Quantification Prediction Soil Losses in Nakhon Ratchasima, Thailand

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Abstract

Soil loss, accelerated by human activity, has become one of the world's most serious environmental problems because it poses significant threat to natural resources and the environment. This research focuses on soil loss in the future for sustainable land use planning for 9 watersheds over 20 years in Nakhon Ratchasima, Thailand. The integrated CA-Markov with GIS was applied to forecast 9 types of land use changes to analyze for soil conservation factors as of International Land Loss Equation (USLE). The land use change maps in 2019, 2023, 2027, 2031, and 2035 had been projected for land use predictions from 2011 and 2015 databases. The validation for the correctness of the production land use change map has 91.46% accuracy. The soil loss analysis of targeted study targets were divided into soil loss for the 9 watersheds and covers the overall provinces to determine the proportion of sediment generated in each watershed encountered the risk. The simulation results showed that the soil loss for the entire province may reach the highest soil loss at 329,271 $T \bullet km^{-2} \bullet y^{-1}$ with the mean at 2,929.06 $T \bullet km^{-2} \bullet y^{-1}$. The amount of soil loss in 2035 will be 551.26×10^6 $T \bullet y^{-1}$. In terms of soil loss of all 9 water watersheds, LTK was found the highest soil loss with 238,606 $T \bullet km^{-2} \bullet y^{-1}$. The average soil loss is estimated at 135.33×10^6 $T \bullet y^{-1}$, accounting for 25% of the total area. In comparison among the watershed areas, the amount of soil loss in LPP with highest soil loss rate per area at 51,100.51 ton per area per year. The future land use maps can be used to assess soil loss and can serve as an early warning system. The determination of policies to prevent future environmental problems is critical to controlling improper changes or adversely affecting the local environment.

Keywords: Land use change, Soil loss method, USLE

Introduction

Soil loss, accelerated by human activity, has become one of the world's most serious environmental problems because it poses significant threat to agriculture, natural resources, and the environment (Parveen & Kumar, 2012). Topography, climate, economic cropping, and tillage contribute to the good transfer of sediment from rain leaching into the river watershed, it is also the principal agent for introducing pollutants into water bodies and watersheds, where small land-type changes can cause soil structural and hydrological changes of the watershed. It produces a million tons of sludge in worldwide every year with the global average rate of soil erosion between 12 - 15 $T \bullet ha^{-1} \bullet y^{-1}$ (Biggelaar, Lal, Wiebe, & Breneman, 2003). It means the soil surface is lost approximately 0.90 - 0.95 mm. In some parts of Thailand, there is soil erosion up to 172,800 km^2. It was concluded that in the lowland and/or less than 35% slope: 66 % the whole area are eroded between 0.00 - 312.50 $T \bullet ha^{-1} \bullet y^{-1}$ of sediment (LDD, 2000).

Many mathematical models have been developed to estimate soil erosion in different spatial areas (Christos, Panos, & Ioannis, 2014). The soil loss model using The Universal Soil Loss Equation (USLE) is widely used in the study of soil erosion due to its ease of use, despite some limitations of requirements for the input data (Parveen & Kumar, 2012). Efforts are being made to study and solve the problem of soil loss in many countries by applying a universal soil loss model to calculate soil loss in each area. Efforts are being made to study and solve the problem of soil loss in many countries by applying a universal soil loss model to calculate soil loss in each area. Thailand also attempts to study soil loss in several areas such as Mae Chan River Watershed, Chiang Rai Province, Kwaew Noi Watershed in Phitsanulok Province, Upper Ping River Watershed in Northern Thailand, Nam Chun Subwatershed in Phetchabun Province, Lam Takhong Watershed and Lam Phra Ploeng River Watershed in Nakhon Ratchasima Province (Rapeepong, 2014; Tharapong, 2010; Pisit, 2011; Pavit, 2007; Teerawate, 2014; Massanit, 2015). The original purpose of the USLE was to calculate soil erosion on slope farmland in the Midwestern United States (Gitas, Douros, Minakou, Silleos, & Karydas, 2009). The USLE is applicable for long-term forecast of average annual soil loss rates by considering 6 factors: rainfall, soil type, topography, cultivation, and management systems. However, when considering the nature of soil loss in each area, the factor that has the greatest control or prevention of soil loss is land use factor, which is a factor in the cultivation and management system (C Factor and P Factor) in the USLE equation. Several previous studies applied land use change models with soil loss models. CA-Markov model was used to predict the land use change for its popularity and high accuracy (Courage, Masamu, & Bongo, 2009). The CA-Markov model is a combination of the cellular automata [CA] model and Markov chain model that is used to determine the probability of land use change. Both of land use change and soil loss models are simplified in Geographic Information Systems (GIS) to simultaneously identify spatial and temporal data. It enables planners and policy makers to easily understand information and deploy them to effectively solve the soil erosion management problems.

Loosed soil is a pollutant that flows into water bodies or watersheds, causing watershed pollution. The Lam Takhong river is the third most degraded in Thailand (Pollution Control Department, 2019), indicating that the problem has to be addressed. Many researchers are trying to study the patterns of land use change and soil loss in the watershed at Nakhon Ratchasima Province. However, Nakhon Ratchasima has 9 main watersheds, but only a few studies have been studies for the soil loss in this area. Therefore, the objectives of this study are 1) evaluate of soil loss in NMA (2011-2035), 2) evaluate the tendency of soil loss into 9 main river watersheds from 2011-2035, and 3) to compare the proportions and relationships between the soil loss of the 9 watersheds (2011-2035) by applying digital land use data from Department of Land Development, Thailand with GIS technology. Land use change was predicted by CA-Markov model from IDRISI program and analysed with the Universal soil loss equation (USLE) of Nakhon Ratchasima, Thailand.

Methods and Materials

1. Study area

The study area is Nakhon Ratchasima Province (NMA), Thailand (latitudes between 15° 45′34.56 to 15° 45′45.27″ N and longitudes between 101° 10′48.04 to 101° 9′41.04). NMA is Thailand's largest province by area and ranked second by population. The province covers an area of 20,726.87 sq.km with a total population of 2,645,927 people, representing 3.98 percent of the total population of Thailand (The National Statistical Office of Thailand, 2019).

Nakhon Ratchasima is located in the northeastern region which is on Khorat plateau at an altitude of 90-1,338 MSL (Figure 1). The province is on a plateau shaped by valleys along with the Dong Paya Yen mountain ranges on the southwest. The elevation gradually decreases from the south (1,338 MSL) to the north (90 MSL). The study area covers many water streams and watersheds, especially the Lam Takhong River watershed. All the streams origins from the Dong Paya Yen Mountain ranges and flow into the Mekong River. The high mountain ranges area on the south are covered by the forest. The forest is strictly reserved and is in UNESCO World Heritage List for its biodiversity. In this area, the average 30-year annual rainfall is 1,034.7 mm with 108.2 rain-day, in which the highest rainfall is in September (226.6 mm) and the lowest is in December (3.0 mm) (Meteorological Department, 2019).

