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ASSESSMENT OF IMPACTS OF LAND USE ON THE FLOW OF VU GIA - THU BON RIVER BASIN

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Abstract

Water resources in the Vu Gia - Thu Bon river basin are under pressure due to population growth, socio-economic development, the impact of climate change, and land use change, which is also considered one factor that changes flow regimes in river basins. Therefore, this article is vital and urgent. This study utilized the GIS-based Soil and Water Assessment Tool (SWAT) model to simulate the flow of Vu Gia - Thu Bon river basin at two hydrological stations - Nong Son and Thanh My, during the calibration period (2004 - 2010) and the verification period (2011 - 2015). The evaluation results of both periods, as measured by the NSE and R2 indexes, were found to be above 0.75. Additionally, the study assessed the impact of land use on the flow regime based on two land use scenarios: One for 2015 and another for 2020, with the evaluation period spanning from 2004 to 2018. The study results showed that groundwater flow tends to decrease, while surface runoff tends to increase due to changes in land use. The forest land area in the basin, which accounts for over 93 % of the total land, only decreased by 1 %, while urban land area increased from 0.95 % to 1.53 %, and vacant land area increased from 1.58 % to nearly 3 %. However, the flow in the whole basin was generally not significantly affected.

Keywords: GIS; SWAT; Land use; Vu Gia - Thu Bon.

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1. Introduction

Vu Gia - Thu Bon is the most extensive river system in the Mid-Central region, the basin provides the primary water source for Quang Nam province and Da Nang city [1]. The Vu Gia - Thu Bon river basin faces pressure from socio-economic development and population growth. The impact of climate change and changes in people's living awareness and land use are also contributing factors that alter the flow regime in the river system. Therefore, it is essential to calculate and evaluate the impact of land use on the flow regime in the basin. Engaging in this process will afford policymakers a comprehensive overview of the existing land use status, facilitating the formulation of strategic land-use management measures for the future. These measures shall meet socio-economic development requirements, protect water sources, and minimize the risk of floods [2].

Around the world, research on the impact of land use change on the basin's hydrological cycle has become a topic of interest in recent years. Suresh Kr Gurjar (2022) studied the effect of land use and land cover change, providing an estimate of the natural river flow and its variation due to land use and land cover change (LULC) over 44 years (1970 - 2014) in the Ramganga River Basin (RRB), a sub-basin of the most fertile and densely populated basin in the world [3]. K. Haleem (2022) studied differentiating the impacts of projected climate and land use change on surface runoff using the soil and water assessment tool (SWAT) through the lens of the Indus Basin, Pakistan [4]. Mohammed Gedefaw (2023) investigated climate change trends and changes in land use and land cover in the Nile basin. Land Use/Land Cover change (LULC) was examined using Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper (ETM+) with 30 m resolution over the period 2012 - 2022 [5].

Conducting thorough research and assessing the impact of land use on flow regimes can enhance the efficacy of land use management and planning initiatives within a river basin. This ensures the need for socio-economic development and balances the requirements to protect natural resources such as land, water, and forests [6]. This study utilizes the Soil and Water Assessment Tool (SWAT) integrated with GIS technology to comprehend the hydrological processes occurring in the basin [7, 8]. The SWAT model has several advantages over its predecessors. It enables the modeling of catchments even in the absence of monitoring networks. It can simulate the impact of changes in input data, such as land use, management practices, and climate management. The integrated GIS interface makes it easy to define watersheds, and manipulate and process related spatial and tabular data [9].

We have updated and supplemented data from recent years, during which there was significant land use and land cover change. The study aims to clarify the impact of these changes on flow volume between 2015 and 2020. These results provide an essential scientific basis for sustainable land use planning in the basin.

