App. Envi. Res. 37(3) (2015): 49-68

**Applied Environmental Research**

Journal homepage : http://www.tci-thaijo.org/index.php/aer

# Landscape Agroforestry Modeling for a Sufficiency Economy in Huai Raeng-Klong Peed Watershed, Trat Province, Thailand

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*Article History*
Submitted: 18 March 2015/ Accepted: 6 June 2015/ Published online: 15 October2015

## Abstract

This research focused on land use modeling at the landscape scale based on the sufficiency economy philosophy (SE). Using land suitability and pair-wise comparison methods, the study aimed to determine key performance indicators of agroforestry under the SE, to develop a landscape agroforestry model under the SE and to apply the derived model to evaluate the suitability of existing land uses within the study area. The key performance indicators were: the agroforestry indices (AFI)-organic matter, soil erosion, species diversity, income distribution, net present value, resources used, land holding size and acceptance of land use; and the landscape agroforestry indices (LAFI)-soil type, slope, distance to water resource, ability to access to main road, watershed class and conservation area. The AFI and LAFI were weighted based on expert judgment and used in weighted linear combinations to develop the landscape agroforestry model based on an AFI equation and an LAFI equation. The AFI equation was obtained from the land use types based on the SE level, and the LAFI equation was determined from the land suitability level (LS level). The final step showed that most land use types were categorized as being at the highest and high LS levels.

**Keywords:** Agroforestry; Landscape agroforestry; Sufficiency economy; Modeling

## Introduction

Global deforestation has accelerated in recent years, and large areas of tropical forests have been converted to agricultural use [15]. Widespread large-scale agricultural expansion [34] has resulted in loss of multiple ecosystem functions and a decrease in land productivity due to soil erosion, flooding and drought so that some land has eventually been abandoned [2]. In the past, Thailand was well known for its rich forest resources; in 1961, forest still occupied more than half of the country; however, by 2009, forest land comprised only 33.56% of the country's total land area [40]. This rapid pace of deforestation is attributed mainly to widespread expansion of large-scale agriculture [46], which continues to modify existing landscape patterns. It is becoming increasingly apparent that an understanding of these landscape level patterns and processes is essential for rational land use planning and ecology management.

Deforestation can be reduced in several ways. One way is to simply restore forest ecosystems within deforested areas. Agroforestry is a technique for cultivating perennial crops together with annual agricultural crops and/or animals on the same land area. Agroforesty is an ecologically based management system that sustains production for social, economic and environmental outcomes [50]. In fact, successful agroforestry operations have increased crop production and farmers' income as well as improving the ecolgical conditions of these areas through reducing soil erosion, increasing tree cover, enhancing biodiversity and maintaining soil fertility [24, 39]. Landscape agroforestry is a set of land-use management practices according to existing ecological system at landscape level which can explain environmental phenomena; it is a mosaic of different land use types on a large-scale, and can also be conceptualized as the spatial interaction of several systems on a farm [29]. Landscape ecology can improve the economic, environmental, and social values of agroforestry [31].

Therefore, policy makers should promote the landscape agroforestry approach to ensure sustainable natural resource management, especially as it can potentially offer an approach to mitigating the impacts of deforestation. Thailand's overarching policy is articulated in the eleventh National Economic and Social Development Plan and it has adopted the Sufficiency Economy philosophy (SE) as its main principle. The sufficiency economy is a philosophy of His Majesty the King, which strives to achieve national development through well-balanced and sustainable growth [55]. The land use plan under the SE considers the farm scale which is also regarded as providing a new sustainable agricultural model to achieve self-reliance for rural households [33]. Extensive cropping often takes place without any overall planning or control to manage the direction of development. Although rural land use planning is undertaken by several governmental institutions, the expansion of indirect cropping has continued unabated. To address this, land use planning at the landscape scale must evolve to address the multiple constraints and demands of stakeholders, as well as policy and institutional development to ensure fair and sustainable use of land and resources. Land use planning based on land suitability is one approach based on the land's productive potential.

Land suitability planning aims to match local land use to its inherent characteristics [13]. This means that assessment of land suitability for any specific type of land use should be based on its assessed potentials [3, 36]. Two of the most useful applications for planning and management are the geographic information system (GIS) integrated with multi-criteria decision making (MCDM) techniques. The combination of these approaches has triggered considerable advances over conventionnal map overlay ap- proaches to land-use suitability analysis [23]. GIS-based, land-use suitability analysis has been applied in a wide variety of situations, particularly to determine the suitability of land for agricultural activities [4, 8, 11, 20]. The Analytical Hierarchy Process (AHP) is the most commonly used evaluation technique for MCDM to allocate resources among land uses and stakeholder actors as a means of undertaking environmental management [21, 38]. The AHP is based on a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales [43].

The analysis of land suitability requires a consideration of a variety of criteria including not only the natural/physical capacity of a land unit but also the socio-economic and environmental impact implications [9]. The basic concept of the SE can be assessed using a criteria-and-indicators approach. Indicators have been based on the philosophy of the SE to evaluate the macro-performance of the Thai government starting since 2005 [25]. In contrast, indicators to evaluate micro performance in land use policy are less distinct. Therefore, investigation of the key performance indicators for land use planning under the SE is an important consideration in the land suitability process.

This research has developed a land suitability model at the landscape scale (landscape agroforestry) under the SE philosophy. The study aimed (a) to determine key performance indicators for agroforestry under a sufficiency economy; (b) to develop the model under a sufficiency economy; (c) to apply the model to establish a landscape agroforestry map of the study area; and (d) to analyze the suitability of the existing land uses in the study area. The model provides a tool that can examine the impact of land uses arising from uncontrolled land use and land use change over time. Such information provides important factual guidance for policymakers and land use planners to quickly detect and evaluate emerging impacts and implement appropriate remedial measures to ensure long term sustainability at landscape level.

## Methods

### 1) Site selection

The Huai Raeng-Klong Peed watershed was selected for the study site. This watershed of 445.37 km$^2$ is a part of Trat province, Eastern Thailand (Figure 1) and has a range of distinct types of land use (Figure 2). Forestry (especially rubber) has expanded rapidly in the area, which also faces serious challenge of encroachment of natural forest areas for agricultural expansion [20].

### 2) Materials

2.1) Topographic map scale 1:50,000 of the Royal Thai Survey Department, sheet numbers 5433 I, 5433 II and 5433 III, 1997.

2.2) Land use map of the Land Development Department, 2010.

2.3) Soil type map scale 1:50,000 of the Land Development Department, 2002.

2.4) Software programs: Arc GIS version 9.3 Geographic Information System (GIS; ESRI; Redlands, CA, USA) and Microsoft Office 2007 (Microsoft; Redmond, WA, USA).

2.5) Notebook computer.

2.6) Soil samples collected in small paper bags using a spatula or knife for loader.

### 3) Methodology

The land suitability methodology was the main process used in this research involving the AHP as the content for MCDM. The pair-wise comparison method is a technique of the AHP and was chosen to determine the weighting criteria. Weighted linear combinations were chosen to weight the values of factors and criteria, and the indicator scores were used to generate land suitability maps by applying the GIS approach. The methodology is shown in Figure 3.

