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RESEARCH ARTICLE

INTEGRATED LAND COVER AND TERRAIN ANALYSIS FOR SUSTAINABLE LAND USE PLANNING AT WATERSHED SCALE: A CASE STUDY OF BAN DAN NA KHAM WATERSHED OF NORTHERN THAILAND

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ABSTRACT

Soil is a fundamental natural resource that is vital to the sustainable development of human societies. However, in many developing countries, increased intensity of use and inadequate land use planning has put a lot of pressure on marginal soil, leading to various forms of land degradation. The purpose of this study is to generate an integrated the land cover and terrain classification of the Ban Dan Na Kham watershed of Northern Thailand as a tool for sustainable land use planning. The watershed boundary and slope classes were delineated using the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM). The slope was subsequently classified into gentle (<8°), moderate (8-30°) and steep (>30°). The land cover map was generated through the supervised classification of Sentinel2 satellite imagery. Both map products were then integrated to provide the basis for land allocation and land use planning. The results show that 58 % of land currently under arable farming is either marginally suitable or practically unsuitable for that purpose. This ultimately leads to increased land degradation and soil loss. The land should consequently be reforested. Nevertheless, up to 10 km² of the watershed that is dedicated to other land use types – almost twice the current arable land area – is suitable for arable cropping. As such, given the proposed reforestation of the marginal and unsuitable arable lands, a large proportion of suitable land is still available to make up for the deficit. This will ultimately lead to increased productivity and reduced land degradation.

KEYWORDS

Remote Sensing, Land Cover, Terrain Analysis, Land Use Planning, Land Degradation, Watershed.

1. INTRODUCTION

The land use / land cover (LULC) existing in an area plays a critical role in the prevention and control of land degradation. Nevertheless, though land use and land cover are sometimes used interchangeably, they are quite distinct. Land cover refers to the surface cover on the ground, like vegetation, urban infrastructure, water and bare soil; while land use refers to the purpose the land serves, like recreation, wildlife habitat or agriculture (Singh, 2015). As such, land use is often a function of human activities, which, when inappropriate, predisposes the land to all forms of degradation, including erosion, pollution, salinization, desertification, etc. The threat posed by land degradation due to inappropriate land use has become so glaring that various researchers reported that land degradation is now a global challenge that impacts negatively on the sustenance and

survival of billions of people (Bajocco et al., 2012; Nkonya et al., 2016; Melaku et al., 2018). This is more so in northern Thailand where population pressure has forced the inhabitants to expand agricultural activities to the steeply sloping hillsides, further aggravating the state of land degradation (Tingting et al., 2008).

Moreover, the impacts of land degradation are not limited to the on-site loss of soil, organic matter, soil quality and growing plants; the off-site impacts, resulting in the submergence of downhill farms, drainage channels and reservoirs by eroded soils, water pollution and the degradation aquatic habitat, may even be more critical (Madueke et al., 2019). These intricate and encompassing impacts necessitate the need for sustainable and proactive land management that tends more towards

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prevention, than to control of a damage that is already in progress. However, effective land management requires a prior understanding of the spatio-temporal dynamics of land degradation in a region and the factors that predispose the land to degradation. This knowledge will enable the implementation of measures that will ensure increased productivity, while preserving the limited natural resources for the future generation. Indeed, as pointed out, holistic knowledge of the land use / land cover will enable an understanding of the prevalent dynamics, while also providing the baseline for policies and programs that will ensure sustainable development (Singh, 2015; Adhikari and Hartemink 2016). However, it has been pointed out that land use / land cover alone, is insufficient for effective environmental assessment and management (Jones, 2008). These data must be combined with comprehensive in-situ data collected from numerous research and monitoring programs (Jones, 2008).

This is more so, as effective land use planning requires the coordination of planning and management across the many sectors that critically depend on the land use / land allocation in a region. Holistic resource evaluation is therefore, a capital-intensive and time-consuming project; sometimes, resulting in increased degradation, even as plans are made to reclaim what has been lost. This necessitates the need for a cheaper and faster option that can be implemented when funds and time are inadequate; or as a preliminary measure while more intensive plans are ongoing. Assessing the land cover / land use of an area, alongside terrain characteristics like slope steepness may provide the needed insight. This is more so, as land degradation generally increases with increasing slope steepness (Ziadat and Taimeh, 2013). Yet, it has been widely reported that the form and extent of degradation is a product of the type of land cover existing on the site (Tingting et al., 2008; Bajocco et al., 2012; Labrière et al., 2015; Dos Santos et al., 2017; Nouri et al., 2018; Chen et al., 2019). Consequently, if the existing land cover types and slopes of a region are known, it will enable the implementation of a land use plan that pairs steep slopes with land cover types like forests, which prevent degradation, while opening up land on gentler slopes to more productive use. It will also enable the implementation of measures that will ensure that the land is not degraded further, even as it continues to generate economic returns.