2. Methods and data used

2.1. Study area

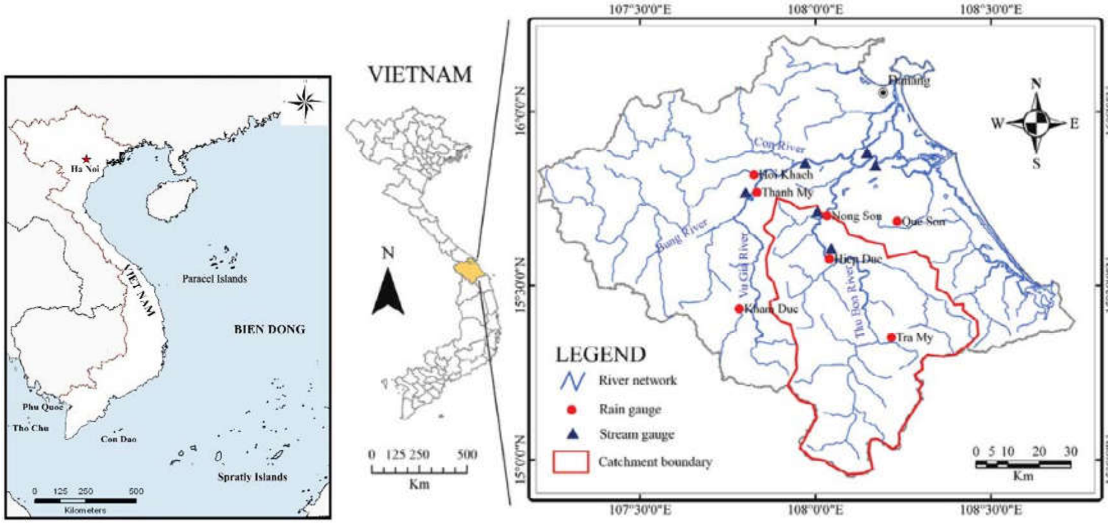


Figure 1: Geographic location of Vu Gia - Thu Bon river basin

The Vu Gia - Thu Bon river system is a vast river network situated in the Central Coast region. The entire basin is located on the eastern slope of the Truong Son mountain range, covering a basin area of 10,350 square kilometers. A part of the region (560.5 km^2) falls within Kon Tum province, while the rest is primarily situated in Quang Nam province and Da Nang city [10].

The terrain of the basin is quite complex, and it can be divided into four regions: mountainous, hilly, plain, and coastal areas [11]. The annual rainfall varies from 2,000 - 4,000 mm, and it is distributed in the following way: 3,000 - 4,000 mm in high mountainous areas such as Tra My and Tien Phuoc, 2,500 - 3,000 mm in medium mountainous areas like Kham Duc, Nong Son, Que Son, and finally 2,000 - 2,500 mm in low mountainous regions and coastal plains such as Hien, Hoi Khach, Ai Nghia, Giao Thuy, and Hoi An [12].

2.2. Data used and methods

2.2.1. Methods

To evaluate the impact of land use on the flow regime in the Vu Gia - Thu Bon river basin, the study is carried out through the steps shown in the diagram Figure 2.

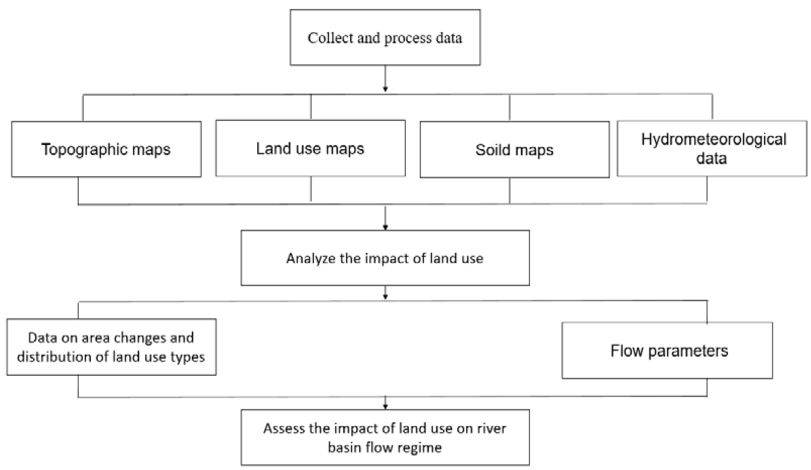


Figure 2: Research diagram

2.2.2. Model SWAT

The SWAT model is a tool for assessing water and soil developed by Jeff Arnold from the US Department of Agriculture’s Agricultural Research Service Center and Srinivasan from the University of Texas A&M, USA [13]. It combines runoff, sedimentation, and nutrient loading data from each sub-basin and hydrological uniformity unit (HRU). Then it channels these results into channels, ponds, and reservoirs to the outlet area [14]. The SWAT model is used to study the hydrological cycle by using a water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

with: SW_o: Total initial water volume on day I (mm);

t: Time (day);

R_{day}: Total rainfall on day i (mm);

Q_{surf}: Total surface water volume of day i (mm);

E_a: Evaporation amount on day i (mm);

W_{seep}: Amount of water entering the underground layer on day i (mm);

Q_{gw}: The amount of water returned at day i (mm).