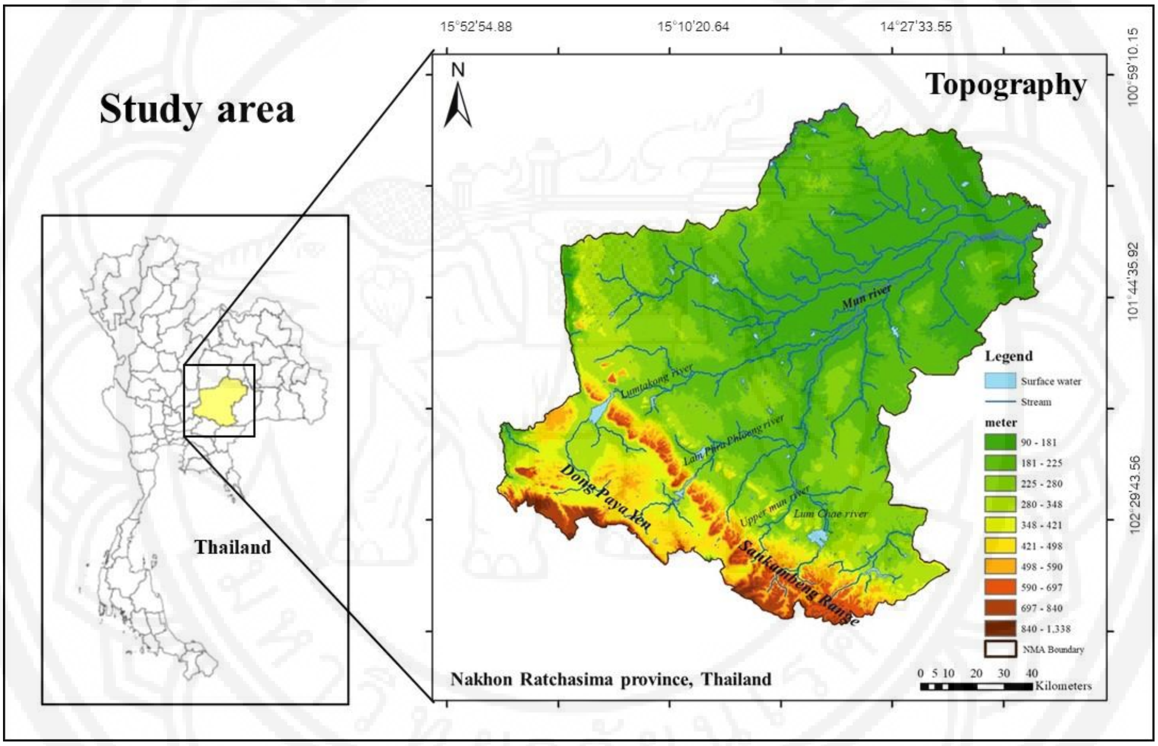


Figure 1 Study area

2. Methods

A study for the tendency of soil loss was divided into 3 main parts: 1) Hydrological model analysis, 2) Soil loss processes, and 3) Analysis of soil loss in the watershed are as follows.

1) Hydrological model analysis; The digital elevation model (DEM) data obtained from the United States Geological Survey (USGS) with resolution of 30 x 30 m. It was analysed to determine the direction of water flow. Flow Direction data will be analysed for flow accumulation and stream order to simulate the flow accumulation, river hierarchy, and the direction of flow from upstream to downstream. The results are 4 stream pattern models that were compared with the watershed received from the Department of Water Resources, Thailand to find the smallest error and use that watershed for further analysis.

2) Soil loss processes; to assess soil loss, used the USLE equation for analysis in GIS with 6 factors that are 1) R Factor; uses 16 stations of 30-year rainfall average data obtained from the Meteorological Department, Thailand. 2) K Factor; uses digital soil data from the Land Development Department (LDD), Thailand. 3) L and S Factor used; DEM from the USGS for analysis, and 4) C and P Factor used; the values obtained from studies and experiments by the LDD, Thailand, to replace each type of land use. Then, predict future land use patterns in the next 20 years (2019, 2023, 2027, 2031, and 2035). Finally, 6 factors in USLE with land use change (LUC) 2011 to 2035 were analysed to estimate soil loss in each watershed.

3) Soil loss was assessed in 9 watersheds: Lam Sae (LC), Upper Part of Lam Nam Mun (UPM1), Lam Phraphloeng (LPP), Lum Takhong (LTK), Lam Choengkrai (LCK), Lam Plaimat (LPM), Lam Chakkarat (LCK), Lam Sa Thaet (LST), Second Part of Lam Nam Mun (UPM2) obtained from Hydrological model analysis in 6 factors according to USLE. Finally, the study obtained a spatial map and the amount of soil loss in all 9 river watersheds of NMA from 2011-2035.

3. Modeling LULC change

The secondary data source is digital base maps from the Land Development Department (LDD), Thailand. The digital base map comprises administrative boundaries, road, waterbody, and land use. The land use data in the years 2007, 2011, and 2015 were used in this study. Before data processing, land use was reclassified into 9 categories; urban and built-up land (U), paddy field (R), corn (M), sugarcane (S), cassava (C), other agriculture (A), forest land (F), water body (W), and miscellaneous land (O). The processing procedure (Figure 2) is as follows: (1) the vector land use data of the three periods with 4 years interval were separately converted into raster data (grid units of 30m x30 m) using the spatial analysis function by ArcGIS10.5. (2) IDRISI Selva, modules, Markov and CA-Markov were used for modelling and simulating land use in the year 2019 by using 2007 and 2011 land use data as the base maps. Data in the year 2015 was used for validation with over 90% accuracy (based on overall accuracy in error matrix). (3) The prediction of LU in 2019, was used to project land use patterns in 2023. (4) The further 4 years interval projection for 20 years period (2023, 2027, 2031, and 2035) was repeatedly simulated. (5) Land use change trend and spatial distribution were analysed and explained with CA-Markov. Future land use patterns will be important information for assessing soil loss in the study area.

4. Hydrological model analysis

The analysis of Watershed is based on a 30-meter DEM, resolution of 30 meters x 30 meters to be used for analysis with ArcGIS 10 functions, can be described as follows.

- **Fill** is the command to fill the areas that are holes or lower than the general area, if any area is higher than the general area, it will reduce to nearby that area to adjust the error of the DEM value and to ensure a continuous flow of water.

- **Flow direction analysis** is the use of data that has been passed by DEM fill to analyse the flow direction of water from the slope of the area.

- **Flow accumulation** is the analysis of the cumulative flow value of every cell to a lower slope cell that is the exit point of the stream to determine the watershed area.

- **Stream Order analysis** is the hierarchy of stream lines from upstream to downstream.

- **Stream to Feature** is the transformation of raster stream data into vector data by selecting the resolution of the stream which resolution depends on the condition of low altitude and the terrain of each area

- **Watershed area**; to create a watershed must have a pour point or outlet, that is where water will flow out of the area, this is usually the lowest area and on the edge of the watershed area. It also must have flow direction inside input data, where forms of water receiving area (Watershed) that depends on the resolution of the pour point setting.

To verify the accuracy of the watershed boundary, the model was compared with the NMA's watershed boundary map prepared by the Office of the National Water Resources, Thailand (ONWR).

