International Journal of GEOMATE, Oct. 2023, Vol. 25, Issue 110, pp.140-147
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.110.3852
Geotechnique, Construction Materials and Environment

IMPACT EVALUATION OF LAND USE–LAND COVER CHANGE ON THE HYDROLOGY OF SALIPIT RIVER BASIN CAVITE, PHILIPPINES

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*Corresponding Author, Received: 10 March 2023, Revised: 15 April 2023, Accepted: 8 Aug. 2023

ABSTRACT: Salipit River Basin is an important tributary of the Maragondon River Watershed in the Philippines, as it is a major source of domestic and agricultural water supply. With that, it is crucial to develop a prediction model for the management of its water resources. The main objective of this study was to quantify the impact of land use-land cover change (LULC) on the hydrology of the Salipit River Basin using the Soil and Water Assessment Tool (SWAT). Since the basin is ungauged, the calibration and validation were performed using the area-discharge ratio-adjusted streamflow records from the nearby Maragondon River from years 2015 to 2018. The model calibration and validation demonstrated satisfactory Pearson correlation values of 0.81 and 0.77, respectively. The calibrated model was used to simulate five (5) future LULC scenarios: baseline scenario, urban development, reforestation, agricultural expansion, and intensified afforestation. A 23% increase in the urban area resulted in a 9%increase in average annual flow. In contrast, a 53% increase in forest cover resulted in an 11% decrease in average annual flow. Overall, decreased (increased) forest and vegetation cover resulted in increased (decreased) surface runoff and decreased baseflow. Land use and land cover changes, therefore, influence the hydrologic response of the Salipit River Basin.

Keywords: SWAT, Salipit River, Maragondon, Land use – land cover change, Hydrology

1. INTRODUCTION

Soil and Water Assessment Tool (SWAT) is one of the most widely used hydrological models worldwide. It was used in many studies to model the effects of land use and land cover change on the hydrology of watersheds [1]. Several studies have also been published investigating Philippine watersheds using SWAT. Models of local watersheds with various drainage areas and durations of simulation performed satisfactorily in simulating streamflow [2-4]. Many investigations on the applicability of SWAT in modeling data scarce basins were also done across the world. Nyeko [5] used different techniques in estimating input parameters such as solar radiation, available soil water content, and saturated soil hydraulic conductivity in modeling the data scarce-basin of Aswa, Uganda. Validation results showed satisfactory performance. Tolentino and Ella [6] investigated the potential of SWAT in ungauged watersheds. The SWAT-predicted monthly streamflow of Macaban Watershed in Laguna, Philippines, was compared to the water balance and SCS-CN computed values. The high correlation suggests that the model is highly applicable for surface runoff and streamflow predictions. In another study, regionalization was utilized in the calibration and validation processes. Due to the unavailability of hydrometric stations within and at the outlet of the Valdora City Watershed in India, river discharge data from nearby river catchments were collected and adjusted using the ratio method instead. Results showed a good agreement between the simulated and observed flow [7].

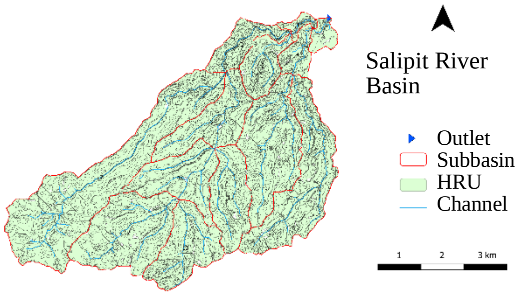

Fig.1 The Salipit River Basin

In Cavite, Philippines, an increase in deforestation and urban land use has been observed in the past several years. Relevant shifts in land use-land cover were especially observed in mountainous areas, including the Salipit River Basin (Figure 1). This basin is an important tributary of the larger Maragondon River Watershed, as it supplies two major water resource facilities [8]. The main objective of this study was to quantify the hydrological impact of land use-land cover change in the Salipit River Basin. Specifically, it aimed to develop a SWAT model of the Salipit River Basin and simulate the effects of LULC changes on its streamflow and water balance.

2. RESEARCH SIGNIFICANCE

Salipit River Basin supplies the irrigation and domestic water demands of its community [8]. As an important asset in water resources, developing sustainable watershed management schemes in the basin is very important. Policies, programs, and interventions must be based on scientific findings [2]. To date, no modeling study has been made on the hydrology of the Salipit River Basin. This model can provide information on the watershed's hydrological behavior, specifically in its response to land use and land cover change. This study might also benefit future studies in the Salipit River Basin.

