



The effects of climate variability and land-use change on streamflow and nutrient loadings in the Sesan, Sekong, and Srepok (3S) River Basin of the Lower Mekong Basin

Dao Nguyen Khoi^{1,2} · Pham Thi Loi^{1,2} · Nguyen Thi Thuy Trang^{1,2} · Nguyen Dinh Vuong³ · Shibo Fang⁴ · Pham Thi Thao Nhi^{1,2,5}

Received: 9 December 2020 / Accepted: 25 August 2021 / Published online: 31 August 2021
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

Abstract

This paper aimed at examining the climate variability and land-use change effects on streamflow and pollutant loadings, namely total suspended sediment (TSS), total nitrogen (T-N), and total phosphorus (T-P), in the Sesan, Sekong, and Srepok (3S) River Basin in the period 1981–2010. The well-calibrated and validated Soil and Water Assessment Tool (SWAT) was used for this purpose. Compared to the reference period, climate variability was found to be responsible to a 1.00% increase in streamflow, 2.91% increase in TSS loading, 11.35% increase in T-N loading, and 19.12% reduction in T-P loading for the whole basin. With regard to the effect of land-use change (LUC), streamflow, TSS, T-N, and T-P loadings increased by 0.01%, 3.70%, 10.12%, and 10.94%, respectively. Therefore, the combination of climate variability and LUC showed amplified increases in streamflow (1.03%), TSS loading (7.09%), and T-N loading (25.05%), and a net effect of decreased T-P loading (10.35%). Regarding the Sekong and Srepok River Basins, the streamflow, TSS, T-N and T-P showed stronger responses to climate variability compared to LUC. In case of the Sesan River Basin, LUC had an effect on water quantity and quality more strongly than the climate variability. In general, the findings of this work play an essential role in providing scientific information to effectively support decision makers in developing sustainable water resources management strategies in the study area.

Keywords Climate variability · Land-use change · Streamflow · Nutrient loading · 3S River Basin

Introduction

Water is one of the most essential and important resources for socioeconomic development and ecosystem conservation (Fu

et al., 2018). Recently, freshwater resources in many regions of the world have deteriorated in terms of quality and quantity due to environmental stressors, namely population growth, urbanization, deforestation, agricultural development, land-use change (LUC), and climate change (Bastia and Equeenuddin, 2016; Hoang et al., 2016; Whitehead et al., 2015). Among them, climate change and LUC have been identified as two important drivers affecting water resources. Climate variability can significantly alter the volume and distribution of local precipitation, affect temperatures and as a result cause changes in hydrological processes and river flow regimes, including low- and peak-flow (Tomer and Schilling, 2009; Wang et al., 2008). The changes in hydrological processes then lead to changes in the transformation and transport features of sediment and nutrient yields. The losses of sediment and nutrient loadings in the catchment can be attributed to changes in soil and water processes as a consequence of climate variability (Buda and DeWalle, 2009; Oeurng, Sauvage and Sánchez-Pérez, 2010). Moreover, changes in land-use types can affect the hydrological components,

Responsible editor: Philippe Garrigues

✉ Dao Nguyen Khoi
dnkhoi86@gmail.com; dnkhoi@hcmus.edu.vn

- ¹ University of Science, 227 Nguyen Van Cu Str., Dist. 5, Ho Chi Minh City, Vietnam
- ² Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc Dist, Ho Chi Minh City, Vietnam
- ³ Southern Institute of Water Resources Research, 658 Vo Van Kiet Str., Dist. 5, Ho Chi Minh City, Vietnam
- ⁴ Institution of Ecological and Agricultural Meteorology, Chinese Academy of Meteorological Sciences, Beijing 100081, PR China
- ⁵ Institute for Computational Science and Technology, Ho Chi Minh City 700000, Vietnam

including evapotranspiration, infiltration, base flow, and surface runoff, as well as soil erosion and degradation (Brodie and Mitchell 2005; Brath et al. 2006; Buytaert et al. 2006; Li et al. 2009; Wan et al. 2014). Delkash et al. (2018) indicated that expansion of agricultural land usually enhances sediment and nutrient loadings more than forest land and shrub land. As proven in many studies at the basin level, water quality parameters and LUC are strongly related (Du Plessis et al. 2014). In general, climate variability and LUC indirectly alter the sediment and nutrient loading through changes in hydrological processes.

Numerous studies have explored the individual and joint effects of climate change and LUC on hydrology and water quality in many different basins around the world. Some studies have found climate change to be the main driver influencing water quality and quantity. For instance, Tan et al. (2015) stated that climate change caused an increase in annual streamflow of the Johor River in Malaysia by 2.9%, while deforestation and the massive expansion of oil palm plantations only contributed to an increase of 0.1%. Fu et al. (2019) reported that the streamflow of the Woken River (Loess Plateau region, China) changed by -39.1% due to climate change and 2.2% due to LUC. Op de Hipt et al. (2019) indicated that climate variability had a larger effect on flow and sediment yield compared to LUC in the Dano catchment in Burkina Faso (West Africa). On the other hand, some researchers have discovered that LUC had a larger impact on water resources than climate change. Specifically, Pirmia et al. (2019) indicated that climate change and LUC contributed to approximately 35% and 65% changes in discharge, respectively, in the Haraz River Basin in Iran. Wu et al. (2019) showed that the contributions to streamflow change due to climate change and human activities were 36% and 64%, respectively, for the Beijiang River during the period 2003–2012. Therefore, it is undeniable that the climate change and LUC effects on water quantity and quality are different depending on the geographic location of the observed area. For this reason, it is necessary to quantify the impact of climate change and LUC on water parameters in specific basins.