Nevertheless, while the integrated effect of slope and land cover on land degradation has been widely studied, not much has been done on the delineation of land cover types in tandem with their corresponding slope type as a tool for sustainable land use planning (Ziadat and Taimeh, 2013; Nabiollahi et al., 2018; Siswanto and Sule, 2019; Wubie and Assen, 2020). Bektas and Goksel (2004) explored the potential of the assessment of slope and land cover as a tool for land use planning, but they did not implement an integrated approach resulting in the production of a single slope/land cover map. Furthermore, they seemed to focus more on the impact of slope on the selection of potential areas for building construction. Similarly, though other researchers assessed the integrated impact of land cover and slope on land degradation, they took it further, by also assessing soil quality and soil loss (Nabiollahi et al., 2018). This is advantageous, but may still be capital-intensive, technical and time-consuming.

This study seeks to lay more emphasis on slope and land cover characterization at the watershed scale. The watershed scale is emphasized because this topographic unit governs the drainage of precipitation and groundwater, along with the dissolved nutrients, pollutants and the suspended sediments into the surrounding streams, rivers and lakes. As such, one form of land degradation in one section of the watershed will ultimately result in another form of degradation in the adjacent section. For instance, excessive soil loss in the upland areas may result in the inundation of growing plants in the lowland areas, silting in of riverbeds by sediments, eutrophication, flash floods and increased preponderance of waterborne diseases. Indeed, the prevalent land use / land cover of an area determines the structure, functions and dynamics of the landscape (Shafiq et al., 2017). Land use planning at the watershed scale is therefore ideal for the holistic assessment of the underlying dynamics of natural resources, as well as for the effective implementation of well-targeted resource management options.

Therefore, the major objective of this study is to generate an integrated classification of the land cover and slope of the Ban Dan Na Kham watershed for effective land use planning. The specific objectives are:

1. To delineate the land use / land cover (LULC) types in the Ban Dan Na Kham Watershed
2. To delineate the slope units of the watershed
3. To make land use recommendations based on the delineated LULC-Slope units.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out at the Ban Dan Na Kham Watershed located in Mueang District, Uttaradit Province, Thailand (Figure 1). It is located within Latitudes 17°40'N – 17°55'N, and Longitudes 99°50'E – 100°20'E. It covers an area of approximately 86.91 km², with altitude ranging from 103 to 789m above sea level. The region is located in the Northern Continental Highlands (Scholten and Siriphant, 1973). It is hilly and mountainous; crisscrossed by a network of valleys and streams, and located within the vicinity of the Nan River. Three major groups of soils predominate, viz. soils of hills and mountains, soils of the higher terraces and low plateaus, and soils of alluvial plains and lower terraces (Figure 2). Nevertheless, due to the very coarse scale (1: 2,500,000) of the soil map, the only soil unit that falls within the watershed is the reddish-yellow podzolic soils on steep lands formed from acid to intermediate rocks (Figure 2).

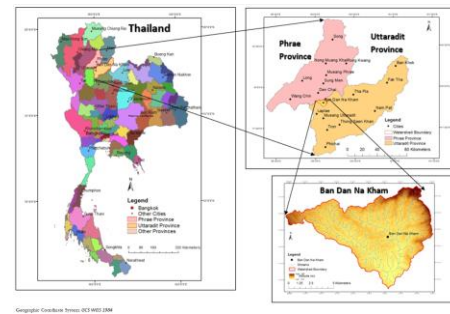
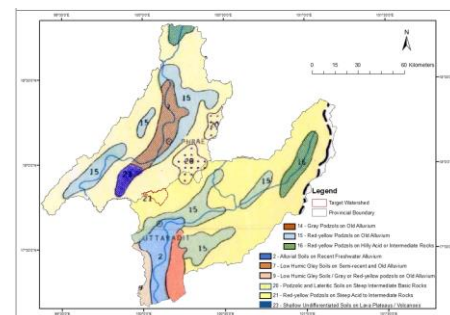


Figure 1: Study area – Ban Dan Na Kham watershed.

The watershed is located in the humid tropics, under the influence of the north-eastern and south-western Monsoons. It has three seasons: dry (winter), hot (summer, with gradually increasing rainfall and thunderstorms) and rainy seasons. Over 90 % of the annual rains fall within the rainy season, which lasts for about 5 months (mid-May to mid-October), with most of the rains coming in August and September. Monsoon rains are unpredictable, so rainfall varies considerably within and between years, but generally ranges from 1,200 to 1,600 mm per annum. Cloud cover is usually least from November to March. Temperatures generally range from 18°C in winter to 37°C in summer. The maximum temperature is usually about 40°C. The temperature decreases at the onset of the rains (mid-May), during which, it is generally below 40°C. Humidity is generally high, ranging from 63 to 81%.



Geographic Coordinate System: GCS WGS 1984

(Source: General Soil Condition of Thailand by produced by Moormann and Rojanasontan in 1967, stored in the EuDASM Archive (Panagos et al., 2011))

Figure 2: Soil map of the study area.