3. MATERIALS AND METHODS

The methodology was divided into four (4) major sections: model input preparation, model development, model calibration and validation, and evaluation of future land use-land cover scenarios.

3.1 Collection and Preparation of Model Inputs

3.1.1 Digital Elevation Model

The Digital Elevation Model (DEM) serves as the basis of the SWAT model in the delineation and stream network creation processes of the watershed. A 5x5-meter resolution Interferometric Synthetic Aperture Radar (IfSAR) DEM acquired from the National Mapping and Resource Information Authority (NAMRIA) was used in the study.

3.1.2 Land Use/ Land Cover

In this study, the baseline land use-land cover map (Figure 2) was derived mainly from the 2020 Sentinel-2 10-m raster map of the Environmental Systems Research Institute. To further improve the accuracy of the map, the forest areas were subdivided into mixed forest, sparse vegetation, and grassland. These adjustments were based on the land cover maps produced in the 2016 Forest Assessment and Geospatial Analysis Technical Report of Mounts Palay-palay – Mataas na Gulod Protected Landscape [9]. The resulting map was then reclassified to SWAT land cover classes to conform to the input format of the model.

3.1.3 Soil

In the soil characterization, two inputs are required by the model: soil map and soil properties database. A soil map from the Bureau of Soil and Water Management (BSWM) was obtained. This map showed that the most dominant soil types in the river basin are Guadalupe Silt Loam (96.59%), Magallanes Clay Loam (1.93%), and Novaliches Soil (1.48%). The physical and chemical properties of the soil were obtained from the FAO Digital Soil Map of the World (DSMW). Compared to the BSWM Soil Map, FAO DSMW has a lower resolution, but it has a built-in soil database in the SWAT model, which can be readily applied to the study area. Pellic Vertisol, a heavy clay with a high amount of swelling clay, is the only soil unit present in the river basin based on the FAO Soil Map.

3.1.4 Climate

Ideally, the climate data requirements of the model should be measured by a network of weather stations within the river basin [2]. However, there are no weather stations or any climate records within the watershed. As a result, the two nearest stations, approximately 12 km from the study area, were considered. Historical climate data such as precipitation, temperature, relative humidity, solar radiation, and wind speed from years 2012 to 2020 were collected from the Cavite State University-Naic Campus Automated Weather Station (AWS) through the Department of Science and Technology – Advance Science Technology Institute (DOST-ASTI). Historical rainfall data of Magallanes-Magallanes, Cavite Automatic Rain Gauge (ARG) with the same interval year were also obtained from the same agency.

3.1.5 Streamflow

Salipit River is an ungauged stream. Since observed streamflow data are required in the calibration and validation processes of the model, the records were estimated using the nearby river discharge records instead. As a reference, 2015-2018 streamflow records of the Maragondon River were obtained from the Department of Public Works and Highways Streamflow Management System. Using the area-discharge ratio, the estimated streamflow is given by

$$Q_y = Q_x \times (A_y / A_x) \tag{1}$$

where Q_y and A_y are the discharge (m^3/s) and area (m^2) of the ungauged river basin, while Q_x and A_x are the discharge (m^3/s) and area (m^2) of the gauged river basin. Since the climate and streamflow data are only available from the years 2012-2018 and 2015-2018 respectively, years 2012-2014 were assigned as warm-up while 2015-2016 and 2017-2018 were calibration and evaluation periods respectively.

3.2 Development of SWAT Model

Using the IfSAR DEM from NAMRIA, the channel networks and the boundary of the river basin were delineated. The minimum area threshold and outlet point were set at 120 hectares and coordinates 14.2701, 120.7345, respectively. Thirteen (13) subbasins were discretized, with a total watershed area of 3,997.52 hectares. Subbasins were then further subdivided into hydrological response units (HRU) using the post-processed land use-land cover, and soil maps. The HRUs were created through filtering by land use, soil, and slope classes. A zero percent threshold was selected in the HRU discretization to prevent dissolving minor classes. The threshold set-up created 1,102 HRUs. Finally, using the daily climate data from the two weather stations and one weather generator, an initial simulation was run. The entire simulation period was from 2012 to 2018, with the first three (3) years assigned as warm-up period. Water balance and streamflow data were then recorded.