There are some popular approaches which have applied to explore the responses of water resources to climate change and human activities, including field investigation, pair catchment approach, statistical analysis, and hydrological modeling (López-Moreno et al. 2011; Wei et al. 2013). The field investigation and pair catchment approaches are recognized as time-consuming and only appropriate for small basins (Li et al. 2009). Analyzing the hydro-climatic observed data is not only unsuited for calculating the physical processes of the watershed but is also unsuited for separating impacts of

the driving factors (Wei et al. 2013). Thus, the hydrological model was selected for the present work because of its advantages in scenario analysis to identify individual and joint effects of environmental factors. There are numerous hydrological models, such as the SWIM (Soil and Water Integrated Model), RHESSys (Regional Hydro-Ecologic Simulation System), HSPF (Hydrological Simulation Program-Fortran), AGNPS (Agricultural Non-Point Source Pollution), and SWAT (Soil and Water Assessment Tool). Among these hydrological model, the SWAT is proven as an effective tool and has been successfully applied worldwide, with more than 3800 studies (https://www.card.iastate.edu/swat_articles/), including Southeast Asia region (Tan et al. 2019).

The Sesan, Sekong, and Srepok (3S) River Basin is the biggest tributary in the Lower Mekong Basin (LMB), and plays a crucial role in providing services of aquatic ecosystem. This basin are facing with the pressures of hydropower dams, LUC, and climate variability. Additionally, the 3S River Basin (3SRB) is recognized as one of most vulnerable areas to climate change in the Mekong River Basin (Hartman and Carlucci 2014). These pressures will have considerable influences on water resources of the 3SRB. Understanding the responses of hydrology and water quality to climate variability and LUC are important for sustainable water resource management and aquatic ecosystem conservation. Thus, the objective of this work was to examine the responses of streamflow and nutrient loadings to separately and jointly climate change and LUC in the 3SRB in the period of 1981–2010. The selected period of 30 years is satisfied for the purpose of the study proven by the previous studies (Khoi and Suetsugi 2014; Tan et al. 2015).

Study area

The 3S River Basin (3SRB) is shared by three countries, namely Vietnam (38% of the total basin area), Cambodia (33%), and Lao PDR (29%). The 3SRB is formed by three main rivers: Sekong, Sesan, and Srepok, and divided into three sub-basins, namely Sekong River Basin (Sekong RB), Sesan River Basin (Sesan RB), and Srepok River Basin (Srepok RB) (Fig. 1). The 3SRB has a total area of approximately 78,650 km² (accounting for approximately 10% of the Mekong River Basin) and contributes approximately 20% of Mekong's total annual flow (Adamson et al. 2009), 30% of the annual nitrate load (Oeurng et al. 2016), and large amounts of sediment with 10–25 Mt/year (Kondolf et al. 2014). Moreover, the 3SRB has been habitat of 40% of Mekong biodiversity. Specially, it has been found that 17 fish species only been in 3S basin, but nowhere else on the world (Baran et al. 2015). The basin is the home of 4.7 million dwellers (Constable 2015a). Agriculture and fisheries are two main economic activities in the study area. The 3SRB belongs to

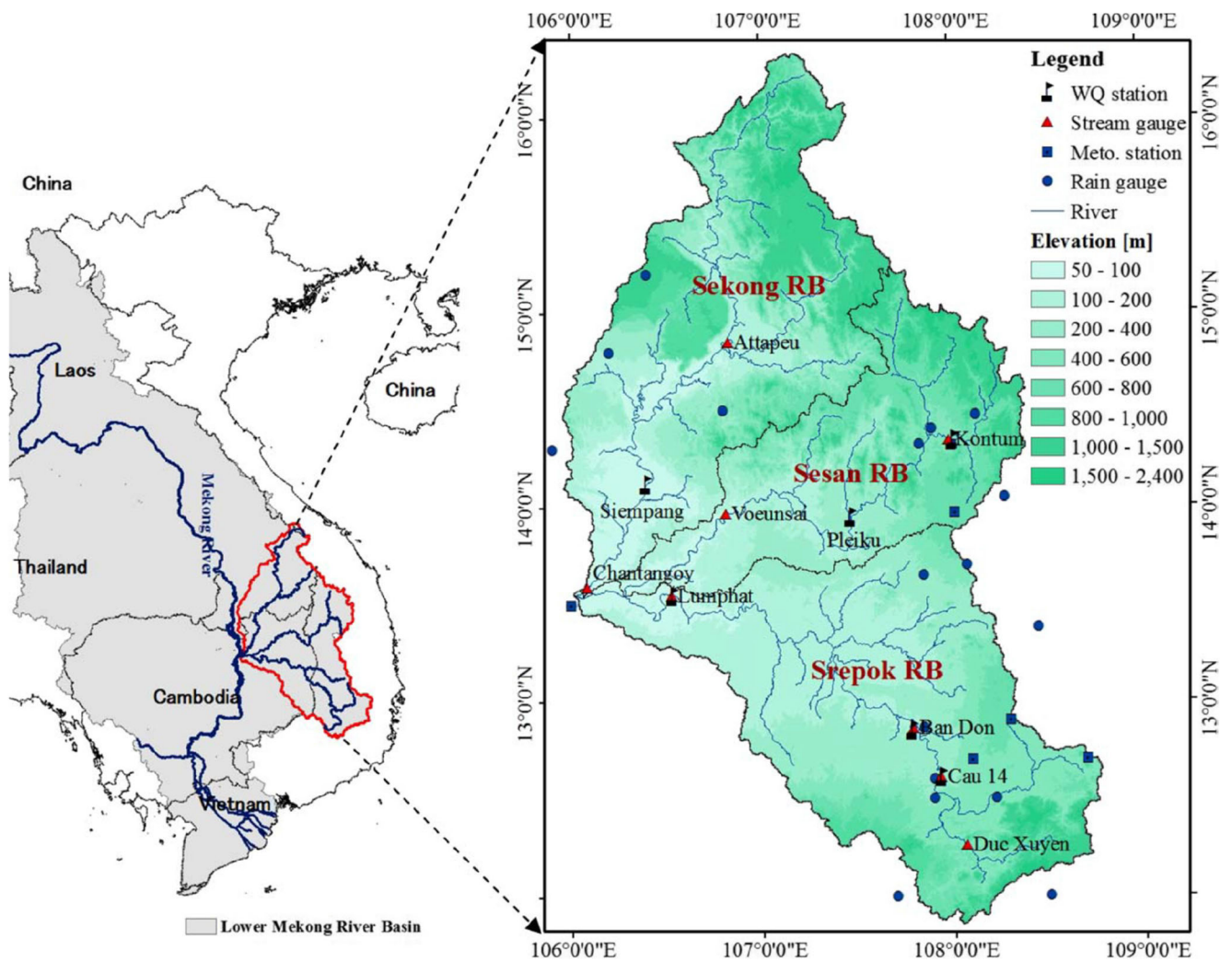


Fig. 1 The 3S River Basin and location of hydro-meteorological and water quality stations

the tropical monsoonal climate and has two distinct seasons. The rainy season begins in May and ends in October and accounts for about 80% of the basin’s annual rainfall of about 2600mm (MRC 2005). In the dry season, typically from November to April, the region is influenced by the northeast monsoon. Temperature varies from 19°C during the coldest period from November to February to up to 36°C during the warmest months of March and April in the period of 1981–2010.

