Assessment of the Impact of Agricultural Land Cover Changes in Aklan River Watershed, Philippines using SWAT+

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Presentation Overview

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- Significance of the Study
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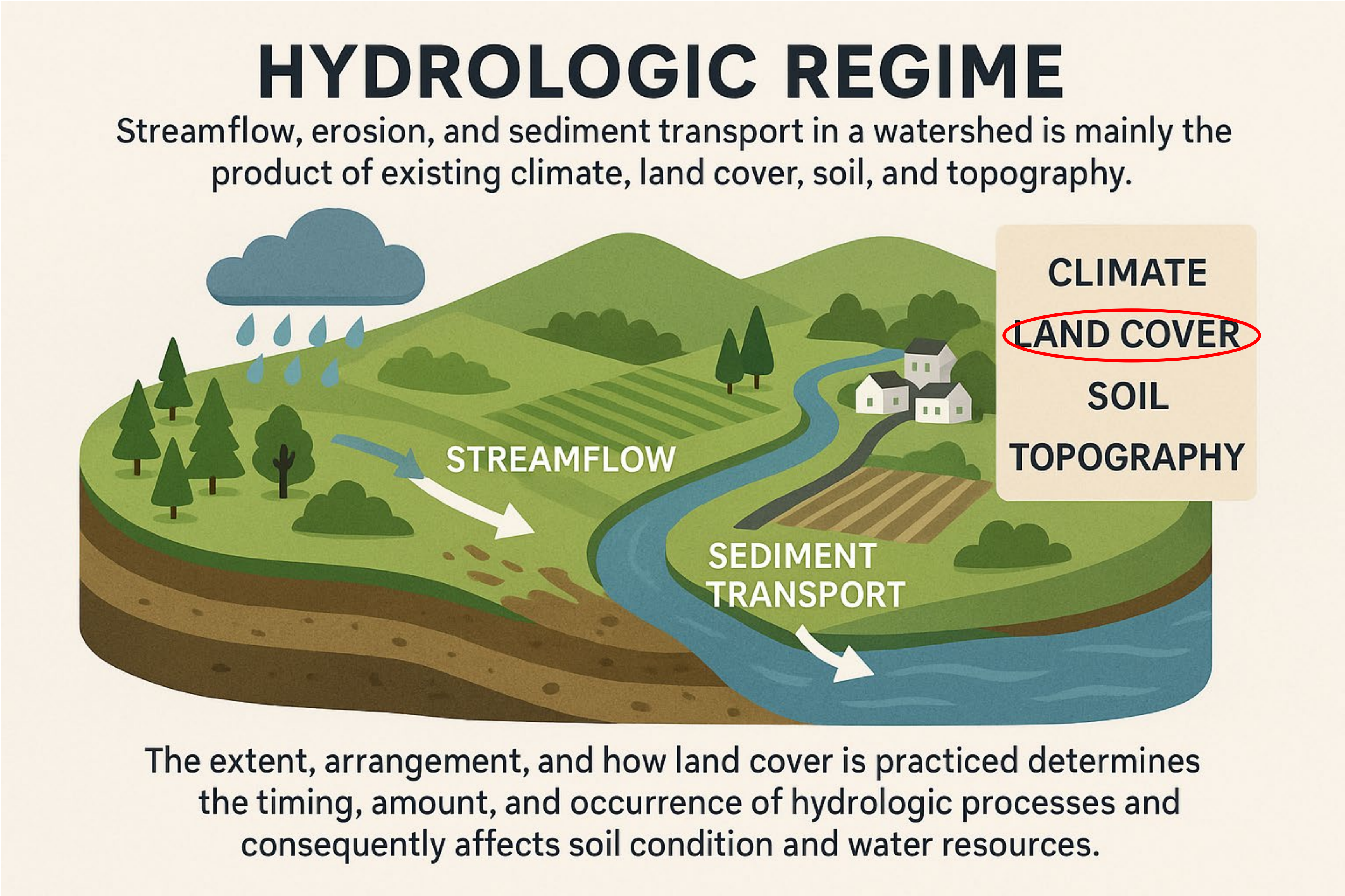
- Summary and Conclusion

Introduction

Soil erosion, a pressing problem of Aklan River Watershed

"The Aklan river watershed, situated within the Aklan province of the Philippines, significantly contributes to the prevalent soil erosion challenges due to its rugged terrain, inadequate vegetation cover, and improper land utilization practices"