3.3 Evaluation, Sensitivity Analysis, Calibration, and Validation of SWAT Model

In this study, SWAT+ Toolbox 1.0 was utilized in performing the evaluation, sensitivity analysis, calibration, and validation of the model. A detailed description of how to use the tool can be found in the SWAT+ Technical Manual [10].

3.3.1 Model Evaluation

Two criteria were utilized in evaluating the performance of the model: the Pearson correlation coefficient (r) and the Nash-Sutcliffe efficiency model (NSE). Pearson correlation coefficient describes the degree of collinearity between simulated and measured data [11]. It is given as

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (2)$$

where r, x_i, $\bar{x}$, y_i, and $\bar{y}$ are the Pearson correlation coefficient, observed flow, mean observed flow, simulated flow, and mean simulated flow, respectively. A correlation value of 1 indicates a perfectly linear relationship between simulated and observed values. It was suggested that values greater than 0.5 indicate satisfactory performance [12].

Nash-Suttcliffe Efficiency (NSE) coefficient, on the other hand, determines the relative magnitude of the residual variance compared to the measured data variance [11]. It is computed as

$$NSE = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (2)$$

Where NSE, x_i, $\bar{x}$, and y_i are the Nash-Sutcliffe efficiency coefficient, observed flow, mean observed flow, and simulated flow, respectively. Generally, an NSE value is regarded as acceptable as long as it is between 0 and 1. Negative NSE, on the other hand, implies unacceptable model performance as it indicates that the mean observed value is a better predictor than the model [11]. Guidelines, however, recommend at least 0.5 minimum NSE value for a model to be deemed satisfactory [12].

3.3.2 Sensitivity Analysis

Identifying the most and least sensitive parameters is crucial in avoiding over parametrization and reducing calibration runtime [12]. In this study, ten (10) parameters were selected for sensitivity analysis. Based on the previous studies, parameters that are found to be typically sensitive were selected [3,5,13].

Table 1 Parameters selected for sensitivity analysis

Parameters	Description
CN2	Initial SCS curve number
ESCO	Soil evaporation compensation factor
K	Hydraulic conductivity
AWC	Available water capacity
PERCO	Percolation coefficient
ALPHA	Baseflow alpha factor
SURLAG	Surface runoff lag coefficient
FLO_MIN	Minimum aquifer storage for baseflow
REVAP_MIN	Threshold depth for revap
BF MAX	Baseflow recession coefficient

Using the SWAT+ Toolbox, the sensitivity of selected parameters in Table 1 was calculated. Monthly river flows from years 2015 to 2018 were used as the observation reference. The top five (5) sensitive parameters were then used in the calibration of the model.

3.3.3 Calibration and Validation

Calibration is essential in hydrologic modelling to ensure model accuracy and precision [2,12]. Using the adjusted monthly streamflow of the Maragondon River from years 2015 to 2016, the most sensitive parameters were automatically calibrated. In the calibration, the algorithm and objective function used were the Dynamically Dimension Search (DDS) and NSE, respectively. A validation simulation was then performed using the calibrated parameters. Model validation was done to prove that the model is valid and not overparametrized [12]. Climate data from the years 2017 to 2018 were used in the simulation of hydrological processes. The simulated monthly streamflow records were then compared to the observed values using the NSE and Pearson R values.

3.4 Evaluation of Future Land Use-Land Cover Change Scenarios

Using the calibrated model, simulations of various land use-land cover scenarios were performed. To isolate the effects of LULC in this study, the same meteorologic condition was used for all the scenarios. Five (5) land use scenarios were developed using various government policies and past studies:

- Scenario 1: Baseline LULC (Figure 2)
- Scenario 2: Unconstrained urban development (Figure 3)
- Scenario 3: Reforestation (Figure 4)
- Scenario 4: Combined reforestation-agricultural expansion (Figure 5)
- Scenario 5: Intense afforestation and reforestation (Figure 6)

3.4.1 Unconstrained Urban Development (Scenario 2)

In 2019, Mishra et al. [14] developed future land use scenario maps for Mega Manila using Land Change Modeler. Their simulation showed a rapid urban expansion in neighboring provinces of Metro Manila, including Cavite. Depletion of forest cover and expansion of urban development were predicted in Mts. Palay-palay – Mataas na Gulod Protected Landscape (MPPMNGPL), which contains a majority of the upstream portion of the Salipit River Basin. As shown in Figure 3, the urban area increased from 1% to 24.3% of the total river basin area. More than 18% of this increase were former shrubland and grassland while the 4% were mixed forest.

