Comparison of Strengths and Weaknesses of NDVI and Landscape-Ecological Mapping Techniques for Developing an Integrated Land Use Mapping Approach

A case study of the Mekong delta, Vietnam

Amjad Ali

February, 2009

Comparison of Strengths and Weaknesses of NDVI and Landscape-Ecological Mapping techniques for Developing an Integrated Land use Mapping Approach

A case study of the Mekong delta, Vietnam

Amjad Ali

February, 2009

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation - Natural Resources Management

Thesis Assessment Board

Chairman: Dr. Ir. E.M.A. Smaling (Department of Natural Resources, ITC)
External examiner: Dr.ir. B.G.J.S. Sonneveld (University of Amsterdam)
Supervisor: Dr. Ir. C.A.J.M. de Bie (Department of Natural Resources, ITC)

Supervisors:

First Supervisor: Dr. Ir. C.A.J.M. de Bie (Department of Natural Resources, ITC)

Second Supervisor: Dr. Ir. E.M.A. Smaling (Department of Natural Resources, ITC)

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

Land use mapping is important for the monitoring and planning of agricultural resources at local, regional and continental levels. The research objective of this study was to identify the comparative strengths and weaknesses of the NDVI versus Landscape-Ecological land use mapping techniques to develop an Integrated Approach. Both techniques were applied separately and identified their strengths and weaknesses. Next, both methods were combined in an Integrated Approach. The NDVI and the Landscape-Ecological Approach used existing methods with available remote sensing and other ancillary data to map agricultural land use systems of the Mekong delta Vietnam. The map produced by NDVI Approach showed 92% and 88% correlation with reported crop statistics, in two and three rice land use systems, with R^2 of 74% and 76% respectively. The Landscape-Ecological Map was also significantly correlated with crops statistics in two rice crops (65%) and three rice crops land use systems (62%) with 64% and 63% explained variability. Keeping in view the strengths and weaknesses, the NDVI Approach was found more accurate, cheap, efficient and useful for agricultural land use mapping in tropical environment than Landscape-Ecological Approach. Regarding Integrated approach, there was significant positive association ($\chi2 = 57.78$, d.f. = 1, N = 106, $p < 0.01$) between land use systems of both the NDVI Map and the Landscape-Ecological Map. Association between flooding regimes and geomorphology was although significant ($\chi2 = 64.54$, d.f. = 12, N = 507, $p < 0.01$) but no strong trends emerged between the classes. Therefore the results of the integrated approach were less clear and complex, hence less useful for improvement in interpretation of agricultural land use systems. Finally geomorphology and soil information were added as additional legends to the NDVI map, because the NDVI Map proved more informative and accurate by explaining 10% more variability than Landscape-Ecological Map. The approach followed in this study can play a key role in characterizing agricultural land use systems and landscape of the area but require further studies to be proved effective.

Keywords: Agriculture; Mapping; Land Use; NDVI; Landscape-Ecological; Integrated approach.

DEDICATION

This thesis is dedicated to Maj Gen (Retd) Raza Husain, who is a constant source of inspiration to my life, and Brig (Retd) Qaiser Viqar Naqvi, who instilled in me the drive and determination to pursue my goals.

All glory and honour to you

Acknowledgements

This study is result of support of a number of organization and people's. I thank Higher Education Commission (HEC), Pakistan Space and Upper atmosphere Research Commission of Pakistan (SUPARCO) for financing and allowing me to study, Nuffic for helping in this process. Most importantly I express my gratitude to all working in "Pakistan Space and Upper Atmosphere Research Commission" notably Maj Gen (Retd) Raza Hussian and Brig (Retd) Qaiser Viqar Naqvi for their support and encouragement.

I feel great pleasure and honour to express my sincere and heart full thanks to my first Supervisor **Dr. Ir. C.A.J.M. de Bie** for his constant supervision, invaluable guidance, keen interest and encouragement in the completion of this research project. Graceful acknowledgment is made for concerted technical guidance and wise counselling received from **Prof Dr. Ir. E.M.A. Smaling**.

I am indebted to the honourable Course Director Dr Michael Weir and MSc advisor for their kind efforts and directions that enabled me to accomplish this degree. Special thanks are extended to all staff and faculty members of NRM department for their help throughout my study in ITC.

Special thanks are extended to the people of the Mekong Delta, Vietnam especially farmers, for their cooperation during field work. I must thank Miss Ha Thi Nguyen (ITC PhD scholar) for their work and outstanding help; she did in guiding and bridging the communication gap between farmers and us.

Special thanks are paid to my sincere friends Muhammad Jahanzeb Malik and Saleem Ullah for their unending kindness and active support throughout my MSC and research work and made this study a success. I assure u guys "I will never forget you". I also acknowledge the services of Mr Muhammad Shafique (DCM) and Mr Muhammad Farooq (Peshawar) in this achievement.

High acknowledgment is made to Mr. Muhammad Shafique, Mr. Mubasher Riaz and Mr. Zahir Ali (PhD Scholars) for their fine cooperation and support that benefited me a lot.

I am grateful to all my friends and colleagues especially Irawam assad, Bramavi Muhammad, Sigit Rustanto , Lelyana Midora (Indonesia), Bharat Babu(Nepal), Rubin, Lucia (Costa Rica), Marcella(Colombia),Claudia Hienze (Germany), Ali Emecen (Turkey), Stella(Uganda) for their unending kindness and active support throughout my MSc.

In the end I would like to cordially thank my parents, brothers, sisters and my family for their support but with an extra sense of gratitude.

"Thank you all"

Amjad Ali.

March 2009

Table of contents

List of figures

List of tables

Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
ETM	Enhanced Thematic Mapper
GLCF	Global Area Coverage
ISODATA	Iterative Self-Organizing Data Analysis Technique
MODIS	Moderate-Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
SPOT 4	Systeme pour l'Observation de la Terre 4
SPOT 5	Systeme pour l'Observation de la Terre 5

1. INTRODUCTION

Land use mapping is required for monitoring and planning of agricultural resources at local, regional and continental levels. Availability of updated and accurate land use information is imperative for planning. In general population growth leads to an increasing demand for food and hence claims more land for food production, characterized by expansion of agriculture into marginal lands, food shortages and conflict in land use decisions (De Bie, 2002).

Landscape-ecological information is considered important for management of land use and spatial planning tasks by contributing to a better understanding of the structure and functions of the area (Forman and Godron 1986; Turner 1989; Groten *et al*., 1994; Blaschke and Strobl, 2001; Raupach and Finnigan, 1997). Landscape influence the flow of materials such as sediment or nutrients (Dalrymple 1968) and other ecologically important processes like species distribution, water flows etc (Turner,1989; Hunsaker, 1992; Forman, 1995, Wondzell, 1996). In many studies, landscapes have been assessed for their effects on land use systems (Groten *et al*., 1994; Moody, 1998; Sader *et al.,* 2003; Vogelmann, 1995; Yu and Ng, 2006; Kasper, 2007).

Recent advancement in remote sensing and geographical information systems has made available a wide variety of data and it is now possible to handle, compare, and integrate landscape data at a range of different scales. So mapping by landscape ecological approach is feasible and it can be helpful regarding land and land use aspects e.g. flooding, soil hazards, nutrients and water availability.

Satellite remote sensing can observe the same area periodically within certain intervals of time which is necessary to study the temporal aspects of agricultural land use. In the past very little work was focused on this aspect and most of the studies were using images of one time or multiple dates. Recently considerable work has been done to classify land use patterns at the regional scale using hyper temporal data (Roderick et al., 1997; Wardlow *et al.,* 2007; De Bie *et al*., 2008).

Time series data of remote sensing have been proven useful for agriculture and ecological studies due to their easy availability and temporal coverage to study dynamic aspects of crop phenology, cropping systems and crop calendars (Reed *et al.,* 1994; Cayrol *et al*., 2000; Toshihiro, 2006). Use of vegetation indices for monitoring and classification of vegetation is a widespread technique (DeFries and Townshend, 1994) and relationships between such indices and green biomass have been proved by many authors (Unganai and Kogan, 1998; Archer, 2004; Davenport and Nicholson, 1993). In recent, the use of NOAA/AVHRR, MODIS and SPOT Vegetation data has offered opportunity to study these aspects of land use in detail (Wessel *et al.,* 2004; Toshihiro, 2006; De Bie *et al*., 2008).

A number of studies have either used the landscape or the NDVI approach (e.g. Baatz & Schäpe 2000; Tilton & Lawrence 2000; De Bie *et al.,* 2008), but none of them specifically made comparison and hence no integration of these two. In order to evaluate the strengths of each method, this study will apply both methods separately. After validation and study of their comparative strengths, an integrated approach will be worked out that will generate a hierarchical structure of segments based on spatial similarity of landscape attributes and temporal profiles of different agricultural land use systems. The field work was carried out in the Mekong delta, Vietnam.

1.1. Mapping Approaches

1.1.1. NDVI Approach

NDVI is an extensively used index for vegetation studies using remote sensing and is defined as: the ratio of near infrared (NIR) and red (R) reflectance.

$$NDVI = \frac{NIR - Red}{NIR - Red}$$

The Normalized difference vegetation index (NDVI) provides an effective measure of photosynthetically active biomass (Sarkar and Kafatos, 2004; Maggi and Stroppiana, 2002).

Some studies found temporal NDVI profiles suitable for studying vegetation phenologies of crops (Groten and Octare, 2002; Gorham, 1998; Hill and Donald, 2003; Murakami *et al*., 2001). Many studies to map land cover phenology, dynamics and degradation used multi temporal NDVI data (Cayrol *et al*., 2000; Budde *et al*., 2004; Eerens *et al*., 2001; Brand and Malthus, 2004). The time series analysis of Normalized Difference Vegetation Index (NDVI) imagery is a powerful tool in studying land use and precipitation interaction in data scarce and inaccessible areas, and the expected NDVI behavior of the upcoming season could be forecast for food security purpose (Immerzeel 2005). NDVI may be used to characterize the temporal extent of the growing season and productive potential of agricultural land on a regional basis (Roderick *et al.,* 1997).

Hyper temporal NDVI has been recently worked out for land use mapping and found very effective by De Bie *et al.,* 2008. Hyper-temporal images are those that are acquired at a "reasonably" fixed time, say every week or every month. They are like hyper-spectral, using many different wavelength bands to extract more information. Instead, they use many different time periods of the same image. They can be used with supervised and unsupervised classification techniques to find out what areas behave in a similar fashion temporally e.g. seasonal variation (De Bie *et al.,* 2008; McCloy, 2006).

1.1.2. Landscape-Ecological Approach

Landscape-Ecology is “the study of land as an ecosystem, which is a system of all biotic and abiotic factors in a certain area at the surface of the earth, it comprises the survey of the spatial, temporal and functional relationships between the landscape components” (Groten *et al*., 1994).

The impact of landscape on land use necessitates a detailed knowledge of the landscape; as land ecology and land use is considered important for planning and decision making in natural resource management (Groten *et al*., 1994). Similarly Turner (1989) considered the landscape composition and configuration, an important function influencing ecosystem and habitat quality.

Landscape influences the migration and accumulation of substances moved by gravity along the land surface and in the soil (Gerrard, 1981); some climatic and meteorological characteristics (Raupach and Finnigan, 1997), soil formation (Huggett, 1975) and vegetation cover properties (Kirkby, 1995). Strahler (1981) and Franklin *et al.,* (1986) used a strategy of scene stratification 1) to improve the classification of forest vegetation at a regional level; and 2) to improve a timber inventory. They employed elevation, gradient and aspect masks. Florinsky and Kuryakova, (1996) showed that vegetation properties correlate strongly with elevation, gradient, aspect, specific catchments area, topographic and stream power indices in a mountainous boreal region. Nguyen *et al., (*1993) considered it important to study landform units and their characteristics for land use planning.

1.2. Problem Statement

The challenges involved in land use studies, are the integration of spatial, temporal and landscape characteristics for land use mapping because agriculture success mainly depends upon these aspects. Similarly huge diversity in methods, spatial and temporal scales stresses for studying strengths and weaknesses or complementarities of approaches. So different potential study approaches like Landscape-Ecological and Hyper temporal NDVI mapping approaches required to be tested for their strengths and weaknesses and integration to produce useful information with sufficient accuracy. This study will first evaluate the hyper temporal NDVI and Landscape-Ecological approaches and then based on their weaknesses and strengths, propose the most useful and accurate approach for agricultural land use mapping.

1.3. Research Objective

The Research Objective is to identify comparative strengths and weaknesses of the hyper-temporal NDVI mapping versus Landscape-Ecological techniques to develop an integrated land use mapping approach.

1.4. Research Questions

1. Which primary and secondary data/maps are used at what methodological steps in the Hyper-temporal NDVI and in the Landscape-Ecological mapping approaches?
2. How to identify strengths and weaknesses by mapping methods?
3. How to integrate the strengths of each mapping techniques into one approach?

1.5. Hypothesis

If the area stratification of the Integrated Approach is derived from combining/crossing land units of the individual approaches then the hypothesis would be as follows:

- The coefficient of determination (R^2) using published crop statistics and the map of the Integrated Approach are 10% better than the R^2 when using the Maps of each underlying approaches separately.

Otherwise the following hypothesis will be tested:

- The map produced by the NDVI Approach explains 10% more variability (R^2) of the published crop statistics than the map produced by the Landscape-Ecological Approach.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Study Area

The Mekong delta is the southernmost region of Vietnam. It is located in between 8° 30' to 11° 00'N and 10° 30' to 106° 50'E and is bounded by the South China Sea in the east, the Gulf of Thailand in the southwest and Cambodia in the northwest (Figure 1). The Mekong river delta is divided into eleven provinces. The Mekong River is divided into an eastern branch called the Mekong River and western branch, the Bassac River (Nguyen *et al.,* 2000).

The climate of the Mekong Delta is dominated by the Southwest Monsoon and is humid tropical. The rainy season is from May to November. The mean annual rainfall is 1700 mm and temperatures vary around 27-30 °C (Nguyen *et al.,* 2000).

Agriculture is the most important economic activity in the area, an estimated 75% of the population earn their livelihood from agriculture in combination with other activities such as fisheries, livestock and forestry. In the Mekong delta, farmers grow three rice crops, two rice crops or two rice crops with one upland crop per year (Nguyen, 2004).

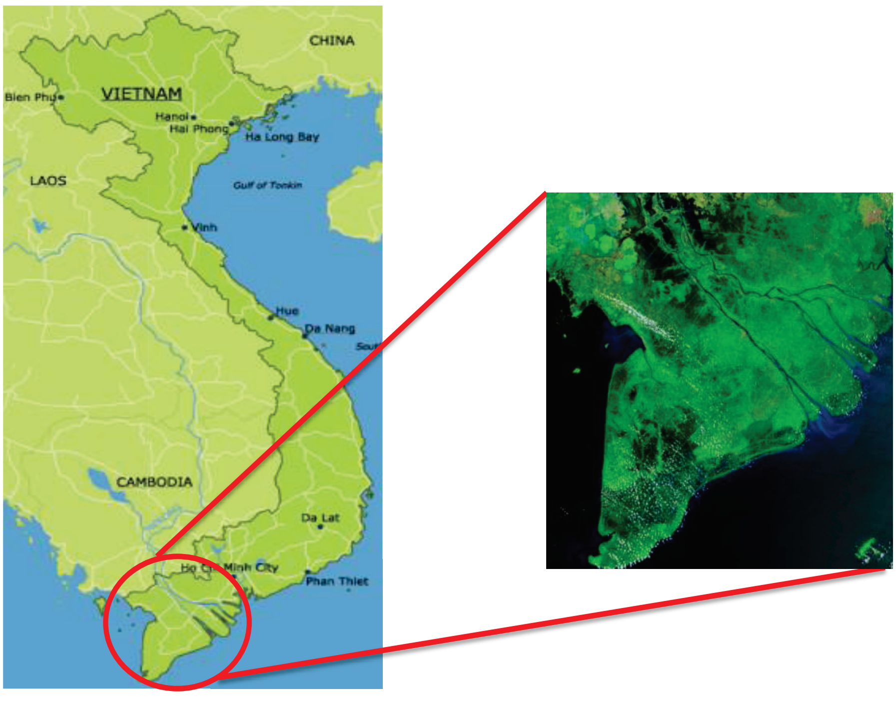


Figure 1: The study area, Mekong delta, situated in South Vietnam

The soils in this region are high in organic matter (5 - 6 %). Floods occur from the middle of August and recede in November and December (De, 2000; Thanh *et al*., 2003). The topography is very flat except for minor areas of hills where hard rocks are exposed; the rest of the delta is occupied by unconsolidated sediments. Although the micro-relief is not large, it greatly influences agricultural production through differences in water regime and quality of soil (Nguyen, 1993).

2.1.2. Data Used

a) Primary Data

Field data including crop calendar information, land observations, coordinates (training data for mapping) were collected from the 20th of September to the 20th of October 2008. The survey yielded 118 digitized fields with cropping patterns/crop calendars data collected from the farmers through interviews (Appendix 1). The spatial distribution of surveyed fields was based on the prepared NDVI map and on the availability of farmers (Appendix 2).

b) Secondary Data

Secondary data used to carry out this study are shown in Table 1 and Table 2.

Table 1: Remote sensing data used in the study

Theme	Description	Source	Year	Resolution
ETM+	images	Landsat 7 (GLCF)	Mosaic Image 1989, 1st December 1992, 6th November 2000, 11th December 2001, 6th January 2001, 4th March 2001,16th January 2002, 4th March 2002, 5th March 2002, 7th March 2002, 17th March 2002.	30*30m
NDVI images	10 day composites	SPOT 4 and SPOT 5 vegetation(www. VGT.vito.be)	April 1998 to January 2008	1 km^2

Table 2: Secondary Data used in the study

Theme	Description	Source
Geomorphology map	Geomorphology classes distribution in the Mekong Delta	Haruyama and Shida (2008)
Soil map	Soil characteristics	Yamashita (2005), Minh (1995)
Topographic map	Topography and other detailed information	Can Tho University Vietnam*
Flooding Map	Inundation depths	Yamashita (2005), Minh (1995)
Administrative areas map	District's boundaries	Ministry of Natural Resources and Environment**
Elevation Data	Detailed Elevation points of the delta	Ministry of Natural Resources and Environment**
Land use statistics	Crops, seasons, areas, production	General Statistics office of Vietnam***
Land use Map 2005	Land use Information	Can Tho University, Vietnam*

*Department of Agriculture, Can Tho University, Vietnam.

