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Impact of Climate Change on Sediment and Nitrate Loads in Prek Thnot River basin of the Lower Mekong River

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Abstract: *Global climate change is cumulatively a significant driver of global environmental changes such as flow regime, sediment, and nitrate. Thus, this study aims to estimate changes in sediment and nitrate loads under future climate change scenarios by using SWAT model in Prek Thnot river basin, Cambodia, and a tributary of the Lower Mekong River. The study included three different models (GCMs) under two emission scenarios (RCPs) for two-time horizons which are 2030s (2021-2040 as the medium-term future) and 2060s (2051-2070 as the medium-term future). As the result, the annual baseline sediment load had an average of 0.093 Mt/year and the average annual baseline sediment yield in Prek Thnot river basin is 186 tons/Km^2/year. Likewise, for annual nitrate load have around 440 tons/year of each sub-basin and nitrate yield over the watershed has an average of ~100 kg/Km^2/year. Furthermore, sediment yield rate in this tropical basin is depending on the slope class whereas nitrate yield follows as land use land cover rather than slope class according to our results, sediment yield gets increasing in high-slope and nitrate yield is higher in agriculture areas because nitrate concentration in fertilizer. Under the difference RCPs and GCMs, sediment loads are expected to be monthly affected in May. The change direction (increase/decrease) will be depending on GCMs rather than RCPs and time horizons where sediment ss would be increased from baseline in May for only model RCP8.5GFDL and RCP2.6GFDL while other models expected to decline for both time horizons (2030s and 2060s). However, RCPs and time horizons are expected to determine the magnitude of change. Nitrate loads in May are predicted to decrease for all models, RCPs, and time horizons.*

Keywords: Climate change; Sediment transport; Nitrate; Prek Thnot river; SWAT

1. INTRODUCTION

Population growth and urban development are affecting land use, and ecosystem services, including the supply of freshwater [1]. Human activities, as well as natural events that occur in a watershed, can affect water quality [2]. Over these few decades, there is much more population growth, so there is a huge climate change. Climate change is known as a main major driving factor of the flow regime [3] and Runoff is extremely important in that not only does it keep rivers and lakes full of water, but it also changes the landscape through the action of erosions it flows over the land surface, stormwater picks up potential pollutants that may include sediment, nutrients (from lawn fertilizers), bacteria (from animal and human waste), pesticides (from lawn and garden chemicals), metals (from rooftops and roadways), and petroleum by-products (from leaking vehicles). Runoff from agricultural land filed could carry amount excessive nutrients, such as nitrogen into streams, and lakes. Sediment transport is the movement of particles that may be purely due to gravity and sediment loads particles have been transported by water flow [4]. It is the result of the flow of water, wind, ice, or a dense mixture of sediments and water [5]. Moreover, the water also brings sediment to the river over the floodplain area of the river when flooding occurs [6].

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Generally, sediment loads affect biodiversity because dissolved nutrients are transported with the water and it adsorbed to sediments are allowed to be deposited with the sediment on the bed of the channel [7] , as example sediment concentration is trapped can cause declining nutrients which is the sources of fish and others aquatic species [8]. It affects the heat balances of water, shades out aquatic plants, abrades contractions in the stream, and interferes with the life process of aquatic organisms [9]. The sources of nutrients in river or lake systems are mostly fertilizer application in agriculture, wastewater treatment effluent, and burning processes via deposition of gaseous nitrogen [10]. The application amounts of nitrogen fertilizers at higher than crop uptake requirement rate in intensive agricultural regions of the plain would contribute to excessive nitrate accumulation in soils and leaching into groundwater and water bodies [11]. And nitrate will be toxic to aquatic and water quality when the concentrations of nitrate increase and exposure times. Recently, nitrate contamination has become a significant environmental concern, with many parts of the world now reporting nitrate pollution on surface water [12].

Climate changes are cumulatively a significant driver of global environmental changes [13]. Water resource managers must consider the potential impacts of climate change and global warming, which could further stress water availability for human use and natural ecosystems on large scale [14]. In 2018, the Intergovernmental Panel on Climate Changes (IPCC) pointed out that the global average temperature has risen by nearly 1.5°C, and it was predicted that it would be increased by another 1.1-6.4°C in 2100. Climate warming has not only directly affected extreme temperature fluctuations but also increase the frequency and intensity of extreme weather, such as high temperatures, droughts, rainstorms, and floods, especially in areas sensitive and vulnerable to climate changes.

