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Determinants of land-use change: A case study from the lower Mekong delta of southern Vietnam

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Abstract

The paper examines forestland conversion in the period from 2001 to 2005, and its socioeconomic determinants affecting changes in the Kien Luong district of southern Vietnam using Geographic Information Systems (GIS), Remote Sensing (RS), and multiple regression techniques. The land use/ land cover (LULC) classes from 2001 and 2005 were classified from Landsat ETM Plus 2001 and digitized from the 2005 district land-use map. Socioeconomic data corresponding to the derived LULC classes were aggregated for the multiple regression analysis of determinants of the forestland conversion. The findings indicated that the loss of forestlands was driven by the quick growth of the rural economy, and the two largest contributors were the prompt expansion of agricultural and aquaculture. Such a land-use change hampered agricultural development and ecological services. Addressing land-use suitability for production systems and the socio-environmental costs of the changes is necessary for informing more effective policies of utilization and management of land resources.

Key words: land-use change, socioeconomic determinants, integrated planning, GIS, land resources management

1. Introduction

Land resources are finite, fragile and non-renewable. They form the basis for human and other terrestrial ecosystems and agricultural production (FAO, 1995a; Wood, Sebastian and Scherr, 2000). Rapid population growth has triggered the transformation of forest resources in many parts of the world into other forms of agriculture. Accompanying this transformation are the problems of socioeconomic degradation and other natural systems from global warming. The climate change has resulted in many negative effects including greater frequency of heat waves, increased intensity of storms, floods and droughts rising sea levels, a more rapid spread of disease, and loss of biodiversity (IPCC, 2001b). In Southeast Asia, the annual economic loss due to such degradation ranges from 1 to 7 percent of the agricultural gross domestic product (GDP) (Scherr, 1999). One case study predicts that due to climate change, 10.8 percent of the population, 10 percent of the GDP, and 28 percent of wetlands in Vietnam, especially in the Mekong and Red deltas, would be impacted by a 1 m sea level rise (SLR) and reaching much higher levels of impact if SLR is 5 m. This would place Vietnam among the top five most impacted countries (Dasgupta, 2007). Therefore, related issues to LULC change have recently attracted interest among a wide variety of researchers to explore either LULC change patterns or causes and effects of land-use change (Long, 2006).

Considered the rice bowl of Vietnam, the lower Mekong delta grows the second largest quantity of rice after Thailand (FAOSTAT, 2003), 80 percent of which is produced for export (Nguyen *et al.,* 2004). The quick expansion of intensive rice cultivation has made soils in many places of the region compact, and has been shown to influence both the crop yields and soil productivity (Khoa, 2003). A recent study emphasized that rice fields can yearly emit an amount of 50-100 Tg CH_4, a green house gas contributing 10-20 percent of total global emissions (Prather and Ehhalt, 2001). Spread of aquaculture along the coastal zones has also triggered an increase of seawater encroachment, and it has been recorded to trespass from 5 up to 60 km inland (Xuan and Dung, 2005).

Although a number of studies have been done in the region to explore changes in LULC patterns (Sakamoto, 2005; Ribbes, 1999; Pham, 2003; Binh, 2005), no study has been conducted to address the interactions between LULC changes and its socioeconomic drivers when formulating interventions for sustainable landscape development. Investigations with an exclusive focus on only biophysical, socioeconomic, or political aspects are commonly seen in the literature, but a single research approach is insufficient for analyzing LULC change (Long, 2005; Velazquez et al., 2003). Therefore, a prevailing challenge today confronting policy makers is how to synthesize biophysical observations, policy factors, and socioeconomic statistics in a systematic manner to generate useful insights for effective management of land resources (Turner et at., 1993; NRM, 2001). This is urgent in the case of Kien Luong district, where the majority of land-use changes are due to socioeconomic driving forces such as rent seeking, market adoption, and other factors (Son, et al, 2006).