Dividing the basin into sub-basins enables the model to account for variations in evapotranspiration among different crops and soil types. Runoff is projected independently for each hydrological uniform unit (HRU), and flood transmission is computed to determine the total runoff for the entire basin. Doing so increases the model's accuracy, and the water balance equation is better represented in physical terms [15].

The model includes data from 2015 to 2020, as well as meteorological and hydrological data, to assess the impact of land use changes on river basin flow.

2.2.3. Data input processing and editing procedures

- DEM elevation model map

The Vu Gia - Thu Bon river basin is displayed using contour lines on a map. The data was obtained from http://gdex.cr.usgs.gov/gdex/ as a digital elevation model (DEM) with a 30-meter spatial resolution. This data was then used in the SWAT model to simulate the flow network of the basin. The DEM data was calibrated to the WGS 84 coordinate system before being included in the SWAT model.

- Soil map

Soil map data on the territory of Vietnam is data about the physical cover on the territory's surface, referenced to the WGS 84 coordinate system. FAO's world soil classification divides soil type codes according to soil type. The data is downloaded from the FAO world site and inserted into SWAT to build a soil classification map [16].

Table 1. Statistics on the area of land types in the Vu Gia - Thu Bon basin

No	Symbol	Soil type	Area (ha)	Percentage (%)
1	Ao90-2/3c	Infertile gray soil on sedimentary and metamorphic rocks	875.118	83
2	Re83-1ab	Sandy soil	13.123	1
3	Af60-1/2ab	Silvery gray and reddish brown soil	102.729	10
4	Gd29-3a	Peat clay	63.350	6

- Land-use map

Data from the Vu Gia - Thu Bon river basin was collected in 2015 and 2020. Before being incorporated into the SWAT model, it must be calibrated to the UTM WGS84 coordinate system. The data should be classified into five land use types based on the land use code table in SWAT. This code table specifies codes for crop types, common land cover types, and urban land, along with their attributes, to facilitate simulating crop development and urban areas.

Table 2. Types of land use in 2015 and 2020 in the Vu Gia - Thu Bon river basin

No	Type of land use	Symbol	Area (ha)	
			2015	2020
1	Urban land	URBN	8.836	14.255
2	Agricultural land	AGRL	30.520	28.799
3	Vacant land	BARR	14.756	23.117
4	Jungle land	FRSD	872.324	859.465
5	Water	WATR	7.698	8.497

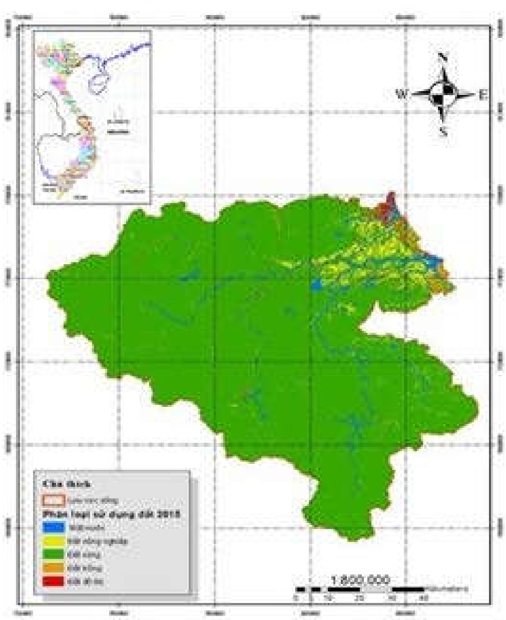


Figure 3: Land use map in 2015

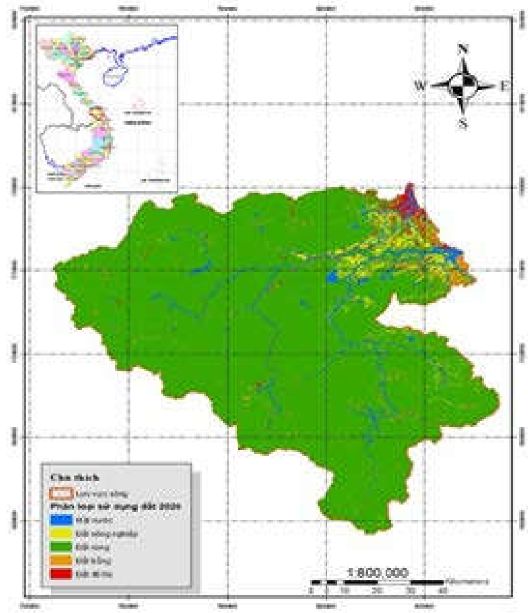


Figure 4: Land use map in 2020

- Real observed data

Collected hydrological documents include the average daily water flow at Nong Son hydrological station on the Thu Bon river and Thanh My hydrological station on the Vu Gia river.