The two main soil types in the 3SRB are aerosols and ferrosols provide great potential for agriculture, resulting in the large cultivated area in the Sesan RB and Srepok RB (Constable 2015b). Forest is the predominant land-use type in the 3SRB accounting for 83% of the entire basin in 1993, followed by a steady decline to 77% in 2003. The reduced area of forest resulted from an extension of the cultivated land area. The agricultural extension combined with hydropower dam construction and mining are also causes of riparian soil erosion and changes in sediment load (Someth et al., 2013; Constable 2015b).

Methods

Hydrological modelling (SWAT model)

The Soil and Water Assessment Tool (SWAT) is catchment scale model developed to predict the impact of land management practices and environmental changes on water, nutrient, pesticide, and sediment loads (Arnold et al., 1998). It is semi-distributed, physically based hydrological model. The SWAT can partition the basin into sub-basins. Within the sub-basin, hydrological response units (HRUs) are created by a unique combination of land use, soil type, and topography, where most of the soil and water processes are simulated and the routed to obtain the streamflow, sediment, and nutrient loadings (Neitsch et al. 2011). The SWAT aggregates land processes and channel systems for each sub-basin composing the catchment behavior.

The SWAT model uses the water balance equation of soil water to simulate the hydrological cycle Modified Universal Soil Loss Equation (MULSE) to simulate sediment yields.

Moreover, the interaction of five nitrogen and six phosphorus pools is considered in simulating the nutrient yield. More information about the SWAT model is provided in the SWAT Theoretical Documentation (Neitsch et al. 2011).

Input data and model setup

This work was conducted using the SWAT version 2012 with an interface supported by ArcGIS. The SWAT was set up for the 3SRB based on the input data listed in Table 1. The 3SRB was divided into 137 sub-basins with a threshold area of 12000 ha. The threshold area represents the smallest sub-basin area. Also, a threshold optimization to define HRU was defined, retaining information of more than 10% of the sub-basin area for land use, soil, and slope classifications—totalizing 837 HRUs. Then, the rain gauges and the weather stations were assigned to each sub-basins based on their proximity to centroids of the sub-basins. The simulation was run first for the reference period of 2000 to 2010 using the first year as a warm-up period to stabilize the model. The simulation results of SWAT model were calibrated and validated with approximately 9 years of discharge data (2000–2008), 9 years of TSS data (2000–2008), and 5 years of T-N and T-P data, using the Sequential Uncertainty Fitting version 2 (SUFI-2) method, which is implemented in SWAT-CUP 2012 (Abbaspour 2015). Depending on the data availability of discharge, TSS, and nutrient loadings, the calibration and validation periods were different.

Table 1 SWAT input data for the simulations hydrology and water quality in the 3SRB

Data type	Sources	Description/properties
Terrain	U.S. Geological Survey (USGS)	Digital elevation model with the spatial resolution of 250 × 250 m
Land use	Mekong River Commission (MRC)	Land-use types in 1993 and 2003 with the spatial resolution of 1 km
Soil	Food and Agriculture Organization (FAO)	Soil types and physical properties with the spatial resolution of 10 km
Weather	Mekong River Commission (MRC), Hydro-Meteorological Data Centre (HMDC)	Daily rainfall and maximum and minimum temperature in the period 1981–2010
Hydrology	Mekong River Commission (MRC), Hydro-Meteorological Data Centre (HMDC)	Daily discharged in the period 2000–2008
Water quality	Mekong River Commission (MRC), Hydro-Meteorological Data Centre (HMDC)	Monthly loadings of TSS, T-N, and T-P in the period 2000–2008

The simulation performance was evaluated by measuring the relationship between simulated and observed data. Two statistical indices, namely the Nash Sutcliffe efficiency (E_{NS}) and percent bias (PBIAS), were used for the SWAT performance assessment. In general term, the model is considered “satisfactory simulation” when E_{NS} values greater than 0.5 and PBIAS values within $\pm 25\%$ for hydrological simulation, and NSE values greater than 0.5 and PBIAS values within $\pm 55\%$ for water quality simulation (Moriassi et al. 2007).

Scenarios of climate variability and LUC

In order to evaluate the individual and joint effects of climate variability and LUC on the streamflow and water quality, the “one-element-at-a-time” approach was implemented using the well-calibrated SWAT model (Zhang et al. 2018). Based on this approach, the meteorological data were divided into two periods, of which the first period of 1981–1995 (representing the 1990s) and the second period of 1996–2010 (representing the 2000s). The changing point of 1995 was selected based on the hydro-meteorological data analysis in the Srepok RB conducted by Khoi and Thom (2015). For both time periods, the land-use types were represented by two land-use maps in 1993 and 2003, respectively. Four modeling scenarios were developed through the combinations of two periods of meteorological data and two land-use maps as follows: Scenario 0 (SN0)—meteorological data of the 1990s and land-use map in 1993, Scenario 1 (SN1)—meteorological data of the 2000s and land-use map in 1993, Scenario 2 (SN2)—meteorological data of the 1990s and land-use map in 2003, and Scenario 3 (SN3)—meteorological data of the 2000s and land-use map in 2003.

The SN0 was selected as the reference period. The variations of streamflow, TSS, and nutrient loadings due to climate variability, LUC, and combination of climate variability and LUC were estimated based on the difference of the simulation results of SN1, SN2, and SN3 to SN0.

