Journal of Hydrology: Regional Studies 44 (2022) 101225

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Effects of local land-use policies and anthropogenic activities on water quality in the upstream Sesan River Basin, Vietnam

Vo Ngoc Quynh Tram[a,b], Hiroaki Somura[a,*], Toshitsugu Moroizumi[a], Morihiro Maeda[a]

[a] Graduate School of Environmental and Life Science, Okayama University, 3-1-1 Tsushima-naka, Kita-ku, Okayama 700-8530, Japan
[b] Nong Lam University, Linh Trung Ward, Thu Duc District, Ho Chi Minh City 700000, Vietnam

ARTICLE INFO

Keywords:
Land-use policies
Land-use changes
Agricultural practices
Water resources management
Hilly areas

ABSTRACT

Study region: This study focuses on the upstream Sesan River Basin in the Central Highlands of Vietnam.
Study focus: Local land-use policies and human activities can significantly affect hydrology and increase the magnitude of erosion and nutrients in downstream areas. The effects in terrestrial regions on water quality of the target area were evaluated during the 2000–2018 period using the SWAT (Soil and Water Assessment Tool) with updated land-use conditions following the local policy decisions and agricultural practices in different periods.
New hydrological insights for the regions: This study indicates that the implementation of the local land-use policies, along with extensive anthropogenic activities, has had significant effects on the downstream aquatic environment as compared with the period before the implementation of the land-use policies. Higher annual sediment, total nitrogen (TN), and total phosphorus (TP) loadings were found upstream from the Poko Watershed, where range land predominated, and in southern and southwestern Dakbla Watershed, where arable land and permanent cropland predominated. Arable land had the highest proportion of sediment and nutrient loadings into the reach, especially in the 2005–2009 period (conducting afforestation, agricultural expansion, and urbanization) and in the 2010–2014 period (applying crop conversion policy involving a shift from mixed forests to rubber forests). Understanding the watershed characteristics along with the combination of spatial land use, local land-use policies, and agricultural practices will support the implementation of regional land use and water resources management strategies more comprehensively.

1. Introduction

Changes in anthropogenic processes in terrestrial regions could have remarkable effects on the aquatic environment, which has diverse and important environmental functions. To comprehensively control and reduce the significant effects impacting water quality, policies are promulgated on the regional and local scales, especially land-use policies. In Asia, land use underwent significant changes in a relatively short-term period (Zhao et al., 2006). Even though land use occurs at the local level, land-use changes can

* Corresponding author.
E-mail addresses: tram.vongocquynh@hcmuaf.edu.vn (V.N.Q. Tram), somura@okayama-u.ac.jp (H. Somura), morot@okayama-u.ac.jp (T. Moroizumi), mun@okayama-u.ac.jp (M. Maeda).

https://doi.org/10.1016/j.ejrh.2022.101225
Received 27 June 2022; Received in revised form 25 August 2022; Accepted 3 October 2022
Available online 6 October 2022

damage economic, environmental, and ecological aspects on the local/regional/global scales if these changes occur indiscriminately (Zhao et al., 2006). These policies require detailed information on the local scale. The two most essential factors for land-use policies are spatial land use and land-use plans (Organisation for Economic Cooperation and Development OECD, 2017). Local governments establish specific land-use planning to adjust land-use conversion under the guidance of the higher levels of government, allowing more reasonable plans for the development of an entire region/the whole nation (Organisation for Economic Cooperation and Development OECD, 2017). Policies concerning water resources and agriculture aspects should be mentioned in the water policy framework with the consideration of all pollutants and polluters at the national and river basin scales (Mateo-Sagasta et al., 2017); additionally, their long-term impacts should also be considered (Holden et al., 2015). At present, the aspect of long-term watershed management has not yet been comprehensively considered in strategies when land-use policies are updated. It is necessary to have inter-ministerial cooperation systems to ensure the coherence of policies (Mateo-Sagasta et al., 2017).

Population growth leads to deforestation, agricultural expansion, and urbanization. In recent years, these human activities have affected landscapes and downstream water quality in Southeast Asia. Agricultural land expansion towards steep-slope regions and deforestation for agricultural purposes, satisfying the food and feed demand for human beings, has led to increased vulnerability in these areas, especially intensive farming areas (Pierret et al., 2011; Fullen et al., 2011; Frohlich et al., 2013; Lin et al., 2016). Intensive farming in agriculture is one of the better ways by which to achieve growth in the agriculture sector but its impact on water quality is significant (Holden et al., 2015). Zeng et al. (2018) estimated that approximately 82 billion m^2 of highland regions have been developed into croplands in Southeast Asian countries. As a result of human-induced changes on the watershed scale, impacts on river discharge (Githui et al., 2009), sediment, and nutrients (Smarzyńska and Miatkowski, 2016; Hanief and Laursen, 2017) have been observed. The nutrients cumulating from non-point sources of agricultural activities were found to be the primary factors increasing the nutrient loadings to watersheds, leading to an accelerated extent of eutrophication in the aquatic environment (Carpenter et al., 1998; Somura et al., 2012). More than 70 % of the delivered nitrogen and phosphorus comes from different sources in agricultural processes to the watersheds (Yang et al., 2018). The sediment yields in agricultural watersheds were much greater than those in areas with non-anthropogenic activities, with an approximately hundredfold value in hilly terrains (Stallard, 1998). Along with a high density of rainfall, excess discharge contributes to accelerating surface erosion, thereby increasing the sediment loading and nutrient loss deposited downstream, especially during the rainy season (Sidle et al., 2006; Folliott et al., 2013; Shi et al., 2021). Controlling the pollutant discharges from point and non-point sources will reduce the nutrient loadings in the watershed without a significant impact on crop productivity (Jha et al., 2007; Alexander et al., 2008). Even though it is undeniable that anthropogenic activities have a great influence on water quality downstream, the magnitude of these impacts would be greatly increased if the crop conversion is unsuitable.

One of the challenges in mountainous areas is that the measured data and the information on pollution sources are limited to evaluating the pollution extent and the water quality monitoring network scattered on the watershed scale. Thus, modeling approaches have been utilized to address these shortcomings and to consider the impacts of local land-use policies and anthropogenic activities on water quality issues. The Soil and Water Assessment Tool (SWAT) has been widely applied around the world to assess the impacts of river discharge, sediment discharge, and pollution loadings from the point and non-point sources that impact the water environment in large watershed scales (Huang et al., 2009; Abbaspour et al., 2015; Hanief and Laursen, 2017; Malagó et al., 2017; Keraga et al., 2019), including the Central Highlands of Vietnam (Vu et al., 2012; Khoi and Thom, 2015). The significant impacts of land-use changes on hydrology (Githui et al., 2009; Li et al., 2019), suspended sediment, and nutrient loadings (Brito et al., 2019) over a long period were also emphasized by using the single static land-use input conditions, which are normally applied to a modeling analysis. However, in the long-term evaluation of water resources in a watershed in Asian countries, this ordinary method cannot comprehensively evaluate the impacts of land-use changes occurring in a relatively short-term period following local land-use policies. Tram et al. (2021) indicated that using multiple land-use input conditions with linear interpolation in a simulation could follow the record of land-use changes in a watershed and evaluate their impact on water resources better than utilizing the single static land-use input conditions. In addition to the multiple land-use input conditions, it is necessary to input information on detailed fertilization in agricultural cultivation. The lack of information regarding both the quantity of fertilizer and cultivation timing affects the accuracy of the model's performance (Chu et al., 2004). The impacts of land-use policies and human activities on a watershed are dissimilar despite belonging to the same river basin because of differences in climate conditions, morphological features, and physical processes within each watershed (Tobin and Bennett, 2009; Piniewski et al., 2017). This means that it is necessary to update both the historical land-use changes and detailed agricultural practices in a model to improve the accuracy of the model's performance adapted to the local situations in each period.

Thus, the main purposes of this study were (1) to evaluate the impacts of different land-use policies and agricultural practices on discharge, sediment, total nitrogen (TN), and total phosphorus (TP) at the Dakbla and Poko watersheds in different periods on the basis of temporal and spatial distributions, (2) to assess the influences of land-use policies and anthropogenic activities in each period on the aquatic environment downstream, and (3) to determine how to improve the erosion and water quality in the target river basin.

2. Data and methods

2.1. Study area

The Sesan River Basin is known as a transboundary basin of the Mekong River. The Sesan River flows through the Kon Tum and Gia Lai provinces in Vietnam. The Poko Watershed (PKW) and Dakbla Watershed (DBW) are two main subbasins of the upstream Sesan River Basin with areas of 3210 km^2 in the former and 3507 km^2 in the latter as shown in Fig. 1. The lengths of the Poko and Dakbla Rivers are 121 km and 152 km, respectively. From the upstream areas, these rivers merge to a confluence before flowing to Yaly Lake downstream. Yaly Lake plays an important role in the upstream Sesan River Basin. It is mostly located in Kon Tum province, occupying 44.5 km^2 of the 64.5 km^2 total area, with an average depth of 48.2 m, a length of 38 km, and a width of 6 km at its widest point. The reservoir capacity is about 1037 million m^3. Water quality observations started in the lake in 2015. From 2015 to 2019, the water quality of Yaly Lake was deemed to be completely suitable for tourism, aquaculture, fishing, irrigation, and hydropower purposes (Kon Tum Provincial Department of Natural Resource and Environment KTDONRE, 2016, 2017, 2019). With the characteristics of a tropical monsoon climate, the rainy season (May–November) and the dry season (December–April) are the two main seasons in this area. The average annual precipitation is 1778 mm and 2000 mm while the average annual temperature is 23.7 °C and 23.6 °C at the Dak To and Kon Tum stations, respectively. Forest areas occupy the highest proportion of the land (>52 %).

In the Central Highlands, the water demand for agriculture encompassed 84 % and 90 % of the total water demand in Kon Tum and Gia Lai provinces, respectively, in 2015/2016 (JICA, 2018). Kon Tum had the lowest share of agriculture in 2016 among the five provinces in this region because of its poorer soil quality and lower agricultural productivity. An expansion of agricultural activities and a shift in cultivation toward the hillslope have been conducted in the target area since 2005 onwards (Tram et al., 2021). According to the 2010 statistical yearbook, there was an increasing tendency of agricultural land, urban areas, and forestry land with values of 39.9 %, 56.6 %, and 1.7 %, respectively, compared to 2005. From 2010 onward, a crop conversion policy that encouraged a move from mixed forests to rubber forests was enacted (Tram et al., 2021). Rubber trees predominated, accounting for 61.0 % (433.2 km^2) of the total mixed forest area (709.6 km^2) in Kon Tum province (Kon Tum Provincial People's Committee, 2016). Rubber trees occupied 23.7 % (113.9 km^2) of the total mixed forest area (479.4 km^2) in Gia Lai province (Gia Lai Provincial People's Council, 2015). According to the 2015 statistical data, there was a continuous increase in urban areas by 2.7 %, whereas the forestry land decreased by a value of 2.7 % compared to 2010. Due to some areas having inefficient rubber trees, a local orchard conversion policy was enacted, leading to an increasing number of orchard areas from 2015 onward, rising by 5.4 % and 19.5 % in Kon Tum and Gia Lai provinces, respectively. Until 2018, agricultural land and urban areas saw an increasing trend, with increases of 28.5 % and 1.5 %, respectively, whereas forestland decreased continuously by approximately 4.0 % in comparison to 2015.

