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Hydrological Components and Catchment Scale Sediment Delivery in Prek Thnot River Basin, Cambodia

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Abstract: *Accelerated soil erosion caused by water is one of the most widespread problems affecting environmental quality, agricultural productivity, and food security in many countries. These issues tend to cause more severe impacts on developing countries, especially in the tropical highland areas. Therefore, this study was conducted in the Prek Thnot Basin, a sub-catchment of the Mekong Basin in Cambodia, to (1) simulate sediment yield at the outlet by using Soil and Water Assessment Tool (SWAT); and (2) identify productive sediment yield area of the catchment. The SWAT model was selected due to the availability of data and the capability to represent the reality of hydrological and water quality processes, which is the best method to determine the answer to the study objectives. In response, the SWAT provided an actual performance in each calibration and validation process of both runoff and sediment yield. The annual soil erosion in most parts of the study area range from approximately 100 to more than 1400 tons/km^2/y. This study indicated that the most erosive part of this study area covers 91.78 km^2, which contributed to 1.64% of the whole watershed with a sediment yield of about 2206 tons/km^2. In addition, the assessments of sediment deposition and erosion using Modified Universal Soil Loss Equation (MUSLE) indicated the annual sediment load along the flow direction of the mainstream, from the upper river to the outlet of the Prek Thnot river basin, about 0.2 million tons. As a result, the middle to the upstream of the watershed is the most sensitive to produce the sediment yield.*

Keywords: Sediment transport; Streamflow; Prek Thnok River Basin; SWAT

1. INTRODUCTION

Soil erosion is regarded as one of the significant and most widespread forms of land degradation, which poses severe limitations to sustainable agricultural land use. It is the main part of the initial process of sediment delivery to rivers; in this process, displaced soil particles are transformed into sediments due to the influence of an agent of erosion. The number of sediments generated can decrease the potential storage capacity of reservoirs and the performance of hydraulics structures. Soil erosion affects the global environment, natural resources, economy, low agricultural productivity, ecological collapse, and high sedimentation. According to Dutta [1], about 80% of the world's agricultural land suffers from soil erosion. Despite the soil nutrient deprivation and degradation caused by erosion, many momentous offsite environmental problems such as flooding, water siltation, and pollution [2]. It is a major setback to the sustainable development of natural resources and the environment [3]. This natural process occurs over geological time. Approximately 84% of the degraded lands worldwide are associated with the most relevant issues about the environment, water, and wind as the primary agents of erosion. The concerns of soil erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activities such as land cover and management changes. Many scientists agree that the rate of erosion, either by wind or water, frequently exceeds the rate of soil formation [4]. However, the direct pressure of severe soil erosion is runoff, whose processes play an important role in analyzing soil erosion intensity and

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measures. 75 billion tons of soils are eroded from the world's terrestrial ecosystems annually [5].

Generally, agricultural land is the most vulnerable area of eroded, losing soil at rates ranging from 13 t/ha/yr to 40 t/ha/yr. The erosion rates range from a low of 0.001-2 t/ha/yr in a flat land with grass and/or forest cover to a rate of 1-5 t/ha/yr in mountainous regions with normal vegetation cover. Erosion reduces on-farm soil productivity and contributes to water quality problems as it causes the accumulation of sediment and agrochemicals in waterways. This is associated with the loss of organic matter and plant nutrients in the erosion process, together with a reduction of soil depth. Water's decrease of infiltration capacity on slopes resulted in increased runoff and decreased water storage [4].

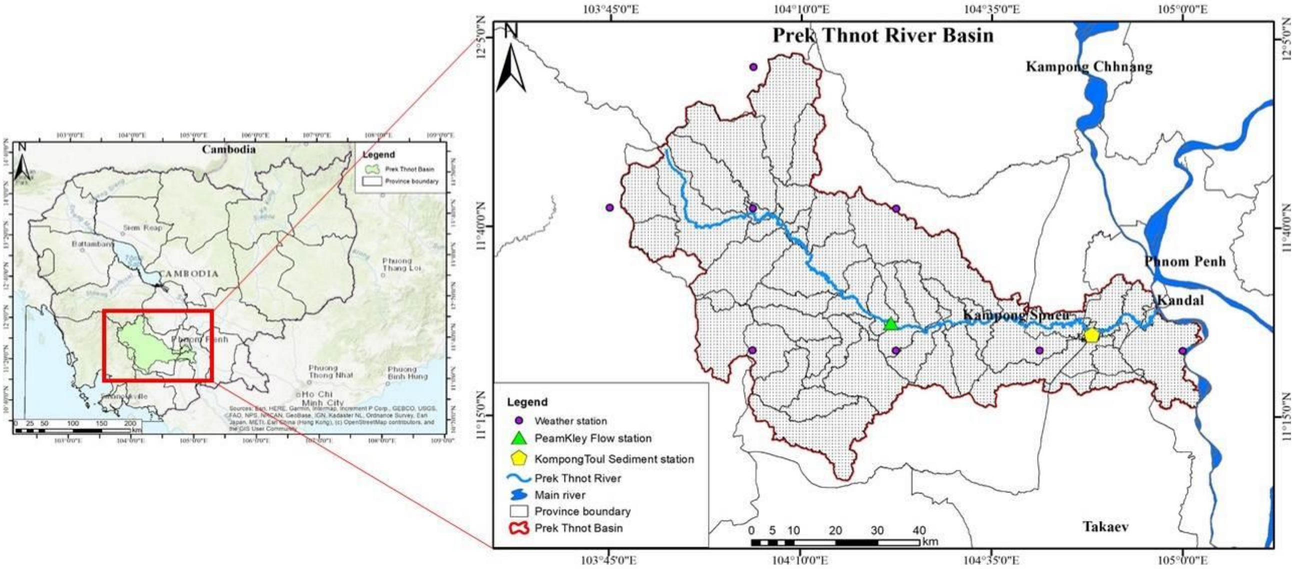

Fig. 1. Geographical location map of the Prek Thnot River Basin

In Southeast Asia, the Lancang-Mekong River basin, an important transboundary river, is one of the largest rivers causing high sediment loads in Asian rivers. The average annual sediment load and the specific sediment yield in the Lancang-Mekong River basin is approximately 50% of the number of sediments in the Lancang-Mekong River basin. In Cambodia, Lal [6] has estimated the total erosion from the Tonle Sap Lake watershed and evaluated sediment transport in 15 rivers, the estimated mean erosion rate to be 0.3 t/ha/yr compared to the global risk. Soil erosion has been drastically accelerated by expanding agricultural and urban activity.