Cambodia is considered one of the most vulnerable countries to the negative impacts of climate change due to the lack of disaster management measures. Thus, Prek Thnot river basin experienced floods which cause by climate change. And it is necessary to take into consideration on climate change factor. This concern can change water characteristics and water quality. It can affect people living along Prek Thnot river basin since it is one of the most important watersheds in Cambodia. It also supports livelihoods throughout the catchment contributing to economic growth in southwestern Cambodia. Likewise, the Mekong River basin will get harmful also because it is a tributary of the Mekong River. Moreover, we have been chosen SWAT model for this study to simulate nutrients in the Prek Thnot catchment because SWAT is widely used in most case studies in Cambodia such as assessment flow and sediment loads as well as nitrate, especially nitrate and phosphorus in the Mekong River basin and 3S (Sesan, Srepok and Sekong) basin, Tonle Sap Lake [15,16]. Hence, SWAT is chosen in the study for assessment of sediment and nitrate transport in Prek Thnot river basin but [17] refer to the detail of assessment of water discharge, sediment and nitrate in Prek Thnot river basin and model performances in the basin. This study aims to estimate the spatial variation of sediment and nitrate in Prek Thnot river basin and the seasonal change of its under future climate change scenarios.

2. METHODOLOGY

2.1 Prek Thnot river basin

Prek Thnot River basin, one of the main tributaries of the Mekong River in Cambodia (Fig. 1) has been chosen as the study area in this case where is covered five provinces such as Koh Kong, Kampong Speu, Kampot, Takeo, Kandal, and Phnom Penh. It lies between latitude 11000’ to 12°10’N and longitude 103°46’20” to 105°00’E [18]. Additionally, its length is about 232 km and has a total catchment area of 5,050 km^2 which is headwaters located in Kravanh Mountain in the western part of Phnom Penh [19]. 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 highest elevation at 1,815 m above means sea level. Furthermore, the Prek Thnot River flows from the Cardamom Mountains east through Kampong Speu and Kandal provinces south of Phnom Penh and empties into the Tonle Bassac tributary of the Mekong [20]. Additionally, it is experienced a tropical monsoon climate in which the rainy season starts from May to October and the dry season from November to April [20]. The average annual rainfall, recorded in the basin, is approximately 1,225 mm, with the rainy season receiving over 90% of precipitation [21].

In 1991, land use in the basin consisted of forests (67.7%), paddy fields (20.6%), other agriculture (6.6%), and urban areas (0.2%) whereas 85% of the total area in the dry season is Agricultural area, especially for rice farming [22]. Especially, Prek Thnot Dam has been constructed in Cambodia upstream of Prek Thnot river within many arguments called Tasal Dam but it is not considered in our case study since it is difficult to access the data and we have not enough time to include it in our model.

