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The Alteration of Flood Peak Discharge by Land Cover Change in Prek Thnot Watershed, Kampong Speu Provine, Cambodia

CHHINH Nyda[1*], RATH Sethik[2], CHOEUN Kimseng[3]

[1]Department of Economic Development, Royal University of Phnom Penh (RUPP), Russia Federation Boulevard, Khan Toul Kork, Phnom Penh, Cambodia.
[2]Dean Office, Faculty of Development Studies, Royal University of Phnom Penh (RUPP), Russia Federation Boulevard, Khan Toul Kork, Phnom Penh, Cambodia.
[3]Department of Natural Resource Management and Development, Faculty of Development Studies, Royal University of Phnom Penh (RUPP), Russia Federation Boulevard, Khan Toul Kork, Phnom Penh, Cambodia.

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*Corresponding author: Department of Economic Development, Royal University of Phnom Penh (RUPP), Russia Federation Boulevard, Khan Toul Kork, Phnom Penh, Cambodia.
E-mail address: chhinh.nyda@rupp.edu.kh (C. Nyda)
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សង្ខិត្តន័យ

ការសិក្សានេះវិភាគពីការប្រែប្រួលធារទឹកក្នុងស្ទឹងព្រែកត្នោត ដោយប្រើប្រាស់វិធីសាស្ត្រអត្រាសន្ទស្សន៍ ដែលបង្កើតឡើងដោយភ្នាក់ងារសេវាអភិរក្សដី (SCS-CN)។ ការសិក្សាធំៗចំនួនពីបានធ្វើឡើងក្នុងតំបន់អាងជលសាស្ត្រស្ទឹងព្រែកត្នោត ដោយប្រើវិធីសាស្ត្រផ្សេងគ្នា ហើយក៏ផ្តល់លទ្ធផលមិនស៊ីសង្វាក់គ្នាដែរ។ ការសិក្សាទីមួយធ្វើឡើងដោយអាជ្ញាធរវារីអគ្គិសនី Snowy Mountain ហើយបានបោះពុម្ពផ្សាយការសិក្សាលើកដំបូងក្នុងឆ្នាំ 1967។ ការសិក្សានេះបានរកឃើញថា ធារទឹកធំបំផុតក្នុងរយៈពេល 10 ឆ្នាំគឺមានបរិមាណ 710 ម3/វិនាទី។ ការសិក្សាលើកទីពីរត្រូវបានធ្វើឡើងដោយទីភ្នាក់ងារសហប្រតិបត្តិការអន្តរជាតិជប៉ុន (JICA) នៅចន្លោះឆ្នាំ 1991 និង 2006 ហើយបានបង្ហាញថា ធារទឹកច្រើនបំផុតគឺ 1,380 ម3/វិនាទី។ មកទល់ពេលនេះ មិនទាន់មានការពិភាក្សាប្រៀបធៀបការសិក្សាទាំងពីរដើម្បីកំណត់ថា ហេតុអ្វីបានជាបរិមាណធារទឹកខុសគ្នាទ្វេដងលើសពីការសិក្សាលើកទី1។ ដោយសារទឹកភ្លៀងប្រចាំឆ្នាំក្នុងអំឡុងពេលសិក្សាទាំងពីរមានបរិមាណប្រហាក់ប្រហែលគ្នា ដូចនេះហេតុដែលនាំឱ្យខុសគ្នា អាចបណ្តាលមកពីការផ្លាស់ប្តូរទិដ្ឋភាពរូបវន្តនៅក្នុងតំបន់អាងជលសាស្ត្រ ដូចជាការផ្លាស់ប្តូរគម្របព្រៃឈើជាដើម។ ការសិក្សានេះបានប្រើប្រព័ន្ធ Hydrologic Engineering Centre-Hydrologic Modeling System ដើម្បីបង្កើតចំហាក និងផ្ទៀងផ្ទាត់ទិន្នន័យធារទឹកជាក់ស្តែងខ្ពស់បំផុតផ្សេងៗរបស់អាងជលសាស្ត្រ។ លទ្ធផលនៃការសិក្សានេះស្រដៀងគ្នាទៅនឹងការរកឃើញរបស់ JICA ។ ដូច្នេះ ការសិក្សានេះអាចកំណត់បានថា ការកើនឡើងនៃបរិមាណធារទឹកគឺពាក់ព័ន្ធនឹងការបំប្លែងគម្របព្រៃឈើចំនួន 26% ក្នុងអាងស្តុកទឹកទៅជាដីកសិកម្ម ចាប់តាំងពីដើមទសវត្សរ៍ឆ្នាំ 2000។ ការរកឃើញនេះមានសារៈប្រយោជន៍សម្រាប់ការគ្រប់គ្រងទឹកជំនន់ ក៏ដូចជាមានន័យថា ការគ្រប់គ្រងធារទឹកហូរលើផ្ទៃដីក្នុងតំបន់អាងជលសាស្ត្រ ដែល

ពាក់ព័ន្ធ យ៉ាងជិតស្និតទៅនឹងការកែប្រែគម្របដីព្រៃមកជាដីកសិកម្ម ។ ហានិភ័យនៃទឹកជំនន់ដែលបង្ក ដោយការប្រែប្រួល អាកាសធាតុ ក៏ជាហេតុផលមួយដែលគេគួរយកចិត្ត ទុកដាក់ផងដែរ។ ឯកសារនេះវិភាគពីផលប៉ះពាល់នៃការផ្លាស់ប្តូរការប្រើប្រាស់ដីមកលើបរិមាណធារទឹកហូរ ហើយផ្តល់ការយល់ដឹងដ៏មានតម្លៃ សម្រាប់ការគ្រប់គ្រងទឹកជំនន់ក្នុងបរិបទនៃការប្រែប្រួល អាកាសធាតុនិងការបាត់បង់ព្រៃឈើ។

