# Analysis of Land Use Change for Food Security Planning in Mae Tun Watershed, Thailand: Applications of Remote Sensing and GIS

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**Abstract**

Changes in the biophysical, social and economic environment are critical issues for watershed development and planning. The impact of these changes will affect to people in various ways, depending on their available resources and opportunities. In the Mae Tun watershed in Chiangmai province, northwestern Thailand, the natural resources have been severely degrading rapidly. This has created adverse impacts on human nutrition in the watershed. In developing solutions to these problems, this research had integrated Satellite Imagery Analyses (SIA) and Geographical Information Systems (GIS) for investigating land use issues that related to food security planning. The applications of these technologies have revealed considerable overuse of land resources. The analysis illustrates that the suitability of available land use options can improve human nutrition by crop production. The framework used in this study provides information to improve human nutrition and ensure the conservation of forest resources and their ecosystems. The outcome of this interdisciplinary research is important to produce useful guidelines for planners and decision-makers for the watershed.

## I. INTRODUCTION

For many watershed management projects, household food security has always been neglected by decision-makers. The problem of household food security is not as simply as agricultural output or just enough rice as food, but also encompasses all factors affecting a household's access to an adequate year round food supply. In many mountainous areas, soil, water and forest resources and farm trees play important roles in household food security. They provide critical support to agricultural production, food and fuel and cash income. Particularly, for the poor they provide insurance against hungry and crop failure. Thus, both directly and indirectly, many watershed development activities have an impact on hill people's food situation. In the remote villages and difficulty to access in mountainous areas, it is impossible for commercialisation, import goods in and export agricultural products out of the area. Thus, the shift from subsistence farming towards a cash economy is not practiced.

The Mae Tun Watershed (209,213 ha) in Chaingmai province is in the Northwestern Thailand. But, the watershed is very remote from Chiangmai town and road accessibility is most difficult. Topographically, the watershed consists mainly of steep mountainous in the west and undulating to rolling in the east. The area used to cover with dense forest, but the resources and environment have been degraded rapidly during the past few decades. The current deforestation, land use and farming practices in the watershed have created adverse impacts to the protected areas and sources of human nutrition. The deforested areas have been converted into upland rice or abandoned fields. The field surveys illustrated that rice production is not enough for consumption, and food and nutrition deficiencies are found in the area. The watershed consists of 57 villages, 6,922 households with a population of 33,918. There are 11,030 children who are less than 14 years old and 22,888 adults. The serious nutrition problem is among children since many of them have a deficiency of calories resulting in what nutritionists call 'protein-energy deficiency'. People have low levels of vitamin A intake, which resulted in blindness. This is one of the notorious dietary problems. There are people who show iron deficiency and low intake of other minerals. Other minerals are also essential for a well-balanced diet. Since, people take non-diversified diet, mainly rice, the quantities of food consumed are not adequate nutritionally, both in terms of quality, quantity and variety.

Therefore, this research intends to develop planning and management schemes for enhancing the sustainability of the Mae Tun watershed using integration of SIA and GIS to investigate land use issues related to small-scale farming. It will address realistic problems arising from natural resource utilization, land misuse and nutrition problems in the Mae Tun watershed. It will identify location for rice and vegetable crop production to provide carbohydrate, vitamins and minerals to the dwellers.

## II. METHODOLOGY

### Materials

The basic data used for preparing the land use map of the study area were Landsat Thematic Mapper (TM) data, topographic maps, and the Digital Elevation Model (DEM). Two dates of Landsat TM, scene 131-48, taken in December

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20,1987 and January 25, 2000 were employed for SIA in land use mapping. The topographic maps, 1:50,000 scale with 10m and 20m contour intervals were employed to derive DEM. Other information including villages, roads, streams and sub-districts boundary were digitized from the topographic maps in the vector format. Field data collections were conducted few times to obtain social and economy, land use types, training areas for SIA and map accuracy assessment.

**Land use map preparation**

The preprocessing was conducted to remove the undesirable image characteristics produced by the sensor. The noise, an unwanted signal in the image was already corrected when received the data. The geometric correction of the image was performed by registered 35 Ground Control Points (GCPs) with the topographic maps. The root mean square error (RMS) of 0.5 pixel was chosen for calculation when using a second-order transformation. The GCP at the RMS of 0.332 were accepted to transfer the raw TM data to a 30m pixel by using nearest-neighbor re-sampling.

