REMOTE SENSING AND GIS TO STUDY THE SUB-URBANIZATION DYNAMICS: A CASE STUDY IN NORTHERN BANGKOK, THAILAND

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ABSTRACT: As Bangkok Metropolitan is expanding, prime agricultural land and water basins are rapidly transforming into land for housing, roads, and industry. Based on a case study in one of the fastest growing suburban areas – the Pathum Thani province – the paper demonstrates the usefulness of remote sensing techniques integrated with GIS to study the dynamics of sub-urbanization and to address the pressured development problems. Various satellite image data from 1986 to 1999 were analyzed within a digital image processing system to provide up-to-date information of the whole area. The extracted information from remotely sensed data was then merged with other sources of geo-coded information in a GIS to create a comprehensive spatial database, including not only physiographic but also socio-economic data. This permitted the integration of several layers of information with the remotely sensed data in both temporal and spatial dimensions. Dynamical pictures of the urban expansion, the infrastructure expansion and the loss of paddy land in the area during the 1970 – 1999 period were derived. On the other hand, with the combination of detailed socio-economic information (from NRD-2C database), the spatial pattern of sub-urbanization was revealed at localized (*tambol*) level. The application of spatial data analysis techniques, then, provided insights into underlying factors of sub-urbanization process during the last 29 years. The trend and resultant important factors in the past development of the area could be used to evaluate existing development programs. The integrated RS/GIS/spatial analysis system was proved effective in defining the dynamics of sub-urbanization in Pathum Thani area, and could be recommended for other sub-urban areas. The case study also demonstrated that RS and GIS techniques have grown far beyond scientific tools and in fact is becoming a semi-operational technical tool for planners and decision-makers at various administrative levels in dealing with complex development problems.

Keywords: Remote Sensing, GIS, Sub-Urbanization, Urban-Rural Interaction, Information Integration, Spatial Data Analysis, Thailand

I. INTRODUCTION

Bangkok, one of fast-growing Asian Metropolis agglomerations with population of more than 10 million, is a primate city of Thailand. Most industries were concentrated in the Bangkok Metropolitan Region (BMR), where geographical and institutional conditions were most favorable. As cities expand, prime agricultural land and habitats such as forests and water basins were transformed into land for housing, roads, and industry. High economic growth and increased employment opportunities caused substantial influx of labor immigration. The sub-urbanization has speeded up with 52% of urban population in 1990, increased to 61% in 1995 and predicted to reach 82% in 2020. The changes of land-use affected social, economic and ecological conditions. Effective urban land use planning can help guide urban development away from vulnerable ecosystems, which appears impossible without deep understanding of processes governing the change dynamics and their inter-relations in Pathum Thani province.

Remote sensing technology has been recognized as a useful means of supplying up to date information on activities, within the urban environment (Lillesan and Kiefer, 1990). The synoptic view of urban land-cover provided by satellite is an important complement to in-situ measurements of physical, environmental and socioeconomic variables in urban settings. Remotely sensed data may also be used to map, monitor and estimate the properties of environmental features. The land cover information, properly classified, can provide an areally and temporally explicit view of societal and environmental attributes. Thematic mapping from remotely sensed data is found in numerous fields of study including land use planning. Operational satellites such as LANDSAT / SPOT provide the ability to monitor spatio-temporal dynamics of built-up and infrastructure features with frequent repetitiveness. Remote sensing data can be readily merged with other sources of geo-coded information in a GIS. This permits the overlapping of several layers of information with the remotely sensed data, and the application of a virtually unlimited number of forms of data analysis (Lillesand and Kiefer, 1990). The integration of RS and GIS provides more effective functional, spatial, and temporal information potential that cannot be achieved by each alone. Hence, in this research an effort had been made to provide all-aspect information of land-use dynamics in Pathum Thani province during 29 years (1970-1999) for planners under the urban expansion pressures. Specifically, the study had concentrated on answering the following questions:

1. How the land-use in the area has been changed during the last 3 decades and where and when most changes have occurred?
2. Which are the important factors affecting those changes? Understanding land-use dynamics of the study area during past 29 years (temporal dimension) and suburban spatial structure (spatial dimension).
3. Which implications could be extracted from these findings?

The other objective of this study was to demonstrate the applications of an integrated GIS/Image Processing System for suburban land-use change analysis.

II. STUDY AREA

Situated about 30 kilometers north of Bangkok, Pathum Thani province is one of the most dynamic suburban areas of the Bangkok City (Figure 1). With an area of 1524 km^2, the province, which is the heart of the Chao Phraya delta, bears highly artificial systematic dense canal networks (under North Rangsit Irrigation Project in the East and Phraya Banlu Project in the West). The natural conditions such as flat topography, good alluvium soil and sufficient irrigation system favor the development of intensive agriculture for years in the study area, primarily for rice crop cultivation. However, with the expansion of Bangkok Metropolitan Administration (BMA), the rice land-use, which has dominated more than 20 years before, has been changed steadily to other land-uses such as urban and industrial areas, fruit tree, vegetables plantation (Figure 2). Indeed, the economic structure of the province has changed dramatically during the last decade due to the relocations of industries from BMA. In 1998, there were 350 factories creating 221,000 employment opportunities in the province. The substantial amount of young working age group were engaged as employees in the growing industrial sector. In 1996 only 22.8 % of total population remained on agriculture activities, the others worked on industrial and service sectors. The Gross Provincial Product (GPP) of Pathum Thani, which was 46,583 million Baht in 1990, has increased rapidly to 91,979 million Baht in 1996. Industrial sector took the largest share in GPP and was followed by trade, electric and water supply and agriculture. GPP per capita of the province is Baht 246,581 in 1996, which became highest as compared to 6 provinces in the BMR.