**Ministry of Natural Resources and Environment, Vietnam.

***Statistical Year Book, 2007, Land Use Statistics, General Statistics office of Vietnam.

2.1.3. Software Used

Software such as Arcpad using Ipaq was used for navigation and digitizing surveyed fields during field work. ArcGIS 9.2 was used for data preparation, analysis and map composition. Erdas Imagine was used for image processing. Microsoft office (Word and Excel) and SPSS was used for reporting and analyses.

2.2. Methods

2.2.1. Methodological Approach

Figure 2 shows the methodology, which is explained in detail in the following sections.

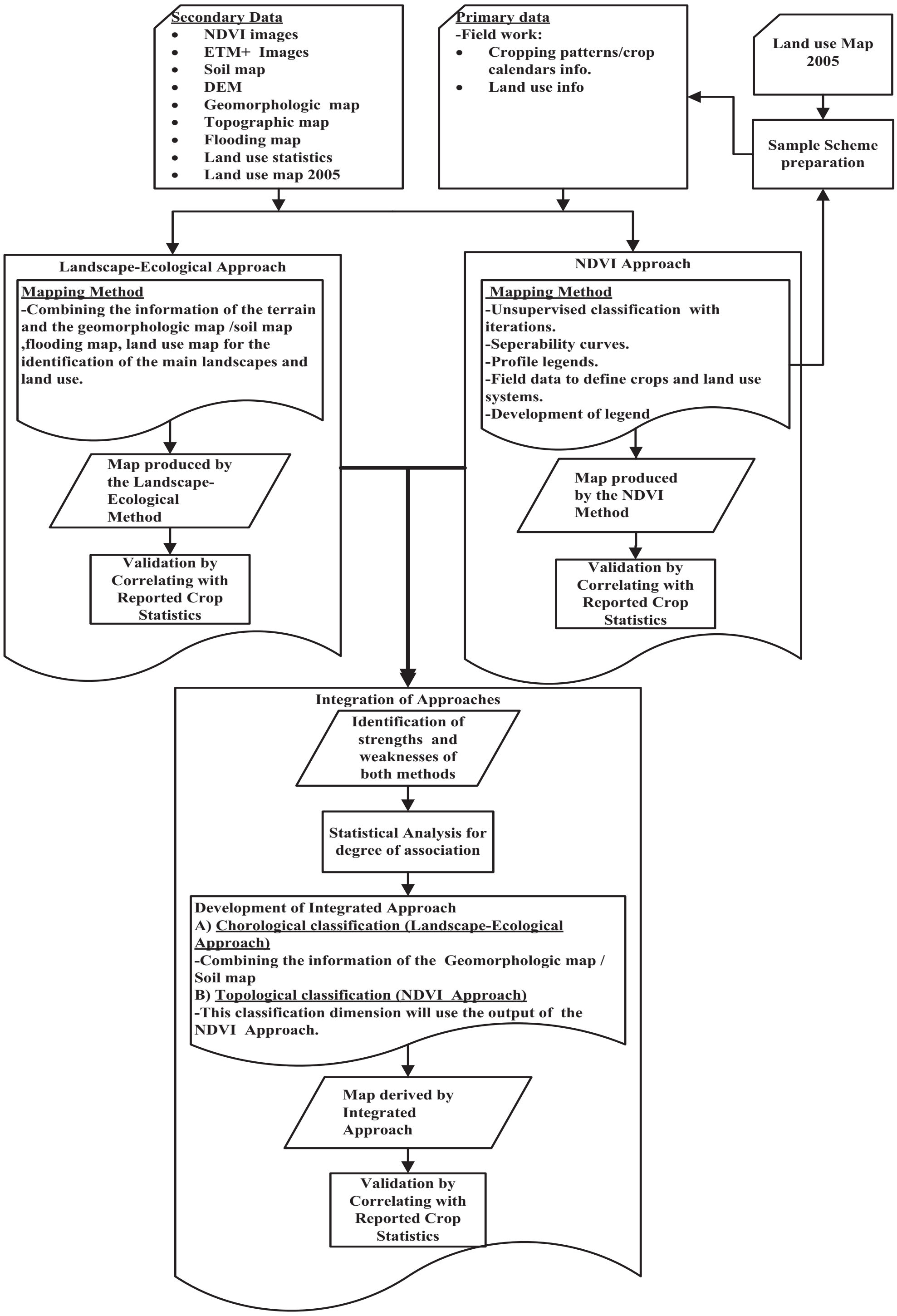


Figure 2: Research Methodology

2.2.2. Field Work

Before field work literature search, pre-processing of images, arrangement of remote sensing data to be used in the field for navigation was done. Preparation of a data form for interview, field observation / sample data collection sheet and organization of field equipment and logistics was also carried out.

Two types of data were collected during the field work. Primary data composed of field data and interview data. Secondary data (maps / statistics etc) were collected from different sources. Sample fields selection was stratified clustered based on the unsupervised NDVI map units. The availability of farmers played a decisive role on final selection (Biging *et al.*, 1999, Lunneta and Elvidge, 1999).

Crop calendar data collected through interviews were used to distinguish rice land use systems. Field data like digitized fields were used for spatial distribution of the different land use systems and soil analysis done during field work was quoted as notes within the final legend of the NDVI map.

2.2.3. NDVI Approach

The data was processed using an approach methodology developed by De Bie *et al.,* 2008. The first step was stacking the 10 day composite spot NDVI images from April 1998 to January 2008. Using ISODATA unsupervised classification in Erdas, the stacked NDVI layer was classified with a pre-defined number of classes (10 to 100). The maximum number of iteration was set to 50 and the convergence threshold set to 1.

The best classified image was selected by using the divergence statistics expressed in separability values. The minimum separability denotes the similarity between the two most similar classes, and the average denotes the similarity amongst all classes; both should be high, while the number of classes should remain limited. Finally the 77 class image and NDVI cluster signature with the best minimum divergence and average divergence statistics was chosen for further analysis and study.

The 77 class image and profiles were studied by visual exploration of their temporal and spatial pattern. Crop calendar class recognition was achieved by visual comparison (IMSD, 1995; Kameswara, 1995) and using field data. Comparing NDVI profiles with crop calendar data showed good spatial identification of rice sequential cropping systems (three rice crops, two rice crops and two rice crops with one upland crop). Flooding regime was also detected by associating low NDVI values in mean stacked NDVI image of ten day composites to flooding. Their extent and temporal variation were recorded in the legend as flooding regime. In Mekong the water regime clearly shows that flooding is associated with low NDVI in respective areas and time. Important points in interviews data and soil analysis were used to find notes related to different classes. After this, the NDVI unit map with a detailed legend showing by NDVI unit was produced. The final map was validated using crop statistics, as explained in section 2.2.6.

2.2.4. Landscape-Ecological Approach

The method for landscape mapping used the following steps:

1. Topological overlay of thematic layers of landscape criteria and analyses of their resultant combinations.

2. Aggregating landscape units to the higher hierarchical level.

3. Linking primary data and generating landscape map and legend.

Elevation data was used to detect terrain units. Geomorphology classes used were extracted from the "Geomorphologic land classification map of the Mekong Delta" by Haruyama and Shida (2008). Soil and Inundation maps were obtained from online thesis work of Yamashita, 2005, submitted to Department of Agriculture, Can Tho University, Vietnam.

For land cover and land use, the information collected during the fieldwork and the Land Use map 2005, collected from Can Tho University was used. Only three rice and two rice areas were selected to be used in this study. Satellite images with different acquisition dates and field data was employed to check the map quality and legend entries of the Land Use map 2005 collected from Can Tho University (Table 1). For this purpose Landsat 7 ETM+, false colour composite 453 (RGB), true colour composite 321 (RGB), of different dates for path 153 and 154 and rows 125 and 126 were employed. The best available images used in this study are given in Table 1.

For map and legend construction, the different sources of information were overlaid in GIS to determine the proportion of land in each category. Final Landscape-Ecological map consists of a hierarchical legend using characteristics of geomorphology, soils, flooding (inundation depths), land cover and land use with estimated areas in km^2.
The resultant map was validated with crop statistics per districts as shown in section 2.2.6.

2.2.5. Integrated Approach

Chi-square test statistic was used to find degree of association between the NDVI and the Landscape-Ecological approach. The chi-square test statistic is designed to test that there are associations between the rows and columns of a table. So this test was used to test the hypothesis that there is association between the NDVI approach and Landscape-Ecological approach and also to find the degree of association between flooding regime as outcome of the NDVI approach and geomorphology of the Landscape-Ecological approach. Interpretation was based on P and chi square values. Cross tables showed the relationship and its combinations with percentages (Moore and McCabe, 2007; Rosner, 2000).

After evaluation of the strengths and weaknesses of each approach and finding degree of association, an Integrated Approach based on the Landscape-Ecological units as chorological dimension and the NDVI map units as topological dimension was tried. After combining the information, various land use types based on the NDVI approach were grouped using the Landscape-Ecological criteria. After that, final classification and interpretations were made.

2.2.6. Validation

The resultant NDVI and Landscape maps were validated with crop statistics per districts. Five years (2000-2004) agricultural land use statistics of rice crop were attained from the general statistics office of Vietnam in tabular format. The statistics included area grown in hectare and production in tons reported at district level. The analogue crop area data reported in hectares was entered into Microsoft Excel and an average crop area statistic was calculated for all districts for five years from 2000 to 2004.

During processing the crop statistics were found poorly compiled as in some districts the areas reported were over-estimated even more than the actual areas e.g. Co Do, Tam Binh, Tan An Town, Than Tri, Vung Liem, Tra On, Tra Vinh town districts. Similarly the seasons reported were also not very clear, keeping in view the crop calendar data collected during filed work.

To validate the maps, the land use classes from the estimated maps were correlated with land use classes in reported crop statistics of Mekong delta Vietnam, using simple linear regression. Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. Coefficient of correlation and R^2 were interpreted for results along with 1-1 line comparison with regression line (Moore and McCabe 2007).

3. RESULTS

The results covered the methodological steps of the two approaches, comparative analysis of both methods and their integration.

3.1. Mapping Approaches

3.1.1. NDVI Approach

3.1.1.1. Methodological Steps

Geo-referenced and de-clouded SPOT- 4 Vegetation 10-day composite NDVI images (S10 product) at 1-km^2 resolution from April 1998 to January 2008 as obtained from www.VGT.vito.be were used in this study. Its specifications were well adapted for terrestrial application like land cover mapping (de Wit and Boogaard, 2001).

The NDVI images from April 1998 to January 2008, were stacked using Erdas Imagine, Finally, there were 354 stacked layers in one composite image. This was done to ensure temporal monitoring of the areas.

An Iterative Self-Organizing Data Analysis Technique (ISODATA) (Duda and Hart, 1974) cited in Campbell (2002) was employed to the final stacked NDVI image using Erdas Imagine software (Ledwith, 2000). The ISODATA is an unsupervised clustering method that uses minimum spectral distance formula to form clusters (Campbell, 2002; ERDAS, 2003). Using this technique, the stacked NDVI layer was classified with a pre-defined number of classes (10 to 100). The maximum number of iteration was set to 50 and the convergence threshold was set to 1. The maximum iterations control the performance of the ISODATA by ensuring that the utility stops at a certain threshold. The convergence threshold prevents the ISODATA utility from running indefinitely (ERDAS, 2003). To compare the classification results, the divergence statistical measures of distance (class separability) between generated clusters signatures were used (ERDAS, 2003; Swain and Davis, 1978). Finally, a classified image and NDVI cluster signatures of “77 classes” with a best minimum divergence and average divergence statistics was chosen for further analysis (Figure 3).

The 77 class signature profiles were further analyzed in Microsoft Excel for their temporal variability and legend construction with the help of field data. Spatial variability was explored using Arc GIS.

The NDVI profiles were analyzed based on visual exploration of their temporal and spatial patterns. Since NDVI profiles provide the distinctiveness of the land cover classes (Defries and Townshend, 1978, Muchoney *et al.*, 1997) and crop calendar information.

Here in this case also the NDVI profiles define temporal seasonal behaviour of the land use classes, based on this and crop calendar information; various classes were distinguished. Profiles showing high NDVI fluctuation thrice in a year reflect that three rice crops are grown while class profiles showing NDVI peak twice represent two rice crops.

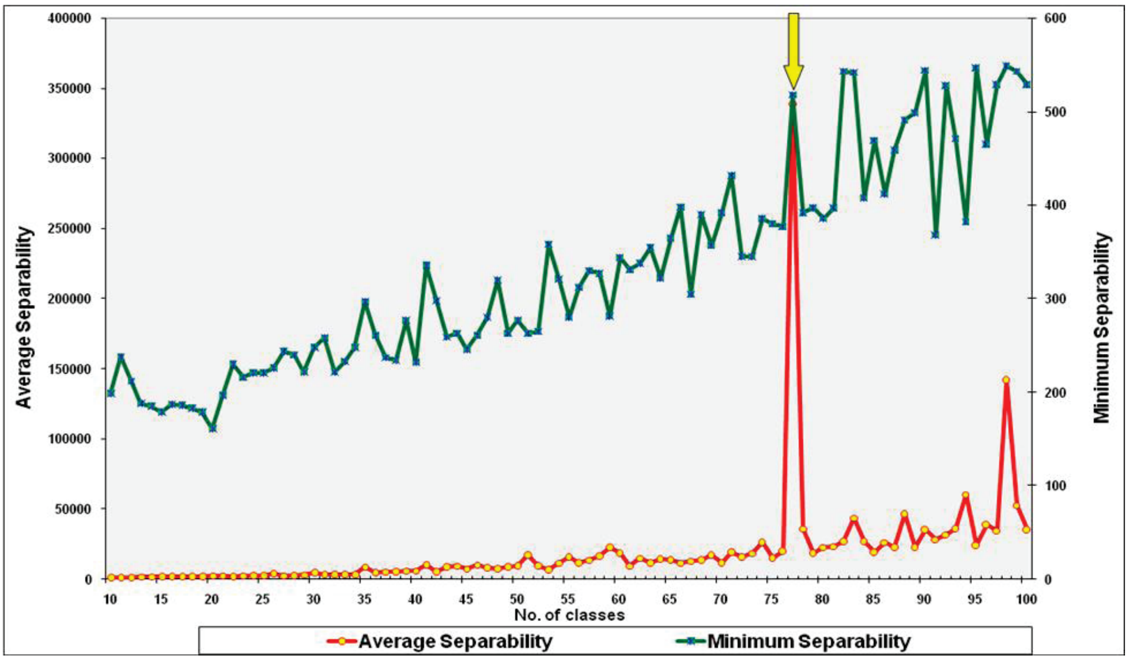


Figure 3: Divergence Statistics (Avg. and Min.) to identify the optimum number of classes

Flooding regime in respective NDVI classes were detected by comparing lower NDVI values (De Bie *et al.,* 2008) in monthly 10 days mean composite layers of NDVI from 1998 to 2008 with the help of Arc GIS. The flooding regimes are shown by NDVI class in the final legend (Figure 6).

Flooding was declared controlled when there was limited effect on crop calendar and it was for short time period as required by farmers verified through field survey. Areas were considered uncontrolled, when flooding is for long time spans and it consequently affect crop calendars by restricting them to grow two rice crops only. Flooding is classified into partial and extensive based on the extent of flooding, if the whole area of a particular NDVI class is affected by flooding for long time then it is called extensive while partial flooding is for short duration and not covering, the whole area of the NDVI class.

The profiles were also assessed by analyzing the temporal variability between years. This approach has been used in many studies using NDVI from NOAA / AVHRR, MODIS and SPOT images (Zhang *et al.,* 2003, De Bie *et al.,* 2008). NDVI class 54 represents an area where one crop was skipped when controlled flooding took place. It served to harvest silt deposition into the fields.

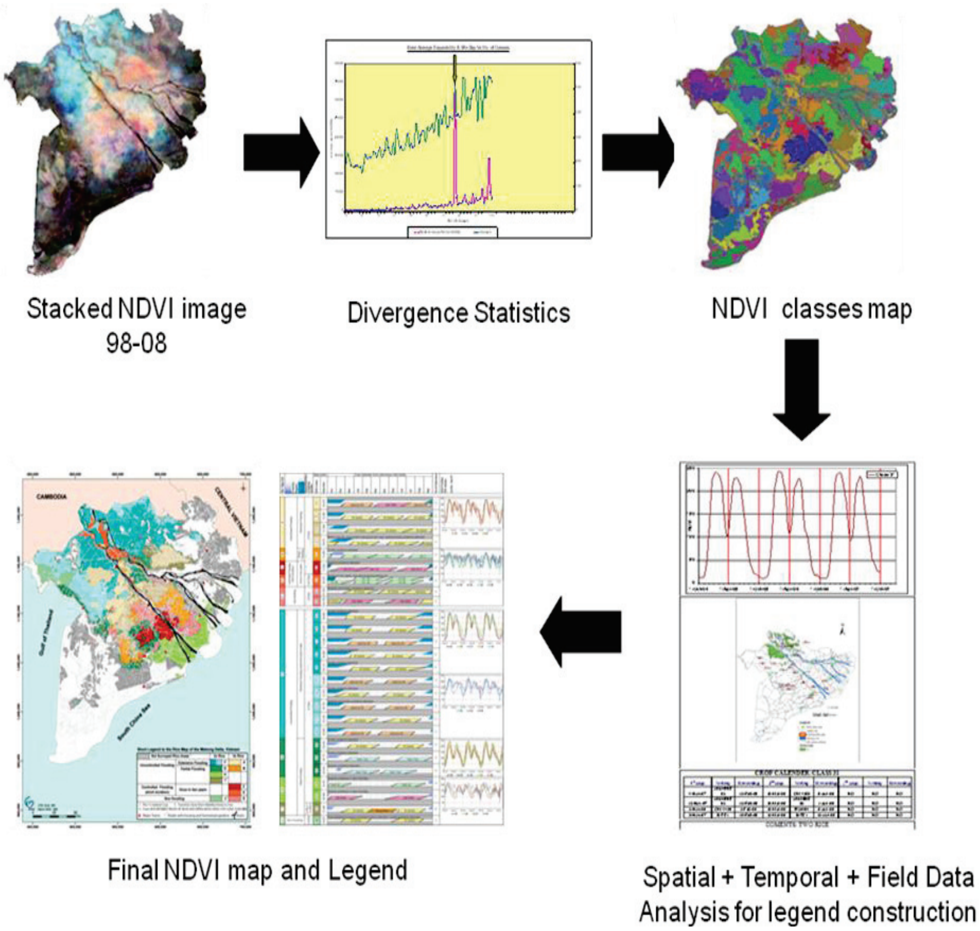


Figure 4: Schematic Diagram showing steps involved in the NDVI Approach

Rice varieties reported by interviews were grouped in five categories. Their lengths of growing period were summarized in box plots (Figure 7). During interviews variety IR50404 was reported the maximum number of times and other varieties (CK 92, HD 1, and VD 20) less frequently.