Abstract

This study analyses the alterations of peak catchment runoff from Prek Thnot watershed using the Soil Conservation Service Curve Number (SCS-CN) methodology. Two major studies using different approaches have previously been conducted in the catchment, albeit producing inconsistent results. The Snowy Mountain Hydro-electric Authority published the first study in 1967 and found that the peak surface flow runoff over a 10-year return period was 710 m^3/s. The second study was conducted by the Japanese International Cooperation Agency (JICA) between 1991 and 2006 and reported a peak catchment discharge of 1,380 m^3/s. To date, there has been no discussion comparing the two studies to determine why the discharge during the later study was double that of the first. As the annual rainfall during the two study periods was similar, it is suggested that this discrepancy may be attributed to physical changes in the watershed, such as changes to forest cover. We deployed the Hydrologic Engineering Centre-Hydrologic Modeling System to simulate the peak runoff of the catchment. Our result was very similar to the JICA finding. Our data suggested that the increase in catchment discharge may be attributed to the conversion of 26% of forest cover in the catchment to agricultural land since the early 2000s. This information is useful for flood management practices, particularly with respect to managing catchment runoff in the context of rapid deforestation and the hydrological impacts of climate change within the watershed. The paper analyzes the impact of land-use changes on catchment runoff and provides valuable insights for flood management practices in the context of climate change and deforestation.

1. Introduction

This study assesses changes to the frequency and intensity of flood hazards in Prek Thnot watershed, Kampong Speu province, Cambodia, through an assessment of land use and land cover (LULC) changes between 1973 and 2014. Specifically, it defines flood intensity within the catchment in terms of a peak catchment runoff within a certain flood return period.

Among the provinces of Cambodia, Kampong Speu is expected to experience significant problems with climate change impacts, such as flash flooding, associated with changing rainfall patterns. For instance, the Ministry of Environment has predicted a 35.0% increase in rainfall volume from a 2000 baseline based on the A2 scenario presented in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Ministry of Environment, 2001). Moreover, a United Nations Development Program (UNDP) study has predicted that the intensity of heavy rainfall events in the wet season, between June and October, will increase by up to 14.0%. While these modeled wet season rainfall projections remain to be seen, citizens in Kampong Speu have reported abnormal weather patterns (Geres-Cambodia, 2009), and it is likely that flood hazards in the province will be exacerbated by the impacts of climate change.

Beyond changing rainfall patterns, a reduction of forest cover in Kampong Speu is expected to increase catchment runoff. For instance, by 2013, forest cover in the Prek Thnot watershed is estimated to have been reduced by half compared to a 1973 baseline, to about 30% of land cover (Open Development Cambodia, n.d). In addition, the Mekong River Commission has ranked Prek Thnot watershed, a sub-basin of the Mekong River, as being at a critical stage due to forest degradation in the upper catchment. Forests are known as natural water storage and buffers for catchment runoff (Calder & Maidment, 1992; Chang, 2006; Ward & Robinson, 2000). Changes to LULC coupled with extreme climate variability are known to have affected rice paddy productivity due to flash floods and droughts in Kampong Speu.

Several modeling methodologies capable of quantifying rainfall-runoff exist, each with different strengths and weaknesses (Daniel et al., 2011). The choice of a runoff model is generally driven by the purpose of a study and data availability (Beven, 2011). A common application of these studies is to develop an understanding of the quantity of catchment runoff associated with dramatic changes in LULC (Costa, Botta, & Cardille, 2003; Matheussen, Kirschbaum, Goodman, O'Donnell, & Lettenmaier, 2000; Tekleab, Mohamed, Uhlenbrook, & Wenninger, 2014).

The impact of changes to peak catchment discharge resulting from changes in LULC has been studied in a range of watersheds of varying scale, from two km^2 to more than 100,000 km^2; land use characteristics (urban, agricultural and forested land); as well as climatic regions. For example, Wehmeyer et al. (2011) identified that minor changes in LULC in a watershed in Iowa resulted in significant changes in peak streamflows associated with heavy rainfall events. Costa et al. (2003) identified that the conversion of 20% of forested land in Southern Amazonia to agricultural use contributed to an increase in peak catchment discharge of about 30.0% compared to a baseline. Siriwardena et al. (2006) found that the conversion of 44% of forested land in central Queensland to grassland and cropland contributed to a 40% increase in catchment runoff. Olang and Fürst (2011) identified that deforestation contributed to increased peak catchment discharge of between 10 and 16% from the Nyando River Basin in Kenya. Negative impacts from LULC changes have also been identified as resulting from increasing urbanisation, where an area changes from low to high residential density; or from parkland to residential land (Pauleit, Ennos, & Golding, 2005).

However, while the experience of LULC change from forested land to agricultural or urban land contributing to increase catchment runoff is common, there are some examples where this is not the case. For instance, when studying the impact of landuse changes from native vegetation to introduced pasture in northern New South Wales, Ring and Fisher (1985) found that catchment runoff decreased. They argued that the establishment of pastured land reduced runoff due to a very low density of native vegetation on the existing land. Wilk et al. (2001) noticed similar results from the conversion of forested to agricultural land in Thailand. While 53% of the forested land in this study was converted to agricultural use, there was no discernible change in peak catchment discharge. This was attributed to scattered regrowth within rice paddies demonstrating a hydrological function similar to the original forest.

In the Prek Thnot watershed in Kampong Speu, catchment discharge has notably increased with the conversion of forested land to agricultural use. However, the causality of the increased discharge is still contested. This paper argues that this increased discharge can be explained by results from separate studies estimating the peak stream discharge over specific flood return periods.