The Mekong River provides food and a transportation system for the Cambodian population. The Mekong River is surrounded by many tributaries, among which the Prek Thnot is located on the right bank of the Lower Mekong River. This tributary is a large rice production area that spreads over the middle and downstream reaches of the basin. The river's total length is 226 km, and the drainage area is approximately 5,591 km^2. At the upper part of the basin, Tasal dam was built with a catchment area of 495 km^2 on Stung Tasal to keep water supply for agriculture purposes downstream. Moreover, Prek Thnot dam was also built with a catchment area of 3630 km^2 for agricultural use, flood control, and hydropower [7]. Recently, the Mekong River has been faced with environmental degradation due to the multiple sources of pressure, including rapid population growth, industrialization, intensive agricultural development, which have addressed hydrological issues, sediment fluxes, climate change, and the impact of upstream dams [8]. The consequences of large dams impact the river's biological, chemical, and physical properties and riparian environment. The dams also trap sediments, which are critical for maintaining physical processes and habitats downstream of the dam [9]. Therefore, this study was carried out at Prek Thnot, which is one of the main tributaries of the Lower Mekong Basin. This tributary is one of the most important watersheds in Cambodia, supporting livelihoods throughout the catchment and contributing to southwestern Cambodia's economic growth [10]. Due to various incompatible landuse, Prek Thnot watershed faces the risk of impairment, which leads to different disasters such as droughts, floods, pests and disease, and storms that affect people's food and nutrition security [11]. Heng [12] has also stated the issue regarding the land allocation and use on forest state land, forest depletion due to logging and concession of natural resources, and soil degradation driven by unsuitable agricultural practice, which made Prek Thnot watershed very complex to manage. Climate and landuse change and upstream hydropower dam development are critical challenges presented in the basin [13]. There were some previous studies on Prek Thnot basin; however, those studies focused on the impact of climate change on hydrology concerning water scarcity for agriculture [13]. Khorn et al. [14]

studied landuse change in the upper Prek Thnot basin. The result showed the rapid decrease of forested and wood shrub areas and a significantly increased agricultural land. Although this issue may lead to erosion, there has been no report regarding soil erosion assessment.

To this extent, it is necessary to quantify and understand the suspended sediment dynamics to control soil erosion, especially implementing appropriate mitigation practices to reduce suspended sediment in streams and associated pollutant loads. Thus, surface water quality downstream could be improved and plan for early adaptation and minimize future impacts on human livelihoods. In this study, Soil and Water Assessment Tool (SWAT) was chosen for its many useful components and function for simulating water balance, sediment loss, climate change, crop growth, and land management practice [15]. This model was wildly used for erosion modelling in several catchments under different climatic conditions, including semi-arid climates [16]. The first segment of this paper begins with describing the area and characteristics of Prek Thnot basin. Later, the following sections are dedicated to the methodology used in SWAT model. Finally, the results from the SWAT model were analyzed to assess streamflow, sediment yield, and sediment transport into the main river of Prek Thnot river basin.