### 3.1) Defining the goal

Two components of the study involved defining the criteria and the indicators of key performance from a review of the literature and policy planning. The agroforestry indices (AFI), represented as factors of land use classification under the Sufficiency Economy, were defined by applying the SE philosophy concept and the land quality concept. The land quality concept was clarified using land degradation (LD) as published by FAO [16] in the Land Degradation Assessment in Dry Lands project (LADA). In addition, the landscape agroforestry indices (LAFI) represented as factors of land potentials in landscape level, were defined by referring to relevant research in terms of land suitability concepts.

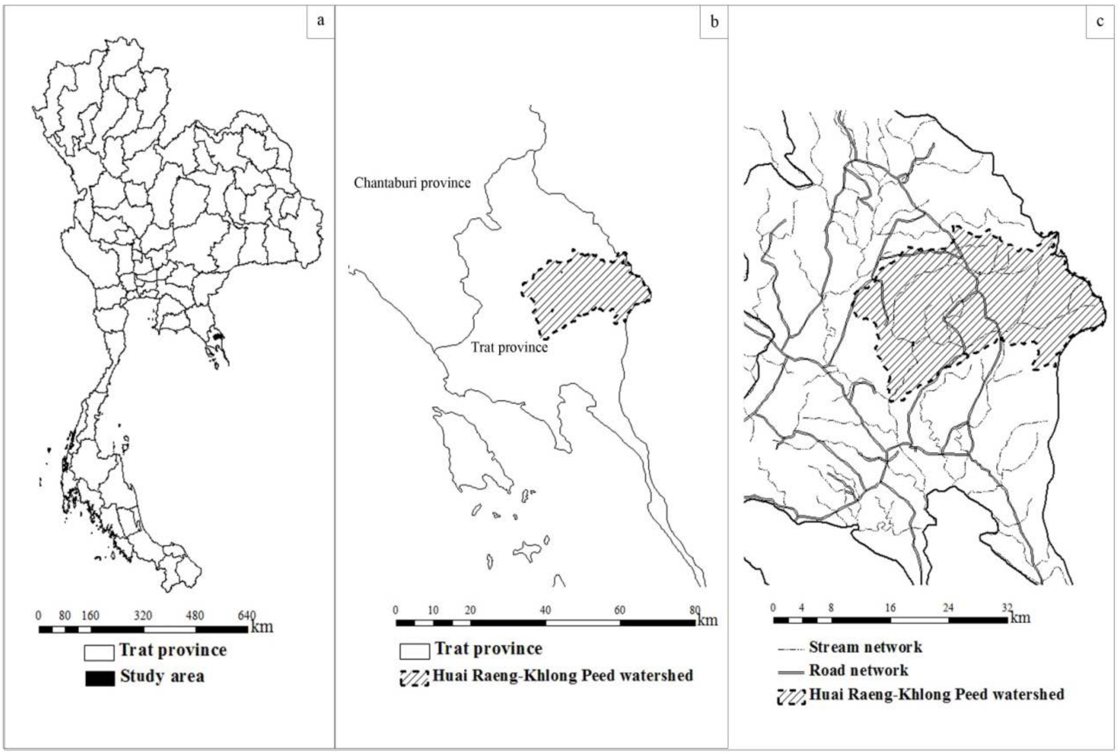



**Figure 1** Study area in Huai Raeng-Klong Peed watershed, Eastern Thailand: (a) National scale; (b) Regional scale; (c) Watershed scale.