As the objective of the study was to produce and improve land use map, several originals and derivative feature sets were tested to classify the original satellite data. The image processing including Band ratios, Normalized Differential Vegetation Index (NDVI) and Principal Component Analysis (PCA) were followed Matheson and Ringrose techniques (Matheson and Ringrose, 1994). There are ten different feature sets (FS) of original band combinations, derived bands and DEM that were selected for the classification (Table1). As these could be a large number of band combinations, the inclusion of bands in each FS was decided based on the relative use of individual bands, and the most widely used band combinations for land use discrimination. The FS1 includes only the standard band combination (4,3,2) used in Thailand for visual interpretation (Charupput, 1997). An unsupervised classification was carried out for each of the 10 FSs using Iterative Self-Organizing Data Analysis (ISODATA) technique. The resulting classes were identified on the basis of information drawn from the field survey, aerial photographs and previous land use map 1977 (Department of Land Development, 1977). Trisurat et al. (2000) conducted his study in the Khao Yai National Park of Thailand, similar bio-climate to that of the Mae Tun watershed, reported that the band ratio 7/5 was useful for discriminating the forest classes. The reason for selecting the ratio of B7 and B5 was that beside the topographic effect (shadow) being reduced, it also showed discrimination between mountain vegetation and water on visual display, which otherwise were observed not to be discriminated in both ratios 4/5 and 5/7. The results of each FS were compared to create the error matrices and the overall classification accuracy. Since, FS-8, FS-9 and FS-10 were similar accuracy for land use discrimination, the FS-10 (B7/B5, NDVI, DEM, PCI) was selected for supervised classification, using Maximum Likelihood Classifier method. The training signatures were established with the field survey knowledge, which was evaluated for possible discrimination of individual class. After obtaining a satisfactory discrimination between the classes during signature evaluation, the final classification was conducted to produce the land use maps.

The land use maps were subject to accuracy assessment. One of the most common means of expressing classification accuracy is the confusion matrix (Short, 1982). The Kappa coefficient of agreement (KHAT) statistic was used to measure of the difference between the actual agreement between the field data and the automated classifier, and the chance of agreement between the reference data and the random classifier (Lillesand and Kiefer, 2000). This analysis has the advantage of taking into consideration of the off-diagonal elements of the error matrix, or errors of commission and omission (Garcia and Alvarez, 1994). The two dates of land use maps derived from the supervised classification were converted into vector format by using ArcView 3.1. They analysis of the land use changes in 1987 and 2000 are illustrated in Table 2.

**Table 1.** Feature Sets and Overall Classification Accuracy of Unsupervised and Supervised Classifications.

| Feature Set (FS) | Band Combination | Classification Technique | Overall classification Accuracy (%) |
|---|---|---|---|
| FS-1 | B4, B3, B2 | ↑ | 58.2 |
| 2 | B4, B2, NDVI | | 60.5 |
| 3 | B2/B1, B7/B5, NDVI | | 65.2 |
| 4 | B2, B4, DEM | | 67.1 |
| 5 | B2/B1, B7/B5, DEM | | 66.3 |
| 6 | B2, NDVI, DEM | Unsupervised | 70.3 |
| 7 | B4, NDVI, DEM | | 71.5 |
| 8 | B2/B1, B7/B5, NDVI, DEM | | 72.3 |
| 9 | NDVI, DEM, PC1 | | 77.4 |
| 10 | B7/B5, NDVI, DEM, PC1 | ↓ | 76.2 |
| 11 | B7/B5, NDVI, DEM, PC1 | Supervised | 84.8 |

Note: B = Band, DEM = Digital Elevation Model, PC1 = Principal Component 1, NDVI = (Band 4 – Band 3)/(Band4 + Band 3)