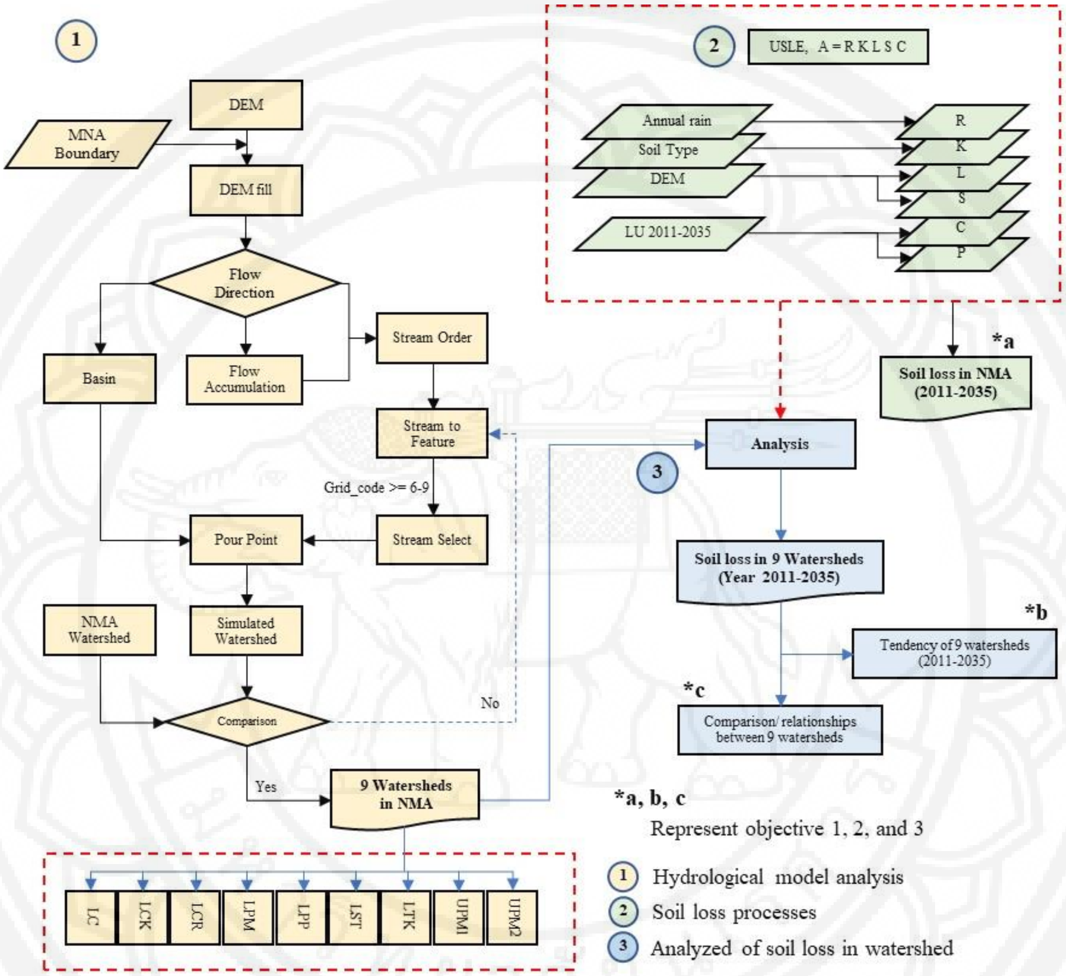


Figure 2 Methodological framework

5. Soil loss processes

The Soil Loss Assessment, proposed by Wischmeier & Smith in 1965 and revised in 1978, is referred to as the Universal Soil Loss Equation (USLE) as a tool used in soil conservation planning, water, forests, and the other in many areas around the world. The Universal Soil Loss Equation is explained as follows.

$$A = R \times K \times LS \times C \times P \quad \text{........ (1)}$$

Where;

A = Annual soil loss per unit area ($T \cdot ha^{-1} \cdot y^{-1}$);

R = Rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot y^{-1}$);

K = Soil erodibility factor ($T \cdot hr \cdot MJ^{-1} \cdot mm^{-1}$);

LS = Slope and length factor (dimensionless);

C = Cover-management factor (dimensionless);

P = Conservation practice factor (dimensionless).

Rainfall erosivity factor (R); It's a complex process and involves long-term gathering of rainfall data. This research uses 19 stations of average 30-year rainfall data around the study area from the Thai Meteorological Department. Prem, So, Chaiwat, and Luminda (2019) proposed the use of the equations recommended by the Land Development Department. Explain it as follows.

$$R = 0.4669V - 12.141559 \qquad \text{........ (2)}$$

Where, R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot y^{-1}$) and V is the annual rainfall (mm).

Soil erodibility factor (K); depends on soil properties, soil physical properties, which an important role in soil conservation strategy (Shabani, Kumar, & Esmaeili, 2014). Soil erosion durability according to the soil texture and soil series in Thailand according to the Nomograph diagram of Wischmeier in 1971 is between 0.00 - 0.56 $T \cdot hr \cdot MJ^{-1} \cdot mm^{-1}$.

Topographic factor (LS); It is the slope factor of the slope length, consisting of L is the slope length and S is the slope, which affects soil loss and sediment displacement. Factor analysis was applied to the Digital Elevation Model (DEM) obtained from the USGS (USGS, 2019). There is a resolution of 30 x 30 m together with the following equations.

$$\square = \left(\frac{\square}{22.12}\right) \times \left(\frac{\left(\frac{\frac{\sin \square}{0.0896}}{(3 \sin \square \times 0.8 + 0.56)} \right)}{1 + \frac{\left(\frac{\sin \square}{0.0896}\right)}{(3 \sin \square \times 0.8 + 0.56)}} \right)$$

S factor = $10.8 \sin \theta + 0.03$ for slope gradients less than 9%

S factor = $16.8 \sin \theta + 0.5$ for slope gradients greater than 9%

Cropping management factor (C); is the second most important factor governing soil loss risk (Knijff, Jones, & Montanarella, 2000) and it reflects the impact of cropping and management on soil erosion rates (Patil & Sharma, 2013). Many researchers calculate the C factor with different equations. LDD has experimented with the determination of plant management factors from natural planting plots in conjunction with local plants in Thailand as of plant types and land use groups. The experiment has also been applied to overseas research to determine the optimal value and determines the plant management factor in the range of 0.00-1.00 (Land Development Department, 2000).

Support practice index (P); is defined as the effect of land use or the soil loss ratio corresponding to the loss of agricultural area on the slope. Wischmeier and Smith (1978) has suggested that P is somewhat dependent on the slope accordingly each area, while others use farming practices to calculate the P value (Stone & Hilborn, 2012), the factor P value ranges from 0.00-1.00, if the land is conserved, the P factor is close to 0.00, if there is no control method, the P value should be 1.0, which is the most uncertain (Morgan & Nearing, 2011). The LDD has experimented with the determination of plant management factors utilizing natural cultivation in conjunction with local plants in Thailand. Plants and land use groups that were tested on the same plot were used for determining factor C.

Results

1. Land use change

Land use change simulation is a process used for estimating soil loss. This was done by the CA-Markov model, using 2011 and 2015 land use data for land use simulations in 2019, 2023, 2027, 2031, and 2035. The simulated result data of land use change during each year is shown in **Table 1** and **Figure 3**. After analysing the changes, it was found that urban land and Urban and cassava land were increased, Corn, sugar cane, other agriculture were decreased, while paddy fields, forest areas, water areas, and miscellaneous land were a few changes in the area. The simulation results show the amount of spatial change over the year, which is important in the analysis of soil loss patterns. Annual land change patterns are shown in Figure 3. However, compared to the real area in 2015, and the validation of the 2015 land use area model obtained from the Markov chain simulation in 2007 and 2011, the accuracy percentage obtained by the model was 91.46% and 0.016% error of the total area.

2. Hydrological model analysis

To define the watershed area, DEM data to determine the flow direction and flow cumulative to analyse the order of the streams (Stream Order) was used. The simulation showed that the stream order of the study area was No.1-11, which from the consideration of the stream resolution that is stream order are No.6-9 and compared with the watershed data obtained from the Department of Water Resources. The results of the stream order were selected No. 8, which most suitable value to calculate the watershed area. The results of the analysis showed that NMA's watershed area was divided into 9 river watersheds, namely Lam Sae (LC), Upper Part of Lam Nam Mun (UPM1), Lam Phraphloeng (LPP), Lum Takhong (LTK), Lam. Choengkrai (LCK), Lam Plaimat (LPM), Lam Chakkarat (LCK), Lam Sa Thaet (LST), and Second Part of Lam Nam Mun (UPM2), where this simulation is based on the watershed boundary determined by the Department of Water Resources, Thailand. The spatial map of the watershed area is shown in **Figure 4**. The simulation model found that LTK is the largest watershed area with 3,287.27 km^2, and LCK, LST, and UPM1 with an approximate watershed area with are 2,722.24, 2,713.68, and 2,707.25 km^2 respectively, as shown in **Table 2.**

