types and land use classes can be classified in processed ERS SAR images:

1. Undisturbed primary forest of at least three types: Peat swamp forest on thin and thick peat layers and lowland *Dipterocarp* forest
2. Secondary forest.
3. Shifting cultivation and agriculture.
4. Alang-Alang grassland
5. Selectively logged forest.
6. Settlements and Transmigrate areas.
7. Clearcuttings for plantations
8. Water bodies

It is anticipated that it will be possible to discriminate different peat swamp forest communities according to their canopy structure, which is know to differ in leave size, leaf water content and canopy roughness. This will allow to estimate the depth of the peat layer. The results will be compared to LANDSAT classifications.
Radar backscatter is mostly influenced by the geometry of an object (roughness) and its humidity (dielectric constant). Different surface roughness has certain impacts to the backscatter characteristics and therefore to image texture. Unprocessed "raw" image show only topographic features and major water bodies. Without texture analysis it is difficult to classify even such simple features like forest - non-forest in this image. In processed ERS-1 SAR images it is possible to discriminate forest types due to the structure of the canopy.
From enhanced SAR-images and LANDSAT TM images land use maps at a scale of 1:100 000 will be created by visual delineation of detectable features and supervised classification. In ERS SAR images areas with a higher relief than 100 m will be excluded from the image interpretation process.

2.3 Signature analysis

A detailed signature analysis of the texture features in SAR images and each land use and vegetation class in LANDSAT TM images will be performed. This analysis will demonstrate the separability of the different classes and the temporal stability in the ERS SAR time series. Furthermore a quantitative comparison with results of the ground truth campaign will be conducted in several training areas.

2.4 Sensor fusion

The two data set used complement each other in spatial and spectral resolution and in availability. Sensor fusion will be performed :

1. in areas where clouds obscure LANDSAT TM images
2. in areas covered by peat swamp forest in order to test the ability of the radar sensor to discriminate forest types
3. in order to verify change detection information detected by the radar sensor. By overlaying ERS SAR GIS information on older LANDSAT TM images it will be possible to identify former vegetation covers and land use with high accuracy.

2.5 Change detection

a.) LANDSAT images:
In areas where two LANDSAT scenes are available supervised classifications will be compared quantitatively in order to identify changes in land use and vegetation cover.

b.) ERS SAR images:
To investigate change detection multitemporal RGB images will be produced by assigning the texture features of the earlier image to one channel, the texture features of the last image in the time series (5/93) to the second channel and the mean of all available speckle filtered images to the last channel. From these composite images change detection maps will be produced in which all major changes in land use patterns become evident.

By applying the principal component transform to processed ERS SAR images the change between two successive data sets will be quantitated. The principle component transformation reduces the amount of data significantly and highlights at the same time major land use changes in the 6th component. These changes are mainly related to new clearcuts and shifting cultivation.
In a third approach the two GIS layers (1994 and 1996) obtained by digital delineation of the enhanced ERS SAR images will be compared quantitatively. This gives detailed information about the changes of all land use classes during this two year period.

2.6 Geographical Information System -GIS

The results of the different image processing steps and the results of the ground truth will be stored in a GIS database (ARC-INFO format, which can be readily used by Indonesian authorities). The following tasks will be performed:

1. Planning and delivery of a general database for land use planning and monitoring in peat areas. It will consist of the following layers:
   1. Mapping level: optical LANDSAT TM images serve as a basis for vegetation and land
      use mapping, (if available), scale 1:50 000 or 1:100 000
   2. Monitoring level : ERS SAR images serve as a basis for change detection monitoring ,
      scale 1:100 000
   3. Geographic maps: peat depth, agricultural potential, soil types, forest types, infrastructure, settlements
2. All available ground truth and helicopter information will be stored in a separate layer
3. The different levels of this database will be analysed separately and combined for planning purposes

2.7 Recommendations, Thematic Maps, Reports, Workshops

1. Report in English containing
    - a description of all applied methods
    - a description of all vegetation types and land use classes relevant to LANDSAT TM and ERS SAR images
    - ecological evaluation of the peat area
    - high resolution DIN A4 video prints of processed LANDSAT ERS SAR images
2. Recommendations for the establishment and conduction of the SAR monitoring system
3. Maps:
    - 12 map sheets at a scale of 1: 100 000 showing a land use classification derived from ERS SAR images
    - 4 map sheets at a scale of 1: 200 000 showing land use changes between 1994 and 1996 as derived from ERS SAR images
    - 8 map sheets at a scale of 1: 100 000 showing a land use classification and forest types derived from LANDSAT TM images
    - 2 map sheets at a scale of 1: 00 000 showing peat depth as derived from a combined analysis of LANDSAT TM and ERS SAR images and ground truth
4. Various LANDSAT TM and ERS SAR image photographs

2 one week Workshops on LANDSAT and ERS SAR image processing can be procured.