Results and discussion

SWAT performance evaluation for the 3SRB

Performance of the calibrated SWAT model for simulation of daily streamflow was evaluated against observed data during 2000–2008. Streamflow calibration and validation statistics displayed the values of E_{NS} and PBIAS in the range of 0.53 to 0.89 and -12 to 18% for all gauging stations (Table 2). In general, the SWAT performance in simulations of streamflow was satisfactory in the 3SRB. Because the water quality data are discontinuous and limited, the SWAT calibration and validation in simulation of water quality were conducted for a short time period at monthly scale. The calibration and

Table 2 SWAT performance statistics for daily simulation of streamflow

Station	Period	Calibration (C)		Validation (V)	
		E_{NS}	PBIAS	E_{NS}	PBIAS
Kontum (Sesan RB)	C: 2000–2005 V: 2006–2008	0.56	6%	0.54	11%
Voensai (Sesan RB)	C: 2000–2002	0.86	18%	–	–
Chantangoy (Sekong RB)	C: 2000–2002	0.89	3%	–	–
Cau 14 (Srepok RB)	C: 2000–2005 V: 2006–2008	0.57	–4%	0.64	–2%
Bandon (Srepok RB)	C: 2000–2005 V: 2006–2008	0.62	–7%	0.74	–8%
Lumphat (Srepok RB)	C: 2000–2005 V: 2006–2008	0.55	9%	0.53	–12%

validation statistics for water quality simulations (TSS, T-N, and T-P loadings) showed the values of E_{NS} and PBIAS in the range of 0.53 to 0.94 and –30 to 33% for all gauging stations (Table 3). Overall, this satisfactorily calibrated SWAT model is applicable to differentiate the effects of climate variability and LUC on soil and water processes of the study area.

Contributions of climate variability and LUC to variations of streamflow, TSS, T-N, and T-P loadings

The effect of climate variability

Among the meteorological factors influencing hydrological regimes and nutrient cycles on the basin scale, rainfall and temperatures are considered to be two most important factors. The annual temperature was approximately 25.05°C in the 1990s. In comparison to the 1990s, annual temperature in the 3SRB exhibited a slight increase of 0.19°C in the 2000s. Regarding the precipitation, the annual rainfall in the 1990s

were 2046mm, 2458mm, 1996mm, and 1864mm for the entire basin, Sekong RB, Sesan RB, and Srepok RB, respectively. The analysis result reveals that annual rainfall increased by 1.08% for the entire basin, 0.32% for the Sekong RB, 6.23% for the Sesan RB in the 2000s with respect to the 1990s. However, a 1.79% decrease in annual rainfall was observed in the Srepok RB.

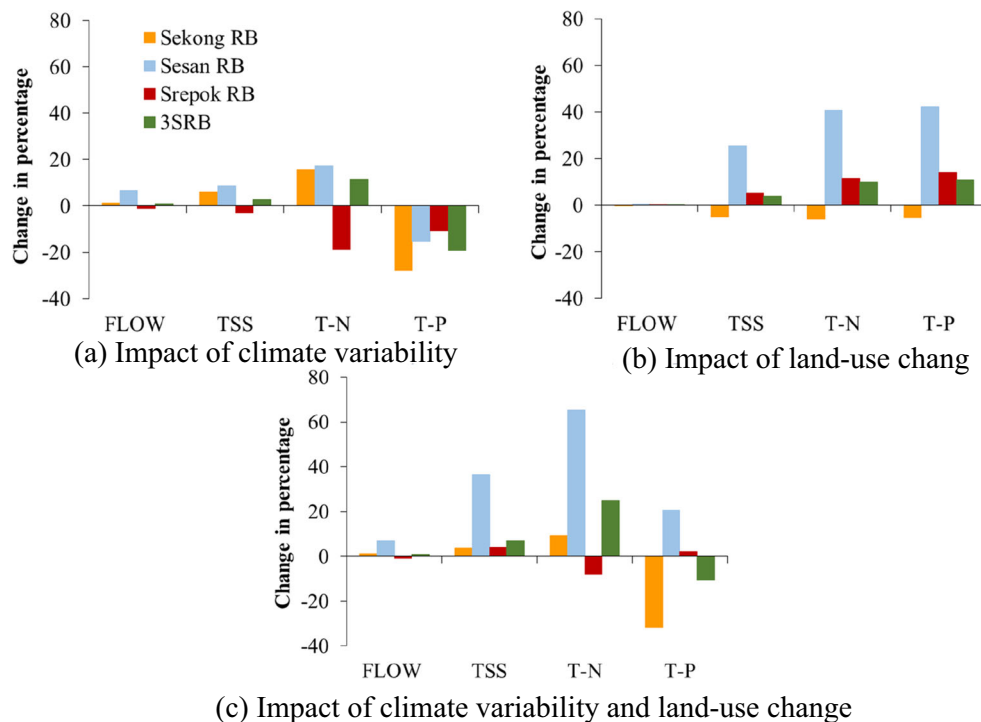
Under the impact of climate variability, annual streamflow in the Srepok RB decreased by –1.04% because of the slight decrease in rainfall and increase in temperature. On the other hand, the streamflow in the Sesan RB and Sekong RB increased by 6.56% and 1.44%. Consequently, the streamflow of the 3SRB tended to increase by 1.00%. The increase in streamflow here agree with some other studies (Fu et al., 2019; Tan et al., 2015; Zhang et al., 2017). Similarly, annual TSS loadings had a decrease of 2.7% in the Srepok RB, and increases of 6.22% and 8.73% in the Sesan RB and Sekong RB, respectively (Fig. 2a). Regarding the whole 3SRB, the TSS loading had a slight increase of 2.91%. Generally, the trend of TSS loading was similar to that of streamflow and this observation is also supported by other studies (Bieger, Hörmann and Fohrer, 2014; de Oliveira et al., 2019).