Table 1 Land use change with time

Year	land use/ land use change (km^2)								
	U	R	M	S	C	A	F	W	O
2011	1349	6841	952	1634	3495	1452	3682	465	859
2015R	1373	6824	736	1519	3958	1335	3669	470	843
2015P	1411	6682	832	2026	3485	1410	3625	468	791
2019	1389	6814	596	1421	4304	1236	3669	474	826
2023	1402	6811	594	1419	4315	1225	3667	474	823
2027	1413	6811	593	1419	4315	1215	3667	474	823
2031	1423	6811	593	1419	4315	1205	3667	474	823
2035	1433	6810	593	1419	4314	1195	3667	474	823
Change area (2015-2035)	61	-13	-143	-100	357	-141	-2	4	-19
% Error (2015R & 2015P)	97.20	97.92	86.92	66.60	88.06	94.38	98.79	99.47	93.82
Change ratio (%)	4.41	-0.20	-19.45	-6.58	9.02	-10.52	-0.06	0.81	-2.31

R is observed map, P is predicted map

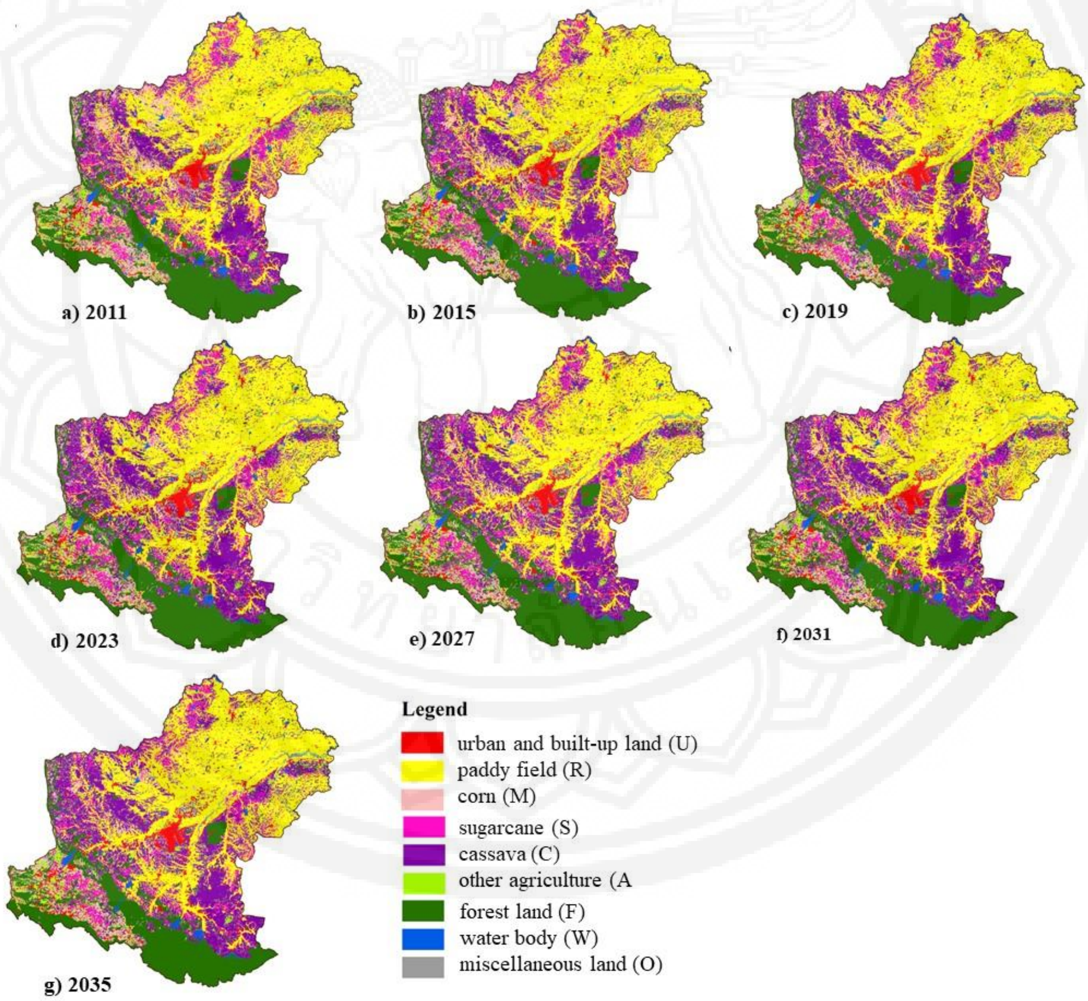
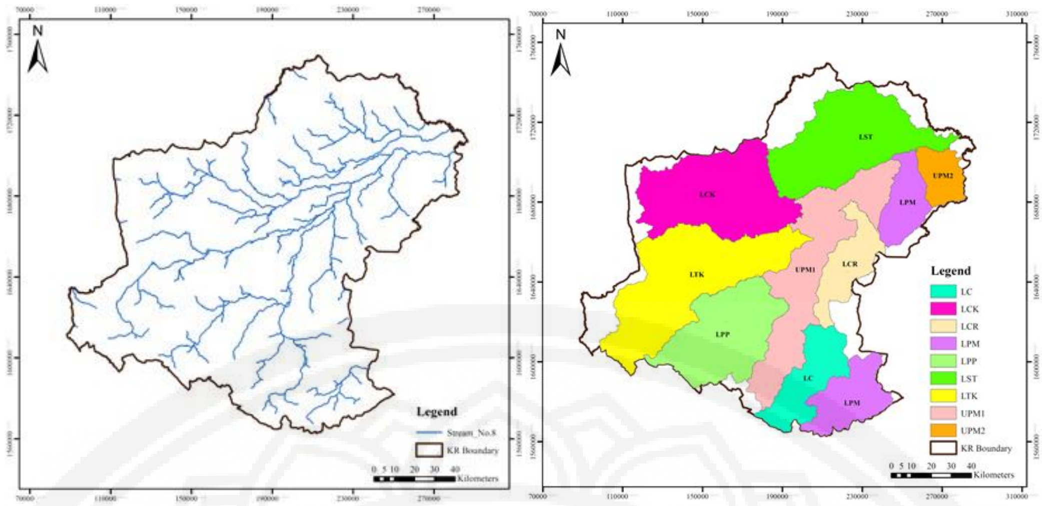


Figure 3 The simulated results of land use change pattern from 2011 to 2035



a) Stream >= No.8 b) The 9 Watersheds in NAM

Figure 4 The characteristics of the stream selected and the watershed boundaries obtained from the hydrological analysis simulation model

3. Watershed Accuracy

To investigate the watershed area, a simulated model was used compared with the NMA's watershed boundary map prepared by the National Water Resources Office. It was found that the total simulated watershed area has 17,927.09 km^2, which is less than the actual area that has an area of 708.58 km^2, accounting for the error of 3.80% as shown in Table 2. However, when considering the error in each watershed, it was found that the LCR watershed had the highest error, with 459.83 km^2 or proportion error 2.47%. This discrepancy is due to the use of DEM data of different resolutions and different sources including determining the resolution of the stream order.

Table 2 Comparison of the accuracy between watersheds simulated model and actual watershed

No.	watershed	Accuracy (km^2)			
		WTS Simulated model	Actual WTS	Error area	% Error
1	LC	1,107.40	1,114.90	-7.50	- 0.04
2	LCK	2,722.24	2,953.35	-231.11	- 1.24
3	LCR	924.18	1,384.01	-459.83	- 2.47
4	LPM	1,761.44	1,944.73	-183.29	- 0.98
5	LPP	2,161.39	2,325.30	-163.91	- 0.88
6	LST	2,713.68	2,756.03	-42.35	- 0.23
7	LTK	3,287.27	3,271.96	15.31	0.08
8	UPM1	2,707.25	2,293.46	413.79	2.22
9	UPM2	542.24	591.94	-49.70	- 0.27
	Total	17,927.09	18,635.67		
	% Error of total WTS area			-708.58	-3.80
	% Error of each watershed			1,566.79	8.41

4. Factor of USLE in NMA

Rainfall erosivity factor (R); The 30 years of rainfall average from 1986 to 2015 with 3 stations in NMA and 16 stations around NMA, prepared by the Meteorological Department, was used to calculate the factor R for the 4 years interval of the study. The value of annual rainfall that was calculated in the range of 1070.20

- 1806.10 mm • y^{-1} with the average is 1307.526 mm • y^{-1}. When calculating Factor R, it was found that the value was between 478.535 - 647.322 MJ • mm • ha^{-1} • hr^{-1} • y^{-1} as shown in **Figure 5**.

