Integration of Remote Sensing and GIS to Land-use/Land-cover Change Detection in the Chiang Mai Area Northern Thailand: A Case Study from the Doi Saket district

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Abstract The documentation of land cover change, from before times of rapid economic development is part of the spatial data information infrastructure support needed to administer the Royal Thai Government 8th Five -Year National Economic and Social Development Plan (1997-9002). Accordingly, the air photo archive is immediately relevant. The technical challenge facing those intent on using it lies in georeferencing, and in integration of land cover classification results obtained with those from satellite image classification. This approach is here exemplified with a study of a test area in the Chiang Mai Basin, chosen as representative of the rapid change in land-use/land-cover, and because data is available from multi-temporal satellite and sequential black-and-white air photography. Georeferencing is through the use of the PhotoGIS® software package. For this, ground control points, the relevant air photo mission camera calibration report and a Digital Elevation Model (DEM) are required for correcting tilt and relief displacement in the air photo data so that all land cover boundaries in the archival data can be brought to the same coordinate system. It is shown that the success with which thematic data from the archival air photos can be integrated with the more economically maintained satellite image archive depends on having access to an adequate number of ground control points and a quality DEM. Apart from checking for planning scheme compliance, first deployment of a land cover archive such as was built for this project depends somewhat upon the motives of those who fund it. One obvious application is in establishing creditability for central planners who would otherwise have to depend upon local folk law, as, for instance, in adjudication for land titling on the edge of the state forest.

1 INTRODUCTION

Many studies, including some based on time-series satellite data analysed in Geographical Information Systems (GIS), offer generalised documentation of the land cover changes that have taken place during the last decade of rapid economic growth in the Chiang Mai area, Northern Thailand This study reports on attempts to improve the spatial resolution in such land cover change studies (eg Sangawongse, 1995) by including land cover boundaries interpreted from air photos. Thus is tested the idea that land cover history, data, and information might serve not only for decision support in formulation of national economic and social development plans, but also in the administration of them. The challenge in making this additional step in deployment of digital land information is in bringing the data that lies in the time-series air photos (of a range of scales and qualities and documentation) to the one georeferencing system (in the form of a land cover time-series spatial data base) with a spatial resolution that will serve administrators needing land parcel level discrimination. This erstwhile very time-consuming task can now be seriously contemplated if digital orthophoto techniques are employed (eg see Jensen, 1995). Thus potential for a digital land cover change archive (in GIS) to be extended back to the 1950s emerges in a way that allows supplementation of the satellite-derived information (some of it, for instance from the 1970s, at low spatial resolution) in preparation for the time when the necessary spatial resolution is provided by the new generation of earth imaging systems, for instance, systems with 3m and <1m spatial resolution soon to be launched by EOSAT of Thornton Colorado, and Earthwatch of Longmont Colorado respectively.

2 THE STUDY AREA

Land cover changes that accompanied the building of the Mae Kwang Dam (Doi Saket district) are depicted on both air photos and satellite images. In that the usual administrative challenges (resettlement, land titling requirements, higher land market activity) were matched by technical ones (high relief bringing significant height displacement to the photographs), and the image data from various sources was available in close enough time series, 42km^2 of this area was chosen to test the idea that a high resolution land cover history dating back to the 1950s could be incorporated into spatial data designed for decision support and administration. Land cover types mapped were; forests, paddy fields, rural residential, bare ground, and water impoundment. Land cover interpretation was informed by the knowledge that dam building was accompanied by establishment and use of the irrigation channels.

3 METHODOLOGY

3.1 Software

The GIS used was ARC INFO (ESRI 1991) (versions 6.1.1 and 7.0.2 on a Sun workstation) with PHOTOGIS®(Salamanca Software 1994) deployed for planimetric correction of boundaries interpreted from air photos by elimination of distortion due to terrain relief and camera tilt. PC-based image processing (IP) was carried out using microBRIAN, and workstation-based IP was with ERDAS version 7.5.

3.2 Data: selection and pre-processing

The spatial data base was constructed by analysis of information in Landsat TM (path 131, row 47 images for 9/2!88, 17/2/91, and 15/2/96), sequential black-and-white aerial photography (1954, nominal scale (ns) 1:40 000; 1972, ns 1:20 000; 1977, ns 1:15 000; 1983, ns 1: 15 000), and the San Sai I :50 000 topographic map sheet. From the archives relating to the latter, digital versions of the contours, stream lines and spot heights were derived, mostly by digitising.