Final legend construction was done using crop calendar data by NDVI class, flooding regimes, location of individual class and temporal profiles of at least three years (October 2004 to December 2007). Grouping of classes is based on their spatial, temporal and flooding regime similarity. Out of 26 classes, 10 groups of land uses with three rice crops, two rice crops and two rice crops plus one upland crop under different flooding regimes were obtained (Figure 5 and Figure 6).

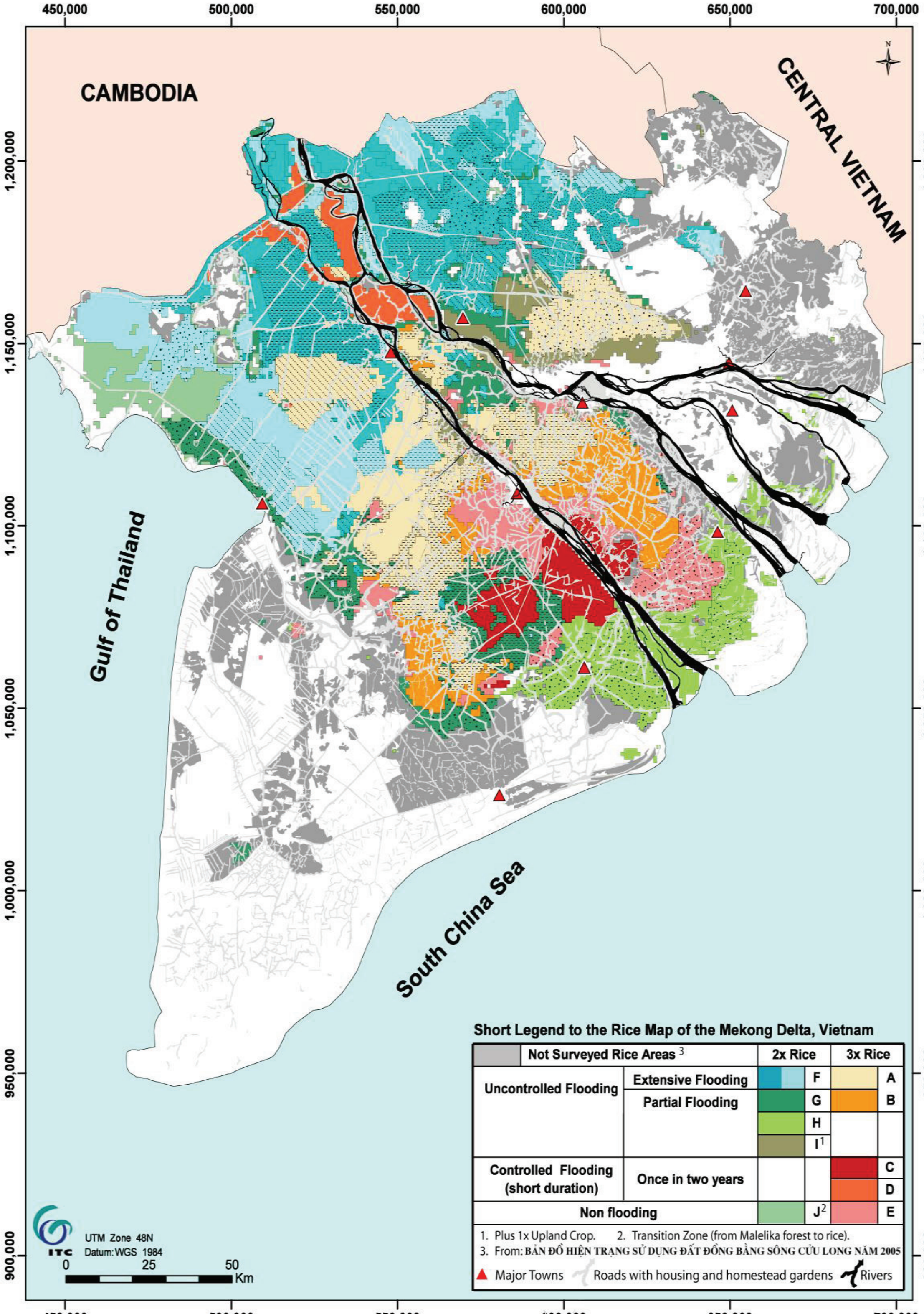


Figure 5: NDVI Unit Map of the Mekong Delta, Vietnam

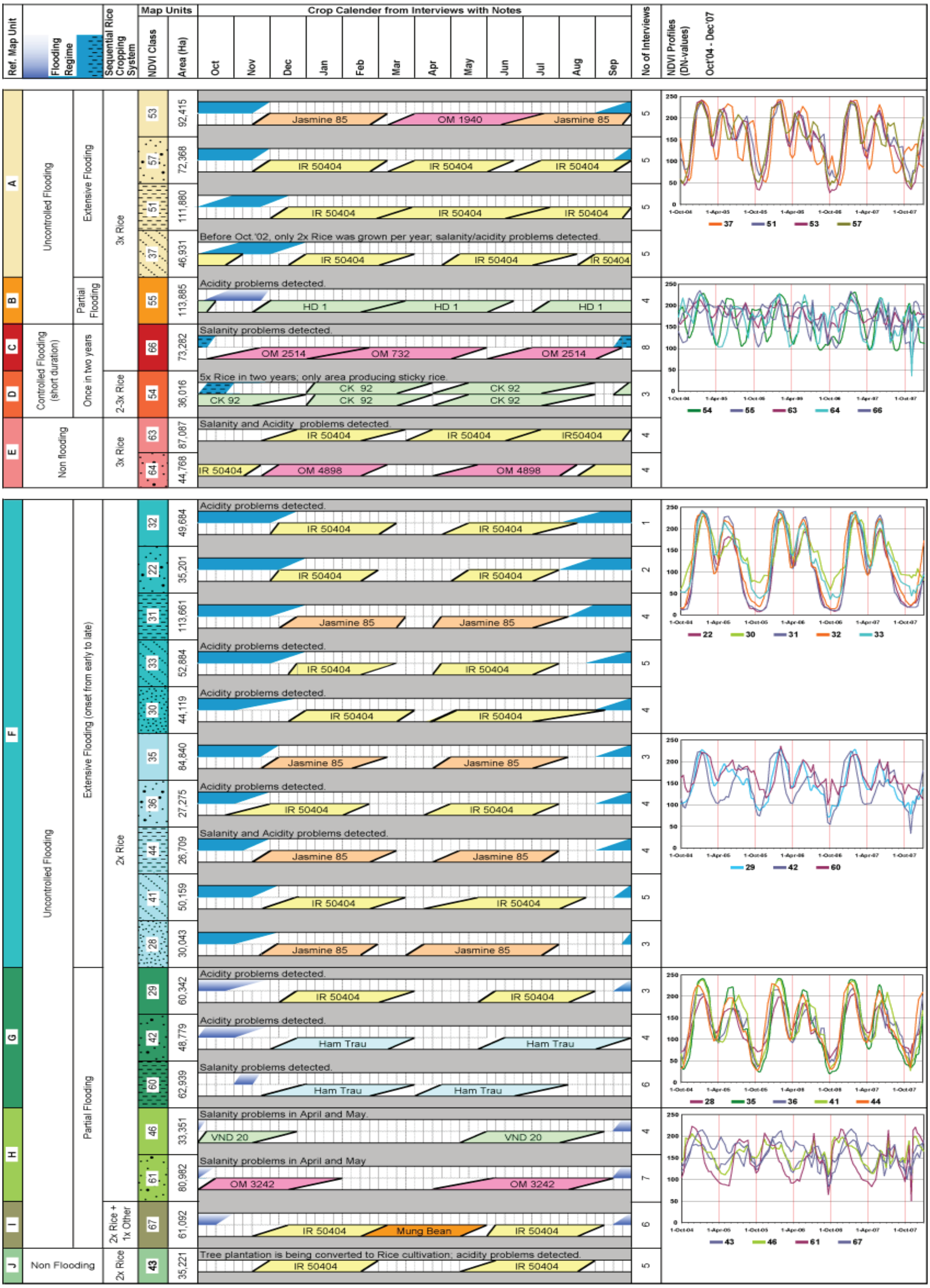


Figure 6: Detailed Legend of the NDVI Map

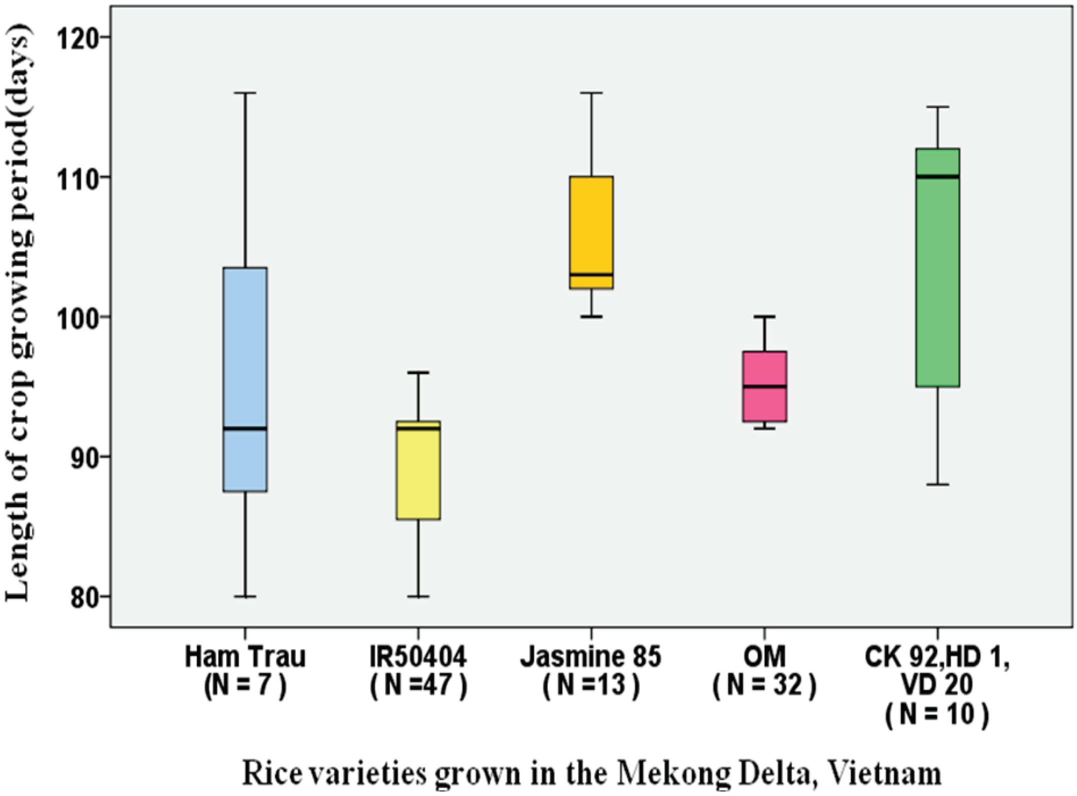


Figure 7: Box Plot showing Rice Varieties against Length of Crop Growing Period

Unit A: is mainly characterized by three rice crops as NDVI profile fluctuates three times and it was easy to identify with very high digital number (NDVI). This unit is under uncontrolled extensive flooding. The flooding mostly occurs in months of October and November but the unit still manages three rice crops in one year cycle. Areas occupied by NDVI Classes 53, 57, 51 mostly grow rice variety IR 50404 while NDVI class 37 grows Jasmine 85 and OM. Only class 37 is detected with acidity and salinity problem. The unit mostly dominates the central parts of the study area (Figure 5).

Unit B: represents NDVI class 55 having partial flooding regime. Area is under three rice crops land use system which is clear from crop calendar and distinct NDVI profile (Figure 6). Flooding mostly occurs from mid of October to mid of November. Farmers are growing HD 1 variety of rice. Soil is acidic and was confirmed by soil samples analysis collected during field work. This class is located in lower central parts of Mekong delta as shown in Figure 5.

Unit C: comprised of class 66 as shown in Figure 6. It is controlled flooded area and the farmers used to flood their fields once in two years in the months of September and October but flooding did not affect crop calendar and they still managed three rice crops in one year. Controlled flooding is usually done to deposit silt and increasing fertility of soils along with flushing of excessive salts from the root zones. Salinity was detected in soil samples collected during filed work. The land is dominated by rice varieties like OM 2514 and OM 732 (Figure 6).

Unit D: represents class 54 (Figure 6). It is mainly three rice crops area but for depositing silt, they skip one crop which is grown in October, once in two years for short time controlled flooding. Farmers are growing CK 92 variety. This unit dominates central upper part of Mekong delta nearby the river main branch as shown in Figure 5.

Unit E: composed of class 63 and 64 (Figure 6). It is the only area growing three rice crops with almost no prominent flooding effects. NDVI class 63 is characterized by three rice crop calendar. Rice variety IR 50404 is preferred in this area. NDVI class 64 is also following three rice crops calendar. This unit is growing rice varieties IR50404 and OM 4898. Salinity and acidity was detected in soil samples collected during field work. It is located in lower mid eastern part of Mekong as shown in Figure 5.

Unit F: are growing two rice crops. Flooding is uncontrolled and extensive; starts in NDVI class 32, and then 22 onward to class 28 in sequence, onset from early to late. Mostly flooding occurs from September to November (Figure 6). NDVI Class 32, 33, 30 is detected with acidity problem only while class 44 is having both salinity and acidity problem evident from soil samples collected during field survey. NDVI classes 32, 22, 33, 30, 36 and 41 is dominated by variety IR 50404 while area under NDVI class 31, 35 and 44 grow Jasmine 85. This unit dominate north-west, some central and eastern parts of Mekong delta (Figure 5).

Unit G: represents NDVI class 29, 42 and 60 following two rice crops calendar. It is uncontrolled partial flooding zone, occurs mostly in the end of September and continued till the end of October. NDVI class 29 and 42 is having acidity problem while class 60 is affected by both acidity and salinity. Farmers in class 29 are growing IR 50404 while rice variety Ham trau is main growing variety in area under NDVI Class 42 and 60. This unit is dominant in lower and central part of Mekong (Figure 5).

Unit H: includes class 46 and 61 as given in Figure 6. It is dominated by two rice crops with partial flooding effects. Farmers are growing rice variety VND 20 in class 46 and OM 2332 in NDVI class 61. This area is facing salinity problem in the months of April and May at the growing time of rice crop. Farmers mostly manage it by pumping water out of the fields. This unit located in lower central part of Mekong delta (Figure 5).

Unit I: represents NDVI class 67 as shown in Figure 6. It is characterized by two rice crops with one upland crop mainly Soya bean or Mung beans. Flooding effects are partial and for short time. Flooding starts from last week of September and finishes till the end of October. The main rice variety grown in this area is IR50404. This unit is located in the north-eastern part of Mekong (Figure 5).

Unit J: characterized by NDVI class 43. This area is in the state of transition, as most of the land is being shifted from inundation forest to rice cultivation, farmers reported two rice crops as shown in legend (Figure 6). This unit was detected with acidity problem in soil samples collected during field work. Rice variety preferred in this area was IR 50404. It is located in north western part of Mekong delta (Figure 5).

3.1.1.2. Validation of the NDVI Map

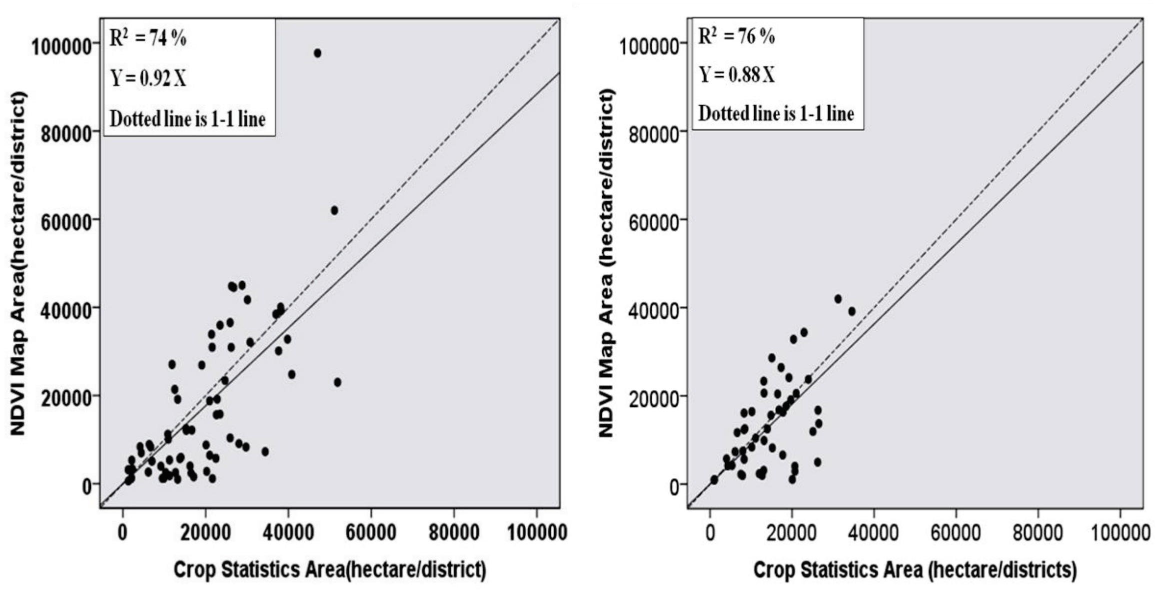
To validate the NDVI map, the land use classes from NDVI map were correlated with land use classes in reported crop statistics of Mekong delta Vietnam. The results showed that NDVI map was in agreement with the observed land use classes as found in the crop statistics data. The NDVI map showed strong correlation coefficient of 92% of the reported crop statistics for two rice and 88% for three rice crops areas (Table 3).