Soil erodibility factor (K); There are 56 types of soils in NMA, with factor K ranging from 0.00 to 0.37 T • hr • MJ^{-1} • mm^{-1}. Soil types were extracted from the soil map obtained from LDD of Thailand in 2005. The water was identified with factor K at 0.00 T • hr • MJ^{-1} • mm^{-1}. Soil types 36b and 40b, which are sandy loam types, are the most common. The values were 0.24 T • hr • MJ^{-1} • mm^{-1} and soil series 33 and 33b were fine sandy soils with the highest K value, given 0.37 T • hr • MJ^{-1} • mm^{-1}.

Topographic factor (LS); NMA is a province on the plateau. DEM data show that the terrain is very complex, the southern area is a mountain range, which is an important headwater source and the middle area to the northern area is a lowland. The results of Factor L analysis showed that most characteristics of the area were slope areas, can be seen from Factor L with a range of 1.50312 - 2.60348, with the low value indicating the little slope-length of the area. Factor S shows that most of the traits are areas without slope, with the values are in the range 0.03- 15.3223. The area with the very steep area has a high Factor S which is a high mountain area.

Cropping management factor (C) and Support practice index (P); Factor C and factor P are factors that vary with land use over time of that studying all 5 regions of Thailand obtained from the data of LDD. NMA is located in the Northeast, so the data for the Northeast was applied to analyse. Land use in Urban (U) has value in factor C & P with 0.00 & 0.00, paddy fields (0.28 & 0.10), corn (0.502 & 1.00), sugarcane (0.40 & 1.00), cassava (0.60 & 1.00), other agriculture. (0.225 & 1.0), forest (0.02 & 1.00), water sources (0.00 & 0.00), and miscellaneous (0.80 & 1.00) (LDD, 2004) respectively

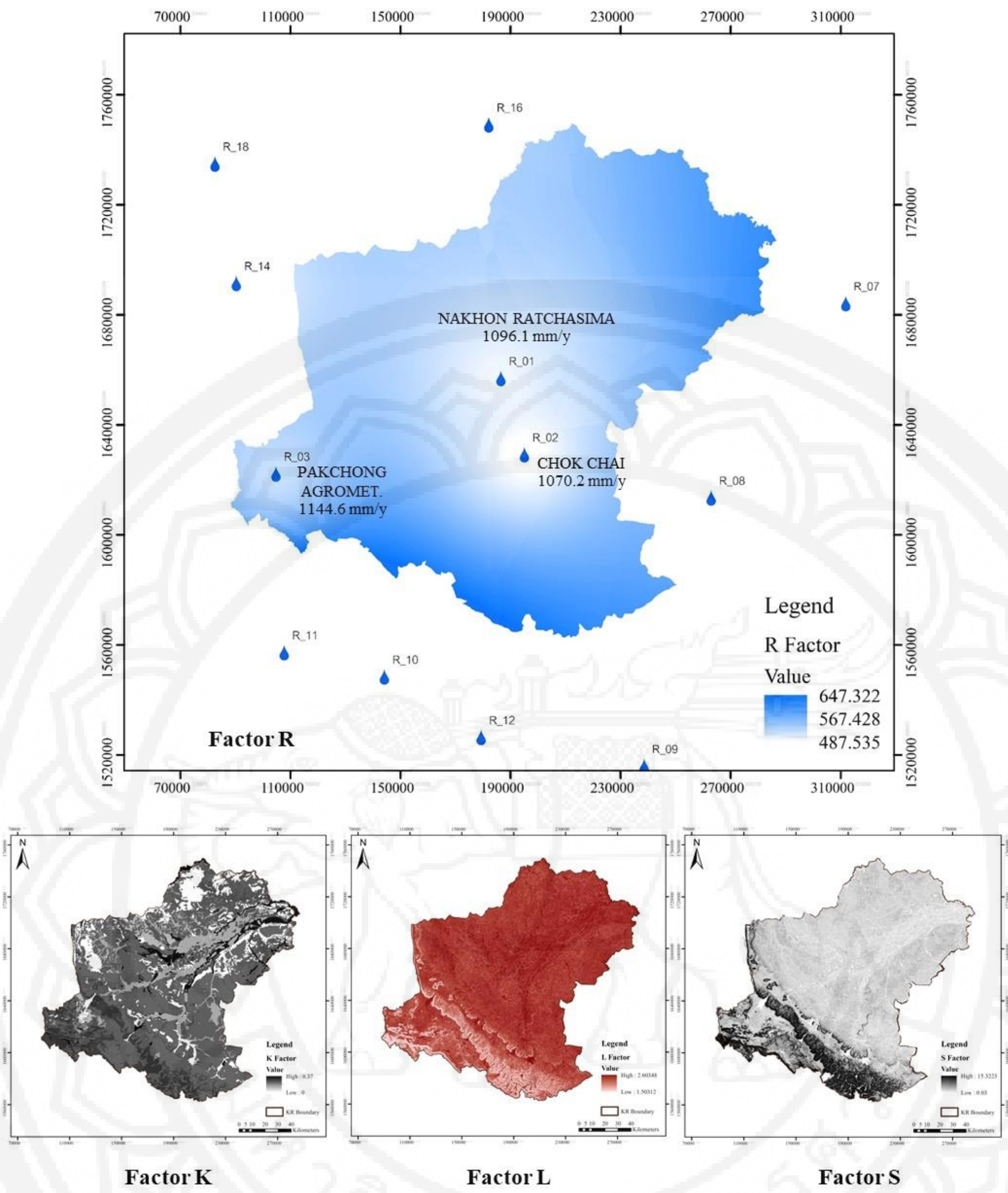


Figure 5 factor used in USLE for Analysis of soil loss in NMA

5. Factor of USLE of 9 watersheds

For the assessment of soil loss in 9 watersheds of NMA, baseline data for the analysis of all 6 factors in USLE were used and provincial assessments using the boundary of each watershed. The analysis results are as follows **Table 3**:

Rainfall erosivity factor (R); UPM1 had the rainfall lowest than 9 watersheds, which were in the middle of the watershed, making Factor R the lowest as well, with 487.54 MJ•mm•ha^{-1}•hr^{-1}•y^{-1}while LPP had the highest Factor R at 642.95 MJ•mm•ha^{-1}•hr^{-1}•y^{-1} at the southern part of the watershed, which is forest and mountain area. The average of the 9 watersheds was 561.02 MJ•mm•ha^{-1}•hr^{-1}•y^{-1}.

Soil erodibility factor (K); All the 9 watersheds had the lowest values of 0.00 T•hr•MJ^{-1}•mm^{-1}, which is the area of the water source that defined factor K of 0.00 T•hr•MJ^{-1}•mm^{-1}. LC watersheds is a lowest factor

K with value of 0.29 T•hr•MJ^{-1}•mm^{-1}. It was a type of loam that formed from sediment complex and foothill debris soil caused by rocky mountain decayed (Soil 60, 61). However, when comparing the 9 watersheds, was found to be the lower than LPP, LTK, and UPM1 having the highest factor K at 0.37 T•hr•MJ^{-1}•mm^{-1}, that is a type of soil group with fine silt or very fine loam which is formed from river sediment or sediment (soil group 33) of high mountain area.

