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Land Use Change using Geospatial Techniques in Upper Prek Thnot Watershed in Cambodia

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ABSTRACT

Monitoring of land use change is crucial for sustainable resource management and development planning. Up-to-date land use change information is important to understand its pattern and identify the drivers. Remote sensing and geographic information system (GIS) have proven as a useful tool to measure and analyze land use changes. Recent advances in remote sensing technology with digital image processing provide unprecedented possibilities for detecting changes in land use over large areas, with less costs and processing time. Thus, the objective of this study was to assess the land use changes in upper Prek Thnot watershed in Cambodia from 2006 until 2018. Geospatial tools such as remote sensing and GIS were used to process and produce land use maps from Landsat 5 TM, Landsat 7 ETM+ and Landsat 8. The post-classification comparison was conducted for analysing the land use changes. Results show forest area was greatly decreased by 1,162.06 km^2 (33.67%) which was converted to rubber plantation (10.55 km^2), wood shrub (37.65 km^2), agricultural land (1,099.71 km^2), built-up area (17.76 km^2), barren land (3.65 km^2), and water body (14.69 km^2). Agricultural land increased by 1,258.99 km^2 (36.48%), while wood shrub declined by 161.88 km^2 (4.69%). Rubber plantation, built-up area, barren land, and water bodies were increased by 10.55 km^2 (0.31%), 33.64 km^2 (0.97%), 4.87 km^2 (0.14%) and 15.89 km^2 (0.46%), respectively. The decrease of forest and wood shrub had resulted due to population growth (1.8% from 2008 to 2019) and land

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conversion for agricultural purposes. Hence, this study may provide vital information for wise sustainable watershed's land management, especially for further study on the effect of land use change on runoff in this area.

Keywords: Cambodia, land use change, Prek Thnot watershed, remote sensing-GIS, sustainable management

INTRODUCTION

Knowledge of land use is very crucial for many planning and management activities; and considered as a significant factor for modelling and understanding the earth's surface (Gribb & Czerniak, 2016). In fact, land use changes are affected by both natural phenomena and human activities. Natural events, including continental drift, glaciation, flooding, and tsunamis, and human activities including conversion of forest to agriculture, urban sprawl, and forest plantations have modified the dynamics of land use types worldwide. Land use changes caused by human activities have proceeded much quicker in recent decades than caused by nature. Consequently, almost all ecosystems of the world have significantly has been changed by humans (Giri, 2012). Moreover, timely and accurate information about land use change detection is significantly vital to understand relationships and interfaces between human and natural phenomena for better decision making (Lu et al., 2004). Therefore, data on land use and possibilities for their ideal use is vital for the selection, planning, and implementation of land use schemes to find such increased demands for basic human needs and prosperity.

Land use is one of the most accessible detectable indicators of human interference on land; thus, land use information is essential in any geographical database. Land use has become a sort of "boundary object" between varied disciplines in modern maps. This advancement enhances the intrinsic value of land cover information. Conversely, it poses new challenges for its harmonization and correct use by further enlarging the base of potential users. Any land surface is diverse, and the mapping standards to acquire, represent, and generalize land characteristics are about as varied as the land surface itself (Di Gregorio & O'Brien, 2012).

In many years geospatial technology such as remote sensing and geographic information system (GIS) are primarily tools which widely used for change detection in late decades. Remote sensing is used broadly to detect and monitor land use at varied scales (Giri, 2012; Sohl & Sleeter, 2012). Meanwhile, GIS provides a flexible environment for digital data collection, storage, display and analysis that is needed to detect changes (Lu et al., 2004). Lu et al. (2004) addressed various land use change detection techniques and showed that image differencing, principal component analysis, and post-classification comparison were the most common methods used for change detection. It is likely to demonstrate a model to estimate the trends in land uses in a particular period through the study of past land use changes. It may provide some basis for scientific and practical land-use planning, management and ecological improvement in a specific study area and instruction for regional socio-economic development. Hence, up-to-date and accurate land cover change information is essential to understand and identify land use changes.