3.4.2 Reforestation (Scenario 3)

In the 2017-2021 Mts. Palay-palay – Mataas na Gulod Protected Landscape Management Plan [15], one of the goals cited was to increase forest cover by 20%.

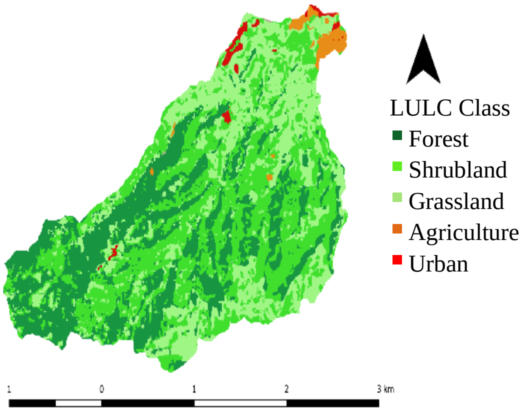

Fig.2 Scenario 1 baseline land use-land cover

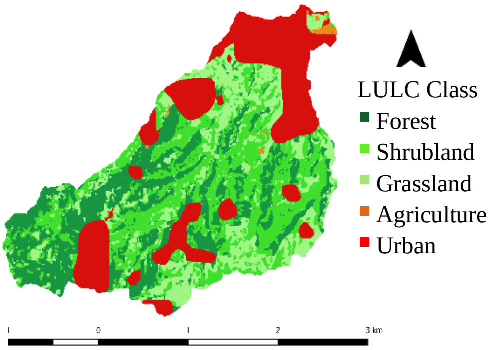

Fig.3 Scenario 2 urban expansion

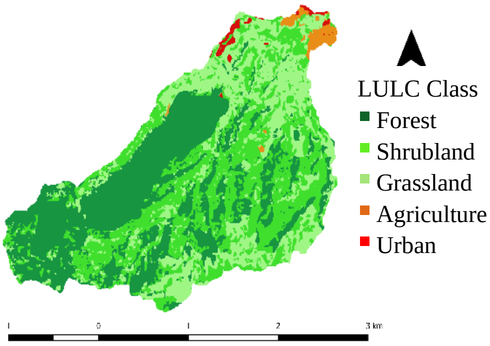

Fig.4 Scenario 3 reforestation

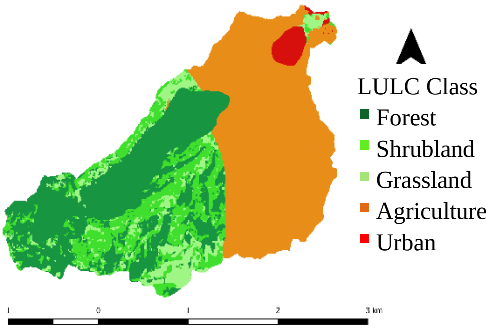

Fig.5 Scenario 4 agricultural expansion

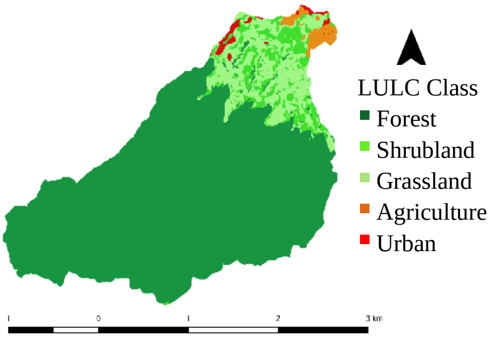

Fig.6 Scenario 5 intense reforestation

Shown in Figure 4 is Scenario 3, where land use change was developed based on the reforestation site map of the said management plan. This includes the 460-hectare reforestation site under the National Greening Program. In this scenario, a total of 7.6% increase in forest cover was observed. Around 5% were converted brushland and the remaining 3% were previous grassland.