Regarding T-N loading, climate variability caused significant changes of 15.55% in the Sekong RB, 17.46% in the Sesan RB, –18.53% in the Srepok RB, and 11.35% in the entire 3SRB (Figure 2a). The change in T-N loading is proportional to changes in streamflow and TSS loading. Nitrogen is embedded in soil particle; therefore, an increase in streamflow causes increases in sediment load as well as T-N load. By contrast, T-P loading had downward trend of approximately 27.83%, 15.25%, 10.49%, and 19.12% in the Sekong RB, Sesan RB, Srepok RB, and the entire basin, respectively, under the impact of climate variability. The decreases in T-P loading can be explained by increases in soil moisture causing increased diffusion of phosphorus that leads to an increase in phosphorus absorption of plant. Consequently, the amount of

Table 3 SWAT performance statistics for monthly simulation of water quality

Station	Parameter	Period	Calibration (C)		Validation (V)	
			E_{NS}	PBIAS	E_{NS}	PBIAS
Siempang (Sekong RB)	NO ₃ ⁻	C: 2005 V: 2006–2008	0.94	11%	0.53	17%
Lumphat (Srepok RB)	NO ₃ ⁻	C: 2004–2006 V: 2007–2008	0.74	26%	0.72	31%
Pleiku (Sesan RB)	T-P	C: 2004–2005 V: 2006–2008	0.78	–30%	0.58	–14%
Ban Don (Srepok RB)	T-P	C: 2004–2005 V: 2006–2008	0.82	25%	0.67	33%
Cau 14 (Srepok RB)	TSS	C: 2000–2005	0.58	21%	–	–
Kontum (Sesan RB)	TSS	C: 2000–2005 V: 2006–2008	0.74	14%	0.69	27%

Fig. 2 Changes in annual streamflow, TSS loading, T-N loading, and T-P loading



total phosphorus can be reduced in the entire area (Dijkstra et al., 2012).

The effect of LUC

The five major LU types in the 3 SRB consist of forestland, agricultural land, grass/shrub, urban areas, and water surfaces. The dominant forestland was recognized to be in the basin, accounting for 87.8% of the total area in 1993 and 77.2% in 2003. The main cause for this change is the expansion of agriculture for the development of commercial plantations of coffee and rubber trees, as well as urbanization (Takamatsu et al., 2014). There was also a significant increase in the percentage of cropland from 14.9% to 18.5% in the decade between 1993 and 2003. In general, the forest area tends to decrease through deforestation due to the boom in cropland, urban and grass/shrub areas for the whole basin. However, the temporal and spatial changes in each land-use type experienced fluctuations in all three sub-basins. An opposing trend was observed in the Sesan RB and Srepok RB, where the forest area experienced a slight increase of 1.1%, while the agricultural area decreased considerably by 16% in the Sekong RB. The changes in the entire area of land use for the whole 3SRB and in the three individual sub-basins are presented in Table 4.

The effects of LUC on various water resource compounds, including streamflow, TSS, T-N, and T-P for the entire and three separate sub-basins, are illustrated in the Figure 2 b. This study concludes that there is a reverse relationship between forest area and streamflow change. For instance, the change in

streamflow was -0.06% for the Sekong RB, 0.46% for the Sesan RB, and 0.16% for the Srepok RB under the LUC impact. Similar results have also been found in other studies (e.g., Tan et al., 2015; Yang et al., 2017). The study also revealed that the combined increases in streamflow of the Sesan RB and Srepok RB account for approximately $58 \text{ m}^3/\text{s}$, which is higher than the decrease in streamflow of the Sekong RB of approximately $-11 \text{ m}^3/\text{s}$, leading to a total combined increase in discharge of the 3SRB.

Figure 2 b shows that a minor decrease in the TSS load of the Sekong RB of approximately -4.99% occurred, while the remaining areas showed substantial increases of 25.60% , 5.17% , and 3.70% for the Sesan RB, Srepok RB, and 3SRB, respectively. The fluctuation of TSS under the LUC impact is determined by erosion problems that are reverse to the change in forest area. This is because the density of vegetation and anti-erosion quality in forestland are higher than those in other

Table 4 The changes in five main LU types in the study area

Land-use type	Change in area 1000 km ²			
	3SRB	Sekong RB	Sesan RB	Srepok RB
Forest	-411	26	-279	-137
Agriculture	277	-46	253	51
Urban	85	0.4	20	65
Grass/shrub	32	11	8	12
Water	21	8	2	10

LU types (Ma et al., 2009). The Sesan RB, Srepok RB, and 3SRB experienced deforestation of 19%, 5.6%, and 5%, respectively, resulting in an increase in TSS load in these basins. For instance, remarkable increases of 36.57% and 6.97% were seen in the amount of TSS in the SSB and SPB. In contrast, the forest area increased by 1.1% in the SKB, inducing a reduction in erosion and the sediment load there. These results also match the findings of previous studies (Khoi and Suetsugi 2014; Ranzi, Le and Rulli 2012).

Among sediment compounds, while both T-N and T-P decreased slightly by -5.74% and -5.35% in the Sekong RB, rapid increases of 40.83% and 42.33% were noted in the Sesan RB, 11.47% and 14.05% in the Srepok RB, and 10.12% and 10.94% in the whole 3SRB (Figure 2b). The main sources of nitrogen and phosphorus in the study area are agricultural activity and accumulate from the discharge of fertilizer. Therefore, as the cultivated area decreased in the Sekong RB and increased in the Sesan RB and Srepok RB, it induced the same trend of T-N and T-P changes in these sub-basins. In general, the effect of LUC on streamflow and sediment and nutrient yields in the study area in these findings agree with those of other studies (Khoi and Suetsugi, 2014; Longyang, 2019; Tan et al., 2015).

Joint effects of climate variability and LUC

To assess the combined impact of the two drivers on the streamflow, and sediment and nutrient loadings, the baseline scenario (SN0) is compared to the simulated results of the SN3 scenario. The results are shown in the Figure 2 c. The combined impact of climate variability and LUC caused increases of streamflow by approximately 1.41% in the Sekong RB, 7.05% in the Sesan RB, and 1.03% in the whole 3SRB, and a decrease of streamflow by 0.88% in the Srepok RB. As previously mentioned, climate variability made a significant contribution to streamflow change as opposed to LUC factor in the study area. For example, the decline of streamflow was caused by climate variability in the Srepok RB. Similar observations were obtained by the studies of Fu et al. (2019), Shao et al. (2018), Yang et al. (2017), and Zhang et al. (2017).