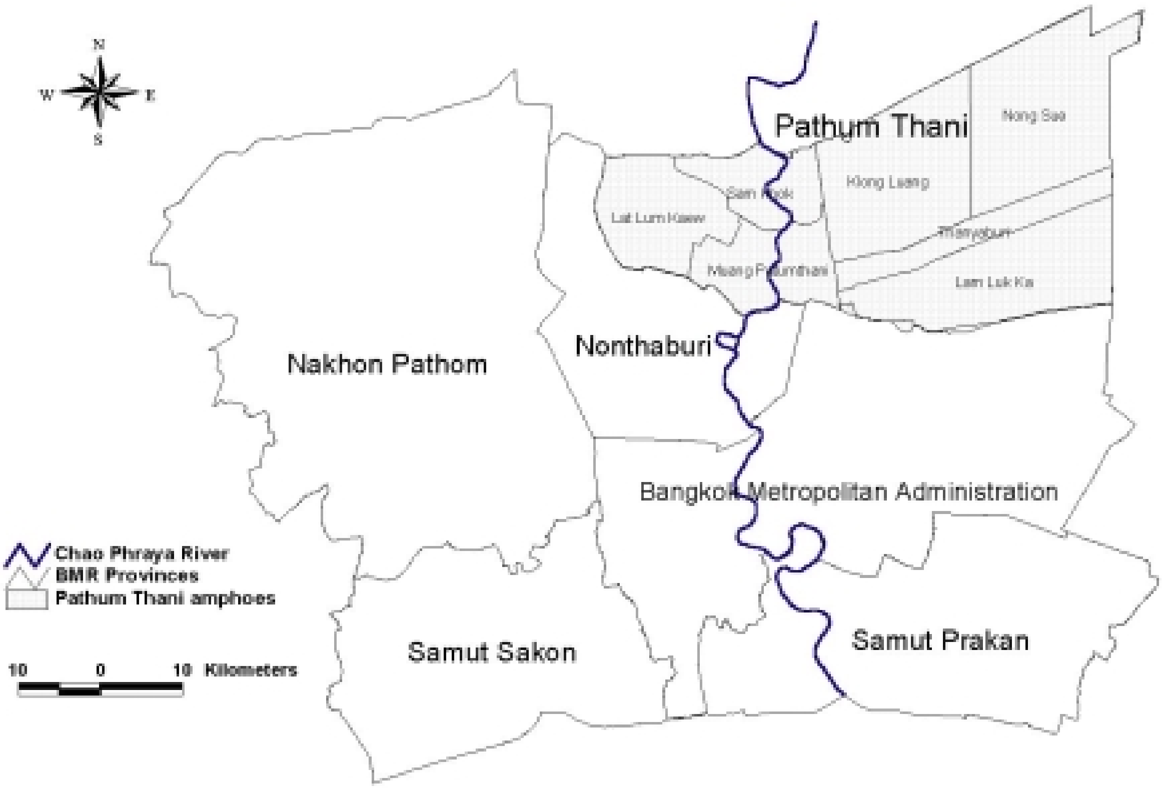

Figure 1. The location map of Pathum Thani province in relation with Bangkok Metropolitan Region and Chao Phraya river