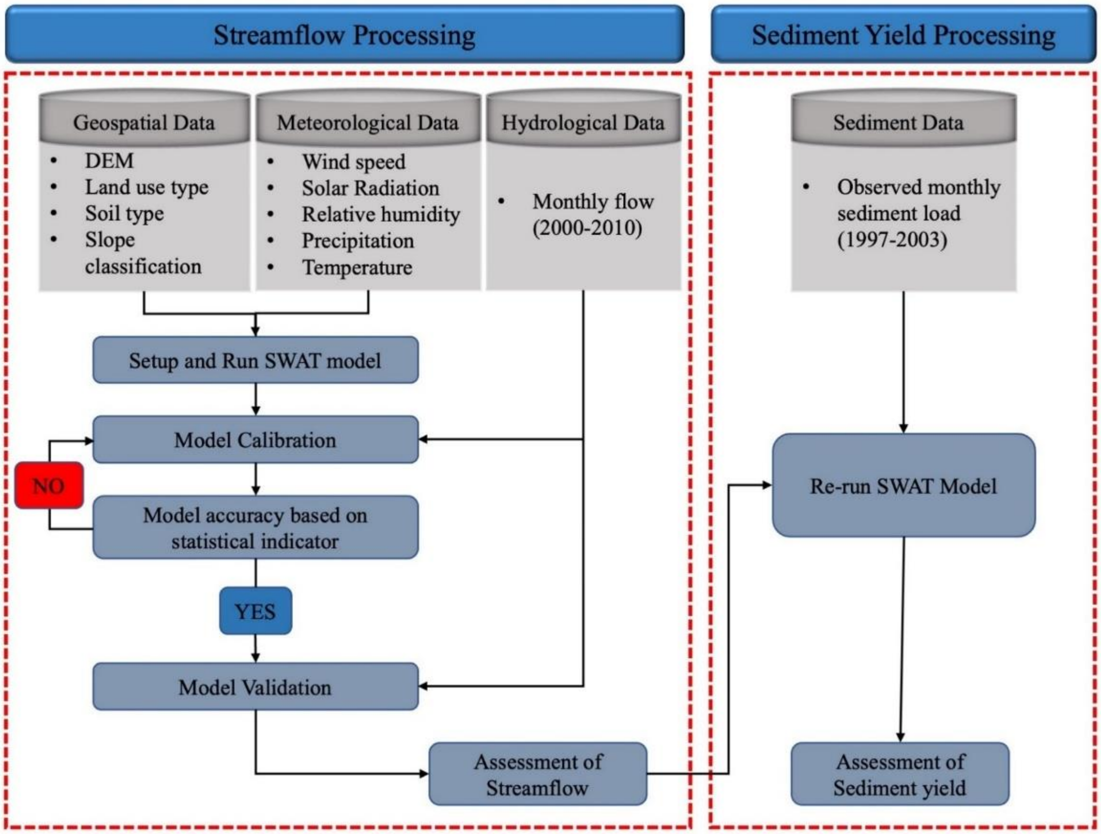

Fig. 2. Flowchart showing the overall methodology of SWAT model

2. METHODOLOGY

2.1 Study area

Prek Tnot river basin is one of the main tributaries of the Mekong River in Cambodia, originating from the Cardamon mountain range. It is located in the southwest of Cambodia and flows in the west-east direction, lies between latitude from 11º06’50”N to 12º02’50”N and longitude from 103º46’20”E to 104º57’00”E (Fig. 1). The total length of the river is 226 km, and the drainage area is 5,591 km^2. The basin elevation ranges from 5 to 1815 m above mean sea level. Seven tributaries flow into Prek Thnot river, including Stung Aveang, Stung Trong Krang, Stung Tasal, Stung Phleach, Stung Tang Haong, and O Krang Ambel. The average annual temperature ranges from 21℃ to 35℃. It receives approximately 1,225 mm of average annual rainfall and more than [17].

2.2 Model description

The SWAT model is a physically-based semi-distributed hydrological model designed to predict the impact of land management practice on water, sediment and agricultural yields in large complex watersheds with varying soil, land use and management condition [18]. ArcSWAT is a user-friendly software that integrates SWAT with the ArcView-Geographic Information System (GIS). Spatial datasets like topographical, land use and soil data are pre-requisite input parameters in SWAT model. It has weather simulation components that predict the missing data in the observed weather data records. The SWAT model spatially delineates the area into several sub-basins based on the Digital Elevation Model (DEM) for runoff simulation through the channel networks within the sub-basins, and further divided into multiple homogenous Hydrological Response Unit (HRUs), which characterized by the unique combination of land use, soil type and average slope. The threshold of 8000 ha was used in this basin, which produced 46 sub-basins consisting of 788 HRUs. The HRUs analysis is portions of increasing the accuracy to the prediction of loading from the sub-basin, where the parameters in SWAT database, the land use, soil type and slope was reclassified [15,19]. Then, all these properties were overlaid for 788 HRUs definitions, where the threshold value for land use were 5%, soil 10% and 5% for slope. The climate parameters consist of rainfall, temperature (maximum and minimum), relative humidity, solar radiation and wind speed were input to generate weather data for each sub-basin independently. The flowchart of the entire methodology of SWAT model is represented in Fig. 2.

The predicted streamflow of SWAT model is based on the water balance equation:

$$SW_t = SWL_o + \sum_{i=0}^{t}\left(R_{day} - Q_{surf} - E_a - Q_{gw}\right) \qquad \text{(Eq.1)}$$

Where SW_t is the final soil water content (mm); SWL_o is initial soil water content (mm); t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil, Q_{gw} is the amount of ground water on day i (mm).

The prediction of sediment yield in the SWAT model is based on Modified Universal Soil Loss Equation (MUSLE) where rainfall and runoff is the main reason of soil loss [20]. The equation is as following:

$$sed = 11.8(Q_{surf} \times q_{peak} \times area_{hru})^{0.56} \times (K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG) \qquad \text{(Eq. 2)}$$

Where sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.13 metric ton ($m^2 hr/m^3$metric ton cm), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, $CFRG$ is the coarse fragment factor. MUSLE is implemented in SWAT model by assuming a simple hydrograph shape to estimate daily runoff volume with a peak flow rate within the sub-watershed area, which is further used to predict the variation of runoff erosive energy. The SWAT simulates the sediment yield in terms of total sediment loadings and also as the fractions of sand, silt and clay from individual sub-watershed.

2.3 *Model input*

In this study, ArcSWAT 2012 was used to simulate flow and sediment yield at the subbasin level for the period from 1997 to 2011. The area of interest was delineated by ArcSWAT, using the digital elevation model (DEM) with a resolution 30m provided by the National Aeronautics and Space Administration of Shuttle Radar Topography Mission (SRTM) in ASTER-GDEM (Advanced Space Borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model), which was subdivided into 46 sub-basins. The topography of the watershed area ranges varies from 5m to 1,813 m above mean sea level, shown in Fig. 3.

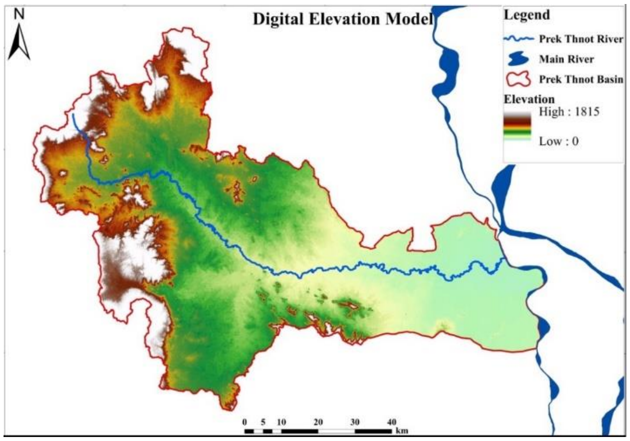

Fig. 3. DEM distribution of Prek Thnot basin

Land use and land cover (LULC) was prepared using satellite image and field data collected in 2002 with resolution 250m, known as the most recent data available for this watershed conducted by Mekong River Commission (MRC). The LULC map of Mekong River basin was clipped and dissolved to Prek Thnot River Basin. The type of LULC was reclassified in SWAT model based on land use types. The different land use was generated and classified into 18 land use types. It is mainly covered by deciduous with a density of approximately 37.33% at the upper part of the basin, following by the agricultural land-intensive (AGRI) with a density of 31.54% at the lower part of the catchment. As a whole, Prek Thnot basin is mainly covered with forest and agricultural land, shown in Fig. 4.