Topographic factor (LS); The 9 watersheds had the slope-length (factor L) range between 1.50 - 2.60, while the factor S of the 9 watersheds had the lowest at 0.03, but the LTK had the highest slope of 15.32 because it is located in Dong Paya Yen mountain ranges at southwest of NMA, while UPM1, LPP, LC, and LPM are located in Sankambeng range at the south of NMA with the values are 12.84, 12.61, 12.17, and 11.50, respectively as shown in Table 3

Cropping management factor (C) and Support practice index (P); All 9 watersheds had factor C in the range between 0.00 - 0.80 and factor P is in the range between 0.00 - 1.00 which is same to NMA's soil loss factor. The determination of the 9 types of land use in the study area as shown in Figure 6.

Table 3 The USLE Factors range in 9 watersheds

Watershed	USLE Factor					
	Fixed factor				Varied factor	
	R	K	L	S	C	P
LC	505.76 - 636.92	0.00 - 0.29	1.50 - 2.60	0.03 - 12.17	0.00 - 0.80	0.00 - 1.00
LCK	503.37 - 540.21	0.00 - 0.36	1.50 - 2.60	0.03 - 8.24	0.00 - 0.80	0.00 - 1.00
LCR	498.68 - 560.15	0.00 - 0.35	1.50 - 2.60	0.03 - 3.20	0.00 - 0.80	0.00 - 1.00
LPM	550.02 - 624.62	0.00 - 0.36	1.50 - 2.60	0.03 - 11.50	0.00 - 0.80	0.00 - 1.00
LPP	488.00 - 642.95	0.00 - 0.37	1.50 - 2.60	0.03 - 12.61	0.00 - 0.80	0.00 - 1.00
LST	519.95 - 598.14	0.00 - 0.36	1.50 - 2.60	0.03 - 4.29	0.00 - 0.80	0.00 - 1.00
LTK	499.63 - 629.55	0.00 - 0.37	1.50 - 2.60	0.03 - 15.32	0.00 - 0.80	0.00 - 1.00
UPM1	487.54 - 626.43	0.00 - 0.37	1.50 - 2.60	0.03 - 12.84	0.00 - 0.80	0.00 - 1.00
UPM2	581.92 - 604.60	0.00 - 0.36	1.50 - 2.60	0.03 - 4.69	0.00 - 0.80	0.00 - 1.00

6. Quantitation of soil loss in NMA Province

Soil loss assessment in NMA conducted from 2011 to 2035 to determine future trends for soil loss. The study found that the lowest soil loss rate was 0.00 T•km^{-2}•y^{-1} and the highest soil loss rate at 329,270.68 T•km^{-2}•y^{-1} with the mean at 2,929.06 and Std Dev. 5,973.77. The results of the study found that in 2011, there was a soil loss of 5,373,767.55 T•y^{-1}, which increased to 5,455,265.65 T•y^{-1} in 2015 and the highest soil loss in 2019 was found at 548,719,802.57 T•y^{-1}, with a total increase in 14,742,286.00 tones. After 2019 and until 2035, there is a slight decrease in soil loss to 551,261,866.00 T•y^{-1}, which is forecasted only 857,175.00 tones. The area in the north eastern part of the province has low soil loss rates, which are with low slope-length and low slope. Most of the land use being paddy fields, including water areas and urban areas, soil loss will be very low until no loss in the area. In the middle, west and southeast where cassava and sugarcane cultivated, the results show in low soil loss. However, on the southwest side of the area with steep mountains (Dong Phaya Yen) and a long and steep slope, very high soil loss value is likely as shown in **Figure 7.**