Weather data in the SWAT model is an integral part of the hydrological cycle. Necessary weather data for SWAT collected in this article includes maximum and minimum precipitation and air temperature by day.

Based on the distribution location, measurement time and data quality of meteorological monitoring stations in the Vu Gia - Thu Bon river basin, the article uses accurate rain measurement data including 12 hydrometeorological stations (City My, Nong Son, Da Nang, Tra My, Cam Le, Ai Nghia, Hoi An, Giao Thuy, Cau Lau, Hiep Duc, Tien Phuoc, Kham Duc) period 1986 - 2018.

3. Results and discussion

3.1. The SWAT model

a. Basin delineation

Select the outlet point (outlet) of the entire basin based on the simulated flow network. Finally, the model will calculate the sub-basin parameters and river and stream sections. The result of delimiting the basin is to divide the basin into 9 sub-basins, including Cua Han, Tuy Loan, Cau Lau, Cua Dai, Song Con, Giao Thuy, Thanh My, Song Bung, Nong Son.

b. Hydrological unit (HRU) identification

A sub-basin can be subdivided into hydrological units, the cells within each hydrological unit will be similar in land use, soil, and management attributes.

After successful watershed delineation, soil and land use maps are included in SWAT. The code value of each land use type and land is assigned according to the SWAT code table and redistributed. Slope division (an essential factor determining the amount of water, sediment movement, leaching, and nutrients) in the basin is divided into 5 layers: Layer 1 from 0 - 8 %; Grade 2 from 8 - 17 %; Grade 3 from 17 - 25 %; Grade 4 from 25 - 35 %: Grade 5 over 35%.

The next step in HRU analysis is to define HRUs. This study chose the multiple HRU method because it better describes internal heterogeneity basin and more accurately simulates hydrological processes.

The final step is setting the land use area, soil, and slope threshold. The study chose the Multiple HRUs method, declaring each data layer's threshold ratio (% or area) 20 %, 10 %, and 20 %, respectively.

c. Enter input data for the model

The study used daily rainfall data and the most significant and minor air temperatures from 1986 to 2018 in the SWAT model. After setting up the data, run the model with simulation calculation time corresponding to the stages.

3.2. Calibration and verification of the model

In the SWAT model, to evaluate simulation results, reliability is based on the actual measured flow value and the indicators: Average value, standard deviation, coefficient of determination R^2 (Krause, 2005), and Nash-Sutcliffe (NSE) index (Nash & Sutcliffe, 1970). The R^2 value ranges from 0 to 1, representing the correlation between the actual measured value and the simulated value NSE index has a value (-∞, 1) to measure the amount of agreement between the actual measured value and the simulated value on a 1:1 line.

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Oi - \bar{O}i)(Pi - \bar{p}i)}{\sqrt{\sum_{i=1}^{n}(Oi - \bar{O}i)^2}\sqrt{\sum_{i=1}^{n}(Pi - \bar{p}i)^2}} \right)^2 \quad (2)$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - \bar{O}i)^2} \quad (3)$$

with: Oi is the observed value (m^3/s); $\bar{O}i$ is the average observed value (/s); P_i is the computed value (m^3/s); $\bar{p}i$ is the average computed value (m^3/s); n is the number of computed values.

To evaluate the results of stream flow simulation in the Vu Gia - Thu Bon basin, the article uses average daily monitoring data at Thanh My hydrological station and Nong Son hydrological station over time:

- Calibration period: From 01/2004 to 12/2010.

- Verification period: From 01/2011 to 12/2015.

- Calibration results.

Calibrating the model parameter set is mainly carried out by changing the parameter set while checking the reasonableness of the input data.