2.2 Data Collection and Preparation

Some of the instrument that were used during this study are the GPS receiver, data sheets, densiometer and measuring tape. The software that were used in this study include ArcGIS, SNAP Desktop, Erdas Imagine, PCRaster, Google Earth, Microsoft Excel and Microsoft Word.

2.2.1 Watershed Delineation

In order to delineate the watershed, flow direction was computed using the SRTM DEM of the Ban Dan Na Kham region of Thailand. Based on the flow direction, an appropriate outlet point was defined. All the surrounding areas on higher elevation contributing runoff to the defined point were then delineated as part of the watershed.

2.2.2 Slope Classification

The slope was generated from the SRTM DEM of the watershed. The rate of change in altitude from one cell to each of the eight neighbouring cells of the DEM was calculated. The maximum rate of change was then identified as the steepest downhill descent from that cell. Furthermore, lower slopes depict flat terrain while higher slopes depict steeper terrain. Slope being a continuous data was reclassified to generate discrete classes that would aid in the assessment of appropriate land use types for parcels of land. In this study, three classes were generated, viz.: less than 8° as gentle slope, 8 - 30° as moderate slope and greater than 30° as steep slope.

2.2.3 Definition of Land Cover Sampling Sites

Sentinel 2 multispectral satellite imagery of the study area acquired on November 6, 2018, was downloaded and pre-processed for atmospheric, aerosol, terrain and cirrus correction in SNAP using the Sen2Cor algorithm. Using ISODATA algorithm, unsupervised classification of the Sentinel 2 image of the watershed was implemented in Erdas Imagine, grouping the pixel values into 7 classes with common characteristics. Using stratified random sampling technique, 30 sites were defined for each delineated land cover type, amounting to a total of 210 sample sites.

2.2.4 Supervised Land Use / Land Cover Classification

60 % of the 210 land cover sample sites, amounting to 126 sites, were used as land use / land cover training sites. These land use / land cover training samples were used to estimate the mean and variance of the pixel values of each land cover class, enabling the determination of the appropriate range of pixel values that belong to each land cover class. Using the Maximum Likelihood approach, the statistical probability of each grid cell belonging to a land cover class was computed. The grid cells were subsequently allocated to the land cover class to which they most likely belong. The accuracy of the classification was assessed using the remaining 84 sample sites. The land cover class type of each of the sample points was compared with the land cover class determined for that site during the fieldwork. This enabled the calculation of the percent accuracy of each land cover class, both individually and collectively.

Land cover related parameters that were measured in the field, like plant height (PH), canopy cover (CC) and surface cover (SC), were built into the Land Use Table that was subsequently associated with the land cover map in PCRaster. Other secondary parameters that were also built into the table are rainfall interception by vegetation ($A = \text{Rainy Days} * \text{Smax} / \text{Annual Rainfall}$), leaf area index ($\text{LAI} = \ln(1 - \text{CC}) / -0.4$) and maximum plant canopy storage ($\text{Smax1} = 0.935 + 0.498 * \text{LAI} - 0.00575 \text{ for field crops}$ or $\text{Smax2} = 1.46 * \text{LAI} * 0.56$ for trees) [where A = rainfall interception by vegetation, LAI = leaf area index, CC = canopy cover, ln = natural logarithm, Smax = maximum plant canopy storage]. Using the lookupscale command in PCRaster, individual maps were generated for each parameter based on the land cover map.

2.2.5 Delineation of Integrated Slope and Land Cover Map

The delineated land cover and slope classes were overlaid in ArcGIS to generate the LULC-Slope map. This enabled the determination of the location and extent of each land cover type and the corresponding slope class of the terrain. Figure 3 depicts a long kong orchard on a sloping

terrain. Figure 4 shows an image of the study area, depicting its extremely undulating terrain and the diversity of the land cover types on different slope units.



Figure 3: Recording the site characteristics of an orchard on a sloping landscape.

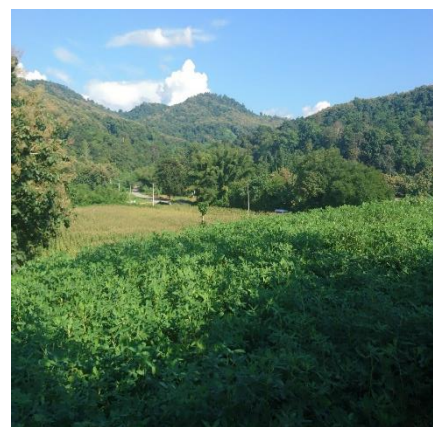


Figure 4: Image depicting the slope-land cover relations in the watershed.

2.3 Flowchart

The flowchart of methods, outlining the relationships between the adopted methods and the input data is shown in figure 5.