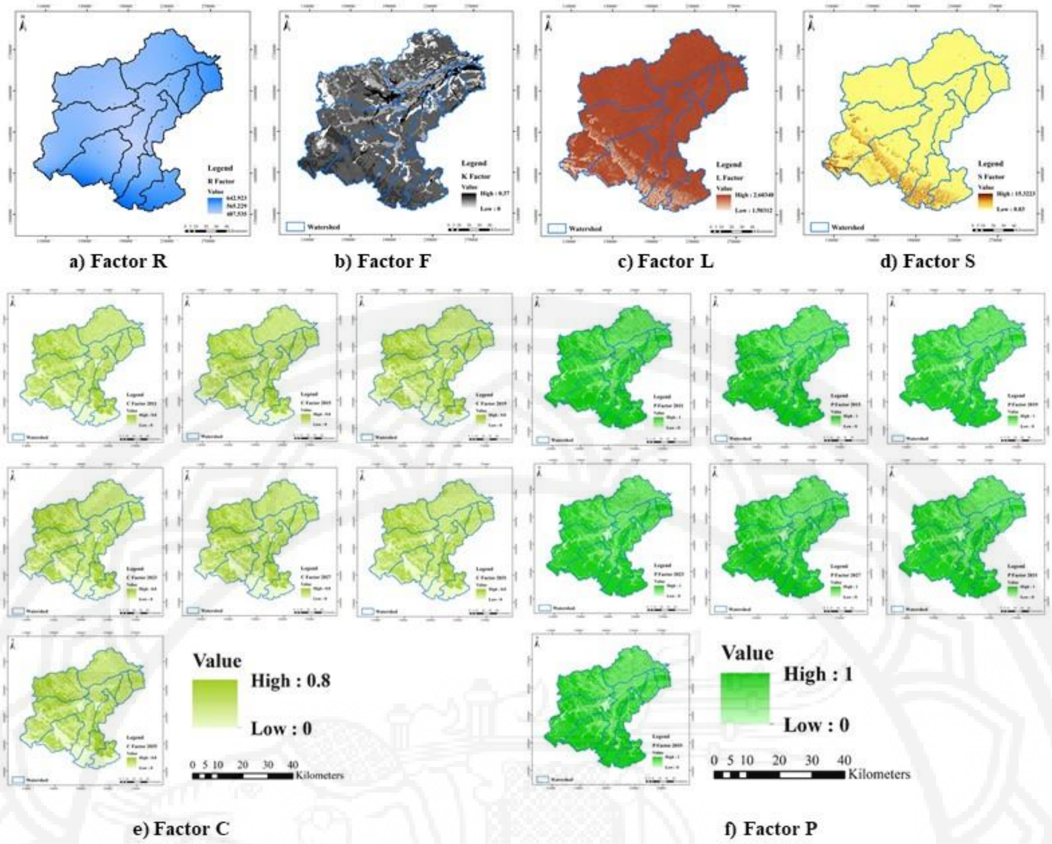


Figure 6 factor used in USLE for Analysis of soil loss in the 9 watersheds

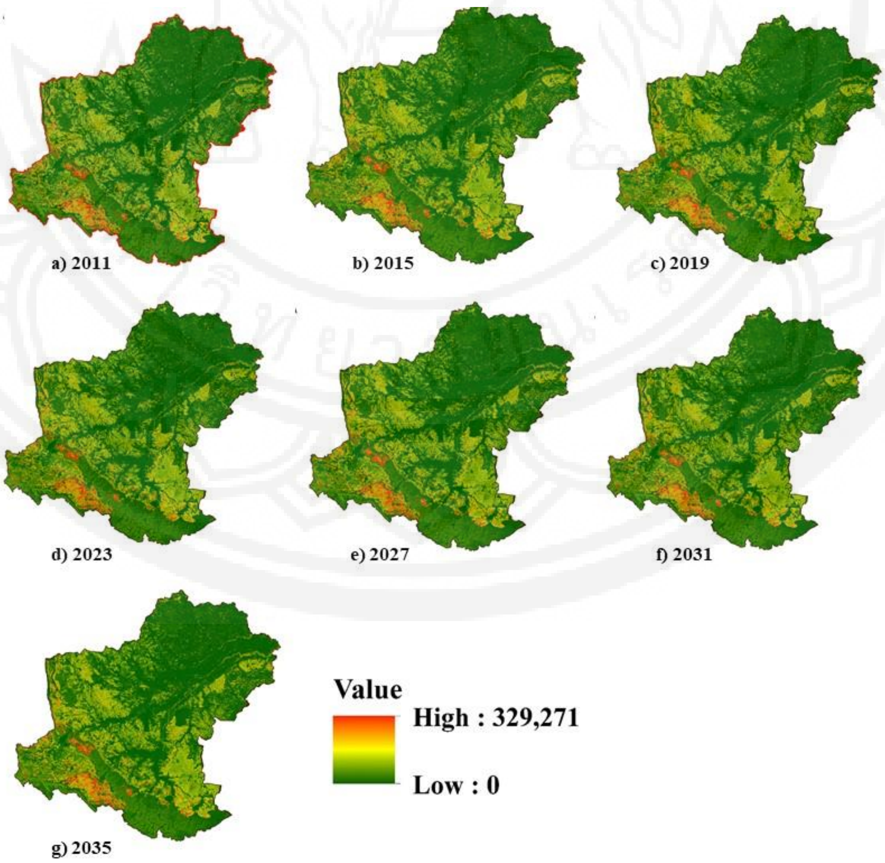


Figure 7 Soil loss rates in NMA from the year 2011-2035

7. Quantitation of soil loss of 9 watersheds in NMA

The results of assessment for soil loss in 9 watersheds from 2011 to 2035 found that the average soil loss was 512.23 x 10^6 T•y^{-1}, with the highest soil loss value in 2019 at 515.64 x 106 T•y^{-1}. When separated by river watersheds, LTK had the highest soil loss, averaging 135.3 x 10^6 T•y^{-1} (Figure 8), accounting for 25% of the entire province and representing 27% of all 9 river watersheds as shown in Figure 10. While, UPM2 had the lowest soil loss rate at 13.98 x 10^6 T•y^{-1}, accounting for 2% of the entire province and accounted for 2% of the 9 river watersheds. However, when considering the amount of soil loss compared with the watershed area, it was found that LPP had the highest soil loss rate per area at 51,100.51 T•total area•y^{-1}, followed by LTK and LC at 41,169.21 T•total area•y^{-1} and 32,944.76 T•total area•y^{-1}, respectively, while LST has the lowest soil loss rate per area at 7,067.19 T•total area•y^{-1}.

Considering the distribution of soil loss in all 9 watersheds, it was found that the LTK watershed had the highest soil loss with a soil loss rate of 238,606 T•km^{-2}•y^{-1}, followed by LPP, UPM1, and LPM were 216,660, 210,800, and 166,990 T•km^{-2}•y^{-1}, respectively. The highest land loss is in the middle of the LTK watershed where there is a dam to store water. It can hold 310 million cubic meters of water. The LPP, LC, UPM1, and LPM are 4 watersheds adjacent to the Sankambeng range which stretch across the southern part of each watershed. The northern part of the province is a plain area without mountain ranges. The land use as paddy-type resulted the rate of soil loss is very low until to no notable soil loss in this area shown in **Figure 10**.

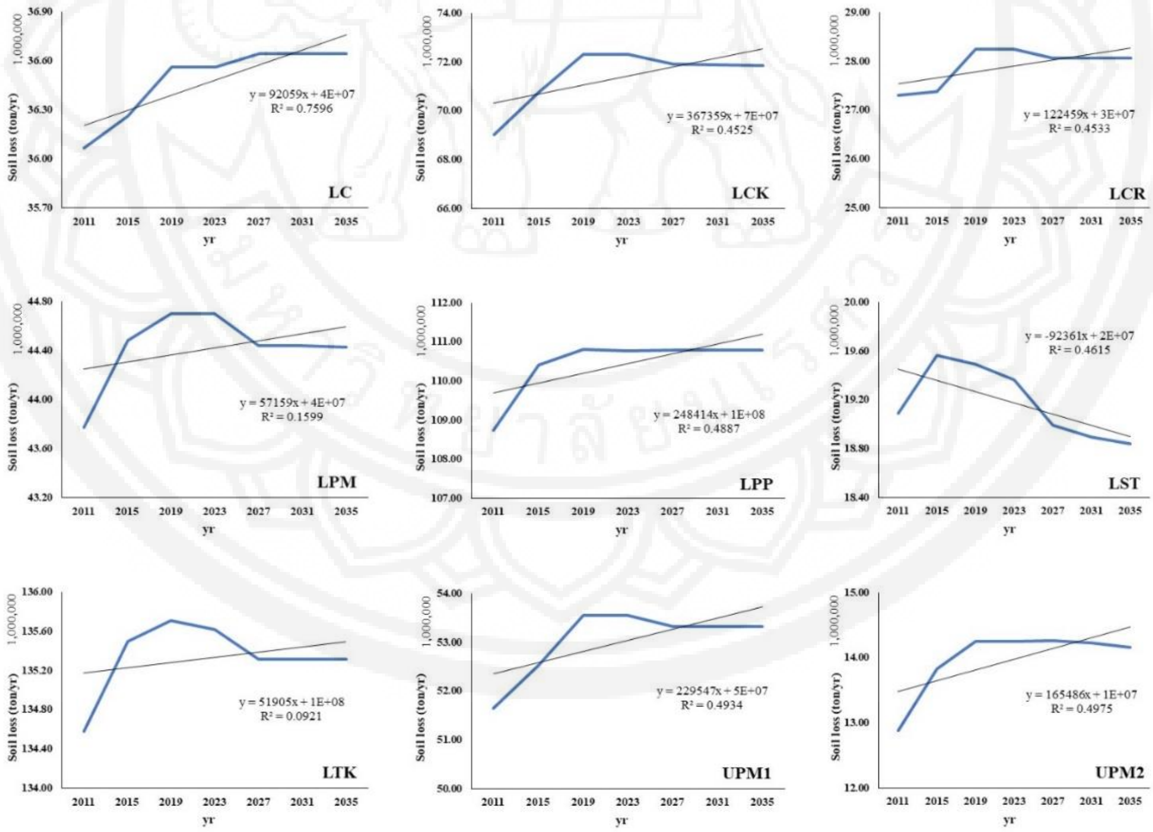
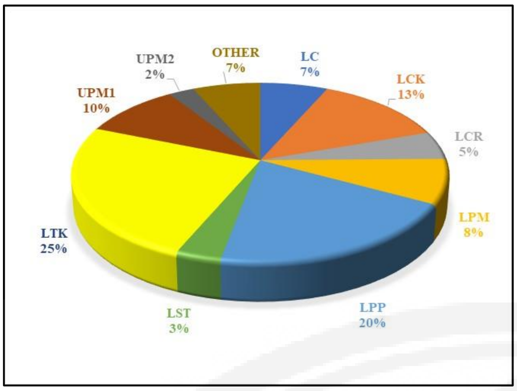
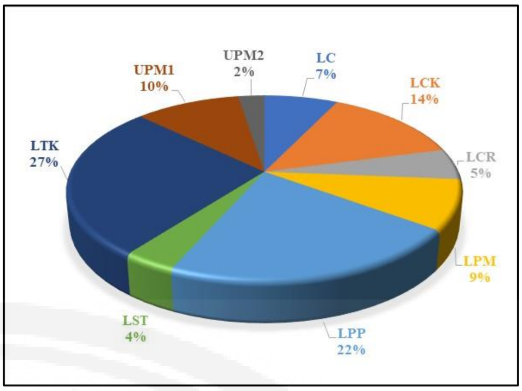


Figure 8 The amount of soil loss in each river watershed



a) The proportion of soil loss in each watershed compared to the whole province



b) Soil loss ratio between all 9 watersheds

Figure 9 The proportion of average soil loss in 9 watersheds (2011-2035)