The SWAT model requires different soil texture and Physico-chemical properties in the form of soil texture, available water content, hydraulic conductivity, bulk density, and organic carbon content for different layers of each group of soil. The database obtained from the soil map was updated with the SOIL-FAO database (FAO: Food and Agriculture Organization of the

United Nations 1995). The soil data of Prek Thnot catchment were then added into the SWAT soil database.

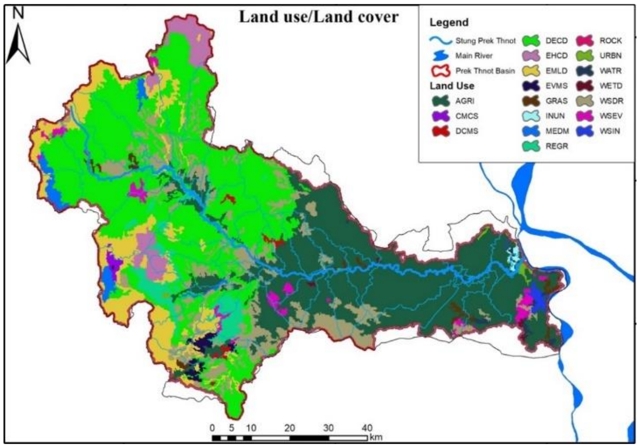

Fig. 4. Land use/Land cover classification

Soil type data of Cambodia was also provided by Mekong River Commission (MRC) with a resolution 250 m x 250 m. The raster data was clipped with the boundary of the study area to obtain the spatial distribution of soil mapping. Then it was reclassified by the establishment of the soil index file in the projection of SWAT model. The soil map is shown in Fig. 5 is categorized into 12 soil types. The most abundant soil type is Cambisol (LPd/CMd), which is about 45.01% in the upper area of the watershed, ensuing by Gleyic Acrisol (ACg) with 39.21% and Gleyic-plinthic (ACp) 12.08% and followed by Acroxic, Umbrisol Gley Gleysol, Water body, Gleyic-plinthic, Gleyic Cambisol, Dystric Leptosol, Areni-gley, Dystric Plintosol/Gleyic, and Haplic Acrisol. These physical soil properties are essential to govern the movement of water and air through the profile and have an impact on the water cycle within the HRU.

After reclassifying both the LULC map and soil maps with respect to their databases using lookup tables, they were overlaid along with the slope layers with the delineated watershed to subdivide the sub-watersheds into 788 HRUs (Land use threshold 5%, soil threshold 10%, and slope threshold 5%). Reducing the number of HRUs to decrease the computation time of the model simulation will cause an error in HRU aggregation by increasing an error in input data. It is as well defining that a greater number of HRUs will present more accurate results but will take a longer simulation time. That is why the above-said adequate threshold values were used to remove minor land use, soil and slope types where the simplified HRU definition could be achieved. The meteorological data required in the SWAT model, including precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity, which could be obtained from the observation or freely global the weather generator model. The precipitation data used in this study was available from the Department of Hydrology and River Works (DHRW) of the Ministry of Water Resources and Meteorology (MOWRAM) for Kampong Speu, Kong Pisey, Oral, O Taroat, Peam Khley, Phnom Srouch, Prey Pdeo, and Trapeang Chor stations. The other data such as wind speed, relative humidity, solar radiation, and maximum and minimum temperature were downloaded from Global weather data for SWAT (globalweather.tamu.edu) within and nearby the watershed boundary. The monthly discharge and sediment data were also obtained from DHRW during the period from 2000 to 2010 at Peam Kley station and 1997 to 2003 at Kampong Toul station, respectively. The observed streamflow and sediment data are essential in performing sensitivity analysis, calibration and validation process in the SWAT model.

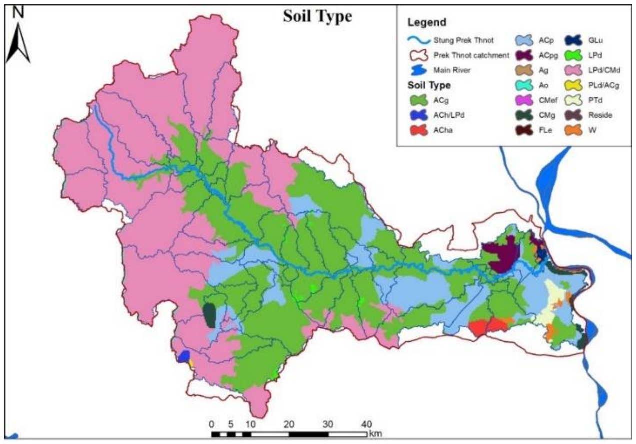

Fig. 5. Soil characteristic in SWAT model

The initial simulation of the model using default parameters did not give satisfactory results; therefore, the sensitivity analysis of the simulated data, calibration and validation were carried out to evaluate the effect of parameters on the performance of SWAT model in simulating flow, sediment yield, and as well as nitrated yield. There are 16 sensitive parameters (12 for discharge and 4 for sediment load) were identified based on the literature review as well as the characteristic of the catchment area, which has beneficially affected the accuracy of the results. However, the sensitive parameters of streamflow analysis were determined using SWAT-CUP. To determine the sensitive parameters, P-value and student's t-distribution were used. This study considered parameters as sensitive when P-value is less than 0.05.

