QUANTIFYING DEFORESTATION IN A PERMANENT FOREST RESERVE USING VECTORISED LANDSAT TM

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KAMARUZAMAN, J. & SETIAWAN, I. 2003. Quantifying deforestation in a permanent forest reserve using vectorised Landsat TM. Vectorising Landsat TM image (127/56 path/row) was carried out in this study to quantify deforestation using integration of remote sensing and geographic information system (GIS) in Permanent Forest Reserve (PFR) of northern Kelantan, Malaysia (latitudes 04° 30' N to 06° 15' N and longitudes 101° 20' E to 102° 40' E). The PFR boundary map in 1989 was digitised to analyse physical factors that affect deforestation. By using minimum distance supervised classification, Landsat TM is an effective tool for distinguishing forested area from non-forested area such as rubber, oil palm and paddy with overall accuracy of about 84.8% and mean accuracy of between 58.3 and 97.7%. The rate of deforestation was about 2.3% per year with 73 236 ha of the PFR in the northern part of Kelantan being converted into non-forested purposes within eight years (1989–1997). The change from forest into mixed crop or rubber within eight years was estimated to be 19 252.1 ha. However, 53 984.1 ha of forest were converted into shrubs, while approximately 1178.5 ha of forest were converted into grassland/open areas. This study implies that RS/GIS technique is a useful tool in quantifying deforestation in PFR.

Key words: Remote sensing - GIS - forest conversion - supervised classification

KAMARUZAMAN, J. & SETIAWAN, I. 2003. Penilaian pelupusan hutan di dalam hutan simpan kekal menggunakan Landsat TM yang divektorkan. Landsat TM (127/56 jalur/baris) yang divektorkan digunakan dalam kajian ini untuk menilai pelupusan hutan dengan mengintegrasikan penderiaan jauh dan sistem maklumat geografik di Hutan Simpan Kekal (PFR) di utara Kelantan, Malaysia (garis lintang 04° 30' U ke 06° 15' U dan garis bujur 101° 20' T ke 102° 40' T). Peta sempadan PFR berkenaan yang diterbitkan dalam tahun 1989 telah didigitalkan dan digunakan untuk menganalisis ciri-ciri fizikal yang mempengaruhi pelupusan hutan. Landsat TM merupakan alat yang menggunakan klasifikasi seliaan jarak minimum untuk membezakan kawasan hutan daripada kawasan bukan hutan seperti getah, kelapa sawit dan padi dengan ketepatan keseluruhan sebanyak 84.8% dan ketepatan purata antara 58.3% hingga 97.7%. Kadar pelupusan hutan adalah lebih kurang 2.3% setahun dengan 73 236 ha daripada PFR di utara Kelantan ditukar kepada kegunaan bukan hutan dalam masa lapan tahun (1989–1997) dengan anggaran 19 252.1 ha. Bagaimanapun, 53 984.1 ha hutan telah ditukar kepada belukar manakala 1178.5 ha hutan telah ditukar kepada kawasan terbuka atau padang rumput. Kajian ini menunjukkan bahawa teknik penderiaan jauh/sistem maklumat geografik merupakan satu alat yang berguna untuk menilai pelupusan di PFR.

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Introduction

Forested areas of Peninsular Malaysia cover 5.8 million ha which is equivalent to 44% of the land area. From the total forested areas, 5.3 million ha are designated as Permanent Forest Reserve (PFR) or Wildlife Reserve, including Taman Negara (The National Park) (Anonymous 1993). It plays an important role in the ecological environment of the country. The function of tropical rain forest is not only limited to timber production but also environmental stability, erosion control and provision for the numerous social needs and has largely contributed to its socio-economic development. The present area, however, has been extensively cleared mainly for conversion into agricultural lands, mining activities, recreational as well as industrial development and indiscriminate logging, especially in the lowlands where only patches of primary forest remain.

Environmental degradation, resulting from economic and social activities of growing population, has increased lately. Environmental problems including deforestation, soil erosion, salinity, prolonged drought and floods have become increasingly recognised in the past 20 years. Environmental conservation and restoration have become important in government policy in almost every country. The dimensions of conservation and restoration action vary considerably according to the local situation and are largely determined by the available resources. Amelioration approaches that are being addressed include revegetation, rehabilitation, management system, establishment of protected areas and control of forest encroachment (Pinoyopursrek 1998).

Remote sensing and GIS have become important tools for forest inventory and monitoring. Forest inventory is the procedure for obtaining information on the quantity and quality of forest resources and characteristics of the land area. Monitoring change in forest resources is done to maintain current inventories, test the implementation of policies and analyse trends for planning purposes. Today, forest degradation is becoming a major problem threatening the sustainability of forest and its productivity potential. As of end 1989, approximately 4.6 million ha of degraded secondary forests existed and were distributed all over the country (Kamaruzaman & Ibrahim 1994).