Earlier, there was a study and published by the Snowy Mountain Hydro-electric Authority (SMHA) in 1967. Table 1 presents the results from this study comparing the average flood return period with the peak catchment discharge occurring where the Highway Bridge traverses the Prek Thnot River. The most reliable rainfall and discharge data within this study was collected by the SMHA between 1960 and 1966 and was accurate to a 50% confidence limit (Snowy Mountains Hydro-electric Authority & Cambodia Ministere des Travaux Publics, 1967).

There was another study in the catchment related to the same by the Japanese Internal Cooperation Agency (JICA) between 1991 and 2006. The results for stream discharge and average flood return period from this study are presented in Table 2. The most reliable data from this study is considered to have been collected by researchers

Table 1: The estimated frequency and occurrence of floods in Prek Thnot watershed.

Average return period (Year)	*Estimated annual max. discharge (m3/s)*
5	600
10	710
25	850
50	940

Source: Snowy Mountains Hydro-electric Authority & Cambodia Ministere des Travaux Publics (1967)

Table 2: The estimated frequency and occurrence of floods in the Prek Thnot watershed.

Average return period (Year)	*Probable discharge (m3/s)*
2	690
5	1,130
10	1,380

Source: Japan International Cooperation Agency (2008)

between 1997 and 2004. The study attributes a long-term increase in the ratio of annual catchment discharge to annual rainfall volume, from 0.09 in 1928 to 0.51 in 1999, to deforestation but needs to be confirmed.

Comparing the results from both studies suggests that the level of peak catchment discharge doubled as a result of the mass conversion of forested land to agricultural use. The conclusion from the latter study warns that further forest degradation in the watershed has the potential to significantly increase the level of peak catchment discharge, which would also occur more frequently. Reports from local citizens of Chbar Mon district in Kampong Speu about the occurrence of severe flooding in 1991 and 2000 are consistent with the catchment discharge results estimated by the JICA study of 1,369 and 1,276 m_3/s, respectively Japan International Cooperation Agency (2008).

2. Study Area and Methodology

Fig. 1 is a map of the study area. Kampong Speu province is in southeastern Cambodia and the total catchment area is 6,124 km^2. This study delineated the study site of Prek Thnot watershed to 4,125 km^2 approximately 40% smaller. Similar to other provinces in Cambodia, Kampong Speu has a tropical climate, with a wet season starting in late May, which generally lasts until mid-November. The climate is mostly warm and humid with a mean temperature of 27°C and a minimum of 16°C. December-January are the month with coolest temperature, while April is the hottest with a maximum temperature of 35°C.

The topography of Kampong Speu varies from extensive lowland paddy fields in the east of the province to a mosaic of lowland and upland forested areas in the west. Phnom Aural, the highest mountain in Cambodia is located in the northwest part of the province and

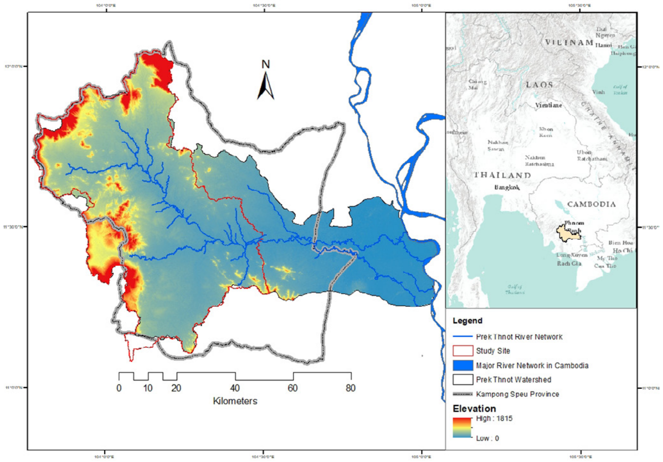

Fig. 1: The Study site showing the administrative boundary and hydrological elements.

has an altitude of 1,813 m. The majority of the Prek Thnot watershed is located within Kampong Speu and it represents the largest and most significant hydrological system in the province.

2.1 Source: Author's watershed delineation

The curve number (CN) method has traditionally been used to quantify changes to catchment runoff associated with LULC change for small, ungauged watersheds (Mishra & Singh, 2003; Ponce & Hawkins, 1996; Sui, 2005). The method, which was developed by the USDA National Resource Conservation Service, was reviewed by Pone and Hawkins (1996), who concluded that the approach had reached maturity. It is now widely used by scholars and practitioners alike to understand the hydrology of watersheds (Ajmal, Waseem, Ahn, & Kim, 2015; Pandey, Panda, & Sudhakar, 2005; Patil, Sarangi, Singh, & Ahmad, 2008; Singh & Frevert, 2010; Xiao, Wang, Fan, Han, & Dai, 2011). For instance, Sanyal et al. (2014) analyzed the effect of LULC changes at the sub-basin level on flood peaks in the catchment using the CN method and confirmed it produced satisfactory results and was easily applicable even in contexts constrained by a lack of data. Other scholars have also demonstrated the practicality of the CN method, particularly when combined with a *water balance assessment* tool, such as the Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS); the Soil and Water Assessment Tool (SWAT); as well as other applications (Daniel et al., 2011).

The CN method is used in combination with the HEC-HMS (Fig. 2) has the capacity to simulate runoff from a small watershed of up to 100,000 km^2 (Daniel et al., 2011; Mishra & Singh, 2004), which has been demonstrated as part of empirical studies in China, Vietnam, and Cambodia. For example, Shi et al. (2007) used this approach to estimate flood discharge under different rainfall scenarios and soil moisture conditions in the Buji river basin in China and concluded that urbanization was leading to higher catchment runoff and imposing a higher flood risk. Ty et al. (2012) used the CN method, with the HEC-HMS to assess different water resources management options in the context of LULC and climate change in the central highlands of Vietnam. Ty et al. study used daily catchment discharge results from the CN method to simulate supply and demand, coupled with the impacts of population growth and different climate change scenarios. However, it did not link LULC changes with changes in catchment discharge. Kawasaki et al. (2010) employed the CN method in conjunction with the HEC-HMS to simulate changes to transboundary catchment discharge from Vietnam to Cambodia in the Srepok River basin as a result of different upstream LULC scenarios in 2025 and 2050. Kawasaki et al. study predicted that these urban and agricultural development scenarios in Vietnam would result in a decrease in catchment discharge to Cambodia associated with increased depression storage in Vietnam and changes to rainfall distribution.