The regression line in both the cases was closed to the 1-1 line which showed that NDVI map has a great deal of generalization of the land use classes in crop statistics data.

Scatter Plots also showed the relationships of both types of land use systems against crop statistics with 1-1 line, fitted regression lines and equation. The explained variability (R^2) was found 74% and 76% in two rice crops and three rice crops land use systems (Figure 8).

Table 3: Results of Correlation Analysis between the NDVI Map and Crop Statistics

Land use systems	Coefficients	t	Sig.
Two Rice crops	0.92	14.02	0
Three Rice crops	0.88	12.32	0



(a) **(b)**

Figure 8: Scatter Plots showing, Two Rice crops (a) and Three Rice crops (b) Land Use systems of the NDVI Map against Crop Statistics.

3.1.2. Landscape-Ecological Approach

The objective of this methodology was to study the merits of land components like terrain, geomorphology, soil and vegetation to map the landscape. Relevant information was extracted from many sources such as available maps, satellite images and field samples. The data sources are given in Table 1 and maps are presented in Appendix 3, 4, 5 and 6.

The terrain of the Mekong delta can only be differentiated in two meaningful classes. They are isolated hills located in the upper delta and very flat areas called the flood plains.

Geomorphology aspects were adopted from Haruyama and Shida (2008), and the classes corresponding with the study area were selected for the study. The legend entries include alluvial terrace and marine terrace which is situated in the north western parts along the border of Vietnam and Cambodia. Natural levee I and natural levee II occupies central part of Mekong delta. Back swamp I and back swamp II are behind natural levee and these two are the largest geomorphologic classes in rice growing areas. Chenir coastal plain is in south while sand bars represent few isolated places surrounded by river branches (Appendix 4).

Inundation map was adopted from Yashimatha, 2005. Map was digitized using Arc GIS. Inundation depths give in the provided legends range from less than 0.3 m depth to more than 1 meter in four classes. Northern parts of delta are shown with more than 1 meter while central delta is in the range of 0.3 to 1 meter. Southern parts towards coastal belts are mostly less prone to high inundation depths but some isolated areas are having more inundation depth up to 1 meter (Appendix 6).

The information collected during the fieldwork and results of the NDVI approach revealed complex land use classes. In this particular condition, two rice and three rice crops defined in the land use map 2005, collected from Can Tho University was used (Appendix 3). Other Land use classes given in Land use map 2005(Can Tho University) were not considered being not of interest in this study. Satellite images with different acquisition dates and field data was employed to check the map quality and legend entries (Table 1). For this purpose Landsat 7 ETM+, false colour composite 453 (RGB), true colour composite 321 (RGB), that gave an acceptable distinction of all the features were utilized.

The soils map was also selected from thesis work of Yashimatha (2005), conducted in Can Tho University Vietnam. Map was digitized using the legend classes corresponding with the study area. The legend showed alluvial soil as one of the main soil class falls in irrigated rice areas. Other soil was saline soil, acid-sulphate soil, slightly and moderately acid sulphate soil and acid sulphate soil, salanized in dry season, along with grey degraded (Appendix 5).

Finally topological overlay of thematic layers of landscape criteria were performed (Figure 9). Then analyses of their resultant combinations and screening out polygons below the representative landscape level were employed. Overlay function produces a considerable number of small polygons below the minimum-mapping unit. Aggregations of landscape polygons into groups corresponding to the higher hierarchical level were performed and finally linking of attributes data and landscape map was generated with detailed legend as shown in Figure 10 and Figure 11.

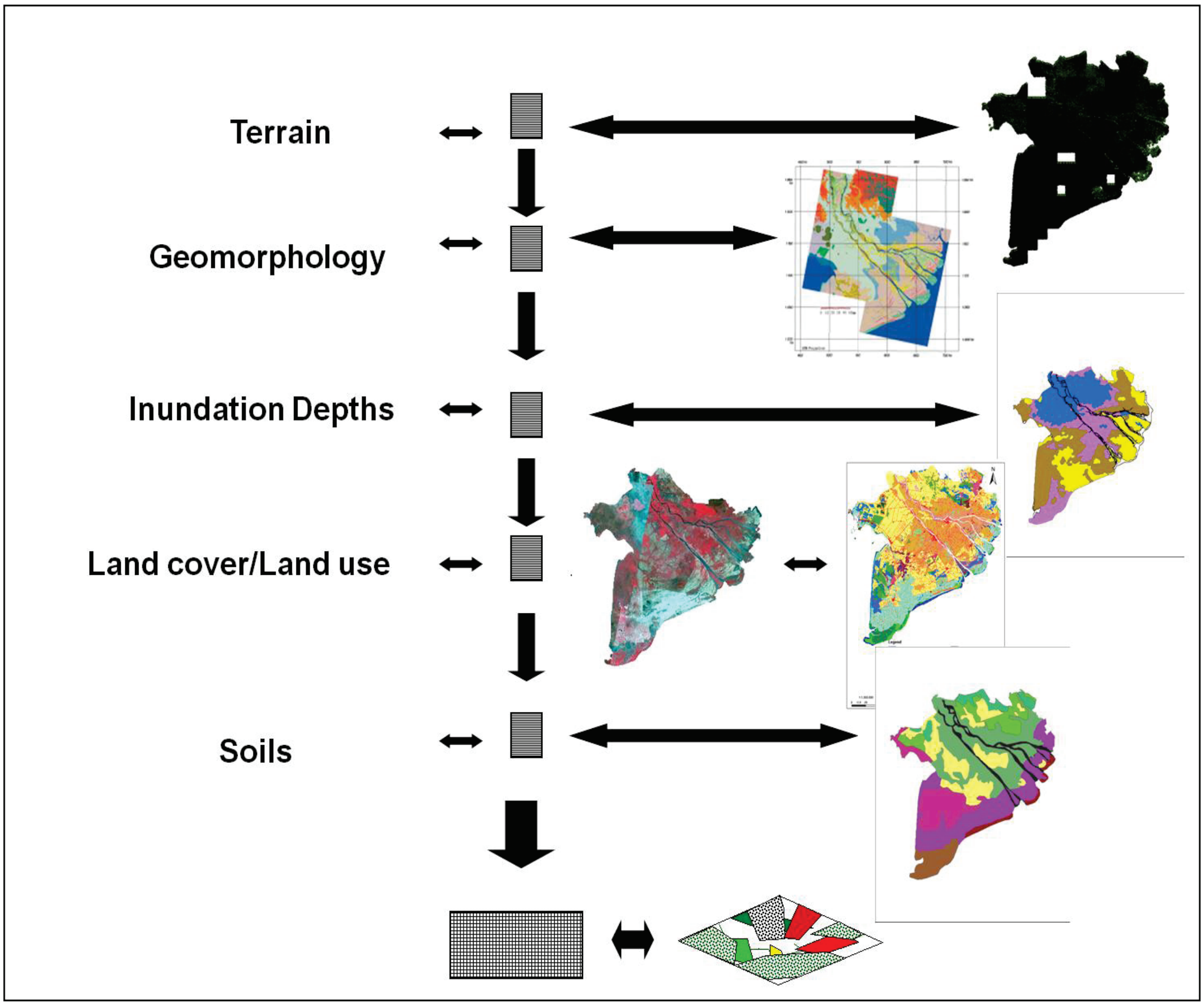


Figure 9: Schematic Diagram showing Methodological steps involved in the Landscape-Ecological Approach

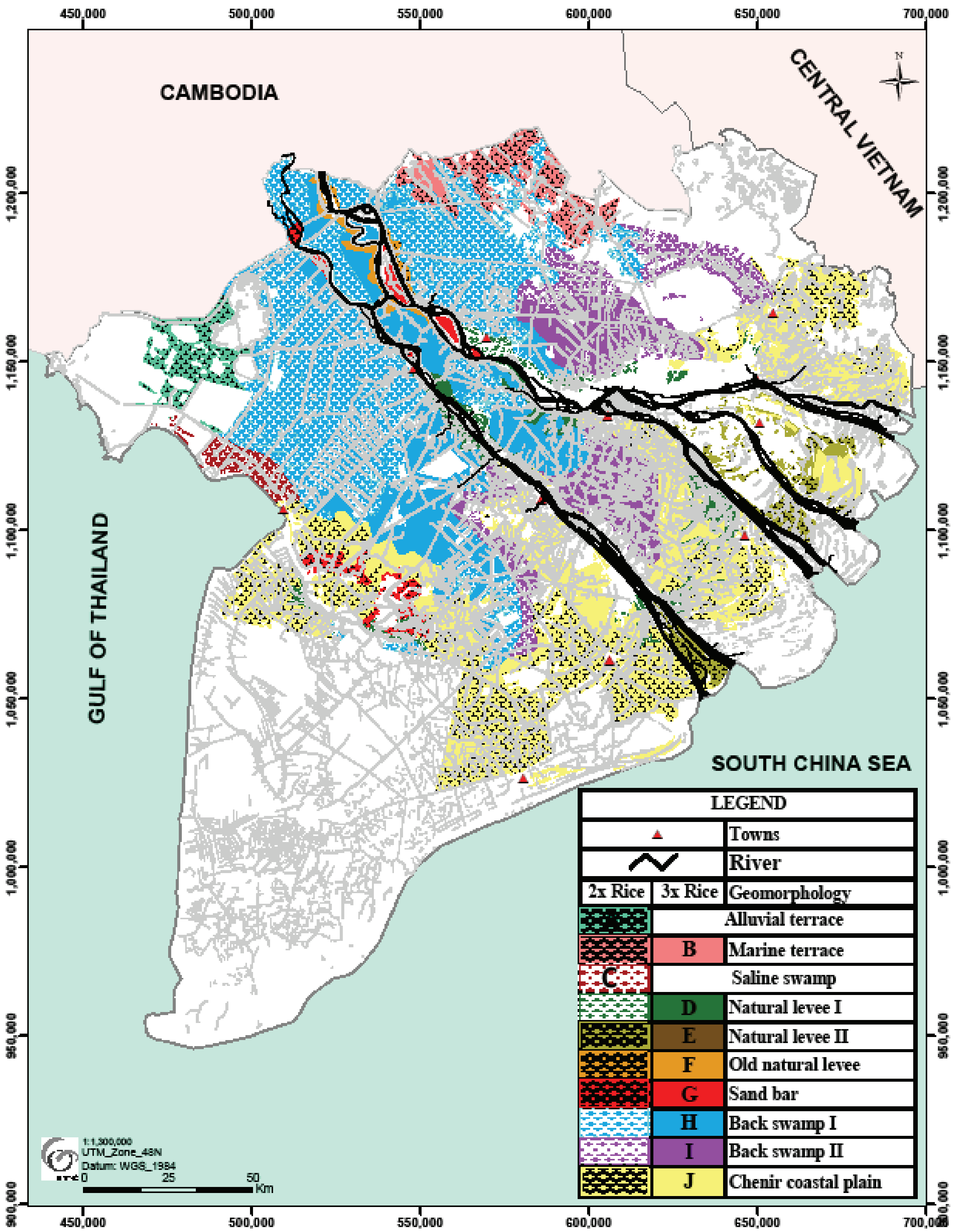


Figure 10: Landscape-Ecological Map of the Mekong Delta, Vietnam

Terrain	Geomorphology	Inundation depths	Map units ref Figure 9	Land use	Soil classes/properties (Area in Km^2)					
					Alluvial soil	Grey degraded soil	Saline soils	Slightly and moderately acid sulphate soil	Strongly acid sulphate soils	Strongly acid sulphate soils,salanized in dry season
Flood plain	Alluvial terrace	< 0.3 m	A	2x Rice		43		50	21	
		0.3 - 0.5 m						13	6	
		0.5 - 1 m				11		29	107	8
		> 1 m				25		22	37	
	Marine terrace	< 0.3 m	B	2x Rice		4				
		0.5 - 1 m				192			34	
		> 1 m				221		64	37	
		0.5 - 1 m		3x Rice		43				
		> 1 m				14				
	Saline swamp	0.3 - 0.5 m	C	2x Rice	40					69
		0.5 - 1 m			11			32		40
	Natural levee I	< 0.3 m	D	2x Rice	2			10		16
		0.3 - 0.5 m								7
		0.5 - 1 m			31		32			
		> 1 m			6					
		< 0.3 m		3x Rice	26					
		0.3 - 0.5 m			101					
		0.5 - 1 m			170		4	13		
		> 1 m			32					
	Natural levee II	< 0.3 m	E	2x Rice	29		209	5		
		< 0.3 m		3x Rice	73		46			
	Old natural levee	> 1 m	F	2x Rice	27				2	
		> 1 m		3x Rice	72					
	Sand bar	< 0.3 m	G	2x Rice	25		3	29		16
		0.3 - 0.5 m			68		12	23		4
		> 1 m			11					
		0.3 - 0.5 m		3x Rice	16					
		> 1 m			46					
	Back swamp I	< 0.3 m	H	2x Rice				17		39
		0.3 - 0.5 m			54			151		
		0.5 - 1 m			195	31		298	17	9
		> 1 m			1789	109		1273	543	
		< 0.3 m		3x Rice	65			11		
		0.3 - 0.5 m			173			376		
		0.5 - 1 m			330	5		311		5
		> 1 m			515	15		3	27	
	Back swamp II	< 0.3 m	I	2x Rice	22					
		0.3 - 0.5 m			71			10	49	
		0.5 - 1 m			33	10		81	72	13
		> 1 m			18	4		81	177	
		0.3 - 0.5 m		3x Rice	74			13		
		0.5 - 1 m			361			307	65	4
		> 1 m			299			46	106	
	Chenir coastal plain	< 0.3 m	J	2x Rice	256		889	83		101
		0.3 - 0.5 m			374		729	267	14	153
		0.5 - 1 m			77		107	134	6	21
		< 0.3 m		3x Rice	219		266	36		
		0.3 - 0.5 m			715		172	161		19
		0.5 - 1 m			413		16	131	13	19

Figure 11: Detailed Legend based on the Landscape-Ecological Approach

Legend is explained as follows;

Unit A: represent Alluvial terrace, which is mainly distributed in the surrounding of hills in northern parts of delta. Mostly two rice crops are grown. Dominated soil types are Grey degraded, Slightly and moderately acid sulphate and Strongly acid sulphate. Inundation classes ranges from 0.5 meter depth to more than 1 meter (Figure 11).

Unit B: included a Marine terrace which is also distributed in the upper part of delta mostly in hilly areas as shown in Figure 10. Dominant soil is Grey degraded, Slightly and moderately acid sulphate and Strongly acid sulphate. Inundation is high with 0.5 – 1 meter and ranges to more than 1 meter depth (Figure 11).

Unit C: include Saline swamp composed of two soil classes as Alluvial, Slightly and moderately acid sulphate soils, salanized in dry season, with two rice crops as dominant land use type. Two classes of inundation i.e. 0.3 – 0.5 meter and 0.5 – 1 meter are present in this unit (Figure 10, Figure 11).

Unit D: represent Natural levee I, dominant in central and lower part of delta all along the Mekong River, one can found both types of rice land use systems but three rice crops are dominant. Soils with Alluvial nature are widely found in area with some small pockets of Slightly and moderately acid sulphate soils and other soil types as shown in Figure 11. Inundation depths are variable, ranges from low to high but large area is having 0.5 – 1 meter flooding depth (Figure 10).

Unit E: composed of Natural levee II which is in upper parts of delta along the Mekong River. Both three rice and two rice cultivation systems are present but vast area is two rice crops. Soils with Alluvial properties are dominant while some parts are also having salt affected soil. Low inundation depths are found in this area mostly less than 0.3 meter (Figure 10, Figure 11).

Unit F: this group (Old natural levee) is represented by small area included in our study area as shown in Figure 10, which is dominated by Alluvial soil. Mainly three rice crops are grown in a year while few isolated places grow two rice crops per year. Inundation depth is more than 1 meter (Figure 11).

Unit G: represented by Sand bars which is mostly sand deposited in between river branches. Being highly scattered, two rice crops and three rice crops depend upon flooding regimes, micro elevation and drainage patterns in respective areas. Soil is mainly Alluvial and inundation is variable depending upon local condition (Figure 10, Figure 11).

Unit H: composed of Back swamp I, the most dominated geomorphic group in delta distributed in eastern and western part of northern delta all along the river. Both types of three rice and two rice cultivations are employed. Dominant soil types are Alluvial and Slightly and moderately acid sulphate. Inundation Depths range from 0.3 - 0.5 meter to more than 1 meter depending upon drainage of area (Figure 10, Figure 11).

Unit I: represents Back swamp II which is distributed in eastern and some central regions. Three rice and two rice crop calendars are followed. Soil type is mostly Alluvial and Slightly and moderately acid sulphate. Inundation Depths ranges from 0.5 to more than 1 meter (Figure 10, Figure 11).

Unit J: characterized by vast area in southern belts called Chenir coastal plain. Farmers are growing both three rice and two rice crops in different part of this unit (Figure 10). Soil types present in this area are Alluvial, Slightly and moderately acid sulphate, Saline and Slightly and moderately acid sulphate, salanized in dry season (Figure 11).