**Table 2.** Land use in 1987 and 2000 and their changes.

| Land Use Types | Land Use 1987 | | Land Use 2000 | | Area of Change | |
|---|---|---|---|---|---|---|
| | Area (ha.) | % | Area (ha.) | % | Area (ha.) | % |
| Water resource | 2071 | 0.99 | 9728 | 4.65 | 7657 | 3.66 |
| City, town & commercial land | 105 | 0.05 | 1631 | 0.78 | 1481 | 0.73 |
| Paddy field | 628 | 0.3 | 5062 | 2.42 | 4434 | 2.12 |
| Village | 2050 | 0.98 | 13536 | 6.47 | 11486 | 5.49 |
| Field crops | 1109 | 0.53 | 12176 | 5.82 | 11067 | 5.29 |
| Orchards | 84 | 0.004 | 146 | 0.07 | 62 | 0.066 |
| Mixed orchards | 42 | 0.02 | 209 | 0.1 | 248 | 0.08 |
| Shifting cultivation | 5712 | 2.73 | 8180 | 3.91 | 2468 | 1.18 |
| Hill evergreen forest | 38349 | 18.33 | 28160 | 13.46 | -10189 | -4.73 |
| Deciduous forest | 77220 | 34.52 | 4038 | 1.93 | -73182 | -32.51 |
| Mixed deciduous forest | 43311 | 21.18 | 14519 | 6.94 | -28792 | -14.24 |
| Disturbed mixed deciduous | 19708 | 9.42 | 56843 | 27.17 | 37063 | 17.75 |
| Disturbed dry dipterocarp | 20482 | 9.79 | 41696 | 19.93 | 21214 | 10.14 |
| Bush & shrubs | 2322 | 1.11 | 13180 | 6.3 | 10858 | 5.19 |
| Bamboo forest | 126 | 0.06 | 4 | 0.002 | -122 | -0.058 |
| Forest plantation | - | - | 105 | 0.05 | 105 | 0.05 |
| Total | 209213 | | 209213 | | | |

## Sustainability Land Use Options for Mae Tun Watershed

The land suitability classification was developed for the sustainability land use option as shown in Figure 1. Because of the different scale upon which the criteria were measured, the diagnostic factors were standardized prior to conducting analysis. The simple standardization is the linear scaling which can be express as:

$X_i = (R_i - R_{min}) / (R_{max} - R_{min})$ * standardized range

where, $X_i$ = calculated X (factor) value, $R_i$ = average value of X (factor) calculated, $R_{max}$ = maximum value of X (factor), and $R_{min}$ = = minimum value of X (factor).