Regarding the water quality parameters, there were significant increases in TSS loading in the study area. In particular, the increased values were approximately 3.8%, 36.57%, 5.17%, and 7.09% in the Sekong, Sesan, Srepok, and 3SRB, respectively (Figure 2c). The contributions of climate variability and LUC to TSS loadings were distinct in the three sub-basins. In the Sekong RB, the significant change in sediment load was strongly related to climate variability. Meanwhile, LUC was the most critical factor affecting the TSS loadings in the Sesan RB and Srepok RB.

Considering the combined impacts of climate and LUC, T-N had upward trends of 9.51%, 65.42%, and 25.05% in the Sekong RB, Sesan RB, and the whole 3SRB, respectively,

and a downward trend of 8.12% in the Srepok RB. Regarding T-P, the combined impacts of climate variability and LUC caused a noticeable reduction of 31.69% in the Sekong RB, and increases of 20.62% and 2.08% in the Sesan RB and Srepok RB, respectively (Figure 2c). The combination of the increased T-P loadings in both the Sesan RB and Srepok RB and the decreased T-P loading in the Sekong RB resulted in a total decrease in T-P loading in the entire 3SRB of -10.35%. Generally, the streamflow, TSS, T-N, and T-P loadings were more sensitive to climate variability than to LUC in the Sekong RB and Srepok RB. In the case of the Sesan RB, the streamflow, TSS, T-N, and T-P loadings were more sensitive to LUC than to climate variability.

Mitigation and adaptation measures to climate variability and LUC

The effects of climate variability and LUC on streamflow, sediment, and nutrient loadings were different in the Sekong, Sesan, and Srepok River Basins. Particularly, the streamflow, TSS, T-N, and T-P loading exhibited more sensitivity to climate variability than to LUC in the Sekong RB and Srepok RB. Thus, mitigation and adaptation measures to minimize the negative impacts of environmental change on water resources and ecosystems should be strongly concentrated on climate change in comparison to LUC. In case of the Sesan RB, water quantity and quality revealed more sensitivity to LUC than to climate variability. Hence, the authorities should take into account land-use planning and agricultural cultivation activities in the Sesan RB to develop sustainable water resources.

The results show that soil erosion and degradation mainly observed in all three sub-basins under the impact of climate variability and LUC. There are management strategies and cultivating techniques to weaken the soil erosion and soil degradation such as reforestation, contour farming, and intensification crop practice. Deforestation and cropland expansion are the reasons causing the increase of soil erosion potential (Borrelli et al. 2017), because the density of vegetation and soil resistance of forestland is higher than other land-use types (Ma et al. 2009). However, the conversions of forestland to cropland and grassland were pronounced in the Sesan and Srepok RB in the period of 1981-2010. Therefore, afforestation is the necessary and efficient measure to prevent soil erosion and degradation. Contour farming is the technique to grow plant in a consistent elevation and across the slope. The farming practice will increase the water conservation ability and slow down water erosion, resulting in decrease in soil erosion and degradation. The best performance of contour technique is found at the low slope of 3–8% (Liu et al. 2013). The average slope in the Srepok RB is 2.4 and 6.8°, in the Sesan RB is 6 and 10° in Cambodia and Vietnam, respectively (Constable 2015b). Thus, the contour farming

practice can be applied for the study area. Regarding the slope cropland, vegetating the bare soil in cropland is the effective measure for soil resistance (Han et al. 2020).

Conclusions

This research aimed to quantitatively assess the separate and combined impacts of climate variability and LUC on streamflow, sediment, and nutrient yields in the 3SRB. The results of SWAT calibration and validation were of satisfactory, and this model could be applied to evaluate the impacts of the climate variability and LUC on water quantity and quality for the study area.

The simulation results indicated that the separate impact of climate variability caused increases in almost all of the considered water components with the exception of T-P loading in the 3SRB. In addition, the separate impact of LUC caused increases in all considered water components. Generally, climate variability plays an important role in the attribution of changes in streamflow and T-P loading, while LUC enormously contributes to change in TSS loading. In addition, the separate contributions of climate variability and LUC were nearly similar for the T-N loading. The combined impact of the two drivers caused a significant reduction by 10.35% in T-P, and upward trends of streamflow, TSS loading, and T-N loading by 1.03%, 7.09%, and 25.05%, respectively.

The effects of climate variability and LUC on water quantity and quality varied across the different sub-basins. In the Sekong and Srepok RBs, the streamflow and water quality exhibited stronger responses to climate variability. In case of the Sesan RB, LUC influenced streamflow and water quality more strongly than the climate variability during the period 1981–2010. In general, the results of the study were able to provide more proof of how climate and land-use changes impact water quality and quantity in these three important rivers, namely the Sekong, Sesan and Srepok Rivers, supporting the need for cross-boundary solutions in the tributaries of the Mekong River.

Author contribution Dao Nguyen Khoi: conceptualization; methodology; investigation; formal analysis; writing - review and editing; and paper administration.

Pham Thi Loi: investigation; formal analysis; visualization; writing - original draft; writing - review and editing.

Nguyen Thi Thuy Trang: formal analysis; visualization; writing - review and editing.

Nguyen Dinh Vuong: formal analysis; visualization; writing - review and editing.

Shibo Fang: formal analysis; visualization; writing - review and editing.

Pham Thi Thao Nhi: formal analysis; visualization; writing - original draft; writing - review and editing.

Funding This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number “105.06-2019.20.”