The SWAT model used for calibration requires specific parameters grouped based on shared physical, chemical, and flow characteristics such as HRU, sub-basin, and underground. Although the model's parameter set includes many parameters, the article's research and calculations have identified the main parameters that significantly affect the change in flow rate. These parameters are as follows:

Table 3. Parameter detection results when calibrating the SWAT model

No	Parameter	Description	Value
I. Parameters for calculating the process of surface runoff formation			
1	CN2	CN index corresponds to humid conditions II	45
2	SOL_AWC	Soil water storage capacity	0,2
3	SOL_K	Hydraulic conductivity at saturation	160

No	Parameter	Description	Value
4	OV_N	Manning roughness coefficient for runoff	10
5	CH_N(1)	Groove roughness coefficient	0,014
6	CH_K(1)	Hydraulic conductivity of the groove	0,1
II. Parameters for calculating underground flow			
8	GW_DELAY	Underground flow delay time	20
9	ALPHA_BF	The philosophy coefficient reduces underground flow	0,05
III. Parameters for calculating flow in the river			
10	CH_N(2)	Roughness coefficient of main river	0,1
11	CH_K(2)	Hydraulic conductivity of the main river	0,2

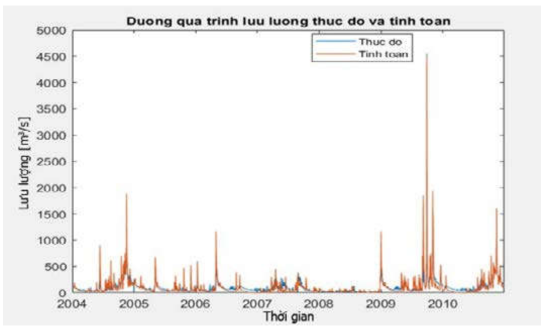


Figure 5: Computed and observed water flow process at Thanh My station in the period 2004 - 2010

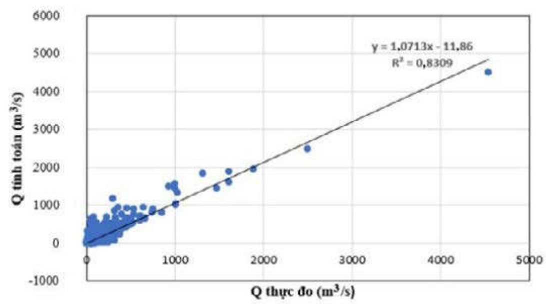


Figure 6: Correlation between computed and observed water flow at Thanh My station in the period 2004 - 2010

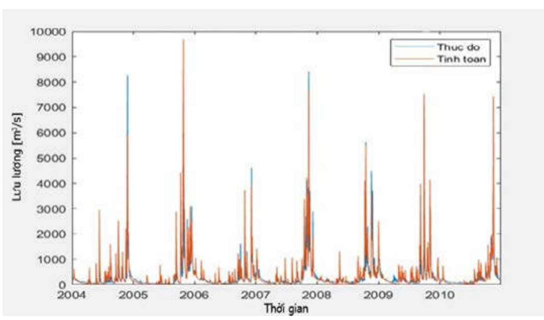


Figure 7: Computed and observed water flow process at the station Nong Son period 2004 - 2010

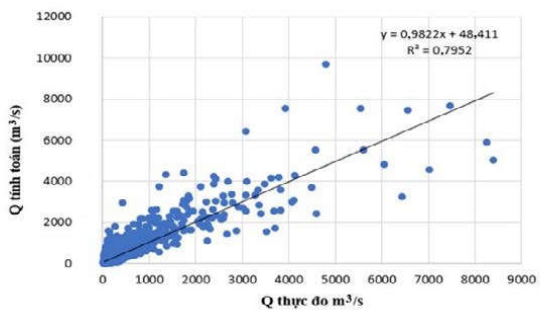


Figure 8: Correlation between computed and observed water flow at Nong Son station in the period 2004 - 2010

Table 4. Evaluation of criteria for model simulation quality (2004 - 2010)

Evaluation index	Hydrological station		Quality
	Thanh My	Nong Son	
NSE	0,76	0,75	Good
R^2	0,83	0,79	Good

The assessment outcomes derived from the NSE index and R2 coefficient indicate high conformity within acceptable limits between the observed and computed water flow processes at both the Thanh My and Nong Son hydrological stations. Therefore, the set of parameters in the model is accepted and used to test for 2011 - 2015.

