Environmental change analysis using satellite imageries: case study of Thai Binh province, Vietnam

Rajesh Bahadur THAPA[1], Frederic BORNE[2], Pham Van CU[3] and Vincent PORPHYRE[4]

[1]Research Associate, AIT, Thailand, rajesh@ait.ac.th
[2]Assistant Professor, CIRAD, France, borne@cirad.fr
[3]Director VTGEO, Vietnam, phamvancu@hn.vnn.vn
[4]E3P Project Director, CIRAD-Vietnam, vincent.porphyre@cirad.fr

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ABSTRACT

The Red River Delta is the hub of all economic activity in Northern Vietnam. The delta alone contributes 18% of total paddy production in the country. This densely populated delta is rapidly changing its agriculture activities to urban. Changing environment is degrading natural resources and greeneries, making water pollution and pushing human health into hazard are major concerns in the delta. In this study, Thai Binh as a representative province in the delta is selected for environmental changes analysis. The main objective of the study is to monitor the environmental changes and help to develop a RS&GIS based diagnostic methodology for pig production at the province. Four LANDSAT satellite images taken in different time period of past two and half decades were used for environmental changes monitoring. ERDAS Imagine and Microsoft Excel software were used for processing the images, analyzing and presenting the results. Four types of spectral signature normalization techniques namely SAVI, BSI, NDWI and UI were applied in each image. The normalized images were further quantified at commune level by computing mean and standard deviation. The mean and standard deviation were evaluated carefully for environmental changes analysis. Natural vegetation and conventional agriculture areas were in decreasing trends but water related activities such as aquatic farming were observed as increasing. Strong negative correlation was found between vegetation and urban index, which interprets less vegetation mainly due to occupancy of land by growing urban activities. These results will be very useful in developing diagnostic methodology further. The methodology used in this paper is easy to use and good enough for environmental and urban change analysis at provincial level, which may help the environmental planners and decision-makers for preparing sustainable environmental planning in the province.

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Presenter and contact: Rajesh Bahadur THAPA

Authors

Rajesh Bahadur THAPA
Key qualification: Spatial Analysis and Modeling.
Research Associate
Remote Sensing and GIS
School of Advanced Technologies

Asian Institute of Technology
P O Box 4, Klong Luang,
Pathumthani 12120, Thailand
Phone: +66 2 5246406, Fax +66 2 5245597
Email: thaparb@yahoo.com

Frederic BORNE
Specialization: Image Analysis, Image Processing, Texture Analysis, 3D Landscape Modeling, Linkage between plant growth modeling and RS/GIS applications
Assistant Professor, AIT-Thailand
CIRAD-France
Centre de Coopération Internationale en Recherche Agronomique pour le Développement
Département AMIS, Amélioration des Méthodes pour l'Innovation Scientifique,
UMR T51 AMAP, Modélisation de l'Architecture des Plantes,
TA40/PS2, Boulevard de la Lironde
34398 MONTPELLIER CEDEX 5, FRANCE
Tel: +33-4 67 61 75 25
Fax: +33-4 67 61 56 68
Email: borne@cirad.fr

Pham Van CU
Specialization: Geomorphology, GIS and Remote Sensing
Professor/Director
Institute of Geology
National Center for Sciences and Technology, Vietnam
Tel: +84-4-83-51493
Fax: +84-4-83-59335
Email: phamvancu@hn.vnn.vn

Vincent PORPHYRE
Specialization: Veterinary medicine, DESS Animal Production in Tropical Regions, CES Statistical methods and medical epidemiology.
Project Director
Asia Pro Eco Programme / E3P Diagnostic Project
CIRAD-Vietnam
Tel:
Fax:
Email: vincent.porphyre@cirad.fr

1. Introduction

The speed of urban growth and land use change might raise many problems such as inadequate infrastructure, population and employment pressure, overcrowding, slum occurred from low-income groups, fresh nutrient rich food insecurity and environmental degradation (Thapa et al, 2004). The challenge of supplying nutritionally adequate and safe food to city dwellers is substantial. Accomplishing these task under conditions of growth and congestion demands that policy-makers seize opportunities for integrating resource management and planning efforts, understanding potential linkages between rural and urban areas, and anticipating the changing needs of a country's citizens – both rural and urban (Nugent and Drescher, 2000). Urban food supply (especially fresh nutrient-rich food) increment, employment and income generation, urban environment improvement, global food insecurity reduction and preserving the natural areas are the major contributions of agriculture (Borne et al 2003). The sustainable agriculture also depends upon market linkages. The market linkage promotes the spatial integration through economic interaction (Rondinelli, 1985). Since the market town is the main channel through which rural people obtain basic goods and services in return for their agricultural products, the impact of the coordination of marketing systems can have widespread effects and provide substantial benefits to the farmer.