The prime goal of this paper is to explore the interactions between forestland conversion, namely seasonally flooded forests with dominant *Melaleuca cajuputi* and *Eleocharis dulcis* species, and major socioeconomic driving forces influencing such changes. The paper has the following goals: (i) to detect changes in LULC during a five-year period between 2001 and 2005, and (ii) analyze socioeconomic determinants of forestland conversion. Based upon the derived findings, it may be helpful for decision makers to make adjustments on existing LULC patterns for long-term landscape development.

The study deploys multiple regression, a statistical technique to predict one variable from values of other variables, as well as a combination of RS and GIS, which have been widely applied and identified as powerful and effective tools in detecting the spatio-temporal dynamics of LULC (Fazal, 2000; Hathout, 2002; Herold et al., 2003; Mapedza et al., 2003; Alphan, 2003; Nagendra et al., 2004; Wang et al., 2005). Specific to this, RS can provide researchers valuable multi-temporal data for monitoring land-use patterns and processes (Lambin et al., 2001; Yildirim et al., 2002), and GIS techniques make possible the analysis and mapping of these LULC patterns (Imbernon, 1999; Zhang et al., 2002).

2. The Study Area

Located in Mekong delta between latitudes 10^0 08' 05'' - 10^0 32' 05'' N and longitudes 104^0 31' 06'' - 104^0 48' 04'' E, the study area covers 90,632.27 ha with nine administrative villages and one township (Fig. 1). The climate is monsoon tropical semi-equatorial with an annual mean temperature of 27.5 ^{0}C (minimum 26.3 ^{0}C, maximum 28.78 ^{0}C), and yearly average rainfall of 1,442 mm. Except for a few mountainous areas, the elevation of the study region is 0.3 to 0.8 m above sea level. Based upon FAO-UNESCO and U.S. soil taxonomy, 89.03 percent of the area is dominated by acid sulfate soils (ASS), namely Sali-Epi-Orthi-Thionic Fluvisols, Sali-Sulfi-Epi-Thionic Fluvisols, Humic Epi-Orthi-Thionic Fluvisols, Endo-Orthi-Thionic Fluvisols, Humic-Endo-Orthi-Thionic Fluvisols ,Endo-Orthi-Thionic Acrisols, Sali-Endo-Orthi-Thionic Fluvisols, Sali-Endo- Prothionic-Thionic Fluvisol, and Thionic Histosols (Nhan, et al, 1991).

We chose this area because it contains several major seasonally flooded ecosystems dominated by *Melaleuca cajuputi* and *Eleocharis dulcis* species, coastal mangroves, and evergreen forest with a number of endemic or rare and endangered species, such as redheaded cranes. Due to its outstanding ecological features (Baltzer *et al.,* 2001), a part of the study area has recently been nominated by the Man and Biosphere Vietnam (Vietnam MAB, 2005) and approved by the United Nations Educational, Scientific and Cultural Organization (UNESCO) for the Kien Giang Biophere Reserve (Tri, 2006).

Although the area is less populated (99 people per sq km) when compared to the national average (253 people per sq km), the study area has being faced with high threat to overall ecological integrity due to the rapid conversion of the forestlands in the buffer zones to irrigated rice fields and shrimp farms. A large amount of forestland is already lost, and the destroyed area increased from 500 ha in 1998 to 14,000 ha in 2003. Of the 14,000 ha, 7,457 ha was converted to irrigated rice monocropping (Sub-NIAPP, 2003), an economic crop important for exports, even though almost all of the soils were found to be marginally suitable for rice cultivation (Son *et al.,* 2008).