Señeris et al., 2024

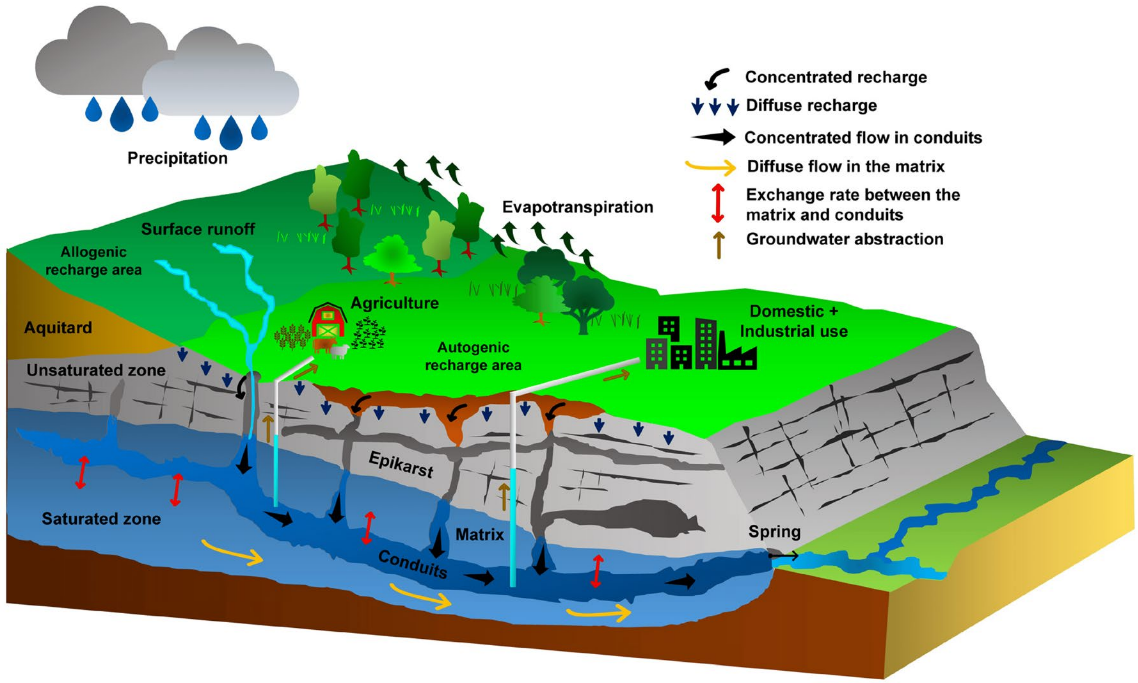

HYDROLOGIC REGIME
Streamflow, erosion, and sediment transport in a watershed is mainly the product of existing climate, land cover, soil, and topography.
CLIMATE
LAND COVER
SOIL
TOPOGRAPHY
STREAMFLOW
SEDIMENT TRANSPORT
The extent, arrangement, and how land cover is practiced determines the timing, amount, and occurrence of hydrologic processes and consequently affects soil condition and water resources.

"**Land cover changes** significantly affect sediment yield…"
(Principe, 2012)

"**Sedimentation** in river basins should be closely monitored due to its negative effects on the riverine and coastal biodiversity and the surrounding community in the area"
(Principe and Blanco, 2014)

"Sediment yield simulations and scenario analysis can serve as an additional tool for the formulation of conservation policies in the locality."
(Arizobal et al., 2024)

Significance of the Study



- The results of this research are expected to provide a scientific basis for local government units, environmental planners, and community stakeholders to develop data-driven policies for watershed conservation and land use planning.
- It also provides insights that can inform the implementation of nature-based solutions and best management practices in the agricultural sector.

Objectives of the Study

The main objective of this study is to provide an assessment of the impact of agricultural land cover changes on streamflow and sediment yield in the Aklan River Watershed using SWAT+.

Specifically, it aims:

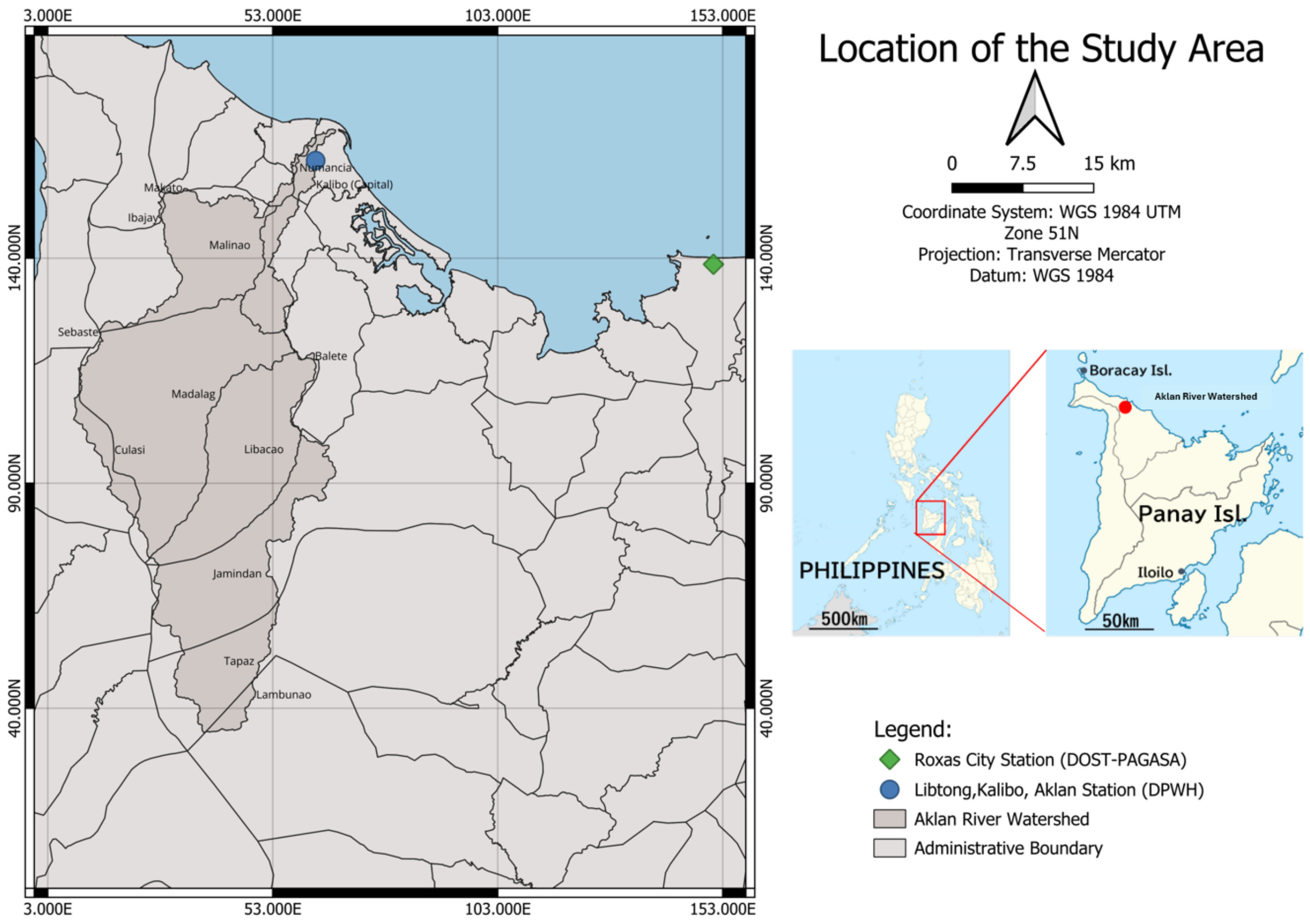
1. To utilize, adapt, and calibrate the Soil and Water Assessment Tool+ (SWAT+) model to assess the streamflow of the Aklan River Watershed;