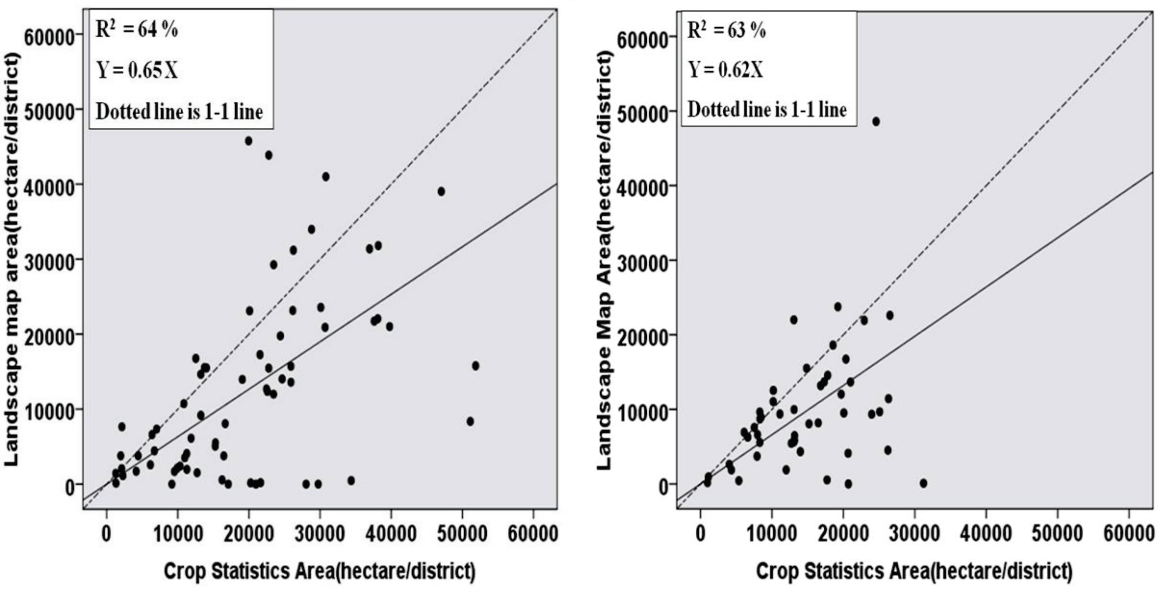
3.1.2.1. Validation of the Landscape-Ecological Map

Correlation analysis were performed for two rice crops and three rice crops land use systems estimated in the Landscape-Ecological Map and crop statistics to validate the map. Table 4 showed that estimated Landscape-Ecological Map was significantly correlated with reported crop statistics having correlation coefficients of 65% and 62% for two and three rice crops land use systems respectively (Table 4).

Scatter plots showed both types of land use systems against crop statistics with fitted regression line. The fitted line is not very close to 1-1 line but still it shows some generalization of reported crop statistics. Furthermore, the explained variability was 64% in two rice and 63% in three rice land use systems (Figure 12).

Table 4: Results of Correlation Analysis between the Landscape-Ecological Map and Crop Statistics

Land Use systems	Coefficients	t	Sig.
Two Rice Crops	0.65	11.21	0
Three Rice Crops	0.62	9.05	0



(a) **(b)**

Figure 12: Scatter Plots showing two rice crops (a) and three rice crops (b) areas of the Landscape-Ecological Map against Crop Statistics

3.2. Strengths and Weaknesses

3.2.1. NDVI Approach

Strengths

- The NDVI approach used in this study allowed ranking of different agricultural areas according to their relative length of cropping period and showed a great potential as a mapping approach to agro-ecological zoning.
- The use of long temporal sequences of long time data series could greatly improved the interpretation and results and hence accuracy and usefulness. Effective identification of intensive agriculture land use systems (sub classes of three rice crops) was only possible with hyper temporal NDVI. It was proved by strong positive correlation and R^2 of NDVI map with crop statistics.
- Studying historical aspects of land use systems and interpreting practices having multiyear characteristics like silt depositing in certain localities of a two year cycle could only be identified by this approach.
- It utilized free available remote sensing data sets.
- It did not require an analyst to know in details the study area well in advance.
- The method used was easy and straight forward involving no complicated algorithms and techniques.

- The NDVI images contained more than sufficient cloud free images of required periods that are not available when relying on high spatial resolution sensors.

Weaknesses

There was no observed limitation associated with the method used in the NDVI approach but still there are some general points to discuss.

- NDVI mapping reflected only specific information of the area (vegetation) while agricultural land use systems are the outcome of a number of elements like geomorphology, soils, water, climate etc.
- NDVI excluded information on hierarchy, pattern and process which is important for studying ecologically relevant aspects of land use systems.

3.2.2. Landscape-Ecological Approach

Strengths

- The Landscape-Ecological Approach showed hierarchy from general to specific i.e. from terrain to geomorphology, to soils and to land use systems.
- It showed static (landscape units) as well as dynamic phenomena (land cover and land use) which are helpful in addressing long term land issues and planning.
- This approach started from small scale like terrain and geomorphology, soil properties and land use at large scale.
- It exhibited useful information e.g. geomorphology, water regime and soil properties

Weaknesses

- Landscape approach used in this study was less sensitive to temporal aspects and hence less suitable for agricultural land use systems.
- The Landscape-Ecological Approach used single time imagery or multi temporal, which cannot be related to the exact land use systems of high cropping intensity and complex crop calendars.
- This Method is subjected to human error as photo-interpreters will not delineate exactly the same things each time.
- It required more resources towards data purchasing and processing.
- This approach could not study phenomena of silt harvesting which is based on two years cycle, and is necessary for correctly classifying the land use systems in the Mekong delta.

3.3. Integrated Approach

a) Association between the Land Use Systems of the NDVI and the Landscape-Ecological Approach

Regarding association between lands uses system of the NDVI and landscape ecological approach, Table 6 showed two columns with two classes of Land use systems in the NDVI approach and rows represent land use classes of the Landscape-Ecological approach. Two rice crops in the NDVI map was observed in 84 % of the cases with two rice crops in the Landscape-Ecological map; similarly in 90 % of the cases, both maps are having three rice land use systems.

The chi square test also rejected the hypothesis that there was no association between the NDVI map and the Landscape-Ecological map land use systems per districts. Figure 13 showed graphical association between land use systems of two maps.

Table 5: Chi-Square test for Association between Land use systems of the NDVI Map and the Landscape-Ecological Map

Chi-Square Test			
	Value	d.f.	Sig. (2-sided)
Pearson Chi-Square	57.78[a]	1	0
N of Valid Cases	106		
a. 0 cells (0%) have expected count less than 5. The minimum expected count is 24.54.			

Table 6: Cross Tabulation between Land use systems of the NDVI Map and the Landscape-Ecological Map

Cross Table		NDVI Map	
		2x Rice	3x Rice
Landscape-Ecological Map	2x Rice	84%	10%
	3x Rice	16%	90%

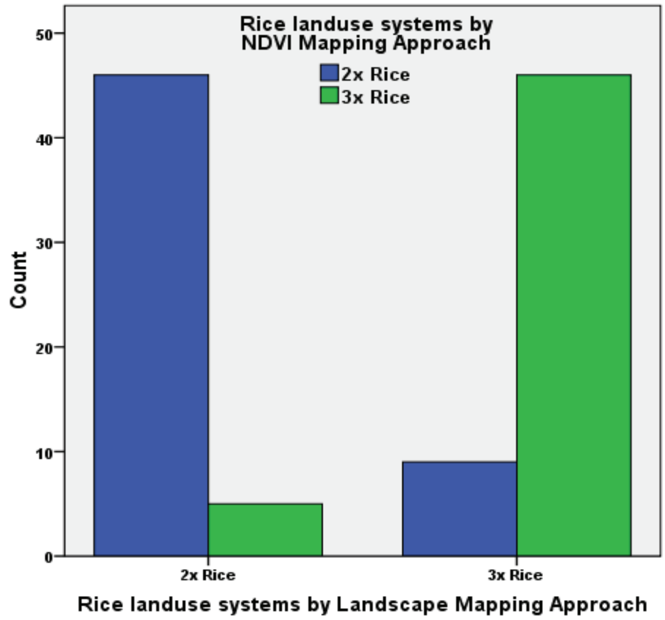


Figure 13: Bar Chart showing the Association between the NDVI Map and the Landscape-Ecological Map

b) Association between Geomorphology and Flooding Regime

Chi square test with cross tabulation was employed to find a degree of association between flooding regime as outcome of the NDVI Approach and geomorphology, a characteristic of the Landscape-Ecological Approach. Smaller and related classes of both criteria were grouped into bigger units, to reduce the number of cells having expected count less than five (5) to 20 % (Moore and McCabe, 2007). The test showed that there is no significant difference between the four classes of flooding regimes and five classes of geomorphology ($\chi2 = 64.54$ d.f. = 12, N=507, $p < .01$) as given in Table 7.

Table 7: Chi-Square test for Association between Geomorphology and Flooding Regime

Chi-Square Test			
	Value	d.f.	Sig. (2-sided)
Pearson Chi-Square	64.54[a]	12	0
N of Valid Cases	507		
a. 4 cells (20%) have expected count less than 5. The minimum expected count is 2.45.			

However, the Table 8 showed frequency of particular geomorphology classes in a flooding class in columns (Column percentage). The relationships between geomorphology and flooding features were not very clear in characterizing different land use systems.

Table 8: Cross Tabulation between Geomorphology and Flooding Regimes

Geomorphology	Flooding			
	Uncontrolled flooding,3x Rice	Controlled Flooding,3x Rice	Non Flooding,2x & 3x Rice	Uncontrolled Flooding,2x Rice
Alluvial terrace + Marine terrace + Saline swamp	0	0	16%	12%
Natural levee I + Natural Levee II + Old Natural Levee + sand bar	12%	29%	16%	18%
Back swamp I	40%	30%	15%	44%
Back swamp II	27%	15%	15%	8%
Chenir coastal plain	21%	26%	38%	18%

Bar charts also showed that there was no distinct trend originated from geomorphology and flooding association which can be used for improvement in land use interpretation in integrated approach (Figure 14).

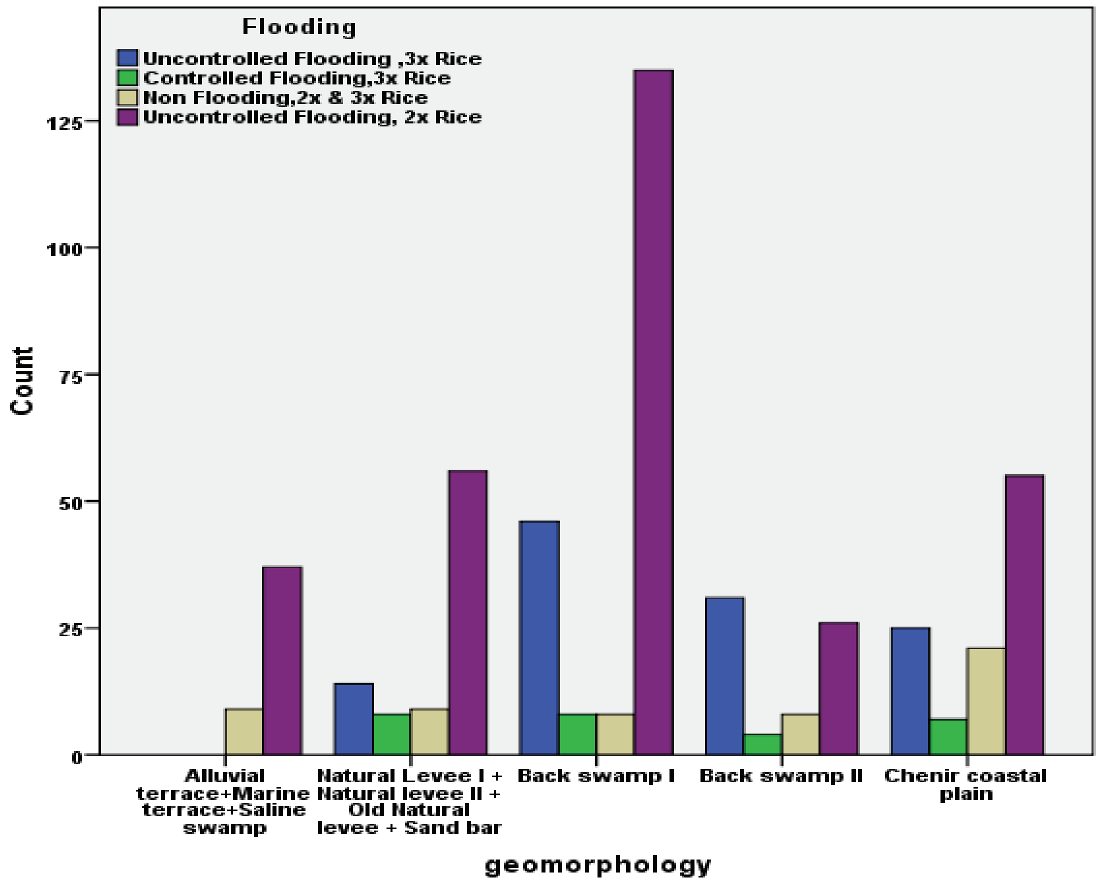


Figure 14: Bar Chart showing Association between Geomorphology and Flooding Regimes

c) Integration of Approaches

Regarding strengths, the NDVI approach accurately partition land use variability, infer flooding regime besides that temporal and historical time series information were provided. Classification based solely on NDVI excludes information on hierarchy, pattern, and process so important in predicting ecologically relevant aspects of land use systems.

Similarly landscape reflected its importance by contributing to a better understanding of the patterns, structure and functions associated with landscape attributes e.g. water movement, soil, nutrient availability etc.

Considered the strength and weaknesses of the NDVI and the Landscape-Ecological approaches and strong degree of association between lands uses systems of both approaches shown by chi square test (Table 5), and similarly there was significant but weak association between flooding and geomorphology classes. Although no distinct relationship originated, which can be specifically associated with particular flooding class (Table 7, Table 8) but still both approaches were combined to check any improvement in final land use mapping by integration.

The classified NDVI map was imported to GIS, where vector layers of geomorphology, inundation depths, soil map and district boundaries were overlaid. Then, a sequential arrangement of attributes is produced in the form of detailed legend as shown in Appendix 7. The legend was less clear and complex, hence less valuable to be used. The legend produced in the process did not suggest any improvement in land use mapping so rather than using the Integrated Map and legend, it was better to associate the important landscape aspects like geomorphology and soil types to already highly effective land use map derived from the NDVI Approach as short legends. The additional information addressed the landscape aspects of the NDVI map units (Figure 5).

Figure 15, Figure 16 and its association with NDVI Map are explained as under;

Unit A is characterized by geomorphology class Back swamp I, Back swamp II, Chenir coastal plains with some parts in Natural levee I and Sand bars, having Alluvial (20%), Slightly and moderately acid sulphate soils (22%).**Unit B**: represented by NDVI class 55, mostly occur in geomorphology back swamp II and Chenir coastal plain, dominated by Alluvial, Slightly and moderately acid sulphate soils and Strongly acid sulphate soils salanized in dry season. **Unit C;** is having Back swamp II (11%), Natural levee I (10%), Chenir coastal plain (10%). Soil present over here is 5% of Alluvial and 5% of Slightly and moderately acid sulphate soil. **Unit D**; represented NDVI class 54, geomorphology is Old natural levee (42%) and Sand bar (13%) with soil dominant is Alluvial (7%). **Unit E** includes Sand bars (21%), Back swamp II (9%), Natural levee I (25%) and Chenir coastal plain (19%) with dominant soils as Alluvial (12%).

Flooding regime		color codes ref Figure 5	2x Rice(Percent Area of geomorphology class) Alluvial terrace	Marine terrace	Saline swamp	Old natural levee	Sand bar	Back swamp I	Back swamp II	Natural levee I	Natural levee II	Chenir coastal plain	color codes ref Figure 5	3x Rice(Percent Area of geomorphology class) Old natural levee	Sand bar	Back swamp I	Back swamp II	Natural levee I	Chenir coastal plain
Uncontrolled Flooding	Extensive Flooding	F	58	100	24	58	29	57	20				A		10	27	36	15	10
	Partial Flooding	G			59		26	10		15		20	B				19		11
		H									100	29							
		I							16	36									
Controlled Flooding(short duration)	Once in two years												C				11	10	10
													D	42	13				
Non Flooding		J	42		17								E		21		9	25	19

Figure 15: Legend showing Association of Geomorphology with the NDVI Map

Flooding Regime		color codes ref Figure 5	2x Rice (Percent area of soils class) Alluvial soil	slightly and moderately acid sulphate soil	Grey degraded soil	saline soil	strongly acid sulphate soil	strongly acid sulphate soils,salanized in dry season	color codes ref Figure 5	3x Rice(Percent area of soils class) Alluvial soil	slightly and moderately acid sulphate soil	strongly acid sulphate soil	strongly acid sulphate soil,salanized in dry season
Uncontrolled Flooding	Extensive Flooding	F	30	41	38		73	10	A	20	22	10	
	Partial Flooding	G	16	17				44	B	10	11		22
		H				100							
		I			62								
Controlled Flooding(short duration)	Once in two years								C	5	5		
									D	7			
Non Flooding		J					17	24	E	12			

Figure 16: Legend showing Association of Soil types with the NDVI Map

Unit F is represented by Alluvial terrace (58%), Saline swamp (24%), Sand bar (29%), Back swamp I (57%), Back swamp II (20%), Old natural levee (58%) and exclusive Marine terrace (100%) with Alluvial soil, Saline soil, Slightly and moderately acid sulphate soils, Strongly acid sulphate soils salanized in dry season but Strongly acid sulphate soils almost 73% falls in this unit. **Unit G** is corresponding with Saline swamp (29%), Sand bars (26%) and Chenir coastal plain (20%). as dominant geomorphology classes. Dominant soils class is Slightly and moderately acid sulphate soils salanized in dry season (44%). **Unit H** is represented by Old natural levee (100%) and Chenir coastal plain (29%). Soil is 100% Saline and only two rice cropping patterns are followed. **Unit I** includes Back swamp II and Natural levee I by 16% and 36 %. Soils are Grey degraded (62%).**Unit J** includes Alluvial terrace by 42% and Saline swamp 17% characterized by Slightly and moderately acid sulphate soils salanized in dry season (24%) and Strongly acid sulphate soils (17%) (Figure 15, Figure 16).

Hence the Integrated Approach was not based on both the maps so we tested the hypothesis that the Map produced by the NDVI Approach explained 10 % more variability (R^2) of the published crop statistics (Two rice crops (R^2) = 74% and three rice (R^2) = 76%) than the Map produced by the Landscape-Ecological Approach which was 64% and 63% for two rice and three rice crops land use systems (Figure 15, Figure 16).