- Verification results

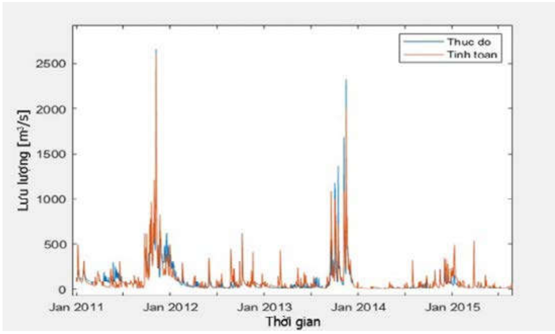


Figure 9: Computed and measured water flow process at Thanh My hydrological station in the period 2011 - 2015

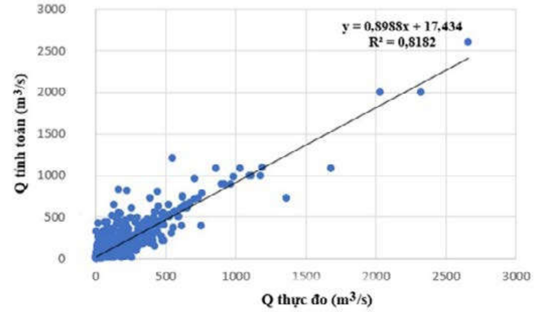


Figure 10: Correlation between computed and measured water flow at Thanh My hydrological station in the period 2011 - 2015

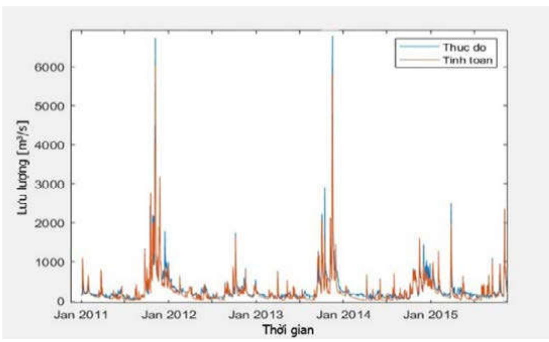


Figure 11: Computed and measured water flow process at Nong Son hydrological station in the period 2011 - 2015

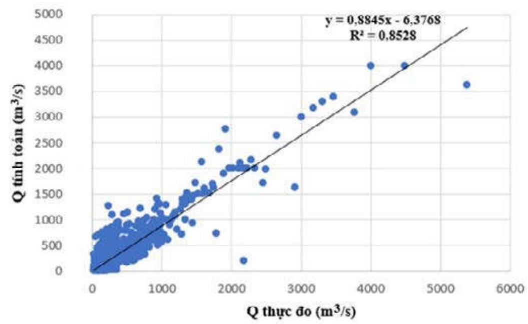


Figure 12: Correlation between computed and actual measured water flow at Nong Son hydrological station in the period 2011 - 2015

Table 5. Evaluation of criteria for model simulation quality (2011 - 2015)

Evaluation index	Hydrological station		Quality
	Thanh My	Nong Son	
NSE	0,80	0,83	Tốt
R^2	0,82	0,85	Tốt

3.3. Changes in land use in the Vu Gia - Thu Bon river basin in 2015 and 2020

The land use in the Vu Gia - Thu Bon river basin can be classified into five main groups: urban land, agricultural land, bare land, forest land, and water surface. Between 2015 and 2020, the land use structure of the basin witnessed the highest proportion of conversion into urban land. The specifics are presented in Table 6.

Table 6. Land use changes in the Vu Gia - Thu Bon river basin in 2015 and 2020

No	Land use name	Area (ha)		Changes 2015-2020	
		2015	2020	Area (ha) increase (+), decrease (-)	Percentage (%)
1	Urban land	8.837	14.255	+5.419	+61
2	Agricultural land	30.520	28.799	-1.720	-6
3	Vacant land	14.756	23.117	+8.361	+57
4	Jungle land	872.324	859.465	-12.858	-2
5	Water	7.698	8.497	+799	+10

The data shows that between 2015 and 2020, there was an increase in the area of urban land, vacant land, and water surface, while agricultural and forest land areas decreased. The proportion of urban land increased the most, with a rise of 5,419 hectares (61 %), followed by vacant land with an increase of 8,361 hectares (57 %) and water surface with an increase of 799 hectares (10 %). On the other hand, agricultural area decreased by 1,720 hectares (6 %), followed by forest land area, which decreased by 12,858 hectares (2 %).