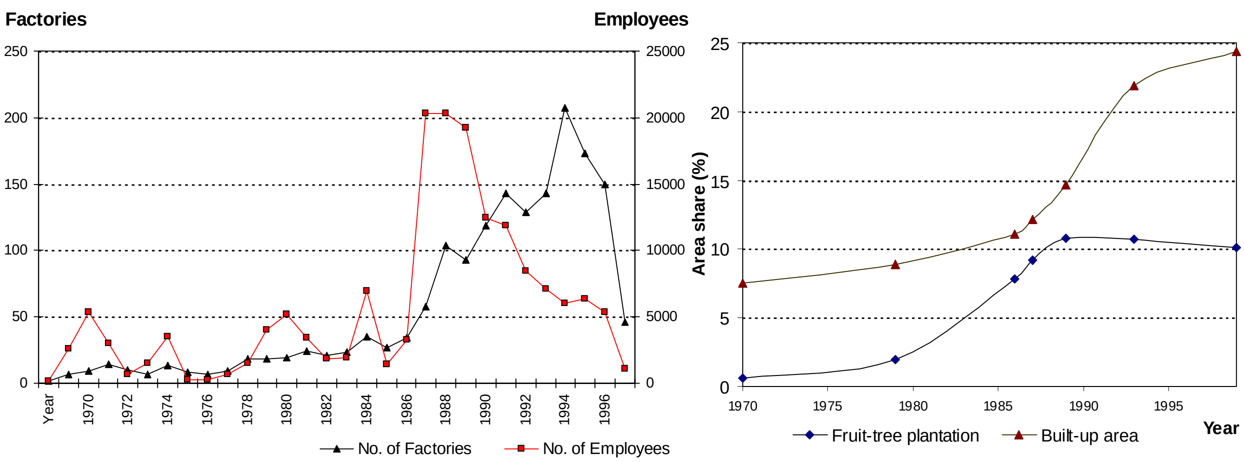

Figure 2. The increases in industrial establishments and the percentages of built-up and fruit-tree plantation in Pathum Thani province during 1970-1999

With increasing institutional building development (9 universities, public and private colleges, and various government departments) Pathum Thani is well connected with Bangkok Metropolis. This together with well-developed road network has added additional urban expansion pressure from Bangkok on the province. High economic growth and rapid sub-urbanization in Pathum Thani province have caused substantial influx of labor immigration, which accounted up to 200,000 unregistered persons as compared to the 616,000 official population figure in 1998. Rapid land-use change in the area gave rise to serious problems such as: inefficiency of land utilization, inadequate urban facilities and infrastructure, traffic congestion, pollution and other environmental problems (Vibulsresth *et al*, 1992). All these rapid developments and associated social and environmental problems have required a systematic up-to-date information base in order to detect and analyze development problems for purposeful and regulative planning. Moreover, as new Tambol Administrative Organization (TAO) came into force in light of Thailand's decentralization strategy since 1995, the coordination between 52 TAO and 13 municipalities in Pathum Thani became an additional issue in development planning.

III. INTEGRATED METHODOLOGY

The overall approach of this study is to utilize the temporal capabilities of remotely sensed data to monitor the land-cover / land-use changes during the 1986-1999 period. The extracted information from satellite images then was integrated with various geo-coded physiographic and socio-economic data within the framework of a comprehensive GIS spatial database to analyze the dynamics of sub-urbanization in Pathum Thani province. The image processing/GIS systems used are ERDAS Imagine 8.5, ARC/INFO, ArcView 3.2, Visual FoxPro 5.0 and statistical analysis used SPSS for Windows 9.0 and SpaceStat 1.90.

3.1 Information extraction from remotely sensed data

Various satellite images such as MSS (1986), SPOT (1989, 1993) and TM (1989, 1992, 1999) were obtained for the study area to provide temporal land cover and land use information. Dry season scenes were used since there are less cloud covers and thus permit a better distinction between forested, agricultural and urban or built-up land covers. Satellite images were corrected for atmospheric attenuation and geo-referenced to a common 1:50,000 UTM topographic map base. The TM and SPOT images were then re-sampled to 25-m squares with a nearest neighbor interpolation algorithm. The geo-corrected images were then submitted to image analysis system (ERDAS Imagine) to update road and irrigation networks, stratify scenes into vegetation/non-vegetation areas using NDVI and built-up/non-built-up areas using Edge Density Texture Measure (Hlavka, 1987). The image classification used the *optimal structure-tree classification* algorithm (Andrianasolo, 1990). The ancillary data such as existing land use maps and stratified maps were used to improve classification maps in the post-classification procedures. The image analysis had been done on single-date images individually and the change detection was based on post-classification techniques with raster GIS functions involving image co-registration and overlaying. The images were classified according to several basic land surface types. Although the classification process was capable of reasonably separating 15-18 land cover classes, given the objectives of the study and real situations of the area, the final analysis consolidated these into 7 land-cover categories: built-up, paddy, fruit-tree plantation, water-body, fallow land and unclassified vegetation (horticulture, coconut, palm trees, etc.) with assistance of existing land-use maps. The aggregating into more broad land-use categories has also increased significantly the accuracy of image classification, making classified images more compatible with existing land use maps. The details of image analysis procedures used in this study could be found in Tran (1994). The classified images were, then, integrated with other environmental and societal data sets through raster-to-vector data conversion to update and build time-series data.

3.2 Spatial GIS Database Integration

With regional development issues in the focus, data in Pathum Thani area, Thailand were collected from various government offices in the form of physio-graphic data (e.g., topographic, administrative, land-use, industrial locations as well as transportation network maps) and socio-economic indicators. The spatial physio-graphic data sets from paper maps were classified, digitized and fed into vector GIS (Arc/Info), which contain following major layers: administrative boundaries, land-use (1970, 1979 and 1987), irrigation- and road-network and industrial locations. With classified images in raster formats, the loose integration approach was applied to manage the GIS spatial database in both formats with the flexibility to convert from one to another in a particular analysis.