2. To assess the effects of different agricultural land cover scenarios on sediment yield in the Aklan River watershed using the SWAT+ model; and

3. Identify potential management options based on SWAT+ simulation results.

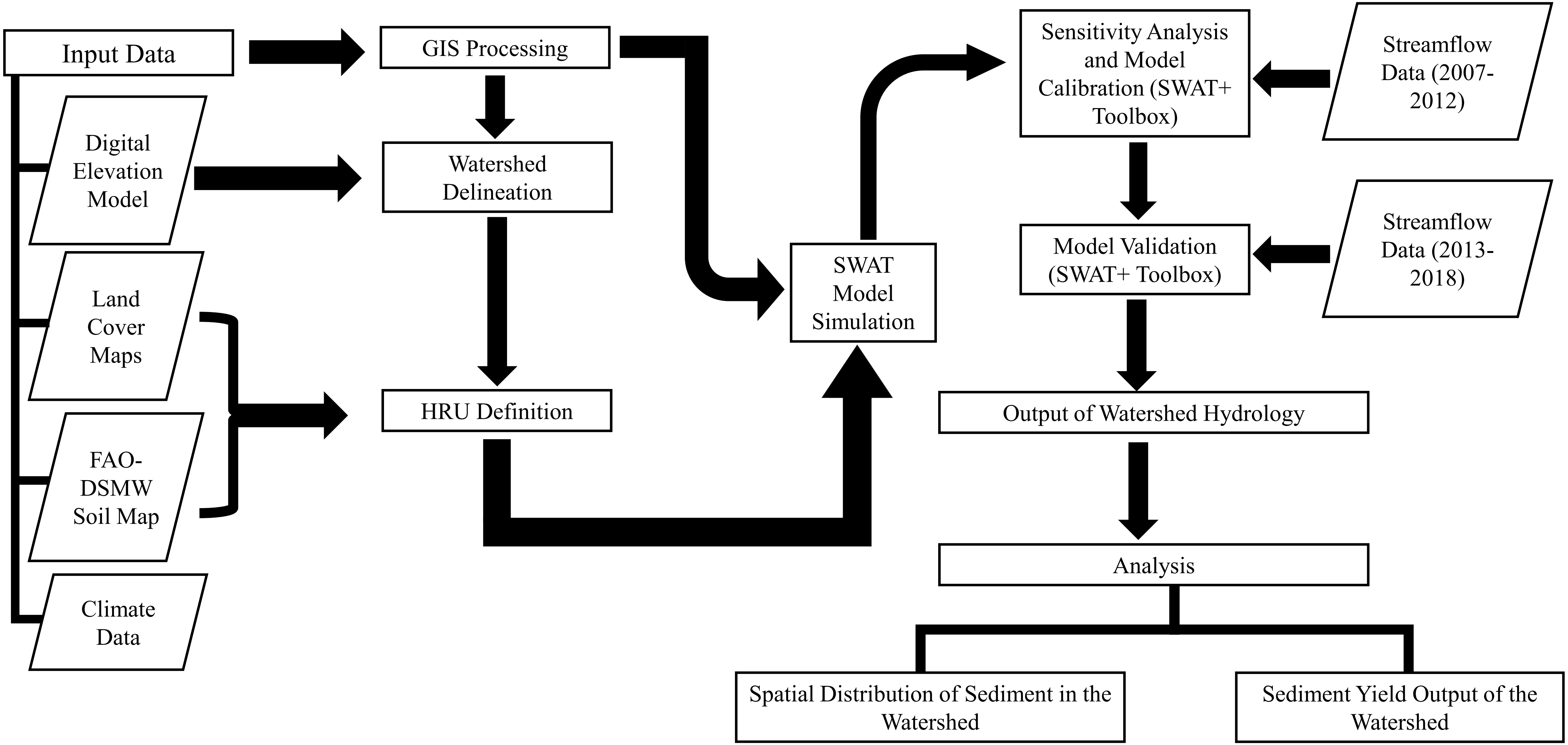
Methodology

Location of the Study Area



- Covering a massive area of about 87,877.98 hectares.
- This watershed traverses four provinces in Panay-Aklan, Antique, Capiz, and Iloilo, and includes a total of sixteen barangays.