Furthermore, the analysis of land use change detection is still an active research topic, and the development of new techniques continues. For a new change detection technique, it is essential to be capable of implementing it effortlessly and of providing accurate change detection outputs related to trajectory change. Even though a variety of change detection techniques have been advanced, it remains difficult to decide a suitable method to implement accurate change detection for a specific research purpose or study area. Selecting an appropriate change detection technique requires deliberated consideration of the main impact drivers (Lu et al., 2004). In most developing countries like Cambodia, for example, such factors associating with population growth, economic development and competing demands for land have been dominant causes of land use change (Vadrevu et al., 2019). There is a significant statistical correlation between population growth and land use conversion in most African, Asian, and Latin American countries (Lambin & Meyfroidt, 2011; d'Amour et al., 2017). Many studies addressed that a change of land use considerably affected other hydrological matters in the watershed or river basin such as water quality (Kumar et al., 2019), runoff (Samie et al., 2019), soil erosion (Tsegaye, 2019), sedimentation (Munoth & Goyal, 2019) and flooding (Szwagrzyk et al., 2018). Beside Prek Thnot watershed is among the basins in Cambodia that are having the highest risk of impairment which leads to different disasters, such as droughts, flood, pest and diseases, and storms that affect people's food and nutrition security, due to various incompatible land uses (FA & APFNet, 2016). Therefore, the objective of this study was to assess the land use changes in upper Prek Thnot watershed in Cambodia from 2006 until 2018.

MATERIALS AND METHODS

Study Area

Prek Thnot watershed area is about 6,666 km^2 (FA & APFNet, 2016) which partly covers several provinces namely Kampong Speu, Kampot, Koh Kong, Preah Sihanouk, Takeo, Kandal, and Phnom Penh city of the Kingdom of Cambodia. The upstream part of Prek Thnot watershed is in Kampong Speu province. Prek Thnot watershed plays a vital role in providing ecosystem services and supporting the livelihoods and production systems of the downstream communities. The Prek Thnot River flows from the Cardamom Mountains in the southwest of Cambodia towards Bassac River, a part of Mekong River, which is between latitudes 11°00' to 12°10' N and longitudes 103°80' to 105°00' E (Figure 1). It is dominated by a tropical monsoon climate that having two specific seasons, such as the rainy season (May-October) and the dry season (November-April). Generally, the slope of the watershed of Prek Thnot River lies in the eastern facing slope.

The delineated boundary was employed by using watershed delineation tool in ArcGIS 10.4.1 software using digital elevation map (DEM). The geospatial data model was created to produce flow accumulation lines and ultimately delineate a catchment using the Spatial Analyst tools. The watershed delineation was based on the 'eight-pour point' algorithm (Jenson & Domingue, 1988; Jenson 1991), which included pit filling, calculation of flow direction and flow accumulation. From the flow accumulation grids, stream networks were extracted. Streams are defined wherever drainage areas are higher than the specified threshold value. The border was created from 30 m spatial resolution from OpenTopography (http://opentopo.sdsc.edu) to determine the entire land area contributing to flow in a stream. As a result, the study area is in the upper Prek Thnot watershed, which widely locates in Kampong Speu province. It covers 3,450 km^2 and lies between latitudes of 11°00' and 12°10' N and longitudes of 103°40' and 104°20' E (Figure 1).