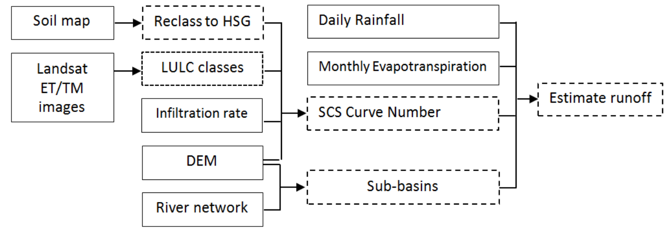

Fig. 2: The modeling framework used to estimate catchment runoff, where HSG refers to the hydrologic soil group DEM refers to the digital elevation model.

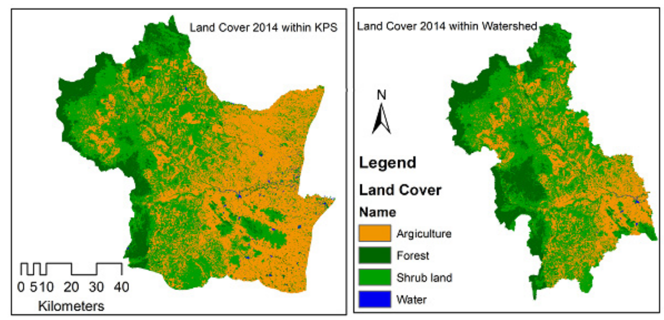

Fig. 3: Land cover classifications for Kampong Speu and Prek Thnot watersheds, respectively (2014).

3. Findings and Results

3.1 LULC change in Prek Thnaot Wather Shed 1973 - 2014

Fig. 3 shows the results of a LULC classification image for the year 2014. The images from left to right show land cover classifications within the provincial and watershed boundaries, respectively. Two maps are presented as forest cover data is generally only available in terms of provincial administrative boundaries, while catchment runoff study data is only available in the context of a watershed. Thus, LULC changes are assessed at the provincial level, while changes to the CN over time are assessed for the watershed.

The map shows that the majority of the forest cover is located in highland areas to the west and northwest, while the majority of agricultural land of the province is in the lowland region to the east, toward the Tonle Sap. The map suggests that the land cover density for forest and shrubland in the upper catchment from roughly the center of the province is relatively high, the accuracy of this data is often questioned.

Similar to other areas in Cambodia, the Prek Thnot watershed has experienced dramatic levels of forest degradation since the 1990s. For instance, the conversion of forested land to other land uses has seen forest cover in the province reduce from about 60% in the early 1960s (National Institute of Statistics, 2008) to about 30% in 2013 (Open Development Cambodia, n.d). This deforestation has been attributed to a range of factors including (i) the expansion of rice paddy production during the Pol Pot regime (Phat, S., & Ueki, 2005); (ii) defoliation and the destruction of forest as strategies during both the Vietnam war and civil war within Cambodia (Le Billon, 2002; Slocomb, 2001; Tully, 2005); (iii) the logging and export of timber to finance political movements (Hong, 1997; Keen, 2000; Le Billon, 2000, 2002; Um, 1994); (iv) 'anarchic' deforestation by elites (Davis, 2005; Le Billon, 1999); (v) the use of forests as natural resources for economic growth (FAO, 2010; McKenney, Chee, Prum, & Evans, 2004); and (vi) economic land concessions (MAFF, 2006; Vriez & Naren, 2012).

An analysis of USGS satellite images shown in Fig. 4 shows that the area of dense forest (DF) in Kampong Speu was reduced very significantly between 1973 and 2013 (Open Development Cambodia, 2014). This data suggest that minimal degradation DF occurred between 1973 and 1989, during a period of civil war. Larger-scale logging of DF areas is shown to have commenced in 1989 when a period of 'anarchic' deforestation began prior to 2000 before timber began to be extracted for export to contribute to the national income. However, the most

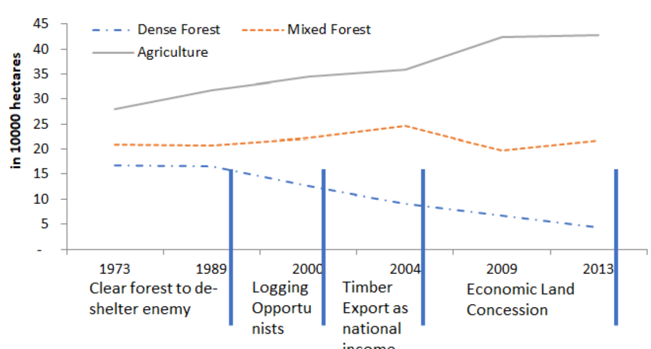

Fig. 4: The decline of dense forest areas in Kampong Speu between 1973 and 2013 (Open Development Cambodia, 2014).

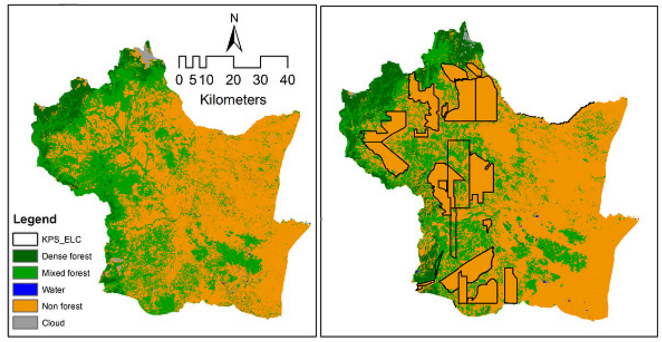

Fig. 5: The differences between dense forest classifications in the ODC study between 2013 and 2014 (ODC, 2014).