In this study, the 2000–2018 period was categorized into four periods (2000–2004, 2005–2009, 2010–2014, and 2015–2018) on the basis of the changes in local land-use policies. The 2000–2004 period represented a base period in which no land-use policies were applied. The remaining periods illustrated the following changes in land-use policies and anthropogenic activities: 2005–2009,

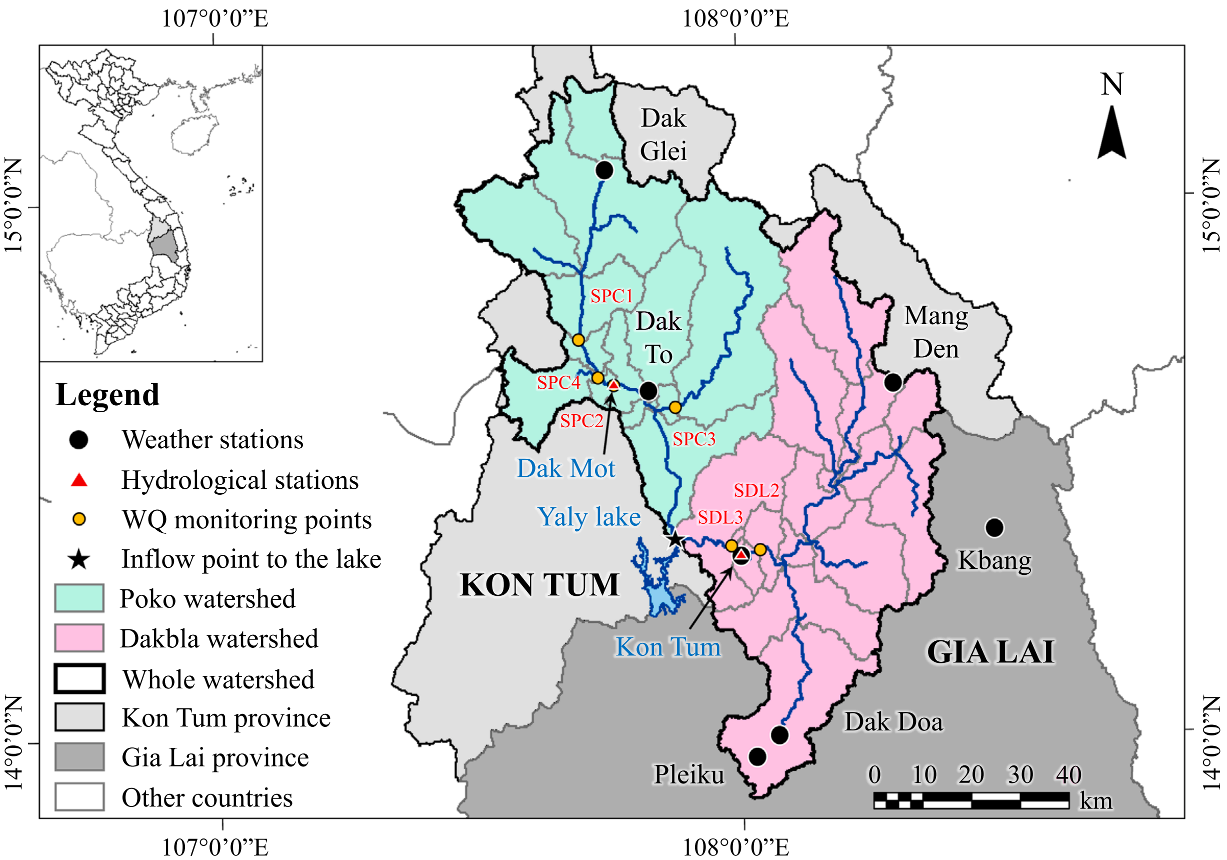

Fig. 1. Location of the PKW and DBW. River discharges were observed at Dak Mot station in PKW and Kon Tum station in DBW. SPCs 1, 2, 3, and 4 represent the four monitoring points of water quality in the PKW, while SDLs 2 and 3 represent the two monitoring points of water quality in the DBW.

conducting for afforestation, agricultural expansion, and urbanization; 2010–2014, crop conversion policy involving the move from mixed forests to rubber forests; and 2015–2018, crop conversion policy involving the move from insufficient rubber forests to orchards.

2.2. Methods

2.2.1. Hydrological modeling

2.2.1.1. SWAT description. SWAT is a well-known physical-hydrological model used to predict the impact of land-use changes and land management practices on river discharge (Hanief and Laursen, 2017), sediment (Shi and Huang, 2021), and nutrients (Epelde et al., 2015; Donmez et al., 2020) over long periods on the river basin scale. The hydrological cycle in SWAT is based on the water balance equation, in which surface runoff is estimated through the SCS curve number equation as follows:

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{\left(R_{day} - I_a + S\right)} \tag{1}$$

where Q_{surf} is the accumulated runoff or rainfall excess (mmH_2O), R_{day} is the rainfall depth for the day (mmH_2O), I_a is the initial abstractions including surface storage, interception, and infiltration prior to runoff (mmH_2O), and S is the retention parameter (mmH_2O).

Sediment loadings are estimated using the Modified Universal Soil Loss Equation (MUSLE), as shown in Eq. (2):

$$sed = 11.8 \times \left(Q_{surf} \times q_{peak} \times area_{hru}\right)^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \tag{2}$$

where *sed* is the sediment yield on a given day (metric tons), Q_{surf} is the surface-runoff volume (mmH_2O/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 (0.013 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, and *CFRG* is the coarse fragment factor.

For the nitrogen simulation, SWAT considers five different pools of nitrogen, with the two pools of NH_4^+ and NO_3^- being the inorganic forms. The movement of nitrate occurs mainly in the organic N and nitrate forms. The amount of nitrate removed during surface runoff is estimated as follows:

$$NO_{3surf} = \beta_{NO3} \times conc_{NO3,\ mobile} \times Q_{surf} \tag{3}$$

where NO_{3surf} is the nitrate removed during surface runoff (kg N/ha), β_{NO3} is the nitrate percolation coefficient, $conc_{NO3,\ mobile}$ is the concentration of nitrate in the mobile water in the top 10 mm of soil (kg N/mmH_2O), and Q_{surf} is the surface runoff generated on a given day (mmH_2O).

For the phosphorus simulation, the model monitors six pools of phosphorus in the soil, of which three are inorganic forms. Phosphorus escapes from the soil through plant uptake and erosion. Soluble phosphorus and organic and mineral P attached to sediment during surface runoff represent the main mechanisms of phosphorus transport. The solution P transported during surface runoff is calculated as follows:

$$P_{surf} = \frac{P_{solution,surf} \times Q_{surf}}{\rho_b \times depth_{surf} \times k_{d,surf}} \tag{4}$$

where P_{surf} is the amount of soluble phosphorus lost in the surface runoff (kg P/ha), $P_{solution,surf}$ is the amount of phosphorus in solution in the top 10 mm (kg P/ha), Q_{surf} is the amount of surface runoff on a given day (mmH_2O), ρ_b is the bulk density of the top 10 mm (Mg/m^3), $depth_{surf}$ is the depth of the surface layer, and $k_{d,surf}$ is the phosphorus soil partitioning coefficient (m^3/Mg).

2.2.1.2. SWAT application. The detailed input data of the model and other necessary local information are described and shown in Text S1 and Table S1. The watershed was delineated into 32 subbasins. In the PKW, the model was calibrated from 2000 to 2015 and validated from 2016 to 2018 for river discharge. The calibration and validation periods for the remaining variables (TN, TP, NO_3-N, and NH_4-N) were from 2014 to 2015 and from 2016 and 2018, respectively. In the DBW, the model was calibrated from 2000 to 2015 and validated from 2016 to 2018 for river discharge and sediment. The TN, TP, NO_3-N, and NH_4-N variables were calibrated and validated by the loads in this study. After calibration and validation of the model parameter values, the impacts on the aquatic environment downstream were evaluated. One of the initial necessary processes is to determine the length of the warm-up period so as to obtain an 'optimal' state in the hydrological model. The rainfall factor significantly affects the time required for the warm-up period even if it depends on the structure of the model (Kim et al., 2017). After achieving the optimal status, the response of the model is suitable for the realistic conditions leading to the higher accuracy of the model performance. The 10-year warm-up period was identified as the best choice for our study. Dak Mot station was utilized to calibrate and validate the river discharge and nutrients for the PKW, whereas Kon Tum station was used to calibrate and validate the river discharge and sediment for the DBW. A total of 28 sensitivity parameters for river discharge, sediment, and nutrients were chosen to improve the accuracy of model performance using the SUFI-2 algorithm in the SWAT-CUP program, as shown in Table S2. The sensitivity analysis for the model simulation after updating the information regarding land-use changes and agricultural practices is also described and illustrated in Text S2 and Fig. S1.

2.2.2. Land-use update module

There have been dramatic land-use changes in the Central Highlands, especially in the study area in the last five years with the expansion of urbanization and agricultural areas, along with deforestation (JICA, 2018). Model performance cannot be evaluated in depth when there is a lack of detailed land-use changes and land management information (Zettam et al., 2017). Updating land-use change information through different approaches is important when seeking to improve the accuracy of the model's performance (Moriasi et al., 2019; Wagner et al., 2019; and Aghsaei et al., 2020). In this study, a method confirmed by Tram et al. (2021) was used to track the frequent and complicated local land-use policies by using R script. For the analysis, multiple land-use maps were developed on the basis of local information and policies reflected by the local land-use conditions (2005, 2010, 2015, and 2018) during the simulation periods as shown in Fig. 2. During a simulation of the 2000–2018 period, three new land-use conditions for 2010, 2015, and 2018 were updated in the model from 2005 onwards for the 2005–2009, 2010–2014, and 2015–2018 simulation periods. This R script can support updating land-use changes by the linear interpolation method at the chosen time.