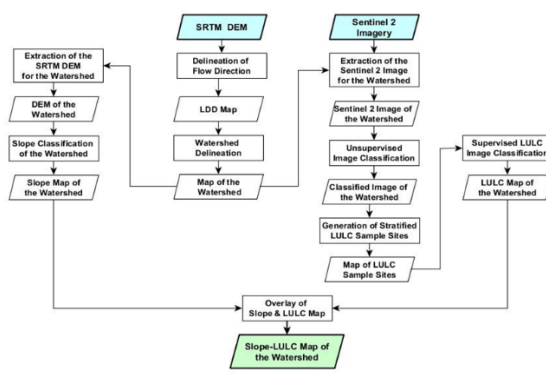


Figure 5: Flowchart of methods.

3. RESULTS

3.1 Land Use / Land Cover Map

The land use / land cover (LULC) map of the watershed is shown in Figure 6. The dominant land uses in the watershed are arable farming, orchards – mostly long kong orchards – teak plantations, natural forests and built-up areas. Arable lands cover an area of 6.68 km²; orchards, an area of 26.07 km²; plantations, an area of 12.76 km²; forests, an area of 39.82 km²; and built-up, an area of 1.59 km² (Table 1).

Table 1: Attributes generated for each land cover type

Land Cover	Area (km ²)	Area (% of Total)	A (%)	CC (%)	SC (%)	PH (m)	LAI (m ² /m ²)	Smax (mm)
Arable Land	6.68	7.69	16	49	16	1.42	1.68	1.77
Orchard	26.07	29.99	20	67	70	10.60	2.77	2.27
Forest	39.82	45.81	55	95	61	19.88	7.49	6.12
Built-up Areas	1.59	1.83	-	-	-	-	-	-
Teak Plantation	12.76	14.68	47	92	26	20.35	6.31	5.16

Where A = Rainfall Interception by Vegetation (%), CC = Canopy Cover (%), SC = Surface Cover (%), PH = Plant Height (m), LAI = Leaf Area Index, Smax = Maximum Canopy Storage (mm)

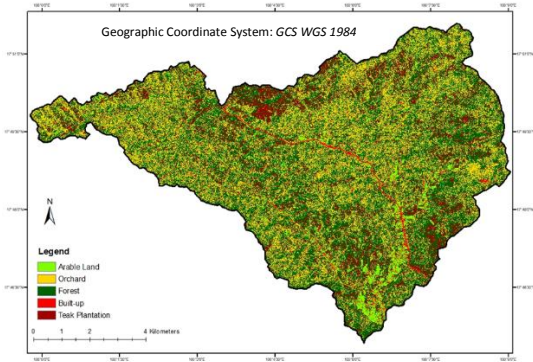


Figure 6: Land use / land cover map of the Ban Dan Na Kham Watershed.

The accuracy assessment report and confusion matrix for the land use classification are shown in Table 2. The overall accuracy of the map is 68 %. Natural Forest had a low accuracy of 43 % and was mostly misclassified as Teak Plantations, and to a limited extent, as Orchards. Forests and Teak plantations generally had similar canopy cover (92 – 95 %), the plant height (19 – 20 m) and leaf area index (6 – 7 m²/m²). Built-up areas also recorded relatively low producer accuracy of 53 %. Forest, arable land and teak had the lowest kappa coefficient of 0.40, 0.53 and 0.56 respectively, whereas, Built-up recorded the highest coefficient of 1.0.

Table 2: Accuracy assessment report for land use / land cover classification

Error Matrix						
Classified Data	Arable Land	Orchard	Forest	Built-up	Teak	Row Total
Arable Land	28	1	0	14	2	45
Orchard	0	23	7	0	0	30
Forest	1	5	13	0	6	25
Built-up	0	0	0	16	0	16
Teak	1	1	10	0	22	34
Column Total	30	30	30	30	30	150

Accuracy Totals					
Class Name	Reference Totals	Producers Accuracy (%)	Users Accuracy (%)	Overall Accuracy (%)	Kappa Coefficient
Arable Land	30	93.33	62.22	68.00	0.5278
Orchard	30	76.67	76.67		0.7083
Natural Forest	30	43.33	52.00		0.4000
Built-up	30	53.33	100.00		1.0000
Teak Forest	30	73.33	64.71		0.5588
Overall	150	-	-	68.00	0.6000

To further explore the impact of the misclassification of the forests as teak plantations, both classes were merged, and the image reclassified (Figure 7). This means that the teak plantations were eliminated, as the regions that were previously classified as teak, were now classified as forests, increasing the forested area to 52.57 km². Table 3 shows that this increased the overall accuracy to 79 % and the overall kappa coefficient to

0.70. Finally, the canopy cover (CC), surface cover (SC), plant height (PH), leaf area index (LAI), maximum plant canopy storage (Smax) and proportion of rainfall intercepted by vegetation (A) were generated for each land cover type (Table 1). The forested land had the highest canopy cover of 96 %, which was only comparable to the 92 % recorded for the teak plantation. Similarly, the maximum canopy storage of intercepted rainfall was highest in the forests and teak plantation, with a range between 5 to 6.2 mm (Table 1).