The main challenge in preparing the image data is, apart from ground truthing, band selection. The main methods for this are: entropy criterion (Chen *et al.*, 1986) calculation of transformed divergence between classes (Awaya *et al.*, 1989; Mausel, *et al.*, 1990) optimum index factor (OIF) (Chevez, *et al.*, 1984); analysis of variance and covariance of the image scene (Sheffield, 1985) and image differencing of a suitable band, and Principal Components Analysis (PCA) of bands (Byrne *et al.*, 1980, Horler and Ahern, 1986). Tests revealed (Sangawongse, 1996) that for the data sets and terrain examined in this study, OIF and PCA offered the best way of band selection. Geometric rectification was conducted using the image-to-image technique: each data set was co-registered into the UTM coordinate system and resampled into 30m by nearest neighbour resampling. The registration error was about 1 pixel (30m).

Archival air photographs depicting the wrong season, and of small nominal scale and/or at too close a time interval were rejected as were any that were without camera calibration reports documenting the coordinates of fuducial marks, and lens focal length (See Table I).

3.3 Classification of multi-temporal Landsat TM data sets

Set-by-set/date-by-date major land cover patterns (eg. forests, paddy field, mixed orchards and water bodies) were obtained. The supervised maximum likelihood classification technique was applied to each Landsat TM data set for obtaining the most accurate classification results. This rule requires that the operator must have the knowledge of the study area, so that representative training sets can be chosen efficiently. These training sets represent a range of land-use/land-cover in the study area, eg. forests, paddy field, vacant land, water bodies and so on. The training sets are used to generate the statistics which are input into the classification function. It has been confirmed by many authors (eg. Curran, 1985) that this method often provides the most accurate results among the others, except it is expensive to implement and is time consuming.

In this analysis, the input pixels are classified into one of the training classes using a probability function. Pixels are allocated to the class to which they have the highest probability (the most likely class) of belonging. For example, class label C1 from a set of N classes {C1,..... Cn} is assigned as the most likely class to any feature vector x as the one with the highest posterior probability P (Ci|x). Then all P(Ci|x),i ε [1 .....N] are calculated, and the C, with the highest value is selected. The calculation of P(Ci|x) is based on Bayes Formula (Gorte, 1995):

$$P(ci|x) = P(x|Ci)|P(Ci)/P(x)$$

where P(Ci|x) Is the highest posterior probability for class Ci in a given feature of vector x;

P(x|Ci) is class probability density;

P(Ci) is prior probability;
P (x) is unconditional probability

The selection of bands used for a classification process was based on the results of PCA and O.I.F. It was found that the use of all TM bands (except band 6) provided good results for the 1988 data . For the 1991 data set, the use of TM bands 2, 3, 4, 5 and the Normalised Vegetation Index Image (NDVI) provided a satisfactory result. The satellite images, although matched for type and season, had to be analysed using different methods because the later image was the more affected by haze. It was the use of bands 4, 5 and NDVI that provided a satisfactory result for the 1996 data set.

3.4 Interpretation and georeferencing of air photo land cover boundaries

Digitisation of land cover boundaries interpreted from air photographs is the first step towards their inclusion in a digital spatial database using a common coordinate system . Each land cover boundary from a single air photograph (transferred onto mylar sheet) was digitised via a Calcomp 9500 digitiser. All air photographs were scanned at 400 dots per inch (dpi) using the program "Adobe Photoshop" (version 2.5.1) on a Mac platform. These scanned images were registered (to the fiducial marks) and resampled before overlay with the land cover data (in vector format). Thus data from the digitising tablet could be supplemented with on-screen digitising when necessary.