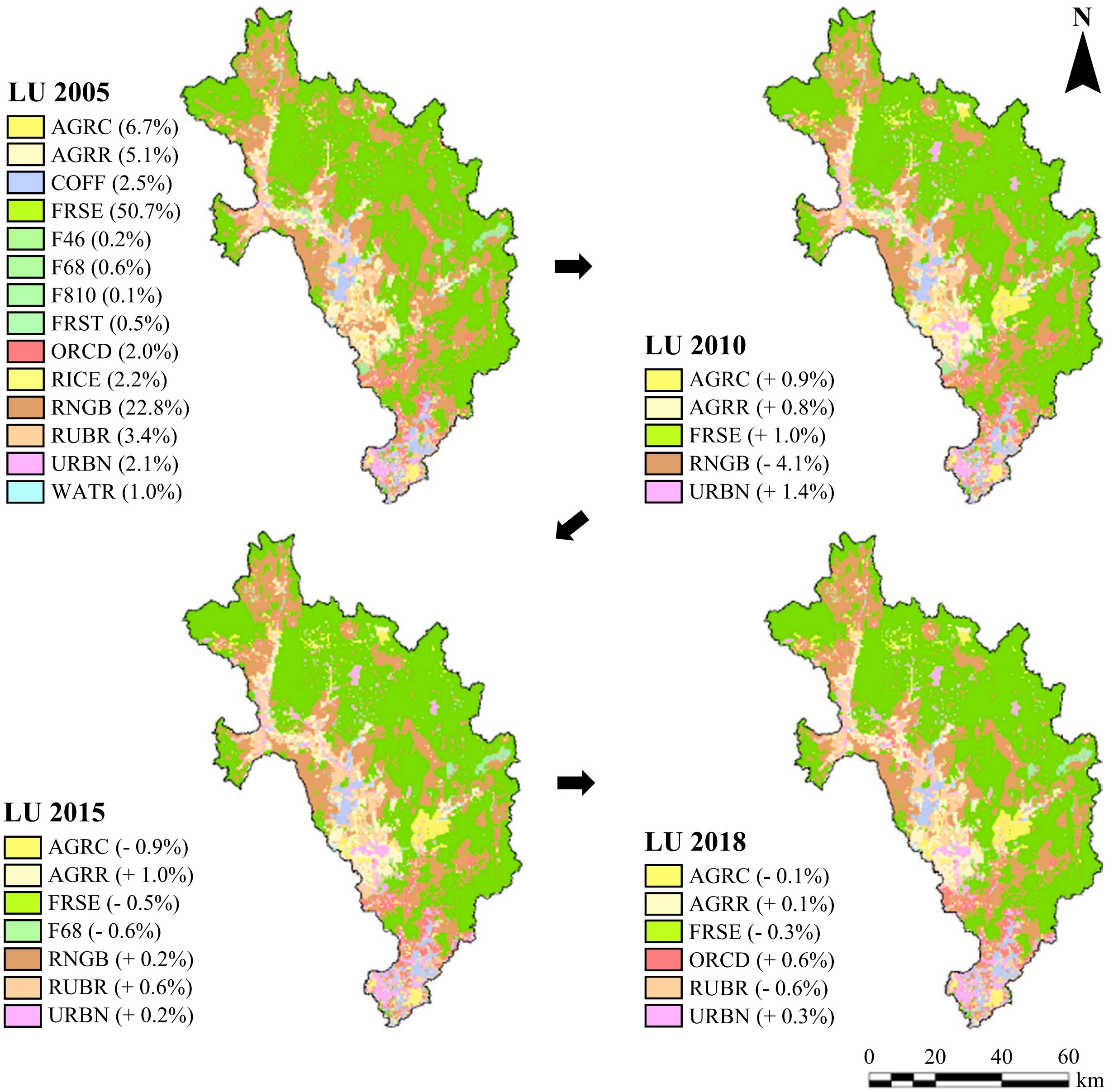

Fig. 2. The land use maps for 2005, 2010, 2015, and 2018 in the target river basin. The main land-use types include AGRC: agricultural land, non-row crops; AGRR: agricultural land, row crops; COFF: coffee; FRSE: forestry land; F46: mixed forest (400–600 m); F68: mixed forest (600–800 m); F810: mixed forest (800–1000 m); FRST: mixed forest; ORCD: orchard; RICE: rice; RNGB: rangeland; RUBR: rubber; URBN: urban; and WATR: water. The symbol "+ /-" indicates the increased/decreased percentage of land use categories of that period compared to the previous period.

2.2.3. Agricultural practice information

Information such as the amount of fertilizer per crop and its timing should be updated in the model along with the changes in land-use policies because the significant impacts of agricultural practices on the hydrology, crop yield, and water quality processes have been emphasized (Arabi et al., 2007; Srinivasan et al., 2010; Donmez et al., 2020). The agricultural practice information for the timing of planting, fertilizing, and harvesting was collected from the local government. One of the most influential factors of agricultural practices on the environment is crop type and cultivation management, along with climate conditions and soil characteristics (Epelde et al., 2015). The three main crops in the target area are rice, coffee plants, and rubber trees. Rice is cultivated twice per year. As permanent crops, coffee beans and rubber latex are normally harvested after 4 years and 6 years of planting. The annual fertilization loads for crops range from 8.3 to 73.6 kg N/ha/year and from 4.2 to 21.2 kg P/ha/year as described in Table 1. Coffee plants and rubber trees are the priority permanent crops in the target area because these crops are strategic commodity crop groups with high economic value and great export potential. Additionally, these crops contribute to the greening of barren hills, creating jobs, reducing the poverty rate, and improving the incomes of local people, especially ethnic minorities (Phuc and Nghi, 2014; Tien et al., 2015). High-quality rubber latex in Kon Tum and Gia Lai provinces is exported to many countries. Because of the significant difference in the net income obtained from annual and perennial crops, a dramatic conversion from annual crops to perennial crops in the hillslope areas was conducted in this region (JICA, 2018).

2.2.4. Model performance evaluation

To assess the accuracy of the model's performance, three statistical indices, the coefficient of determination (R^2), the Nash–Sutcliffe index (*NSI*), and the percentage bias (*PBIAS*), were used. The performance evaluation criteria of variables in the watershed scale were described by Moriasi et al. (2015), as shown in Table S3.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \overline{P})^2}}\right]^2 \tag{5}$$

$$NSI = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \tag{6}$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n}(O_i)} \times 100 \tag{7}$$

where O_i denotes the observed variables, $\overline{O}$ denotes the average observed variables, P_i denotes the simulated variables, $\overline{P}$ denotes the average simulated variables, and n is the number of existing variables.

2.2.5. Nutrient load calculation

The nutrient load was calculated on the basis of the concentration of water quality variables and the discharge, as described in Eq. (8).

$$L = \sum_{t=1}^{t=T}(86.4 \times Q_t \times C_t) \tag{8}$$

Table 1
Agricultural practice information.

Agricultural activities	Crops			
	Rice		Coffee plants	Rubber trees
Planting period	May	December	June	May
Fertilizer period	May (46[a], 21.2[b]) June (34.5, 11.5) June (34.5, 5.8)	December (46, 21.2) December (34.5, 11.5) January (34.5, 5.8)	**Year 1:** June (27.6, 15.4); August (24.2, 13.5); October (17.3, 9.6) **Year 2:** June (46, 15.4); August (40.3, 13.5); October (28.8, 9.6) **Year 3:** June (64.4, 15.4); August (56.4, 13.5); October (40.3, 9.6) **Year 4:** June (73.6, 16.8); August (64.4, 14.7)	**Year 1:** June (11, 5.6); July (8.3, 4.2); September (8.3, 4.2) **Year 2:** June (22.1, 8.4); July (16.6, 6.3); September (16.6, 6.3) **Year 3:** June (27.6, 9.8); July (20.7, 7.3); September (20.7, 7.3) **Year 4:** June (36.8, 11.2); July (27.6, 8.4); September (27.6, 8.4) **Year 5:** June (36.8, 12.6), July (27.6, 9.4), September (27.6, 9.4) **Year 6:** June (46, 14); July (34.5, 10.5)
Harvest period	October (harvest and kill)	April (harvest and kill)	October (harvest only)	October (harvest only)

[a] The amount of nitrogen per hectare (kg N/ha).
[b] The amount of phosphorus per hectare (kg P/ha) (Source: Kon Tum Provincial People's Committee, 2019).

where L is the nutrient load (kg), C_t is the daily concentration of water quality variables (mg/l), Q_t is the daily discharge (m^3/s), and t is the time (days).

3. Results

Reproducibility of river discharge, sediment, and nutrient loadings during the 2000–2018 period is described in detail in Text S3. Additionally, the relationship between the observed and simulated daily river discharge, sediment, TN, TP, NO_3-N, and NH_4-N loadings for PKW and DBW is shown in Figs. S2 and S3. The statistical evaluations of the model performance using R^2, *NSI*, and *PBIAS* are listed in Table S4.

3.1. The changes in river discharge, sediment, and nutrient loadings at the outlets (PKW and DBW outlets)

3.1.1. Total annual river discharge, sediment, and nutrient loadings at the outlets

The total annual river discharge, sediment, TN, and TP loadings at the two outlets from 2000 to 2018 are shown in Fig. 3. Additionally, the summary of the highest and lowest values during the simulation periods is shown in Table S5. The fluctuation of the total annual loadings at the two outlets was different in the four periods based on the changes in local land-use policies and anthropogenic activities. The highest total annual loadings were found in 2013 for river discharge, sediment, TN, and TP. The year 2013 belonged to the 2010–2014 period, in which a crop conversion policy involving a move from mixed forests to rubber forests was applied and agricultural activities were changed. In 2013, the total annual river discharge reached the maximum value of 2115.6 m^3/s in the PKW, which was 7.8 % higher than in the DBW. Similar to the river discharge, the total annual sediment loading in the PKW reached the highest value of 692.8 thousand tons in 2013, which was 24.0 % lower than in the DBW. In both watersheds, the maximum values of TN were found in 2013 with a value of 33.1 thousand tons in the PKW, which was 13.0 % smaller than in the DBW. In addition, TP reached the highest value of 9.6 thousand tons in the PKW, which was 6.7 % lower than in the DBW. Even though the river discharge in the PKW was slightly higher than that in the DBW in 2013, the large number of agricultural practices conducted in the DBW led to the higher annual sediment, TN, and TP loadings from this watershed in comparison to the PKW.

3.1.2. Average monthly total river discharge, sediment, and nutrient loadings at the PKW and DBW outlets

During the target period, the average monthly total river discharge and sediment loadings were the highest in September in both watersheds (Fig. 4). The highest river discharges were 326.7 m^3/s for the PKW and 256.8 m^3/s for the DBW. Additionally, the highest sediment loadings were 102.8 and 94.9 thousand tons in the PKW and DBW, respectively. The river discharge and sediment values in the PKW were higher than in the DBW by 27.2 % and 8.3 %, respectively. The maximum TN values were reached in August at 4.7 and 4.1 thousand tons in the PKW and DBW. Similar to TN, the highest TP values of the PKW and DBW were 1.5 and 1.1 thousand tons, respectively. It is clear that the TN and TP values in the PKW were higher than those in the DBW by 14.6 % and 36.4 %, respectively.

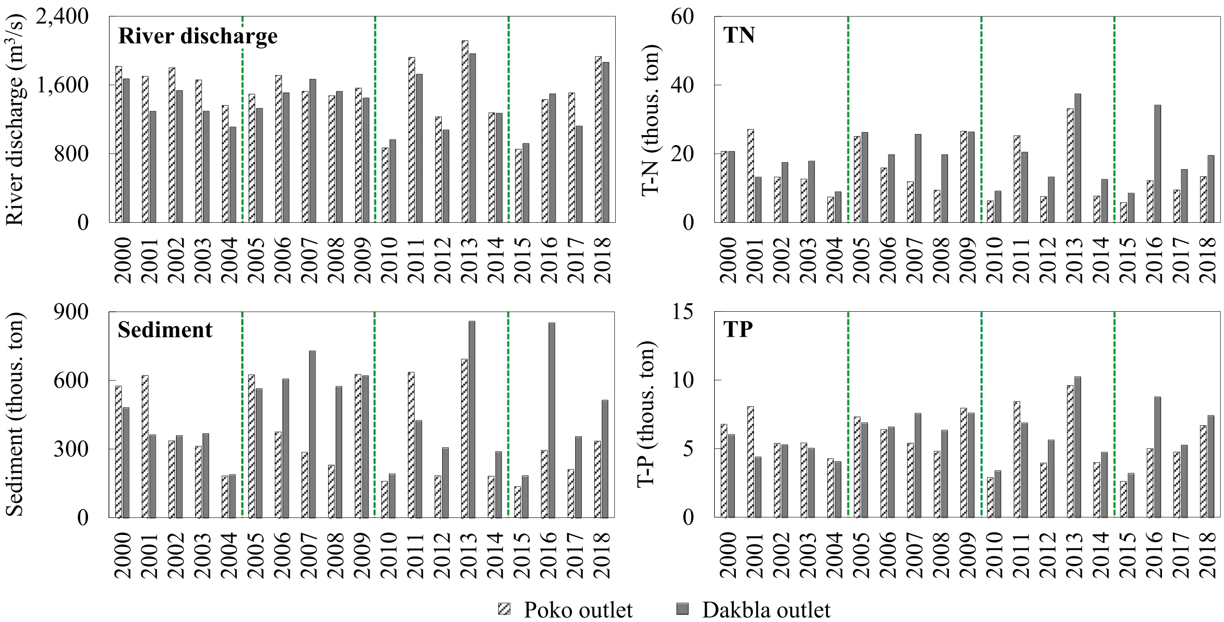

Fig. 3. Total annual river discharge, sediment, TN, and TP loadings at the outlets from 2000 to 2018.