4. DISCUSSION

4.1. Mapping Approaches

4.1.1. NDVI Approach

The use of Hyper-temporal NDVI for agriculture land use mapping is a useful approach (De Bie *et al.,* 2008). NDVI Approach used unsupervised ISODATA clustering algorithm. The divergence statistics is the basis to determine the number of NDVI classes. The NDVI cluster signatures with 77 classes are selected based on divergence statistics. Swain and Davis (1978) considered it a good strategy to select the signatures with maximum average divergence. Defries and Townshend (1978) also showed the usefulness of divergence statistics in working with NDVI-derived land cover mapping.

The resultant map (Figure 5) shows that the NDVI approach delineates distinctively various land use classes. The NDVI map covers substantial variability in land use system of the Mekong delta, Vietnam. Each land use class has been defined by related NDVI profiles. Following the characteristic pattern of the crop growth curve, lower values are associated with low biomass and water in the fields. As the rice crop grows, the values of NDVI increased achieving a peak to the maximum as the crop keeps developing (Schowengerdt, 1997; Kouchoukos *et al*., 1997).

The nature of rice land use system in the Mekong Delta is very well clear from crop calendar and which is also classified by the NDVI Approach. The two rice crops are dominant in the northern part of the Delta towards right and left side of Mekong River which is uncontrolled extensive flooding area. Three rice land use system is dominant in central districts and southern parts of Mekong delta because of low flooding for short period of time.

The study also showed the flooding regime of NDVI classes which is one of the main factors influencing the distribution of land use system in the Mekong delta, Vietnam, and to some extent by soil and salinity. To understand flooding regime as a comprehensive system is essential to study crop calendar and agricultural land uses in the Mekong Delta, Vietnam. Although, the complicated conditions such as inland waterway network and completely flat configuration make the understanding difficult. However flooding regimes were successfully detected by associating low NDVI values with the onset of flooding in different layers of mean staked NDVI image of ten days composite and its coverage was observed by overlaying with NDVI land use classes.

Low NDVI in between two crops (NDVI peaks) for extended time is mainly associated with flooding. This is evident from temporal variability of the NDVI profiles and crop calendars information (Figure 6). Some of the NDVI profiles were having a missing peak in two or more year's cycle, which is showing one rice crop missing in the rice cropping system due to silt harvest. Silt harvest is the phenomena, in which farmers decide to skip one crop, to deposit silt in their fields and also flushes out excessive salts using controlled flooding. This was confirmed from farmers during field work. So, the NDVI Approach successfully gives spatial and temporal information about this multi year phenomena.

De Bie *et al.,* 2008, also used multi date NDVI images to capture the variability in time of inundation. Similarly, Harris & Mason, 1989; Liu *et al.,* 2002 and Xiao *et al.,* 2002 also mentioned that NOAA/AVHRR and SPOT/VEGETATION data are commonly employed to detect inundation and temporal changes in flooded areas.

NDVI Approach successfully delineates all the crop calendars prevailing in the Delta. It helps in understanding of flooding and their relationship with land use systems. The derived legend not only has categorical classes; but also has a temporal dimension (NDVI profiles) that showed how the NDVI classes were behaving over entire period of interest (Delli, *et al.,* 2002; De Bie *et al.,* 2008; Kameswara, 1995).

For validation of the NDVI map, due to time constraint it was not possible to collect independent dataset, randomly selected for accuracy assessment. So the NDVI map was validated by correlating with reported crop statistics. There is significant positive correlation between rice land use systems and crop statistics with correlation coefficient of 92% and 88% for two and three crops areas. NDVI map shares about 74% of its variability in two rice crops and about 76% in three rice land use systems. The regression lines in both cases are closed to 1-1 line and the estimated map has great deal of generalization of the crop statistics. So the NDVI approach has provided considerable accurate and effective spatial and.

4.1.2. Landscape-Ecological Method

The process of Landscape-Ecological mapping involves analyzing landscape parameters to produce homogenous land units. The method employed topological overlay of thematic layers of geomorphology, soil properties and inundation depths along with land Use classes (based on ETM+ and Land Use map 2005) and analyses of their resultant combinations. Further landscape units were aggregated and landscape map and legend was generated (Figure 10 and Figure 11).

Land use systems are decided by farmers based on natural conditions in Mekong Delta. Therefore, terrain, geomorphology, soils (acid sulphate soil and saline intrusion) and degree of flooding are important features to be considered in landscape criteria to study farming system.

The terrain in the Mekong delta can only be differentiated in to two classes, isolated hills in upper delta and Flood plains. Flood plains are subjected to floods and remain submerged annually (Nguyen, 1993).

In geomorphology classes corresponding to the study areas and relevant to rice cultivation were selected for the study as reported by Haruyama and Shida, 2008. Alluvial terrace and Marine terrace are situated in the surroundings of Hills. Natural levee I and Natural levee II occupies central part of Mekong delta. Back swamp I and Back swamp II are behind Natural levee. These two form the largest geomorphologic classes in rice growing areas. A Chenir coastal plain is affected by sea water (Nguyen, 1993). Sand bars are in few places surrounded by river branches.

The soils of Mekong delta are mainly constituted of alluvial soil. However, the existence of acidic and saline soil makes the soil status more complicated. Alluvial soil is found most suitable for rice cultivation. Saline soils are distributed along the coastal zone of the Mekong Delta. This area is extremely vulnerable to saline intrusion and is suffered from salinity. Acid-sulphate soil groups are widely present in the Mekong Delta (Yashimatha, 2005, Minh, 1995).

Flooding is severe in areas near Cambodia border, inundated for long time. Inundation depths are more than 1 meter while central delta areas are in the range of 0.3 to 1 meter. While lower areas towards coastal belts are mostly less prone to high inundation (Nguyen, 1993 and Nguyen, 2000).

Landscape-Ecological approach has improved our knowledge of landscapes and the complexities associated (Frissell *et al.,* 1986; Poole, 2002). It also provides a framework for studying land use dynamics and its relation with landscape (Naiman *et al.,* 1992). The valid description and information about landscape of area provides a foundation for effective, efficient monitoring and recovery strategies (Richards *et al.,* 1996, Cohen *et al.,* 1998, Jensen *et al.,* 2001).

The validation results showed that the output of the Landscape-Ecological approach was significantly correlating with the reported crops statistics in two rice land use system (65%) and in three rice land use systems (62%) with explained variability of 64% and 63% respectively. The regression line is not very close to 1-1 line which shows less agreement with crop statistics. The low correlation can be attributed to the limitations of this technique in delineating complex land use systems by employing limited time imagery.

Although a comparison with statistics data give a good validation but independent investigation of all the landscape parameters based on detailed survey has to be arranged for good results in future studies.

4.2. Strengths and Weaknesses

NDVI approach shows the ability to accurately identify different land use systems even in complex crop calendars and flooding regime. NDVI approach has taken in to consideration the long historical trends which helps in delineation of important land use related phenomena like flooding and silt harvesting. Agriculture land use is highly dynamic system so NDVI time series is a good solution to address this issue and to produce accurately and valid information for land use management (Wessel *et al.,* 2004, Sakamoto *et al.,* 2005; De bie *et al.,* 2008)

NDVI approach does not consider hierarchy from general to specific which is important to study patterns and process responsible to create condition for a particular type of land use systems (Naiman *et al.,* 1992, Schlosser, 1995).

Hierarchical landscape classification from upper to lower scales (from national scale to regional, zones and area scales) can help in comparing landscapes of different zones to each other. It can also be predicted how each unit will respond to any disturbance from outside and that will help making sustainable land use decisions without exceeding the carrying capacity of a certain area (Groten *et al.,* 1994; Nguyen, 1993; Turner, 1989).

Landscape-Ecological units will have similar potentials for any land use type and will face with similar intervention regimes. So that will support making decisions of conservation and usage within that ecological unit. The importance of Landscape attributes for land use systems regarding availability of base nutrients, water and other landscape dependent aspects like drainage etc is also vital(Hunsaker, 1992; Forman, 1995, Sader *et al.,* 2003; Vogelmann, 1995; Yu and Ng, 2006).

The map produced by the NDVI approach is highly correlated with reported crop statistics than the map produced by the Landscape-Ecological approach. The NDVI map is having good agreement with crop statistics showing correlation of 92% and 88% in two rice crops areas and three rice areas with R^2 of 74% and 76% respectively. The Landscape-Ecological map is having 65% and 62% correlations with explained variability of 64% and 63% in both two rice and three rice land use systems respectively.

4.3. Integrated Approach

Agriculture Land use mapping requires appropriate spatial and temporal scales (Wesels *et al.,* 2004) as well as levels of landscape organization (Nguyen, 1993). So far there is no agreed upon approach to address these dimensions, both the NDVI and the Landscape-Ecological approaches vary in their utility to address specific questions as well as their ability to convey information about high cropping intensity land use systems.

NDVI approach improved our ability to map land use variability across spatial and temporal scales. While Landscape-Ecological approach provides a framework (landscape attributes) for land use study and their management aspects.

Agricultural land use systems in both maps are significantly associated. Table 13 shows, that two rice land use class given in the NDVI map are in association with 84% of the sites with two rice land use system in the Landscape-Ecological map, similarly three rice was observed in 90 % of the cases ($\chi2$ = 57.78, d.f. = 1, N= 106, p < 0.01). Similarly chi square test with cross tabulation shows that there is significant but no distinct correlation between flooding regimes and geomorphology classes ($\chi2$ = 64.54, d.f. = 12, N = 507, $p < 0.01$). There is no outstanding and clear trend observed in both geomorphology and flooding classes association to help in improving the interpretation of land use systems. But keeping in view the overall significant association both maps can be integrated for further analyses and study of combinations of landscape attributes and NDVI classes.

Integration of the NDVI map and landscape attributes are found not clearly decisive in identifying particular land use systems. In case of geomorphology and flooding, this may be due to very flat terrain and certain arrangements like construction of dikes, improved crop management practices and better drainage of areas and availability of technology which has altered the flooding regimes and management aspects in different geomorphological units (Nguyen, 1993). Haruyama and Shida (2008) also discussed the effects of artificial embankments. Furthermore, he mentioned the role of artificial dikes using mobile rubber dams and soil dredged from the riverbed in flood controlling. The intensive development of infrastructure and urbanization in the lower reaches of the Mekong River Delta has altered the flood characteristics in the region.

The effects of soils on land use distribution might be minimized by the high rainfall and available inland waterways network. Most importantly annual flooding is used to flush the excessive salts and minimise acidity and hence improve the conditions for rice cropping. In some coastal areas excessive salts were even pumped out to manage the crops (Nguyen 1993). Similarly, Van Mensvoort and Dent, 1997 also mentioned that characterization of significant variability in acid sulphate soil areas is not easy. Within the dynamic environments of flood plains and wetlands, patterns of soil texture, acidity or potential acidity are not always clearly expressed by surface patterns. Furthermore, establishment of the relationships between landform and soil profile morphology, between morphology and the key physical and chemical characteristics need detailed studies in land units.

Although interpretations of the land use systems were not improved due to integration of both approaches in this case. But important useful information in the form of geomorphology and soils were added to the NDVI map in the form of additional legends. This will be beneficial for management aspects of the area (Husson *et al.,* 2000).

The hypothesis that the map produced by the NDVI approach explains 10% more variability (R^2) of the published crop statistics (Two rice, $R^2 = 74\%$ and three rice, $R^2 = 76\%$) than the map produced by the Landscape-Ecological approach which is 64% and 63% for two rice and three rice crops is proved by the fact that both approaches are having the difference of 10 % in their abilities to explain variability with crop statistics.

Further study to investigate landscape attributes along with the NDVI approaches can only prove useful in areas with clear and distinct landscape-ecological characteristics e.g. terrain, soils, climate etc. Secondly the landscape aspects were derived from already available data sources and there was no ground check done so it would be difficult to make inference on this but the overall methodology successfully shows the potential to be used for further study in areas with clear and distinct landscape-ecological units.

5. CONCLUSIONS AND RECOMMENDATIONS

The conclusions summarized the acquired results of the study, whereas recommendations addressed what need to be done to improve the results and conclusions.

5.1. Conclusions

The NDVI approach is found highly effective and accurate for classifying land use in heterogeneous and highly intensive crops areas like Mekong Delta, Vietnam. The NDVI approach successfully managed the phenomena of annual flooding and its interaction with agricultural land use systems.

Landscape-Ecological approach also identified landscape units and land use systems based on already available data sources but with limited scope.

The NDVI Map proved more accurate by showing strong correlation and explained 10% more variability than the Landscape-Ecological Map.

The results of the integrated approach were found very complex and less clear with respect to different Land use systems, as a result important landscape attributes like geomorphology and soils are added as separate legends to the NDVI Map for effective land use management aspects.

The methodology followed in this study provides a framework for characterizing and quantifying the agriculture land use systems and landscape of the area but require further studies to be proved effective.

5.2. Recommendations

1. Though the products were validated with crop areas statistics but independent field data should be used for validation of the maps in any future studies.
2. Landscape-Ecological aspects should also be investigated through field work in more details using sophisticated techniques.
3. This methodology followed in this study, required to be tested in areas having different terrain and other landscape-Ecological features.
4. The approach should also have been worked out in areas having different agro-climatic conditions then Mekong delta, Vietnam.

REFERENCES

Archer E.R.M., 2004, Beyond the "climate versus grazing" impasse: using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo. Journal of Arid Environments 57: 381-408.

Baatz, M & A. Schäpe, 2000, Multi resolution segmentation and optimization approach for high quality multi-scale image segmentation. In: Strobl, J., Blaschke, T., Griesebner,(Eds.), Angewandte Geographische Informationsverarbeitung XII, Wichmann-Verlag, Heidelberg: 12–23.

Biging, G. S., Colby, D. R., & R. Congalton, 1999, Sampling Systems for Change Detection Accuracy Assessment. In Lunetta, R. S e Elvidge, C. D. (Eds.) Remote Sensing Change Detection, Taylor & Francis, 281-308.

Blaschke, T & J. Strobl, 2001, What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. GIS Zeitschrift für Geoinformationssysteme 6: 12–17.

Brand, S & T.J. Malthus, 2004, Evaluation of AVHRR NDVI for monitoring intra-annual and interannual vegetation dynamics in a cloudy environment (Scotland, UK). In: Proceedings of the XXth ISPRS Congress, Commission-II, Istanbul, Turkey. 6pp.

Budde M.E., Tappan G., Rowland J., Lewis J & L.L. Tieszen, 2004, Assessing land cover performance in Senegal, West Africa using 1-km NDVI and local variance analysis. Journal of Arid Environment*s* 59: 481-498.

Campbell, J. B., 2002, Introduction to Remote Sensing, London and New York, Taylor and Francis.

Cayrol P., Chehbouni A., Kergoat L., Dedieu G., Mordelet P & Y. Nouvellon, 2000, Grassland modelling and monitoring with SPOT-4 Vegetation instrument during the 1997-1999 SALSA experiment. Agricultural and Forest Meteorology, 105: 91-115.

Cohen, P, H. Andriamahefa, and J.G. Wasson, 1998, Towards a regionalization of aquatic habitat: distribution of mesohabitats at the scale of a large basin. Regulated rivers: Research and Management 14: 391-404.

Dalrymple, J. B., Blong, R.J & A.J. Conacher, 1968, A hypothetical nine unit land surface model Z. Geomorphol. 12: 60-76.

Davenport M.L & S.E. Nicholson, 1993, On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa. Int. Journal of Remote Sensing, 14, 12, 2369-2389.

De Bie, C.A.J.M., 2002, Novel approaches to use RS - products for mapping and studying agricultural land use systems. Proceedings of ISPRS commission VII international symposium: Resource and environmental monitoring, December 3-6.

De Bie, C.A.J.M., Khan, M.R., Toxopeus, A.G., Venus, V & A.K.Skidmore, 2008, hyper temporal image analysis for crop mapping and change detection. In: ISPRS 2008: Proceedings of the XXI congress: Comm. VII, WG VII/5, Beijing: 3-11 July, pp. 803-812.

DeFries, R. S & J. R. G. Townshend, 1994, NDVI-derived land cover classifications at a global scale. International Journal of Remote Sensing, 15, 3567−3586.

Delli, G., Sarfatti, P & A.Cadi, 2002, Classification of historical series of NDVI: an application for northern Algeria. Journal of Agriculture and environment for international development, 96, 3 /4.

De, N., 2000, Crop improvement at community level in Vietnam. In 'Participatory Approaches to the Conservation and Use of Plant Genetic Resources' (Eds.Friis-Hansen and B. Sthapit) International Plant Genetic Resources Institute, 103-110.

Dent, D., 1986. Acid Sulphate Soils: A Baseline for Research and Development Vol. 39 ILRI

Pub., Wageningen, The Netherlands, p. 204.

Duda, R & P. Hart, 1974, Pattern Classification and Scene Analysis, Wiley.

Eerens, H., Kempeneers, P., Piccard, I & Y. Verheijen, 2001, Crop monitoring and yield forecasting with NOAAAVHRR or SPOT-Vegetation. http://www.geosuccess.net/ geo success / documents / Dry_Matter_Productivity.pdf (accessed 21 Apr'08).

ERDAS, 2003, ERDAS Field Guide, 7th ed. Leica Geosystems GIS & Mapping*, LLC.*

Florinsky, I.V & G.A. Kuryakova, 1996, Influence of topography on some vegetation cover properties. Catena 27, 123-41.

Forman, R., 1995, Land mosaics, The ecology of landscapes and regions. Cambridge University Press, Cambridge. 632.

Forman, R.T & M. Godron, 1986, Landscape Ecology, New York: Wiley.

Franklin, J., Logan, T.L., Woodcock, C.E & A.H.Strahler, 1986, Coniferous forest classification and inventory using Landsat and digital terrain data. IEEE Transactions on Geoscience and Remote Sensing GE-24, 139-49.

Frissell, C.A., W.J. Liss, C.E. Warren & M.D. Hurley, 1986, A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10(2): 199-214.

Gerrard, A.J., 1981, Soils and landforms. An integration of geomorphology and pedology. London.

Gorham, B., 1998, Mapping multi-temporal agricultural land use in Mississippi Alluvial valley of Arkansas. In: Proceedings of the Spatial Technologies in Agricultural and Natural Resources: SRIEG-10 Annual Conference, Global Hydrology and Climate Centre, Huntsville, USA.

Groten, S.M.E & R.Ocatre, 2002, Monitoring the length of the growing season with NOAA, International Journal of Remote Sensing, 23.14: 1271-1318.