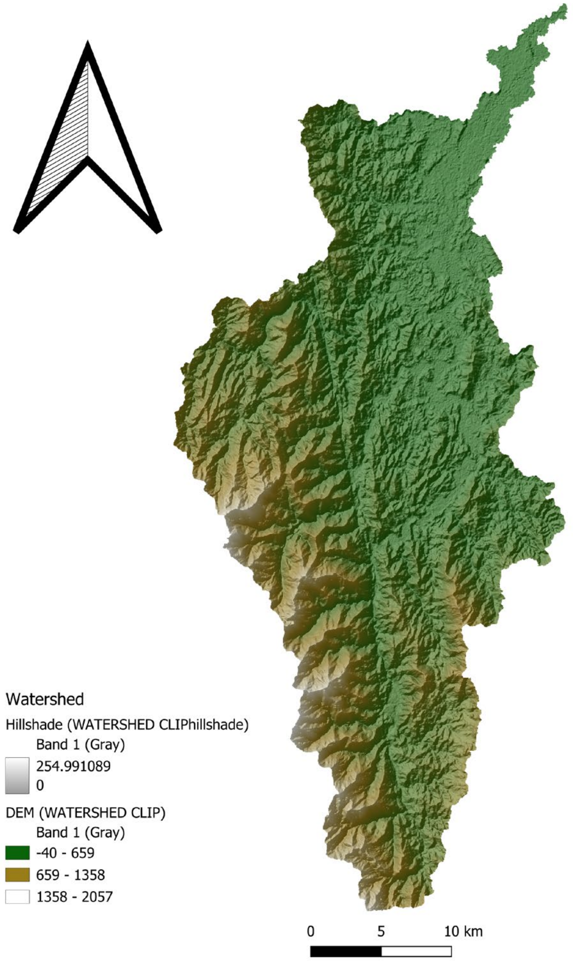
SWAT Model Components and Methodology



Materials and Methods

Data	Sources
Digital Elevation Model (DEM)	US Geological Survey- Shuttle Radar Topography Mission (USGS-SRTM)
Land Cover Maps (2010, 2015, 2020)	National Mapping and Resources Information Authority (NAMRIA)
Soil Map	Food and Agriculture Organization- Digital Soil Map of the World (FAO-DSMW)
Climate Data (1960-2023)	Department of Science and Technology- Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA)

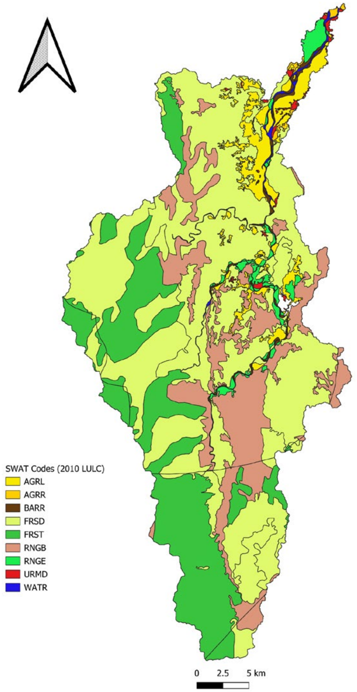
Watershed Delineation



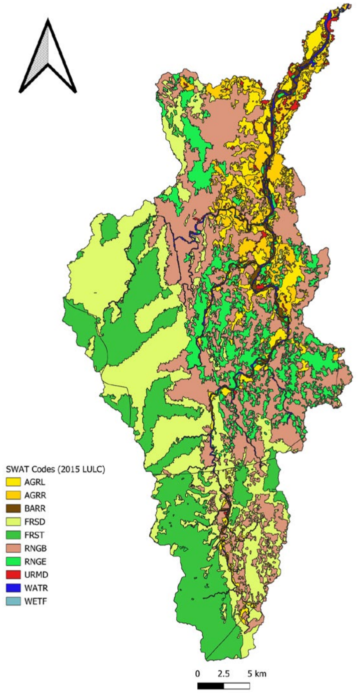
Digital Elevation Model

HRU Definition

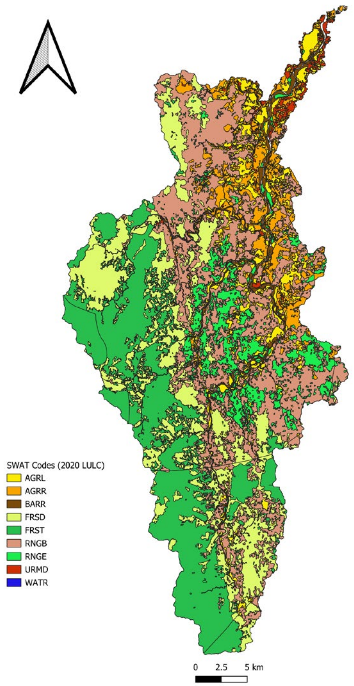
(Land Cover)