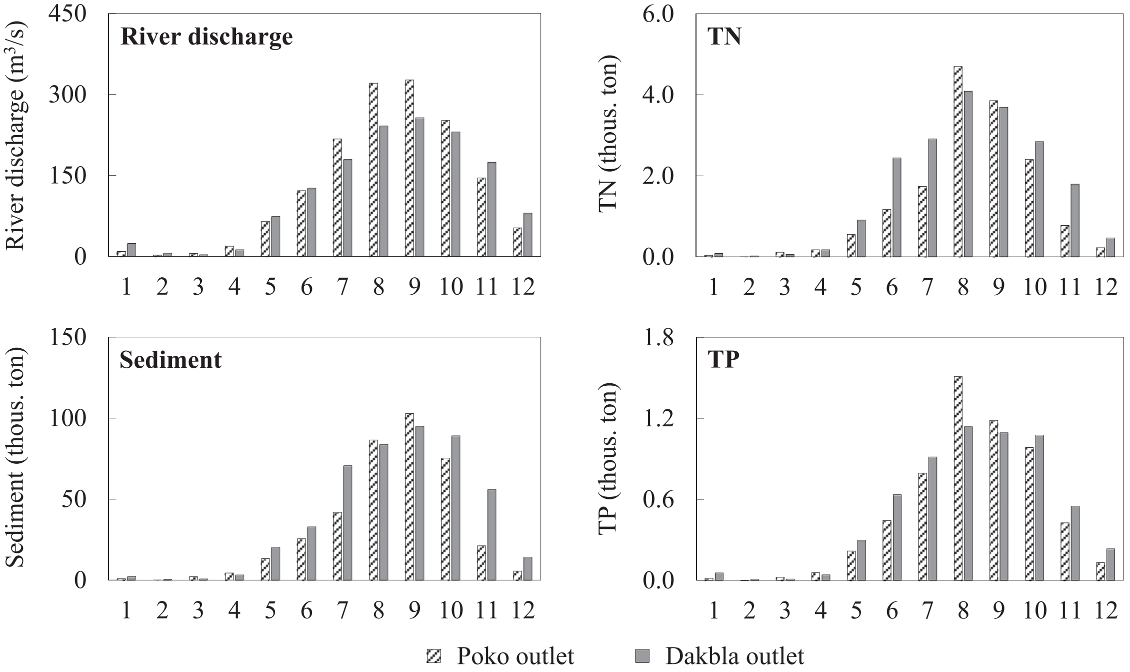

Fig. 4. Average monthly total river discharge, sediment, and nutrient loadings at the outlets during the 2000–2018 period.

3.1.3. Total cumulative sediment, TN, and TP loadings at the PKW and DBW outlets

In the 2000–2004 period, many agricultural practices were conducted in the PKW instead of in the DBW. Consequently, the total cumulative values in the DBW were moderately lower than those in the PKW, by 15.3 % (268.4 thousand tons) for sediment, 3.9 % (3.0 thousand tons) for TN, and 20.6 % (5.2 thousand tons) for TP as shown in Fig. 5. In the 2005–2009 period, the total cumulation in the DBW increased significantly as compared to the previous period. These cumulative values in the DBW exceeded those in the PKW by 42.9 % (985.7 thousand tons) for sediment, 33.3 % (31.7 thousand tons) for TN, and 10.4 % (3.6 thousand tons) for TP.

During the 2010–2014 period, the total cumulative values in the PKW were lower by 12.8 %, 15.9 %, and 7.4 % for sediment, TN, and TP, respectively, as compared to those in the DBW. In the remaining period, from 2015 to 2018, the total cumulative sediment, TN, and TP values in the PKW were lower than those in the DBW by 105.0 %, 97.2 %, and 30.4 %, respectively. Generally, the two periods (2005–2009 and 2015–2018) showed drastic differences in the two watersheds during the whole target period.

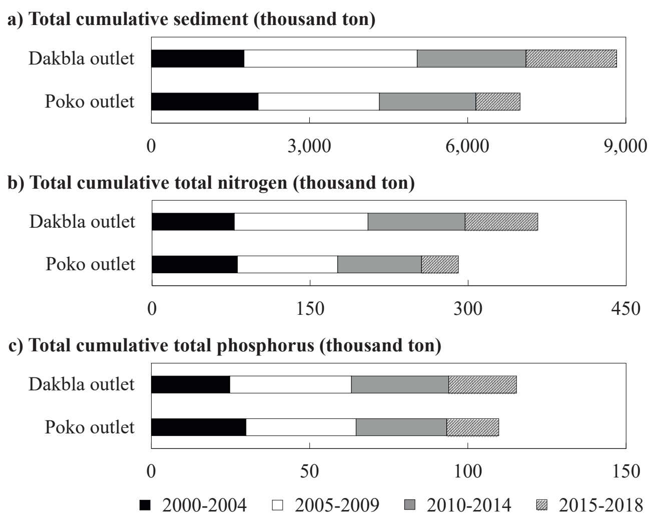

Fig. 5. Total cumulative sediment, TN, and TP at the outlets during the whole period.

3.2. Spatial distribution of annual sediment, TN, and TP loadings in each subbasin in the four periods

The spatial distribution of annual sediment, TN, and TP loadings is illustrated in Fig. 6 to allow for a better understanding of their characteristics according to differences in land use, soil, and slope at the subbasin scale. For sediment loading, the annual value ranged from 41.4 tons/km^2 in subbasin 9 (2010–2014) to 666.7 tons/km^2 in subbasin 23 (2005–2009). In subbasin 23, arable land and permanent cropland predominated, accounting for 74.0 % of the total land, and approximately 50.8 % of this area had a slope greater than 15 %. Compared with the 2005–2009 period, the maximum annual values in the remaining three periods were lower by 75 % (2000–2004), 19.7 % (2010–2014), and 4.2 % (2015–2018). In the 2005–2009 period, the annual sediment loading was higher than in the eastern and southern areas. In subbasin 32, arable land and permanent cropland predominated, accounting for 50 % of the total land, and approximately 45.8 % of this area had a slope greater than 15 %. The annual loading increased slightly in the northwestern, southwestern, and eastern directions, whereas there was a dramatic decrease in the northeastern and southern areas in the 2010–2014 period. In the 2015–2018 period, the annual value exhibited a significant decline in the northwestern area, while there was an increasing tendency in the northeastern and southern parts.

For the TN loading, the lowest annual value was 1.4 tons/km^2 in subbasin 9 in the 2010–2014 period, while the highest value was 22.7 tons/km^2 in subbasin 23 in the 2005–2009 period. In the 2005–2009 period, the maximum annual TN loadings were higher than those in the 2000–2004, 2010–2014, and 2015–2018 periods by 35.5 %, 14.6 %, and 7.8 %, respectively. Compared to that in the 2000–2004 period, the annual TN loading increased moderately in the southern and northeastern areas, whereas a dramatic decrease was seen in the northwestern and western areas in the 2005–2009 period. There was a slight increase in the northwestern, southwestern, and eastern areas, while a significant decrease was observed in the northeastern and southern areas from 2010 to 2014. Moreover, the TN loading increased in the southwestern area and slightly decreased in the northwestern area in the 2015–2018 period.

For the TP loading, the annual value ranged from 1.1 tons/km^2 (subbasin 9 for the 2010–2014 period) to 4.1 tons/km^2 (subbasin 23 for the 2005–2009 period). Compared with the 2005–2009 period, the maximum annual TP loadings were lower than in the remaining three periods by 30.3 % (2000–2004), 20.7 % (2010–2014), and 7.6 % (2015–2018). There was a similar tendency to sediment load during the whole period.

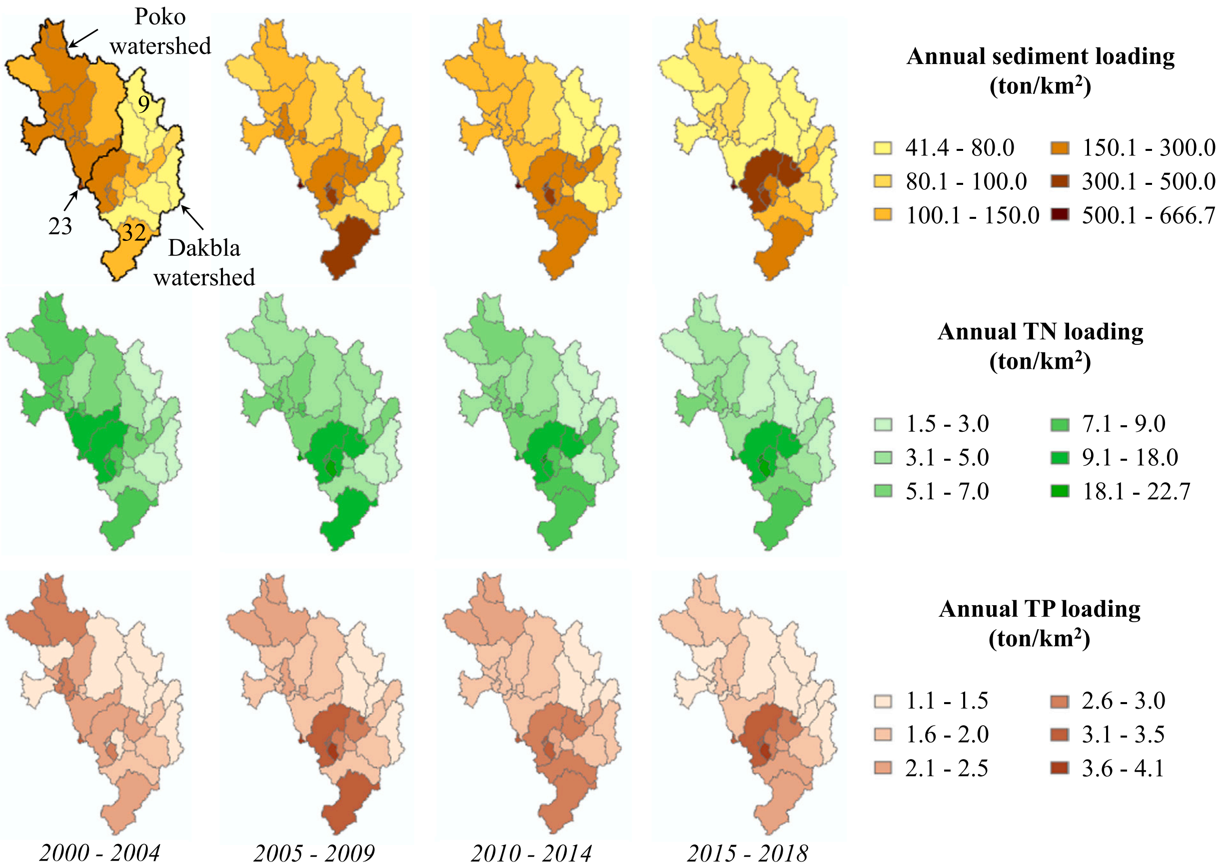

Fig. 6. Spatial distribution of annual sediment, TN, and TP loadings in each subbasin.