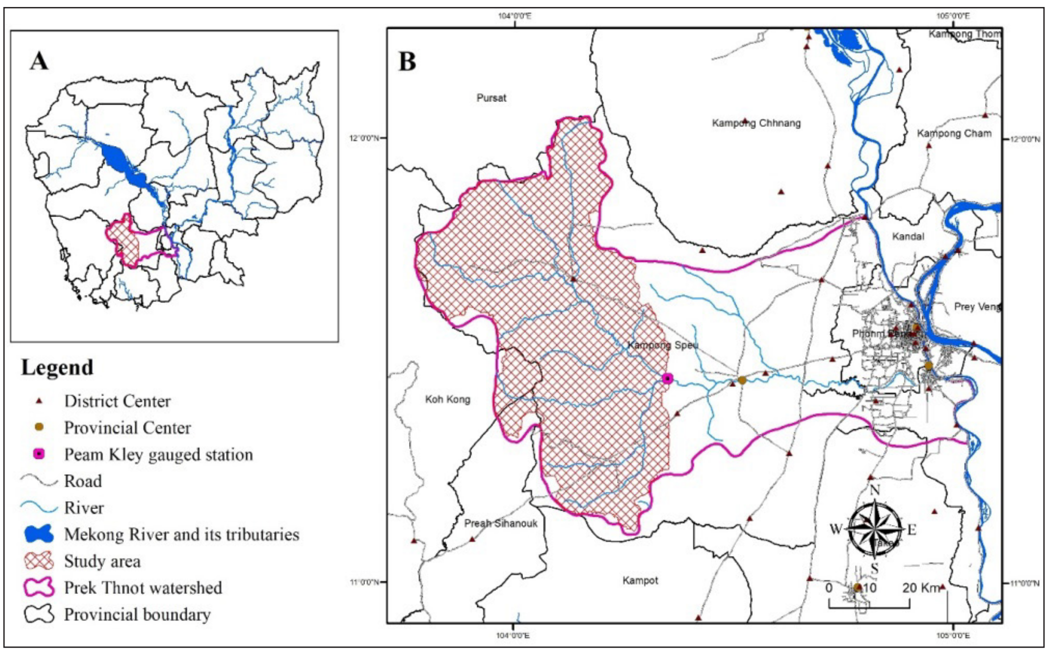

Figure 1. Study area; (A) Cambodia map and (B) Prek Thnot watershed area

Data Source

The land use data in 2006 and 2018 were obtained from remote sensing imageries (Landsat 5 TM, Landsat 7 ETM+ and Landsat 8). These imageries were provided by the Forestry Administration (FA) and the Ministry of Environment (MOE) of the Kingdom of Cambodia. The image processing, classification and accuracies of the land use maps were carried out in collaboration with national and international experts including from FAO-UNREDD, JICA-CAMREDD and international universities, Forestry and Forest Products Research

Institute, Japan (FFPRI) (FA, 2016; MOE, 2018). Maximum likelihood classification (MLC) approach was used for land use change assessment. It was found that MLC was appropriate and most used and convenient to apply with satisfactory accuracy. All maps projection was projected to Universal Transverse Mercator (UTM) coordinate system, zone 48, with World Geocoded System (UTM WGS 84) projection parameters. The overall accuracies reported form the land use classification ranging from 85% to 90%. The original land uses type were classified under the national level scheme for the country based on the classification as shown in Table 1. Based on this classification, there are 17 land use classes were used for the country namely evergreen forest, semi-evergreen forest, deciduous forest, pine forest, forest regrowth, bamboo, tree plantations, rubber plantation, wood shrub, grassland, paddy field, cropland, built-up area, village, rock, sand, and water.

Table 1
Description of land use classes in Cambodia

No	Land use class	Descriptions
1	Evergreen forest	Areas covered by trees maintaining their leaves during the whole year.
2	Semi-evergreen forest	Contain variable percentages of evergreen and deciduous trees.
3	Deciduous forest	Comprised of dry mixed deciduous forest and dry Dipterocarp forests
4	Bamboo	Areas dominated by bamboo
5	Wood shrub	Areas dominated by evergreen and deciduous woodland with a height less than 5 meters
6	Mangrove forest	Areas dominated by Mangroves i.e. coastal salt tolerant species
7	Rear Mangrove	Mostly growing in coastal zone after mangrove spp. Salt tolerant species but only infrequent floods
8	Rubber plantation	Areas currently supporting, and areas reserved for, rubber plantation
9	Flooded forest	This forest type is found in Tonle Sap Lake. Most of the forests are low and disturbed. In many cases, there is only a mosaic remaining
10	Forest regrowth	Areas of naturally regenerated forest where there are clearly visible indication of human activities such as selective logging, areas regenerating following agricultural land use, areas recovering from human induced fire, including: - Forest where it is not possible to distinguish whether planted or naturally regeneration. - Forests with mix of naturally regenerated trees and planted/seeded trees, and where the naturally regenerated trees are expected to constitute more than 50 percent of the growing stock at stand maturity. -Abandoned forest land and bare land which will regrow into forest within ten years
11	Pine tree	The area dominated by coniferous trees
12	Pine plantation	The area dominated by pine tree plantation
13	Oil palm	The area dominated by oil palm tree.
14	Tree plantation	This class includes the following types: Teak, Eucalyptus, Acacia, Jatropha and others