2010



2015

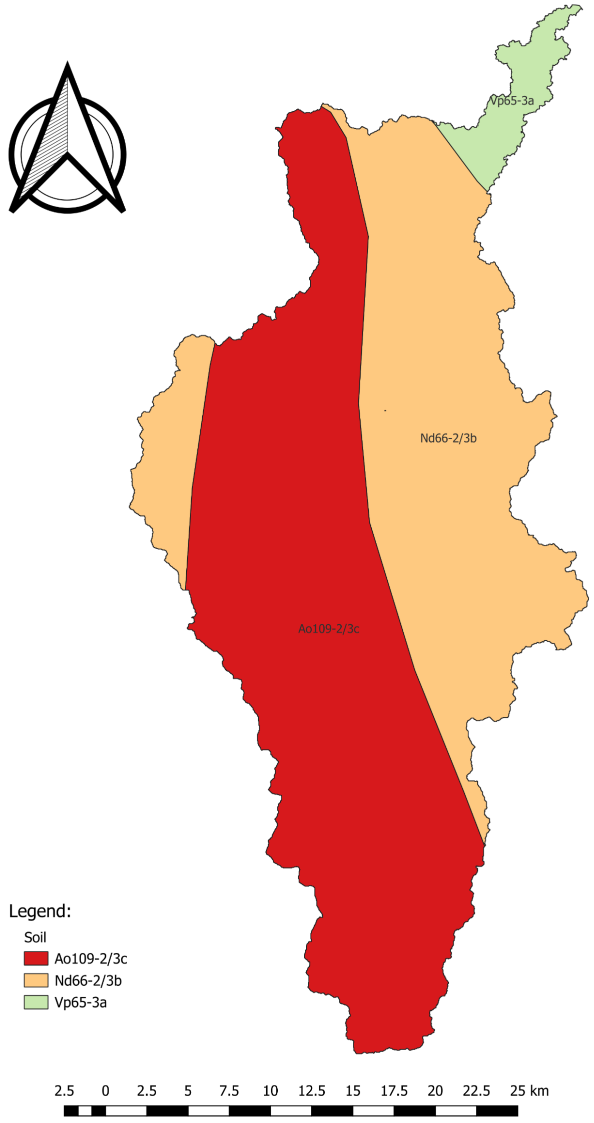


2020

Conversion of Land Cover into SWAT Class

Land Cover (NAMRIA)	Number	Land use	Detail
Annual Crop	1	AGRL	Agricultural land-generic
Brush/Shrubs	2	RNGB	Shrub and Brush Rangeland
Built-up	3	URMD	Residential
Closed Forest	4	FRST	Mixed Forest
Fishpond	5	WATR	Water
Grassland	6	RNGE	Range-grasses
Inland Water	7	WATR	Water
Mangrove Forest	8	WETF	Wetlands-forested
Open Forest	9	FRSD	Forest-Deciduos
Open/ Barren	10	BARR	Barren
Perennial Crop	11	AGRR	Agricultural land-row crops

Source: https://oldgeni.isnew.info/landuse.html



Soil Lookup Table

Value	Soil
4465	Ao109-2-3-4465
4413	Nd66-2-3b-4413
4589	Vp65-3a-4589
0	WATER-6997

User soil

OBJECTID	MUID	SEQN	SNAM	S5ID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EX	SOL_CRK	TEXTURE	SOL_Z1
2911	0	4465	Ao109-2-3	0	0	2	C	770	0.5	0.5	LOAM	300
2871	0	4413	Nd66-2-3b	0	0	2	D	1000	0.5	0.5	CLAY_LOA	300
3016	0	4589	Vp65-3a-4	0	0	2	C	1000	0.5	0.5	CLAY	300
4931	0	6997	WATER-69	0	0	1	D	25.4	0.5	0.5	WATER	25

Temporal Data Sets

Location: Roxas City Capiz Station

Latitude 11.600265º North and longitude 122.749621º east, with a ground elevation of 2.495 meters above sea level

Meteorological Data	Unit
Precipitation	mm
Temperature a. TMAX (Maximum Temperature) b. TMIN (Minimum Temperature)	ºC
Relative Humidity	%
Wind Speed	m/s
Solar Radiation	Simulated

Source: Department of Science and Technology- Philippine Atmospheric, Geophysical, and Astronomical Services Administration

Temporal Data Sets

Hydrological Data	Unit
Streamflow	*Daily (l/s)*
Location	*Bgy. Libtong, Kalibo, Aklan*
Gauging Station	*Latitude 11º41'56" and 122º21'47"*
Calibration	*2007-2012*
Validation	*2013-2018*

Source: Bureau of Design, Department of Public Works and Highways (DPWH)

SWAT+ Calibration, Validation, and Sensitivity Analysis

- SWAT Simulation= 12 years (2007-2018)
- Warm-up or Equilibration Period= 4 years (2007-2008; 2013-2014)
- Calibration= January 2007 to December 2012
- Validation= January 2013- December 2018