The general objective of this study was to assess the usefulness of integrating remote sensing data and GIS quantifying deforestation in Kelantan, Malaysia. The specific objectives of the study were to quantify the extent of PFR and to map out deforestation.

Materials and methods

Study area

Kelantan is one of the 14 states in Malaysia. This state which is richly endowed with natural resources covers a land area of about 15 000 km^2. It is located in the northeast of Peninsular Malaysia facing the South China Sea. Kelantan is covered with almost 60% of forest, that is situated within latitudes 04° 30' N to

06° 15' N and longitudes 101° 20' E to 102° 20' E (Figure 1). The total land area of Kelantan is approximately 1 493 181 ha. Of this, 894 276 ha are forested areas where 626 372 ha are forest reserves and the remainder are state land forest and Taman Negara. This implies that 60% of total land in Kelantan is still forested with 42% under forest reserve (Anonymous 1993).

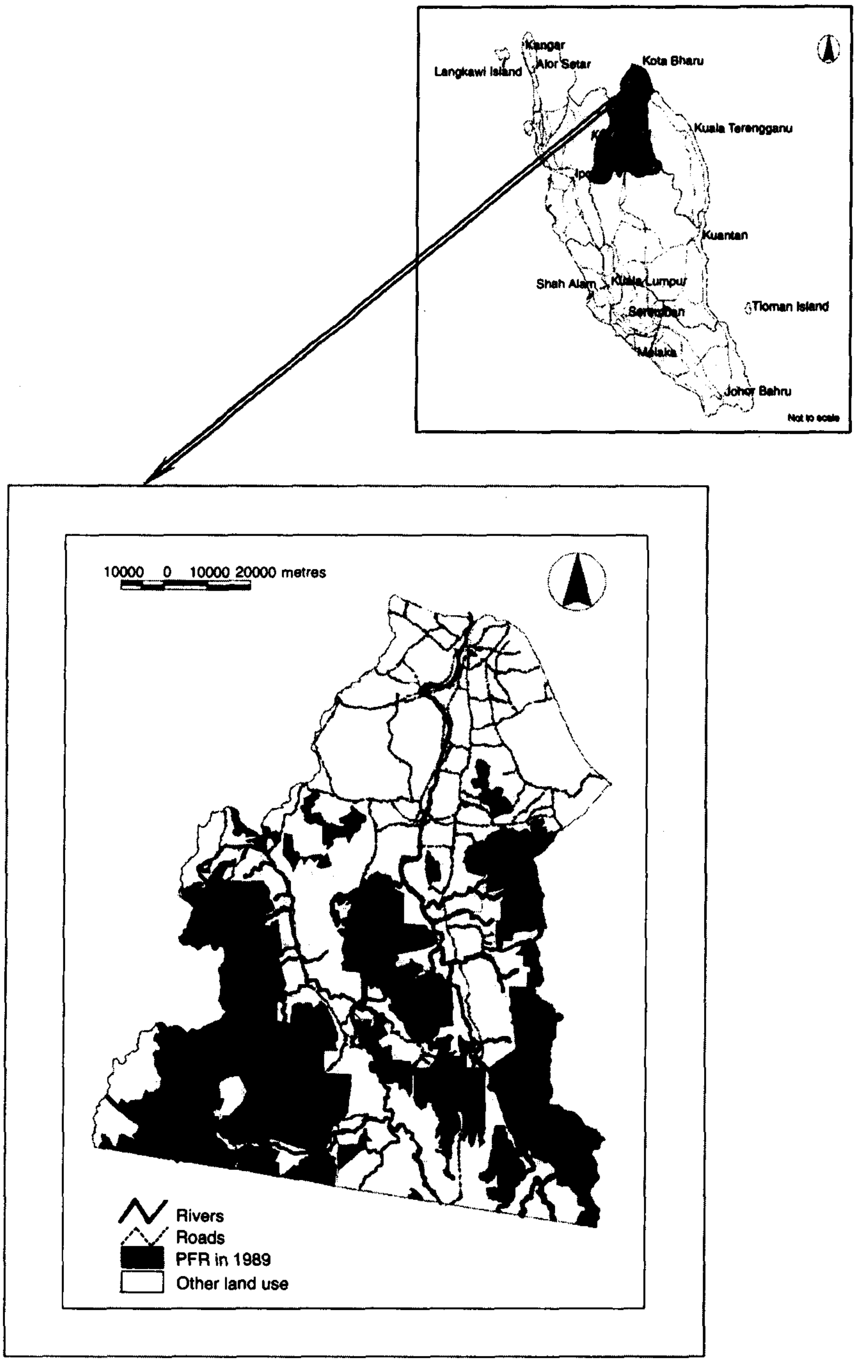

Figure 1 Map of Peninsular Malaysia showing northern Kelantan as the study site

Imagery

The primary data used in this study were a set of Landsat TM images of 1997 acquired on 13 June 1997 from the Malaysian Centre for Remote Sensing (MACRES). The image was geometrically corrected by MACRES. The geometric correction process involves identifying the image co-ordinates (i.e. row, column) of several clearly discernible points, called ground control points (GCPs), in the distorted image and matching them to their true positions in ground co-ordinates (e.g. latitude, longitude). The true ground co-ordinates are typically measured from a map, either in paper or digital format. This is called image-to-map registration. Once several well-distributed GCP pairs have been identified, the co-ordinated information is processed by the computer to determine the proper transformation equations to apply to the original (row and column) image co-ordinates to map them into their new co-ordinates. Geometric registration may also be performed by registering one (or more) images to another image, instead of to geographic co-ordinates. This is called image-to-image registration and is often done prior to performing various image transformation procedures.