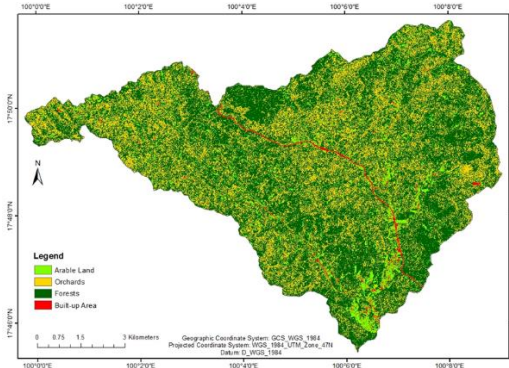


Figure 7: Land use / land cover map of the watershed (without the teak plantation).

Table 3: Accuracy assessment report for land use / land cover classification (without teak plantation)

Error Matrix					
Classified Data	Arable Land	Orchard	Forest	Built-up	Row Total
Arable Land	28	1	1	14	44
Orchard	0	22	7	0	29
Forests	2	7	52	0	61
Built-up	0	0	0	16	16
Column Total	30	30	60	30	150

Accuracy Totals					
Class Name	Reference Totals	Producers Accuracy (%)	Users Accuracy (%)	Overall Accuracy (%)	Kappa Coefficient
Arable Land	30	93.33	63.64	78.67	0.5455
Orchard	30	73.33	75.86		0.6983
Forests	60	86.67	85.25		0.7541
Built-up	30	53.33	100.00		1.0000
Overall	150	-	-	78.67	0.7032

3.2 Topography and Hydrology

The watershed is located on a predominantly undulating landscape, with altitude ranging from 103 m above sea level in the southern fringes and along river beds to 789 m above sea level in the northeastern fringes of the watershed (Figure 8). The slope of the watershed ranges from 0 to 60° but is dominated by slope ranges between 8 to 30° (Figure 9). The gently sloping areas (less than 8°), mostly in the low-lying areas along riverbeds cover an area of 16 km²; the moderately sloping area (8 to 30°) cover an area of 64 km²; while the steeply sloping regions (greater than 30°) cover an area of 6 km².

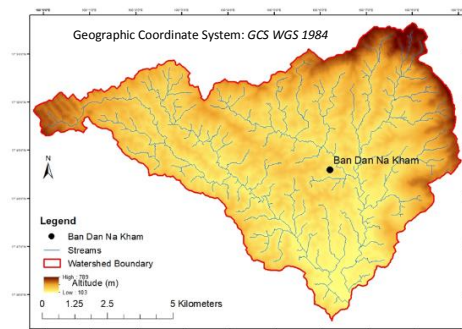


Figure 8: Physiography and hydrology of Ban Dan Na Kham watershed.

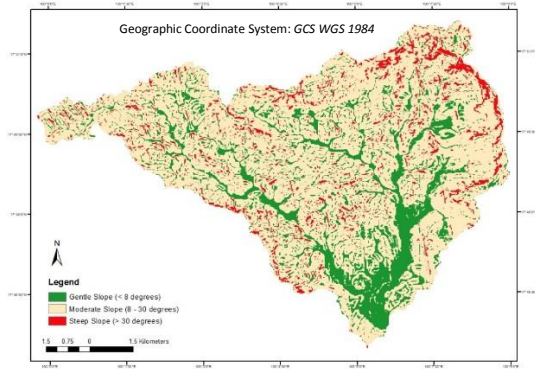


Figure 9: Slope classes of Ban Dan Na Kham watershed.

3.3 LULC-Slope Classes

The map of the watershed depicting the different land cover types and their corresponding slope classes is shown in Figure 10, while Table 4 shows the corresponding area of each unit and the recommended land use / land management option. Generally, the arable lands amounted to a total of about 5.99 km². Out of this, 2.49 km² is located on gentle slopes and is suitable for arable farming; 3.16 km² on moderate slope is marginally suitable, while the 0.34 km² on steep slope is not suitable for crop production. 24.82 km² of the watershed is currently dedicated to orchards. Out of these, the 3.39 km² on gentle slopes and the 9.82 km² on moderate slopes are suitable for the prevailing land use. Nevertheless, the 1.61 km² on steep slopes is unsuitable for orchards, and may need to be reforested

Table 4: Area and land use / management recommendations for the LULC-Slope classes.