Variable	**Units**		**Calibration**		**Validation**	
	Original	Model Input	Period	Time Step	Period	Timestep
Flow	li/s	m^3/s	2007-2012	Daily	2013-2018	Daily

Source: *DPWH-Streamflow Management System*

Note:

1. *The observation files should be in CSV format with two columns- date (dd/mm/yyyy) and value.*
2. *If you have missing data, use -99 in the place where you have missing data.*

(SWATplus Toolbox User Manual by C.J.Chawanda, 2021)

Model Efficiency

Parameters	Equations
Coefficient of Determination (R^2)	$R^2 = \frac{\sum_{i=1}^{n}(Y_{obs} - \bar{Y}_{obs})(Y_{sim} - \bar{Y}_{sim})}{\sqrt{\sum_{i=1}^{n}(Y_{obs} - \bar{Y}_{obs})^2} \sqrt{\sum_{i=1}^{n}(Y_{sim} - \bar{Y}_{sim})^2}}$
Nash-Sutcliffe Efficiency (NSE)	$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_{obs} - Y_{sim})^2}{\sum_{i=1}^{n}(Y_{obs} - \bar{Y}_{obs})^2}\right]$
Percent BIAS (PBIAS)	$PBIAS = \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})X100}{\sum_{i=1}^{n}(Y_i^{obs})}\right]$
Root Mean Square Error-observation Standard deviation Ratio (RSR)	$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}}$

Model Efficiency

Performance Rating	R^2*	NSE*	RSR**	PBIAS**
Unsatisfactory	$R^2 \leq 0.6$	NSE ≤ 0.5	RSR > 0.7	PBIAS ≥ ±25
Satisfactory	$0.6 < R^2 \leq 0.75$	0.5 < NSE ≤ 0.70	0.6 < RSR ≤ 0.7	±15 ≤ PBIAS < ±25
Good	$0.75 < R^2 \leq 0.85$	0.70 < NSE ≤ 0.80	0.5 < RSR ≤ 0.6	±10 ≤ PBIAS < ± 15
Very Good	$R^2 > 0.85$	NSE > 0.80	0.50 ≥ RSR ≥ 0	PBIAS <±10

*Source: *Moriasi et al. (2015) **Ang and Oeurng (2018); Ayele et al. (2017)*

Materials and Methods

Comparison of 2015 and 2020 Land Cover Area (hectares)

Classification	Land Cover	2015 Area (Ha)	2020 Area (Ha)	Difference in Area	Percent Increase/(Decrease)
Annual Crop	AGRL	6490.72	6920.21	429.49	6.62%
Brush/Shrubs	RNGB	24824.01	23513.31	-1310.7	(5.28%)
Built-up	URMD	672.97	1450.69	777.72	116%
Closed Forest	FRST	16743.97	21953.61	5209.64	31.12%
Inland Water/Fishpond	WATR	1597.42	1163.85	-433.57	(27.14%)
Grassland	RNGE	9504.79	6924.88	-2579.91	(27.12)
Mangrove Forest	WETF	4.90	3.22	-1.68	(34.29)
Open Forest	FRSD	22063.99	18443.70	-3620.29	(16.41%)
Open/Barren	BARR	1314.46	1509.02	194.56	14.80%
Perennial Crop	AGRR	4660.73	6019.18	1358.45	29.15%

- Annual crop increases by 429.49 hectares.
- Perennial crop (AGRR) steadily increased by 1358.45.
- Open forest continues to lower by 3620.29 hectares.

Materials and Methods

Comparison of 2010 and 2020 Land Cover Area (hectares)

Classification	Land Cover	2010 Area (Ha)	2020 Area (Ha)	Difference in Area	Percent Increase /(Decrease)
Annual Crop	AGRL	4560.54	6920.21	2359.67	51.74%
Brush/Shrubs	RNGB	14744.59	23513.31	8768.72	59.47%
Built-up	URMD	447.17	1450.69	1003.52	224%
Closed Forest	FRST	20114.97	21953.61	1838.64	9.14%
Inland Water/Fishpond	WATR	681.25	1163.85	482.6	70.84%
Grassland	RNGE	1917.76	6924.88	5007.12	261%
Mangrove Forest	WETF		3.22	3.22	
Open Forest	FRSD	45042.99	18443.70	-26599.29	(59.05%)
Open/Barren	BARR	601.10	1509.02	907.92	151%
Perennial Crop	AGRR	245.89	6019.18	5773.29	2347%

- Annual crops (AGRL) increased from 4,560.54 hectares in 2010 to 6,920.71 hectares in 2020.
- Perennial crops (AGRR) experienced a remarkable surge, increasing from 245.89 hectares in 2010 to 6,019.18 hectares by 2020.
- On the other hand, this growth came at the expense of natural ecosystems, most notably open forest areas, which declined sharply from 45,042.99 hectares in 2010 to 18,443.70 hectares in 2020.

Materials and Methods

Scenario No.	Description
0	Baseline
1	Reduction of 16.41% Open Forest to Agricultural Crop (AGRL)
2	Reduction of 16.41% Open Forest to Perennial Crop (AGRR)
3	Reduction of 59.05% Open Forest to Agricultural Crop (AGRL)
4	Reduction of 59.05% Open Forest to Perennial Crop (AGRR)

- Scenario 0 represents the baseline condition, serving as a reference with no changes or interventions, and provides insights into the status of the watershed under current land use patterns.
- Scenarios 1 and 2 involves the reduction of open forest by 16.4% while scenarios 3 and 4 increases the reduction by 59.05%.
- These percentages are the actual reduction of open forest in a span of 5 years and 10 years, respectively.