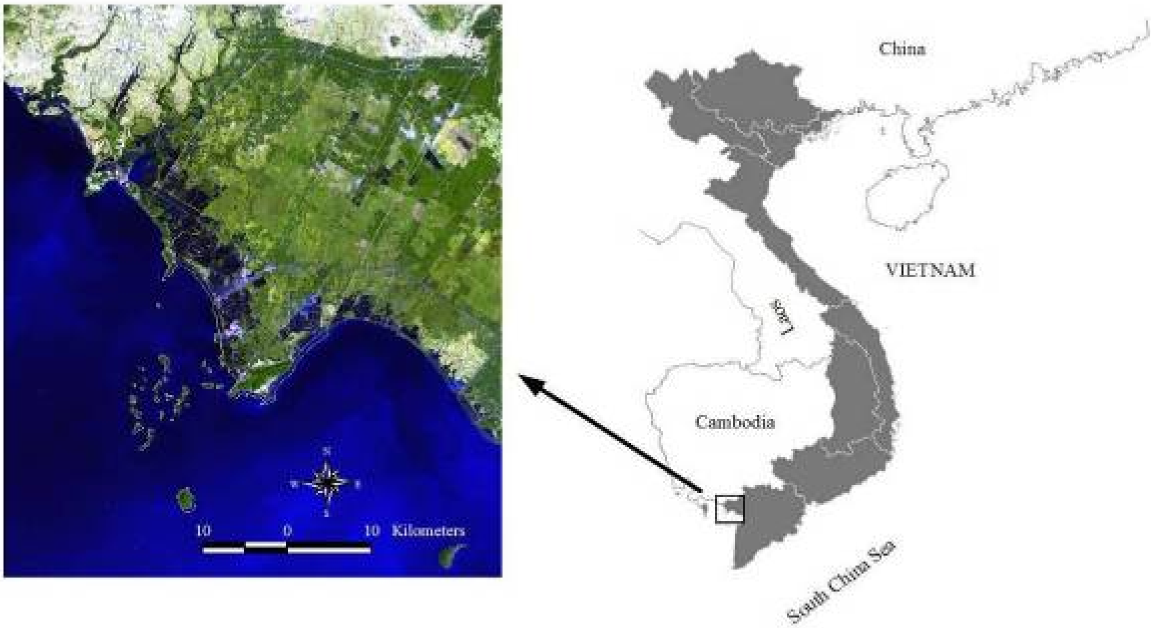

Fig.1. Map of Vietnam showing the location of the study area.

3. Materials and Methods

Fig. 2 outlines the research procedure. It employs GIS, RS, and multiple regression methods to detect LULC changes, and subsequently examine the relationships between forestland conversion and socioeconomic factors affecting such losses. The data used in this study consisted of Landsat ETM Plus (Enhanced Thematic Mapper) imagery acquired in January 2001 from the U.S. Geological Survey (USGS). The image was used because it corresponds with the period when large changes in land use took place. The study also utilizes the 2005 LULC map sheet (1:25,000 scale) from the Department of Natural Resources and Environment in Kien Giang, as well as relevant socioeconomic data such as land-use areas and annual input and output values from different land-use types. Socioeconomic data was taken from the statistical yearbooks of the statistical offices at all administrative levels and non-governmental organizations.

Additional information related to land-use change in the study was gathered through administering semi-structured interviews with long term residents, as well as meetings throughout the agricultural landscapes using the participatory rural appraisal (PRA). This method places emphasis on empowering local people to assume an active role in analyzing problems and drawing up plans, with outsiders acting mainly as facilitators (Schonhuth and Kievelitz, 1993)