The planimetric distortion inherent in air photographs must be eliminated or greatly reduced if the interpreted boundaries are to be included in a digital spatial data base. It has always been possible to do this by including themes in topographic map production by photogrammetry, and indeed some topographic maps include land cover information. However most topographic mapping authorities prefer to include terrain data that is least likely to change over time so that the currency of map sheets is maximised. Land cover mappers have therefore been faced with repeating the photogrammetric mapping procedure, or using other methods (eg photoscope transfer techniques) that were satisfactory enough in the era of paper maps but which fail the "map overlay" test after conversion to digital form. Very few thematic mappers have had the resources needed to repeat the photogrammetry, and so it is with enthusiasm that the alternative methods offered by techniques focussed on digital orthophoto production have been embraced. PHOTOGIS® offers such an approach. Input data sets are, thematic boundaries on air photos, and a high quality Digital Elevation Model (DEM).

In this study, a DEM was created from contour lines as well as from point and stream data, derived from a topographic map at 1:50,000 scale (Royal Thai Survey Department, 1969). Lines and points were converted into a digital form by manual digitising. The creation of the vector DEM (in the form of TIN) in this study followed ARC/INFO User's Guide Surface Modeling in TIN (ESRI, 1991) whereby three inputs: (1) contour lines; (2) stream lines and (3) point data (mountain peaks) were used. A DEM must be assessed for an acceptable accuracy before it can be used effectively for correcting relief displacement in PHOTOGIS® analysis. An assessment of DEM in this study followed Pilouk (1991). DEM accuracy obtained by this method is approximately 6 metres.

The elimination of tilt displacement can be achieved using an affine transformation of the image points and can be performed by ARC/INFO using suitable ground control points (at least four). Relief displacement will vary according to the elevation of each image point, and its distance from the centre of the photograph, and so must be corrected on a point by point basis. Tilt displacement can be corrected by stereo plotters by allowing the images to be oriented so that their relative position at the time of photography is duplicated. PHOTOGIS® follows this rule, but uses a digital surface model (DEM) to mathematically intersect a single photogrammetric ray, without the need for a second photograph (Driessen and Zwart, 1992). The success of resection and correction procedures in PHOTOGIS® is dependent upon (1) accurate knowledge of the flying height/ scale of the photography; (2) the accuracy of the fiducial marks; (3) the accuracy of digitising; (4) the accuracy of the control points; and (5) the accuracy of air photo interpretation.

3.5 Data integration

This was carried out in ARC INFO. Coverages for the time series 1954, 1972, 1977, 1983, 1988, 1991, 1996 land cover were assembled. Land cover change detection was carried out in GRID. A change detection between two grids can be performed by simply using the following formula:

Change (T1 to T2) = lug (T1) - lug (T 2)

when lug = land use grid, and T = time

For example, change from 1988 to 1991 can be determined by subtracting grid (1988) from grid (1991):

Change (1988 to 1991) =lug88 - lug91

Change in specified time intervals provided in the data sets (from 1954 to 1996) can thus be determined, the information being available for tabular and/ pictorial display.

4 RESULTS AND CONCLUSIONS

The results of querying the spatial data base about land cover changes evidenced in the time series air photographs and those documented from analysis of satellite imagery are presented in Table 2.

Forest cover change was the main feature of the change detection mapping reported here. Within the 37 years time frame (1954-1991), forest cover was reduced from 3944 ha in 1954, to 1212 ha in 1991, indicating a decline of 2732 ha during the survey period. The area under rice cultivation (paddy held) in 1954 was approximately 140 ha, which is not much different from that found in the later years (eg. 1977). This is because agricultural activities and settlement were at lower densities in the 1950s. Between 1972 and 1983, the paddy field area increased slightly (only 13 ha). However, the area used as paddy field was much increased in 1988 (430 ha) due to the increased demand for land during the economic boom in Chiang Mai Province. The wet paddy field cover type increased between 1983 and 1991 as a result of more water being available after the filling of the Mae Kwang dam in April 1991.

The class "mixed orchard" identified in both air photography and Landsat TM data sets cannot be classified as a pure class, because it is mixed with rural residential land use. This type of mixture can be clearly seen in the 1:15,000 scale air photography of the study area. The accuracy with which these classes can be mapped is not high in comparison to other classes. The mixed orchard land cover for 1954 is 55 ha and for 1972 is 31 ha (small values). This land cover type was more prominent by 1977 (183 ha). There was little change between 1983 and 1989, but by 1991 this land cover type was 159 ha. The class "vacant land" did not change much from 1954 to 1983, but from 1988 to 1991 it has increased extensively due to the encroachment into the marginal forested areas in search of settlement and timber benefits. As identified by Landsat TM data, within the 3 year period (1988-1991), the amount of vacant land increased by about 1414 ha. However, from 1991 to 1996 it decreased due to the expansion of rural settlement and its replacement by forest plantations organised by the Royal Thai Forestry Department.