Landscape Unit	Area (km ²)	Area (%)	Land Use / Land Management Recommendations
AL-Gentle Slope (< 8°)	2.49	3.00	Suitable for arable farming
AL-Moderate Slope (8-30°)	3.16	3.81	Marginally suitable for arable farming; may be converted to orchards
AL-Steep Slope (> 30°)	0.34	0.41	Unsuitable for arable farming; needs to be forested
OR-Gentle Slope (< 8°)	3.39	4.09	Suitable for orchards; may be suitable for expansion of arable farmland
OR-Moderate Slope (8-30°)	19.82	23.90	Suitable for orchards
OR-Steep Slope (> 30°)	1.61	1.94	Should be reforested
FO-Gentle (< 8°)	4.97	5.99	Suitable for arable farming
FO-Moderate Slope (8-30°)	30.25	36.47	Suitable for forests; moderately suitable for orchards
FO-Steep Slope (8-30°)	3.10	3.74	Should be left forested
TP-Gentle Slope (< 8°)	2.08	2.51	Appropriate; may be suitable for expansion of arable land
TP-Moderate Slope (8-30°)	9.22	11.12	Needs to be reforested or intercropped with shade-loving plants
TP-Steep Slope (> 30°)	0.92	1.11	Should be reforested
BA-Gentle Slope (< 8°)	0.90	1.09	Adequate for buildings, but may be prone to flash floods
BA-Moderate Slope (8-30°)	0.62	0.75	Adequate for buildings, but with appropriate soil conservation measures
BA-Steep Slope (> 30°)	0.07	0.08	Not suitable for buildings; if it is to be built up, it should be sparingly distributed, as was the case; and with appropriate soil conservation measures

AL = Arable Land, OR = Orchard, FO = Forests, TP = Teak Plantations, BA = Built-up Areas

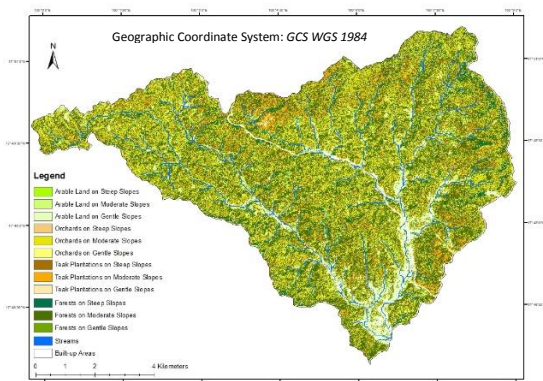


Figure 10: Map of the watershed showing the different land use types and their respective slope classes.

The teak plantation covers an approximate area of 12.22 km². Out of this, the 2.51 km² on gentle slopes and the 11.12 km² on moderate slopes are

suitable for teak plantations. Land conservation measures may however be necessary on moderate slopes. 0.92 km² of teak plantation on steep slopes is domiciled on inadequate land. 38.32 km² of the watershed, amounting to 46.2 % of the total area, is forested. 4.97 km² is located on gentle slopes, 30.25 km² on moderate slopes and 3.1 km² on steep slopes. 1.59 km² of the watershed is built up. Out of this, 0.9 km² is located on gentle slopes, 0.62 km² on moderate slopes and 0.07 km² on steep slopes.

4. DISCUSSION

4.1 Land Use / Land Cover Map

Table 2 shows the tendency to misclassify Natural Forests as Teak Plantation and vice versa. This misclassification, resulting in reduced overall accuracy (68 %) and low kappa coefficient (0.60) is in consonance with the findings of other researchers, who reported an accuracy of 50 % for secondary forest because it was usually confused with primary forests (Gebhardt et al., 2015). Similarly, while trying to understand the dynamics of a fragmented forest landscape in coastal Ecuador, it was reported that the majority of the existing primary forests were classified as secondary

forests; and that plantations also tend to be mistaken for forest (Haro-Carrión and Southworth, 2018). Another group of researchers, while working in Costa Rica, also reported that tree plantations, secondary and mature forests were usually confused with each other (Fagan et al., 2015). These may be attributed to the fact that the forest, the teak plantations and the orchards are populated by trees. The similarity in canopy cover (92 – 96 %), plant height (approximately 20 m), leaf area index (6.3 – 7.5 m²/m²) and maximum canopy storage (5 – 6 mm) of the forests and teak plantations, as evident in Table 1, translates into similar pixel values.



Figure 11: Understory in the forested landscape.

Indeed, the spectral confusion between tree-based land cover types has been widely reported (Fagan et al., 2013, 2015; Gutiérrez-Vélez and De Fries, 2013; Senf et al., 2013; Haro-Carrión and Southworth, 2018). As such, when teak plantations and forests were merged, and the image reclassified, the accuracy of the classification increased from 68 to 79 %, while the kappa coefficient increased from 0.60 to 0.70. A kappa coefficient as high as 0.70 implies substantial agreement between the classified and the field-based data (Mchugh, 2012). Nevertheless, even though merging the Teak Plantation and Natural Forest increased the accuracy of the classification, the original map with 68% accuracy was retained and used for further computations. This was because the forest (Figure 11) and the teak plantation (Figure 12) had distinct features, with particular reference to surface cover, which ranges from 26 % in the plantations to 61 % in the forests (Table 1). This, in the light of the report that in the humid tropics, forest understory plays a crucial role in determining the rate of land degradation within the watershed, meant that they should be treated differently (Labrière et al., 2015).