The major source for socio-economic data was the National Rural Development Database (NRD-2C), which provides surveyed data at village level after each two years from 1986 composing of more than 100 economic and social indicators. The data were also collected from other government documents, statistical records at provincial and municipal offices. They were selected, reclassified and combined based on the basic administrative unit IDs – village code number in dBase IV format. A program in Visual FoxPro 5.0 was written to automate the process of extracting, normalizing and combining socio-economic indicators including population, income, education, health, natural environmental conditions, services, agriculture and industrial activities, work force, capital investment, employment, etc. (Tran, 1998).

As for regional researchers to produce regional empirical models of urban-rural interactions or for policy makers to formulate strategic development plans, social and environmental data must be converted into a common spatial structure (e.g., set of areal units). As indicated by Tran and Yasuoka (2000), it is recommended to summarize/regionalize spatial physio-graphic data by *administrative units* in order to be compatible with socio-economic data. Based on the internal homogeneity criteria (within-unit variance and spatial autocorrelation index), *tambol* level was chosen as the desirable level of aggregation for data integration (Tran and Yasuoka, 2000). The selected socio-economic data were aggregated from village to *tambol* level, and were normalized as relative shares of the total population of each respective *tambol*, in order to further reduce the effect of unequal sizes of *tambol*. The data management in GIS used to integrate those diverse data sets (physio-graphic and socio-economic data) to a common spatial structure (e.g., set of areal units) and to determine analyses possible with those data. The spatial physio-graphic data such as land use types, road networks, irrigation networks, industrial factories were aggregated to tambol level using spatial overlay and logical-statistical analysis functions in GIS (Arc/Info). Some accessibility measures such as median distance from residential areas to nearest roads and nearest factories were derived through GIS spatial joins functions utilizing the locational information of data (Tran and Yasuoka, 2000).

With all aggregated socio-economic data and regionalized spatial physio-graphic data to common tambol level, the GIS join function through a key item – *tambol* ID – was used to complete the spatial GIS databases for Chiang Mai – Lamphun and Pathum Thani areas. The GIS databases, thus, containing comprehensive spatial information characterizing development states of the Pathum Thani area (in 1979, 1989 and 1999) for each tambol in terms of:

- *spatial physio-graphic data*: % of urban land-use, industrial land-use, agricultural land-use, road length density, irrigation length density, median distance from industrial land to closest residential areas, median distance from residential area to the nearest road;
- *demographic aspect*: population density; *economic aspect*: average household property taxes, travel time to nearest town and commercial center, % of farmer, per capita number of vehicles, number of factories, per capita industrial capital investment, % factory employees, average household income, % people working far from home; and *social aspect*: level of primary education, secondary education, illiterate rate, etc.

3.4 Change Analysis

From the integrated GIS database, the land use changes were extracted. The land-use category under interest was reclassified and reselected from simplified classified images and existing land-use maps (for all of 7 dates – 1970, 1979, 1986, 1987, 1989, 1993, 1999) using the Boolean logic and then aggregated to respective administrative level. For each administrative unit (e.g., for whole province, a particular amphoe or tambol) time series were constructed for paddy loss, plantation expansion, built-up area expansion and associated socio-economic indicators to show the trends of development in time. On the other hand, to understand the land-use conversion over time, the change detection between 1979 and 1999 (Table 1) was done on respective classified images in raster format using image registration and overlaying functions.

Based on the time series curves (Figure 3) the period of 1979-1989 was selected as the representative stage of land use change in the area. The averages speed of change during that period in terms of paddy loss, urban expansion, road network expansion were used as surrogate variables to study the land-use dynamics in spatial dimension. The trend surfaces were then generated using sloping weighting spatial interpolation for road network, built-up area and fruit-tree plantation expansion with speeds of changes calculated for each grid cells size of 1 x 1 km (Figure 5).

3.5 Spatial Analysis to study Urban-Rural Relations

The resulting spatial data sets in unique format are useful for further empirical analysis of regional spatial development patterns and relationships between land-use and socio-economic variables using various multivariate statistical and spatial statistical analysis techniques. With these GIS databases, policy makers can easily explore data and their spatial coincidences at locations of interest, visualize spatial patterns in economic, social and demographic aspects at times of interest, visualize time trend of regional development based on social / environmental indicators of interest, and create various tambol development index based on combined indicators for planning and management. On the other hand, with more sophisticated analysis and modeling tools, researchers could go further in analysis to gain insights into regional development problems.

IV. RESEARCH FINDINGS AND DISCUSSIONS

4.1 Land Use Changes during 1970-1999

The general structure of land-use in the study area has changed significantly for three most important land-use types: paddy land, fruit-tree plantation and built-up areas. During the period of 1979-1999 as shown in Table 1, there were two dominant changes in land-use patterns occurring in the study area as follows: (1) considerable areas of paddy fields were converted into built-up construction and wasteland-preconstruction areas (13.65 % of paddy land in 1979) and; (2) considerable areas of paddy fields are converted into fruit-tree plantation (11.03 % of paddy land in 1979). However, this tendency of changes was slightly shifted during the last few years: the paddy land was continued be converted into built-up areas, while some of plantation farms were abandoned and/or replaced by built-up constructions (28.92 % of plantation areas in 1989).