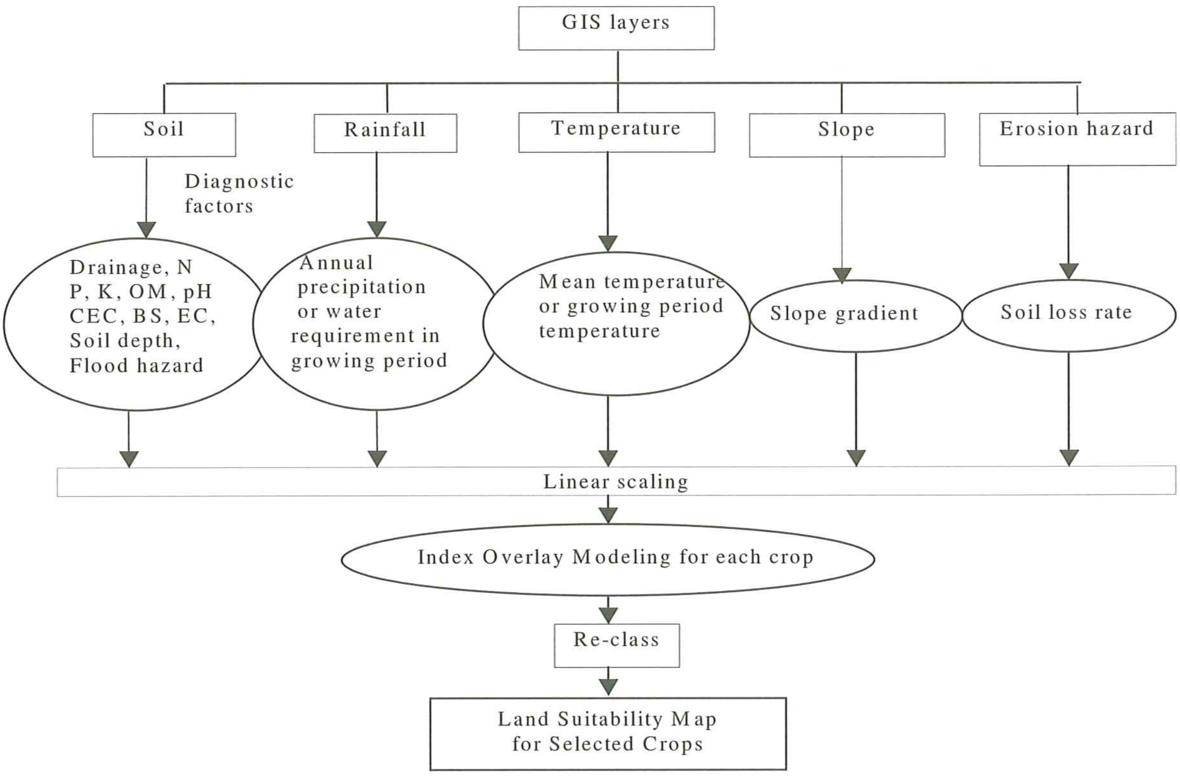



**Figure 1**. GIS procedure of suitability map for selected crops

An index overlay modeling technique of GIS was performed to determine the land suitability classes for the selected crops under study which is expressed in the following equation (Bonham-Carter, 1994):

$$\bar{S} = \frac{\sum_{i=1}^{n} S_{ijk} W_i}{\sum_{i=1}^{n} W_i}$$

where, $\bar{S}$ = Weight score for a mapping unit (location), $S_{i\,jk}$ = Score for the k$^{th}$ parameter of j$^{th}$ class of the i$^{th}$ input map, $W_i$ = Weight for i$^{th}$ input map

This technique gives an average score of a location in relation to physical suitability for the specific crop. In this process, the diagnostic factor occurring in each class and the map classes were assigned different scores. The land suitability for paddy, orchard, corn, mung-bean, groundnut, soybean, and vegetables were produced. The sustainability land use options map was developed by overlaying the land suitability of all selected crops, human nutrient deficiency, village location, road network, irrigation, and watershed class (Figure 2).

## III. RESULTS AND DISCUSSION

### Analysis of land use classification

The unsupervised classification of Landsat TM data used a classifier algorithm to examine unknown pixels in the image and group them into classes based on the natural reflectance of land cover. Mean spectral values for the different land use classes in different FS are presented in Figure 3. The error bars for each class in each FS represent the standard error calculated for the group of sub-classes that merged into a single class. For FS-1 only upland paddy area and mixed deciduous forest were distinguished. A mixed class was observed between field crops, forests and orchards. Band 2 was not very useful, since it has similar response for all classes. Band 3 has high responses for upland paddy area. Band 4 has high responses for natural vegetation such as hill evergreen forest in mountainous areas. In FS-2, NDVI responded the highest for vegetation and the lowest for water and village area. Some of the upland rice areas were clearly discriminated, but the others were found mixed with forest area. In FS-3, water bodies and villages could be differentiated due to the higher response from the village area in ratios of B7 and B5. But the ratios of B2 and B1 did not add enough information for discrimination of other classes.

In FS-4, DEM showed good results for differentiating three different classes of forest, namely hill evergreen forest, mixed deciduous forest and dry dipterocarp forest. However, other land use classes were mixed due to less information in B2 and B4. In FS-5, the ratio of B7 and B5 in conjunction with DEM helped to differentiate water body, village and upland rice areas. However, there remains some confusion between vegetation, particularly forest types, and other vegetation. In FS-6 and FS-7, two unique classes were discriminated due to NDVI and DEM bands. These were scrub areas with relatively few large trees and secondary forest on the foothills. Forest types were easily distinguished, unlike the earlier mixing between