Data availability Not applicable.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

References

- Abbaspour KC (2015) SWAT-CUP: SWAT Calibration and Uncertainty Programs - a user manual. Swiss Federal Institute of Aquatic Science and Technology, Eawag
- Adamson PT, Rutherford ID, Peel MC, Conlan IA (2009) The hydrology of the Mekong River. In: Campbell ICBT-TM (ed) The Mekong. Elsevier, San Diego, pp 53–76
- Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment - Part I: Model development. *J Am Water Resour Assoc* 34:73–89. <https://doi.org/10.1111/j.1752-1688.1998.tb05961.x>
- Baran E, Guerin E, Nasielski J (2015) Fish, sediment and dams in the Mekong. In: WorldFish, and CGIAR Research Program on Water, Land and Ecosystems (WLE), Penang
- Bastia F, Equeenuddin SM (2016) Spatio-temporal variation of water flow and sediment discharge in the Mahanadi River, India. *Glob Planet Change* 144:51–66. <https://doi.org/10.1016/j.gloplacha.2016.07.004>
- Bieger K, Hörmann G, Fohrer N (2014) Simulation of streamflow and sediment with the soil and water assessment tool in a data scarce catchment in the Three Gorges Region, China. *J Environ Qual* 43: 37–45. <https://doi.org/10.2134/jeq2011.0383>
- Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, Meusburger K, Modugno S, Schütt B, Ferro V, Bagarello V, Oost KV, Montanarella L, Panagos P (2017) An assessment of the global impact of 21st century land use change on soil erosion. *Nat Commun* 8:2013. <https://doi.org/10.1038/s41467-017-02142-7>
- Brath A, Montanari A, Moretti G (2006) Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). *J Hydrol* 324:141–153. <https://doi.org/10.1016/j.jhydrol.2005.10.001>
- Brodie JE, Mitchell AW (2005) Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments. *Mar Freshw Res* 56:279–302
- Buda AR, DeWalle DR (2009) Dynamics of stream nitrate sources and flow pathways during stormflows on urban, forest and agricultural watersheds in central Pennsylvania, USA. *Hydrol Process* 23:3292–3305. <https://doi.org/10.1002/hyp.7423>
- Buytaert W, Céleri R, De Bièvre B et al (2006) Human impact on the hydrology of the Andean páramos. *Earth-Science Rev* 79:53–72. <https://doi.org/10.1016/j.earscirev.2006.06.002>
- Constable D (2015a) The Sesan and Sre Pok River Basins. Bangkok, Thailand
- Constable D (2015b) Atlas of the 3S Basins. IUCN, Bangkok

- de Oliveira VA, de Mello CR, Beskow S, Viola MR, Srinivasan R (2019) Modeling the effects of climate change on hydrology and sediment load in a headwater basin in the Brazilian Cerrado biome. *Ecol Eng* 133:20–31. <https://doi.org/10.1016/j.ecoleng.2019.04.021>
- Delkash M, Al-Faraj FAM, Scholz M (2018) Impacts of anthropogenic land use changes on nutrient concentrations in surface waterbodies: a review. *CLEAN - Soil, Air, Water* 46:1800051. <https://doi.org/10.1002/clen.201800051>
- Dijkstra FA, Pendall E, Morgan JA, Blumenthal DM, Carrillo Y, LeCain DR, Follett RF, Williams DG (2012) Climate change alters stoichiometry of phosphorus and nitrogen in a semiarid grassland. *New Phytol* 196:807–815. <https://doi.org/10.1111/j.1469-8137.2012.04349.x>
- Du Plessis A, Harmse T, Ahmed F (2014) Quantifying and predicting the water quality associated with land cover change: a case study of the Blesbok Spruit Catchment, South Africa. *Water* 6(10):2946–2968. <https://doi.org/10.3390/w6102946>
- Fu Q, Li L, Li M, Li T, Liu D, Hou R, Zhou Z (2018) An interval parameter conditional value-at-risk two-stage stochastic programming model for sustainable regional water allocation under different representative concentration pathways scenarios. *J Hydrol* 564:115–124. <https://doi.org/10.1016/j.jhydrol.2018.07.008>
- Fu Q, Shi R, Li T, Sun Y, Liu D, Cui S, Hou R (2019) Effects of land-use change and climate variability on streamflow in the Woken River basin in Northeast China. *River Res Appl* 35:121–132. <https://doi.org/10.1002/rra.3397>
- Han J, Ge W, Hei Z, Cong C, Ma C, Xie M, Liu B, Feng W, Wang F, Jiao J (2020) Agricultural land use and management weaken the soil erosion induced by extreme rainstorms. *Agric Ecosyst Environ* 301:107047. <https://doi.org/10.1016/j.agee.2020.107047>
- Hartman P, Carlucci K (2014) Climate change impact and adaptation study for the Lower Mekong Basin: Key final results, Bangkok
- Hoang LP, Lauri H, Kumm M, Koponen J, van Vliet MTH, Supit I, Leemans R, Kabat P, Ludwig F (2016) Mekong River flow and hydrological extremes under climate change. *Hydrol Earth Syst Sci* 20:3027–3041. <https://doi.org/10.5194/hess-20-3027-2016>
- Khoi DN, Suetsugi T (2014) Impact of climate and land-use changes on hydrological processes and sediment yield—a case study of the Be River catchment, Vietnam. *Hydrol Sci J* 59:1095–1108. <https://doi.org/10.1080/02626667.2013.819433>
- Khoi DN, Thom VT (2015) Impacts of climate variability and land-use change on hydrology in the period 1981–2009 in the central highlands of Vietnam. *Glob Nest J* 17:870–881
- Kondolf GM, Rubin ZK, Minear JT (2014) Dams on the Mekong: cumulative sediment starvation. *Water Resour Res* 50:5158–5169. <https://doi.org/10.1002/2013WR014651>
- Li Z, Liu W, Zhang X, Zheng F (2009) Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *J Hydrol* 377:35–42. <https://doi.org/10.1016/j.jhydrol.2009.08.007>
- Liu R, Zhang P, Wang X, Chen Y, Shen Z (2013) Assessment of effects of best management practices on agricultural non-point source pollution in Xiangxi River watershed. *Agric Water Manag* 117:9–18. <https://doi.org/10.1016/j.agwat.2012.10.018>
- Longyang Q (2019) Assessing the effects of climate change on water quality of plateau deep-water lake - a study case of Hongfeng Lake. *Sci Total Environ* 647:1518–1530. <https://doi.org/10.1016/j.scitotenv.2018.08.031>
- López-Moreno JI, Vicente-Serrano SM, Moran-Tejeda E, Zabalza J, Lorenzo-Lacruz J, García-Ruiz JM (2011) Impact of climate evolution and land use changes on water yield in the ebro basin. *Hydrol Earth Syst Sci* 15:311–322. <https://doi.org/10.5194/hess-15-311-2011>
- Ma X, Xu J, Luo Y, Prasad Aggarwal S, Li J (2009) Response of hydrological processes to land-cover and climate changes in Kejie watershed, south-west China. *Hydrol Process* 23:1179–1191. <https://doi.org/10.1002/hyp.7233>
- Moriasi DN, Arnold JG, Van Liew MW et al (2007) Model Evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans ASABE* 50:885–900
- MRC (2005) Overview of the hydrology OF the Mekong Basin. Mekong River Comm, Vientiane
- Neitsch AL, Arnold JG, Kiniry JR, Williams JR (2011) Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas A&M University, Texas
- Oeurng C, Sauvage S, Sánchez-Pérez J-M (2010) Temporal variability of nitrate transport through hydrological response during flood events within a large agricultural catchment in south-west France. *Sci Total Environ* 409:140–149. <https://doi.org/10.1016/j.scitotenv.2010.09.006>
- Oeurng C, Cochrane TA, Arias ME, Shrestha B, Piman T (2016) Assessment of changes in riverine nitrate in the Sesan, Srepok and Sekong tributaries of the Lower Mekong River Basin. *J Hydrol Reg Stud* 8:95–111. <https://doi.org/10.1016/j.ejrh.2016.07.004>
- Op de Hipt F, Dieckrüger B, Steup G et al (2019) Modeling the effect of land use and climate change on water resources and soil erosion in a tropical West African catchment (Dano, Burkina Faso) using SHETRAN. *Sci Total Environ* 653:431–445. <https://doi.org/10.1016/j.scitotenv.2018.10.351>
- Pimia A, Darabi H, Choubin B, Omidvar E, Onyutha C, Haghghi AT (2019) Contribution of climatic variability and human activities to stream flow changes in the Haraz River basin, northern Iran. *J Hydro-environment Res* 25:12–24. <https://doi.org/10.1016/j.jher.2019.05.001>
- Ranzi R, Le TH, Rulli MC (2012) A RUSLE approach to model suspended sediment load in the Lo river (Vietnam): effects of reservoirs and land use changes. *J Hydrol* 422–423:17–29. <https://doi.org/10.1016/j.jhydrol.2011.12.009>
- Shao G, Guan Y, Zhang D, Yu B, Zhu J (2018) The Impacts of climate variability and land use change on streamflow in the Hailiutu River Basin. *Water* 10
- Someth P et al (2013) Basin profile of the Lower Sekong, Sesan and Srepok (3S) Rivers in Cambodia. Project report: Challenge Program on Water & Food Mekong project MK3. In: Optimizing the management of a cascade of reservoirs at the catchment level. ICEM – International Centre for Environmental Management, Hanoi
- Takamatsu M, Kawasaki A, Rogers PP, Malakie JL (2014) Development of a land-use forecast tool for future water resources assessment: case study for the Mekong River 3S Sub-basins. *Sustain Sci* 9:157–172. <https://doi.org/10.1007/s11625-013-0225-5>
- Tan ML, Ibrahim AL, Yusop Z, Duan Z, Ling L (2015) Impacts of land-use and climate variability on hydrological components in the Johor River basin, Malaysia. *Hydrol Sci J*:1–17. <https://doi.org/10.1080/02626667.2014.967246>
- Tan ML, Gassman PW, Srinivasan R, Arnold JG, Yang XY (2019) A review of SWAT studies in Southeast Asia: applications, challenges and future directions. *Water* 11:914. <https://doi.org/10.3390/w11050914>
- Tomer MD, Schilling KE (2009) A simple approach to distinguish land-use and climate-change effects on watershed hydrology. *J Hydrol* 376:24–33. <https://doi.org/10.1016/j.jhydrol.2009.07.029>
- Wan R, Cai S, Li H, Yang G, Li Z, Nie X (2014) Inferring land use and land cover impact on stream water quality using a Bayesian hierarchical modeling approach in the Xitiaoxi River Watershed, China. *J Environ Manage* 133:1–11. <https://doi.org/10.1016/j.jenvman.2013.11.035>
- Wang S, Kang S, Zhang L, Li F (2008) Modelling hydrological response to different land-use and climate change scenarios in the Zamu River basin of northwest China. *Hydrol Process* 22:2502–2510. <https://doi.org/10.1002/hyp.6846>