Table 1. Transitional Matrix of Land-Use Conversion during 1979-1999

Major Land use	Year 1979 Area (ha) (%)	Year 1999					
		Paddy	Plantation	Horticulture	Fallow	Waterbody	Built-up
Paddy	**122752.80 (80.84%)**	**75312.80 (61.35%)**	**13541.76 (11.03%)**	**20100.48 (16.37%)**	**133.28 (0.11%)**	**0**	**13555.52 (11.04%)**
Plantation	**3224.48 (2.12%)**	**0**	**1616.32 (50.13%)**	**0**	**1296.96 (40.22%)**	**0**	**302.72 (9.39%)**
Horticulture	**2184.32 (1.44%)**	**0**	**417.44 (19.11%)**	**456.48 (20.9%)**	**494.72 (22.65%)**	**0**	**815.68 (37.34%)**
Fallow-land	**4043.36 (2.66%)**	**0**	**0**	**0**	**2030.56 (50.22%)**	**0**	**2012.80 (49.78%)**
Water-body	**1193.76 (0.79%)**	**0**	**0**	**0**	**0**	**1193.12 (100%)**	**0**
Built-up	**18454.72 (12.15%)**	**0**	**0**	**0**	**0**	**0**	**18454.76 (100%)**
Total	**151853.44 (100%)**	**75312.80 (49.65%)**	**15575.52 (10.68%)**	**20556.96 (14.98%)**	**3955.48 (0.84%)**	**1193.12 (0.60%)**	**35141.48 (20.37%)**

In the time dimension, the figure 3 clearly shows significant and in-conversable losses of paddy land over the years to the expansion of urban areas and fruit-tree plantations. These losses were not evenly distributed across the province though, as Thanyaburi and Muang were the leading suburbanized amphoes with only 30 – 34% of total land left for paddy plantation in 1999. Within agricultural practice, the most common change was the transformation of paddy land (mostly wet season rice) to orange tree plantation, orchards or vegetable cultivation. The spatial distribution of fruit-tree plantations slightly changed over the years but is mainly concentrated in Nong Sue and Thanyaburi districts, which had the share of 32.5 and 24.5% of total land in 1999 respectively. The trend of the fruit-tree plantations expansion (as illustrated in Figure 3) could be described as a three-stage expansion model with slow introduction stage (before 1979), rapid expansion stage (1979-1987), and smooth mature stage (1987-1999). This land conversion was mainly due to favorable natural condition (soil, irrigation and road network) and relative cheap land price and its availability, which attracted the investment of rich farmers from south of

Bangkok. In Thanyaburi and Klong Luang amphoe since 1987, however, some plantation areas have been replaced by built-up construction or were sold for pre-construction wasteland.