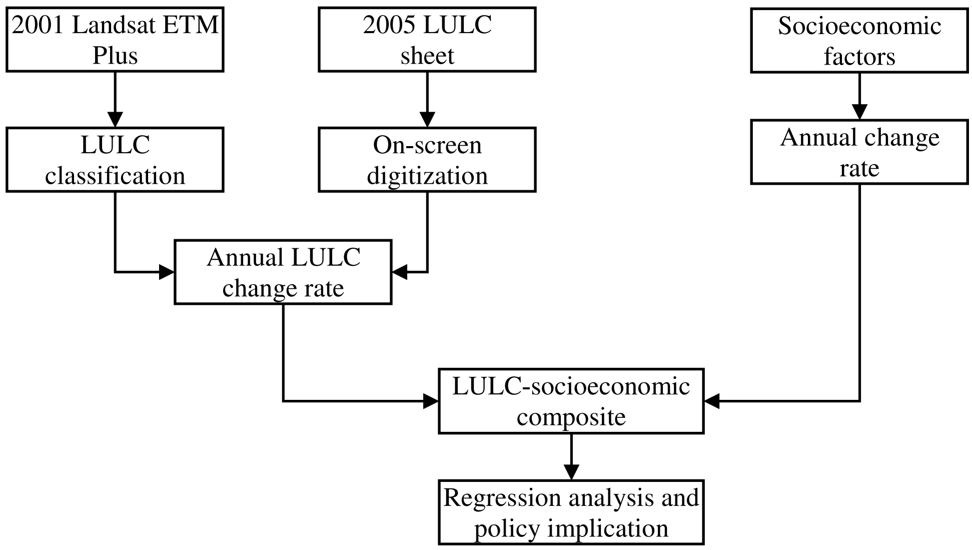

Fig. 2. Schematic presentation of the study.

3.1. LULC classification

A series of geometric and atmospheric corrections were initially performed on the imagery to remove noise and customize the coordinate system with the help of Environment for Visualizing Images (ENVI 4.0). The image was displayed in a false color composite of bands 4, 3, and 2 in RGB respectively for enhanced visual interpretation of healthy vegetation, soils, and clearings. Imagery was also enhanced using the Gaussian method.

To differentiate among vegetation types for easier classification, unsupervised classification (Isodata) was utilized. An advantage of this technique lays in its ability to avoid errors in classification by overlapping classes of the training areas (Brook and Kennel, 2002). The convergence threshold of 95 percent and a maximum number of 24 iterations were chosen to perform the Isodata clustering. After that, the preliminary spectral classes were visually compared with reference information derived from existing secondary land-use information.

To obtain representatives for each land-use type, it was necessary to define training data areas or regions of interest (ROI) across the study area (Littesand and Kiefer, 1987). The supervised (Maximum Likelihood) classification algorithm was performed on these areas of interest, and the probability threshold of 0.9 was set for the classes. Post-classification evaluation was done using the Confusion Matrix method, which compares reference pixels with classified pixels. The result was also re-calibrated by comparing the geographical data derived from ground truthing to remove uncorrelated pixels. Each layer of the produced map was labeled, saved as a GeoTIF or TIF world file (.tfw), and finally converted into a grid for area calculation and map layout with the help of ArcInfo. The annual conversion rate for each LULC type was calculated by using the formula introduced by FAO (1996).

3.2. Composite of LULC-socioeconomic factors

Relevant socioeconomic and agricultural factors to LULC changes were determined by utilizing expert knowledge of the district's socioeconomic structure, and were confined to the availability of statistical data. These variables were then placed into a regression analysis. A challenge of data acquisition was spatial and temporal differences between villages, and as a result the villages far inland were not considered for the analysis. The socioeconomic and agricultural factors selected for the analysis including total population, land under irrigated rice, land under upland crops, land under aquaculture, land under forestry, built-up areas, gross output of paddies, upland crops, pineapple, total input values from agriculture, husbandry, aquaculture, gross domestic product value (GDPV), income from the rural economy, expenses from the rural economy, and number of enterprises. These variables were initially computed for annual change rate and subsequently merged with derived LULC types through geo-processing using Boolean functions in ArcInfo.

3.3. Regression analysis of land-use determinants

Statistics in terms of analyses of correlation, multiple regression and econometric models have been recognized as useful to identify determinants of land use change based on time series socio-economic data (Xie, 2005). We produced socioeconomic drivers, which are significantly corresponsive for the conversion of forestlands, using the combined socioeconomic and remotely sensed data with the help of Statistical Package for the Social Sciences (SPSS 13.0). A correlation matrix was constructed through bivariate analysis to evaluate the relationships between coefficient factors. These correlated variables were then entered into the regression analysis. The step-wise search technique was used to estimate coefficients of the linear model. The entry into the stepping method criteria was set at $\alpha < 0.05$.