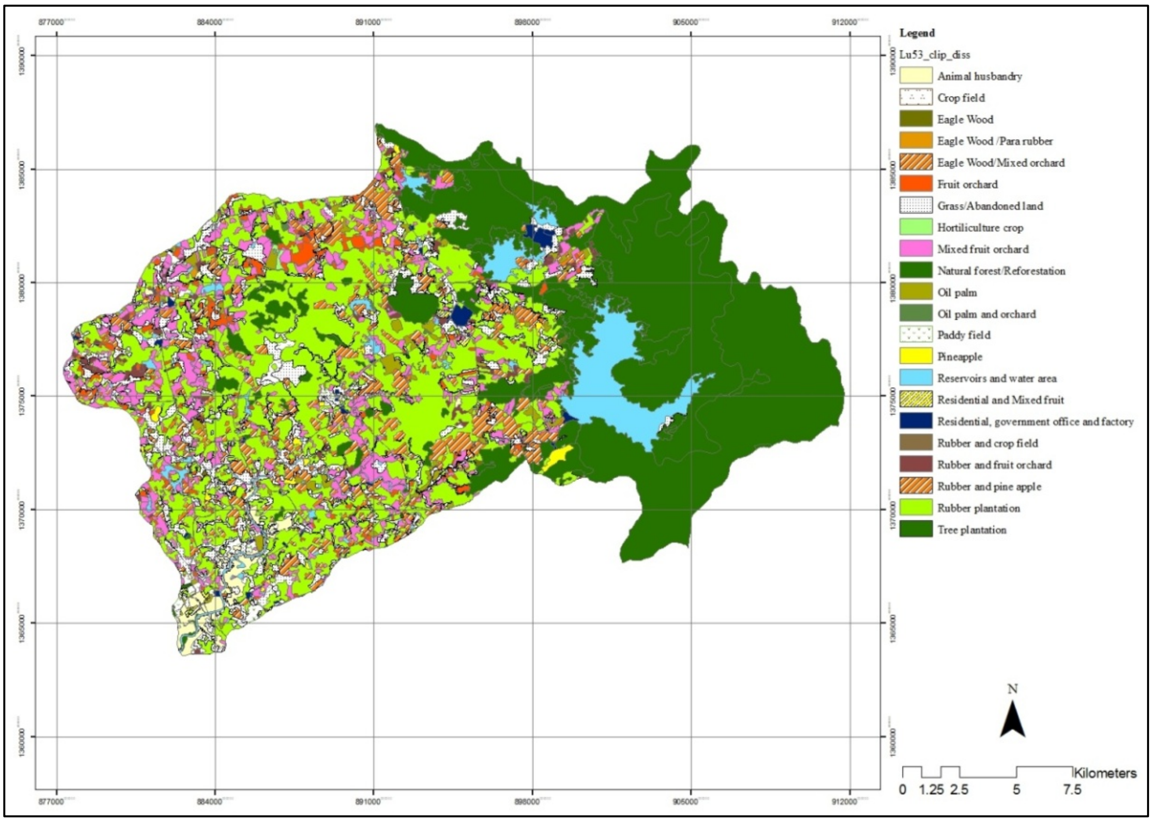



**Figure 2** Land use types of Huai Raeng-Khlong Peed sub-watershed in 2010.

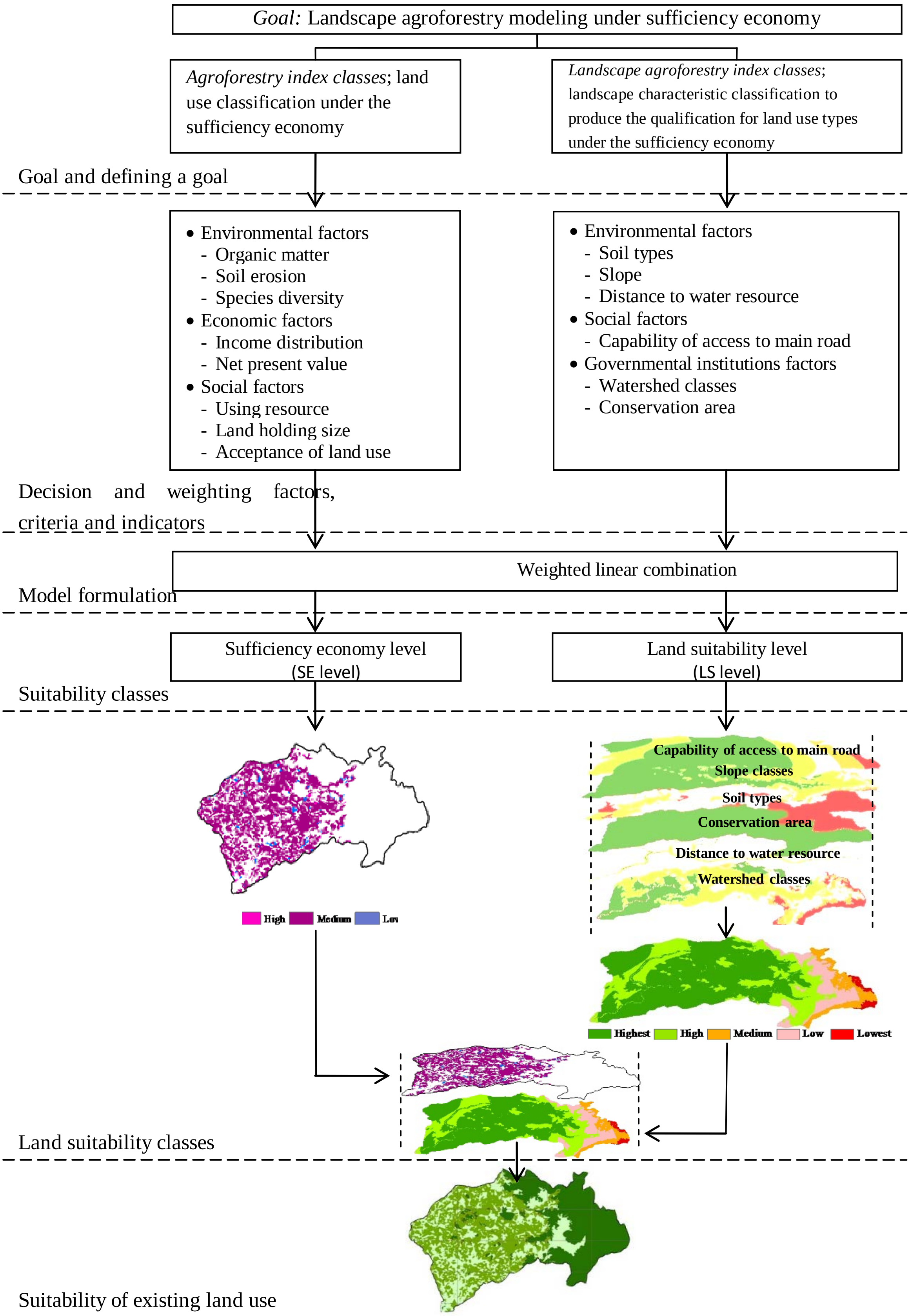



**Figure 3** Research methodology framework.

### 3.2) Decision and weighting of criteria and indicators

Estimation of each key factor and indicator was based on a questionnaire sent to experts. The AFIs were made up of three factors-the environmental aspect (three indicators for soil properties and four indicators for vegetation), economic aspects (two indicators), and the social aspect (two indicators). The pair-wise comparison method was used to determine the weighting for each criterion and indicator. Sixty two questionnaires were sent to the experts by mail and 18 were hand-delivered. The highest weighted values of the three indicators for soil properties and four indicators for vegetation were selected with the highest value for each criterion as the indicator for the respective criterion. These were then used in the modeling process, together with weighted values for other criteria. The weighted values of factors and criteria, and the indicator were used to generate a land use plan under the principles of the Sufficiency Economy, based on land potentials at landscape level.

### 3.3) Model formulation

The model was generated from weighted linear combinations for the land suitability process. The model comprises an agroforestry index equation and a landscape agroforestry index equation, with each equation weighted by values of AFI and LAFI, respectively. The equation is:

$$S = \frac{\sum_{i=1}^{n} W_i R_i}{\sum_{i=1}^{n} W_i} \quad \text{(Eq. 1)}$$

where S is the sum of overall cumulative suitability, $W_i$ is the weighted value of each criteria, $R_i$ is the ranking score of each indicator and *i* is the criterion number from 1 to n.

### 3.4) Suitability classes

The suitability classes consisted of the classification of land use types under the sufficiency economy philosophy as agroforestry index classes (AFICs) and the classification of landscape characteristics as a qualification for land use types under the sufficiency economy philosophy as landscape agroforestry index classes (LAFICs).

The AFICs were generated from the collected data in each indicator, then equally ranked into 5 levels according to the concept of land suitability as defined by the Food and Agriculture Organization of the United Nations [13]. Each level was taken as a representative value from the lowest (1) to the highest (5) as an interval class value. Next, the collected data in each land use type were compared with the interval class value and these collected data were used as representative values for each level. The complete process produced the AFIC for each land use type in the study area under the SE.

The LAFICs were generated from secondary data maps that indicated soil type, slope, distance-to-water-resources, watershed classes, conservation areas and ability to access to a main road. Each attribute on each map were ranked using 5 levels; with each level taken as a representative value from the lowest (1) to the highest (5) as an interval class value. The complete process produced the LAFIC for each indicator in the study area under the SE. The data collection process and calculation for each indicator are detailed below.

#### (1) Agroforestry index classes (AFIC)

***Data collection***

Land use types were chosen based on a proportion of the land use types in the study area based on woody perennials or agroforestry and monocropping. The land use types chosen are listed in Table 1. Then, selected land use types were sorted into two slope classes (0-6% and 6-25%) and into soil series using spatial matching analysis based on land use type map in 2010. Land use types were analyzed using a completely randomized design. The land use type was considered as the treatment. Two sample plots from each land use type resulted in 20 sample plots, each sized 40x40 m. Each plot in the study area was assessed for each indicator as follows.

***Data calculation***

**Environment factors**

**<u>Soil properties</u>**

Organic matter (OM); soil samples were randomly collected from 3 points, with 2 samples at each point at soil depths of 0-15 cm and 15-30 cm. The samples were analyzed in the laboratory of the Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok, Thailand.

Soil erosion; The Revised Universal Soil Loss Equation (RUSLE) was used as an alternative model based on USLE style applicability and usability by Renard [41]. The soil loss in RUSLE is calculated using Eq. 2. Where A is soil loss (tones/ ha/yr), R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness, C is the crop management factor and P is the erosion control practice factor. The values were determined as follows.