Ancillary data

Additional data were obtained from the Department of Forestry, Kelantan and Agriculture Department. The ancillary data used were as follows:

- Permanent Forest Reserve map published in 1989
- Landuse map of 1990

Methodology

Ancillary data such as the 1989 Permanent Forest Reserve map published by Kelantan Forestry Department was digitised manually using A0 size digitiser table and geographic information system software. The satellite image data were interpreted using both digital and visual image analysis using a remote sensing software. To quantify the change from forest to other land cover, the clipped vectorised classified image of 1997 (127/56 path and row) was overlaid with digital map of PFR in 1989. Before vectorising, the classified image had to be registered for dataset header, datum, projection, types of co-ordinate, units and co-ordinates in order to overlay with the digital map. Vectorised image was exported from ER Mapper format (erv) to autocad format (dxt) and finally converted to ARC/INFO format for GIS analysis and to quantify deforested area inside the PFRs in the northern part of Kelantan.

Results and discussion

Kelantan state consists of two mosaic scenes of Landsat TM image, i.e.127/56 path and row for the northern part and 127/57 path and row for the southern part.

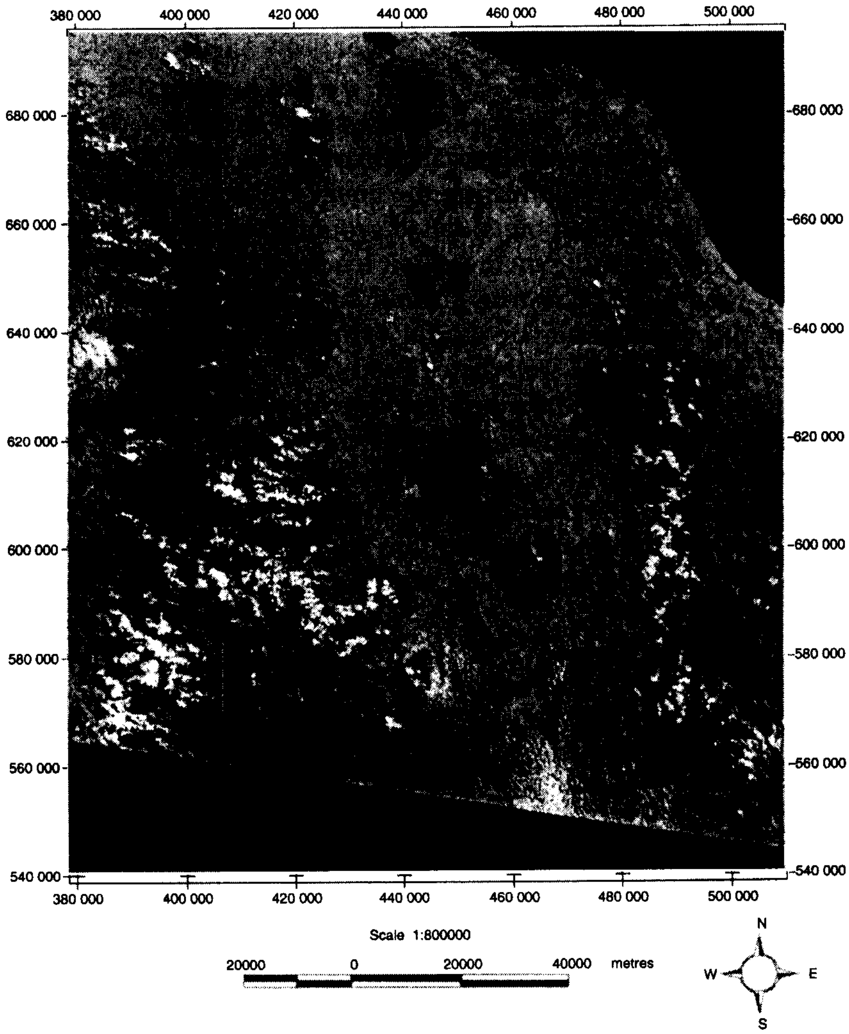

Figure 2 Landsat TM image (127/56) of the northern part of Kelantan

However, in this study, image processing was conducted only on the northern part image of Kelantan (scene 127/56) covering north, west and a small portion of south Kelantan. This part covers about 70.0% of the total land or 64.3% of the total PFR in Kelantan (Figure 2).