3 RESULTS AND DISCUSSION

3.1 Calibration and validation for SWAT model

Calibration is carried out for the simulation of discharge and sediment load of the model by modifying sensitive parameters to get a good agreement between observed and predicted values. The parameters were input in SWAT-CUP for the simulation of discharge on the basis of monthly observed data for the period of 2000-2005 (Fig. 6). The validation was performed without changing these values of calibrated parameters to verify the model's ability to simulate the discharge during the period from 2007-2010 (Fig. 7). The sediment load simulation was performed after the satisfactory result of calibration and validation of simulated discharge. The period of calibration and validation period was selected according to the availability of observed data of the watershed. The model was performed 500 times to get optimum calibrated values of input parameters. The statistical measures were employed to evaluate the performance of the model accuracy and consistency on assessment of discharge and sediment load (Table 1). The discharge and sediment load were calibrated and validated with respect to their statistical indices. It was assumed that throughout the simulation period, there was no spatial variation of land use and soil properties [21]. The result was analyzed quantitatively without any significant tests on the quality of water.

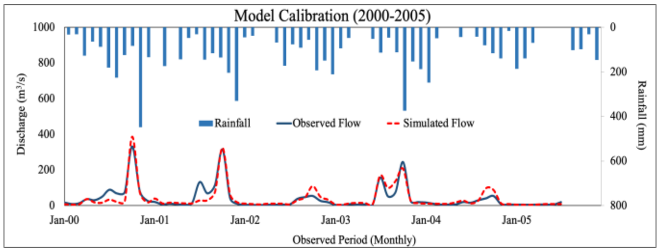

Fig. 6. Monthly observed and simulated flow of calibration from 2000-2005 for Prek Thnot River Basin

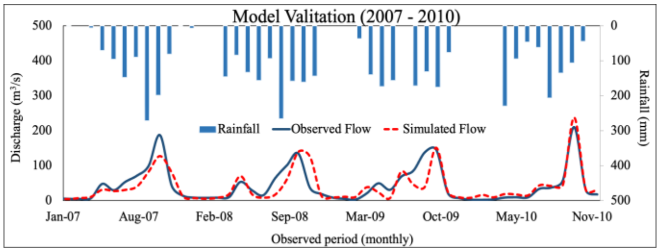

Fig. 7. Monthly observed and simulated flow observed flow of validation from 2007-2010 for Prek Thnot River Basin

The comparison of statistical evaluations between observed and simulated monthly discharge indicated that the model performed well to represent the dynamics of the basin. It has shown that both the rising and falling limbs of the hydrographs are well-illustrated, and the peak flow responsible for predicting soil erosion and sediment transport are well expressed. Timing of occurrence of the peaks for both observed and simulated runoff matched well. The hydrological characteristic, as well as the peak flow during excessive rainfall events, were well presented. After proceeding with the applicable water discharge simulation, it was then used as the baseline for further processing sedimentation modeling. The sediment parameters subjected to the final calibration were separated into parameters for sediment from landscape and sediment from channel. The results of statistical tests were performed on the agreement between measured and simulated monthly sediment yield. Additionally, the graphical representations were illustrated to provide a visual comparison (Fig. 8 and 9).

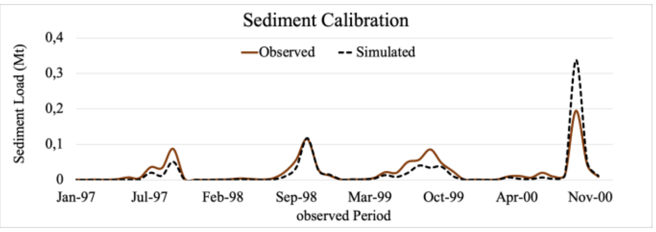

Fig. 8. Monthly sediment calibration result from 1997-2000

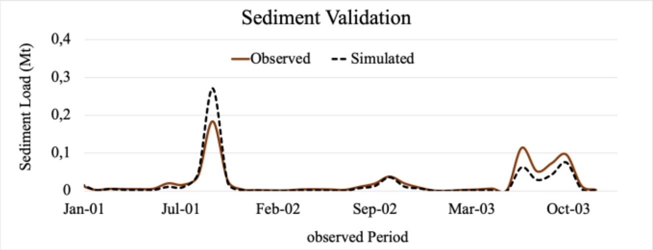

Fig.9. Monthly sediment validation result from 2001-2003

3.2 Spatial pattern of hydrological components

It is essential to understand the characteristic of hydrological components in the basin to analyze the characteristic of streamflow and erosion and sediment transport. In Fig. 10a, the map shows high precipitation at the middle-downstream in sub-basin 20, 21, and 31. The precipitation is higher than 1250 mm. An evapotranspiration map in Fig. 10b has shown that the highest average annual evapotranspiration is in sub-basin 32, which is higher than 1000 mm, covered with intensive agricultural land with Gleyic Acrisol, at the downstream with the annual evapotranspiration rate between 900 mm to 1000 mm. The percolation process involves the characteristic of soil. The highest percolation in Prek Thnot river basin is located at the upper part of the basin with an average annual value above 100 mm in sub-basin 1, 2, 4, and 10. These sub-basins are covered by forest with Cambisol (LPd/CMd) soil type. Likewise, the stimulated result of surface runoff in this basin has shown that sub-basin 9, 6 and 45 generated the highest runoff, above 100 mm/year It is similar to the output of surface runoff; water yield has shown that sub-basin 6 and 9 also generated the highest amount of water yield, higher than 450 mm/year