Furthermore, the relatively low producer accuracy recorded for built-up areas (53%) may be attributed to the misclassification of built-up areas as arable land. Ideally, it is expected that arable land and built-up areas would have very distinct pixel values. Nevertheless, the watershed is located in a rural setting, where buildings may be surrounded by or located in close proximity to farms, orchards, trees or forests (FAO, 2018). As such, some buildings may be located in pixels dominated by arable land, resulting in their classification as arable land. This phenomenon, referred to as mixed pixels, has been widely reported (Amalissana et al., 2017; Maclachlan et al., 2017; Yang et al., 2017). However, with respect to the impact of the misclassification on the assessment and management of land degradation in the watershed, most of the built-up areas are located on gentle to moderately sloped low-lying areas that are less prone to erosion and other forms of degradation, especially when they are surrounded by trees with understory of farmlands.

The forested land had the highest canopy cover (96 %), as also reported by other researchers (Siswanto and Sule, 2019). This value was only comparable to the 92 % recorded in the teak plantation. The high canopy cover engenders a greater shield for the land from the direct impact of precipitation and sunlight (Zuazo and Pleguezuelo, 2008; Siswanto and Sule, 2019). As such, the loss of forest canopy through deforestation has a devastating effect on the environment and the ecosystem (Olagunju, 2015; Chen et al., 2019). Nevertheless, while high canopy cover can reduce soil detachment by raindrops, it has been reported that it may also result in retarded growth for shaded plants (Hou et al., 2018; Wagner et al., 2011).

As such, if crops are to be grown under the canopy of the teak plantation, shade-loving plants should be preferentially selected (Wagner et al., 2011).

The high maximum canopy storage of forests and teak plantations (Table 1) buttress the impact of canopy cover on the prevention and control of soil erosion and other forms of land degradation. This is reiterated by the higher leaf area index (7.50 m²/m²) and rainfall interception by vegetation (55%) recorded in the forests, which reportedly, reduces soil degradation (Seitz et al., 2016). Nevertheless, with a plant height of approximately 20 m, the intercepted rainfall that falls through the tree foliage will have a greater erosive energy due to the accumulated kinetic energy of the throughfall. Therefore, increase in tree height and the attendant erosive energy exposes the soil to increased risk of degradation (Seitz et al., 2016). The least erosive throughfall was recorded on the arable land due to a low plant height of 1.42m (Table 1).

Fortunately, irrespective of the erosive energy of the throughfall, a high surface cover of 61 %, which is a product of the forest understory (Figure 11), will reduce detachment by throughfall on forested land as has also been reported by other researchers (Seitz et al., 2016). This is not the case in the teak plantation (Figure 12), with a surface cover of 26 %. Nevertheless, it is recommended that an understory of annual plants will restrict soil erosion to negligible levels (Zuazo and Pleguezuelo, 2008). Incidentally, arable land also had the lowest surface cover of 16 % and is consequently least protected from the erosive impact of rainfall, runoff and other agents of land degradation, irrespective of its low plant height.



Figure 12: Lack of understory in the teak plantation.

4.2 Topography and Hydrology

It has been reported that the slope of the landscape is one of the most important factors that must be taken into consideration in the course of land use planning (Tilahun and Teferie, 2015). This is because the steepness, shape (uniform, concave, convex or complex) and length of the slope has a fundamental impact on the rate and degree of runoff and soil erosion within a landscape (Sensoy and Palta, 2009; Gray, 2016; Ahmadu et al., 2019). Consequently, land uses that predispose the land to degradation should be avoided in specific sections of the landscape, particularly on steep slopes (Tilahun and Teferie, 2015; Karamage et al., 2016; Madueke et al., 2019).

In line with this, arable cropping should be discouraged on the steep slopes, which amounts to 6.98 % of the Ban Dan Na Kham watershed. The steep slopes are better left forested as reduced erosion is evident on forested soils (Chalise et al., 2019). This is also in line with the contention that steeply sloping land are unsuitable for crop production and hill slopes are generally suitable for tree crops (AbdelRahman et al., 2016; Mazahreh et al., 2018).

On the moderate slopes (74.42 % of the watershed), cropping has to be accompanied by extensive investment on soil conservation measures like

terracing, contour ploughing, alley farming, cover cropping, etc. Orchards and plantations may be established on the moderate slopes, with arable crops grown between the rows of trees. This would increase the economic returns of the farmers, while at the same time, preventing excessive soil degradation (Zuazo and Pleguezuelo, 2008). Arable farming may be sustainably implemented on the gentle slopes (18.60 % of the watershed). This agrees with the recommendation of that gentle slopes are optimal for arable crop production (Li et al., 2015; Mazahreh et al., 2018).