Table 1 *(continue)*

No	Land use class	Descriptions
15	Paddy field	Paddy field is a flooded parcel of arable land used for growing semiaquatic rice
16	Crop land	This category includes arable and tillage land and agro-forestry systems where vegetation falls below the thresholds used for the forest land category
17	Grassland	Grasslands are characterised as lands dominated by grasses rather than large shrubs or trees. It is crucial that the rainfall is concentrated in six or eight months of the year, followed by a long period of drought when fires can occur
18	Built-up area	The patch of land with building and construction
19	Village	The patch of land with houses and garden surrounding house.
20	Rock	Land of naturally exposed rocks or strip mines, quarries and gravel pits
21	Sand	In general, land of sand having thin soil or sand including deserts, dry salt flats, beaches, sand dunes
22	Water	Area of fresh and sea water

Source: (FA, 2016; MOE, 2018)

Reclassification of Land Use

In general, land use reclassification is often used to update existing land use data files, to group land-use types, or to assess water quality impacts or management options regarding alteration to land use over time. Similar characteristics of land use classes can be grouped into a single classification to simplify modelling (www.aquaterra.com/basins3/BASINS%20 Utilities/Land%20Use%20Reclassification). In this study, both land use in 2006 and 2008 were reclassified by grouping the identified classes in the study area into seven classes (Table 2). The reclassification is needed in order to synchronise the limitation of satellite imagery resolution with the land use data in a GIS. Land use reclassification was conducted by using ArcGIS 10.4.1 software functions by merging polygons in Table 1 to a new class as developed and described in Table 2.

Table 2
New classes of land use of upper Prek Thnot watershed

No	Land use class	Code	Descriptions
1	Forest	F	Evergreen forest, semi-evergreen forest, deciduous forest, pine forest, forest regrowth, bamboo and tree plantations
2	Rubber plantation	RP	Rubber plantation
3	Wood shrub	WS	Wood shrub and grassland
4	Agricultural land	AL	Paddy field and crop land
5	Built-up area	BU	Built-up area and villages
6	Barren land	BL	Rock and sand
7	Water	W	Water

Land Use Changes Detection

Change detection is a significant process in monitoring and managing natural resources. Urban development provides a quantitative analysis of the spatial distribution of the population of interest (Singh, 1989). One of the important uses of land use data is for change analysis, and various methods have been designed to identify conversion in the land surface (Singh, 1989; Lu et al., 2004). The most apparent method of change detection is a comparative analysis of spectral classification for times t1 and t2 produced independently. The base map of satellite imageries area was prepared by the Forestry Administration (FA) and the Ministry of Environment (MOE) of the Kingdom of Cambodia. The subset images were combined and used to recognize different features in the study area. For image interpretation, ERDAS Imagine and ArcGIS software were used to prepare land use category map of the study area. The post-classification technique was used to assess land use change in this study. The post-classification comparison was conducted by using ArcGIS 10.4.1 software. The percentage change (trend) for each land use type was then calculated by dividing magnitude change by the base year (the initial year) and multiplied by 100 as shown in Equation 1.

$$\text{Percentage change} = \frac{\text{Magnitude of Change}}{\text{Base year}} * 100 \qquad (1)$$

The data of the land-use change from periods of 2006 and 2018 went through the process of overlaying, intersecting and dissolving of vector data layers, thus providing the basis for the evaluation of data applicability for this purpose.

RESULTS AND DISCUSSION

Land Use Status

The Multi-temporal land use of 2006 and 2018, covering seven main classes such as forest, rubber plantation, wood shrub, agricultural land, built-up area, barren land and water (Figure 2). Meanwhile, the spatial distribution pattern of land use, obtained from reclassification, is illustrated in Table 3.