Table 3: Land Use and Land cover change in Kampong Speu (2003-2014).

No	*LULC name*	*JICA 2002*	*LULC 2003*	*LULC 2014*
1	Agriculture	26.5	35.0	54.6
2	Forest cover	49.9	49.2	23.1
3	Grasslands	6.5	15.5	16.8
4	Shrublands	16.6		
5	Soils and rocks	0.2	n/a	n/a
6	Urban, built-up area	0.1	n/a	n/a
7	Water	0.3	0.3	4.1
8	Cloud	n/a	n/a	0.5
9	Cloud shadow	n/a	n/a	0.8

significant degradation of dense forests in the study area is shown to have occurred from this point onwards, as compared to the period before 2000, where timber largely extracted to contribute to the national income. The next phase of degradation of DF occurred as economic land concessions (ELCs) were granted during the 2000s. It should be noted that Open Development Cambodia (ODC) updated its forest cover analysis (1973-2013) with new data for 2014 after receiving feedback from the Cambodia Forestry Administration. The LULC data made available in 2014 has significantly less forest cover than the 2013 data. No clarification about the replaced 2013 data is available online. However, Fig. 5 of this paper shows significant differences between the LULC data from the ODC study in 2013 (left) and 2014 (right). It appears that the 2014 map is not purely derived from remotely sensed data, but rather has a land-use map of ELCs superimposed onto it as a non-forested area. A further discrepancy shows that the area of dense forest on the maps increased from 44,161 ha in 2013 to 53,367 ha in 2014. Moreover, there is a reduction of the mixed forest from 217,851 ha in 2013 to 153,067 ha in 2014. These changes are questionable and while the ODC land cover maps from 2013 and 2014 are contested, other LULC maps produced between 1973 and 2009 are consistent with other sources, as shown in Table 3.

The LULC classifications available for Kampong Speu show that the area of agricultural land in the province almost doubled in size between 2003 and 2014, while the area of forested land decreased by more than half (**Table 3**). The table also compares a land cover map from JICA produced in 2002 with the thematic map produced in 2003. As the land cover classifications in a thematic map produced in 2003 are very similar to the JICA classifications, suggesting a forest cover of approximately 49% the 2003 thematic map is appropriate for conducting a hydrological study.

As mentioned previously, forests and shrubland in Kampong Speu are spatially distributed to the northwest of the province, while the low-lying area in the southeast of the province is primarily used for agriculture. Between 2003 and 2014, a large proportion of the shrubland and abandoned grasslands had been converted to agricultural use. At the same time, significant areas of forest had been cleared to become classified as shrubland or agricultural land in the north-west. These changes have predominantly occurred along with the river network, indicating that farmers have cultivated land near the Prek Thnot River to benefit from easy access to water. An increase in the area of water bodies in the province can also be observed, concentrated in two particular locations. The first is in the central area of the province to the east within a few kilometers of the main channel of the river. This is believed to be associated with an increase in the cultivation of dry-season rice in this region, where water is stored in paddy fields. It has been wrongly classified as a new water body and should be defined as water stored in paddy fields. The second location is in the north of the province, where new irrigation infrastructure has been developed.

3.2 Sub-basin curve number change

When applying the SCS-CN methodology, the curve number tends to change with LULC data. The data available from ODC between 1973 and 2009 is considered to be valid as it is consistent with information available from other sources. Thus, this study uses the LULC data from ODC for the period between 1989 and 2009; and a land cover map for both 2003 and 2014 to analyse the change in the CN. It should be noted that a CN is assigned based on an iterative process conducted on a 30x30 meter grid, which is then averaged across the sub-basin. Then, a hydrological analysis is conducted for each sub-basin within the Prek Thnot watershed. Table 4

Table 4: **Parameters used to simulate daily rainfall and peak catchment discharge in the HEC-HMS model.**

Sub-basin	*W370*	*W390*	*W490*	*W530*	*W560*	*W600*	*W660*	*W670*
Area (km^2)	333.56	456.73	733.71	286.84	570.53	405.33	687.14	651.71
Initial Abstraction								
1997	13.76	13.22	12.70	11.72	6.54	4.23	10.39	8.47
2001	8.83	12.20	7.46	11.26	6.54	2.98	10.82	9.58
2002	8.83	12.20	7.46	11.26	6.54	2.98	10.82	9.58
2003	26.99	23.59	25.78	23.59	21.62	16.16	22.58	14.32
2004	52.87	52.87	50.80	46.89	26.17	7.59	43.27	32.48
Curve number								
1989	48	49	50	52	66	75	55	60
2000	59	51	63	53	66	81	54	57
2003	32	35	33	35	37	44	36	47
2004	49	49	50	52	66	87	54	61
Impervious (%)	0	0	0	0	0	0	0	0
Standard Lag (hr)	15.84	22.59	37.26	34.73	38.82	48.14	64.27	78.75
Peaking Coeff.	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial Discharge (m^3/s)								
1997	6.29	6.29	6.29	6.29	6.29	6.29	6.29	6.29
2001	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80
2002	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26
2003	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78
2004	8.36	8.36	8.36	8.36	8.36	8.36	8.36	8.36
Recess Constant	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