3.4. Impact of land use change on flow rate in Vu Gia - Thu Bon river basin

The SWAT model simulates basin flow under two scenarios: scenario 1 (KB1) corresponds to the 2015 land use map, while scenario 2 (KB2) corresponds to the 2020 land use map. The sole disparity between the two scenarios lies in the land use data, while the soil and weather data remain constant. The flow-related SWAT outputs are then compared between the two scenarios to assess the impact of land use changes on streamflow. The land use in 2015 and 2020 uses a familiar meteorological data series from 2004 - 2018, which allows for a quantitative assessment of the impact of land use changes on streamflow. The evaluation period is from 2004 to 2018.

- Effects of land use change on water balance components

Based on the calculations, the underground water flow (GW_Q) in the Vu Gia - Thu Bon river basin will decrease in two land use scenarios for 2015 and 2020. During the eight months of the dry season, the total flow saw a reduction of 1 %, while the total flow in the flood season decreased by 0.9 %. On the other hand, the surface flow (SUR_Q) in the Vu Gia - Thu Bon river basin is expected to increase. During the eight months of the dry season, the total surface flow increased by 0.6 %. The entire flow in the flood season in the Vu Gia - Thu Bon river basin increased by 0.2 %.

- Effects of land use change on stream flow

In general, the flow of water tends to decrease during the dry season, and increase during the flood season. The January, February, and March data of both the 2015 and 2020 land use scenarios show that the total flow decreased by 0.11 %. Moreover, both scenarios' entire flow from January to August decreased by 0.02 %. However, the total volume of flood season months from September to December increased by 0.02 %.

Table 7. Statistical table of total monthly flow volume in the Vu Gia - Thu Bon river basin corresponding to the 2015 land use scenario and 2020 land use scenario in the period 2004 - 2018

Unit: m^3/month

Month	Year 2015	Year 2020
01	1.263.119	1.262.065
02	643.823	642.767
03	526.699	526.154
04	310.108	310.125
05	612.389	613.120
06	557.522	557.890
07	510.239	510.606
08	743.991	744.379
09	1.677.669	1.678.383
10	3.653.669	3.654.444
11	4.816.243	4.817.364
12	2.662.381	2.662.563

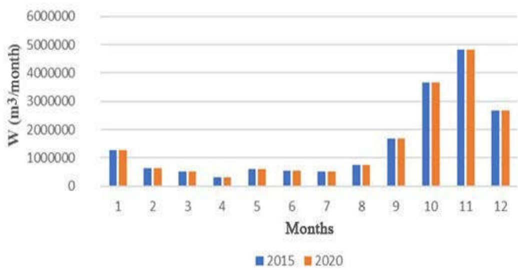


Figure 13: Total monthly flow volume corresponding to the 2015 land use scenario and 2020 land use scenario for the period 2004 - 2018 in the Vu Gia - Thu Bon river basin

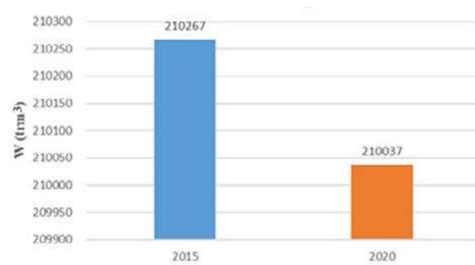


Figure 14: The largest total flow volume in 3 months of the dry season corresponding to the 2015 land use scenario and 2020 land use scenario for the period 2004 - 2018 in the Vu Gia - Thu Bon river basin

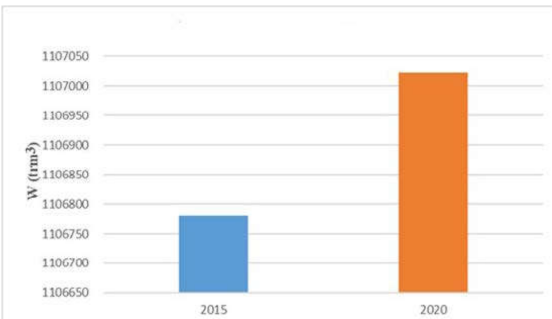


Figure 15: Total flow volume for 8 months in the dry season corresponding to the year 2015 land use scenario and 2020 land use scenario for the period 2004 - 2018 in the Vu Gia - Thu Bon river basin