The final Land Use and Land Cover (LULC) data base developed as an outcome in this study offers the greatest benefits with respect to monitoring land cover change in the Chiang Mai area. It contains information on LULC patterns dating from 1954 to 1996, useful for studying land cover change history. Users can query the data base according to their interests. The digital ARC/INFO GRID format allows conversion between different formats, and the data can be updated over time. In conclusion, land cover change documentation necessarily involves time series data which must be brought to the same spatial data base before change detection methods can be applied. Clearly digital spatial data bases are required, because all the data needs to refer to the same georeferencing system so that repeatable and acceptable measurement of the changes can be made. The longer the land cover change record, the more scope there is for all parties to land use disputes (eg,. illegal loggers versus forest license administrators, or, say, dam builders versus resettling villagers) to refer to the one accurate spatial data (information) base. The need for digital spatial data handling is emphasised by the fact that the archive will refer, progressively, to data of different types (old maps, air photos, satellite imagery offering a variety of spectral and spatial resolution, hyperspectral imagery, digital photogrammetry, thematic maps etc.) that will all need to be brought to the same geospatial reference system, and many will need digitally-based analysis before past investment in them can be realised in the spatial data base. Each of these data types will have its own data handling requirement: the challenge will be to adapt it to the requirement of the data base so that the time series digital spatial archive becomes more comprehensive, and thereby, more useful. Many of the uses to which the data base will be put will centre upon its role as a common spatial information base to which all parties to a particular conflict over choice of use of land may refer. Clearly digital data handling using PHOTOGIS® will bring spatial data now held in the air photo archive into the digital spatial data base for land cover change detection. The prerequisite for using this approach to capture thematic boundaries from air photo interpretation is a DEM of high quality. In that the kind of digital spatial data base envisaged here would draw on many different kinds of data, many/most of the rules of validation and data /information quality assurance in thematic mapping will have to be considered during its application to monitoring, and to land use problems and conflicts. Application of PHOTOGIS® will improve positional accuracy in air photo land cover boundary transfer to the digital spatial data base. One obvious application of data sets assembled in the way reported here is in establishing creditability for central planners who would otherwise have to depend upon local folk law, as, for instance, in adjudication for land titling on the edge of the state forest.

~ ACKNOWLEDGMENTS

The LANDSAT data was supplied by the Thailand Remote Sensing Centre. The sequential aerial photography and topographic data was supplied by the Royal Thai Survey Department. The research was supported by the Department of Geography and Environmental Science, Monash University, and by the University of Chiang Mai.

6 REFERENCES

Awaya, Y., Ohnulii. I., Sawada, H., Nakakita.O. and Hamzah, Khali Aziz B., Remote Sensing for Forestry Applications in the tropical rain forest of peninsular Malaysia, *Proceedings of the lOth Asian Conference on Remote Sensing*, November 23-29, Kuala Lumpur, Malaysia, 1989.

Byrne, G. F., P. F. Crapper and K. K. Mayo., Monitoring Land Cover Change by Principal Component Analysis of Multi-temporal Landsat Data, *Remote Sensing of Environment*, 10, pp. 175184, 1980.

CSIRO and MPA microBRIAN *Application Notes*. MPA Communications and CSIRO Australia, 1993.

Chavez, P. S., C. Guptill, and I. A. Bowell, Image Processing Techniques for Thematic Mapper Data, *Technical Papers*, 50th Annual Meeting of the American Society of Photogrammetry, Vol. 2, pp. 728742,1984.

Chen, Sherry Chou, Landsat TM band combinations for crop discrimination, *Symposium on Remote Sensing for Resources and Environmental Management.* Enschede, pp. 211-214, 1986.

Curran, P. J. *Principles of Remote Sensing* Longman: London, 1985.

Driessen, R. J. and Zwart, P. R., Detecting Forest Boundary Updates From Aerial Photographs: Reverse PHOTOGIS, *ESRI User Conference, Palm Springs,* USA, 1994.