3.4.3 Reforestation and Agriculture Expansion (Scenario 4)

In Scenario 4, reforestation under the National Greening Program and the zoning plan under the 2020 Maragondon Comprehensive Land Use Plan (CLUP) were integrated [16]. According to the 2011-2020 CLUP of Maragondon, open grasslands shall be cultivated for agriculture under intensive farming. Existing forest areas under the National Integrated Protected Area System, on the other hand, will be preserved. Shown in Figure 5 is Scenario 4, which was developed based on the zoning map stipulated in the CLUP and the reforestation site map of the MPPMNGPL Management Plan. Net increases of 1.4% and 41.1% were observed in forest cover and agricultural land, respectively. Both shrubland and grassland contributed around 20% each to the total land conversion.

3.4.4 Intense Reforestation and Afforestation (Scenario 5)

In this scenario (Figure 6), another proposal in the 2011-2020 CLUP was investigated. Under future development, it was proposed that lands with a slope of 18% and above will constitute the forest area of the municipality. Through slope analysis, a map for future forest expansion was developed. It was assumed that an intense reforestation and afforestation program would cover a large portion of the river basin. A total of 50.2% increase was observed in forest cover. A large portion of this was converted from shrubland and grassland, with a percentage of 34% and 16% respectively.

4. RESULTS AND DISCUSSION

4.1 Pre-calibrated Simulation

The pre-calibrated model yielded an NSE value of -0.05 and a Pearson R-value of 0.89. Results of the simulation show that while a satisfactory Pearson correlation was observed, the negative NSE still indicates an unacceptable model performance.

The resulting hydrographs showed that while the model significantly underestimated the peak flows, it tends to follow the same trend as the observed data, which explains why the model yielded a very high correlation value. For example, in July 2015, a 300 m^3/s difference in discharge was observed. This explains why the initial evaluation resulted in a negative NSE. A previous study explained that the NSE is oversensitive to high extreme values and tends to neglect low values because of the squared difference in its equation [17]. Moreover, it was mentioned that poor model performance can be partially attributed to inadequacy or error in precipitation inputs [18]. As recommended, precipitation data were reexamined in the study. It was found that there was indeed an error in the spatial distribution of rainfall data. Almost half of the total number of subbasins recorded zero rainfall on dates that should have had precipitation. After correcting the errors in the precipitation input, the NSE significantly improved from -0.05 to 0.14, while the Pearson value increased to 0.90 from 0.89. With the improvement of its efficiency, the model was tested for parameter sensitivity.

4.2 Sensitivity Analysis, Calibration and Validation

Sensitivity analysis showed that the most

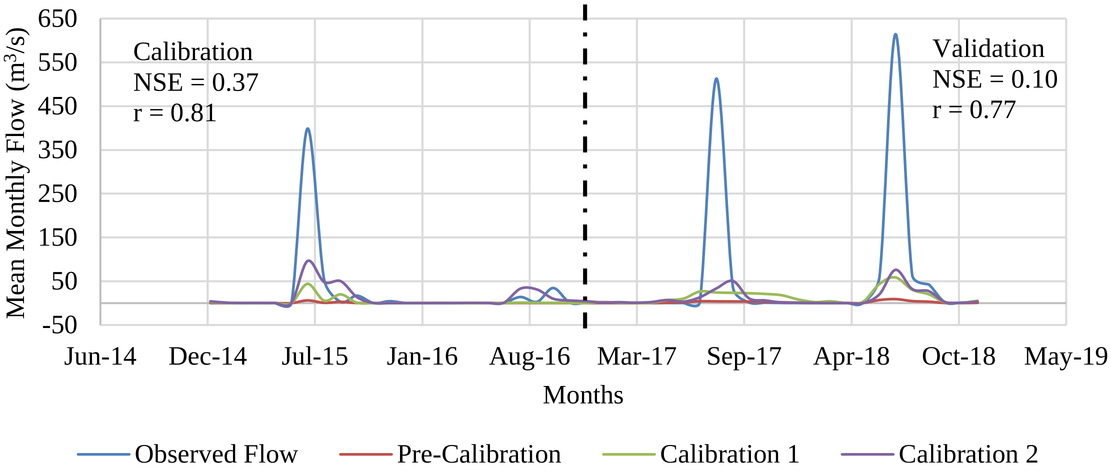

Fig. 7 Simulated and observed monthly flows based on the daily simulation

sensitive parameters were CN2, ESCO, AWC, ALPHA, and SURLAG. Automatic calibration exhibited an improvement in the model's performance, as evidenced by the increase in Nash-Sutcliffe efficiency from 0.14 to 0.37. While the NSE improved during the calibration, a slight decrease in Pearson R was observed. The initial R-value of 0.90 has been reduced to 0.81.