Results from classified 2006 maps indicated that an area occupied by different classes are as follows; forest shared the majority with 2,819.60 km^2 which account for 81.71% and following by agricultural land and wood shrub which were 380.93 km^2 (11.04%) and 239.39 km^2 (6.94%), respectively. Built-up area covered 10.64 km^2, corresponding to 0.31%, while water body and barren land occupied by 0.23 km^2 (0.01%) and 0.09 km^2 (0.00%), accordingly. At the same time, no rubber plantation exists in the study area in 2006. In 2018, forest and agricultural land were estimated to have covered almost the same rate, which was 1,657.54 km^2 (48.03%) and 1,639.91 km^2 (47.52%), respectively. Wood shrub shared a proportion almost double as built-up area, which was 77.51 km^2 (2.25%) and 44.28 km^2 (1.28%), individually. Meanwhile, rubber plantation was found in the study area with coverage of 10.55 km^2, accounting for 0.31%. Finally, the water body was 16.12 km^2 (0.47%), whereas barren land covered 4.96 km^2 (0.14%) (Table 3).

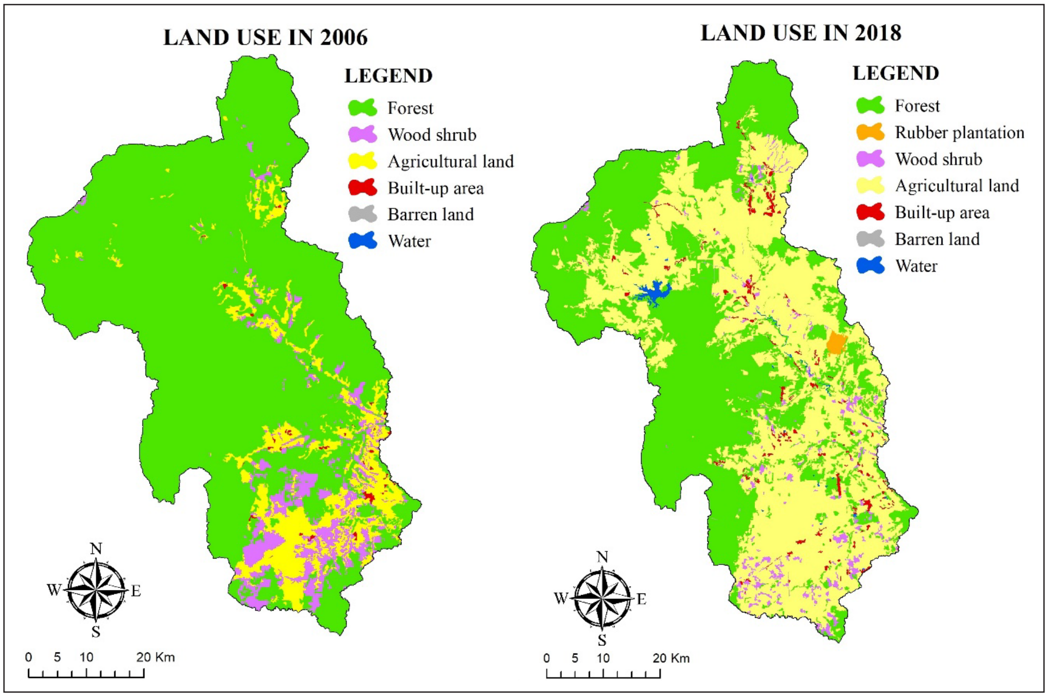

Figure 2. Land use types in 2006 and 2018 in the Prek Thnot watershed area

Table 3
Land use status (2006-2018) in the study area

Land Use Class	2006		2018	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Forest	2819.60	81.71	1657.54	48.03
Rubber Plantation	0.00	0.00	10.55	0.31
Wood shrub	239.39	6.94	77.51	2.25
Agricultural land	380.93	11.04	1639.91	47.52
Built-up area	10.64	0.31	44.28	1.28
Barren land	0.09	0.00	4.96	0.14
Water	0.23	0.01	16.12	0.47
Total	**3450.87**	**100**	**3450.87**	**100**

Land Use Changes in Prek Thnot Watershed

Relative land use change in study area was assessed based on data presented in Table 4, 5, and Figure 3. The relative changes showed some irregular pattern in this study area from 2006 to 2018. From 2006 to 2018, forest and wood shrub areas were rapidly declined by 1,162.06 km^2 (33.67%) and 161.88 km^2 (4.69%), respectively. This might be considered as a serious risk to the resource's sustainability of Prek Thnot watershed. However, agricultural land significantly increased by 1,258.99 km^2 (36.48%). Most forest and wood shrub areas were altered into agricultural land. An increase in agricultural land and a decrease in forest and wood shrub regions were affected by the growth in agricultural land requirements. Such factors including sugarcane and other agro-industry crop plantations conversions by economic land concession (ELC) companies and by local people (FA & APFNet, 2016), and an increase of paddy field demands (Chann & Frewer, 2017), all distributed to alteration of these areas. Furthermore, the built-up area increased by 33.64 km^2 which correspond to 0.97% of a total change. It was caused by residential expansion due to population growth and economic development matters. The population growth rate is increased by about 1.8% from 2008 to 2019 (NIS, 2019).