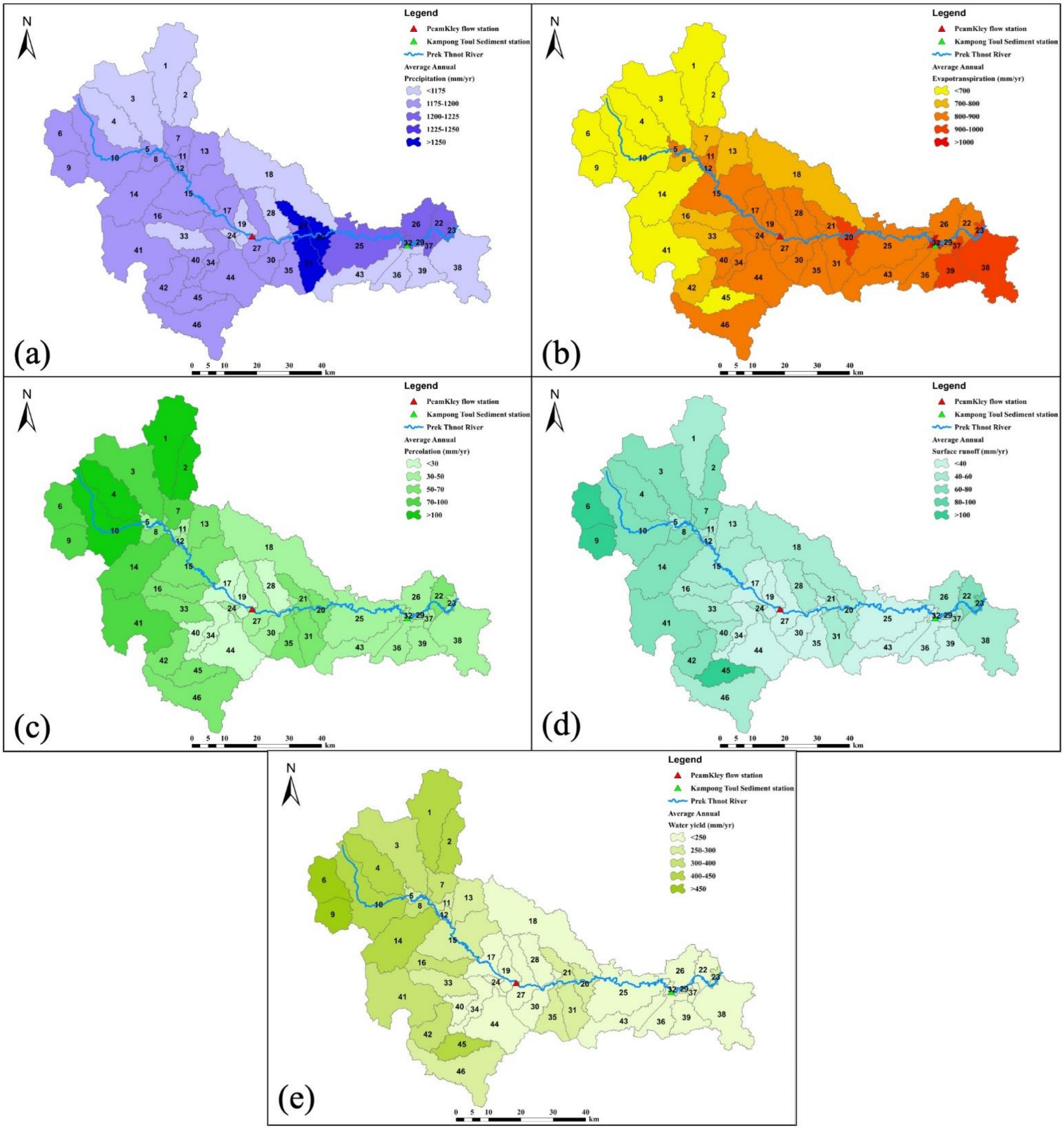

Fig. 10. Hydrological components; (a) Precipitation (mm), (b) Evapotranspiration (mm), (c) Percolation (mm), (d) Surface runoff (mm), (e) Water yield (mm)

Table 1 Statistical performance of mean monthly flow at Peam Kley station and sediment load at Kampong Toul station

Statistical indicators	Calibration		Validation	
	Flow (2000-2005)	Sediment (1997-2000)	Flow (2007-2010)	Sediment (2001-2003)
NSE	0.84	0.51	0.70	0.76
R^2	0.86	0.79	0.72	0.85
PBIAS	-2.17%	23.61%	-7.46%	13.89%
RSR	0.40	0.70	0.54	0.49

3.3 Temporal and seasonal variability of streamflow and sediment load

From the Prek Thnot River basin outlet, the result extracted from the SWAT model shows a simulation of temporal variability of annual discharge and sediment load for the baseline period from 1997 to 2011. Without considering any change in LULC through time, a 15-years baseline series at Prek Thnot basin showed a comprehensive difference from year to year (Fig. 11). However, the overall trend of the changing amount of discharge and sediment load throughout the baseline period is dependent. In general, the sediment load rise when the discharge increase. The minimum discharge of Prek Thnot river is approximately 11,275 million cubic meters, which occurred in 2005, with a minimum sediment load of about 0.08 million tons in 1997. In other views, the maximum streamflow was around 31,427 million cubic meters in 2001 and the maximum sediment load is about 0.5 million tons happened in 2000. The mean value of streamflow and sediment load is 20,414 million cubic meters and 0.2 million tons, respectively. The characteristic of these basins is identical, covered by the evergreen/deciduous forest at the upper part where the slope is steep and agricultural with a gentle slope downstream. The estimated sediment load was approximately 0.38 Mt/yr from Stung Sen and 0.24 Mt/yr from Stung Chinit.

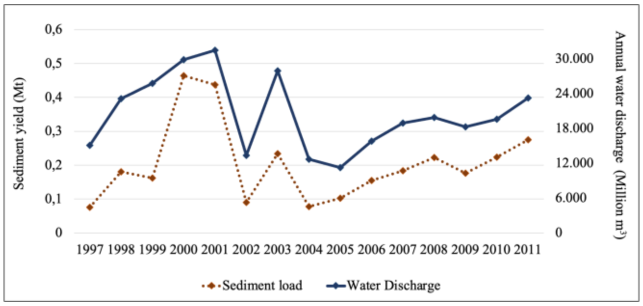

Fig. 11. Temporal variability of simulated annual discharge and sediment load from 1997-2011

Fig. 12 has shown the average monthly streamflow and sediment load throughout the simulation period from 1997 to 2011 at the outlet of the basin. The correlation has shown that the relationship between discharge and sediment load varied seasonally. The discharge ranged from 10 m^3/s to 230 m^3/s, and the sediment load ranged from around 1 kiloton to 104 kilotons. he general pattern of discharge and sediment load in In the rainy season, the result shows the overall trend that streamflow and sediment load started to rise from May (26 m^3/s and 5.1 kilotons) and reached their highest in October. It can be seen in the hydrograph that the value is declined in the dry season from November to April. The lowest value is in February with the discharge of approximately 10 m^3/s and sediment load 1 kiloton, and then slightly increased for March and April.