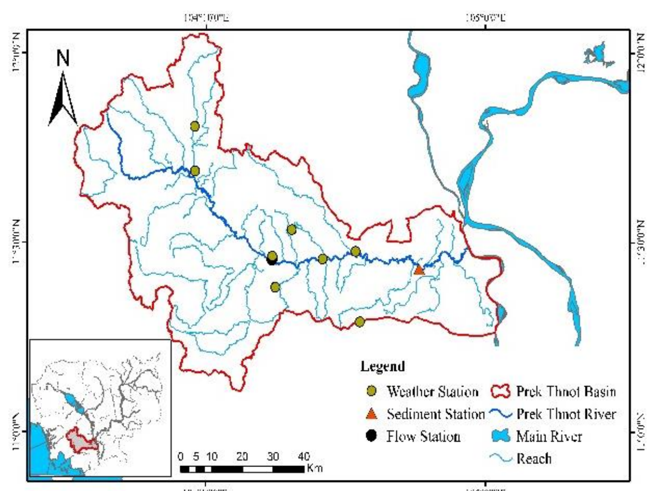

Fig. 1. Rain gauges and water quality station in Prek Thnot river basin

2.2 SWAT model

Soil and Water Assessment Tool (SWAT) was developed by USDA Agriculture Research Service (ARS) for nearly 30 years [23] and was selected to assess the impacts of climate change on sediment and nitrate loads in this case study. SWAT is a physically-based, continuous-time, long-term, semi-distributed, agro-hydrological simulation model for daily time steps and SWAT interface with ArcGIS [24]. Moreover, SWAT is used to simulate flow rate in the catchment as temporal and spatial variation in a catchment, sediment transportation, and nutrient movement through watershed management [24]. And SWAT can analyze small or large catchments by discretizing them into subbasins, which are then further subdivided into hydrological response units (HRUs) with homogeneous land use, soil type and slope. The authors refers to Neitsch et al. [25] for a detailed description of the model and to Khen et al. [17] for detail of model inputs and their application to the Prek Thnot river basin to simulate flow rates and sediment yield.

The calibration and validation were carried out and done for the simulation of discharge and sediment loads of the model by modifying sensitive parameters to obtain a good performance of observed and predicted values. Therefore, the sediment loads and yield was assessed after getting satisfactory results [17] before the process of nitrate calibration and validation. The result for nitrate model performance with satisfactory result to process the assessment. The simulation flow was carried out for 16 years from 2000 to 2010 where the observed location flow is at the Peam Khley station in Kompong Speu province. The monthly flow calibration period is 5 years from 2000 to 2005 and the validation period from 2007 to 2010 within lack of data in the middle of August 2005 to January 2007. The calibration period of sediment and nitrate loads in Prek Thnot river basin has four years from 1997 to 2000 while the validation period has three years from 2001 up to 2003 and its observed station is located at Kompong Toul. The model performance of flow, sediment and nitrate loads are shown in Table 1 which is the acceptable results.

2.3 Future climate change scenarios and downscaling

An increase in the concentration of greenhouse gases and aerosols from anthropogenic which can change substantially in the 21st century as the evidence [26]. Climate warming has not only directly affected extreme temperature fluctuations but also increase the frequency and intensity of extreme weather, such as high temperatures, droughts, rainstorms, and floods, especially in areas sensitive and vulnerable to climate changes [27]. Thus, there are climate models within four Representative Concentration Pathway (RCP) scenarios that developed as a basis for the Couple Model Intercomparison Project phase 5 (CMIP5) long-term and short-term modelling [4]. RCPs have been developed by the International Geosphere-Biosphere Program's earth system modelling project, the World Climate Research Programmer's Working Group on Couple Modelling (WGCM), and the integrated assessment Modelling Consortium coordinator that there are four scenarios such as the lowest forcing level scenario RCP2.6, two medium stabilization scenario (RCP4.5 and RCP6) and the highest forcing scenario RCP8.5 [28].

When modelling the impact of climate change within SWAT, global coupled ocean-atmosphere general circulation models (GCM) are used to simulate future meteorological variables. GCMs are mathematical models developed to examine the Earth's climate. Various GCMs have been developed by many institutions to analyze the upcoming future impact of climate change on Earth [29]. GCMs are used to generate large-scale climate scenarios. When performing an impact assessment on a smaller region, it is necessary to downscale the outputs from the GCMs. The development of climate change scenarios was based on multiple Global Circulation Models (GCMs), emission scenarios, time horizons and locations. The uncertainty associated with the different GCMs has been previously identified as the most significant source of uncertainty in flow and sediment modelling. Three-time horizons (near-term future 2021–2040, medium-term future 2051–2070 were considered in this study, as these time horizons are being used by the MRC in other planning contexts. Based on the study by MRC report, three GCMs (GISS-E2-R-CC, IPSL-CM5-MR, and GFDL-CM3) (Table 1).

Downscaled climate change data sets (IPCC 5th Assessment Report) were obtained from the MRC Climate Change and Adaptation Initiative (CCAI). This dataset includes the SWAT model ready monthly 'change factors' for precipitation, temperature, solar radiation and relative humidity. MRC CCAI uses SIMCLIM software to downscale the climate. SimCLIM uses pattern scaling plus bilinear interpolation algorithm to downscale the GCM outputs. MRC CCAI uses change factors to quantify the projected alterations to climate because the change factor approach represents the simplest and most practical way to produce scenarios based on multiple GCMs, emission scenarios, sensitivities, time horizons and locations.