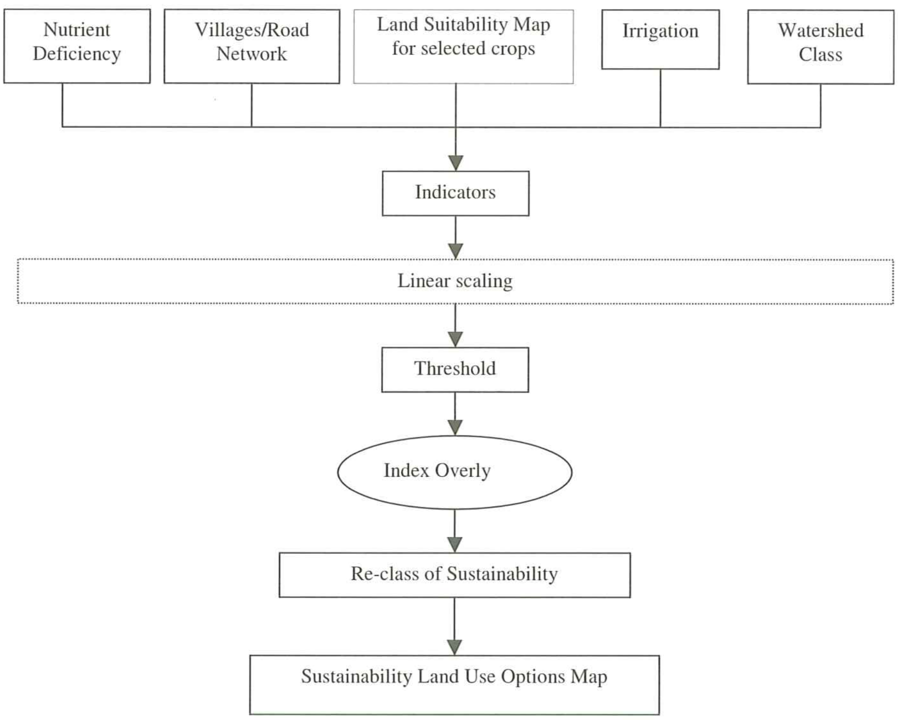
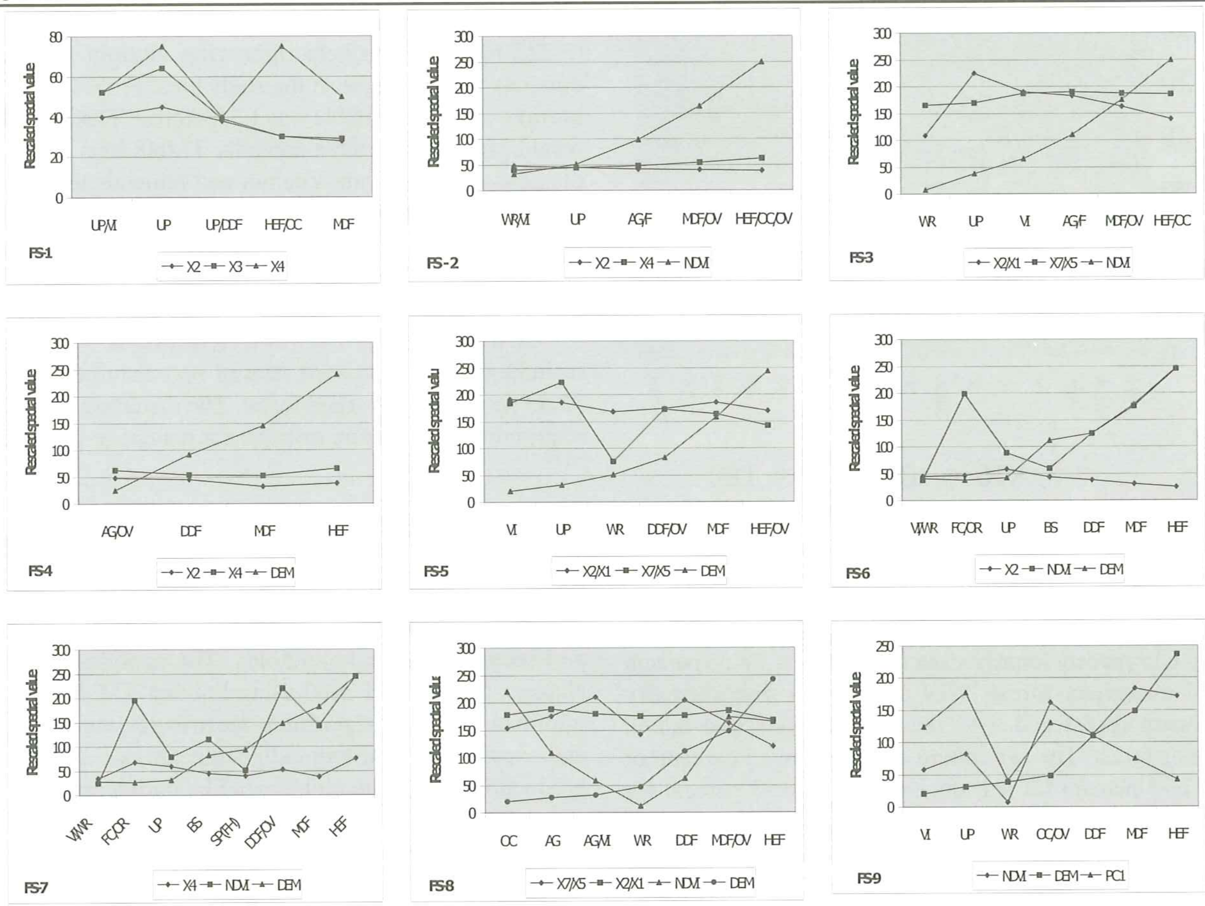
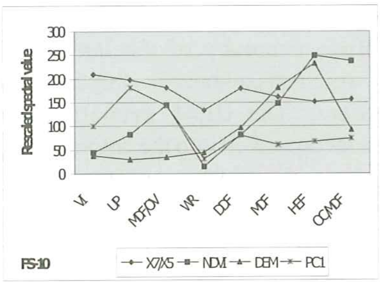