To confirm the soundness of the model, validation was done using 2017–2018 streamflow data. A decrease in the model's performance was observed in the validation period. This is common in most SWAT modeling [2] and is usually attributed to uncertainties in model structure and model parametrization. The model yielded an NSE value of 0.10 and a Pearson value of 0.77. The improvement in the goodness-of-fit is evident in the calibration plot in Figure 7, where there is a visible increase in the monthly streamflow. While peaks are still underestimated, the gap between the values has significantly decreased as compared to the pre-calibrated simulation. The calibration and validation results indicated satisfactory performance in terms of Pearson value and acceptable NSE. Notably, these NSE values are relatively low compared to other SWAT models developed in the Philippines [2-4]. Although below the satisfactory NSE value of 0.5, a positive NSE is still considered acceptable as it is a better predictor than a negative NSE model [11].

In assessing the performance of the model, it is important to note the limitations of the input data in this study [12]. First, it must be pointed out that, due to the absence of actual flow measurements on the outlet point, the monthly streamflow data used in this study were only estimated from the records of an adjacent reference stream, the Maragondon River. Differences in the physical and hydrological characteristics of the two watersheds might affect their responses. Second, the two weather stations utilized are located outside the river basin. The climate data used in this paper is not the actual meteorological conditions in the study area. Third, the calibration period is relatively shorter than the intervals mostly used. With a longer calibration period, dry and wet years are considered, thus capturing a more complete cycle.

4.3 Impact of Land Use-Land Cover Scenarios

The results of the scenario simulations indicate variations in streamflow and water balance. Growth in urban areas increased runoff and streamflow, while expansion of forest cover and agricultural land caused a decrease in their volume.

4.3.1 Impact on Streamflow

The baseline scenario simulated an average annual streamflow of 4606.75 cu. m/s. When the urban area is increased by 23.3%, an average annual flow of 4995.50 cu. m/s is simulated. Reforestation scenarios with varying increases in cover by 7.6% and 52.3% simulated an annual flow of 4541 and 4091.5 cu. m/s respectively. In contrast, combined reforestation and agricultural expansion resulted in an annual flow of 4370.25 cu. m/s.

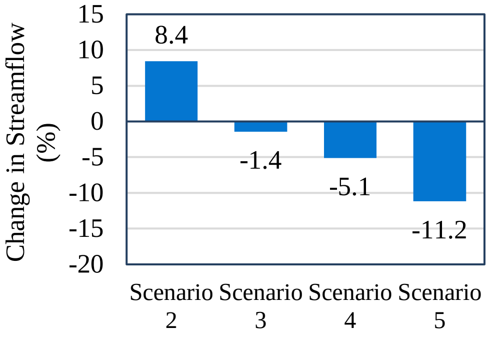

Fig.8 Change in mean annual flow

It appears that, in general, urbanization increases the volume of streamflow while forest conservation and agricultural expansion tend to decrease it. The expansion of impervious areas in urbanization prevents infiltration, causing a reduction in hydrologic losses and therefore allowing more runoff. In contrast, the increase in vegetation and porous surfaces in the latter scenario

Table 2 Salipit River Basin water budget

Hydrologic Variables	Baseline	Urban Expansion	Reforestation	Reforestation-Agricultural Expansion	Intensified Reforestation
Precipitation (mm)	1958	1958 (0%)	1958 (0%)	1958 (0%)	1958 (0%)
Surface runoff (mm)	960	1089 (13%)	947 (-1%)	911 (-5%)	873 (-9%)
Evapotranspiration (mm)	691	641 (-7%)	712 (3%)	788 (14%)	825 (19%)
Baseflow (mm)	137	101 (-27%)	134 (-3%)	113 (-18%)	108 (-22%)
Revap from shallow aquifer (mm)	23	24 (0%)	24 (0%)	24 (0%)	24 (0%)
Deep aquifer recharge (mm)	129	98 (-24%)	126 (-3%)	109 (-16%)	106 (-18%)

leads to an increase in hydrologic losses through interception, evapotranspiration, and infiltration processes in forest canopies and aquifers [19]. This result is consistent with other studies that investigated the effect of land use change on streamflow [20]. As shown in Figure 8, an average increase of 388.75 cu. m/s or 8.44% is observed when urbanization is simulated. In contrast, an 8% increase in forest cover results in a less than 2% decrease, or 65.75 cu. m/s. A more extreme reforestation scenario likewise resulted in an 11.2% decrease in annual volume, or 515.25 cu.m /s.