The rainfall erosivity factor, R (Eq. 3), in a tropical rain forest climate, the equation is satisfied in Trat province [46]. In which R is the rainfall erosivity factor and X is the mean amount rainfall in mm. Rainfall data 30 years average (1983-2013) obtained from the meteorological stations of the Thai Metrological Department in Trat province, it were used to determine the X factor as 4,888.7 mm.

The soil erodibility factor, K, is most widely used and frequently cited using the relationship of the soil erodibility nomograph [57]. The nomograph Tew equation [48] for the soil erodibility factor of the Peninsular Malaysia soil series was applied from the soil erodibility nomograph by Wischmeier (Table 1). The nomograph Tew equation was suitable for representing soils with a size sand of 0.10-2.00 mm. The nomograph comprises the soil profile parameters: percenttage of clay, silt, very fine sand (defined as sand passing through a 0.06-2 mm sieve) and the values of organic matter content (OM), the soil structure class (s) and the soil permeability (p). A useful algebraic approxi- mation of the nomograph is Eq. 4. In which K is the soil erodibility index in tonnes/ac (100 ft-tons in/ac.hr), OM is the organic matter as a percentage, M is a product of the primary particle size fraction (% modified silt or the 0.002-0.1 mm size fraction), x is the % silt plus the % sand, s is the soil structure class and p is the soil permeability. OM was investigated from collected data in each land use type. M was investigated from collected data in each land use type based on a primary particle size fraction (% modified silt or the 0.002-0.1 mm size fraction). Both OM and M were determined in the laboratory of the Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok, Thailand.

The slope length and steepness factor, LS (Eq. 5), where L is the slope length factor and S is the slope steepness, was determined using the equation defined by Wischmeier and Smith [56]. Where LS is the slope length and steepness factor, $\lambda$ is the slope length in meters, m is a representative value for the slope class (0.2 for slope $< 1\%$, 0.3 for slope $\geq 1\%$ and $< 3\%$, 0.4 for slope $\geq 3\%$ and $< 5\%$, 0.5 for slope $\geq 5\%$ and $< 12\%$, 0.6 for slope $> 12\%$) and s is the slope steepness as a percentage. Based on the sample plot size of 40x40 m, $\lambda$ equals 40 m. The sample plots on the two slope classes had slopes ranging from 0 to 6% and greater than 6 to25%, respectively; thus, the slope steepness percentages were averaged as 3 and 12.5%, respectively. The m value was represented as 0.5 due to most slope steepness being < 12%.

The CP factor is composed of the crop management factor, C, and the erosion control practice factor, P. The CP factor can be represented as the vegetation management factor. The Department of Land Development of Thailand has assessed soil erosion prediction for use in the CP factor and these predictions were applied in each land use as shown in Table 1.

$$A = R.K.LS.CP \quad \text{(Eq. 2)}$$
$$R = 0.1960X - 13.3905 \quad \text{(Eq. 3)}$$
$$K = [1.0x10^{-4}(12 - OM)M^{1.14} + 4.5(s - 3) + 8.0(p - 2)]/100 \quad \text{(Eq. 4)}$$
$$LS = (\lambda/22.13)^m(0.065 + 0.045s + 0.0065s^2) \quad \text{(Eq. 5)}$$

**Table 1** Selected land use types in Huai Raeng-Klong Peed watershed in 2010 and CP factor of each land use types

| | Land use types | K factor | C | P | CP factor |
|---|---|---|---|---|---|
| 1 | Oil palm | 0.36 | 0.60 | 0.80 | 0.48 |
| 2 | Para rubber plantation /fruit orchard | 0.39 | 0.15 | 1.00 | 0.15 |
| 3 | Para rubber plantation | 0.38 | 0.15 | 1.00 | 0.15 |
| 4 | Mixed fruits orchard | 0.35 | 0.23 | 1.00 | 0.23 |
| 5 | Eaglewood /para rubber | 0.41 | 0.15 | 1.00 | 0.15 |
| 6 | Home garden | 0.30 | 0.09 | 1.00 | 0.09 |
| 7 | Rambutan | 0.27 | 0.30 | 0.80 | 0.24 |
| 8 | Mangosteen | 0.27 | 0.30 | 0.80 | 0.24 |
| 9 | *Acacia mangium* plantation | 0.34 | 0.15 | 1.00 | 0.15 |
| 10 | Eaglewood | 0.36 | 0.15 | 1.00 | 0.15 |

Source: K factor modified from [48] and CP factor modified from [49]

**Vegetation**

The vegetation criterion was investigated using a mixed species index through species diversity, with the most popular of the heterogeneity indices being those based on information theory. The expression for the information content per individual within an infinite population is given by the Shannon-Weaver formation[32]. The Shannon index (*H'*) was used as an index to measure the species abundance and richness as shown in the equation:

$$H' = \sum_{i=1}^{s} p_i \, In \, p_i \quad \text{(Eq. 6)}$$

where $s$ is the number of species and $p_i$ is the relative cover of the $i^{th}$ species.

**Socio-econmic factors**

**Income distribution, resources used and acceptance of land use**

A questionnaire was used as the tool for the investigation of these indicators. An ordinal scale was represented as one of five levels, from the highest (5) to the lowest (1).

**Land holding size and net present value**

A structured interview was used for the investigation of these indicators. A ratio scale was used to represent the value. The net present value was defined using the equation:

$$(\text{NPV}) = \sum_{i=1}^{n} (\text{B}^t - \text{C}^t)/(1 + \text{r})^t \quad \text{(Eq. 7)}$$

where $B^t$ is the benefit in cost year t, $C^t$ is the initial cost in year t, r is the discount rate and $t$ is the year (1, 2,…, $n$) and $n$ is the number of periods. The Bank of Thailand has set the bank rate of retail loans at 0.8% per year [5]; thus, r was represented as 0.8 while t was represented as 25 years as the usual period of productivity.

**Statistical analysis**

To test the different population medians among the indicators of land use, the Kruskal-Wallis test was chosen to evaluate the population medians of a dependent variable having the same distribution.

**(2) Landscape agroforestry index class (LAFIC)**

***Data collection***

The landscape agroforestry index consists of soil type, slope, conservation area, distance to water resources, and access to a main road. The landscape agroforestry map was conducted from secondary data from related institutions. The LAFICs were developed from the following secondary data maps of governmental institutions: a topography map dated 1997 at a scale of 1: 50,000 from the Royal Thai Survey Department, sheet numbers 5433 I, 5433 II and 5433 III; a soil type map dated 2002 at a scale of 1:50,000 from the Land Development Department; a watershed class map dated 2001 at a scale of 1:50,000 from the Natural Resources and Environmental Management Division; and a National Park map dated 2004 at a scale of 1:50,000 from the Royal Forestry Department.

***Data calculation***

The data for each indicator were all ranked using 5 levels, from the lowest (1) to the highest (5). Suitable value classes were defined using the concept of land suitability developed by FAO [13]. According to the FAO methodology, this is strongly related to the land qualities. The suitability is defined as: S (suitable), where the land has a sustainable use expected to provide good benefits; N (not suitable) indicating land whose qualities do not allow the considered type of use or do not provide sufficiently sustainable outcomes. The classes (S1, S2 and S3 for suitable order; N1 and N2 for unsuitable order) express the degrees of suitability or unsuitability. The representative values were modified to 5 (S1), 4 (S2), 3 (S3), 2 (N1) and 1 (N2), respectively.