The Red River Delta (RRD) is second rice bowl of Vietnam after Mekong River delta. The delta alone produces 18% of total paddy production in the country (Thapa, 2003). It is now becoming the hub of all economic activity in Northern Vietnam where the majority of the region's population is concentrated. It is under threat due to significant population growth that is putting an increasing strain on resources. Population densities exceed 1000 inhabitants per square kilometer in the delta. Water pollution and Human health are grave risks in this delta area. The RRD is underlain by a number of highly productive aquifers, which are very important both for large-scale water supply and for drinking and domestic purposes in rural areas. But, as recharge is mainly from the river system, rainfall, and irrigation water, water quality depends strongly on human economic activities. Pollution due to agriculture (crops and livestock) is one of the main issues. Fuelled by a growing population, rising incomes and urbanization, demand for livestock products is growing at a dramatic high rate. Thus, livestock production's intensification, and pig production in particular, is bringing authorities and producers together to meet the challenges of the next decades.

2. Study area and objective

The pig production is one of the major official priorities for rural development in Vietnam. On the provincial level, agricultural services have been dedicated to national development plans especially the National Program for Lean Meat Pig Development with clear quantitative goals. Thai Binh province from eastern part of the delta is selected for the study. This province turns already from its low-income rice production (1,050,000 tonnes/ per year) to increase maize and soya bean production (20,000 tonnes and 6,500 tonnes/ year respectively) for animal feeding. Well-balanced pig manure's transfer would remain critical for sustaining soil fertility and would change a polluting material into a fertilizing product. Even if farming systems are mainly based on livestock-crop integration, decision makers are set upon increasing the number of low-land industrial large-scale models. One priority of the province for 2010 is to convert the lower areas used presently for rice culture with very low yields into fish ponds and intensify the production systems by increasing the availability of fish, improving the feeding of fish, manuring of ponds using animal wastes especially pig. Such intensive agricultural methods in the highly populous (1183 persons per square kilometre) province may damage soils, water and other environmental consequences.

The current research aims to highlight existing situation and expected threats against environment. This preliminary work will be the base for a decision making and strengthening tool for the Thai Binh's authorities in order to define urgently suitable technologies for land-use and investment planning, and to enforce the regulation considering environment. The main objective of this paper is to highlight the environmental situation using multi-temporal satellite imageries and contribute to develop a RS&GIS based diagnostic methodology for pig production at the province.

3. Database and methodology

Remote sensing provides an efficient tool to monitor land-cover changes in and around urban areas since the past thirty years. With time series satellite data we can monitor long-term changes. Geographic information system is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose (Thapa et al, 2004; Burrough and McDonnel, 1998; Nualchawee, 1996). Since 1972, Landsat satellites (series 1 to 7) have been providing repetitive, synoptic, global coverage of high-resolution multispectral imagery. The

Landsat sensor that simultaneously records reflected or emitted radiation from the earth's surface in the blue-green, green, red, near-infrared, mid-infrared, and the far-infrared portions of the electromagnetic spectrum (NASA, 2003). Landsat data have potential applications for monitoring the conditions of the Earth's land surface. The characteristics of the MSS and TM bands with different electromagnetic region (table 1) were selected to maximize detecting and monitoring different types of Earth resources. Landsat 1 to 4 and 6 were decommissioned in the past. Currently, Landsat 5 and 7 are working with 15 to 60 meter ground resolution from the altitude of 705 km.

Table 1: Landsat characteristics

Sensor	Band	Spectral Range (μm)	Resolutions (m)
PAN ETM+	8	0.52-0.90	15
TM, MS	1(blue)	0.45-0.52	30
	2(green)	0.52-0.60	
	3(red)	0.63-0.69	
	4(nir)	0.76-0.90	
	5(swir)	1.55-1.75	
	6(fir)	10.40-12.50	60
	7(swir$_2$)	2.08-2.35	30

Efficient integration of temporal, spectral and spatial resolution information is important for analysing and mapping of environmental change analysis (Thapa, 2003). Multi-sensor and multi-temporal data are useful for assessing change dynamics but seasonal variances could affect in images for quantitative analysis (Doung et al, 2003). Multi-temporal Landsat images of two and half decades (table 2) were analysed for environmental change analysis in Thai Binh province. ERDAS Imagine and Excel software were used for image processing, analysing and presenting the results.

Table 2: Database used for change analysis

Database	Date	Available bands	Source
MSS	1975 December	4	GLCF
TM	1989 November	7	GLCF
ETM	2001 November	5	VTGEO
ETM	2001 September	8	GLCF
GIS data	Boundary map		VTGEO

Remotely sensed data always experience some geometric distortion due to various causes such as earth's rotation, platform's instability, etc (Richards and Jia, 1999). Therefore, geometric correction (figure 3.1) was performed as a primary step while processing the images. ETM (2001 November) image was geometrically corrected to UTM WGS-84 Projection system in Zone 48N using ortho-rectified image of 2001 September. Image sub-setting is necessary to avoid the unnecessary volume of data (Thapa, 2003), which can help to reduce the image processing time as well as the storing space. The boundary map of Thai Binh province was set as a region of interest (ROI) while sub-setting the all images. Soil Adjusted Vegetation Index (SAVI, eq 1) was computed for each image to identify the greenery patterns in the province.