Isodata classifier was performed on the unsupervised classification of the image data. The results from the isodata are presented in Figure 3. From the unsupervised classification, seven classes were automatically selected using this algorithm with 100 iterations. Isodata are useful when the number of clusters to use is not certain. It will give some control over the number of cluster that will be generated by allowing specification of the minimum and maximum numbers of cluster. Unsupervised classification was performed in order to examine large numbers of data to divide them into classes based on natural grouping of the original Landsat/ SPOT data. In this classification, ground truth data were not used.

Figure 3 Unsupervised image classsification for deforested area of northern Kelantan with mode filtering using isodata classifier

From the additional information acquired from the field and with a 1990 landuse map and unsupervised classification, the supervised classification image was performed on the Landsat TM. For this purpose, training samples that were taken from the Landsat TM image were first selected from various land cover types such as forest, rubber, oil palm, settlement or cleared land (open area). The training stage was where the process was supervised by locating (in video) pixels, which are examples of each land cover that is to be classified or detected. These trained pixels were determined from previously prepared map, ground-truth visits to the scene or familiarity with the location. The training areas for this classification were selected from inventory maps (PFR maps) after careful examination of topographic maps, landuse map and information collected on site and related literature. By using minimum distance algorithm, eight classes were identified from the image as shown in Figure 4.

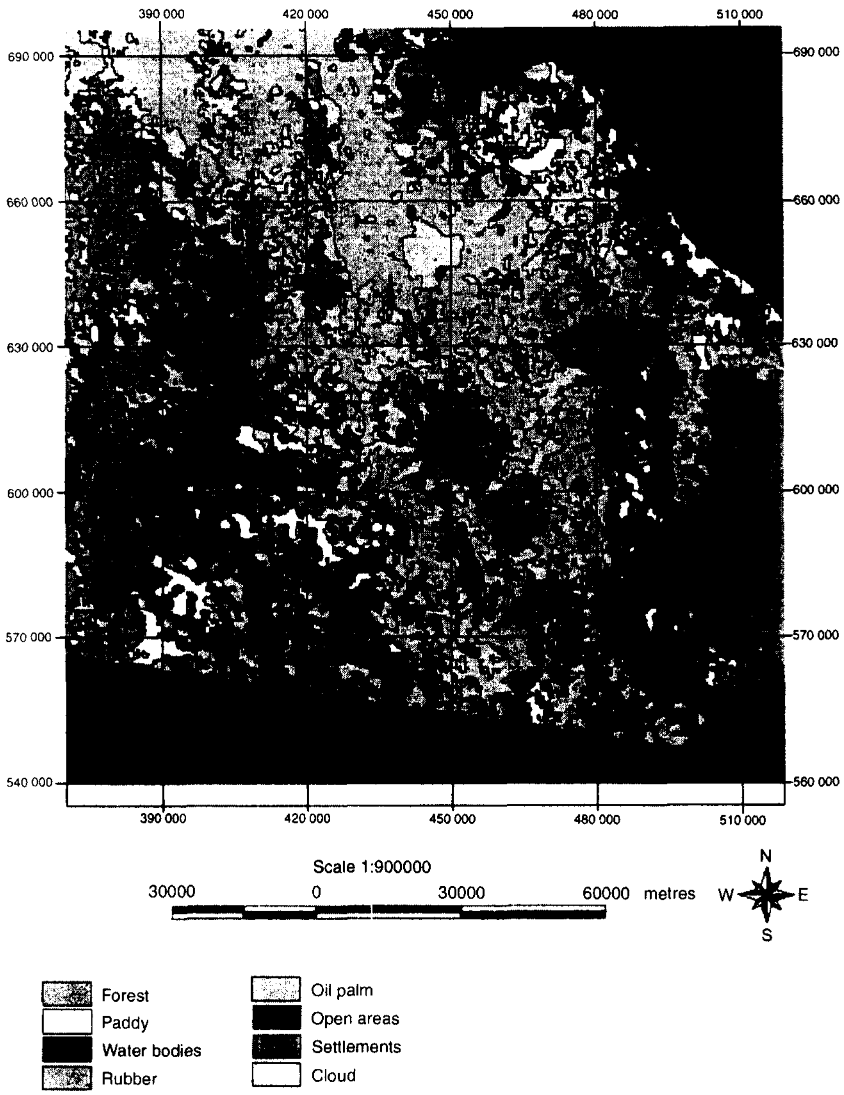

Figure 4 Eight classes of supervised classified image using minimum distance algorithm and more filtering technique

Using the confusion matrix, the overall accuracy and the average accuracies by classes are shown in Table 1. A confusion matrix contains information on actual and predicted classifications done by a classification system. Performance of such system is commonly divided by the total number of pixel number in the matrix.