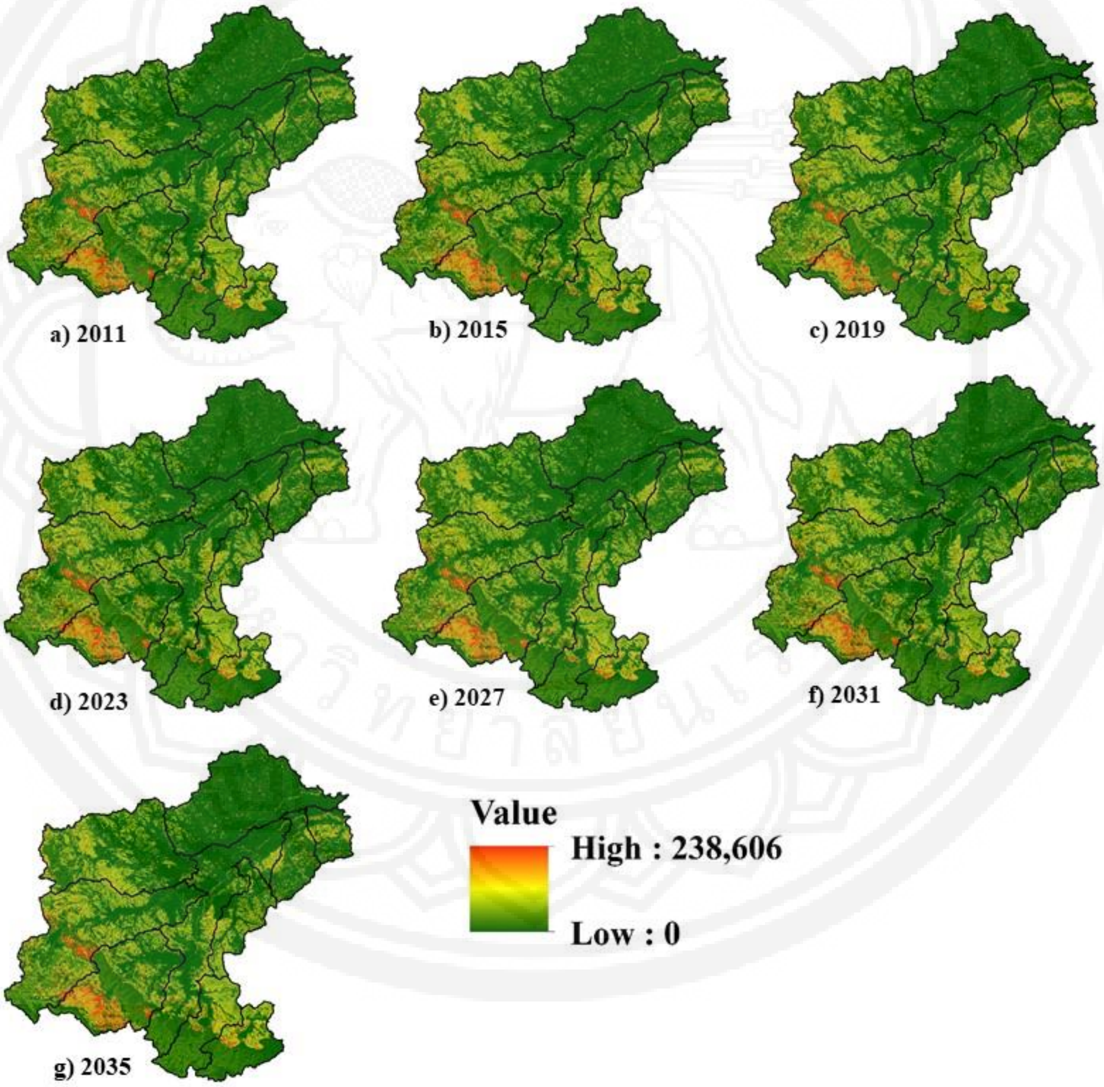


Figure 10 Soil loss rates in each watershed from the year 2011-2035

Conclusion and Suggestions

Several models were used in this study with GIS. First, this study demonstrates that CA - Markov combined with GIS technology can be applied to simulate land use change in Nakhon Ratchasima. The land use models were based on land use maps of 2007, 2011, and 2015 from the Land Development Department, Thailand, and reclassified into 9 types. 2007 and 2011 data were used for model development and 2015 data were used for model validation. The analysis results provide with 91.46% accuracy with 0.016% error which considered highly accurate and reliable. The CA - Markov model simulated future land use changes up to 2035 with a 4 years interval, this simulated model represents a situation arising from 2 years of land use without any other factors. Secondary, Hydrological model analysis was used to find watershed areas in Nakhon Ratchasima Province. The results of the analysis showed that NMA's watershed area was divided into 9 river watersheds, namely Lam Sae (LC), Upper Part of Lam Nam Mun (UPM1), Lam Phraphloeng (LPP), Lum Takhong (LTK), Lam. Choengkrai (LCK), Lam Plaimat (LPM), Lam Chakkarat (LCK), Lam Sa Thaet (LST), and second part of Lam Nam Mun (UPM2). The total area of the simulated watershed is 17,927.09 km^2. After catchment area verified, the model was compared with the NMA's watershed boundary map prepared by the National Water Resources Office, covering an area of 18,635.67 km^2, accounting for the error of 3.80% of total watershed area and an error of each watershed is 8.41%. In the simulation, LTK watershed has the largest watershed area at 3,287.27 km^2, accounting for 15.86% of the province, there is a percentage error of 0.08% of actual area. Third, for soil loss simulations the USLE equation had been used with GIS to assess the overall province and boundaries of the 9 watersheds. Soil loss simulation for the whole province had the highest soil loss at 329,271 $T{\bullet}km^{-2}{\bullet}y^{-1}$, with the average mean at 2,929.06 $T{\bullet}km^{-2}{\bullet}y^{-1}$ or 4.68 $T{\bullet}\ rai^{-1}{\bullet}\ y^{-1}$ which is in the range of values being researched by the Land Development Department (2000). The amount of soil loss in 2035 is 551.26 x 10^6 $T{\bullet}y^{-1}$. In terms of soil loss of all 9 watersheds, LTK was found having the highest soil loss with a rate of 238,606 $T{\bullet}km^{-2}{\bullet}y^{-1}$. The average soil loss is estimated at 135.33 x 10^6 $T{\bullet}y^{-1}$, accounting for 25% of the total area, while UPM2 has the lowest soil loss rate at 13.98 x 10^6 $T{\bullet}y^{-1}$, accounting for 2% of the whole province. However, when considering the amount of soil loss compared to its watershed, it was found that LPP had the highest soil loss rate per area at 51,100.51 ton per its area per year, followed by LTK at 41,169.21 ton per its area per year. The LST has the lowest soil loss rate per area, at 7,067.19 ton per its area per year. The area with the highest soil loss rate was the southern part which is an area of mountain pass and steep slopes with high potential of landslide risk. The simulation results are consistent with Nakhon Ratchasima's landslide risk map prepared by the Department of Mineral Resources, 2004 (Department of Mineral Resources, 2004), which differs significantly in the spatial area because the topography is the main factor in the effect on soil loss. However, the USLE model is a soil loss model caused only by the topsoil leaching process, excluding the trench leaching and coastal erosion.

In conclusion, our study presents a spatial land use modelling using CA-Markov in conjunction with GIS. The future land use maps can be used to assess soil losses as an early warning system. The results obtained are useful for other sites with similar patterns of change of land use. The simulation results can be used for land use planning for complex changes and can help local authorities understand land use systems and can improve land use management, then determine policies to prevent future environmental problems which is critical to controlling improper land use change or adversely affecting the local environment. However, in the next study should be studied in a short-term because simulating future land use with Model CA-Markov is suitable for short-term predictions.

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