**3.5) Suitability of existing land use based on the LAFIC map**

The landscape agroforestry map was produced using spatial matching analysis between the AFIC map and the LAFIC map. The zonal analysis method in the GIS application was used to determine the land use types under the land suitability or AFIC as appropriate for each LAFIC (Figure 4).

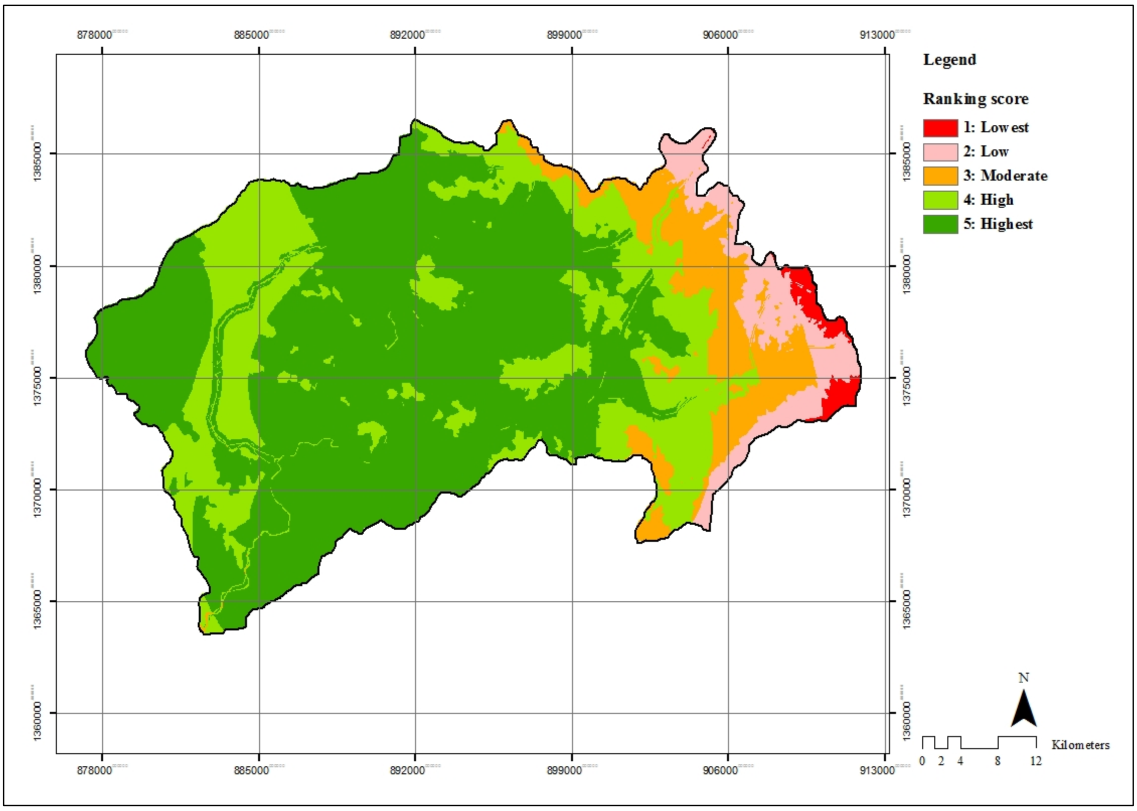
**Results and discussion**

**1) Key performance indicators**

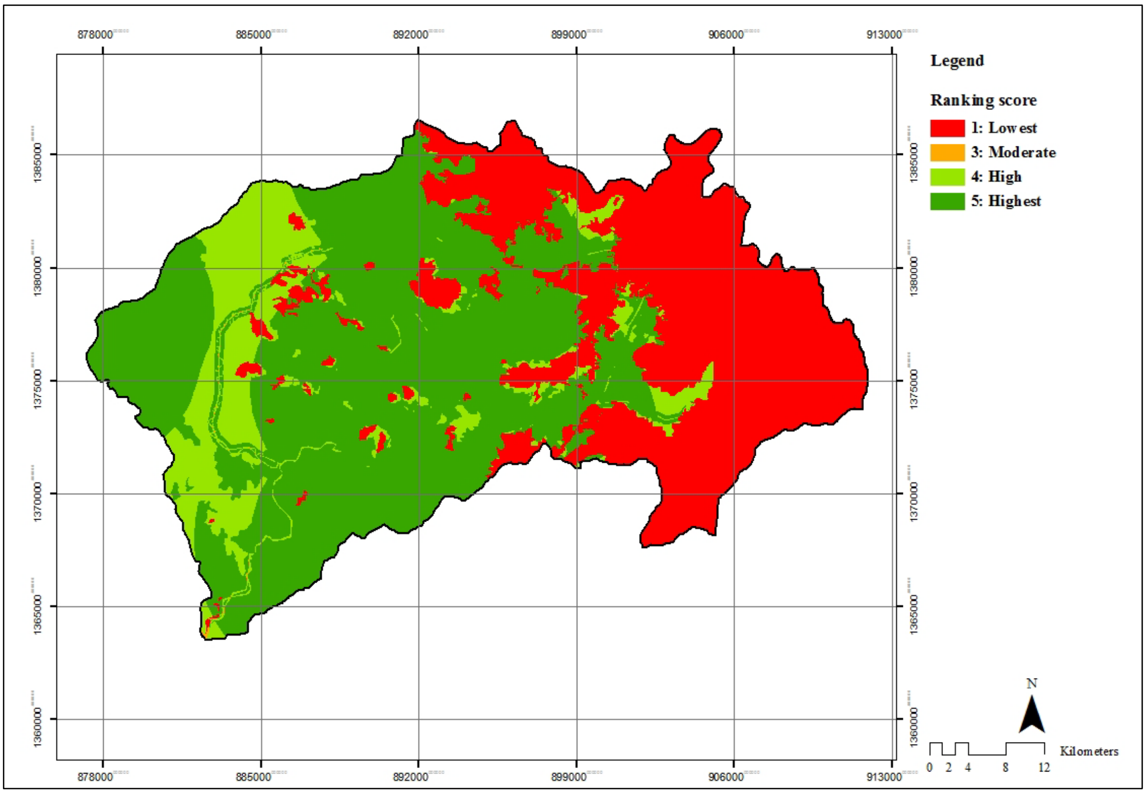
Of the 80 questionnaires distributed, 58 (72.5%) were returned. The ratio method and pair-wise comparisons method were used to determine the AFI and LAFI as shown in Table 1.4. The highest weighted value of the three soil properties and four vegetation classes, and the organic matter and species diversity were chosen as the indicators of their respective criteria. Weighted values of other criteria were used in the modelling. Thus, there were 8 and 6 key performance indicators of AFI and LAFI, respectively.