4. Results

4.1. LULC change detection

The result of classifying the 2001 Landsat ETM Plus image indicated nine LULC classes that were useful for discriminating agricultural parcels and forested areas. The matrix of post classification showed the overall percentage of map accuracy was 90.56% and Kappa coefficient of 0.81. A total of 66,697 pixels were checked to determine the accuracy in each class (Table 1). Two classes with the lowest accuracy levels were water body (62.98%) and winter rice (79.16%). Water body had high occurrence of error, because it is often confused with shrimp ponds. Winter rice error is mainly due to the combination of built-up areas and mixed forests which are covered with very little vegetation. The area of each land-use type is reported in Table 2.

Table 1
Confusion matrix derived from the classified imagery.

LULC	IR	SF	FL	PA	WR	BA	MF	EF	WB	Total
Irrigated rice (IR)	95.50	0.00	0.01	0.00	0.50	0.00	0.10	2.91	0.00	7.47
Shrimp farm (SF)	0.00	97.06	0.02	0.00	0.00	0.00	0.00	0.00	33.93	2.5
Forestland (FL)	0.04	0.27	90.71	1.42	15.14	0.10	0.50	0.04	0.00	0.1
Pineapple (PA)	0.04	0.00	0.47	94.45	1.54	0.19	0.40	0.12	0.00	1.41
Winter rice (WR)	0.22	0.00	6.75	2.13	79.16	4.58	1.39	0.38	2.02	7.78
Built-up area (BA)	0.02	0.18	0.68	0.00	0.95	90.35	0.00	0.02	0.77	1.95
Mangrove forest (MF)	0.20	0.71	95.53	1.99	1.36	0.00	95.53	0.68	0.06	2.04
Evergreen forest (EF)	3.88	0.00	0.44	0.00	0.95	0.00	1.89	95.46	0.00	7.8
Water body (WB)	0.02	1.78	0.06	0.00	0.41	0.10	0.20	0.00	62.98	1.68
Total	100	100	100	100	100	100	100	100	100	100
Overall accuracy = 90.56%										
Kappa coefficient = 0.81										
Total pixels = 66,697										

During the period from 2001 to 2005, the conversion rate of irrigated rice had the biggest negative conversion (0.77), followed by shrimp farms (0.59) while upland crops such as pineapple were a bit increased (0.20). The forestlands and winter rice witnessed the biggest losses in this period. The areas and spatial distribution of LULC types are presented in Table 2 and Fig. 3 and 4.

Table 2
Land-use change and annual conversion rate.

LULC	2001	2005	2005-2001	Annual conversion rate
Irrigated rice	4,489.38	44,177.08	39,687.70	0.77
Winter rice	17,168.67	3,213.70	-13,954.97	-0.34
Pineapple plantation	356.40	737.30	380.90	0.20
Forestland	54,667.17	12,530.03	-42,137.14	-0.31
Shrimp farm	3,326.31	21,471.26	18,144.95	0.59
Evergreen forest	2,815.38	2,199.62	-615.76	-0.06
Mangrove forest	429.39	676.83	247.44	0.12
Built-up area	4,040.37	3,986.73	-53.64	0.00
Water body	3,082.59	1,790.54	-1,292.05	-0.13

Out of 42,137.14 ha of forestland lost, 27,511.34 ha, or 65.29 percent, was converted to irrigated rice, and 12,274.55 ha, or 29.23 percent, to shrimp farms (Table 3). The losses of forestlands were most likely due to people's pressing basic needs, rent-seeking behavior, and lobbying for the use of resources for an increased net benefits of special interest groups (Tietenberg, 2004). Such lobbying usually occurs between local bureaucrats, political parties and better-off land users. These groups convert an enormous amount of forested areas into irrigated rice and shrimp farms (Son et al, 2008). Moreover, the rapid expansion of shrimp farms and irrigated rice fields is being driven by the high market value of shrimp, as well as the marketing attractiveness of rice for export. These push factors are in stark contrast to the low market value of *Melaleuca cajuputi.*

Table 3
Conversion percentages of forestlands to other LUTs.