3.3. The changes in sediment, TN, and TP loadings for each land use during the four periods

Forest represented the highest percentage of land use, accounting for more than 52 % of the study area across all four periods (Fig. 7). Permanent cropland had the lowest proportion of annual sediment loading and the smallest total area, while the highest proportion of sediment loading was found in arable land, despite its area, ranging from 14.0 % to 15.9 % of the total during the four periods. From 2005–2009, extensive agricultural activities took place, as evidenced by the increase in arable land from 14.0 % (2000–2004) to 15.7 % (2005–2009). In this period, the sediment loading from arable land accounted for 61.3 % of the total, a 7.6 % increase compared to the previous period. Nevertheless, the percentage of sediment loading in forestry land decreased by 2.2 % because of the increase in forest area from 52.1 % to 53.1 %. Considering the 2010–2014 period, the areas of arable land and permanent cropland occupied 24.3 % of the total area. The sediment loading from these areas reached 67.0 %, decreasing by 0.9 % compared to the previous period. Between 2015 and 2018, the sediment loading tended to increase by 3.2 % in the other land-use types and by 0.7 % in forestry land, while there were decreasing trends of 3.4 % in arable land and 0.5 % in permanent cropland compared to the previous period. The 2005–2009 period had the largest percentage of sediment loading in arable land and permanent cropland.

Considering TN loading, forest had the lowest proportion of annual TN loading, while the highest percentage was recorded in arable land. The 2005–2009 period had the highest proportion of TN loading in arable land and permanent cropland at 72.3 %, higher than other periods by 7.9 % (2000–2004), 1.6 % (2010–2014), and 3.2 % (2015–2018). During the 2015–2018 period, the TN loading of forestry land also reached the highest percentage of 9.3 %, increasing by 0.5 %, 1.4 %, and 0.3 % as compared to the 2000–2004, 2005–2009, and 2010–2014 periods, respectively. For the other land-use types, the TN loadings occupied 26.8 %, 19.8 %, 20.3 %, and 21.6 % in the four periods, respectively.

Similar to sediment, permanent cropland exhibited the lowest percentage of annual TP loading, while the highest proportion was observed in arable land. Arable land and permanent cropland accounted for 65.0 % in the 2005–2009 period, which is higher than the 2000–2004, 2010–2014, and 2015–2018 periods by 9.2 %, 2.5 %, and 5.0 %, respectively. Forestry land had the highest proportion of TP loading at 15.8 % in the 2015–2018 period, exhibiting 1.0 %, 2.0 %, and 0.7 % increases as compared to the three remaining periods, respectively. The highest percentage of other land-use types was 29.4 % in the first period, followed by 24.2 % (2015–2018), 22.4 % (2010–2014), and 21.2 % (2005–2009).

3.4. The changes in total annual sediment, TN, and TP loadings at the inflow to the lake

The influence of local land-use policies and anthropogenic activities on downstream water quality was indicated by the increase in total annual sediment, TN, and TP loadings at the inflow to the lake after the enactment of land-use policies as compared to before the enactment of land-use policies. The 2000–2004 period featured no changes in land-use policies. From 2005 onward, changes in the local land-use policies and anthropogenic activities were enacted. The total annual loadings at the inflow to the lake were calculated by dividing the total annual sediment, TN, and TP for the whole target area by the total average annual rainfall of the whole target area. Changes in the total annual loadings at the inflow to the lake are illustrated in Fig. 8 and Table S6.

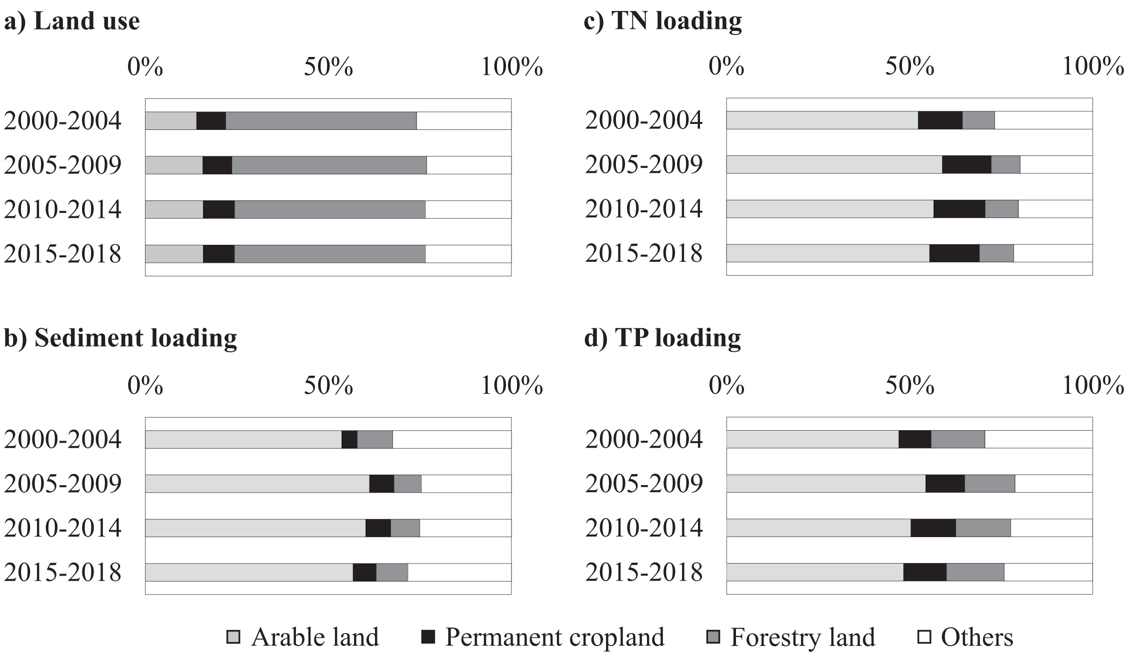

Fig. 7. Changes in sediment, TN, and TP loadings into the reach according to land-use type during the four periods.

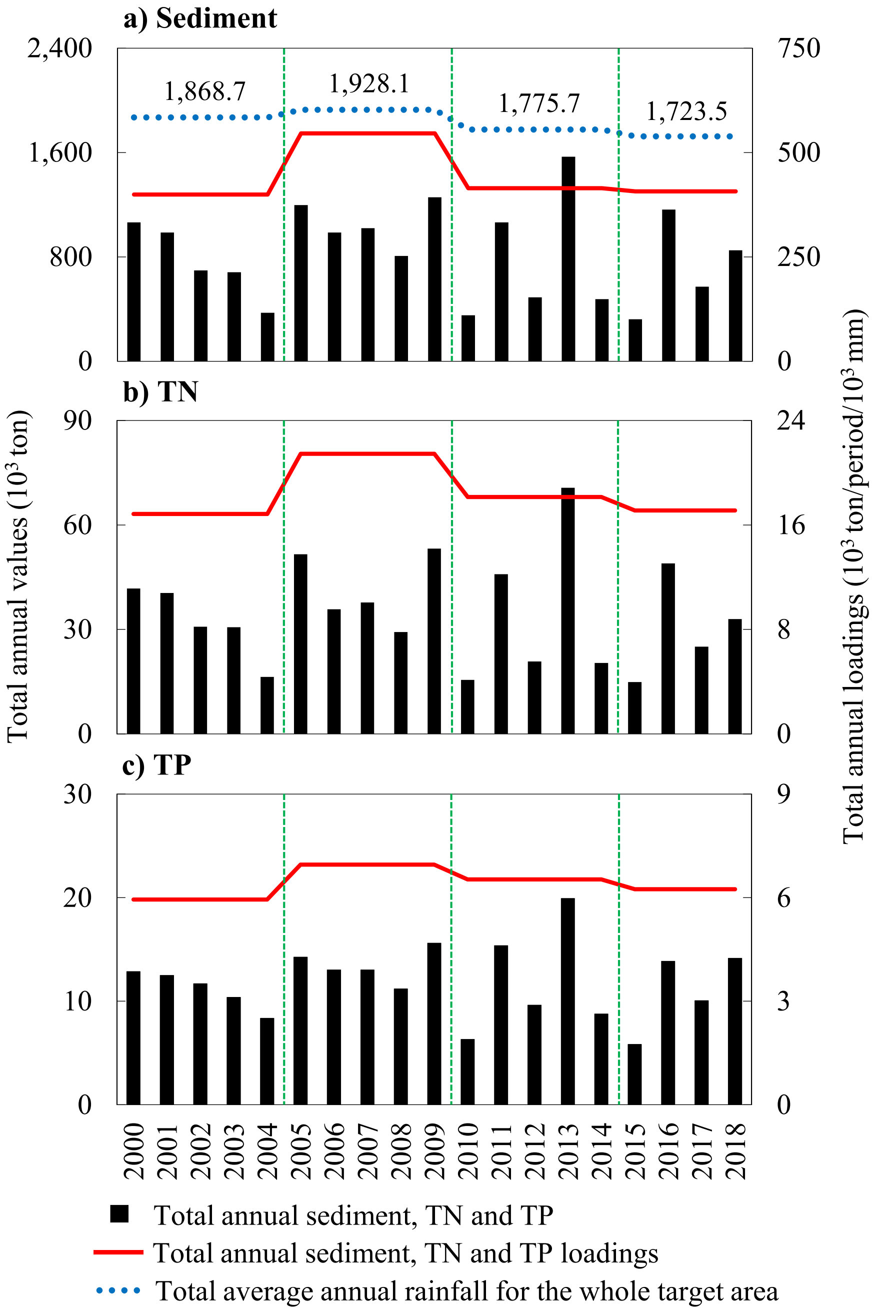

Fig. 8. Changes in the total annual sediment, TN, and TP loadings at the inflow to the lake during the four periods. The total average annual rainfall (mm) was calculated using the Thiessen method.

Compared to that in the 2000–2004 period, the total average annual rainfall in the 2005–2009 period was slightly higher, by 3.2 % (59.4 mm). The total annual sediment, TN, and TP loadings in the 2005–2009 period were significantly higher than those in the 2000–2004 period by 36.6 %, 27.4 %, and 17.1 %, corresponding to 146.4, 4.6, and 1.1 thousand tons/period/10^3 mm, respectively.

Additionally, the total average annual rainfall in the 2010–2014 period (1775.7 mm) was lower than that in the 2000–2004 period (1868.7 mm) by 5.2 %. However, the total annual sediment, TN, and TP loadings in the 2010–2014 period were higher than those in the 2000–2004 period by 15.1, 1.3, and 0.6 thousand tons/period/10^3 mm, corresponding to differences of 3.6 %, 7.1 %, and 9.0 %, respectively.

The total average annual rainfall in the 2015–2018 period was also lower than that in the 2000–2004 period by 8.4 %, corresponding to 145.2 mm. However, the total annual loadings in the 2015–2018 period were higher than those in the 2000–2004 period by 1.9 % (7.6 thousand tons/period/10^3 mm) for sediment, 1.6 % (0.3 thousand tons/period/10^3 mm) for TN, and 4.8 % (0.3 thousand tons /period/10^3 mm) for TP.

As for the 2015–2018 period, the total average rainfall was lower than in the 2010–2014 period by only 3.0 % (52.2 mm). The total annual sediment loading in the 2015–2018 period was lower than in the 2010–2014 period by 1.9 %, equivalent to 7.6 thousand tons/period/10^3 mm. With a similar tendency to that of sediment, the total annual TN and TP loadings in the former period were moderately lower than those in the latter period by 6.0 % (1.0 thousand tons/period/10^3 mm) and 4.6 % (0.3 thousand tons/period/10^3 mm), respectively.