**Figure 2.** GIS procedure of sustainability land use options




Class abbreviation:

UP = Upland paddy, DDF = Disturbed dry dipterocarp, F = Forest,
MDF= Mixed deciduous forest, OC = Orchards, FC = Field crops,
HEF = Hill evergreen forest, OV = Other vegetation, VI = Village,
SP (FH) = Sparse forest at foot hill, BS = Bush & Shrubs,
WR = Water resource, AG = Agriculture

**Figure 3.** Spectral values for different land use classes in FS

hill evergreen forest and orchards. However, an orchard was observed mixing with other vegetation. In FS-8, the former mixed class of orchard areas and other classes were improved due to the ratio of B7 and B5 and the forest types and agriculture areas were easily differentiated. In FS-9, the major land use classes were differentiated, including forest types. However, an orchard was still found mixing with other vegetation. Not much improvement in the classification results was observed in FS-10. The results were similar to those of FS-9, with some mixed deciduous forest clearly separated, but some forests were mixed with orchards and other vegetation. The Overall Classification Accuracy (OCA) ranged from 58 to 77 percent for unsupervised techniques (Table 1). Among the ten FSs, the inclusion of DEM showed very promising results. It helped to differentiate vegetation types such as forest types and orchards which otherwise it would be in possible to differentiate with NDVI due to similar signatures of these two classes.

The supervised classification of FS-10 had improved the OCA as the pixels already assigned into the unknown identity. The spectral signatures of the training areas for individual classes showed satisfactory indication for reparability of the classes selected in either ratio 7/5, NDVI, DEM and PC1 bands The mean spectral values for the different land use classes are presented in Figure 4. An overall map accuracy of 84.8 percent was obtained by mean at the error matrix.

### Analysis of land use changes

Land use change analysis was preformed using the two land use data sets of 1987 and 2000 (Table 2). In 1987, large area

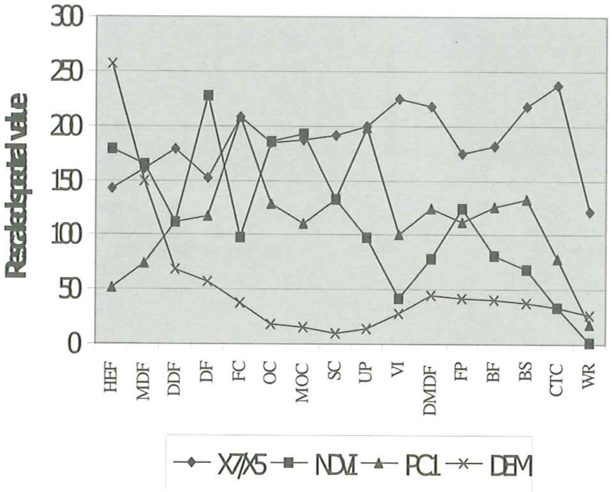



**Figure 4.** Spectral values of training areas of different land uses

of the land was covered by forest, 34.52 percent for deciduous forest, 21.18 percent for mixed deciduous forest, 18.33 percent for hill evergreen forest, 9.79 percent for disturbed dry dipterocarp forest and 9.42 percent for disturbed mixed deciduous forest. The agriculture area was only 5 percent, of which 2.73 percent for shifting cultivation, 0.53 percent for field crops and 0.3 percent for upland rice. In 2000, large areas of forest in 1987 were converted to agricultural use, mainly under upland crops. The forest areas were decreased due to the increase in population and the demand for food supply. The forest areas have been converted into the disturbed/ opened forest. The areas under village and city have increased from 1.04 percent in 1987 to 7.25 percent in 2000. Through the questionnaires, it was found that crop yields are declined, more shifting cultivation areas and less incomes earning opportunities.