**2) Landscape agroforestry modeling for sufficiency economy**

The weighed values of AFI and LAFI (Table 2) were determined using Eq. 1, to develop the AFI and LAFI equations in Eq. 8 and Eq. 9, respectively. The agroforestry indices were divided into 5 classes using a class interval technique to produce the agroforestry index classes and landscape agroforestry index classes shown in Table 3. Each agroforestry index class contained a Sufficiency Economy level (SE level) and each landscape agroforestry index class contained a land suitability level (LS level) based on the S Economy approach.




a: LAFIC map based on the model




b: LAFIC map based on the model which excludes conservation area and existing forest area

**Figure 4** Landscape agroforestry index class map in study area.

$$AFI = \frac{[[10[(0.10R_{OM})+(0.69R_{ERO})+(0.21R_{MSI})]]+[8[(0.30R_{ICD})+(0.09R_{NPV})+(0.61R_{RU})]]+[10[(0.17R_{LHS})+(0.83R_{ALU})]]]}{28}$$

(Eq. 8)

where
AFI = agroforestry indices
$R_{OM}$ = ranking of organic matter
$R_{ERO}$ = ranking of soil erosion
$R_{MSI}$ = ranking of mixed species index
$R_{ICD}$ = ranking of income distribution
$R_{NPV}$ = ranking of net present value
$R_{RU}$ = ranking of resource using
$R_{LHS}$ = ranking of land holding size
$R_{ALU}$ = ranking of acceptance of land use

$$LAFI = \frac{[[10[(0.09R_{SOT})+(0.61R_{SLP})+(0.30R_{DTW})]]+[7[(0.83R_{WCL})+(0.17R_{CON})]]+[10R_{ACC}]]}{27} \quad \text{(Eq. 9)}$$

where
LAFI = landscape agroforestry indices
$R_{SOT}$ = ranking of soil types
$R_{SLP}$ = ranking of slope
$R_{DTW}$ = ranking of distance to water resource
$R_{WCL}$ = ranking of watershed classes
$R_{CON}$ = ranking of conservation area
$R_{ACC}$ = ranking of ability to access to main road

**Table 2** Weighted value of agroforestry indices and landscape agroforestry indices

| **Weighted value of AFI (factors and criteria)** | | | | | |
|---|---|---|---|---|---|
| Environmental factor (CR = 0.066) | | Economic factor (CR = 0.066) | | Social factor (CR = 0) | |
| Weighted value of factor | 10.00 | Weighted value of factor | 8.00 | Weighted value of factor | 10.00 |
| Soil property | 0.10 | Income distribution | 0.30 | Land holding side | 0.17 |
| Soil erosion | 0.69 | Net farm income | 0.09 | Acceptance of land use | 0.83 |
| Vegetation | 0.21 | Resources using | 0.61 | | |

| **Weighted value of AFI (indicator)** | | | |
|---|---|---|---|
| Indicators of vegetation (CR = 0.078) | | Indicators of soil properties (CR = 0.066) | |
| Percentage of crown cover | 0.06 | Organic matter | 0.69 |
| Stratification of crown cover | 0.15 | Bulk density | 0.10 |
| Biomass | 0.22 | Soil moisture | 0.21 |
| Species diversity | 0.57 | | |

| **Weighted value of LAFI (factors and criteria)** | | | | | |
|---|---|---|---|---|---|
| Environmental factor (CR = 0.066) | | Governmental institutions factor (CR = 0.066) | | Social factor (CR = 0) | |
| Weighted value of factor | 10.00 | Weighted value of factor | 7.00 | Weighted value of factor | 10.00 |
| Soil properties | 0.09 | Watershed classes | 0.83 | | |
| Topography | 0.61 | Conservation area | 0.17 | | |
| Water resources | 0.30 | | | | |

**Table 3** Agroforestry index classes and Landscape agroforestry index classes

| Agroforestry index class (AFIC) and Landscape agroforestry index class (LAFIC) | Agroforestry index (AFI) and Landscape agroforestry index (LAFI) | Sufficiency economy (SE) level and Land suitability (LS) level |
|---|---|---|
| 1 | 4.2-5.0 | Highest |
| 2 | 3.4-4.2 | High |
| 3 | 2.6-3.4 | Moderate |
| 4 | 1.8-2.6 | Low |
| 5 | 1.0-1.8 | Lowest |

**3) Agroforestry classes (AFICs)**

Key indicators which were used in the AFI were collected for the ten agroforestry land uses. The collected data were ranked and the representative values used as the ranking scores of AFI. The application of Eq. 8 produced the SE levels shown in Table 4.

Only two indicators-species diversity (0.02, $P$<0.05) and income distribution (0.04, $P$<0.05)- were found to be significant. Clearly, the results showed that home gardens contained the highest species diversity, confirming a previous study [26] that found the number of plant communities along with the number of species decreased constantly and significantly with increasing land use intensity and on abandoned land. Likewise, intensive commercial monocropping is likely to result in low species diversity [52] and reduced biodiversity [6, 37, 51]. Although OM did not differ significantly among the agroforestry land uses, this demonstration was able to explain the land use pattern related to OM, as land use change has a negative impact on the soil, especially on levels of soil organic matter [18, 27]. OM is reduced by reduced physical protection or increased water erosion [12, 30]. Isicheia and Muoghalua [19] stated that soils under tree canopies were found to have significantly higher levels of organic matter. This conclusion supports the results that the OM was slightly higher beneath a closed tree canopy than under a sparse tree canopy; soil OM levels were lower than 2% under mangosteen, rambutan and oil palm plantations. Soil erosion showed no significant effect in the current study. Clearly, soil erosion is a complex process that depends on soil properties, ground slope, vegetation and the rainfall amount and intensity [44]. A change in land use is widely recognized as being capable of greatly accelerating soil erosion [54]. Studies involving different environments agree that the runoff and sediment yield decrease with an increase in vegetation cover [10, 17]. These conclusions support the results that oil palm produced the highest soil erosion because it had the lowest crown cover. These results also confirmed the previous finding of Quinton, Edwards and Morgan [35] that the canopy cover showed a significant relationship with soil loss and runoff, with the greatest reduction in soil loss taking place at canopy cover.

Most of the fruit-based cultivation such as mixed fruit orchard, rambutan and mangosteen produced the lowest values in terms of economic factors. Oil palm had the lowest value in terms of environmental factors. The total weighed value of the environmental, economic and social factors produced the SE level; land uses with high SE levels consisted of home gardens, followed by eaglewood (*Aquilaria* spp.) and eaglewood/para rubber, respectively. At the moderate SE level was para rubber/fruit orchard, followed by *Acacia mangium* plantations, para rubber plantations, mixed fruit orchards, rambutan and mangosteen, respectively. Oil palm had the lowest SE level. The highest and the lowest SE levels of land use were not identified in the study area.

**4) Landscape agroforestry index classes (LAFICs)**

The LAFICs were defined as representative values as shown in Table 5. The GIS technique and the LAFI Eq. 9 were applied to develop the map. The LAFIC map was generated under two conditions: 1) using the model and 2) using the model which excluded any conservation area and existing forest area, which were fixed at the lowest LS level.