Table 4
The changes in land use from 2006 to 2018

Land Use Class	Net change	
	Area (km^2)	Area (%)
Forest	-1162.06	-33.67
Rubber Plantation	10.55	0.31
Wood shrub	-161.88	-4.69
Agricultural land	1258.99	36.48
Built-up area	33.64	0.97
Barren land	4.87	0.14
Water	15.89	0.46

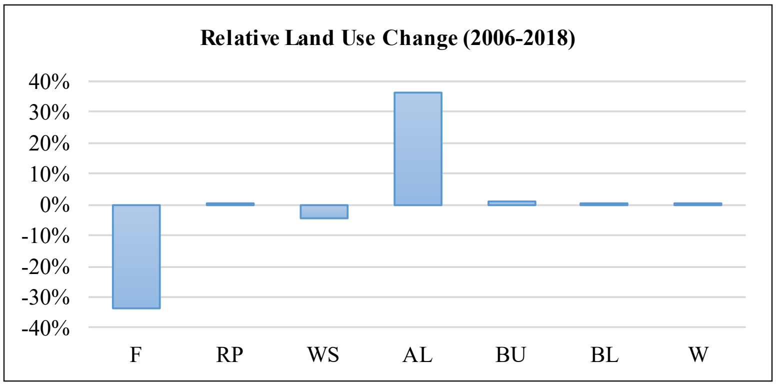

Figure 3. Diagrammatic illustration of relative land use change (2006-2018)

Table 5
Land use change matrix as observed in the study area

	Land Use Classes	2018 Area in km^2							
		F	RP	WS	AL	BU	BL	W	Total 2006
2006 Area in km^2	Forest (F)	**1635.59**	10.55	37.65	1099.71	17.76	3.65	14.69	2819.60
	Rubber plantation (RP)	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
	Wood shrub (WS)	16.53	0.00	**26.06**	189.84	6.34	0.29	0.33	239.39
	Agricultural land (AL)	5.39	0.00	13.80	**345.98**	13.86	1.02	0.88	380.93
	Built-up area (BU)	0.03	0.00	0.00	4.38	**6.24**	0.00	0.00	10.64
	Barren land (BL)	0.00	0.00	0.00	0.00	0.09	**0.00**	0.00	0.09
	Water (W)	0.00	0.00	0.00	0.00	0.00	0.00	**0.23**	0.23
	Total 2018	1657.54	10.55	77.51	1639.91	44.28	4.96	16.12	**3450.87**

The rubber plantation increased by 10.55 km^2, representing 0.31% of a net change, while the barren plantation grew moderately by 4.87 km^2 (0.14%). Finally, the water body was rapidly increased from 0.23 km^2 to 16.12 km^2 with a net change of 15.89 km^2, accounting for 0.46% of a total transformation. The installation of a water dam called Tasal Dam in the upper part of the study area might be caused of the increment. Based on the results the land use practices in the study area have changed significantly in 12 years. The land use change in the watershed area was obvious by the decline in the area of forest and wood shrubs and expansion of area by agriculture and built-up area. The alteration or depletion of forested land and wood shrubs may adversely affected water which may prove a limiting factor in the future for both urban growth and agriculture practice the watershed areas (Butt et al., 2015). From now, proper management of the watershed is essential to ensure the watershed area can play their role in socio-economic development of the area.