- Wei X, Liu W, Zhou P (2013) Quantifying the relative contributions of forest change and climatic variability to hydrology in large watersheds: a critical review of research methods. *Water* 5:728–746. <https://doi.org/10.3390/w5020728>
- Whitehead PG, Barbour E, Futter MN, Sarkar S, Rodda H, Caesar J, Butterfield D, Jin L, Sinha R, Nicholls R, Salehin M (2015) Impacts of climate change and socio-economic scenarios on flow and water quality of the Ganges, Brahmaputra and Meghna (GBM) river systems: low flow and flood statistics. *Environ Sci Process Impacts* 17:1057–1069. <https://doi.org/10.1039/C4EM00619D>
- Wu C, Ji C, Shi B, Wang Y, Gao J, Yang Y, Mu J (2019) The impact of climate change and human activities on streamflow and sediment load in the Pearl River basin. *Int J Sediment Res* 34:307–321. <https://doi.org/10.1016/j.ijsrc.2019.01.002>
- Yang L, Feng Q, Yin Z, Wen X, Si J, Li C, Deo RC (2017) Identifying separate impacts of climate and land use/cover change on hydrological processes in upper stream of Heihe River, Northwest China. *Hydrol Process* 31:1100–1112. <https://doi.org/10.1002/hyp.11098>
- Zhang L, Karthikeyan R, Bai Z, Srinivasan R (2017) Analysis of streamflow responses to climate variability and land use change in the Loess Plateau region of China. *CATENA* 154:1–11. <https://doi.org/10.1016/j.catena.2017.02.012>
- Zhang L, Nan Z, Yu W, Zhao Y, Xu Y (2018) Comparison of baseline period choices for separating climate and land use/land cover change impacts on watershed hydrology using distributed hydrological models. *Sci Total Environ* 622–623:1016–1028. <https://doi.org/10.1016/j.scitotenv.2017.12.055>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.