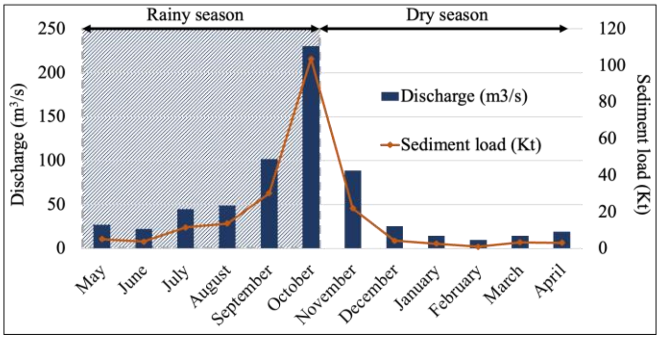

Fig. 12. Seasonal and monthly variability of discharge and sediment load for 15 years (1997-2011)

3.4 Spatial pattern of average annual sedimentation

The areas where soil erosion was serious can be identified from the simulated results. Fig. 13 indicates the spatial pattern of annual sediment load in the river and the average annual sediment yield in the catchment throughout the 15 years. The sediment load ranges from approximately 0.02 million tons to more than 0.2 million tons annually. It can be seen that the most erosive zone is sub-basin number 9 located upstream of the Prek Thnot catchment, covers an area of 91.78 km^2, contributed to 1.64% of the watershed with a sediment yield of 2206 tons/km^2. This sub-basin has high annual average surface runoff and water yield throughout the baseline years, as shown in Fig. 14, which is the main driving force of high erosion. As mentioned above, the sub-basin number 9 is covered with forest (Evergreen, medium-low cover density, mixed (evg&dec) med-low cover density and Deciduos), which generally has low erosion. However, it is located at the upper part of the basin, where the elevation is a relatively high and steep slope and has well contributed with the factor of soil type (Cambisol). This soil type is levelled to mountainous terrain under a wide range of vegetation types. It can be seen commonly in the areas with active geologic erosion where they may occur in association with mature tropical soils [22]. On the other aspect, the rising inland erosion rate increases the load of sediment in the river. The accumulation of sediment load caused by erosion and channel degradation transported to the outlet of Prek Thnot with a value of approximately 0.5 million tons after deposition along the channel.

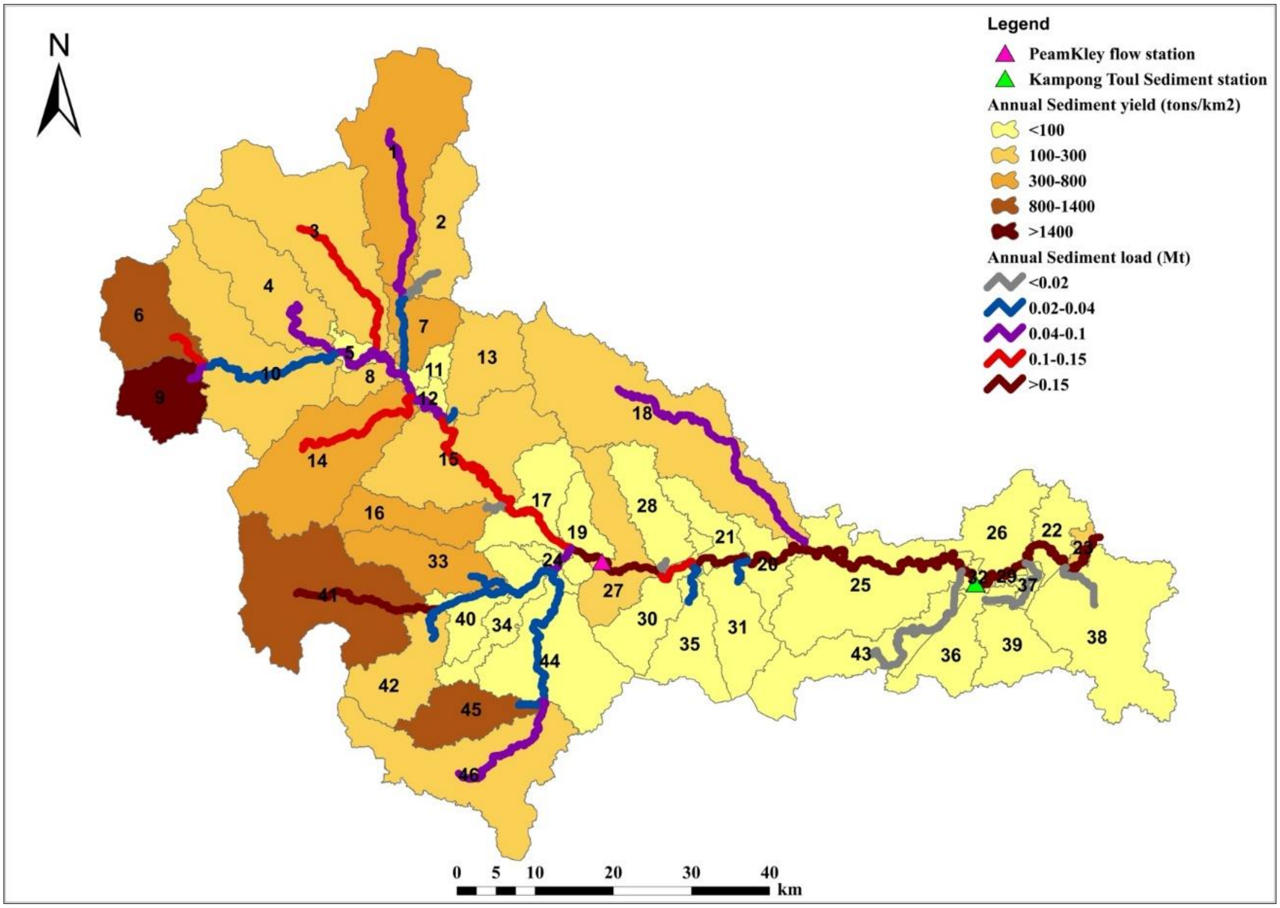

Fig. 13. Mean annual sediment load (Mt/year) and annual sediment yield (t/km^2/year) for the Prek Thnot river sub-basins