Groten, S.M.E., De Bie, K., Bronsveld, K., Huizing, H., Leew, J.D., Looijen , J & van. Wijngardardan, 1995, Land ecology and land use study. Eds 1994/1995.ITC Lecture series.

Harris, A. R & I. M. Mason, 1989, Lake Area measurement using AVHRR. International Journal of Remote Sensing, 10, 885−895.

Haruyama, S., & K. Shida, 2008, Geomorphologic land classification map of the Mekong Delta utilizing JERS-1 SAR images (Hydrol. Process 22, 1373–1381, published online (www.interscience.wiley.com).

Hill, M.J & G.E. Donald, 2003, Estimating spatio-temporal patterns of agricultural productivity in fragmented landscapes using AVHRR NDVI time series. Remote Sensing of Environment 84: 367–384.

Huggett, R.J., 1975, Soil landscape systems: a model of soil genesis. Geoderma 13, 1–22.

Hunsaker, C. T., Levine, D.A., Timmins, S.P., Jackson, B.L & R.V. O'Neill, 1992, Landscape characterization for assessing regional water quality. Ecological Indicators. Elsevier, New York (McKenzie, D.H., Hyatt, D.E., McDonald, V.J. Eds.): 997–1006.

Husson, O., Verburg, P.H., Phung, M.T., M.E.F. Van Mensvoort, 2000, Spatial variability of acid sulphate soils in the Plain of Reeds, Mekong delta, Vietnam. Geoderma 97-2000:1–19.

Immerzeel, W.W.Q & S. M. R. A.De Jong, 2005, Understanding precipitation patterns and land use interaction in Tibet using harmonic analysis of SPOT VGT-S10 NDVI time series. International Journal of Remote Sensing, 26(11): 2281-2296.

IMSD, 1995, Integrated Mission for Sustainable Development – Madnur Area, Nizamabad District; AP. Integrated Survey Group, NRSA, Dept.of Space, Govt. of India. Hyderabad.

Jensen, M.E., I.A. Goodman, P.S. Bourgeron, N.L. Poff, and C.K. Brewer, 2001, Effectiveness of biophysical criteria in the hierarchical classification of drainage basins. Journal of the American Water Resources Association 37(5): 1155-1167.

Kameswara Rao, S.V.C, 1995, Cropping Pattern Analysis using Temporal IRS-LISS II Data – A Case Study of Madnur Watershed, Nizamabad District, AP. Agric.and Soil Division, IIRS, NRSA, Dept.of Space, Gvt.of India. Dehradun.

Kasper, K., Peter, H.Verburga & J. O. T(A.) Veldkamp, 2007, Integrated Assessment of the land system: The future of land use. Land Use Policy, 24(3): 517-520.

Kirkby, M., 1995, Modelling the links between vegetation and landforms, Geomorphology 13,319-35.

Kouchoukos, N., Smith, R., Gleason, A., Thenkabail, P., Hole, F., Barkoudah, Y., Albert, J., Gluhosky, P & J. Foster, 1997, Monitoring the distribution, use, and regeneration of natural resources in semi-arid Southwest Asia. Paper presented at the Transformations of Middle Eastern Natural Environments: Legacies and Lessons, Yale University.

Ledwith, M., 2002, Land cover classification using SPOT Vegetation 10-day composite images - Baltic Sea Catchment basin. GLC2000 Meeting, Ispra, Italy, April 18-22.

Liu, Z., Huang, F., Li, L & E. Wan, 2002, Dynamic monitoring and damage evaluation of flood in north-west Jilin with remote sensing, International Journal of Remote Sensing,23, 3669−3679.

Lunneta, R. S. & C. D. Elvidge, 1999, Remote Sensing Change Dectetion: Environmental Monitoring Methods and Applications, London, Tailor and Franscis, Ltd.

Maggi M & D., Stroppiana, 2002, Advantages and drawbacks of NOA-AVHRR and SPOT-VGT for burnt area mapping in a tropical savannah ecosystem. Canadian Journal of Remote Sensing 28.2: 231-245.

McCloy, K.R., 2006, Resource Management Information Systems: Remote Sensing, GIS and Modeling (Edition: 2) illustrated, revised, Published by CRC Press, 575 pp.

Minh, V.Q., 1995, Use of Soil and Agro hydrological Characteristics in Developing Technology Extrapolation Methodology: A Case Study of the Mekong Delta, Vietnam. Master of Science (Soil Science) Thesis, Department of Soil Science, University of the Philippines.

Moody, A., 1998, Using landscape spatial relationships to improve estimates of land-cover area from coarse resolution remote sensing. Remote Sensing of Environment, 64, 202–220.

Moore, D.S & G. P. McCabe, 2007, Introduction to the Practice of Statistics. New York: W. H. Freeman and Company.

Muchoney, D. M., Hodges, J., Hyman, A. & A. Strahler, 1997, A test site network for EOS-MODIS global land cover classification based on representativeness criteria. Geo science and Remote Sensing, IGARSS 97, Remote Sensing - A Scientific Vision for Sustainable Development, IEEE International, 3, 1227-1229.

Murakami T., Ogawa S., Ishitsuka N., Kumagai K & G. Saito, 2001, Crop discrimination with multi-temporal SPOT/HRV data in the Saga Plains, Japan. International Journal of Remote Sensing 22.7: 1335-1348.

Naiman, R.J., Beechie, T.J., Benda, L.E., Berg, D.R., Bisson, P.A., MacDonald, L.H., O'Connor, M.D.,Olson, P.L., & E.A. Steel, 1992, Fundamental elements of ecologically healthy watersheds in the Pacific Northwest Coastal Ecoregion. Pages 127-188 in R.J. Naiman, (ed.). Watershed Management:Balancing Sustainability and Environmental Change. Springer, New York, New York, USA.

Nguyen, H.C., 1994, Former and present cropping patterns in the Mekong Delta, Southeast Asian Studies, Vol. 31, No. 4, March 1994. Kyoto University, Japan.

Nguyen, H.C., 1993, Geo - PedologicaI Study of the Mekong Delta, Southeast Aszan Studies, Vol. 31, No.2.

Nguyen, N.H., Ta, T.K.O & M. Tateishi, 2000, Late Holocene depositional environment and coastal evolution of the Mekong River Delta, Southern Vietnam. Journal of Asian Earth Sciences,18: 427-439.

Nguyen, V. N., Do, M. H., Nguyen, N. A., & V. K. Le, 2004, Rice production in the Mekong delta Trends of development and diversification. Mekong Rice Conference 2004: Rice the Environment and Livelihoods for the Poor. 15– 17 October, in Ho Chi Minh City, Vietnam.

Poole, G. C., 2002, Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwater Biology 47(4): 641-660.

Raupach, M.R & J.J. Finnigan, 1997, The influence of topography on meteorological variables and surface atmosphere interactions. Journal of Hydrology 190, 182-213.

Reed, B. C., Brown, J. F., VanderZee, D., Loveland, T. R., Merchant, J. W., & D. O. Ohlen, 1994, Measuring phenological variability from satellite imagery. Journal of Vegetation Science, 5, 703– 714.

Richards, C., Johnson, L.B., & G.E. Host, 1996, Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Science 53(Suppl. 1): 295-311.

Roderick, M. L., Smith, R & G. Lodwick, 1997, Annual growth dynamics over continental scale regions using satellite derived vegetation indices. In N. E. West (Ed.), Rangelands in a sustainable biosphere. Proceedings of the fifth international rangelands congress pp. 477 – 478).

Rosner, B., 2000, Fundamentals of Biostatistics, 5th edition. Pacific Grove. CA: Duxbury Press.

Sader, S.A., Bertrand, M & E.H. Wilson, 2003, Satellite change detection of forest harvest patterns on an industrial forest landscape. Forest Science 49 (3), 341–353.

Sakamoto, T., Yokozawa, M., Toritani, H., Shibayama, M., Ishitsuka, N & H. Ohno, 2005, A crop phenology detection method using time-series MODIS data. Remote Sensing of Environment, 96, 366–374.

Sarkar, S & M. Kafatos,2004, Inter-annual variability of vegetation over the Indian sub-continent and its relation to the different meteorological parameters. Remote Sensing of Environment 90: 268-280.

Schlosser, I.J., 1995, Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 303: 71-81.

Schowengerdt, R. A., 1997, Remote sensing models and methods for image processing (Second Edition ed.). San Diego: Academic Press Limited.

Strahler, A.H., 1981, Stratification of natural vegetation for forest and rangeland inventory using Landsat digital imagery and collateral data. International Journal of Remote Sensing 2, 15-41.

Swain, P.H & S.M. Davis, 1978, Remote Sensing: The Quantitative Approach. McGraw-Hill, USA.

Thanh, D.N., Hossain, M & F.L. Porciuncula, 2003, Changes in agriculture and livelihood in the coastal areas of the Mekong Delta, Vietnam: Insights 1997-2001. Paper presented at Flood-prone rice annual review and planning meeting, Prachinburi, Thailand, 20-21

Tilton, J.C & W.T. Lawrence, 2000, Interactive analysis of hierarchical image segmentation. Geoscience and Remote Sensing Symposium. Proceedings. IGARSS. IEEE International.2: 733-735.

Toshihiro S., Nhan,V.N., Hiroyuki, O., Naoki I & Y, Masayuki, 2006, Spatio-temporal distribution of rice phenology and cropping systems in the Mekong Delta with special reference to the seasonal water flow of the Mekong and Bassac rivers. Remote Sensing of Environment 100:1 -6.

Turner, M.G., 1989, Landscape ecology: the effect of pattern on process. Annual Review of Ecology and Systematics, 20, 171–197.

Unganai, L.S & F.N. Kogan, 1998, Drought Monitoring and Corn Yield estimation in Southern Africa from AVHRR Data. Remote Sensing of Environment, 63: 219-232.

Van Mensvoort, M.E.F., Dent, D.L., 1997. Acid sulphate soils. In: Lal, R., Blum, W.H., Valentine, C., Stewart, B.A._Eds.., Methods for Assessment of Soil Degradation. Advances in Soil Science. CRC Press LLC, Boca Raton, FL, USA, pp. 301–335.

Van Mensvoort, M.E.F., Nhan, N.V., Tinh, T.K., Tri, L.Q., 1993. Coarse land evaluation of the acid sulphate soil areas in the Mekong Delta based on farmers' experience. In: Dent, D.L., Van Mensvoort, M.E.F._Eds.., Selected Papers: Hoˆ Chi Minh City Symposium on Acid Sulphate Soils Vol. 53 ILRI, Wageningen, The Netherlands, pp. 321–329.

Vogelmann, J.E., 1995, Assessment of forest fragmentation in Southern New England using remote sensing and geographic information systems technology. Conservation Biology 9 (2), 439–449.

Wardlow, B. D., Stephen L.E & J.H. Kastens, 2007, Analysis of time-series MODIS 250 m vegetation index data for crop classification in the U.S. Central Great Plains. Remote Sensing of Environment, 108:290–310.

Wessels, K. J., DeFries, R. S., Dempewolf, J., Anderson, L. O., Hansen, A. J & S. L. Powell, 2004, Mapping regional land cover withMODIS data for biological conservation: Examples from the Great Yellowstone Ecosystem, USA and Para State, Brazil. Remote Sensing of Environment, 92, 67−83.

Wondzell, S. M., Cunningham, G.L & D. Bachelet, 1996, Relationships between landforms, geomorphic processes, and plant communities on a watershed in the northern Chihuahuan Desert. Landsc. Ecol, 11: 351–362.

Xiao, X., Boles, S., Frolking, S., Salas, W., Moore III, B., & C.Li, 2002, Observation of flooding and rice transplanting of paddy rice fields at the site to landscape scales in China using VEGETATION sensor data. International Journal of Remote Sensing, 23, 3009−3022.

Yamashita, A., 2005, Zoning for risk assessment of water-related natural disasters in the Mekong Delta. Master Thesis. Can Tho University, Can Tho, Vietnam.

Yu, X., & C. Ng, 2006, An integrated evaluation of landscape change using remote sensing and landscape metrics: a case study of Panyu, Guangzhou. International Journal of Remote Sensing,27, 1075–1092.

Zhang, Y.H., M.J. Wooster, O. Tutubalina & G.L.W. Perry, 2003, Monthly burned area and forest fire carbon emission estimates for the Russian Federation from SPOT VGT. Rem.Sens. Environ., 87: 1-15.

APPENDICES

Appendix 1: Questionnaire used for Interview of farmers

Part: 1

Q1: Farmers field size (In Labour days (big =1300 m^2 or small=1000m^2)

Part 2: Crop Calendars (Start from September last year (2007))

Q1: 1st crop

a) When did you sow?

b) What variety did you sow?

c) When did you harvest?

Q2: 2nd crop, a) Sowing time?

b) Variety grown?

c) Harvesting Time?

Q3: 3rd crop, a) Sowing time?

b) Variety grown?

c) Harvesting Time?

Part 3: Management (Specify 1st crop growing date)

Q1: What was the seeding rate? (In labour days… specify big/small)

a) What was the sowing method?

b) Did you buy the seed from the shop?

Q2: Did you apply fertilizer?

If so:

a) When?

b) What type?

c) How much did you apply?

Part 4: Harvesting **(Emphasize 1st crop again!)**

Q1: How much Yield did you obtain? (In total or per big/small Labour Day)

Q2: How did you harvest the crop?

Q3: How much did you sell?

Q4: What amount of yield did you expect?

Q5: General problems

Did you encounter any notable problems during the 1st crop?

If so,

a) What type?

b) How much yield did you lose?

c) How did you manage for them?

Q6: Did you encounter any notable problems during the 1st crop with?