3. RESULTS AND DISCUSSION

3.1 Sediment loads and yield

The calibration and validation were carried out and done for the simulation of discharge and sediment loads of the model by modifying sensitive parameters to obtain the best performance of observed and predicted values. Therefore, sediment yield has approximately 186 tons/km^2/year (Fig. 2). Additionally, the large amount of sediment yield mostly occurs in the upper part of Prek Thnot river basin more than 50 tons/km^2/year whereas the lower part has a low sediment yield which is lower than 50 tons/km^2/year.

Fig. 3 and 4, express the relationship information of Land use/Land cover (LULC), slope and sediment yield over Prek Thnot river basin. Fig. 3, there is less amount of sediment yield in deciduous (DECD) and agricultural land the sediment loads and yield was assessed after getting satisfactory results [17] before the process of nitrate calibration and validation. The result for nitrate model performance with satisfactory result to process the assessment. The average annual sediment load in Prek Thnot river basin is about 0.093 Mt/year. A spatial variation of annual even though there are a large area in Prek Thnot river basin about 37.33% of total catchment and 31.54%, respectively. while Mixed evergreen and deciduous medium-low density (MEDM) and evergreen high cover density (EHCD) have a very small area but there is the highest sediment yield, as an average have about 1100 tons/km^2/year and 900 tons/km^2/year. According to Fig. 4, sediment yield in Prek Thnot river basin increases based on slope class since the first group (0-3%) has sediment yield lower than 100 tons/km^2/year whereas the fifth group (>60.9%) (0.85% of total area) have more than 2500 tons/km^2/year. Hence, there is a very high sediment yield in MEDM and EHCD can cause slope class because these two land use types appear in the upper part of Prek Thnot (higher slope).

Table 1 Model performance of flow, sediment and nitrate

Statistical indicators	Calibration			Validation		
	Flow (2000-2005)	Sediment (1997-2000)	Nitrate (1997-2000)	Flow (2007-2010)	Sediment (2001-2003)	Nitrate (2001-2003)
NSE	0.84	0.51	0.55	0.7	0.76	0.55
R^2	0.86	0.79	0.57	0.72	0.85	0.72
PBIAS	-2.17%	23.61%	14.10%	-7.46%	13.89%	25.18%
RSR	0.4	0.7	0.67	0.7	0.49	0.67

Table 2 Climate change scenarios used for extreme analysis

Emission scenarios	Emission rate	GCMs model	Pattern of change
RCP2.6	Low	GFDL-CM3 GISS-E2-R-CC PSL-CM5A-MR	Wetter overall Drier overall Increased seasonal variability
RCP8.5	High	GFDL-CM3 GISS-E2-R-CC PSL-CM5A-MR	Wetter overall Drier overall Increased seasonal variability

1

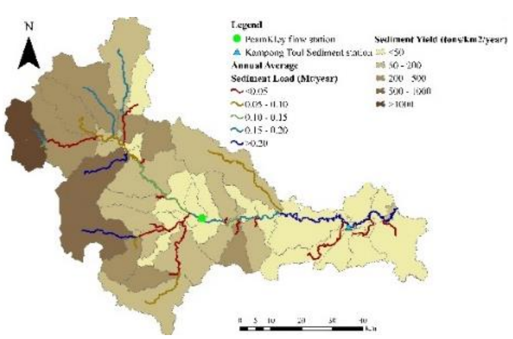

Fig. 2. Sediment loads and yield in Prek Thnot river basin

3.3 Nitrate loads and yield

Based on Fig. 5, nitrate loads in the basin have about 440 tons/year of each sub-basin as an average. In detail, nitrate loads in the upper part of the stream are noticed as less than 200 tons/year while near the outlet is higher (more than 1500 tons/year). Besides, nitrate yield over watershed has an average of about 100 kg/km^2/year. Most upstream have nitrate yield of less than 50 kg/km^2/year while the middle of the watershed was more than 150 kg/km^2/year. And the lower part of the basin varies from 50 to 150 kg/km^2/year. Nitrate loads and yield reverse to sediment which is less in the upper part, but it is noticed higher in the middle and the lower of the catchment.