LULC	%
Irrigated rice	65.29
Winter rice	2.04
Pineapple	1.09
Shrimp farm	29.13
Built-up area	1.95
Water body	0.50

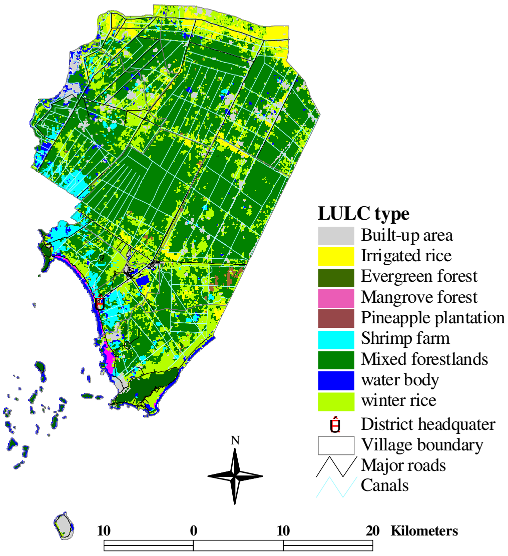

Fig. 3. 2001 LULC patterns.

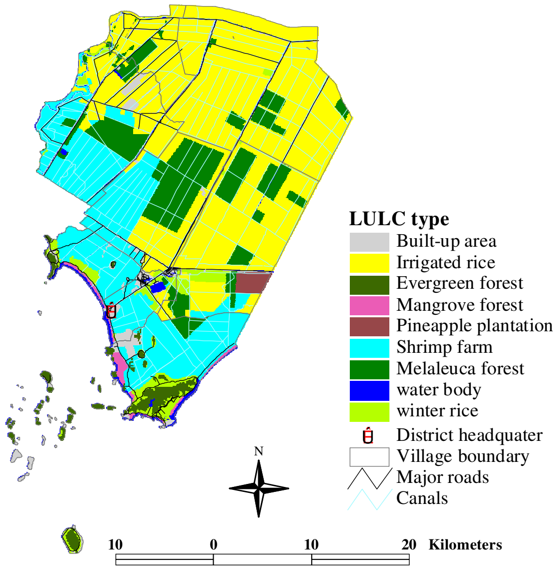

Fig.4. 2005 LULC patterns.

4.2. Determinants of land-use change

The Pearson correlation matrix exhibited that ten out of fifteen variables that were entered into the bivariate correlation analysis were highly correlated with the coefficient of forestland conversion. These variables were land under aquaculture, land under irrigated rice, land under forestry, land under upland crops, total population, total output value from agriculture, total output value from aquaculture, GDPV, total income from rural economy, total expenses of rural economy, and number of enterprises. The output of multiple regression analysis confirmed that six major socioeconomic factors were driving forestland conversion (Table 4). The p-values smaller than 0.05 revealed that the relation was significant at a 95 percent confidence level and the fitted model explained 99.6 percent of variance (R^2 = 0.991). The standard error (S.E.), which showed the standard deviation (S.D.) of the residuals, was 0.0054. The Durbin-Watson (DW) statistics of 0.093, which was close to 0, indicated a positive significant autocorrelation in the residuals.

Table 4
Regression analysis of land-use change determinants.

Parameter	Coefficient	S.E	t-statistic	P-value
Intercept	-0.699	.002	-292.831	0.000
Gross domestic product value (mil. dongs)	1.356	.009	142.806	0.000
Land under irrigated rice (ha)	0.013	.001	12.671	0.000
Land under upland crops (ha)	0.227	.003	73.350	0.000
Land area under aquaculture (ha)	0.314	.002	168.444	0.000
Total output value from cropping (mil. dongs)	1.256	.010	123.586	0.000
Number of enterprises (pieces)	-0.862	.007	-118.376	0.000
R^2 = 0.996; R^2 (adjusted for d.f.)= 0.991				
Standard error of estimate (S.E.) = 0.0054				
Durbin-Watson (DW) statistic = 0.093				

Note: winter rice and upland crops such as pineapple were spatially combined for regression analysis
1 USD = 15,960 dongs (Vietnamese currency)

Aquaculture and total income of the rural economy had the highest change rate at 0.23 (Table 5). This rapid economic growth heavily impacted the forestland conversion. While aquaculture specifically had the highest change rate, the largest contributor to forestland conversion overall between 2001 and 2005 was the total output from agriculture.