The map produced using the model indicated five LAFIC levels, with the highest to the lowest representing 256.01 (57.20%), 117.37 (26.22%), 42.92 (9.59%), 25.85 (5.78%) and 5.42 (1.21%) $km^2$, respectively. The map using the model which excluded any conservation area and existing forest area produced four LAFIC levels excluding the moderate level. The highest LS level to the lowest LS level represented 229.76 (51.33%), 59.10 (13.20%), 0.30 (0.07%) and 158.41 (35.39%) $km^2$, respectively. Both results classified more than half of the total area at the highest LS level under both sets of conditions. The most obvious difference between the highest and lowest LS levels was their location, with the highest LS level area distributed in the middle and on the western side of the watershed on gentle slopes. In contrast, the lowest LS level was distributed on the eastern side of the watershed in the forest area and on steep slopes.

**Table 4** Sufficiency economy level in study area

| Land use type | Total weighted value | Agroforestry index (AFI) | Agroforestry index class (AFIC) | Sufficiency economy level (SE level) |
|---|---|---|---|---|
| Oil palm | 68.38 | 2.44 | 4 | Low |
| Para rubber/fruit | 96.44 | 3.44 | 3 | Moderate |
| Para rubber plantation | 94.00 | 3.36 | 3 | Moderate |
| Mixed fruits orchard | 91.88 | 3.28 | 3 | Moderate |
| Rambutan | 86.68 | 3.10 | 3 | Moderate |
| Mangosteen | 86.68 | 3.10 | 3 | Moderate |
| *A. mangium* plantation | 95.60 | 3.41 | 3 | Moderate |
| Eaglewood /para | 106.44 | 3.80 | 2 | High |
| Home garden | 116.08 | 4.15 | 2 | High |
| Eaglewood | 109.64 | 3.92 | 2 | High |

**Table 5** Ranking score of LAFI in study area

| Land suitability Class | S1 (Highly suitable) | S2 (Moderately suitable) | S3 (Marginally suitable) | N1 (Currently not suitable) | N2 (Permanently not suitable) |
|---|---|---|---|---|---|
| Ranking score | 5 | 4 | 3 | 2 | 1 |
| Soil properties: soil texture | Moderate | Moderately fine | Moderately coarse | Fine | Very coarse and Coarse |
| Topography: slope classes (%) | <6 | 6-25 | 25-35 | 35-50 | >60 |
| Water resources: distance to water resources (m.) | 30-50 | 50-200 | - | >200 | <30 |
| Watershed classes (WSC) | 5 | 4 | 3 | 2 | 1A,1B |
| Conservation area | Other land | | | | National Park |
| Ability to access to main road (km) | <5 | 5-7.5 | 7.5-10 | 10-12.5 | >12.5 |

Ranking score was modified as relevant from [1], [7], [14], [22], [28], [42], [47], [53]

**5) Suitability of existing land use based on the LAFIC**

The LAFIC map and the recommendations for land use provide a description of land use types under SE or AFIC which are appropriate for each LAFIC as shown in Table 6. The existing land use was represented as the AFIC to establish the AFIC map, which was then spatially matched with the LAFIC map as shown in Figure 5 and in Table 7. Both conditions had a similar distribution of existing land use under the SE levels-more than 90% was at the moderate SE level, which was distributed in the highest, high and moderate LS levels, respectively and only less than 4 percent was in the high and low SE levels, which was distributed in the highest and high LS levels, respectively. A comparison of the existing land use and the LAFICs identified that all agroforestry land uses in the study area were consistent with the suitability classes based on LAFIC.

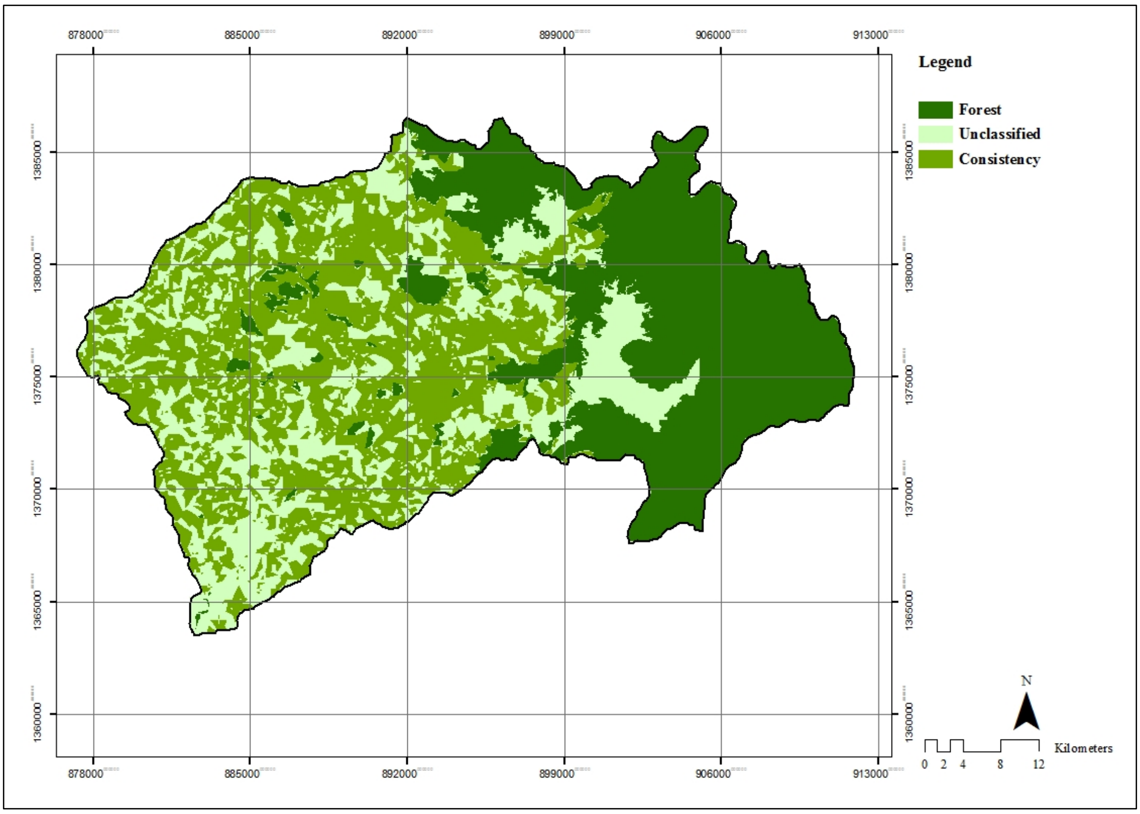
**Table 6** LAFIC and recommended land use

| LAFIC | AFIC | Agroforestry land use in study area |
|---|---|---|
| Highest | Lowest, low, moderate, high and highest | Home garden, eaglewood, eaglewood /para rubber, para rubber /fruit orchard, *Acacia mangium* plantation, para rubber plantation, mixed fruit orchard, rambutan, mangosteen and oil palm |
| High | Low, moderate, high and highest | Home garden, eaglewood, eaglewood /para rubber, para rubber /fruit orchard, *Acacia mangium* plantation, para rubber Plantation, mixed fruit orchard, rambutan, mangosteen and oil palm |
| Moderate | Moderate, high and highest | Home garden, eaglewood and eaglewood /para rubber, para rubber /fruit orchard, *Acacia mangium* plantation, para rubber plantation, mixed fruit orchard, rambutan and mangosteen |
| Low | High and highest | home garden, eaglewood and eaglewood /para rubber |
| Lowest | - | - |