a) Pests

b) Diseases

c) Soil

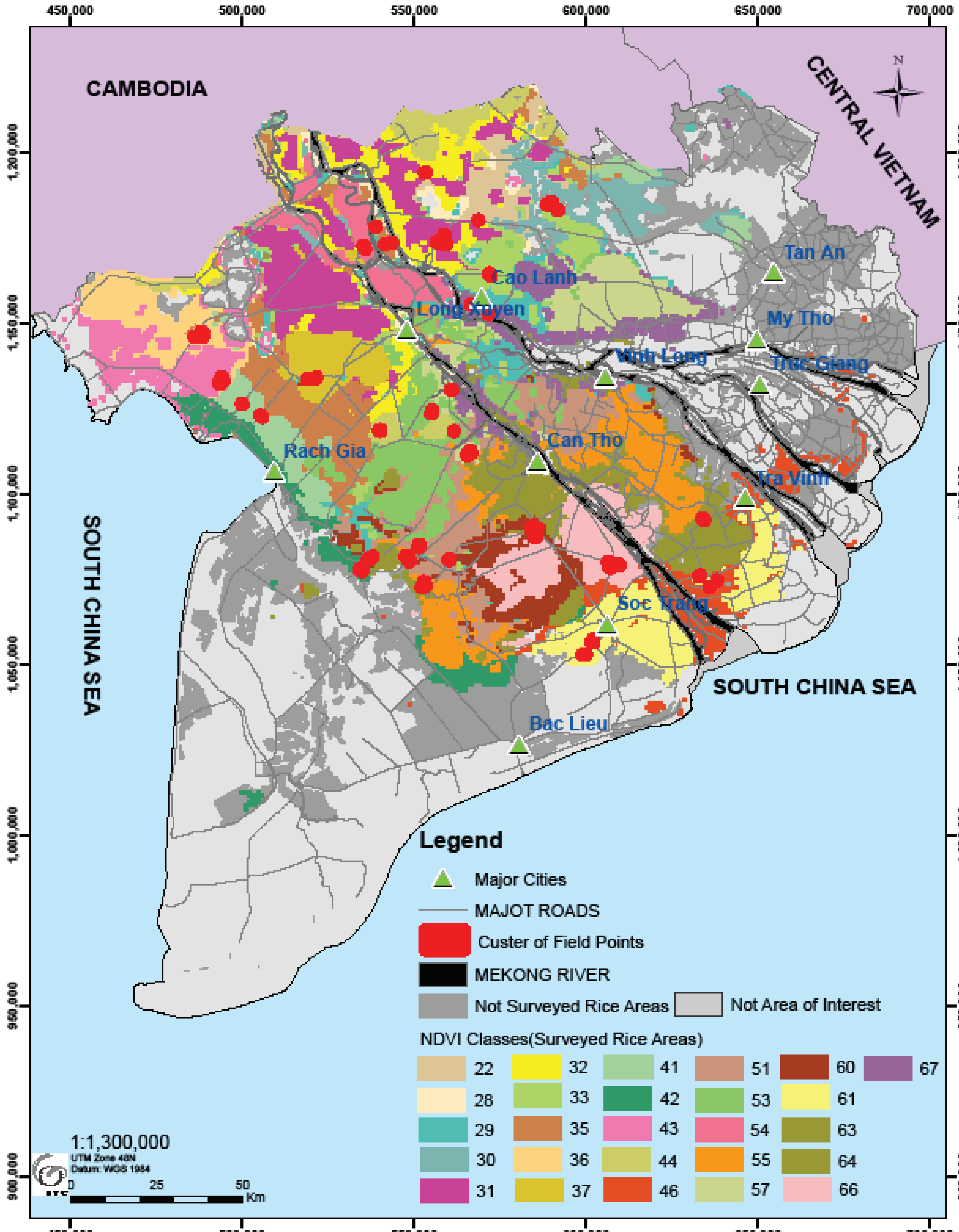
d) Water management

e) Weather

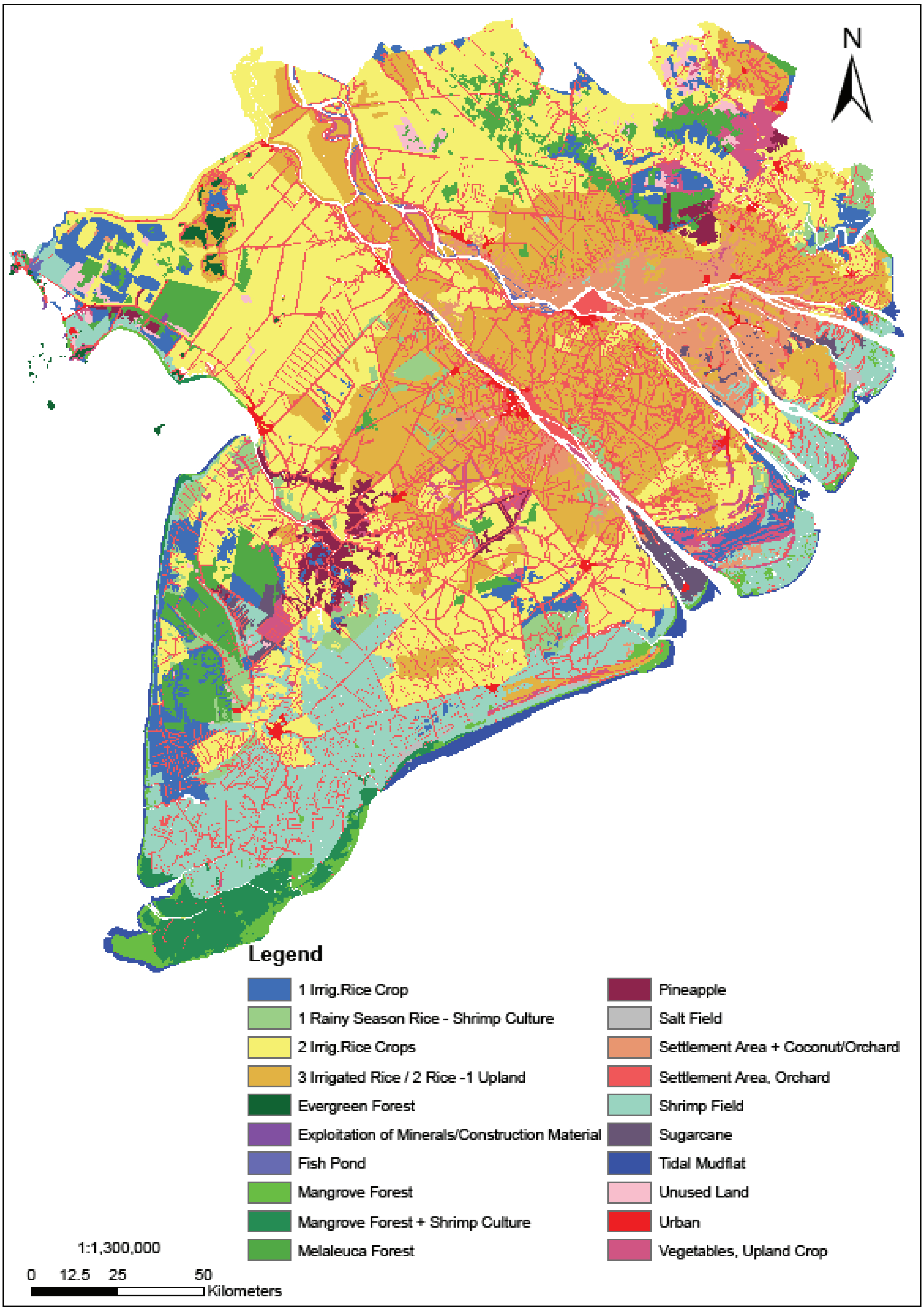
…Leading questions

If so: - What was it?
- How much yield did you lose?
- How did you manage for them?

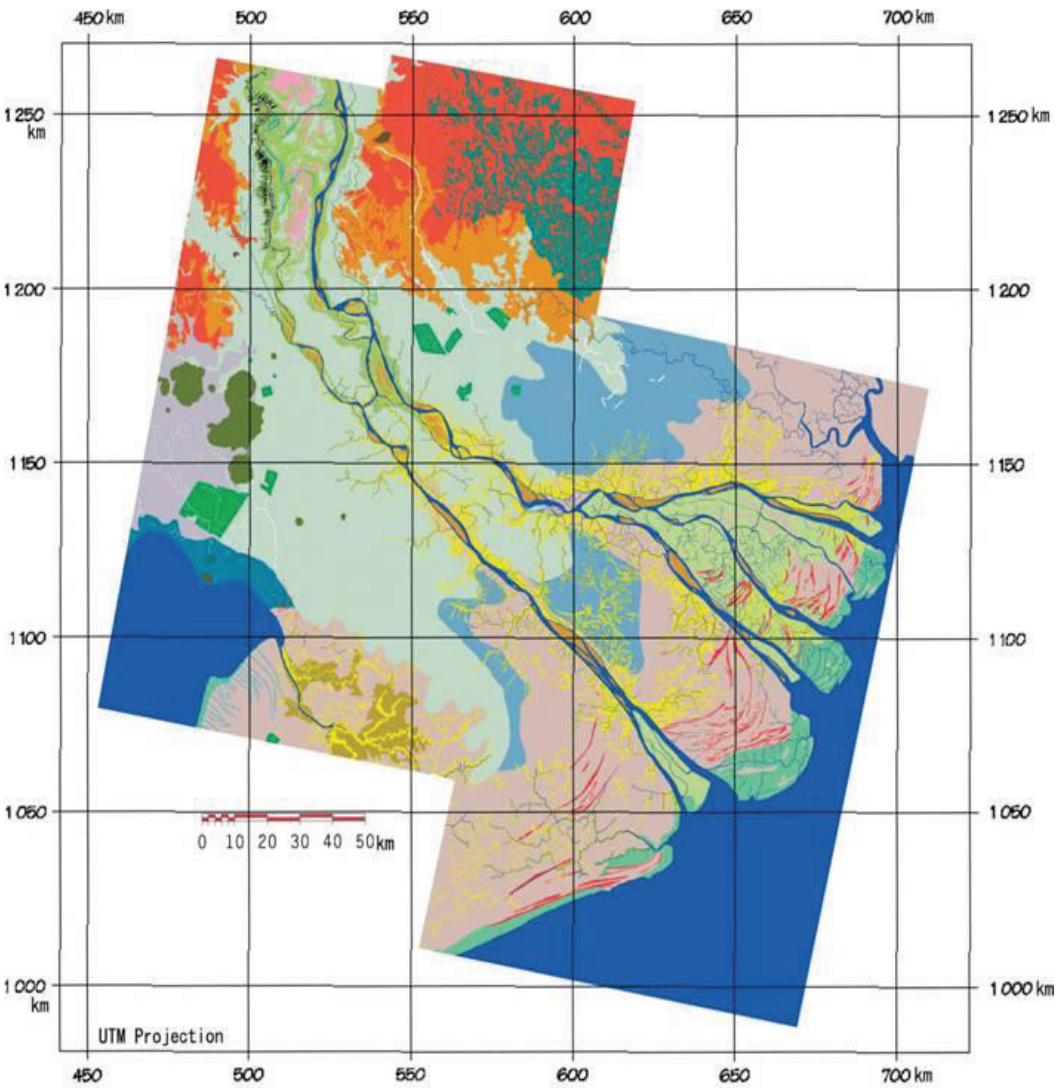
Appendix 2: Location of Field Points in Clusters in the Mekong Delta, Vietnam



Appendix 3: Land Use Map of the Mekong Delta, Vietnam

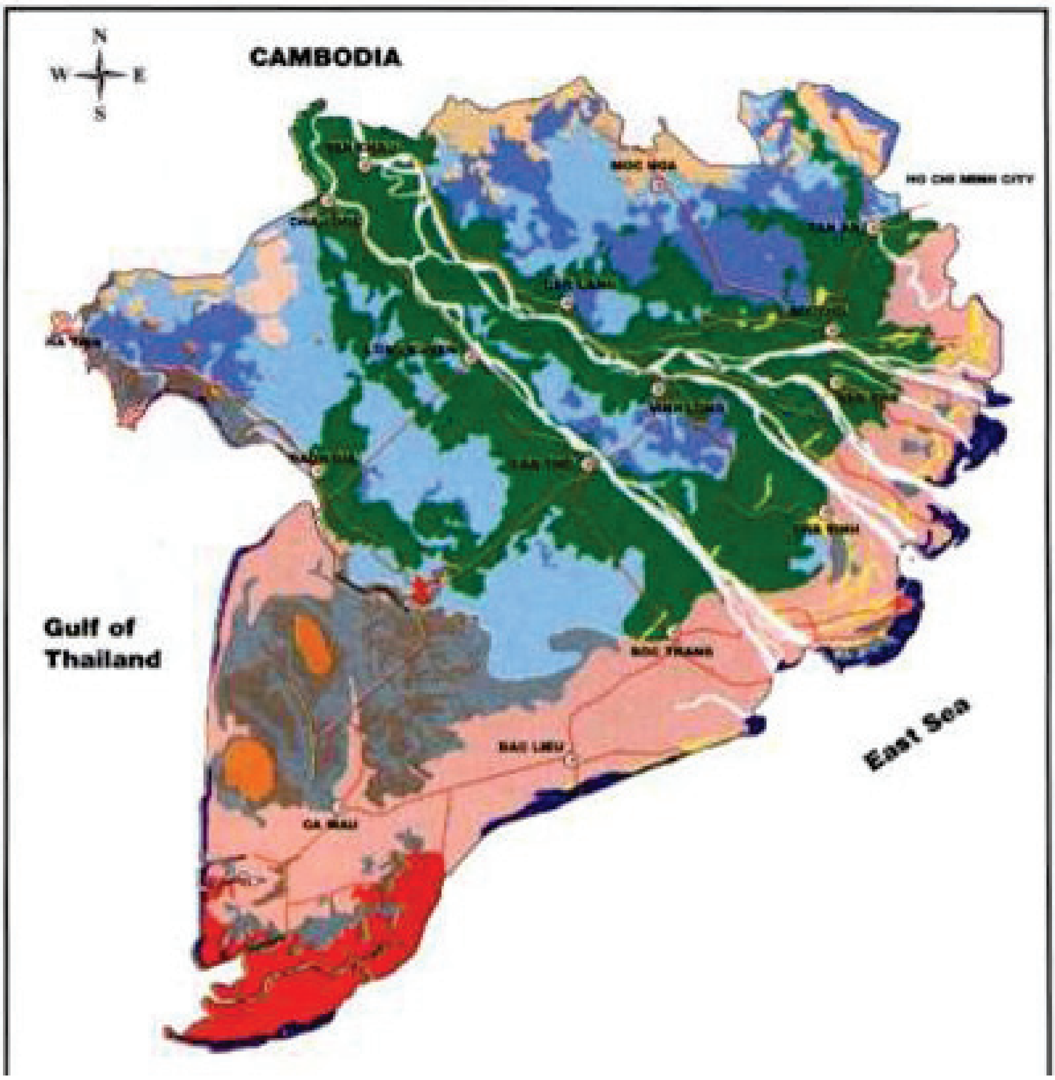


Appendix 4: Geomorphological Map of the Mekong Delta, Vietnam



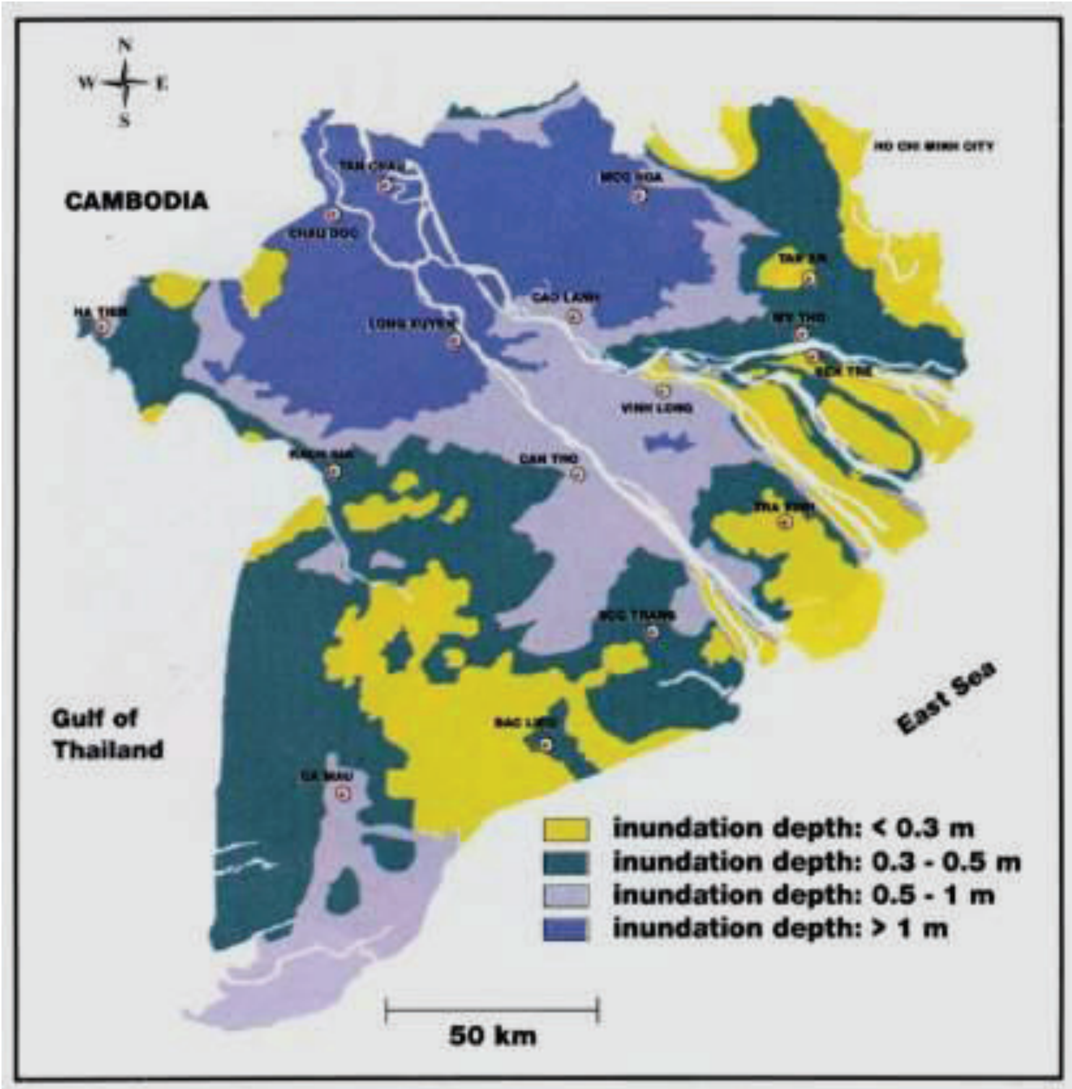
Legend	
Residual hill	Back swamp I
Marine terrace I	Back swamp II
Marine terrace II	Former river course
Alluvial terrace	Unclear former river course
Natural levee I	Chenir coastal plain
Natural levee II	The main Mekong River course
Old natural levee I	Tidal creek
Old natural levee II	Saline swamp
Sand bar	Inundation forest
Sand dune	Mangrove forest
Tidal canal levee	Artificial canal deposit
Barrier	Permanent swamp

Appendix 5: Soil Map of the Mekong Delta, Vietnam



	Legend
	Sandy ridge Soil
	Mangrove saline soil
	Saline soils
	Potential acid sulpahte soils
	Slightly and moderately acid sulpahte soils,salanized in dry season
	Strongly acid Sulpahte soils,salanized in dry season
	Strongly acid sulphate soils
	Slightluy and moderately acid sulphate soils
	Alluvial soils
	Peat soils
	Grey degraded soils
	Strongly eroded skeletol soils

Appendix 6: Map of Inundation Depths in the Mekong Delta, Vietnam



Appendix 7: Detailed Legend based on Integrated Approach.

Integrated Approach		NDVI Mapping Appraoch																									
		Uncontrolled Flooding					Controlled Flooding		Non Flooding		Uncontrolled Flooding																Non Flooding
		Extensive Flooding				Partial Flooding	Once in two years				Extensive Flooding										Partial Flooding						
Landscape-Ecological Approach		3x Rice						2-3x Rice	3x Rice		2x Rice															2x Rice + 1x Other	2x Rice
Geomorphology	Soil classes/properties	53	57	51	37	55	66	54	63	64	32	22	31	33	30	35	36	44	41	28	29	42	60	46	61	67	43
Alluvial terrace	Grey degraded soil										14					5	25	46									7
	Slightly and moderately acid sulphate soil										36					4	100	3									59
	Strongly acid sulphate soils															10	230										190
	Strongly acid sulphate soils,salanized in dry season																					4					77
Marine terrace	Grey degraded soil										101	22	23	7	55	65		263	26	10	6						
	Slightly and moderately acid sulphate soil											15	17	3	56						6						
	Strongly acid sulphate soils										27	6	35					6		5							
Saline swamp	Alluvial soil																		36			25					
	Slightly and moderately acid sulphate soil																		32			3					
	Strongly acid sulphate soils,salanized in dry season																		8			160					55
Natural levee I	Alluvial soil		38	22		28	73		49	75										5	26		3	14		248	
	Saline soils																							12	14		
	Slightly and moderately acid sulphate soil								41												4					3	
Natural levee II	Saline soils																							152			
	Slightly and moderately acid sulphate soil																							11			
Old natural levee	Alluvial soil							51			33					2		2		16	7						
	Strongly acid sulphate soils										3																
Sand bar	Alluvial soil			13		10		35	19			6				27		2	11	4	14	39	21				
	Slightly and moderately acid sulphate soil			2		21			47												8	4	5				
Back swamp I	Alluvial soil	486	90	260	362	30		287	7		361	38	871	179	51	232		79	90	52	264					39	
	Grey degraded soil										50	28	22		19	9	3	13		10	8						13
	Slightly and moderately acid sulphate soil	415		372	112	12	81	6	25		53	212	316	130	174	575	28	55	130	62	104		178			6	24
	Strongly acid sulphate soils	3									92	170	230	31	56		3		4	17	3		7				
Back swamp II	Alluvial soil	17	466	58		147	77		160					3	18				25		9		40			154	
	Grey degraded soil														9												
	Slightly and moderately acid sulphate soil	5	4	134		361	58		55					50	38						11		32			11	
	Strongly acid sulphate soils	14	140											101	59				26		32					57	
	Strongly acid sulphate soils,salanized in dry season																						21				
Chenir coastal plain	Alluvial soil	55		118		251	275		386	307				8		49			149		85	57	80	92	36	48	
	Saline soils									4												35		220	780		
	Slightly and moderately acid sulphate soil	14		148		251	144		17	59				35		35			4		41	84	214	9	22		
	Strongly acid sulphate soils		2																							12	
	Strongly acid sulphate soils,salanized in dry season			12		64			4	14												99	31				