**Land use options for malnutrition planning of Mae Tun watershed**

As sustainability is relative and differs according to the given characteristics of land, the indicators used in this study were productivity, food security, protection, economic and acceptability. The chosen sustainability indicators represent biophysical, socioeconomic and environmental criteria. These information were collected during field and questionnaire surveys. Each of the land units was evaluated in a GIS environment using multi-criteria evaluation techniques, which were later regrouped in five major classes. Figure 5 illustrates the suitability of available land use options for improving human nutrition in the Mae Tun watershed. The statistical result of suitability land use options is shown in Figure 5. There is 33.44% percent of the area suitable for field crops, such as corn, soybean, mungbean, and groundnut. There is 4.47 percent of land that suitable for upland rice that would provide enough carbohydrate and nutrition calories. The average upland rice yield is 1.5 $tha^{-1}$. This suitable land would produce annually 7,958 tons that is just enough for the total population in the watershed. The area suitable for vegetable is 3.93 percent (8,222 ha), that can help improving vitamin A and other minerals for the people in the study area. From field data the average yield of vegetable was 1,343 $kgha^{-1}$. This suitable area would produce vegetable annually 11,048 tons that is more than enough to provide Vitamin and minerals to the people. The annual vegetable required in the area is about 3,311 tons. In addition, according to their study in Thailand, Indonesia and Philippines, Gershon et al., 1985 suggested that a vegetable plot of 4x4m would provide sufficient vitamins and minerals for each household. The protected area is 58.16 percent including 22.33 percent of natural non-disturbed forest and 35.83 percent of disturbed forest. The disturbed forest would require for re-plantation or leave for natural re-growth.

## IV. CONCLUSIONS

The research results demonstrated that SIA and GIS are suitable techniques to monitor and manage natural resources and secure food for households. The analysis of land use changes in 1987 and 2000 using Landsat TM data provided information on land degradation due to increasing deforestation and expansion of shifting cultivation for rice and cash crop productions. The main problem in SIA during generating land use maps is the confusion of spectral responses from different features. The area is always cover by cloud, hence prohibits obtaining cloud free data during wet and dry seasons to distinguish deciduous and evergreen forests. Various band combination techniques and unsupervised classification have been tested to improve accuracy of the land use maps. However, the results were not satisfactory, only 58-65 percent of OCA were obtained. The DEM, prepared from the topographic map was incorporated into the combinations. The results of the unsupervised classification had improved greatly, up to 77 percent. However, when the supervised classification was performed on band combination of B7/B5, NDVI, DEM and PC1, the result has showed superior accuracy (84.8 percent) as compared to the unsupervised classification (76.2 percent).

Throughout the Mae Tun watershed, forest resources are rapidly degraded mainly for crop productions. The demand of agricultural land is the result of population expansion and expansion of city and villages. The high demand of food implies the diminishing availability and use of forest food and resources. The people have low education and low income earning opportunities in the rural and hence increasing burdens on household efforts to meet their basic needs. Since the area is very remote and transportation of goods to markets is expensive, the people are mainly subsistence farmers. The analysis of land use changes provided information on the need of land for agriculture and the degradation of forests on steep slope land. Large areas of disturbed forests are found elsewhere. The main crops produced in the area are mainly carbohydrate source as rice and corn.