Table 2 shows how nitrate changed in each slope class and LULC type. It means at the same slope class how nitrate yield differs in each land use type. This table has been calculated by estimating the average nitrate yield in each slope and each LULC type so we can know how it changes. As a result, nitrate yield rise as slope class since the value in each LULC type increases based on slope class increases. Thus, slope class also affects nitrate yield in Prek Thnot river basin (Table 2). On the other hand, nitrate yield was very high in AGRI, deciduous mosaic (DCMS) and urban area (URBN) approximately 212, 154 and 108 tons/km^2/year.

Overall, agricultural land has the largest nitrate among another land-use type in Prek Thnot river basin so the agricultural land impact nitrate yield in the catchment mostly. Moreover, agricultural land is the main part area in the lower part of the basin that is the cause of higher nitrate yield and loads downstream.

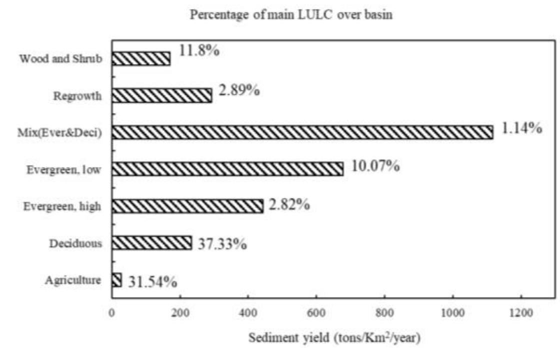

Fig. 3. Average annual nitrate yields in each main LULC

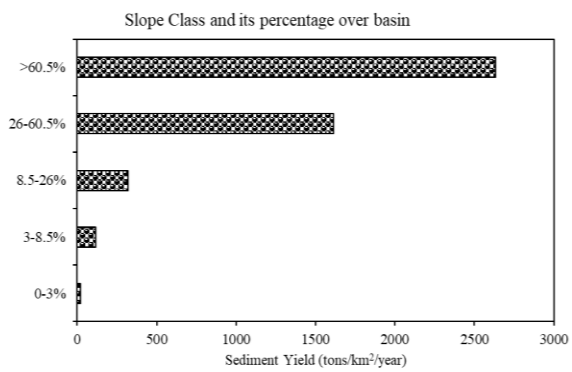

Fig. 4. Average annual nitrate yields for each slope class

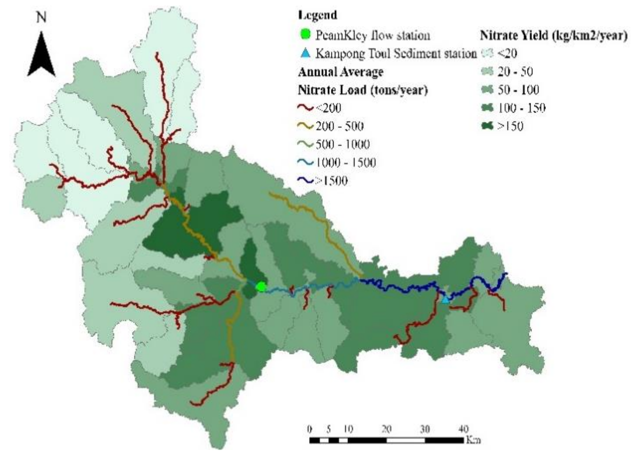

Fig.5. Nitrate loads and yield in Prek Thnot river basin

3.4 Future Climate Change on Sediment and Nitrate Loads

Future climate change scenarios on sediment loads have been considered for the lower emissions scenarios RCP2.6 and the higher emissions scenarios RCP8.5 which have three models included GFDL, GISS and IPSL by comparing the average monthly sediment loads between the baseline (1997-2003) and two different future periods which is the future time horizons 2030s (2021-2040) and 2060s (2051-2070). The peak sediment loads of baseline occur in October (rainy season) about 0.11 Mt/month within a very low amount in the dry season.