Additionally, the changes in rainfall in the 2000–2004 and 2010–2014 periods (93 mm) were smaller than those in the 2000–2004 and 2015–2018 periods (145.2 mm). The changes in total annual sediment loading in the 2000–2004 and 2010–2014 periods (3.6 %) were slightly larger than those in the 2000–2004 and 2015–2018 periods (1.9 %). The annual TN and TP loadings in the 2000–2004 and 2010–2014 periods (7.1 % and 9.0 %) were moderately higher than those in the 2000–2004 and 2015–2018 periods (1.6 % and 4.8 %).

The total annual loadings at the inflow to the lake in the 2005–2009 period were dramatically higher than those in the three remaining periods, despite rainfall in the 2005–2009 period only being slightly higher. Compared to the 2000–2004 period, there were higher total annual loadings in the 2010–2014 and 2015–2018 periods despite the rainfall in these periods being lower than that in the 2000–2004 period.

4. Discussion

4.1. Impacts of different land-use policies and agricultural practices on river discharge, sediment, and nutrients

Before 2005, although the total area of the DBW was larger than that of the PKW by 297 km^2, equivalent to a difference of 9.3 %, it was observed that the river discharge, sediment, and nutrient loadings in this watershed were significantly lower than those in the PKW, as shown in Fig. 5. From 2005 onward, the total cumulative values in the DBW became higher than those in the PKW during the 2005–2009 period. This increase in the river discharge, sediment, and nutrient loadings was due to implemented land-use policies which influenced agricultural expansion and urbanization mainly in the DBW despite afforestation being conducted. The rates of agricultural expansion and urbanization were faster than the rate of afforestation. In recent years, a higher migration rate, especially in rural areas than urban areas in Kon Tum province, has led to an increase in residential and agricultural areas which slowed the afforestation rate (JICA, 2018).

From 2010 onward, crop conversion from mixed forests to rubber forests has been carried out, the majority of which took place in the DBW. Conversion to rubber forests in low-fertility areas was conducted despite these activities having the potential to destroy the biodiversity available in poorer forests (Hong et al., 2013). Rubber trees were planted instead of maintaining the mixed forests that had been exhausted and had not been able to provide timber products for a long time (Ministry of Agriculture and Rural Development MARD, 2009). During the 2010–2014 period, the total cumulative values in both watersheds showed almost no significant differences; however, these values in the DBW were still slightly higher than those in the PKW. As can be seen, the important role of protecting natural forests and afforesting policies in the upstream areas in the previous period enabled a reduction in the sediment and nutrient discharging downstream, especially in the DBW.

From 2015 onward, urbanization, agricultural expansion, and deforestation were conducted continuously. Along with these anthropogenic activities, crop conversion from insufficient rubber forests to orchards was conducted by the local government. The majority of these activities also took place mostly in the DBW; thus, the total cumulative sediment and nutrient loadings in this watershed were significantly higher than those in the PKW. Evidence revealed that the changes in local land-use policies and human activities during different periods significantly impacted the hydrological processes and changed the magnitude of erosion and nutrient loadings in the target area. Understanding the characteristics of each watershed can support decision makers in implementing more effective short-, middle-, and long-term land-use and water resources management strategies during different periods.

4.2. Spatial changes in river discharge, sediment, and nutrient loadings during the different periods

The sediment and TP loadings were higher in the northwestern PKW where range land predominated, as well as in the western and southern DBW where arable land and permanent cropland predominated. For TN loading, the downstream of both watersheds and the southern upstream of the DBW exhibited higher values because of the occurrence of agricultural activities. These locations should be considered from the agricultural perspective in policies aiming to minimize the sediment and nutrient loadings into the reaches. Despite the predominance of forestry land, there were lower annual TN and TP loadings, whereas arable land occupying a smaller area had the highest percentage of sediment loadings during all the periods, as also indicated for a mountainous watershed in Japan (Somura et al., 2012). The main sources of nitrogen and phosphorus in the target area are agricultural activities. Agricultural land receives a significantly greater amount of fertilizer than forestry land (Rodríguez-Blanco et al., 2015). Nitrate and phosphorus exhibit an increasing tendency with the expansion of the upland area (Somura et al., 2019). For arable land, the 2005–2009 and 2010–2014 periods had a higher proportion of sediment, TN, and TP loadings. Moreover, the conversion to rubber forests was represented by an increase in sediment, TN, and TP loadings in permanent cropland during the 2010–2014 period compared to the 2005–2009 period. Subsequently, the conversion from rubber forests to orchards successfully reduced the proportion of these loadings during the 2015–2018 period. Khoi et al. (2019) emphasized the important role of spatial land-use strategies to manage local water resources management. Similar to their analysis, some areas with efficient land-use policies were found to reduce soil erosion and nutrient loadings into the reaches.

4.3. Impacts of different land-use policies and agricultural practices on the downstream aquatic environment, particularly Yaly Lake

The impacts of applying local land-use policies and agricultural practices on the downstream area were delineated by a comparison of the four different periods (Fig. 8). Compared to the 2000–2004 period baseline, afforestation, agricultural expansion, and urbanization along with extensive anthropogenic activities significantly contributed to increasing erosion and affected the downstream water quality despite afforestation being conducted during the 2005–2009 period. As for the 2010–2014 period, crop conversion policy involving a move from mixed forests to rubber forests and human activities had a significant influence on downstream areas compared to the 2000–2004 period. Also, the crop conversion policy involving a move from insufficient rubber forests to orchards during the 2015–2018 period was capable of minimizing the erosion and nutrient loadings to the lake despite the total annual loading during this period being higher than that in the 2000–2004 period. Comparing the 2010–2014 and 2015–2018 periods, this also reinforces the point that crop conversion from mixed forests to rubber forests and anthropogenic practices during the 2010–2014 period were some of the main practices affecting soil loss and water quality in the study area. This finding reveals that water quality was highly sensitive to local land-use policy change and anthropogenic activities, and their influence appeared on the water quality relatively in a short time.

In Yaly Lake, water quality measurements started in 2015; the water quality in the rainy season of 2016 (the second measurement in 2016) was poorer than that in the remaining years from 2015 to 2019 (Kon Tum Provincial Department of Natural Resource and Environment KTDONRE, 2019). The NO_3-N concentration was close to the A1 threshold, while the NH_4-N concentration was close to the B1 and B2 levels of the national standard. Furthermore, the PO_4-P concentration nearly reached the B2 level in the middle of Yaly Lake and exceeded this threshold in the eastern area of the lake. In the Vietnamese national standard QCVN 08:2008/BTNMT for surface water quality, the A1 threshold is used for domestic water supply, aquatic plants and animal conservation, and other uses as the A2, B1, and B2 criteria mentioned. The B1 threshold is used for irrigation, water transportation, and other uses as the B2 criterion mentioned. The B2 threshold is applied for water transportation and other uses with low-water-quality requirements. From 2017 onward, the surface water quality in Kon Tum province tended to be better than that in 2016, especially in terms of TN and TP (Kon Tum Provincial People's Committee, 2018), due to the new national technical regulations on surface water quality (QCVN 08-MT:2015/BTNMT) and crop conversion policy moving from insufficient rubber forests to orchards. If the crop conversion to inefficient rubber forests during the 2010–2014 period had been continuously applied during the 2015–2018 period, the water quality would have been worse.

Water quality parameters are less sensitive to climate change than land-use changes (Khoi et al., 2019). Most of these parameters are impacted by cultivation in upland areas (Somura et al., 2019). It is difficult to reduce large nutrient loadings into the lake in a short period, especially in rural areas (Yang et al., 2016), because this requires the use of advanced technology in agricultural activities and capital investment in building infrastructure, as well as changes in residents' behavior. Additionally, the limited data for water quality from these rivers were a noticeable issue when determining intra-seasonal changes in water quality or recognizing specific pollution sources. Thus, more frequent water quality monitoring should be conducted when considering water resources management at the regional and sub-watershed scales (Somura et al., 2018). Nevertheless, it is clear that promulgating reasonable changes in land-use policies for particular local conditions will play a crucial role in tackling the water quality issues of Yaly Lake, especially during the rainy season featuring excess discharge and high rainfall intensity.

4.4. Land-use and crop conversion policies for the future in the Central Highlands of Vietnam, including the target watersheds

From 2006–2020, three strategies of forestry were implemented in Vietnam, which can be categorized into the three periods of 2006–2010, 2011–2015, and 2016–2020 (Ministry of Agriculture and Rural Development MARD, 2019). In the 2006–2010 period, the project of planting five million hectares of forest, called Program 661, was conducted (Prime Minister, 1998). Afforestation planning in this period was conducted to reduce erosion and nutrient flow downstream, especially in the northwestern and western areas of the whole watershed. In the 2011–2015 period, strategies for forest protection and development were implemented (Prime Minister, 2012). In 2014, an afforestation project was promulgated in the mountainous areas. The necessary areas for afforestation activities were 2083 ha and 4460 ha in Kon Tum and Gia Lai provinces, respectively (Ministry of Agriculture and Rural Development MARD, 2014). In the 2016–2020 period, the target program for sustainable forestry development (Program 886) was implemented in 2017 (Prime Minister, 2017). Additionally, strategies for sustainable forestry development in the Central Highlands for the 2021–2030 period were proposed in 2019, with priority given to the tasks that were not successfully completed in the 2016–2020 period, including forest protection and development, high-tech forestry development, community forest management, livelihood improvement, forest product development, sustainable forest management, and forest certification (Prime Minister, 2018). The role of forests in the Central Highlands is important in reducing the significant effects impacting aquatic biodiversity downstream. These strategies also depend on differences in the climate conditions, soil types, land-use types, and hydrological characteristics of each province.

In the Central Highlands, the forest area decreased by 416,994 ha from 2006 to 2019. As a result, the forest cover rate decreased from 54.6 % in 2006 to 45.9 % in 2019, representing the largest decrease in the country. The area of natural forest in this region decreased by 633,613 ha, whereas the planted forest area increased by 216,619 ha from 2006 to 2019. The main reasons for forest clearance in this region were urbanization, agricultural expansion, and crop conversion. Planted forests accounted for 5.11 % of the total forest area in 2006 and 14.4 % of the total forest area in 2019 (Ministry of Agriculture and Rural Development MARD, 2019). The forest cover rate is expected to increase to 49.2 % by 2030. Protection of the natural forest system in the upstream areas will be extremely important in order to maintain the natural forest cover by encouraging co-management and community forest management systems. As can be clearly seen, the DBW and PKW belonging to the upstream Sesan River Basin play a key role in improving downstream water quality. Using these strategies, expectations for finding possible long-term solutions in the target area are necessary, especially in watershed management. The model approach, combined with consideration of local policies and agricultural practices, can contribute quantitative information for the identification of the impacts of terrestrial activities on the aquatic environment, as well as for comparisons of the different characteristics of the two watersheds, which can support local land-use planning and water resources management policies toward the sustainable development of both the terrestrial and the aquatic environments in particular areas.