$$SAVI = \left[\frac{\lambda_{NIR} - \lambda_{RED}}{\lambda_{NIR} + \lambda_{RED} + L} (1 + L) \right] + 1 \quad \text{................(eq 1)}$$

Note: $\lambda = wavelength, L = 0.5$

This index computes the ratio between red and near infrared spectral region with some added terms to adjust for different brightness of background soil (Huete, 1988). Due to paddy harvested time ends in October, the result of SAVI images during November-December presents the situation of natural vegetation in the province. The SAVI image of September helps to understand the agricultural activities in greater details. The Normalized Differential Water Index (NDWI, eq 2) was used to oversee the situation of water in the province. The ratio between red and swir spectral region clearly enhanced water bodies to the brighter pixels (CPM, 2003).

$$NDWI = \frac{\lambda_{RED} - \lambda_{SWIR}}{\lambda_{RED} + \lambda_{SWIR}} + 1 \text{ ....(eq 2)}$$

Bare Soil Index (BSI, eq 3) was also computed to identify difference between agriculture and none agriculture vegetation. The bare soil areas, fallow lands, vegetation with marked background response are enhanced using the BSI index (Jamalabad and Abkar, 2004).

$$BSI = \frac{(\lambda_{SWIR} + \lambda_{RED}) - (\lambda_{NIR} + \lambda_{BLUE})}{(\lambda_{SWIR} + \lambda_{RED}) + (\lambda_{NIR} + \lambda_{BLUE})} + 1 \text{ ....(eq 3)}$$

Urban index mostly enhanced the urban activities such as housing, road, industrial complex and so on (Thapa 2003). Kawamura et al (2003) suggested Urban Index (UI, eq 4) was applied in September 2001 images for detecting the urban built-up areas.

$$UI = \frac{\lambda_{SWIR2} - \lambda_{RED}}{\lambda_{SWIR2} + \lambda_{RED}} + 1 \text{ .... (eq 4)}$$

Originally all the equations produce relative value ranges from –1 to +1. We have added +1 in each equation to avoid the negative value in further analysis. Therefore, the entire resulted images will have the value between 0~2 where higher value represents better existences of the selected environmental parameters (SAVI, NDWI, BSI and UI). Mean (eq 5) and Standard Deviation (eq 6) were computed from each index at commune level that improves the evaluation procedure of environmental situation.

$$Mean(\mu) = \frac{\sum X}{n} \text{ .... (eq 5)}$$

$$Std.Dev(\sigma) = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \mu)^2}{n-1}} \text{ .... (eq 6)}$$

X = a set of value and n = number.

Furthermore, correlation coefficient (eq 7) is also computed to see the relation between vegetation and urban activities.

$$\text{Correlation coefficient}(r) = \frac{\sum_{i=1}^{n} z_X z_Y}{n-1} \text{ ....(eq 7)}$$

Where z can be computed as $z = \frac{X - \mu}{\sigma}$

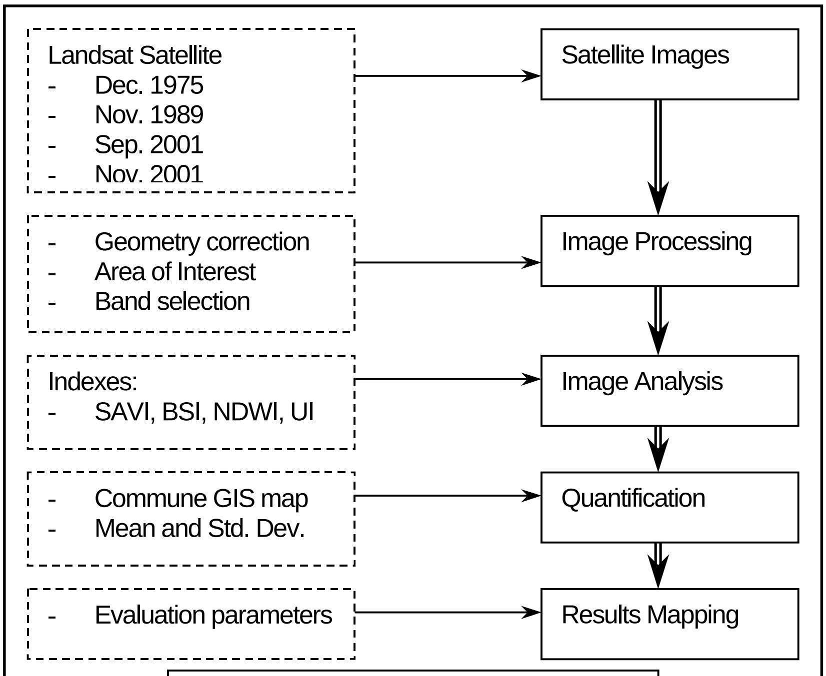

Figure 3.1: Methodology design

4. Results and Discussion

SAVI, BSI, NDWI and UI indexes were computed in multi-temporal Landsat images and tried to analyze the environmental changes in respect of vegetation, agriculture, water and urban activities. The indexes have produced relative results based on electromagnetic spectrum recorded in the images. The mean score and coefficient of standard deviation of each index were carefully evaluated at commune level. Standard deviation of mean helped to understand the distribution pattern of the objects in land surface. Principally the SAVI shows brighter in healthy vegetation areas whereas BSI seems brighter in bare land areas. Water can be seen as brighter in NDWI index where urban areas more highlight in UI index.