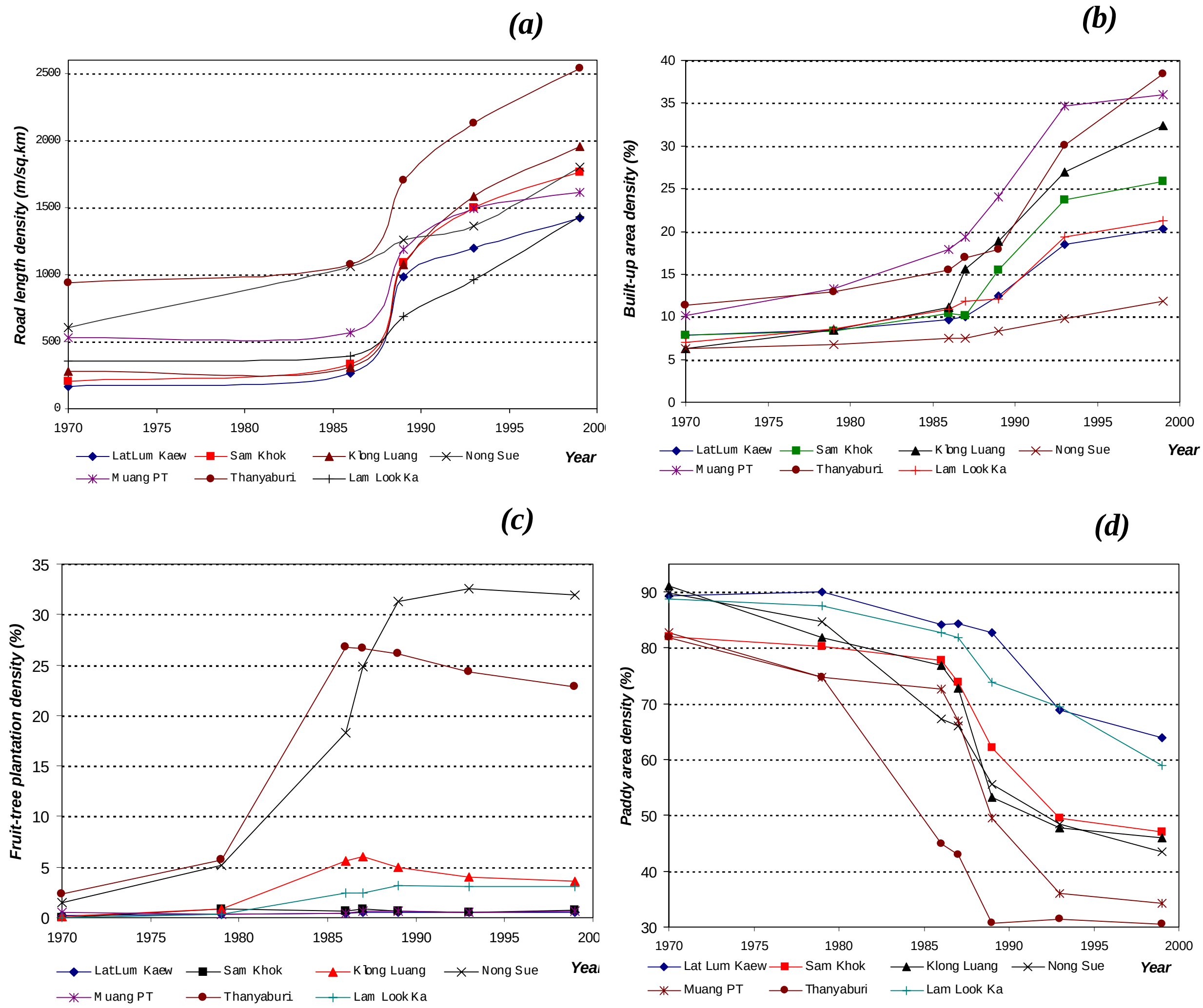

Figure 3. The expansion of (a) road network; (b) built-up areas; (c) fruit-tree plantation and loss of (d) paddy land in each district of Pathum Thani province during 1970 - 1999

4.2 The Sub-Urbanization Dynamics

The sub-urbanization process in the study area had started about 20 years ago with rapid growth occurred since 1984 closely following the expansion of the road network (as shown by a high correlation between the speed of road expansion and speed of built-up areas expansion in figure 3). The sub-urbanization appeared to slow down after 1990 with mainly in-fill development as it reached the mature stage. Among Pathum Thani amphoes, Muang, Thanyaburi and Klong Luang districts had most densely built-up areas with their share of 38.7, 30 and 26.5% of total land in 1999. The speeds of expansion are also highest in Muang and Thanyaburi districts – about 3.2-3.8% per year during the 1979-1989 period. The Nong Sue has the least built-up area in the province – only 11.4 % of total land in 1999 and also lowest speed of expansion – 0.5% per year during 1979-1999 period. The spatial patterns of urban development were changing over the years. It started expanded from Bangkok Metropolis along national highway No. 1, then other major roads (Rangsit – Nakhon Nayok, highways No. 306, 346) creating the axis of development. The later in-fill development in the form of industrial and associated residential establishment has enlarged the urbanized area in perpendicular to the "ribbon" direction. The trend surface of built-up expansion shown in Figure 5 represents the hierarchy of suburban centers: Rangsit, Muang municipal area. They were serving as growth centers, connected by highways and interact with each other to give the patterns of the spatial urban expansion in the study area. The two centers have rapidly filled in between with highest speed of built-up expansion. The main direction of urban expansion in Pathum Thani was along the so-called Northern Corridor (Rangsit – Bang Pa-in), where most industries and major infrastructure projects located. During the last decade, the urban expansion was shifted to the east along Rangsit – Nakhon Nayok highway, to the west along highway No. 346 (Figure 4). With Bangkok outer ring roads completed in 1996, it will certainly attract new urban and industrial expansion along. In addition, as shown in figure 4, there were quite a number of scattered new urban and industrial developments in forms of infrastructure and housing projects into the protected areas, indicating the difficulties in controlling urban development in Pathum Thani province.