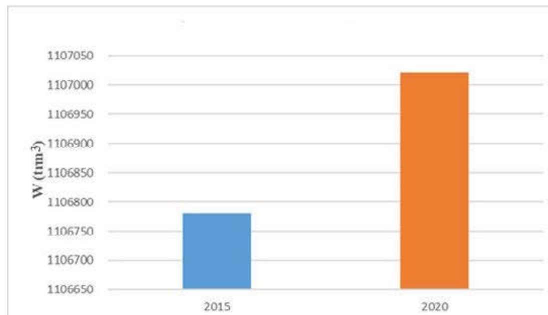
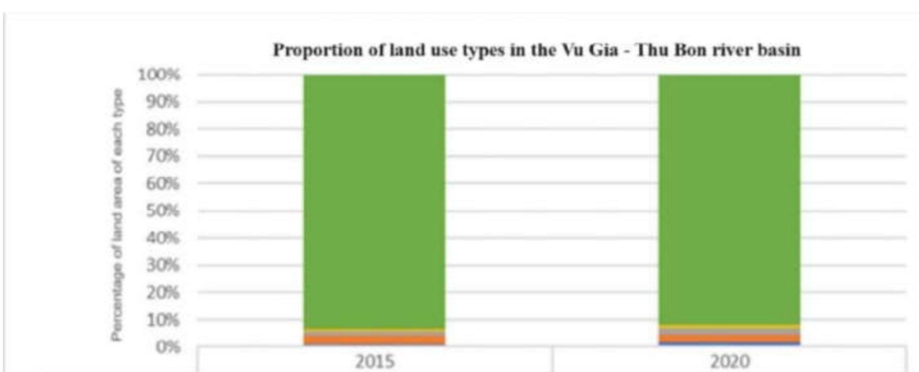


Figure 16: Total flow volume in 4 months of flood season corresponding to the year 2015 land use scenario and 2020 land use scenario for the period 2004 - 2018 in the Vu Gia - Thu Bon river basin

Throughout the basin, the forest land area accounts for over 93 % and has only decreased by 1 %, leaving it at more than 92 %. The urban land area has increased from 0.95 % to 1.53 %, while the vacant land area has increased from 1.58 % to nearly 3 %. These are the main reasons for the changes observed.



	2015	2020
Jungle land	93,38	92,01
Water	0,82	0,91
Vacant land	1,58	2,47
Agricultural land	3,27	3,08
Urban land	0,95	1,53

Figure 17: Proportion of land use types in the Vu Gia - Thu Bon river basin

The current land use situation in the area significantly impacts the flow in the Vu Gia - Thu Bon river basin. Appropriate land use management measures must be implemented to protect and sustainably develop water resources while simultaneously undergoing socio-economic transition.

4. Conclusion

The article presents a comprehensive study and assessment of the study area's topography, geology, soil, vegetation cover, river network, hydrometeorological characteristics, and socio-economic characteristics. This information was used to simulate the flow of the Vu Gia - Thu Bon river basin using the SWAT model. The results were quite good, with R^2 and NSE values above 0.75 at Thanh My and Nong Son hydrological stations during both calibration (2004 - 2010) and verification (2011 - 2015) periods.

After analyzing the data, it has been found that the groundwater flow (GW_Q) in the Vu Gia - Thu Bon river basin has decreased under two different land use scenarios in 2015 and 2020. The total amount of groundwater flow in the three most extensive dry season months (January to March) in the 2015 land use scenario decreased by 0.8 % compared to the 2020 land use scenario. Similarly, the total flow from January to August during the 8-month dry season decreased by 1 %. The flood season in the Vu Gia - Thu Bon river basin is from September to December, and the total flow volume during this season decreased by 0.9 %.

On the other hand, the surface flow (SUR_Q) in the Vu Gia - Thu Bon river basin is increasing. The total surface flow in the three most extensive dry season months (January to March) in the 2015 land use scenario increased by 0.5 % compared to the 2020 land use scenario. Similarly, the total flow during the 8-month dry season, from January to August, increased by 0.6 % in both scenarios. The flood season in the Vu Gia - Thu Bon river basin occurs from September to December, and the total flow volume during this season increased by 0.2 % in both scenarios.

Generally, during the dry season, the water flow tends to decrease while increasing during the flood season. This may be because despite a decrease of only 1 % in the forest land area, which accounts for over 93 % of the entire basin, the urban land area has increased from 0.95 % to 1.53 %, and the vacant land area has increased from 1.58 % to nearly 3 %. However, it is essential to note that the flow throughout the basin is generally not significantly affected.

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