Table 1 Confusion matrix of minimum distance classification algorithm

Item	Total pixel	Forest	Water body	Paddy	Oil palm	Rubber	Open area	Settlement	Cloud
Forest	3 526	76.32	69.90	0.14	0.00	0.6	0.00	0.00	0.00
Water body	9 634	0.29	69.90	29.81	22.91	0.00	0.00	0.00	0.00
Paddy	848	0.00	2.36	97.64	0.00	0.00	0.00	0.00	0.00
Oil palm	2 059	2.19	0.00	0.00	97.72	0.10	0.00	0.00	0.00
Rubber	1 915	0.00	0.00	0.00	2.98	97.02	0.00	0.00	0.00
Open area	2 367	0.00	0.00	0.00	0.04	4.27	60.08	35.61	0.00
Settlement	223	0.00	0.00	0.00	0.00	1.35	40.36	58.30	0.00
Cloud	25 595	0.02	0.02	0.07	0.03	0.00	2.16	6.08	91.60

The overall accuracy performance of the Landsat TM image data was 84.8%. Most of the individual classes had a classification accuracy of more than 69.0%, except for settlement (58.3%) and open area (60.1%). Examining the confusion matrix individually, it could be seen that the minimum distance classification had a high accuracy ranging from 58.3% for settlement to 97.7% for oil palm. Minimum distance gave the highest accuracy for oil palm trees because they could be easily detected by image characteristics and the training areas in image which were not mixed with other land cover. For settlement and open areas, minimum distance gave the lowest accuracy because it was confused by the same texture and tone of both land cover.

Fourty-eight sample points were chosen randomly during ground verification. A total of 62.5% was correctly interpreted from the Landsat TM image. Compared with the classified image from Landsat TM, the results from ground verification are shown in Table 2. It was realised that shrub and mixed crop were misclassified as oil palm or rubber. This is due to the spectral reflectance of oil palm or rubber, which is almost similar to shrub or mixed crop. In the classification process, shrub and mixed crop were classified as oil palm or rubber. However, forest, water bodies, open areas and paddy can be easily identified because of their different reflectance characteristics.

In this study, filtered classified image in raster data was converted to vector data. Vectorising was done based on class-by-class that were already classified as shown in Figure 5. Raster to vector conversion, sometimes called vectorisation, is

Table 2 Accuracy check from ground truthing/verification

Land cover	Sample number	Correct	Percentage
Oil palm	13	3	23.08
Rubber	13	6	46.15
Forest	15	15	100.00
Open area	6	5	83.33
Settlement	1	1	100.00
Total	48	30	62.50

converting data from a raster data structure to a vector data structure. Raster data structure is very efficient for spatial analysis, overlay analysis and location data retrieval. However, raster system has difficulties in accurately depicting information due to the very nature of its construction. The cells which make up a digital image are not pure. The information content of a particular cell often does not represent a single object or land cover. Very often, the single grey level of a cell represents a combination of land cover on the ground. This is particularly the case along the boundaries of objects. Boundaries are abstract; they exist as a result of the juxtaposition of two objects. Boundaries have no width. They have length and direction. In other words, they are vectors and as such can only be accurately represented by vector structures. Vector data are a valuable complement to image data, both as an analysis tool and as a way of making results more understandable (Anonymous 1997). Raster to vector is an especially valuable feature for extracting timely information from satellite images to quickly update vector-based information stored in GIS product.