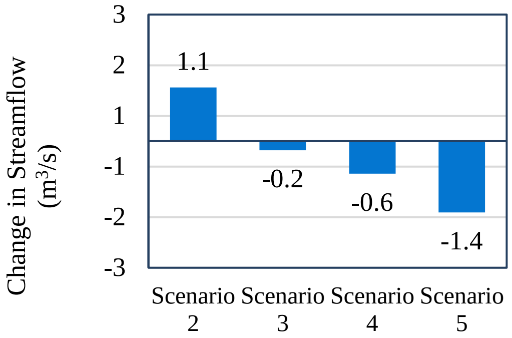

Fig.9 Change in mean monthly flow

The case is similar in monthly streamflow, but changes are minimal, as shown in Figure 9. Compared to the baseline scenario, an increase from 12.53 cu. m/s to 13.58 cu. m/s was observed in Scenario 2. In contrast, Scenarios 3, 4, and 5 saw a decrease in flow to 12.35, 11.88, and 11.12 cu. m/s, respectively.

4.3.1 Impact on Water Balance

Shown in Table 2 is a summary of the hydrologic variables in the Salipit River Basin and their corresponding quantities in each scenario. A decrease in the amount of surface runoff was observed in all scenarios except for the urban expansion. The decrease in surface runoff can be mainly attributed to the rise in evapotranspiration caused by the increase in forest and vegetative cover. Similarly, in the case of Scenario 2, the decrease in vegetative cover permits the amount of evapotranspiration to also decrease. In addition, surfaces in urban regions become more impervious and compacted, allowing increased runoff [3].

In all scenarios, there was a decrease in baseflow and deep aquifer recharge. The largest drop in baseflow was documented in the urban expansion (Scenario 2), and the second is in intensified reforestation (Scenario 5). The case is the same for deep aquifer recharge, except that the decline in the urbanization scenario was considerably larger than the intensified reforestation. Studies have demonstrated that increases in vegetative cover result in reduced baseflow [2,4,20]. This is attributed to the high evapotranspiration rate that causes a reduction in the baseflow yield. A decrease in baseflow is also common in cases of urbanization where the quantity of impervious surfaces plays a major role. In a study by Aboelnour et al. [21], urbanization, agriculture losses, and deforestation were identified as causes of the reduction in groundwater recharge.

5. CONCLUSION

This study showed how the SWAT+ model can be utilized in evaluating the impacts of land use-land cover change on the hydrology of the Salipit River Basin. Despite the inadequacy of primary data, as in the case of ungauged basins, the model obtained satisfactory Pearson correlation values of 0.81 and 0.77 during the calibration and validation periods. A positive NSE value of 0.37 and 0.10 indicates that the model is a better predictor than the mean observed data, albeit still lower than the recommended NSE value of 0.50. With this, it can be concluded that SWAT+ can be a valuable tool in understanding the behavior of the Salipit River Basin.

In this study, five (5) scenarios were developed and simulated to assess the impact of LULC change on the hydrology of the river basin. Overall results showed that a decrease in forest cover and vegetation causes an increase in annual flow and surface runoff. Similarly, an increase in vegetation results in a rise in evapotranspiration, causing a reduction in surface runoff and annual flow. Furthermore, land conversion, to a more significant extent, yields a higher percentage difference. Hence, it is proven that LULC changes influence the hydrologic response of the Salipit River Basin.

With this in mind, it is recommended that any policy or program that will induce significant land use and land cover change on the Salipit River Basin be considered thoroughly, as the hydrologic impact is proven to be significant through this study. It is suggested to conduct scientific studies before implementation. However, the limitations of the models must be carefully examined when using the outputs.

6. ACKNOWLEDGEMENTS

We would like to extend our sincere thanks to the agencies and organizations that gladly assisted us in this research project specially the DOST-ASTI, NAMRIA, and MPPMNGPL Management Board.

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