The SAVI index of 1975 (figure 4.1), 1989 (figure 4.2) and 2001 (figure 4.3) are displaying the representation of natural vegetation coverage in brighter areas. The result of SAVI (figure 4.4) has brighter areas more compared to other SAVI images. It is because of seasonal variance in agriculture practices. High content of chlorophyll can be observed in paddy field in September. Paddy is completely harvested until end of October. So the image taken in November and December shows the harvested paddy field making bare soil index (figure 4.7) brighter in corresponding pixels of SAVI figure 4.4. Some inconsistencies in distribution pattern of the mean of SAVI are observed in some communes. Decreasing trend of natural vegetation is observed in past three decades (figure 4.5). Bare soil index of 2001 (figure 4.6) is also getting lower as compared to year 1989 (figure 4.7 and 4.8) results. Mean distribution of the bare soil index seems more consistent as compared to SAVI mean. Comparison of BSI (figure 4.7) with SAVI (figure 4.4) makes sense of conventional agriculture occupancy as well as practices. There are not so much fluctuations in distribution of objects in BSI. Decreasing patterns in SAVI and BSI exposed the decreasing of conventional agriculture practices (i.e. paddy).

The result of NDWI is quite different than SAVI and BSI. Increasing pattern is observed in water bodies (figure 4.9, 4.10 and 4.11) although inconsistency in distribution of the water bodies is found in some communes. Several farmers in the province are changing their traditional agriculture land to modern aquatic practices. It is one of the major factors that increased the water properties and reduced the vegetation properties as compared to 1980s. Direct relation of fish farms to the pig production was observed during field visit. Pig waste is being used as a source of input for aquatic farming fertilization of ponds, nutrient for fishes. Due to high demand of lean pork meat to the growing cities and flexible government policies farmers are attracted to the integrated agriculture practices (pig and fish ponds). There is very good compromise between water index (figure 4.12) and urban index (figure 4.13). Most of the urban functions are observed along the water bodies; near by rivers, canals and lakes. The increased urban activities in the province do not have significant impact in reducing water properties. But it has significant impact in reducing the vegetation. The figure 4.14 has clearly shown the decreasing of agriculture land because of urban activities. The UI mean increased as a peak in some communes whereas the SAVI mean decreased just like a gorge in the corresponding communes. So, the land of agriculture is being occupied by urban function. The conversion of agriculture land to urban uses is natural economic process in widely growing human population. Relation between vegetation activities and urban function was checked in September 2001 results and found correlation coefficient at –0.606. It has strong negative linear relation between the UI and SAVI mean, which suggest the urban activities replacing the natural environment significantly. So vegetation is getting sparse day by day because of growing urban activities, integrated agriculture practices, government priorities on intensification of pig production and aquatic products, and so on.

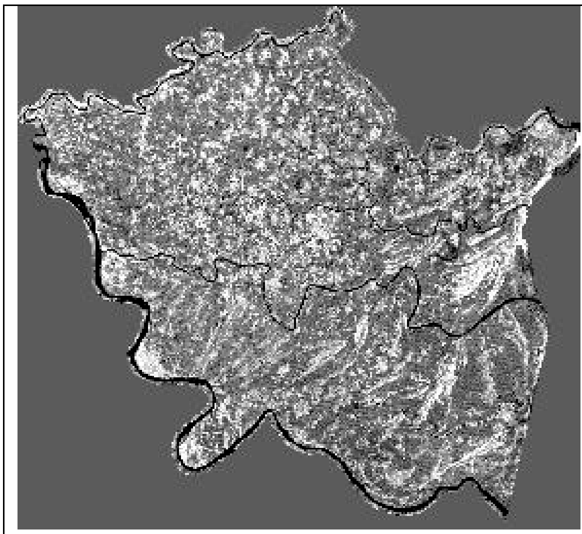

Figure 4.1: SAVI 1975 Dec.