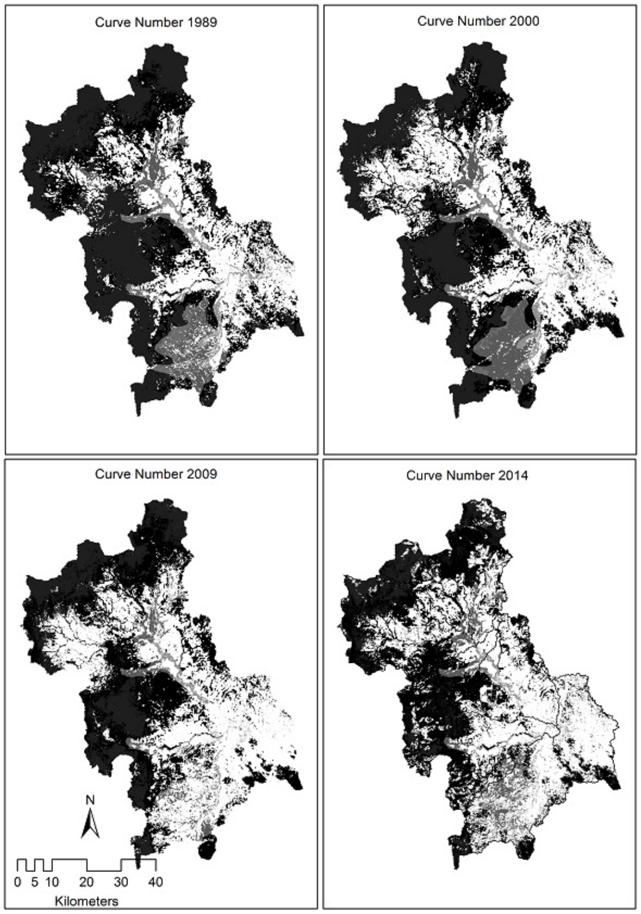

Fig. 6: CN calculated in Prek Thnot watershed (1989-2013).

shows the parameters used to simulate catchment runoff across each of the eight sub-basins.

Fig. 6 demonstrates how changes to LULC data (ODC, 2013) affect the resultant CN over time, where a darker shade indicates a lower catchment runoff potential. It should be noted that the analysis of the CN data was limited to an assessment of this LULC data. To reduce the potential error resulting from pixels missed as a result of the land area classified as either clouds or cloud shadows, the relevant pixels were replaced with pixels from a later year using the raster calculator in ArcGIS.

As the analysis of catchment, discharge is conducted from 1995 but the CN in calculated in Fig. 6 is conducted on only 4 occasions (1989, 2000, 2009 & 2014), the analysis is based on the result for the CN preceding the analysis of runoff. For example, the catchment discharge calculated for 1996, will use the CN determined from the LULC data from 1989. This is based on an assumption that LULC data from 1989 does not vary significantly in 1996. Following on from this, the CN from 1989 is also used to simulate catchment discharge in 1997 and the CN from 2000 is used to simulate catchment discharge for 2001 and 2002. To simulate the catchment discharge for 2003 and 2004, the land cover maps used for this study are used to determine the CN. All the parameters used to conduct the simulation in the HEC-HMS are defined in Table 4.

Using the CN from 1989 as a baseline, an increase is observed for the data collected in 2000, 2009 and 2014, indicated by the red boxes marked A, B, and C; respectively. Significant LULC change between 1989

Table 5: Peak catchment discharge results at gauging stations along the Prek Thnot River.

No	*Date*	*Amount (m3/s)*	*Total annual rainfall*	*Discharge data Source*	*Gauging station*
1	6 Nov 1904	570	n/a	SMHA	Anlong Touk
2	4-Aug-1922	730	1,765.1	SMHA	Anlong Touk
3	12 Oct 1924	683	1,244.6	SMHA	Anlong Touk
4	26 Jul 1962	484	1,493.0	SMHA	Anlong Touk
5	26 Sept 1964	414	1,273.6	SMHA	Anlong Touk
6	1991	1,369	1,219.5	JICA	n/a
7	1996	1,380	1,338.6	JICA	n/a
8	4-Aug-1997	826.5	952.5	JICA	Peam Khley
9	5-Oct-1998	506.9	1,333.5	JICA	Peam Khley
10	1-Nov-1999	797.9	1,485.8	JICA	Peam Khley
11	16-Oct-2000	1,276.1	1,444.6	JICA	Peam Khley
12	11-Oct-2001	893.3	1,512.7	JICA	Peam Khley
13	22-Aug-2002	131.9	1,043.5	JICA	Peam Khley
15	26-Jul-2003	926.2	1,205.0	JICA	Peam Khley
16	7-Oct-2004	214.0	925.6	JICA	Peam Khley
17	2005	220	1,084.0	JICA	n/a
18	2006	1,237	1,080.2	JICA	n/a
19	2007	547	1,304.0	JICA	n/a

Sources: (Japan International Cooperation Agency, 2008; Snowy Mountains Hydro-electric Authority & Cambodia. Ministere des travaux publics, 1967) and 2000 occurred in Box A, which is located within the headwaters of the catchment at a high elevation. This area is known as the Ta Sal sub-basin. Between 2000 and 2009, significant LULC change occurred in Box B as well as in some parts of Box C. Both of these areas are located within the Tang Haong sub-basin. It appears that LULC changes expanded from Box B to Box C, over the period between 2000 and 2014. The main changes that occurred during this period were the conversion of forested land to agricultural land. LULC changes occurred primarily in the northwest of the province, where Landsat images from 2014 show a significant expansion in the area of land converted to agricultural use.

3.3 Estimated catchment runoff

Table 5 is a compilation of peak discharge results from the Prek Thnot catchment from various sources. The peak discharge generally occurs between July and November, however in some years, the date was not recorded precisely. Most of the peak discharge events occurred in October when the peak discharge was higher compared to other months. It seems that the peak discharge in the first period (1904–1964) by SMHA was relatively low compared to the second period (1991-2007) by JICA. At the same time, the total rainfall in the first period seemed to be more than the second period. The peak discharge in 1997 was the most interesting phenomenon, for the total rainfall was very less (at 952.5 millimeters) while the peak discharge in August was 826.5 m^3/s which was among the highest rate among the observed data.