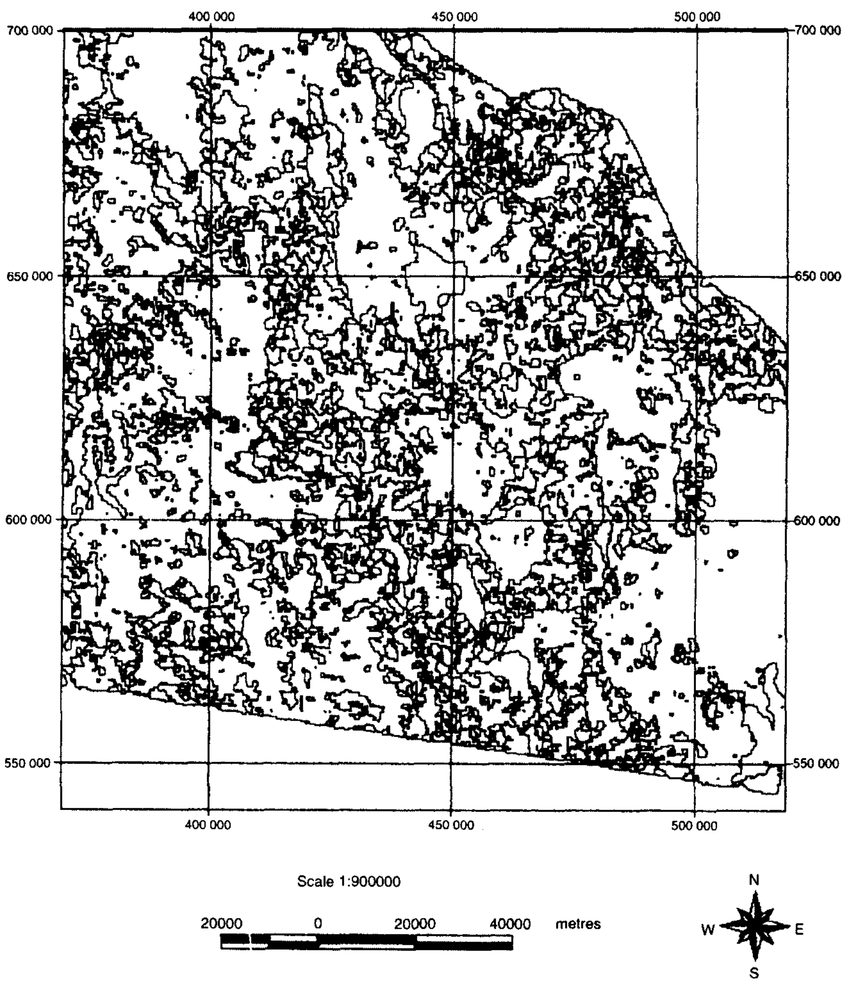

Figure 5 Vectorising of supervised classified image

Data from the digitised map of PFR in 1989 (Figure 6) and clipped vectorised classified image of Landsat TM in 1997 showed that the total extent of PFR of 1989 in northern Kelantan was about 402 585.4 ha compared with 329 349.2 ha in 1997 (Table 3). The area extent of the total PFR loss was 73 236.2 ha in eight years (from 1989 till 1997). About 18.2% of the total PFR was lost within eight years and the average forest lost per year can be as high as 2.3%. Deforestation almost occurred in every PFR from west to south Kelantan where the highest deforestation occurred in Sungai Satur (2478.0 ha or 97.7% PFR loss from the total) in west Kelantan followed by Sungai Terah PFR (1559.9 ha or 36.8%) in south and Sungai Sam PFR (2645.1 ha or 61.0%) in east Kelantan (Figure 7).