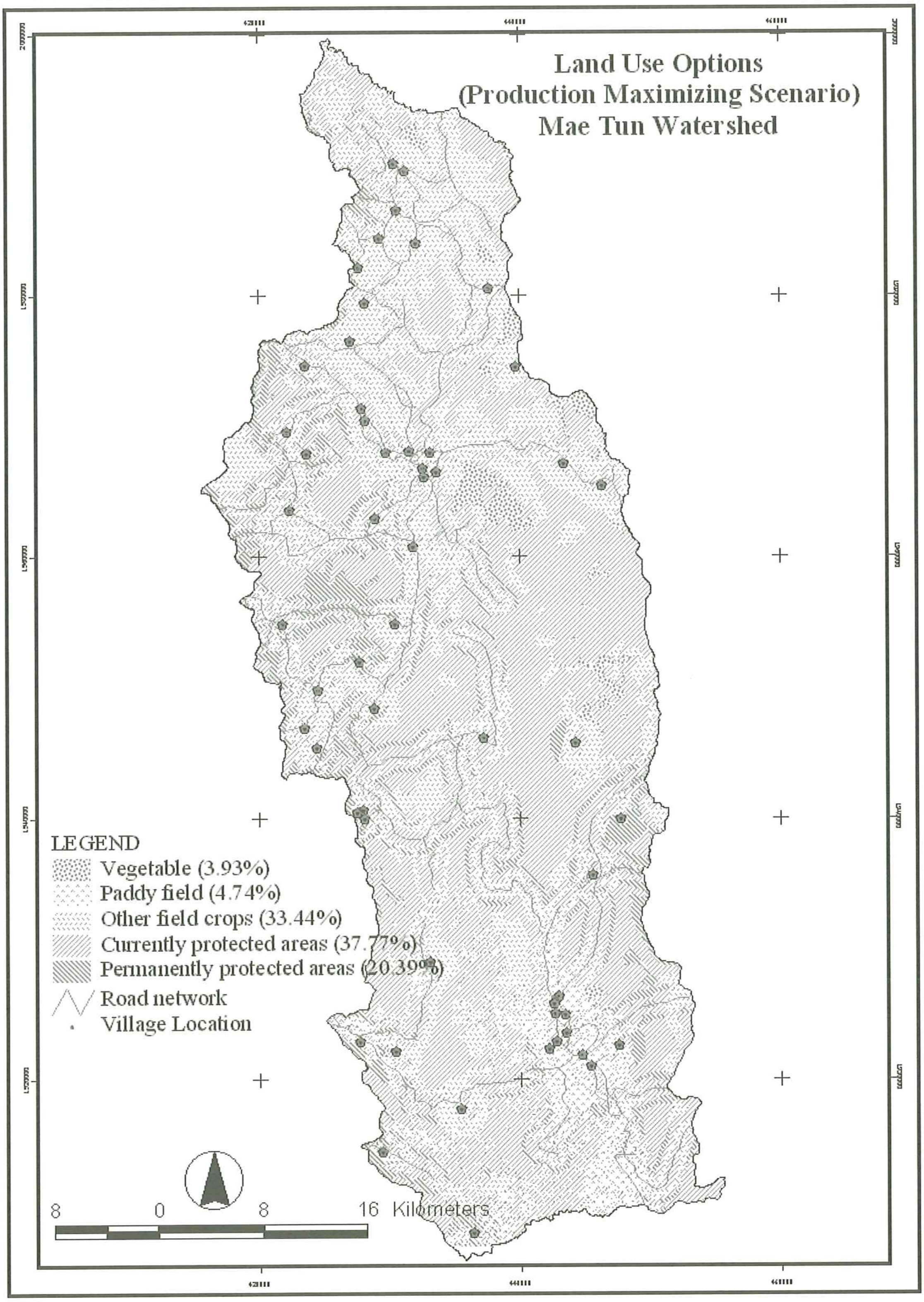



**Figure 5.** Land use options map of Mae Tun watershed

The GIS analysis of land characteristics, land qualities and the distance from villages provided land suitability classes for specific crop types. The land suitability for upland rice, beans and vegetable in the area were produced. There is 4.74 percent of suitable land for upland rice that would increase nutrition calories from rice. This suitable land would produce rice annually 7,958 tons that is enough for the total population in the watershed. The suitable areas for vegetable production (3.93%) will be sources of vitamins and minerals. About 33.44% percent of the area are suitable for field crops, such as maize, soybean, mungbean, and groundnut. Currently, most households raise chicken and pig in their homeland. Freshwater fish culture is rare and should be promoted.

The integration of SIA and GIS has provided important information and tools to decision makers from various organizations on where and how to improve natural resources and secure qualified food in the communities of the Mae Tun watershed.

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