3 Viewgraphs
3.1 Available Satellite-Images to Kalteng Consultants

Different LANDSAT 5 Thematic Mapper images with 30m x 30m resolution and 180km x 180km res. 90km x 90km were selected and ordered.

- LS TM 118-061 from 30th of June 1991 (northern area of Palangkaraya)
- LS TM 118-062 from 30th of June 1991 (southern area of Palangkaraya
- LS TM 118-062 from 24th of July 1994 (southern area of Palangkaraya)

- LS TM 118-062 quarter image No. 5 from 8th of July 1994
- LS TM 119-060 quarter image No. 4 from 18th of October 1988

- LS TM 120-061 quarter image No. 4

In the northern area of Palangkaraya two ERS-1 SAR images (an ESA product) of a 12.5 m x 12.5 m resolution; (each 100 km x 100 km, 5.3 GHz, C-Band) were available

- ERS-1 Orbit 9438 from 6th of May 1993 frame 3645
  (northern area of Palangkaraya)

- ERS-1 Orbit 9438 from 6th of May 1993 frame 3627 (eastern area of Schwaner Mountain)

During the Space Shuttle mission in April 1994 one strip of Kalimantan was monitored. (9.6 GHz, X-Band of a 25 m x 25 m resolution; approx. 25 km x 100 km at Banjarmasin).

- X-SAR from 17th of April 1994 17:15:49

3.2 Image Enhancement

Contrast stretching:
linear, 2%, equalisation, Gaussian, Square Root Min

Filtering:
Convolution:
High Pass, Low Pass, Laplacian, Gaussian, Median, Sobel, Roberts

Texture Filters:

Adaptive Filters:
Lee, Frost, Gamma, Kuan, Local Sigma, Bit Errors

FFT Filtering:
Forward FFT, Inverse FFT, Filter definition

3.3 Image Classification

supervised and unsupervised classification
Threshold Class.
Hyperbox Class.
Minimum-Distance
Mahalanobis-Distance Class.
Maximum-Likelihood Class.
Region of Interest (ROI) -Texture Class.
Spectral Angle Mapper (SAM) Class.
Neuronal Net (Fuzzy Logic)
ISODATA

3.4 Change Detection Techniques

Various procedures have been proposed and used to detect changes in land use or land cover from LANDSAT or ERS multitemporal data. The fundamental assumption is that any changes in land cover will result in changes in reflectance values which are sufficiently large to monitor despite other parameters.

1. A side-by-side comparison of two multitemporal satellite images (LANDSAT or ERS1)
2. Overlay of one LANDSAT band only,
    e.g. RGB: band 4 for 1994(red); 1991(green) and blue zero.
3. Overlay of one LANDSAT band for two different times only,
    e.g. RGB: band 2 for 1994(red); 1991(green) and again 1994 (blue) .

Note: The change detection technique using image overlay first a passpoint process with Ground Control Points, GCP, called image-to- image warping, has to be apply for one of both image.

3.5 Supervised classification

3.5.1 Classes of Kalimantan-Tengah around Palangkaraya:

1. Clear Cuts, Shifting cultivation	**Kahlschlag, Brandrodungsbau**
2. Peat Swamp Forest 1 (PSF)	**Torf Sumpf Wald 1**
3. Peat Swamp Forest 2 (PSF)	**Torf Sumpf Wald 2**
4. River under trees	**Fluß unter Bäumen**
5. Dig at YUM	**Graben bei YUM**
6. YUM	**YUM**
7. Gravel/Podsol	**Kiesgrube/Quartz**
8. Street, Road	**Straße, Wege**
9. Tangkiling Granite	**Tangkiling Granit**
10. Alang Alang	**Gras, Farn**
11. River Rungan	**Fluß Rungan**
12. Settlement Sei Gohong	**Siedlung Sei Gohong**
13. Brushland	**Buschland**
14. Transmigration	**Transmigranten 3 years**
15. Clouds/Shadows	**Wolken/Schatten**
16. Logging Road	**Holzfällerweg**
17. Fire, smoke, dust	**Feuer, Rauch, Dunst**
18. Swamp areas	**Überschwemmungsgebiete**
19. Plantage; Horticulture	**Plantagen; Gemüseanbau**
20. Heathforest	**Heidewald**
21. Logging-rails	**Forst-Eisenbahnen**

3.5.2 after Jack Rieley: Peat Swamp Forest, PSF
(Torf Sumpf Wald)

a riverine sedge swamp (RSS)
b. mixed swamp forest (MSF)
c. low pole forest (LPF)
d. tall interior forest (TIF)
e. degraded forest

LANDSAT TM-Canals:
Red, Green, Blue: 7, 4, 1 or 5, 4, 2 are good compared to the visible canals 3, 2, 1
Arbitrary Profiles (Transect-Function) is good, for spectral analysis
3.5.3 Soiltyps after Dr. G.Sieffermann:

Dominant Soil Material

1. **Xanthic ferralsol on granite (Tangkiling granite)**
2. **Podzol, with thin humus layer on white quartzsand**
3. **Organosol, high position, 0.5 to 1m thick peat, on white quartz sand, permanent water level in peat**
4. **Organosol, high position, thick peat >1m, no clay content, permanent water, level in the peat**
5. **Hydromorphic Fluvial, yellow-brown clayey soils, generally not flooded**
6. **Gleyic Fluvisol, grey clayey soils, flooded in the rain saison**
7. **Basin Organosol, thickness >1m,, some clay content, surface flooded more than 4 month/year**
8. **Basin Organosol, thickness >1m,, very low clay content, surface flooded more than 6 month/year**
9. **Basin Organosol, thickness >1m,, no clay content, surface flooded more than 6 month/year**
10. **Basin Organosol, thickness >1m,, low clay content, surface flooded more than 6 month/year**

Main agronomic suitability:

1. **Moderately good**
2. **Heath forest**
3. **Lower canopy forest**
4 a. **High canopy forest**
4 b. **Low canopy forest**
5. **Good for food crops**
6. **Suitable for food-crops in the dry saison**
7. **High canopy forest**
8. **High canopy forest**
9. **Pole forest, low canopy**
10. **Low scrub vegetation, burning most year**

The colour-coded result of the supervised maximum likelihood classification of Palangkaraya region is shown in the figures.

3.5.4 Other classifications can be done accordingly:

1.) closed forest/not burnt (crown closure 100% - 75%),
2.) mangrove forest,
3.) lightly burnt forest (crown closure 75% - 60%),
4.) medium burnt forest (crown closure 60% - 40%),
5.) heavily burnt forest (crown closure 40% - 10%),
6.) swamp forest,
7.) coastal forest,
8.) shrubland with single trees,
9.) lowgrowth,
10.) freshly burnt area,
11.) agriculture,
12.) alang- alang,
13.) grazing,
14.) swamps,
15.) urban area,
16.) heavily sediment loaded water,
17.) sediment loaded water,
18.) deep sea water,
19.) clouds,
20.) cloud shadow.

Ground truth measurements are always necessary.

4. Conclusion

Kalteng Consultants can give expertise in the following area:

Biodiversity and Forestry
Environmental Helicopter
Geology
GIS
Hydrology
Land Use Planning
Peatland Analysis
Remote Sensing
Soil Analysis

The most important applications of the proposed project will be the identification of arable land in areas covered by peat in Kalimantan Tengah. Peat is a natural resource which has to be managed carefully if agriculture is planned. It is well established that rice does not grow well if the peat layer is more than 1-2 meter deep. In the light of the project recently proposed by president Soeharto to cultivate 1 Million Hectare of swamp land in Kalteng it is very important to know **the depth of the peat layer** before assigning land for agriculture.
With the help of two complementary Remote Sensing data sets it is planned to determine the depth of the peat in the proposed area for rice production as well as in other parts of Kalteng. Preliminary results show that it is possible to determine the type of peat forest from processed LANDSAT TM images and it is anticipated that this will be also possible from enhanced ERS SAR images. This allows to map all the forests growing on peat in Kalteng since the SAR sensor is weather independent and SAR images are available on a monthly basis.

Extensive field work showed that if the forest type is known in many cases it is possible to infer peat depth. Using Remote Sensing this will facilitate planning and save money by reducing the amount of time invested in ground exploration and mismanagement due to lack of reliable data.
Major result of this work package will be maps of all texture for agriculture at a scale 1:100 000 produced from space images, which indicate peat depth, forest type and the potential for agriculture.
Examples of images analysis and interpretation has shown the viewgraphs of this presentation.
For a selected PSF-area Kalteng Consultants can prepare detailed image classification from LANDSAT and or ERS 1+2 satellite images in this tropical rainforest region. PSF-types, - canopy structure and -depth associated with soil-types can be prepared in the research area near Sungai Sebangau in combination with Ground truth campaigns.
Multitemporal and Multispectral Image Analysis is the goal over a longer period.

The following image processing methods will be used: Image statistic (greylevels, histograms, variance, CO-variance), RGB, NDVI (Vegetation Index), Hyperspectral Analysis with Z-Profiles
Image enhancement: filtering, contrast stretching: linear, 2%, equalisation, Gaussian, Square Root Min,
Image Classification: Supervised (Maximum Likelihood Class, Minimum Distance Class., Spectral Angle Mapper, Mahalanobis Distance Class., Neural Net Class.)
Unsupervised (IsoData Class.)
Image Fusion, Change Detection, GCP, Warping, RST, Mosaicking, Geocoded Mappings, UTM and Printing.
The results are thematic and geocoded maps with grids, annotations using a GIS.
The quality is much better than existing maps from Kalteng.
An important factor is the transfer of Remote Sensing Technology to Indonesia.

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