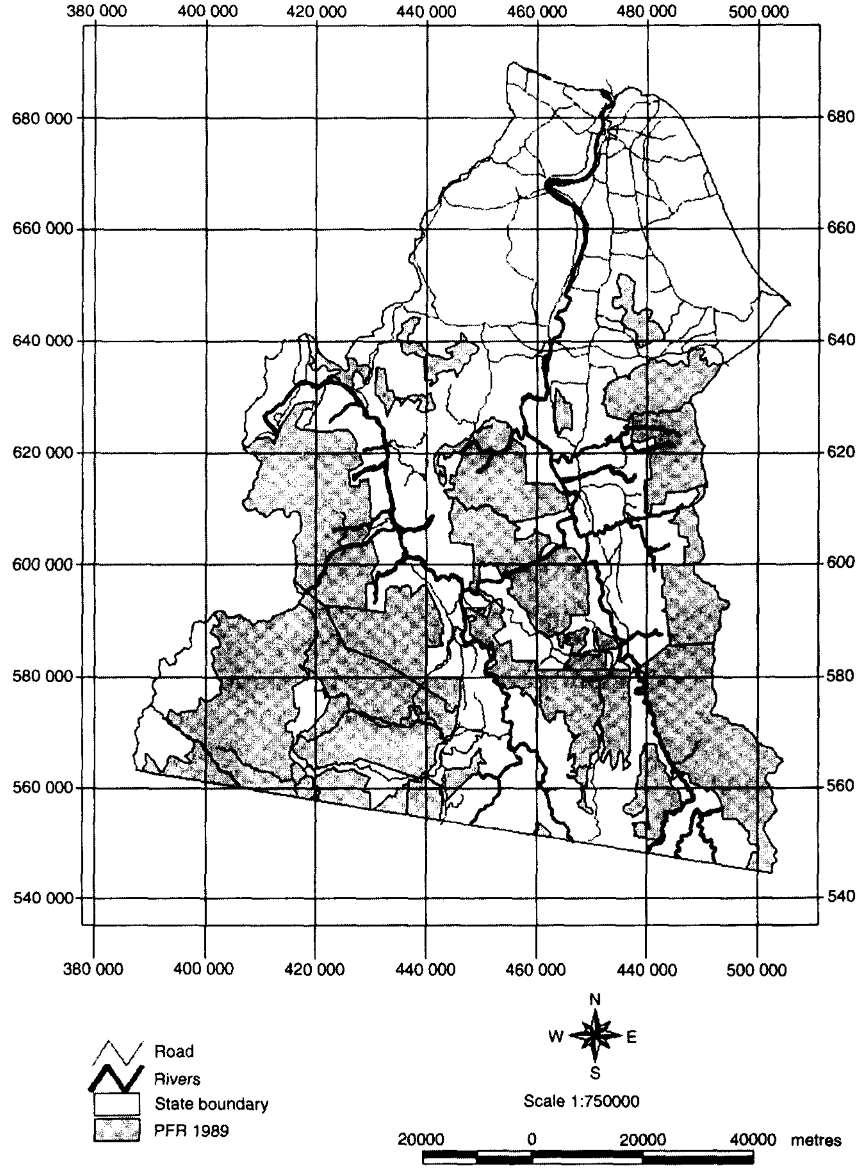

Figure 6 Vectorising of supervised classified image

Table 3 The area extent and loss of permanent forest reserve in the northern part of Kelantan based on a 1989 digitised map and 1997 Landsat TM image

PFR	PFR in 1989	PFR in 1997	PFR loss (ha)	PFR loss (%)
Sungai Satur	2 536.85	58.89	2 477.96	97.68
Bukit Akar	925.72	213.53	712.19	76.93
Jeli	3 266.26	865.05	2 401.21	73.52
Jedok	4 875.62	1 486.52	3 389.09	69.51
Sungai Sam	4 339.37	1 694.27	2 645.10	60.96
Sungai Terah	4 243.82	2 683.90	1 559.92	36.76
Cabang Tongkat	5 005.29	3 166.05	1 839.24	36.75
Gn. Stong Tengah	23 853.59	15 217.69	8 635.90	97.68
Limau Kasturi	2 348.97	1 514.56	834.41	35.52
Serasa	8 982.64	6 043.09	2 939.55	32.72
Temangan	1 688.00	1 171.66	516.34	35.52
Relai	31 233.56	22 610.36	8 623.21	27.61
Sokor Taku	21 156.77	15 781.34	5 375.43	25.41
Jentiang	14 016.35	11 109.01	2 907.34	20.74
Gn. Setong Selatan	28 081.20	22 937.03	5 144.17	18.32
Berangkat	19 773.87	16 169.95	3 603.92	18.23
Gn. Stong Utara	9 833.51	8 070.11	1 763.40	17.93
Nenggiri	7 662.07	6 346.46	1 315.60	17.17
Balah	53 517.06	46 553.01	6 964.05	13.01
Perias	6 103.61	5 468.07	635.54	10.41
Ulu Sat	15 146.94	13 990.21	1 156.73	7.64
Sungai Rek	16 159.73	14 945.18	1 214.55	7.52
Lebir	45 582.47	42 573.64	3 008.83	6.60
Gunung Basor	40 764.33	38 210.80	2 553.53	6.26
Chiku	523.99	494.33	29.66	5.66
Sungai Durian	15 239.52	14 590.69	648.83	4.26
Ulu Temiang	15 724.29	15 383.83	340.46	2.17
Total	402 585.39	329 349.23	73 236.16	18.19

The deforestation rate here is on a higher side compared with that of the world. The rates of deforestation in Southeast Asian countries in 1981–1985 were 0.3% (Cambodia), 0.5% (Indonesia), 1.2% (Lao PDR), 0.7% (Philippines), 2.4% (Thailand) and 0.6% (Vietnam). The average deforestation rate in Amazonia in the 1980s was 1.2% per year (Anderson 1993) while in some states of Brazil higher at 6% (Repetto 1988). The results from the classified image and field data showed that a high intensity of deforestation had occurred which includes conversion from forest into shrubs (53 984.1 ha), from forest into mixed crop or rubber (19 252.1 ha) and from forest into grassland (1178.5 ha).

The distribution of deforested area was analysed in relation to distribution of roads and rivers. From the analysis (road and river buffers), most deforestation occurred closed to the readily available infrastructure such as roads and rivers. Deforestation area was located in a radius of 1 km from the road, river or both (Figure 7). The number of deforested areas decreased when the distance from the road, river or both increased. Forest accessibility, thus, plays an important role in supporting the presence and extent of deforestation. Normally, when the disturbed forest is located within the logging concession areas, some deforested areas accompany the cutting block or harvesting block movement. This suggests that forest reserves closer to roads and rivers are prone to be deforested compared with forest farther away.