This study compared the observed secondary data for peak catchment discharge shown in Table 5, with a simulated result generated using the CN method and the HEC-HMS software. Simulated peak discharges were estimated using the model for 1997, 2001, 2002, 2003 and 2004, corresponding with periods where daily rainfall records were available.

Table 6 identifies the ideal 14-day simulation periods used as inputs to the model based on the date of peak discharge occurring on the 9th day. These parameters were selected on the basis of: (i) daily rainfall records being available for the period of the simulation; (ii) the watershed having an area of about 4,200 km^2 and requiring 4 or 5 days for runoff from the watershed to reach outlet of the catchment; and (ii) allowing sufficient time for maximum soil moisture retention to be reached to enable a stable CN to be used for the HEC-HMS model.

Fig. 7 shows the correlation between the results of the simulation and observed rainfall figures. The model is shown to perform well, with an observed discharge very similar to the simulation (E = 0.91). Despite this result, there were some discrepancies related to the discharge and the amount of time required to reach a peak discharge. In general, the model reached a peak discharge, one day before this was observed and estimated a much higher discharge than what was observed. This resulted in fewer peaks being demonstrated in the simulated hydrograph than what was observed. It should be noted that the simulation was run based on a one-day rainfall interval, which was the maximum period allowed by the software. This was selected based on the observed catchment discharge and rainfall data also being observed on this basis.

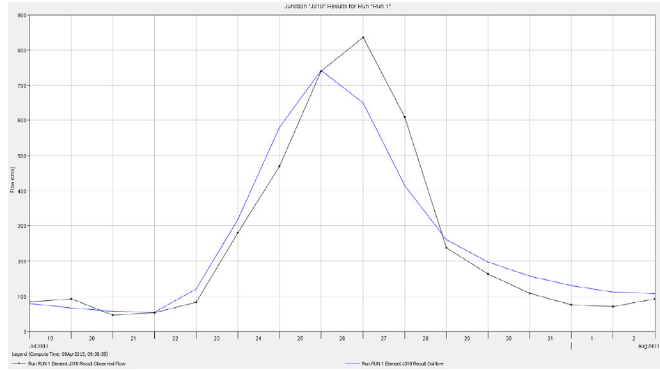

Fig. 7: Observed and simulated discharge for the Prek Thnot River (July 2003).

Table 6: The simulation periods used for the analysis of daily rainfall and peak catchment discharge.

No	1997	2001	2002	2003	2004
1	28-Jul	4-Oct	30-Sep	19-Jul	30-Sep
2	29-Jul	5-Oct	1-Oct	20-Jul	1-Oct
3	30-Jul	6-Oct	2-Oct	21-Jul	2-Oct
4	31-Jul	7-Oct	3-Oct	22-Jul	3-Oct
5	1-Aug	8-Oct	4-Oct	23-Jul	4-Oct
6	2-Aug	9-Oct	5-Oct	24-Jul	5-Oct
7	3-Aug	10-Oct	6-Oct	25-Jul	6-Oct
8	4-Aug	11-Oct	7-Oct	26-Jul	7-Oct
9	5-Aug	12-Oct	8-Oct	27-Jul	8-Oct
10	6-Aug	13-Oct	9-Oct	28-Jul	9-Oct
11	7-Aug	14-Oct	10-Oct	29-Jul	10-Oct
12	8-Aug	15-Oct	11-Oct	30-Jul	11-Oct
13	9-Aug	16-Oct	12-Oct	31-Jul	12-Oct
14	10-Aug	17-Oct	13-Oct	1-Aug	13-Oct

Table 7: Timeframe for daily rainfall and peak discharge analysis.

Year	Observed	Simulated
1997	713.5	620.9
2001	800	1065.5
2002	115.6	322.9
2003	835.7	741.8
2004	165.8	260.4

Table 7 below the shows observed and simulated results for peak discharge for 1997, 2001, 2002, 2003, and 2004. Generally, there is a good correlation between each result observed. The model appears to predict higher flows, such as those that occurred in 1997, 2001

Table 8: Simulated peak catchment discharge from the Prek Thnot watershed (1995-2013).

Year	*Simulated discharge*	*Rainfall at Chbar Mon*
1995	1,142.2	1,058.2
1996	1,338.9	1,338.6
1997	614.7	952.5
1998	679.7	1,335.5
1999	829.6	1,485.8
2000	1,093.2	1,444.6
2001	800.0	1,512.7
2002	1,15.6	1,043.5
2003	835.7	1,205.0
2004	165.8	925.6
2005	810.5	1084
2006	512.6	1,080.2
2007	639.4	1,298.9
2008	542.5	1,348.8
2009	548.4	1,168.2
2010	1,254.1	1,240.5
2011	998.8	1,200.2
2012	399.0	1,188.3
2013	580.7	1,350.7

Table 9: The estimated frequency and occurrence of floods in the Prek Thnot watershed.

Average return period (Year)	*Probable discharge (m3/s) by JICA*	*Probable discharge (m3/s)*
2	690	880
5	1,130	1,132
10	1,380	1,283

better than results for lower flows, with a Nash-Sutcliffe efficiency of 0.85 and 0.91 were calculated respectively. This is consistent with the intention of the SCS-CN method to study flood behavior associated with high rainfall and catchment discharge.

Upon having established a reliable simulated result, the peak catchment discharge was estimated on the basis of a CN determined for 2014. The parameters, such as initial discharge was again then used to simulate peak discharge results. To differentiate these results for catchment discharge from the original simulations recorded in Table 7, they were labeled with CN 2014. In general, the volume of catchment runoff increased but did not increase much for higher runoff volumes. This suggests that once the soil becomes saturated, the interception of rainfall by the catchment reaches full capacity and the watershed begins to behave as if it were impervious.