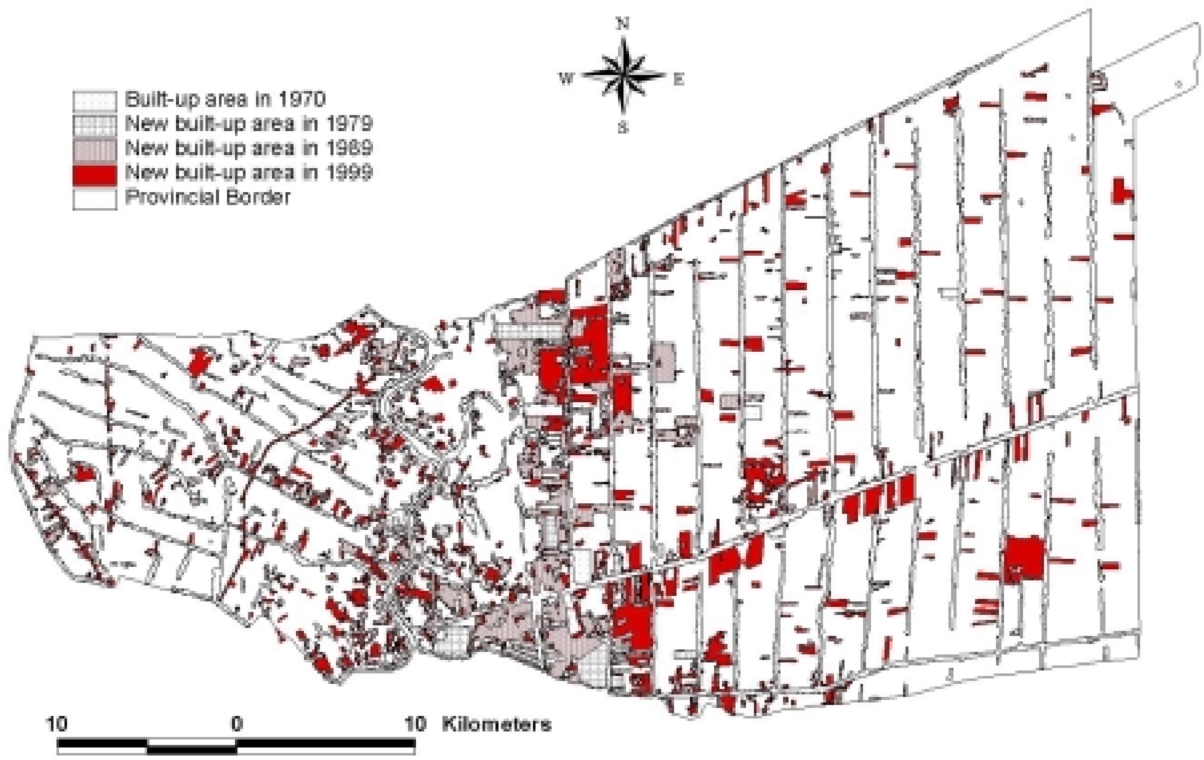

Figure 4. The built-up area expansion during 1970 – 1999 in Pathum Thani province (based on comparison of existing land use maps and classified satellite imageries)

Industrialization and urban-biased development policies have resulted in very imbalance growth patterns in the province. New factories, particularly medium and large-sized, were further likely to concentrate in the suburban areas due to: relatively lower price of land, convenience of transportation due to the location near the roads and highways, easier access to cheap local labor, and lack of regulative planning. The rapid sub-urbanization process appeared significantly affect the socio-economic life of the population in the province. Factor analysis based on all surrogated physio-graphic and socio-economic variables revealed two major development processes during the 1979-1999 period in the province namely: *industrialization* and *changing* *in agricultural practice* (Tran, 1994). The *industrialization*, which closely relates to industrial establishments, built-up expansion, has caused major influx of labor immigration into the province (based on correlation analysis). Furthermore, it significantly changed the labor structure by attracting the farmers from agriculture activities, increasing female labors in factories and services. Figure 6 shows the spatial distribution of the changes in labor structure between 1986 and 1996 by tambols, which very much resembles the spatial patterns of urban expansion (Figure 4 & 5) in the province. The *changing in agricultural practice*, which closely relates to the expansion of fruit-tree plantation, has almost no impact on population distribution and mainly governed by well-developed road- and irrigation-networks.