Table 5
Annual socioeconomic change rate.

Factors	2001	2005	Change rate
Total population (pers.)	77,213	81,362	0.01
Total output value from cropping (mil. dongs)	102,150	192,140	0.17
Total output value from aquaculture (mil. dongs)	125,800	291,300	0.23
Total output value from husbandry (mil. dongs)	23,867	33,043	0.08
Gross domestic product value (mil. dongs)	433,165	816,062	0.17
Total income of rural economy (mil. dongs)	4,654	10,621	0.23
Total expenses of rural economy (mil. dongs)	4,171	8,597	0.20
Number of enterprises (pieces)	454	453	0.00

During the five-year period, the average annual increase of the total output from agriculture was much greater (11.9%) than that of aquaculture 5.48% (Fig. 5). This was not contradicted by the determinants derived from the fitted regression model since a large proportion of land under crop cultivation and shrimp culture was significantly correlated with the forestland conversion.

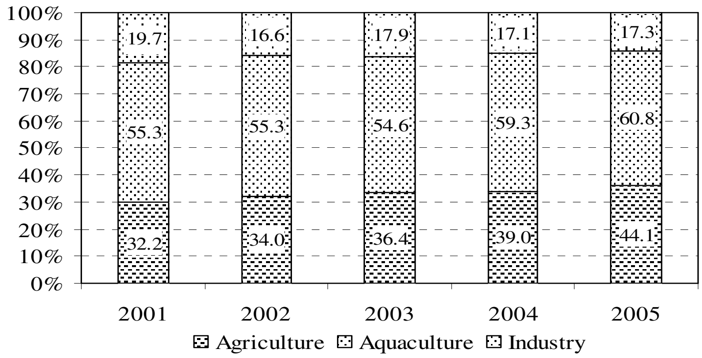

Fig. 5. Changes in the economy sharing agriculture, aquaculture and industry.

The areas of shrimp culture were rapidly expanded, especially from 2002 (Fig. 5), with support from the local government, which launched supportive land-use policies in order to raise shrimp production. These land-use policies were implemented when the year before, production had drastically been reduced. The fluctuations in shrimp production reflect the instability of the production system due to the fact that the environmental conditions are marginally suitable for shrimp farming. In terms of economic concerns, the benefit-cost ratio (BCR) of the production system decreased from 6.97 in 2003 to 0.13 in 2005 (Son et al, 2008).

Agriculture of irrigated rice was likewise on the trend of widening its area (Fig. 6), because it is a short-term crop and is a favorable market for export. A large number of local people chose to increase irrigated rice production as a potential method of improving their livelihoods. However, according to Son et al (2008), just a small proportion of land used for irrigated rice (0.83 percent) actually has soil suited for the crop. Thus, this increase of land use for irrigation rice would be an alarm for land-use policy-makers concerned with sustainable development.

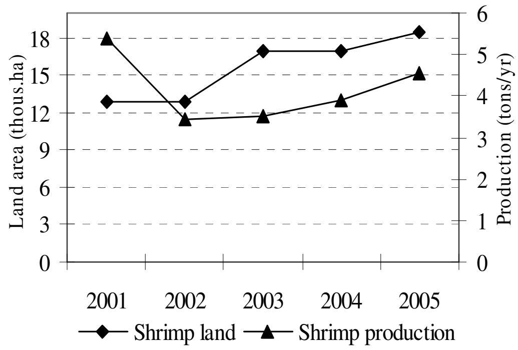

Fig. 6. Changes in shrimp land and production.

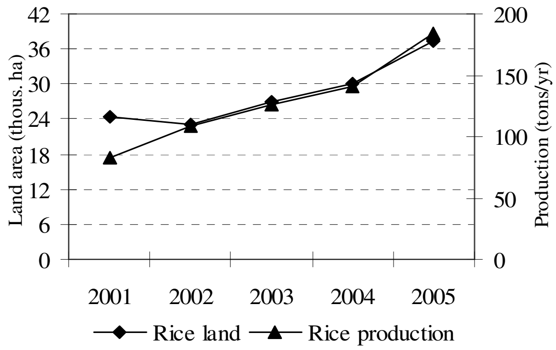

Fig. 7. Changes in rice land and production.