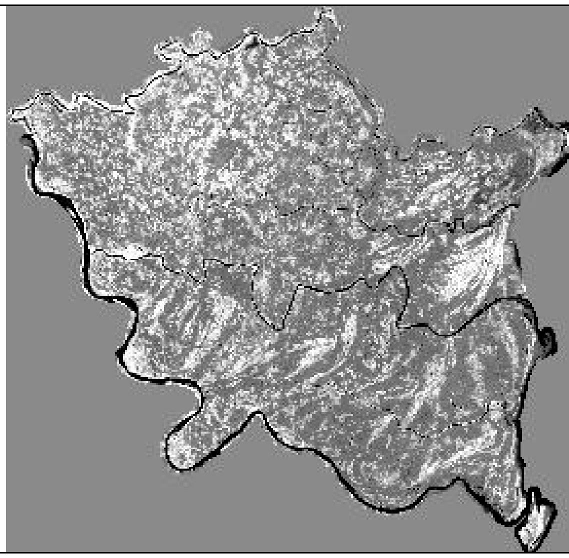

Figure 4.2: SAVI 1989 Nov.

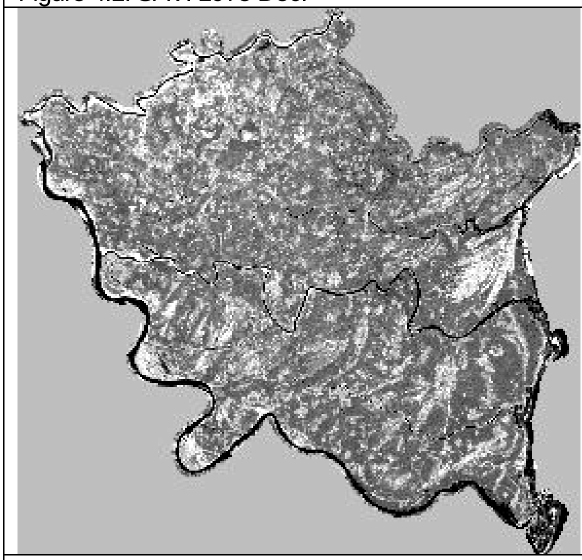

Figure 4.3: SAVI 2001 Nov.

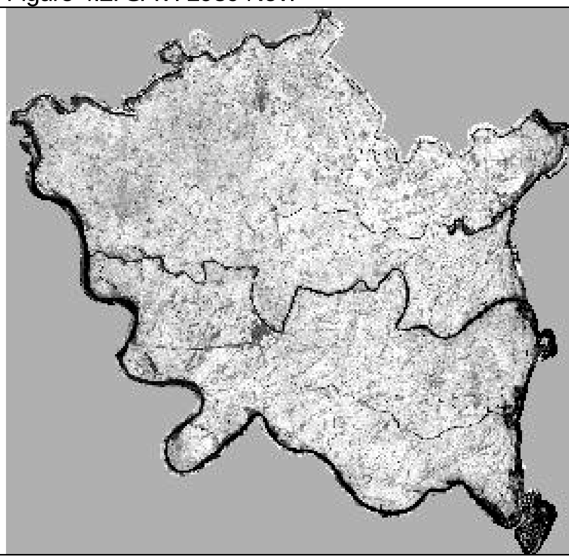

Figure 4.4: SAVI 2001 Sept.

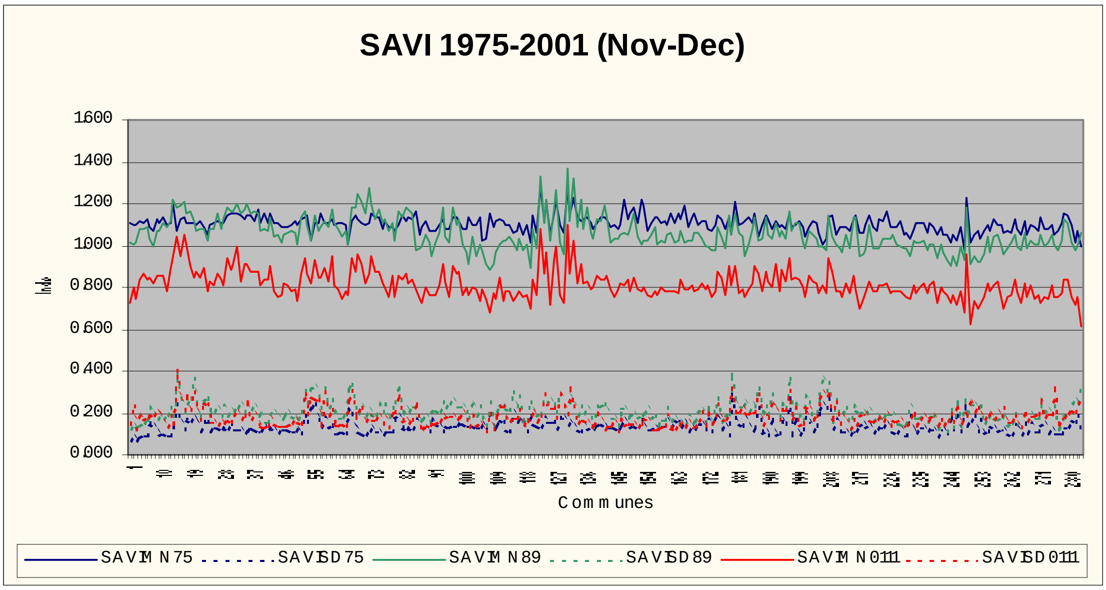

Figure 4.5: Soil Adjusted Vegetation Index 1975-2001 (Mean & Std. Dev.)