3.4 Assessing the current intensity and frequency of flood hazards

Fig. 8 shows a regression curve between the observed peak discharge and simulated peak discharge for CN 2014 represented by the equation displayed on the graph. This

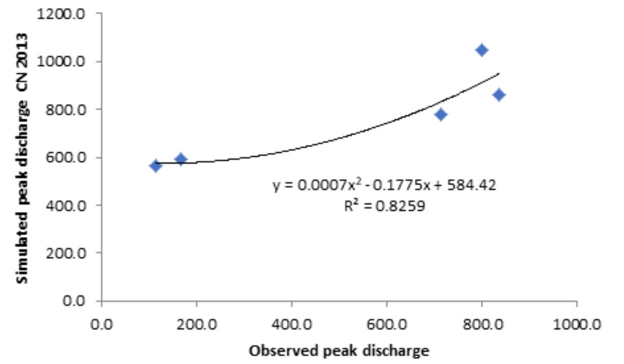

Fig. 8: Observed and simulated catchment discharge from the Prek Thnot watershed (2003).

equation was used to adjust the simulated discharge results for the years 1995 to 2013 (Table 8) in years where daily discharge data was not available.

Based on the results of the HEC-HMS simulation, Table 9 shows a comparison between the flood return period determined by JICA and the results from this study. It appears that the peak discharge for high flow discharges are very similar, while simulated catchment runoff tends to increase during years with low rainfall. This suggests that once the soil is saturated, results for peak discharge determined for each study become very similar, such as those recorded for the 10-year return period.

These results were confirmed by key informant interviews, in which it was suggested that the volume of catchment discharge had become stronger over time with increased sediment. The informants attributed this outcome with mass deforestation in the upper catchment. Observations made along the course of the river of bank erosion also suggest that the rapid runoff of large discharge volumes was affecting the hydrology of Prek Thnot.

4. Discussion

The study finds that a 26% reduction in forest cover in Kampong Speu province and subsequent conversion to agricultural use has resulted in a peak discharge of about 30%. This finding of forest cover change in the Kampong Speu/ Prek Thnaot watershed shared similar land cover change in Cambodia (Senevirathne, Mony, Samarakoon, & Hazarika, 2010) which contributes to the increased peak of catchment discharge is related to increased runoff. The risks associated with this are apparent in the assessment of the flood return period, which suggests that there will be a higher runoff volume in the catchment compared to previously.

These findings suggest that the intensity of flash floods will increase with a faster return period. While these predictions are yet to manifest themselves, they are supported by other studies. For example, JICA demonstrated that increased peak discharges have occurred over the period between 1991 and 2007 (Japan

International Cooperation Agency, 2008) compared to a previous study conducted by the SMHA (Snowy Mountains Hydro-electric Authority & Cambodia Ministere des Travaux Publics, 1967). In the future, the 30% increase in peak discharge, driven by changing land cover, is expected to result in an increased intensity of flash floods, which when combined with the impacts of climate change effects is expected to result in unprecedented disasters. Flash flood events has been oberved more frequencies in Prek Thnoat.

While higher total rainfall per annum does not automatically translate into flash flooding within the Prek Thnot watershed, intense rainfall over a period of one week does. For example, significant flood damage occurred in 2006 where an annual rainfall of about 1000 mm was recorded, while in 2011, no flood damage was recorded for an annual rainfall of 1200 mm. It should be noted that as most of the flood damage by flash flooding is caused by overland flow, increased catchment runoff from deforestation is likely to result in greater damage to paddy rice production on the floodplain.

Other literature has also demonstrated that changes to LULC have altered peak catchment discharge runoff (Sumarauw & Ohgushi, 2012; Wehmeyer et al., 2011). Thus, further research is required to collect catchment discharge data and observe how floods caused by catchment runoff impact rice paddy production. In addition, the findings of this study were constrained by data availability, particularly with respect to observed discharge rates and daily rainfall data. This limits how effective the SCS-CN curve number method for ungauged watersheds in contexts such as Prek Thnot. The future development of runoff models should consider the Cambodian context, where there is a range of unique features and characteristics specific to the watershed.

5. Conclusion

This paper analyses the historical peak catchment discharge and its association with LULC change within the Prek Thnot watershed. Various studies have shown that this level of peak discharge increases over time, particularly during active periods of rapid land-use conversion. Historically, changes to the peak catchment discharge of the Prek Thnot watershed have been recorded systematically over two periods, through hydrological studies conducted by the SMHA (1902-1966) and the JICA (1991-2007). More recently changes to LULC were classified by ODC based on satellite images recorded between 1973 and 2014, which show that approximately 26% of all forested land was converted to shrubland or agricultural use during this period.

This study also used CN methods to show that peak discharge in the catchment will increase by approximately 30% as a result, with the intensity of flash flooding also increasing. These results for peak catchment discharge were found to be consistent with the JICA study, as well as other hydrological literature. As the peak catchment discharge has increased, flood frequency and intensity flood frequencies and intensity have also increased. However, to date, this is yet to be coupled with the impacts of climate change. This information may be useful for informing flood management practices, particularly in regard to how catchment runoff in the context of climate change and dramatic forest degradation within the watershed may be addressed. The findings of the paper may inform related authorities or agents who manage floods or drought in general and in Cambodia in particular.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported. All authors have read and approved the final, published version of the manuscript.

Credit authorship contribution statement

Chhinh Nyda: Conceptualization, data interpretation, visualization, drafting, reviewing, and editing. Rath Sethik: Data interpretation, visualization, reviewing, and editing. Choeun Kimseng: Data interpretation, visualization, reviewing, and editing. All authors have read and agreed to the published version of the manuscript.

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