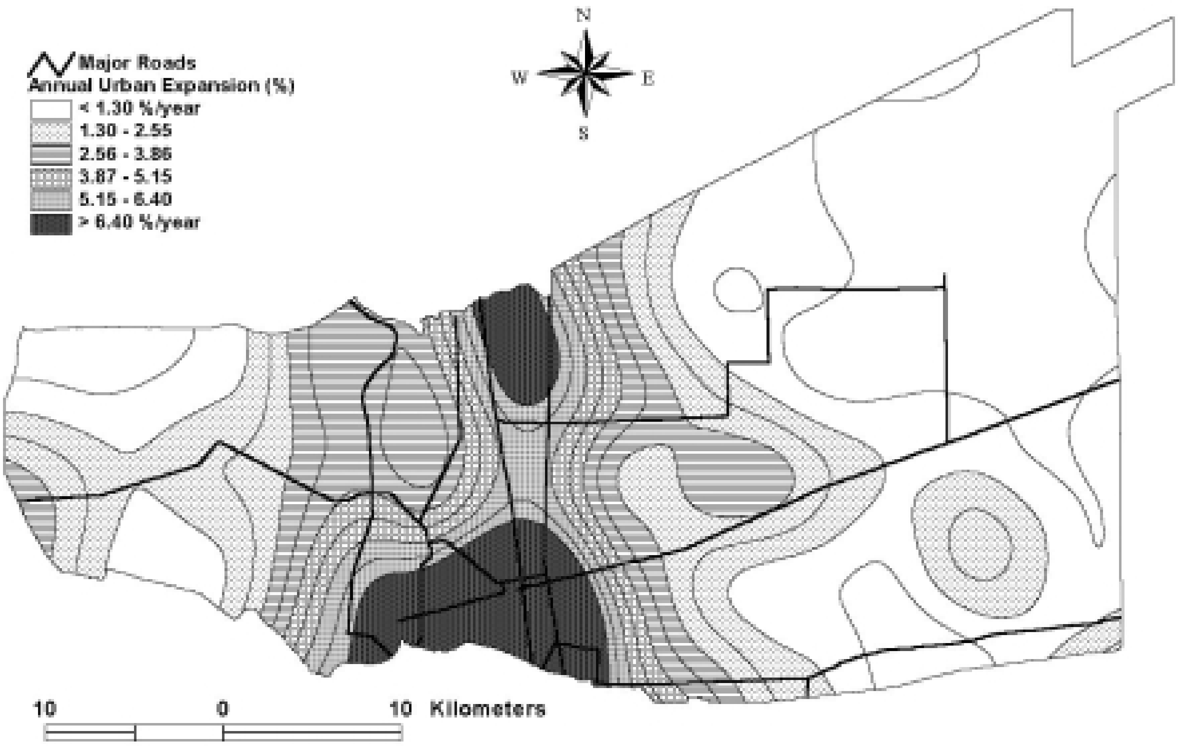

Figure 5. Interpolated surface of average speed of urban expansion in Pathum Thani province during 1979 – 1989 period (using *slope weighting interpolation* method)

V. CONCLUSIONS

The case study of Pathum Thani province in this paper highlighted the importance of satellite remote sensing in providing accurate and up-to-date land-use/land cover information. The multi-approach was well illustrated by incorporation of various satellite imageries and of various types of physio-graphic and socio-economic information within a framework of comprehensive GIS. The integrated GIS were efficient and useful technical tool in integrating social and environmental data in order to build an integrated GIS database for monitoring and analysis purpose. With decentralization planning on increase in Thailand, these comprehensive GIS databases at tambol level could provide needed details to local decision makers at the newly-created administrative level – Tambol Administrative Organization

(TAO). On the other hand, provincial planners could use this integrated methodology as a semi-operational technical tool in dealing with continued urban expansion pressure from Bangkok Metropolis at various administrative levels.

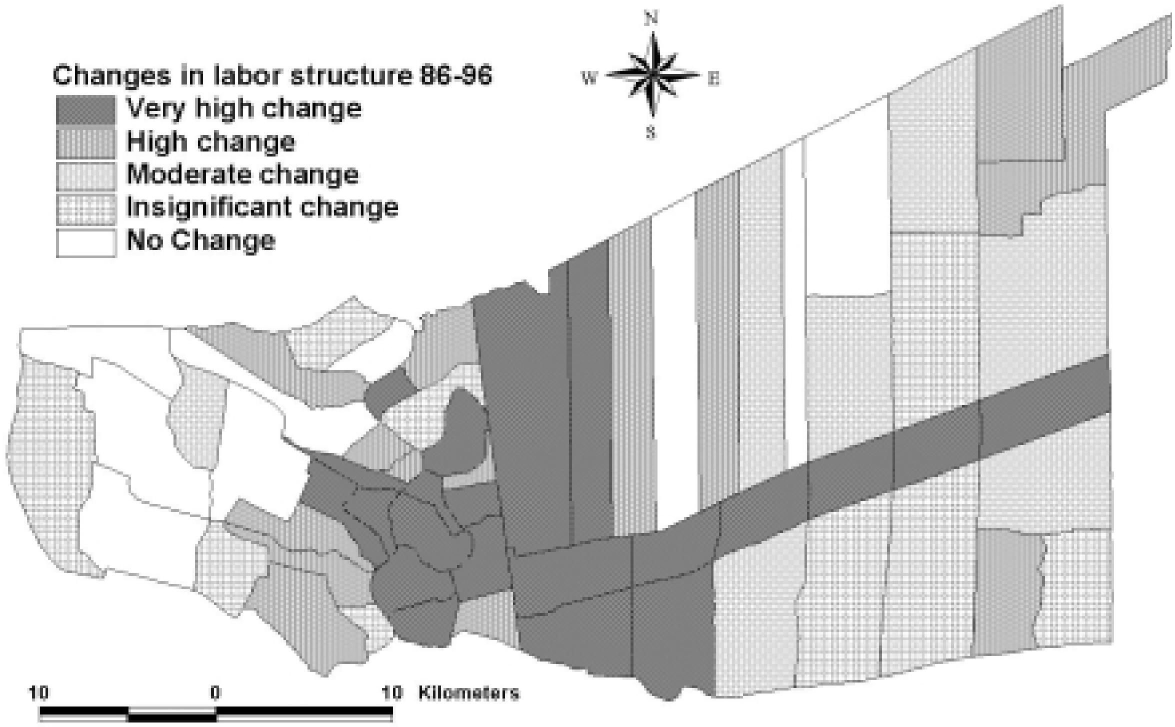

Figure 6. The changes in labor structure between 1986 and 1996 by tambols in Pathum Thani province

Furthermore, with the developed spatial databases, GIS can serve as an efficient technical vehicle for spatial analysis and spatial modeling functions to gain insights into regional development problems, e.g., to evaluate development impacts in the past, and to enhance regional development strategies through facilitating various scenarios. At the present, some analyses, which involve also environmental aspects, are undertaking in order to have more understanding on urban-rural interactions and its impacts on the environment in the area.

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