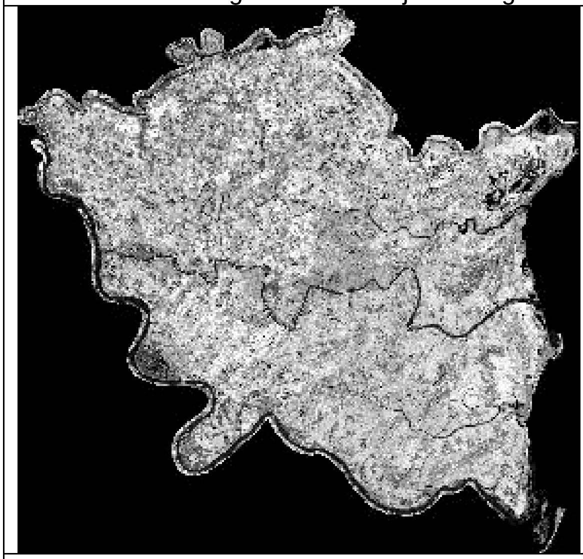

Figure 4.6: Bare Soil Index 1989 Nov.

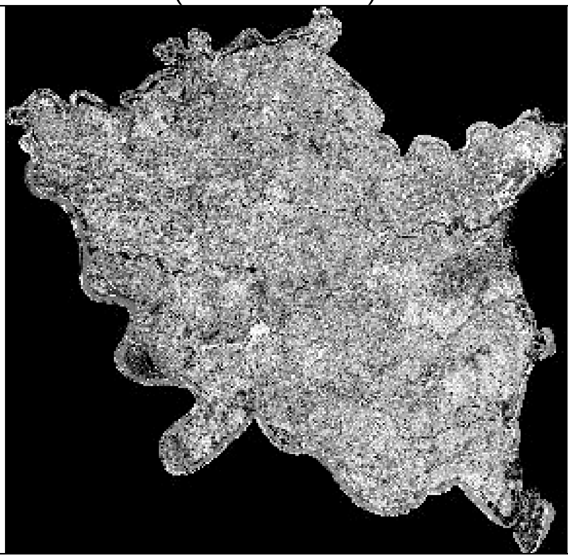

Figure 4.7: Bare Soil Index 2001 Nov.

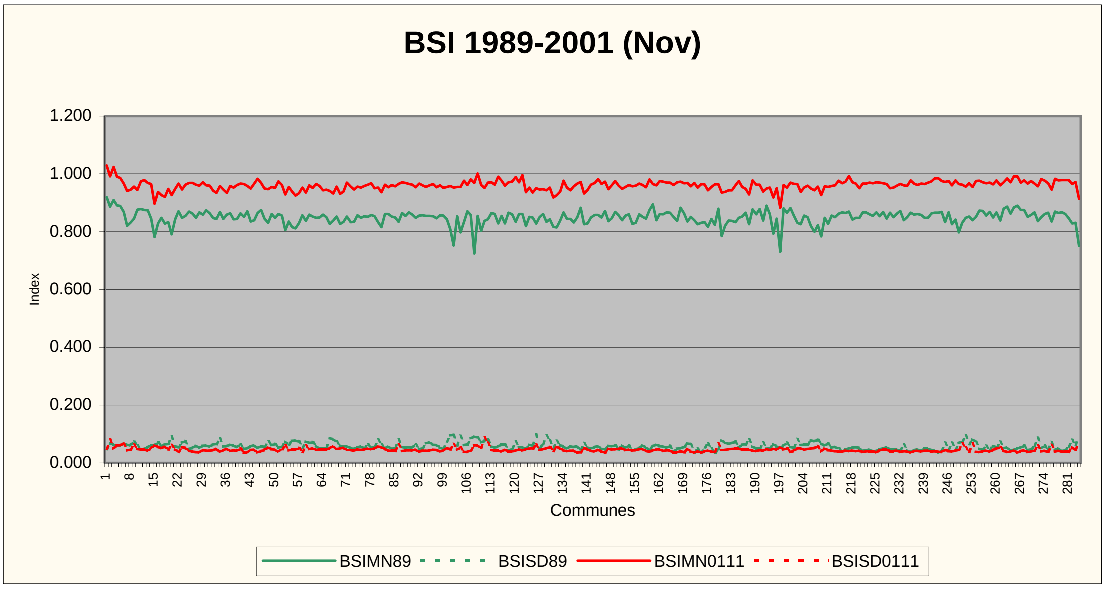

Figure 4.8: Bare Soil Index 1989-2001 (Mean & Std. Dev.)