5. Discussion

The paper demonstrates how the use of integrated methods are superior to ones in which socioeconomic factors are exclusively considered when evaluating LULC changes. Utilizing remotely sensed imagery, GIS, and regression analysis can allow policy makers to have a better understanding of causes and effects of the changes of land use, and gives them the tools to make appropriate adjustments for long-term utilization and management of land resources. Based upon the findings, we emphasize three aspects that should be employed whenever taking socioeconomic factors into account of land-use change analysis.

First, time-series socioeconomic data related to causes and effects of land-use changes are elaborately reviewed through both statistically published and unpublished reports in order to shape the best factors for the multiple regression analysis. In the case of Kien Luong district, we consider eight factors at a village scale when conducting a LULC analysis. The next step is computing the annual change rate so that socioeconomic data is incorporated with spatial LULC data, and is undertaken by using the formula introduced by FAO (1996). The GDPV exhibits a relatively high change rate of 0.17 as a consequence of enormous changes of output values from the development of agriculture and aquaculture. The two largest contributors within agriculture are cultivating irrigated rice and practicing salt-water shrimp production, which have developed due to the pressing needs of local people and rent-seeking behavior (Son, et al., 2006).

Secondly, employing the RS technique in interpreting the temporal Landsat ETM imagery with a focus on LULC changes fills gaps in the study area, as historical LULC data is insufficient in this area of Vietnam. Improvement of the accuracy of image interpretation is solved through ground truthing and comparing the results with historically statistical data to explicitly include or exclude pixels which are not corresponsive to each land-use type.

Thirdly, in ArcInfo we utilize the Boolean functions to geo-process different thematic layers and to merge spatial land units with socioeconomic data at a village scale. Examination of socioeconomic driving forces is fulfilled with the help of SPSS 13.0. The analysis indicates that the serious loss of forestlands from 2001 to 2005 ranges from 54,667.17 ha in 2001 to 12,530.03 ha in 2005 due to six contributors as shown in Table 5. The conversion of forestlands may be hampering long-term agricultural development, as displayed by the instability of shrimp aquaculture, and inappropriate soil for rice cultivation. These ecological impacts are exemplified by the sharp decline of the BCR of land use change in the region. This study demonstrates that land-use suitability for major land-use types, and ecological and environmental costs of land use change need to be urgently addressed if local livelihoods are to be sustained, and protection of the land resources and environment are to be achieved.

These methods can be extended to a larger spatial scale of provinces and regions, as well as a larger temporal scale to include more years of LULC change. Additionally, other socioeconomic aspects associated with LULC dynamics such as land-use policies, land tenure, cultural characteristics, etc could also be considered as part of the regression analysis. Expansion of these methods could further inform LULC management strategies.

5. Conclusions

We conclude that the rapid growth of the rural economy has impacted forestland conversion and hampered utilization and management of land resources. The findings revealed that from 2001 to 2005 the loss of forestlands was 42,137.14 ha in which the two largest change types were irrigated rice (65.29%) and shrimp culture (29.13%). The major socioeconomic driving forces responsible for these losses were rice production and GDPV through increased expansion of land areas of irrigated rice and shrimp culture. The total production from shrimp monoculture did not correlate with the changes of forestlands. This reaffirmed the less productive aquaculture system due to environmental issues as confirmed by BCR analysis. Similarly, the quick conversion of forestlands to irrigated rice fields under less suitable soils may easily loose productive potential if no timely appropriate measures are employed.

Since forestland conversion had initially affected the stability of existing production systems and ecological services in the study area, further studies of evaluating land-use suitability and environmental costs are required. Because there is an inherent relationship between socioeconomic factors and the changes of forestlands, we encourage land-use policy makers to utilize mixed methods of analysis to ensure that interventions are equitable and applicable for years to come.

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