5. Limitation of the study

The simulated results can be used to comprehensively assess the great changes in land use and anthropogenic activities in the target area. Additionally, the multiple land-use change approach should be applied to evaluate the impacts of land-use change in the future instead of using a single static land-use input condition or the delta approach, which is evaluated according to the differences in simulated outputs between two periods. Although the improvement in the simulation results was confirmed by this study, several limitations still exist that may affect the accuracy of our results, such as: (1) the reproducibility of river discharges in the upstream of the target area; (2) the limited observation data for water quality from the rivers and Yaly lake; (3) the accuracy of the information regarding local agricultural practices; (4) the sparse distribution of rain gauges; and (5) the poor representation of the model in pollutant transport simulation. The first thing is that the river discharges were observed by the two hydrological stations located downstream of the target watersheds. This means upstream flow conditions may not be reproduced accurately, leading to the appearance of biases affecting the simulation of hydrological processes. Secondly, the amount of information on water quality from the rivers and Yaly lake was limited because water quality observation began in 2014, and these data are reported four times per year. This may not be sufficient to capture the local water quality conditions appropriately. Thirdly, the agricultural practice information was collected from the local government and used in the model. However, the local practices, such as the timing and amount of fertilizer, may be slightly different among farmers. This may affect the reproducibility of simulated outputs. Another reason is the lack of rainfall gauges in the central part of the area. The spatial distribution of rainfall can also influence the spatiotemporal uncertainty of the model in hydrology and water quality simulations (Cho et al., 2009). Finally, the simulation of pollutant transport in the river bed phase is one of the weaknesses of this model (Baffaut and Benson, 2009).

However, the calibrated outputs can be useful for different purposes, especially for controlling agricultural management practices on the watershed scale, even though there are several limitations in the observed information and the uncertainty of the model (Özcan et al., 2017).

6. Conclusions

The impacts of land-use policies and anthropogenic activities on river discharge, sediment, and nutrient loadings were assessed in the upstream Sesan River Basin across different periods from 2000 to 2018. The multiple land-use change conditions, along with the local agricultural practice information, were established in the original SWAT. The main findings of the study are as follows:

- The total cumulative river discharge, sediment, and nutrient loadings in the DBW were significantly lower than those in the PKW before 2005, despite the total area of the former being larger than the latter. From 2005 onward, these values were higher in the DBW, where the majority of anthropogenic activities occurred, especially in the 2005–2009 and 2010–2014 periods.
- Higher annual sediment and TP loadings were found upstream from the PKW, where range land predominated, and in southwestern and southern DBW, where arable land and permanent cropland predominated. The higher TN loadings were found upstream and downstream from the PKW as well as in southwestern and southern DBW.
- Arable land had the highest proportion of sediment, TN, and TP loadings across all four periods. The 2005–2009 and 2010–2014 periods exhibited higher proportions of these loadings from arable land and permanent cropland into the reaches.
- The important role of efficient land-use policies and afforestation in reducing erosion and improving the downstream water quality in this area has been emphasized.
- The crop conversion policy involving a shift from insufficient rubber forests to orchards applied in the 2015–2018 period seems to be efficient for the improvement of the water quality in the target area.

From this study, it has been proved that our methodology and results can be used to quantitatively evaluate the influences of local land-use policies on local water resources in the target river basin. By using our approach, future conditions of water resources also can be evaluated under future land-use projections in terrestrial zones on the aquatic environment downstream. The information will be useful for developing inter-ministerial cooperation systems to ensure the coherence of policies. However, to consider and execute water resources management comprehensively, several aspects need to be taken into account, such as: (1) the local water demand and its changes, with the selection of suitable crop types and advanced technologies; (2) the available water amount and its distribution over time under future climate conditions; (3) the participation of stakeholders in discussion, allowing them to share the conditions they consider to be ideal for the watershed and to prioritize necessary actions in the management of water resources; and (4) the acquisition of understanding from local residents regarding water environment protection. In addition to our results, this information and the necessary activities will assist decision makers in determining appropriate water resources management practices in the area.

CRediT authorship contribution statement

Vo Ngoc Quynh Tram: Conceptualization, Methodology, Data Collection, Visualization, Writing – Original Draft. **Hiroaki Somura:** Conceptualization, Methodology, Resources, Supervision, Visualization, Writing – review & editing. **Toshitsugu Moroizumi:** Writing – review & editing. **Morihiro Maeda:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ejrh.2022.101225. These data include Google maps of the most important areas described in this article.

References

Abbaspour, K.C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., Kløve, B., 2015. A continental-scale hydrology and water quality model for Europe: calibration and uncertainty of a high-resolution large-scale SWAT model. J. Hydrol. 524, 733–752. https://doi.org/10.1016/j.jhydrol.2015.03.027.

Aghsaei, H., Dinan, N.M., Moridi, A., Asadolahi, Z., Delavar, M., Fohrer, N., Wagner, P.D., 2020. Effects of dynamic land use/land cover change on water resources and sediment yield in the Anzali wetland catchment, Gilan, Iran. Sci. Total Environ. 712, 1–11. https://doi.org/10.1016/j.scitotenv.2019.136449.

Alexander, R.B., Smith, R.A., Schwarz, G.E., Boyer, E.W., Nolan, J.V., Brakebill, J.W., 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Technol. 42 (3), 822–830. https://doi.org/10.1021/es0716103.

Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold, J.G., 2007. Representation of agricultural conservation practices with SWAT. Hydrol. Process. 22, 3042–3055. https://doi.org/10.1002/hyp.6890.

Baffaut, C., Benson, V.W., 2009. Modeling flow and pollutant transport in a karst watershed with SWAT. Trans. Am. Soc. Agric. Biol. Eng. 52 (2), 469–479. https://doi.org/10.13031/2013.26840.

Brito, D., Neves, R., Branco, M.A., Prazeres, Â., Rodrigues, S., Gonçalves, M.C., Ramos, T.B., 2019. Assessing water and nutrient long-term dynamics and loads in the Enxoé temporary river basin (Southeast Portugal). Water 11 (2), 354. https://doi.org/10.3390/w11020354.

Carpenter, S.R., Bolgrien, D., Lathrop, R.C., Stow, C.A., Reed, T., Wilson, M.A., 1998. Ecological and economic analysis of lake eutrophication by nonpoint pollution. Aust. J. Ecol. 23 (1), 68–79. https://doi.org/10.1111/j.1442-9993.1998.tb00706.x.

Cho, J., Bosch, D., Lowrance, R., Strickland, T., Vellidis, G., 2009. Effect of spatial distribution of rainfall on temporal and spatial uncertainty of SWAT output. Trans. Am. Soc. Agric. Biol. Eng. 52 (5), 1545–1555. https://doi.org/10.13031/2013.29143.

Chu, T.W., Shirmohammadi, A., Montas, H., Sadeghi, A., 2004. Evaluation of the SWAT model's sediment and nutrient components in the piedmont physiographic region of Maryland. Trans. Am. Soc. Agric. Eng. 47 (5), 1523–1538. https://doi.org/10.13031/2013.17632.

Donmez, C., Sari, O., Berberoglu, S., Cilek, A., Satir, O., Volk, M., 2020. Improving the applicability of the swat model to simulate flow and nitrate dynamics in a flat data-scarce agricultural region in the Mediterranean. Water 12 (12), 3479. https://doi.org/10.3390/w12123479.

Epelde, A.M., Cerro, I., Sánchez-Pérez, J.M., Sauvage, S., Srinivasan, R., Antigüedad, I., 2015. Application of the SWAT model to assess the impact of changes in agricultural management practices on water quality. Hydrol. Sci. J. 60 (5), 825–843. https://doi.org/10.1080/02626667.2014.967692.

Folliott, P., Brooks, K., Neary, D., Roberto, T., Chevesich, P., 2013. Soil erosion and sediment production on watershed landscapes: Processes and control. UNESCO Special Technical Publication No. 32. Montevideo, Uruguay: UNESCO, International Hydrological Programme, Regional Office for Science for Latin American and the Carribbean.

Frohlich, H.L., Schreinemachers, P., Stahr, K., Clemens, G., 2013. Sustainable Land Use and Rural Development in Southeast Asia: Innovations and Policies for Mountainous Areas. Springer Environmental Science and Engineering. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-33377-4.

Fullen, M.A., Booth, C.A., Panomtaranichagul, M., Subedi, M., Mei, Y.L., 2011. Agro-environmental lessons from the "Sustainable highland agriculture in South-east Asia" (SHASEA) project. J. Environ. Eng. Landsc. Manag. 19 (1), 101–113. https://doi.org/10.3846/16486897.2011.557476.

Gia Lai Provincial People's Council, 2015. Rubber trees development under the rubber development project in Gia Lai province from 2008 to present. Assessment report, Gia Lai province, Vietnam, 9 pages (in Vietnamese).

Githui, F., Mutua, F., Bauwens, W., 2009. Estimating the impacts of land-cover change on runoff using the soil and water assessment tool (SWAT): Case study of Nzoia catchment, Kenya. Hydrol. Sci. J. 54 (5), 899–908. https://doi.org/10.1623/hysj.54.5.899.

Hanief, A., Laursen, A.E., 2017. SWAT modeling of hydrology, sediment and nutrients from the grand river, Ontario. Water Qual. Res. J. 52 (4), 243–257. https://doi.org/10.2166/wqrj.2017.014.

Holden, J., Haygarth, P., MacDonald, J., Jenkins, A., Spaiets, A., Orr, H., Dunn, N., Harris, B., Pearson, P., McGonigle, D., Humble, A., Ross, M., Harris, J., Meacham, T., Benton, T., Staines, A., Noble, A., 2015. Farming and water 1: Agriculture's impacts on water quality. Global Food Security.

Hong, T., Hue, T.T.M., Tri, P.C., Phuc, V.N., Ngoc, N.Q., Uyen, D.T.L., 2013. Basin profile of the upper Sesan River in Vietnam. Project report: Challenge Program on Water & Food Mekong project MK3 "Optimizing the management of a cascade of reservoirs at the catchment level". ICEM – International Centre for Environmental Management, Hanoi, Vietnam.

Huang, Z., Xue, B., Pang, Y., 2009. Simulation on stream flow and nutrient loadings in Gucheng lake, Low Yangtze river basin, based on SWAT model. Quat. Int. 208, 109–115. https://doi.org/10.1016/j.quaint.2008.12.018.

Jha, M.K., Gassman, P.W., Arnold, J.G., 2007. Water quality modeling for the Raccoon river watershed using SWAT. Trans. Am. Soc. Agric. Eng. 50 (2), 479–493. https://doi.org/10.13031/2013.22660.

JICA, 2018. Final report: Data collection survey on water resources management in Central Highlands. Japan International Cooperation Agency, Nippon Koei Co., Ltd.

Keraga, A.S., Kiflie, Z., Engida, A.N., 2019. Evaluation of SWAT performance in modeling nutrients of Awash River basin, Ethiopia. Model. Earth Syst. Environ. 5 (1), 275–289. https://doi.org/10.1007/s40808-018-0533-y.

Khoi, D.N., Thom, V.T., 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 (4), 870–881. https://doi.org/10.30955/gnj.001706.

Khoi, D.N., Nguyen, V.T., Sam, T.T., Nhi, P.T.T., 2019. Evaluation on effects of climate and land-use changes on streamflow and water quality in the La Buong river basin, Southern Vietnam. Sustainability 11 (24). https://doi.org/10.3390/SU11247221.

Kim, K.B., Kwon, H.-H., Han, D., 2017. Exploration of warm-up period in conceptual hydrological modelling. J. Hydrol. 556, 194–210. https://doi.org/10.1016/j.jhydrol.2017.11.015.

Kon Tum Provincial Department of Natural Resource and Environment (KTDONRE), 2016. Report of environmental monitoring results in 2016. Assessment report, Kon Tum province, Vietnam, 130 pages (in Vietnamese).