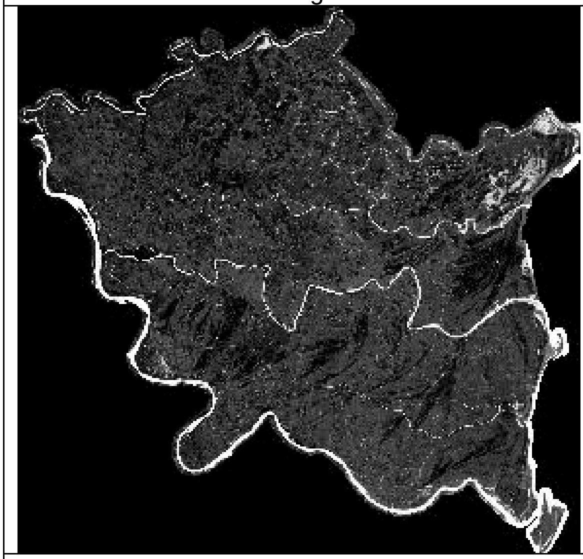

Figure 4.9: NDWI 1989 (Nov.)

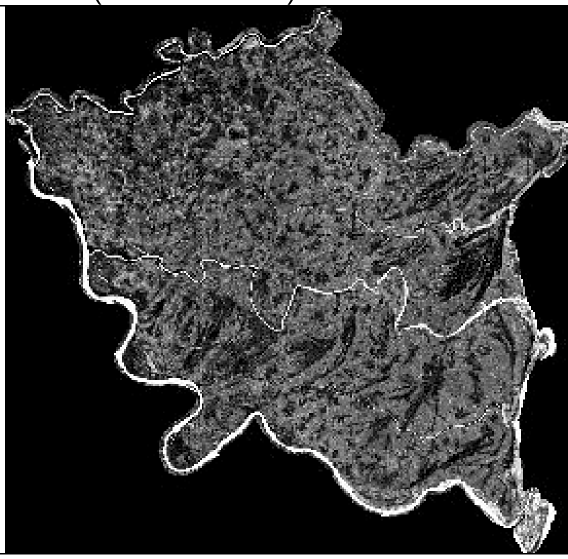

Figure 4.10: NDWI 2001 (Nov.)

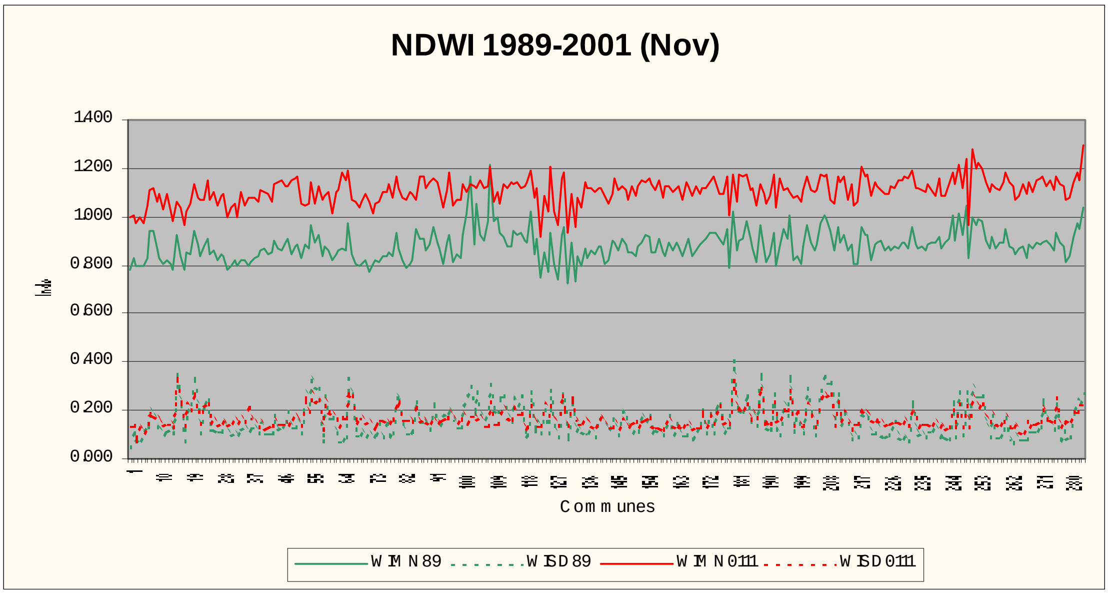

Figure 4.11: Normalized Differential Water Index 1989-2001 (Mean & Std. Dev.)

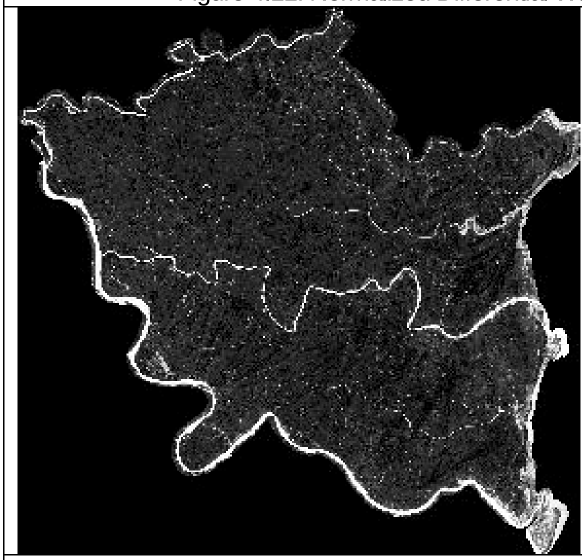

Figure 4.12: NDWI 2001 (Sept.)