Table 3 Average annual nitrate yield of each LULC and slope class

LULC	Nitrate yield of each slope class					Nitrate yield (tons/km²/year)
	0-3%	3-8.5%	8.5-26%	26-60.5%	>60.5%	
Agricultural land-intensive	161.5	-	271.3	-	203.5	212.1
Crop mosaic, cropping area <30	8.0	-	43.0	-	96.0	49.0
Deciduous mosaic	95.0	-	189.0	-	178.0	154.0
Deciduous	40.2	10.8	72.7	-	104.4	66.7
Evergreen, high cover density	0.0	11.0	2.5	14.8	6.2	9.7
Evergreen,medium-low cover density	34.8	28.0	44.5	35.6	64.6	45.0
Evergreen mosaic	76.5	-	122.0	-	127.5	108.7
Grassland	37.3	-	65.0	-	81.0	59.3
Inundated	39.0	-	74.5	-	87.5	67.0
Mixed(evgreen&deciduous) med-low cover density	23.8	10.7	39.3	-	56.3	33.9
Regrowth	32.7	7.8	57.2	-	62.4	46.5
Urban or built-over area	65.5	-	122.5	-	137.5	108.5
Wood- and shrubland, dry	34.4	39.8	53.2	11.6	58.7	47.4
Wood- and shrubland, evergreen	24.3	32.8	35.8	8.0	35.0	31.2
Wood- and shrubland, inundated	23.0	-	44.3	-	85.0	41.0

The percentages change of each future climate change scenario for all models in both time horizons (2030s and 2060s) have no significant change in the rainy season and early dry season but there are huge changes in the dry season especially December till April 2030s, changes of sediment loads in March are the highest for all models which RCP8.5GFDL and RCP2.6GFDL predicted to increase about 140% and 30%, respectively while others four models expected to decrease (Fig. 6). Increasing sediment loads are affected by wetter overall for GFDL model so this might cause this trend of change. Likewise, sediment is expected to be more increase in 2030s for RCP8.5GFDL. Additionally, there is no necessary change compared to other months in the dry season which there are RCP8.5GFDL and RCP2.6GFDL expected to rise a bit but RCP8.5IPSL and RCP8.5GISS are predicted to decrease by about 20%. There are only RCP8.5GFDL and RCP2.6GFDL would be an increase in 2030s and more increase in 2060s (Fig. 7) from baseline in May while other models expected to decline.