Agriculture Performance Statistics for the year 2022

Source: Department of Agriculture-Western Visayas

Commodity	Growth Rate	Yield (MT/hectare)
Irrigated Palay	7.13%	4.06

Commodity	Growth Rate	Area (hectare)
Abaca	1.76%	415,727
Eggplant	13.21%	4,099
Cassava	15.71%	63,521

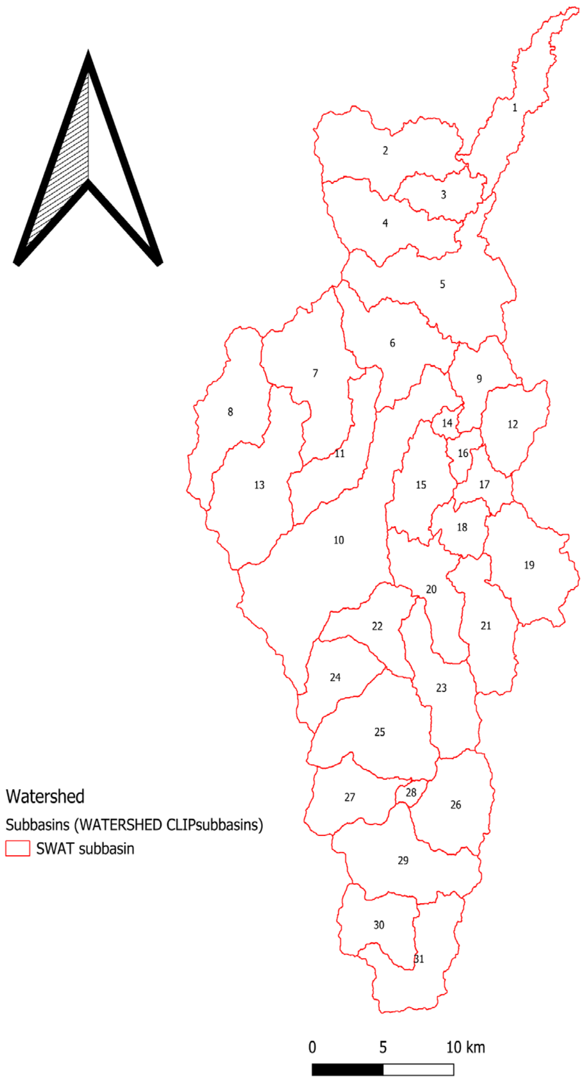
In terms of producing high-value crops, such as abaca, eggplant and cassava, as well as irrigated palay, the Province of Aklan leads the region, according to regional reports from the Department of Agriculture-Western Visayas.

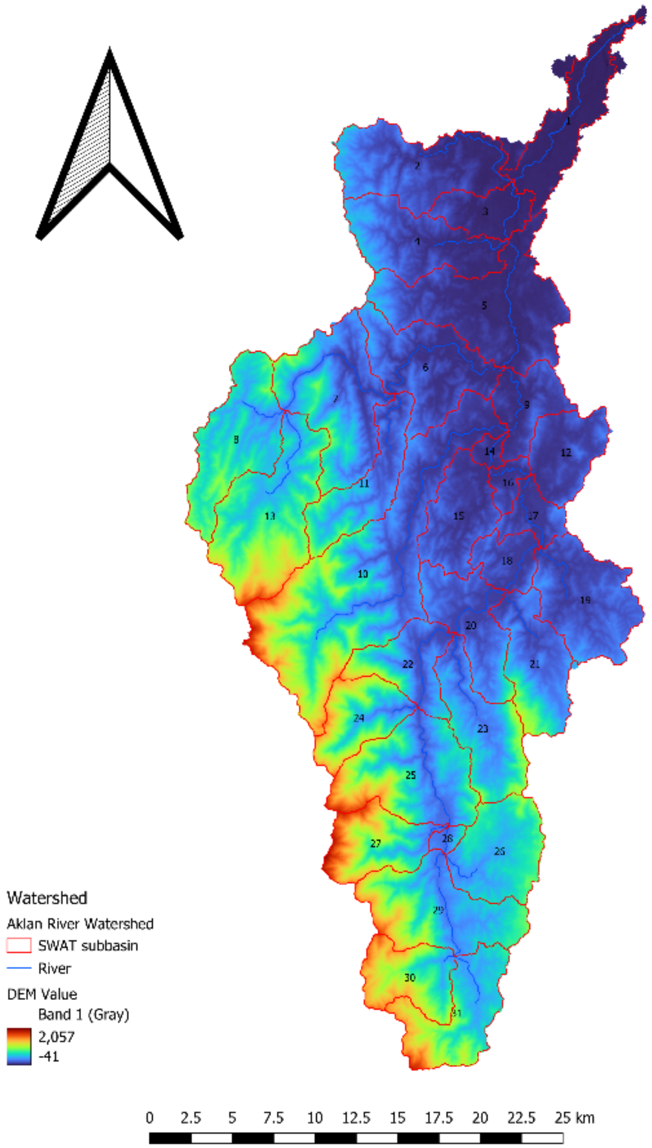
Materials and Methods

Scenario No.	BMP	Description
0	-	
1	Conservative Tillage of Cassava Production	Minimal disturbance and better residue cover, soil is less prone to compaction and improve root penetration.
2	Mulch Tillage of Eggplant Production	Mulch tillage leaves crop residues on the surface, reducing evaporation and helping maintain consistent soil moisture
3	Grass Waterways (Medium) *Manning's Coefficient=0.03*	Moderate grass waterways to slow runoff and capture sediments
4	Grass Waterways (High) *Manning's Coefficient=0.05*	Denser grass waterways for greater erosion control