Sustainable Resource Management

Based on the results, the changes in the forested areas were 34 % from 2006 to 2018. This proportion is represented by 48 % of the total study area. The tendency of changes occurred in the flatland areas rather than highland areas, which focuses on agricultural areas. According to Cambodia National REDD+ Strategy 2017-2026, it was stated that deforestation and forest degradation in Cambodia were mainly driven by (i) uncertain land tenure, land speculation, unauthorized encroachment of forest lands, (ii) rapid expansion of agriculture into forest lands, the grant of large scale agro industrial-economic land concessions, and distribution of land titles under social land concessions between 1996-2012, (iii) unauthorized logging and unsustainable harvesting of forest and non-timber products, (iv) weak forest governance, law enforcement, and monitoring of forest and land-use sector, and (v) other drivers. The others include inadequate implementation of environmental and social impact assessment regulations and a lack of state land registration and forest estate demarcation.

However, several transformative actions were taken and the sustainable management of national resources, including forestry and primary policy priority, was initiated by the Royal Government of Cambodia. The government is committed to implementing the sustainable management of national resources by adopted National REDD+ Strategy, National Forest Programme, and other governmental policies, strategies and programmes. Strategic plans were designed such as (1) improving management and monitoring of forest resources and forest land use, (2) strengthening implementation of sustainable forest management, and (3) mainstreaming approaches to reduce deforestation, build capacity and engage stakeholders (NRS, 2017). The strategy 1 aimed to strengthen the management of forest conversation areas, to promote forest land tenure through forest land classification, zoning, demarcation, and registration, to enhance law enforcement activities to address unauthorised logging, and encroachment, and to strengthen capacity for data management and establish decision support systems for forest and land-use sector. Strategy 2 focused on enhancing and scaling up community-based forest management, engaging and encouraging the private sector to implement alternative and sustainable supply chains from agro-industrial plantations, expanding afforestation, reforestation and restoration activities, and identifying and implementing alternative and sustainable livelihood development programmes for local communities most dependent on forest resources. Finally, strategy 3 was developed to support mechanisms to mainstream policies and measures that reduce deforestation in relevant government ministries and agencies. It also strengthened capacity, knowledge and awareness of stakeholders to enhance their contribution to reducing deforestation and forest degradation, and to encourage public engagement, participation and consolations in forestry and land use planning, and promote the involvement of multiple stakeholders.

The land use of upper Prek Thnot watershed has been under pressures where the land resources have been transformed into various land uses. This watershed area is situated in fertile plains and is lush with vegetation. An area is an attractive place for agriculture and people to reside. Due to this, the extensive amount of deforestation occurred. Contrary to the deforestation, agriculture area has been increased remarkably from 2006 to 2018, followed by the built-up area. The trend of land use changes found in this study, especially significant percentage decreased on the forest cover will be helpful to policymakers to take appropriate decision to revert the situation and to conserve the watershed area for sustainable development. The socio-economic variables are well-thought-out highly related to the changes in land use of an area (Verburg et al., 2004). Hence incorporating socio-economic and demographic data of the study area along with temporal change pattern would give critical reasoning for land use assessment and management in the area.

CONCLUSION

The land use notably forested land of the upper Prek Thnot watershed has been under various pressures from the surrounding populations. The forests have been decreased severely, and land has been fragmented and converted into several lands uses. The study has irrevocably shown that modifications induced by humans have triggered the processes of land cover conversion. As a result, land use significantly changed in the study area in the period between 2006 and 2018. The analysis showed that there was a rapid decrease in the forested area by 1,162.06 km^2 and wood shrub by 161.88 km^2, while agricultural land significantly increased by 1,258.99 km^2. The same trend occurred to a rubber plantation, built-up area, barren land and water where the areas increased by 10.55 km^2, 33.64 km^2, 4.87 km^2, and 15.89 km^2, respectively. The decrease in forest and wood shrub areas led to an increase in other areas including agricultural land, rubber plantation, built-up area, barren land and water. These changes also are driven by the influenced of the growth of population and land demands for agricultural purposes, such as sugarcane and other agro-industry crop plantations conversions by economic land concession (ELC) companies and by local people (FA and APFNet, 2016), an increase of paddy field demands, residential expansion (Chann and Frewer, 2017), and economic development matters. The sustainable resource management is needed to be instigated in this area based on the availabilities of national strategies, policies and programmes. Therefore, this study may provide vital information for wise sustainable watershed's land management, especially for further study on the effect of land use change on runoff in this watershed area.

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