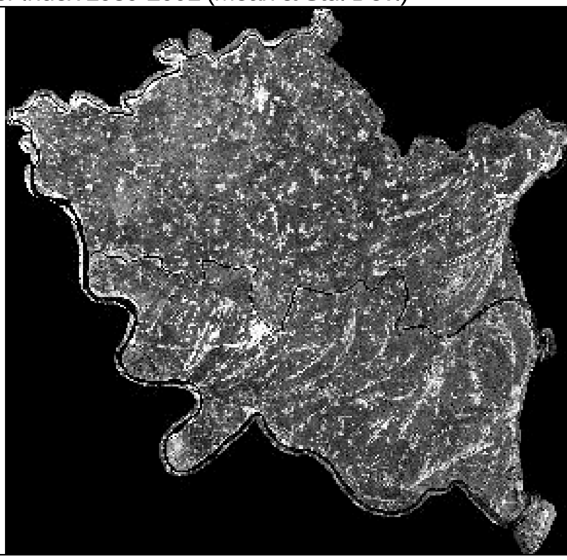

Figure 4.13: UI 2001 (Sept.)

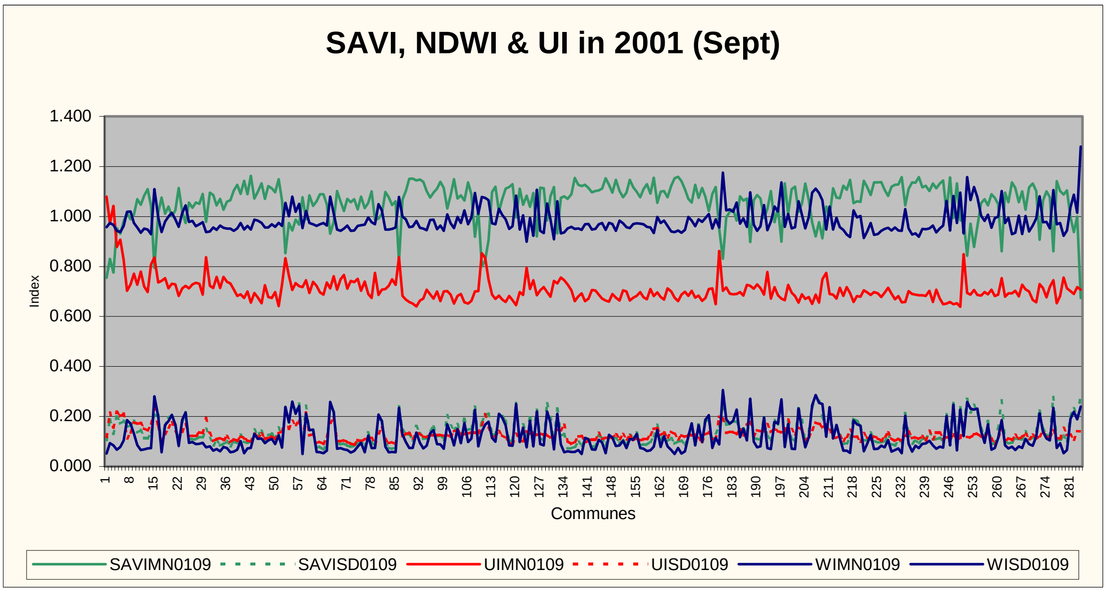

Figure 4.14: SAVI, WI, UI 2001 September

5. Conclusion

The time series Landsat satellite images are found very resourceful to monitor and analyze the changes of environment in Thai Binh province. The province is an agricultural province where much of the land is being used for paddy production. During the past two and half decades, natural vegetation and conventional agriculture areas were in decreasing trends but the water related activities such as integrated aquatic farming was observed as increasing. It does not reflect the water resources increasing and water quality as well. Urban houses and intensified aquatic projects replaced the vegetation. Strong negative linear correlation was found between vegetation and urban index, which interprets less vegetation mainly due to growing urban activities. Greenery in the province is in decreasing order. But the growing population needs healthy environment, more greenery for better living. Balance between pig production and required land surfaces to manage animal effluents are also mandatory. Although it is a preliminary result of the diagnostic project, it is urgent necessary to review the ongoing activities, monitor the water and soil quality at larger scale and make policies to maintain the minimum greeneries in the province. These results will be very useful in developing diagnostic methodology further. The methodology used in this paper is easy to use and good enough for environmental change analysis at province level, which may help the environmental planners and decision-makers for preparing sustainable environmental planning in the province.

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