4.3 LULC-Slope Classes

Due to intense monsoon rains in Southeast Asia, the sloping lands are susceptible to landslides, flash floods, soil erosion and other forms of land degradation (Xu et al., 2013). This is more so for arable lands on slopes. In line with this, destructive degrees of soil degradation has been reported for arable lands on slope classes above 7 % (Nabiollahi et al., 2018). It is noteworthy that trees play a crucial role in the prevention and control of these diverse forms of land degradation (Zuazo and Pleguezuelo, 2008; Xu et al., 2013; Nabiollahi et al., 2018). As such, the marginal arable lands on the moderate slopes of the Ban Dan Na Kham watershed may need to be converted to orchards or forests to forestall further land degradation. If plantations or orchards are to be established on such land, agroforestry systems like alley farming may be recommended. This will provide additional returns to the farmer while maintaining the integrity of the soil. Furthermore, the arable land on the steep slopes should be reforested. This is in line with the contention that steep slopes are unsuitable for arable crop production (AbdelRahman et al., 2016; Karamage et al., 2016; Mazahreh et al., 2018; Madueke et al., 2019).

Out of the 24.82 km² currently dedicated to orchards, 23.21 km² may be suitable for orchards, but, in line with the contention of Li et al. (2015), the 3.39 km² on gentle slopes may also be suitable for the expansion of arable land. The remaining 1.61 km² is located on steep slopes and should be reforested. This will forestall aggravated land degradation (AbdelRahman et al., 2016; Karamage et al., 2016; Mazahreh et al., 2018; Madueke et al., 2019). The 38.32 km² of forested land is not at risk of degradation, a situation which is attributed to the increased canopy cover, soil organic matter, structural stability, porosity and capacity to conserve water efficiently (Tingting et al., 2008; Siswanto and Sule, 2019). Nevertheless, if there is the need for expansion of arable farmlands, the 4.97 km² of forested land on gentle slopes may be suitable, while the 3.10 km² on the steep slopes should be left untouched. This is because steep slopes are neither suitable for arable farming, plantations or orchards (Madueke et al., 2019).

The 2.08 km² of teak plantation on gentle slope may be left in its current state. However, these plantations, along with the 9.22 km² on moderate slopes, need to be intercropped with shade-loving plants to protect the bare soil from the direct impact of raindrops and throughfall. The crops will provide the needed understory which, reduces soil degradation in the humid tropics (Zuazo and Pleguezuelo, 2008; Labrière et al., 2015; Seitz et al., 2016). The remaining 0.92 km² of teak plantation on steep slope may need to be reverted to natural forests as it has been reported that plantations are relatively more prone to erosion (Tingting et al., 2008; Madueke et al., 2019).

Only 1.59 km², amounting to 1.83 % of the watershed, is currently dedicated to built-up areas. This buttresses the rural setting of the watershed as FAO (2018) pointed out that the inhabitants of a rural area usually live far apart from one another in relatively small, widely spaced settlements that may be located in close proximity with farms or forests. Out of the total built-up area, the 0.90 km² on gentle slope is adequate, but may be prone to flash floods. The 0.62 km² on moderate slope is also adequate but may require the implementation of soil and water conservation measures like proper drainage / waterways and prevention of unnecessary deforestation. The 0.07 km² on steep slope may be inadequate, but its sparing distribution, and the implementation of adequate soil conservation measures, including maintenance of adequate forest and understorey, may preclude undue land degradation.

5. CONCLUSION

The integrated land cover and slope map of a watershed can be used as a preliminary tool for land use and land management planning. Furthermore, when constrained by time and finance, the integrated assessment can serve as a sustainable and proactive instrument for land allocation to ensure increased productivity with minimal land degradation. Generally, with regards to the Ban Dan Na Kham watershed, the current extent of the arable lands is 5.99 km². Out of this, 0.34 km² is unsuitable due to its steep slope, while 3.16 km² is marginally suitable due to its moderate slope. Nevertheless, the total area on gentle slope which may be suitable for the expansion of the arable land in the watershed amounts to as much as 10.44 km²; about 12.14 % of the total extent of the watershed, as opposed to the current total arable land proportion of 6.97 %. As such, a coordinated land use planning based on the integrated land cover and slope map will engender sustainably increased soil productivity.

RECOMMENDATIONS

- Up to 2.87 km² of land occupied by agricultural fields, orchards and plantations may need to be afforested due to the steepness of the slope.
- The portion of the watershed located on moderate slopes, amounting to about 32.20 km² may need to be reforested or subjected to soil and land management options that would ensure sustainable use.
- The teak plantation should be intercropped with shade-loving plants to protect the soil from the direct impact of precipitation, runoff and other agents of denudation.

FURTHER STUDIES

Given the relatively low accuracy of the LULC classification of the rural watershed, there may be the need to explore other classification options, like the fuzzy classification and the random forest, both of which may give better accuracy. It may be necessary to assess the rate of land degradation within each delineated unit, to ensure a more precise land use and management recommendation. Finally, determining the land capability classes within the watershed may also be necessary as it will provide insight on proactive and sustainable land use / land management options.

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