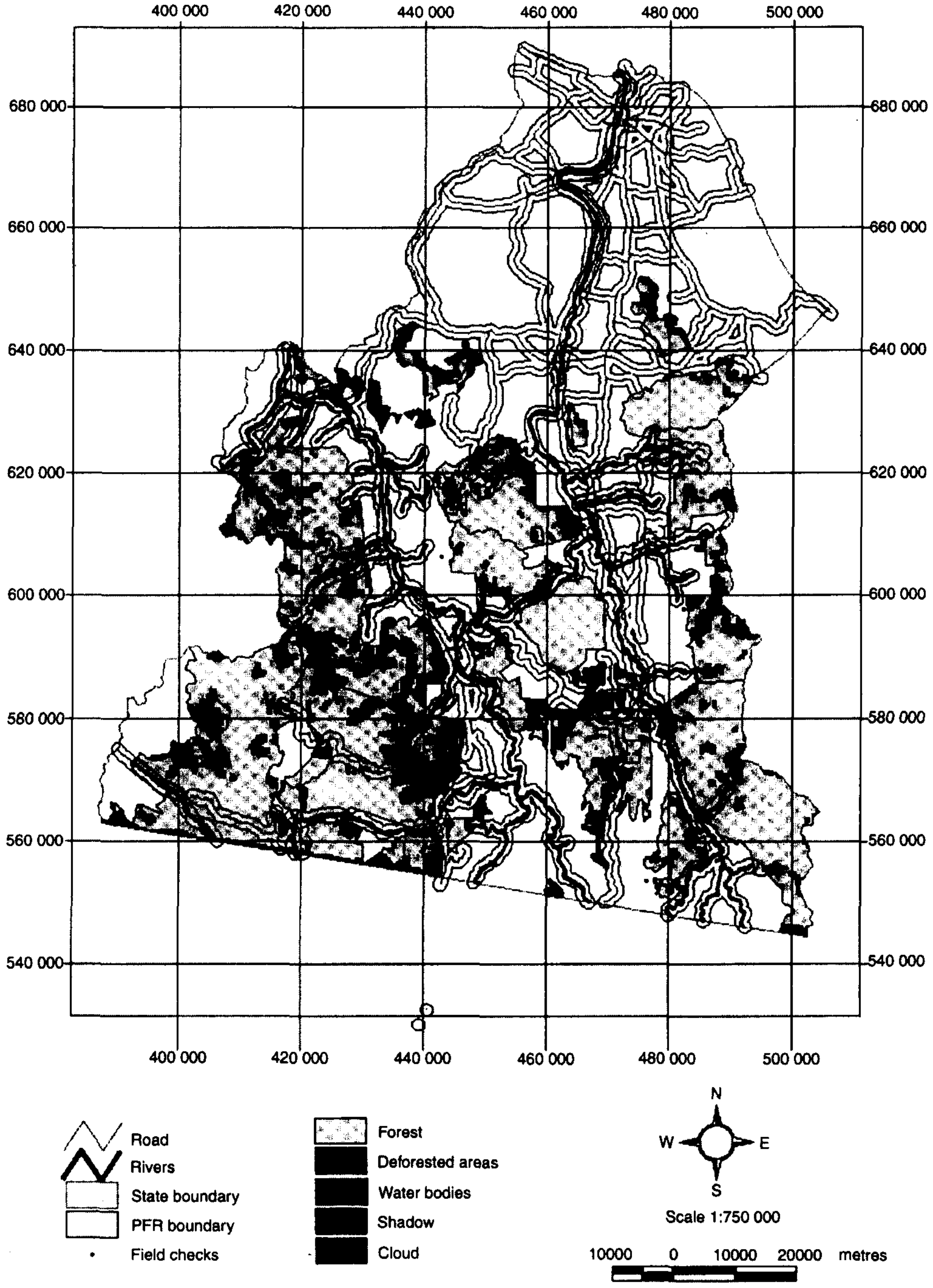

Figure 7 Map of deforestation and GIS analysis of deforestation in relation to rivers and roads in northern Kelantan (1989–1997)

Conclusions

Raster data have difficulties in accurately depicting information due to the very nature of their construction. This study shows that vectorised image is a valuable complement to image data, both as an analysis tool and as a way of making results more understandable. Vectorising images (raster data) is an especially valuable feature for extracting timely information from satellite images to quickly update vector-based information stored in GIS product.

Based on the vectorised supervised classification of Landsat TM image of 1997, the area extent of PFR in northern Kelantan was about 32 349.2 ha. The rate of deforestation was 2.3% per year. The PFR's area extent declined from 402 585.4 ha in 1989 to 329 349.2 ha in 1997. The exercise clearly showed that about 73 236.2 ha of PFR had been converted into non-forestry purpose in eight years (1989–1997) in northern Kelantan. The change from forest into mixed crop or rubber within eight years was estimated to be 19 252.1 ha, from forest into shrubs about 52 984.1 ha and from forest into grassland/open areas about 1178.5 ha.

Deforestation was mostly located close to transportation features like roads, logging roads and rivers. The accessibility of the forest plays an important role in supporting the present extent of deforestation. Deforested areas were mainly located in a radius of 1 km from the roads, rivers or both.

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