Kon Tum Provincial Department of Natural Resource and Environment (KTDONRE), 2017. Report of environmental monitoring results in 2017. Assessment report, Kon Tum province, Vietnam, 166 pages (in Vietnamese).

Kon Tum Provincial Department of Natural Resource and Environment (KTDONRE), 2019. Report of environmental monitoring results in 2019. Assessment report, Kon Tum province, Vietnam, 156 pages (in Vietnamese).

Kon Tum Provincial People's Committee, 2016. The status of forest in Kon Tum province. Decision number 637/QĐ-UBND, Kon Tum province, Vietnam, 9 pages (in Vietnamese).

Kon Tum Provincial People's Committee, 2018. Report on environmetal protection in 2018. Assessment report number 239/BC-UBND, Kon Tum province, Vietnam, 40 pages (in Vietnamese).

Kon Tum Provincial People's Committee, 2019. Technical and economic norms of plant and livestock in Kon Tum province. Decision number 31/2019/QĐ-UBND, Kon Tum province, Vietnam, 139 pages (in Vietnamese).

Li, Y., Chang, J., Luo, L., Wang, Y., Guo, A., Ma, F., Fan, J., 2019. Spatiotemporal impacts of land use land cover changes on hydrology from the mechanism perspective using SWAT model with time-varying parameters. Hydrol. Res. 50 (1), 244–261. https://doi.org/10.2166/nh.2018.006.

Lin, C., Ma, R., He, B., 2016. Identifying watershed regions sensitive to soil erosion and contributing to lake eutrophication — A case study in the Taihu lake basin (China). Int. J. Environ. Res. Public Health 13 (1), 77. https://doi.org/10.3390/ijerph13010077.

Malagó, A., Bouraoui, F., Vigiak, O., Grizzetti, B., Pastori, M., 2017. Modelling water and nutrient fluxes in the Danube river basin with SWAT. Sci. Total Environ. 603–604, 196–218. https://doi.org/10.1016/j.scitotenv.2017.05.242.

Mateo-Sagasta, J., Marjani, S., Turral, H., Burke, J., 2017. Water pollution from agriculture: a global review - Executive summary. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy; International Water Management Institute (IWMI), Colombo, Sri Lanka.

Ministry of Agriculture and Rural Development (MARD), 2009. The criteria for the identification and classification of forests. Circular number 34/2009/TT-BNNPTNT, Hanoi city, Vietnam, 5 pages (in Vietnamese).

Ministry of Agriculture and Rural Development (MARD), 2014. Project on afforestation when changing the forest use purpose to other purposes. Decision number 829/QĐ-BNN-TCLN, Hanoi city, Vietnam, 7 pages (in Vietnamese).

Ministry of Agriculture and Rural Development (MARD), 2019. The sustainable forestry development strategies for the period 2021–2030, and a vision to 2050. Assessment report, Hanoi city, Vietnam, 149 pages (in Vietnamese).

Moriasi, D.N., Gitau, M.W., Pai, N., Daggupati, P., 2015. Hydrologic and water quality models: performance measures and evaluation criteria. Trans. Am. Soc. Agric. Biol. Eng. 58 (6), 1763–1785. https://doi.org/10.13031/trans.58.10715.

Moriasi, D.N., Pai, N., Steiner, J.L., Gowda, P.H., Winchell, M., Rathjens, H., Starks, P.J., Verser, J.A., 2019. SWAT-LUT: a desktop graphical user interface for updating land use in SWAT. J. Am. Water Resour. Assoc. 55 (5), 1102–1115. https://doi.org/10.1111/1752-1688.12789.

Organisation for Economic Cooperation and Development (OECD), 2017. The governance of land use: Policy highlights. OECD, France. https://doi.org/10.4324/9781315438689-25.

Özcan, Z., Başkan, O., Düzgün, H.Ş., Kentel, E., Alp, E., 2017. A pollution fate and transport model application in a semi-arid region: is some number better than no number? Sci. Total Environ. 595, 425–440. https://doi.org/10.1016/j.scitotenv.2017.03.240.

Phuc, T.X., Nghi, T.H., 2014. Rubber expansion and forest protection in Vietnam rubber expansion and forest protection in Vietnam. Tropenbos International Vietnam, Hue city, Vietnam, p. 55.

Pierret, A., de Rouw, A., Chaplot, V., Valentin, C., Noble, A., Suhardiman, D., Drechsel, P., 2011. Reshaping upland farming policies to support nature and livelihoods: Lesson from soil erosion in Southeast Asia with emphasis on Lao PDR. In Marseille, France: Institut de Recherche pour le Développement (IRD). International Water Management Institute (IWMI), Colombo, Sri Lanka. https://doi.org/10.5337/2011.213.

Piniewski, M., Szcześniak, M., Kardel, I., Berezowski, T., Okruszko, T., Srinivasan, R., Schuler, D.V., Kundzewicz, Z.W., 2017. Hydrological modelling of the Vistula and Odra river basins using SWAT. Hydrol. Sci. J. 62 (8), 1266–1289. https://doi.org/10.1080/02626667.2017.1321842.

Prime Minister, 1998. Project of planting new five million hectares of forest. Decision number 661/QĐ-TTg, Hanoi city, Vietnam, 9 pages (in Vietnamese).

Prime Minister, 2012. Plan for forest protection and development in the 2011–2020 period. Decision number 57/QĐ-TTg, Hanoi city, Vietnam, 12 pages (in Vietnamese).

Prime Minister, 2017. Target program for sustainable forestry development. Decision number 886/QĐ-TTg, Hanoi city, Vietnam, 12 pages (in Vietnamese).

Prime Minister, 2018. Project for forest protection, restoration and sustainable development in the Central Highlands from 2016 to 2030. Decision number 297/QĐ-TTg, Hanoi city, Vietnam, 6 pages (in Vietnamese).

Rodríguez-Blanco, M.L., Taboada-Castro, M.M., Taboada-Castro, M.T., Oropeza-Mota, J.L., 2015. Relating nitrogen export patterns from a mixed land use catchment in NW Spain with rainfall and streamflow. Hydrol. Process. 29 (12), 2720–2730. https://doi.org/10.1002/hyp.10388.

Shi, W., Huang, M., 2021. Predictions of soil and nutrient losses using a modified SWAT model in a large hilly-gully watershed of the Chinese Loess Plateau. Int. Soil Water Conserv. Res. 9 (2), 291–304. https://doi.org/10.1016/j.iswcr.2020.12.002.

Sidle, R.C., Ziegler, A.D., Negishi, J.N., Nik, A.R., Siew, R., Turkelboom, F., 2006. Erosion processes in steep terrain - Truths, myths, and uncertainties related to forest management in Southeast Asia. For. Ecol. Manag. 224 (1–2), 199–225. https://doi.org/10.1016/j.foreco.2005.12.019.

Smarzyńska, K., Miatkowski, Z., 2016. Calibration and validation of SWAT model for estimating water balance and nitrogen losses in a small agricultural watershed in central Poland. J. Water Land Dev. 29, 31–47. https://doi.org/10.1515/jwld-2016-0010.

Somura, H., Takeda, I., Arnold, J.G., Mori, Y., Jeong, J., Kannan, N., Hoffman, D., 2012. Impact of suspended sediment and nutrient loading from land uses against water quality in the Hii river basin, Japan. J. Hydrol. 450–451, 25–35. https://doi.org/10.1016/j.jhydrol.2012.05.032.

Somura, H., Kunii, H., Yone, Y., Takeda, I., Sato, H., 2018. Importance of considering nutrient loadings from small watersheds to a lake – A case study of the Lake Shinji watershed, Shimane Prefecture, Japan. Int. J. Agric. Biol. Eng. 11 (5), 124–130. https://doi.org/10.25165/j.ijabe.20181105.4351.

Somura, H., Yuwono, S.B., Ismono, H., Arifin, B., Fitriani, F., Kada, R., 2019. Relationship between water quality variations and land use in the Batutegi Dam watershed, Sekampung, Indonesia. Lakes Reserv.: Res. Manag. 24, 93–101. https://doi.org/10.1111/lre.12221.

Srinivasan, R., Zhang, X., Arnold, J., 2010. SWAT ungauged: hydrological budget and crop yield predictions in the upper Mississippi river basin. Trans. Am. Soc. Agric. Biol. Eng. 53 (5), 1533–1546. https://doi.org/10.13031/2013.34903.

Stallard, R.F., 1998. Terrestrial sedimentation and the carbon cycle: coupling weathering and erosion to carbon burial. Glob. Biogeochem. Cycles 12 (2), 231–257. https://doi.org/10.1029/98GB00741.

Tien, T.M., Truc, H.C., Bo, N.V., 2015. Research findings: potassium application and uptake in coffee (Coffea robusta) plantations in Vietnam. Electron. Int. Fertil. Corresp. 42, 3–9.

Tobin, K.J., Bennett, M.E., 2009. Using SWAT to model streamflow in two river basins with ground and satellite precipitation data. J. Am. Water Resour. Assoc. 45 (1), 253–271. https://doi.org/10.1111/j.1752-1688.2008.00276.x.

Tram, V.N.Q., Somura, H., Moroizumi, T., 2021. The impacts of land-use input conditions on flow and sediment discharge in the Dakbla watershed, Central highlands of Vietnam. Water 13 (5), 627. https://doi.org/10.3390/w13050627.

Vu, M.T., Raghavan, S.V., Liong, S.Y., 2012. SWAT use of gridded observations for simulating runoff - a Vietnam river basin study. Hydrol. Earth Syst. Sci. 16 (8), 2801–2811. https://doi.org/10.5194/hess-16-2801-2012.

Wagner, P.D., Bhallamudi, S.M., Narasimhan, B., Kumar, S., Fohrer, N., Fiener, P., 2019. Comparing the effects of dynamic versus static representations of land use change in hydrologic impact assessments. Environ. Model. Softw. 122, 103987 https://doi.org/10.1016/j.envsoft.2017.06.023.

Yang, Q., Almendinger, J.E., Zhang, X., Huang, M., Chen, X., Leng, G., Zhou, Y., Zhao, K., Asrar, G.R., Srinivasan, R., Li, X., 2018. Enhancing SWAT simulation of forest ecosystems for water resource assessment: a case study in the St. Croix river basin. Ecol. Eng. 120, 422–431. https://doi.org/10.1016/j.ecoleng.2018.06.020.

Yang, X., Liu, Q., Fu, G., He, Y., Luo, X., Zheng, Z., 2016. Spatiotemporal patterns and source attribution of nitrogen load in a river basin with complex pollution sources. Water Res. 94, 187–199. https://doi.org/10.1016/j.watres.2016.02.040.

Zeng, Z., Estes, L., Ziegler, A.D., Chen, A., Searchinger, T., Hua, F., Guan, K., Jintrawet, A., Wood, E.F., 2018. Highland cropland expansion and forest loss in Southeast Asia in the twenty-first century. Nat. Geosci. 11, 556–562. https://doi.org/10.1038/s41561-018-0166-9.

Zettam, A., Taleb, A., Sauvage, S., Boithias, L., Belaidi, N., Sánchez-Pérez, J.M., 2017. Modelling hydrology and sediment transport in a semi-arid and anthropized catchment using the SWAT model: the case of the Tafna River (Northwest Algeria). Water 9 (3), 216. https://doi.org/10.3390/w9030216.

Zhao, S., Peng, C., Jiang, H., Tian, D., Lei, X., Zhou, X., 2006. Land use change in Asia and the ecological consequences. Ecol. Res. 21 (6), 890–896. https://doi.org/10.1007/s11284-006-0048-2.