4 CONCLUSIONS

This study is a preliminary attempt to simulate monthly discharge and sediment load in Prek Thnot river basin. The objective of this study was to assess the most soil erosive prone area in the catchment by using the SWAT model. The availability of limited data input degraded the model performance to some extent. Even so, the SWAT model still provided a good agreement between simulated and observed data, which is applicable for estimating sediment. From the analysis of the SWAT model from 1997 to 2011, the most eroded area falls under loamy soil type and forest land cover. The sediment yields entirely varied by surface runoff rate and water yield. In 2001, approximately 0.46 million tons of sediment were transported into the Prek Thnot river by nearly 900 m^3/s which was the highest peak in this study. However, the SWAT model was unable to identify the reasons of the occurring soil erosion. The spatial pattern of erosion rate in average from 1997 to 2011 in Prek Thnot river basin showed the most erosive zone in sub-basin number 9 located at the upstream covering the area of 91.78 km^2. This sub-basin is covered by forest and contributed to 1.64% of the watershed with the sediment yield of 2205 tons/km^2. Furthermore, this sub-basin has high surface runoff to transport sediment to the stream. The rising inland sediment yield increases the load of sediment in the river. The accumulation of sediment load caused by erosion and channel degradation transported to the outlet of Prek Thnot with an average value of 0.2 million tons annually after deposition along the channel. Hence, it is essential to recognize the most erosion-prone area in the whole Prek Thnot basin to identify soil type and land use conditions whose properties are mainly responsible for causing erosion. The impact of soil erosion on the upstream dams should be considered.

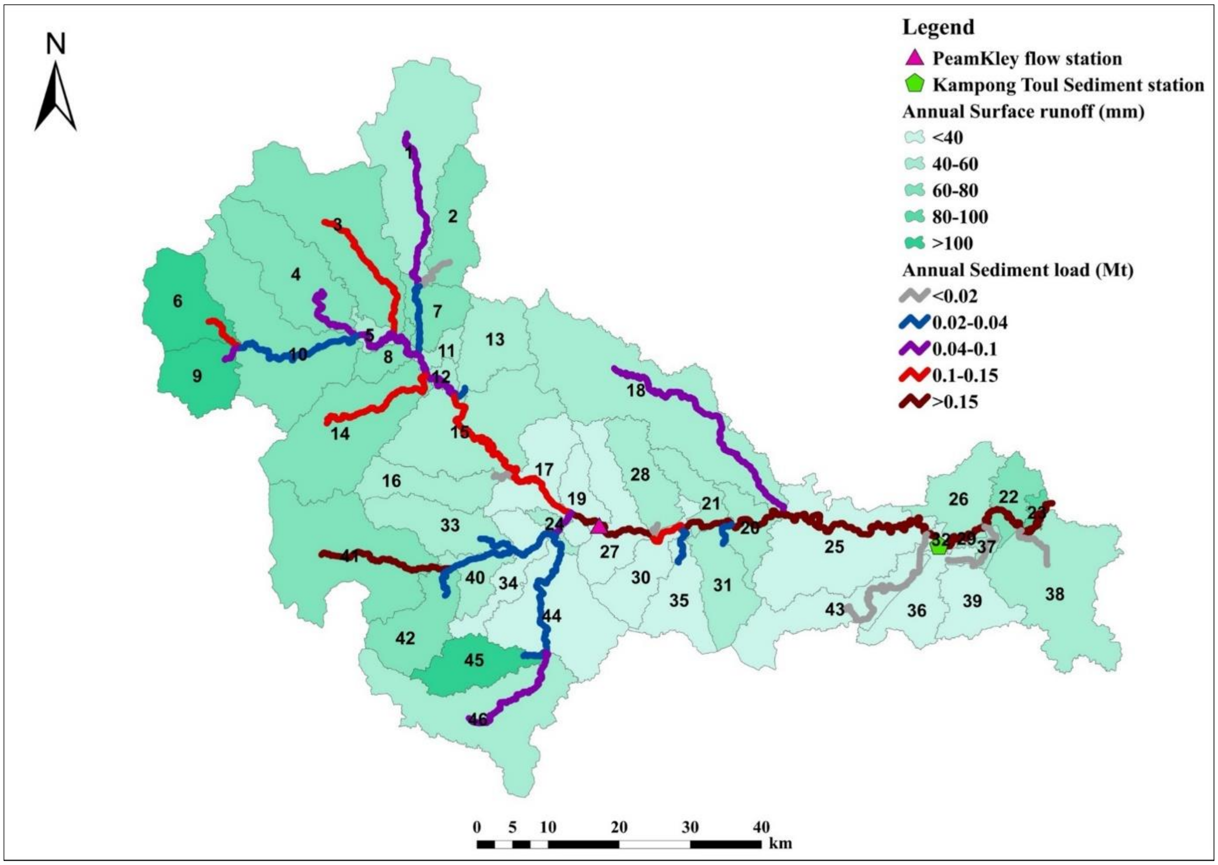

Fig. 14. Mean annual surface runoff (mm) and annual sediment load (Mt/year) for the Prek Thnot river major sub-basins

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