ESRI, Cell-based Modelling with GRID: Analysis, Display and Management *ARC/INFO User's Guide,* The Bath Press: Great Britain, 1991.

Gorte, B. ,Digital Image Processing Subjects, in *Workbook for the MSc course on Geographic Information Systems,* Edited by C. J. van Westen, pp4/43-4/37, ITC, Enschede 1995.

Horler, D. N. H. and F. J. Ahern,, Forestry Information Content of Thematic Mapper Data, *International Journal of Remote Sensing,* Vol.7/3, pp. 405-498, 1986.

Jensen, J. R. . Issues Involving the Creation of Digital Elevation Models and Terrain Corrected Orthoimagery Using Soft-Copy Photogrammetry *Geocarto International,* Vol. 10, No. 1, pp. 5-91, 1995.

Mausel, P. W., Kramber, W. J. and Lee, J. K. Optimum Band Selection for Supervised Classification of Multi- spectral Data, *Photogrammetric Engineering and Remote Sensing,* Vol. 56(1), pp. 55-60, 1990.

Pillouk, M., Fidelity/improvement of DTM from contours. *MSc. Thesis*, International Institute of Aerospace Survey and Earth Sciences (ITC), Department of Geo-informatics, Enschede, the Netherlands, I 991.

Royal Thai Survey Department-RTSD, Topographic map (I :50,000), sheet 48461V, 1969.

Salamanca Software Pty Ltd. ,. *PHOTOGIS® User's Guide- Direct from Aerial Photograph to Geographic Information Systems,* 1994.

Sangawongse, S., Land use/Land cover Change Detection in the Chiang Mai Basin: Using Landsat TM", in *Proceedings of the 16th Asian Remote Sensing Conference.* held at Suranaree University of Technology trom 20-74 November 1995.

Sangawongse, S., Landscape Change Detection in the Chiang Mai Area: An Appraisal from Remote Sensing, GIS and Cartographic Data Developed for Monitoring applications, *Ph. D dissertation,* Department of Geography & Environmental Science, Monash University, Australia, 1996.

Zwart, P. R., Updating ARC/INFO Coverages with PHOTOGIS® and ORTHOPHOTOGIS®, Centre for Spatial Information Studies, University of Tasmania, Hobart, Australia, 1992.

Table 1
Description of the air photographs used for PHOTOGIS analysis in the test area

Date	Scale	Run number	Camera type	CAL.FL (mm)
1954	1:40,000	13205,13206	unknown	153.64
1972	1:20,000	146-149	Wild Heerbrugg	152.17
		0521-0524	"	152.58
		496-499	"	152.58
		336-339	"	152.58
1977	1:15,000	217-223	Wild Heerbrugg	151.93
		142-148	"	"
		049-055	"	"
1983	1:15,000	9430-9433	Zeiss Jena	152.23
		9623-9626	"	152.23
		9292-9295	"	152.23

Source: Royal Thai Survey Department

Table 2
Information on Land-use/Land-cover change in the test area
From 1954 to 1996

	Area (ha)							
Land-use/land cover	1954	1972	1977	1983	1988	1989*	1991	1996
Forest	3944	3865.14	3592	3568	3356	3656	1212	2145
Paddy field	144	227.61	104	240.4	430	331	407	200
Mixed field crops	5	38.97	50	31	55	169	13	88.91
Mixed orchards	55	30	183	77	4	175	16	200
Bare ground/Open land	17	5.13	11	19	104	nc	39	0.54
Swidden areas	nc	223.5	10	6	nc	77	nc	1.77
Vacant land use	19	9.09	156	144	114	92	1588	155.54
Rural Residential	10	14.04	33	46	62	38	669	400
Dam site/Development land	nc	nc	nc	59	46	242	245	95.58
Water Bodies	nc	nc	nc	nc	23	nc	5	907**
Total area	4194	4213.5	4194.0	4193.0	4195.00	4191.94	4194	4194.34

NB. Approximate test area = 42 sq.km (4,200 ha); nc = not classified
Source: (Sangawongse, 1996)[1]

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* Official figures from land use map (Land Use Division, Department of Land Development)
** Includes the new reservoir (Mae Kwang)