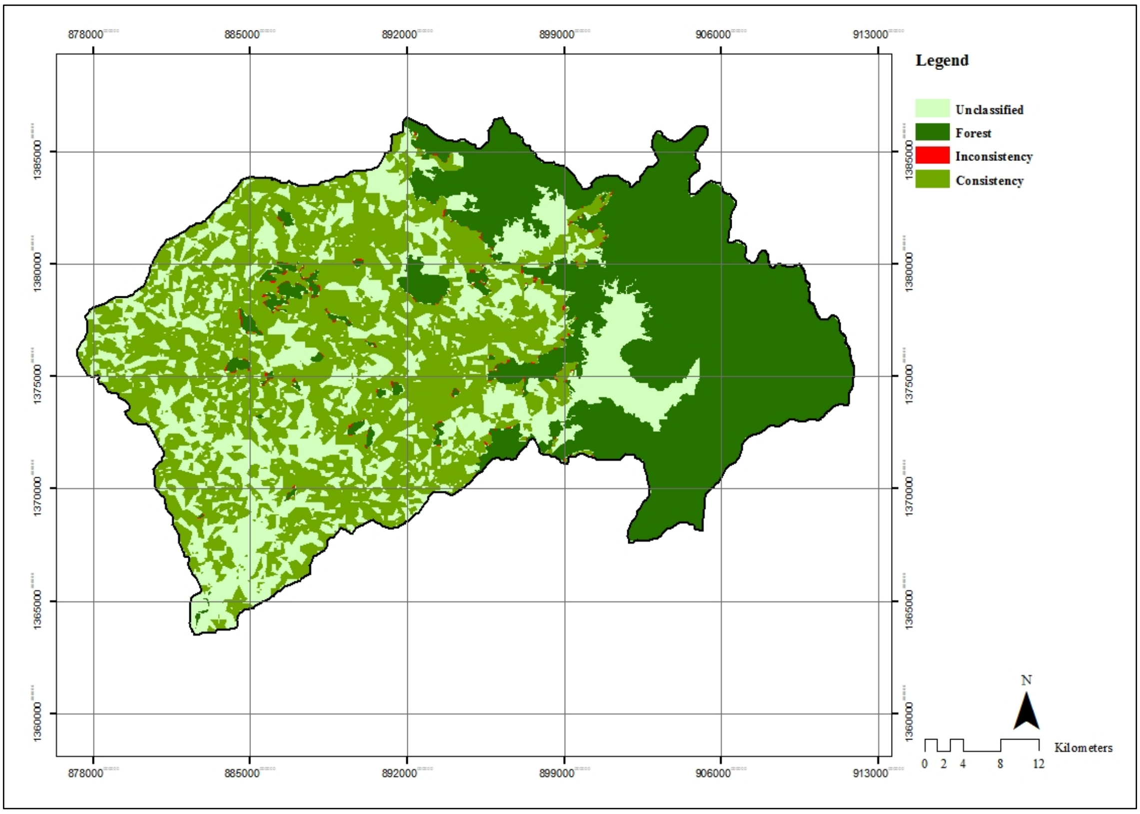
**Table 7** Area of AFIC map under LAFIC map

| LS level | High SE level (km$^2$) (%) | | Moderate SE level (km$^2$) (%) | | Low SE level (km$^2$) (%) | |
|---|---|---|---|---|---|---|
| | a | b | a | b | a | b |
| Lowest | - | 0.04 | - | 1.19 | - | 0.02 |
| | - | (0.02) | - | (0.70) | - | (0.01) |
| Low | - | - | - | - | - | - |
| | - | - | - | - | - | - |
| Moderate | - | - | 0.08 | 0.08 | - | - |
| | - | - | (0.05) | (0.05) | - | - |
| High | 0.32 | 0.30 | 34.74 | 34.36 | 1.11 | 1.10 |
| | (0.19) | (0.18) | (20.52) | (20.30) | (0.66) | (0.65) |
| Highest | 1.98 | 2.00 | 126.87 | 126.00 | 4.19 | 4.20 |
| | (1.17) | (1.18) | (74.94) | (74.43) | (2.48) | (2.48) |

a = area based on model, b = area based on model excluding conservation area and existing forest area




a: LAFIC map based on model.




b: LAFIC map based on model excluding conservation area and existing forest area.

**Figure 5** AFIC map under LAFIC map.

## Conclusions

### 1) Key performance indicators

The agroforestry indices (AFIs) in terms of environmental factors consisted of three criteria-soil properties (organic matter), soil erosion and vegetation (mixed species index). In terms of economic factors, the AFIs comprised two criteria-income (income distribution and net present value) and resource use; and in terms of social factors, the AFIs comprised two criteria-land holding size and acceptance of land use. The landscape agroforestry indices (LAFI) consisted of environmental factors-soil properties (soil types), topography (slope) and distance to water resources; social factors-access to a main road; and governmental institutional factors-watershed classes and conservation area.

### 2) Landscape agroforestry modeling for sufficiency economy

The weighed values of the factors were similar, particularly among the environmental and social factors. Weighted values among criteria showed some clear differences, with the highest value representing more than half of the total for soil erosion, resource use, acceptance of land use, topography and watershed classes, indicating that these criteria were efficient in the modeling process. The model indicated the land use that was sufficient for the respective land user along with the value of resource use, and identified the landscape potential through key performance indicators. Thus the application of this model can provide impartial guidance on optimal land use for the land user, which focuses on high value production in small fields under an agro-ecological system that can reduce deforestation.

### 3) Landscape agroforestry map in study area

The analysis of SE levels in the study area found the high SE level consisted of home garden followed by eaglewood and eaglewood/para rubber, respectively. The moderate SE level consisted of para rubber/fruit orchard followed by *Acacia mangium* plantation, para rubber plantation, mixed fruit orchard, rambutan and mangosteen, respectively. Oil palm was reported at the low SE level. The highest and the lowest SE levels were not found in the study area. Therefore, the highest SE level should be identified as the best land use for all LS levels; it might be developed from the existing land use or established as a new land use.

More than half of the total area was classified in the highest LS level on the gentle slopes in the middle and on the western side of the watershed. In contrast, the lowest LS levels were distributed on the eastern side of the watershed where there is forest and steep slopes. Not only are most characteristics of the study area associated with a gentle slope but also they do not relate to the critical land for cultivation. Consequently, the existing land use map matched the LAFIC map, with all agroforestry land use in the study area being consistent with the suitability classes based on LAFIC.

## Acknowledgments

The authors sincerely thank the National Science and Technology Development Agency Thailand for providing a financial scholarship, and the Faculty of Forestry, Kasetsart University and the Trat Agroforestry Research and Training Station for providing the research laboratory and the study area, respectively.

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