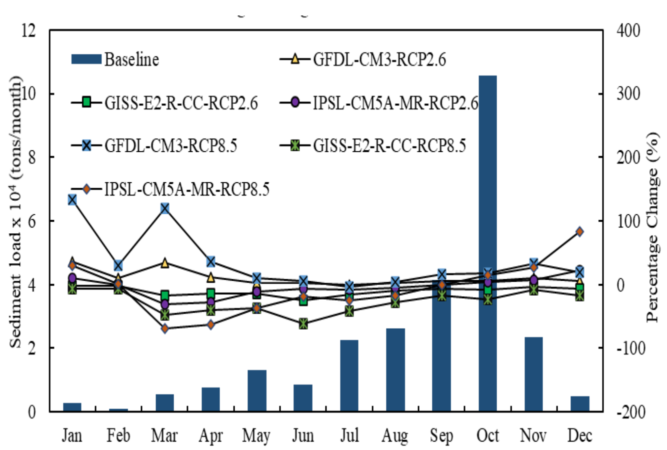

Fig. 6. Sediment loads and percentages under future climate change 2030s

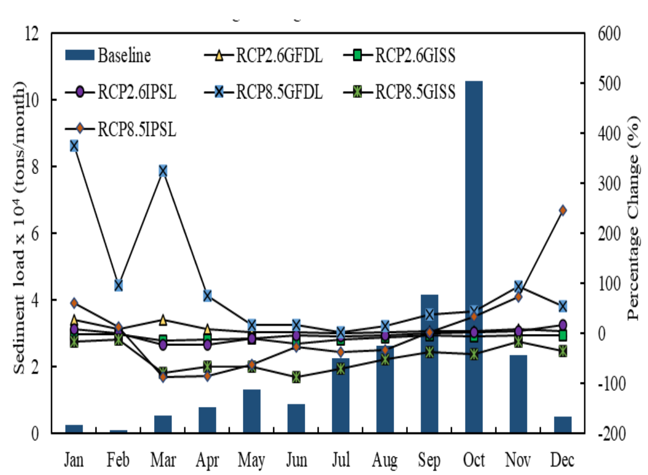

Fig. 7. Sediment loads and percentages under future climate change 2060s

Fig. 8, the peak point of nitrate loads was nitrate loads about 110 tons/month of baseline. As the result, there are not many differences in nitrate loads under future climate change scenarios in the rainy season especially from July to October while it was changed much from baseline in March for 2030s and 2060s. Based on graph percentages change of nitrate, it is noticed that RCP8.5GFDL increases in two-time horizons (2030s and 2060s) but there are more serious in 2060s than 2030s. For May in 2030s and 2060s, nitrate loads are expected to decrease from baseline and in 2060s are predicted to be more decrease than in 2030s for all models (Fig. 9).

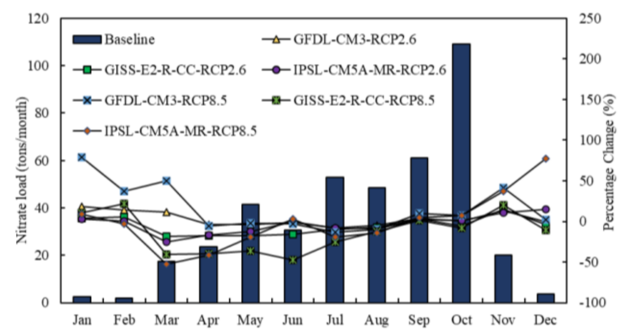

Fig. 8. Nitrate loads and percentages under future climate change 2030s

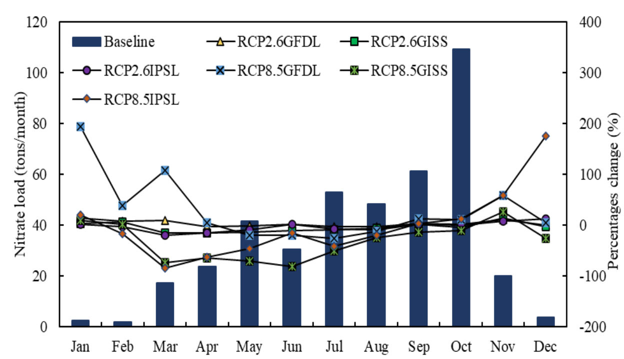

Fig. 9. Nitrate loads and percentages under future climate change 2060s

4. CONCLUSIONS

This study aims to assess objectives: spatial variation of sediment and nitrate in Prek Thnot river basin, another objective to estimate the change of sediment and nitrate loads under future climate change scenarios. The average annual sediment loads have about 0.093 Mt/year and nitrate loads are around 440 tons/year. Moreover, the average annual sediment yields approximately 200 tons/km^2/year and nitrate yields 100 kg/km^2/year, which is very high upstream while very low in the downstream part. High sediment yield presents at high slope whereas it has low sediment yield at gentle slope class. Sediment yield is very high in evergreen and deciduous which is not in agricultural land because mostly evergreen and deciduous occurs in high slope class rather than gentle slope whereas agricultural land located on a gentle slope. Additionally, nitrate loads in the basin have about 440 tons/year on average, and nitrate yield over the watershed has an average of about 100 $kg/km^2/year$ the downstream which is higher than the upstream part opposite to sediment in the basin. Moreover, nitrate occurs in agricultural land rather than in other types. For sediment loads under future climate change scenarios would be an increase in 2030s and more increase in 2060s from baseline in May for only model RCP8.5GFDL and RCP2.6GFDL while other models expected to decline. And nitrate loads in Prek Thnot river basin is expected to decrease from baseline and 2060s predicted to be more decrease than 2030s for all model in May in 2030s and 2060s. The perspective of this study on land-use change would be included in the next study since there is a huge development in diverse sectors that there will be significant land-use change over there.

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