- BMP 1, which involves conservative tillage for cassava production with minimal disturbance and improved residue cover, results in a soil that is less prone to compaction and enhances root penetration.
- BMP 2, mulch tillage of eggplant production, leaves crop residues on the surface, reducing evaporation and helping maintain consistent soil moisture.
- BMP 3 utilizes moderate grass waterways to slow runoff and capture sediments, while BMP 4 employs denser grass waterways for enhanced erosion control.

Results and Discussion



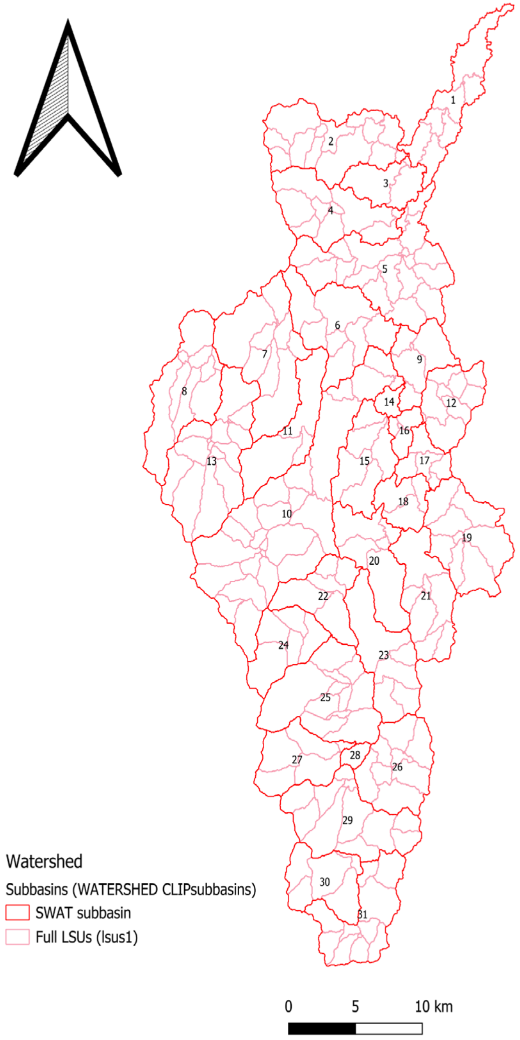


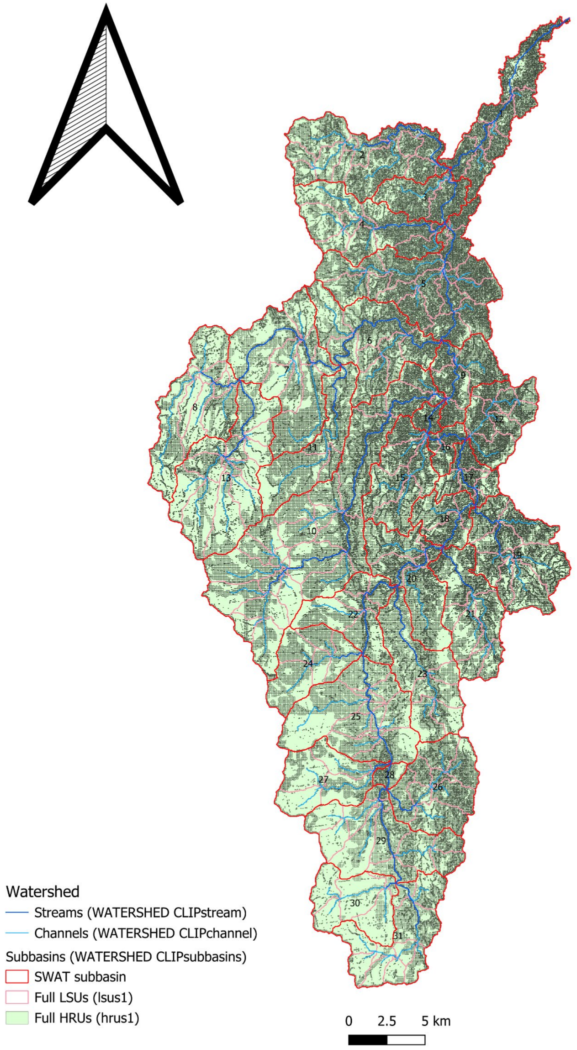
Watershed Delineation

- Watershed delineation depends on DEM within the SWAT.

- Total Area: 87,877.98 ha
- Largest Area: 9,684.36 ha
- Smallest Area: 256.50 ha

- As a result, 31 subbasins were created in the Aklan River Watershed.

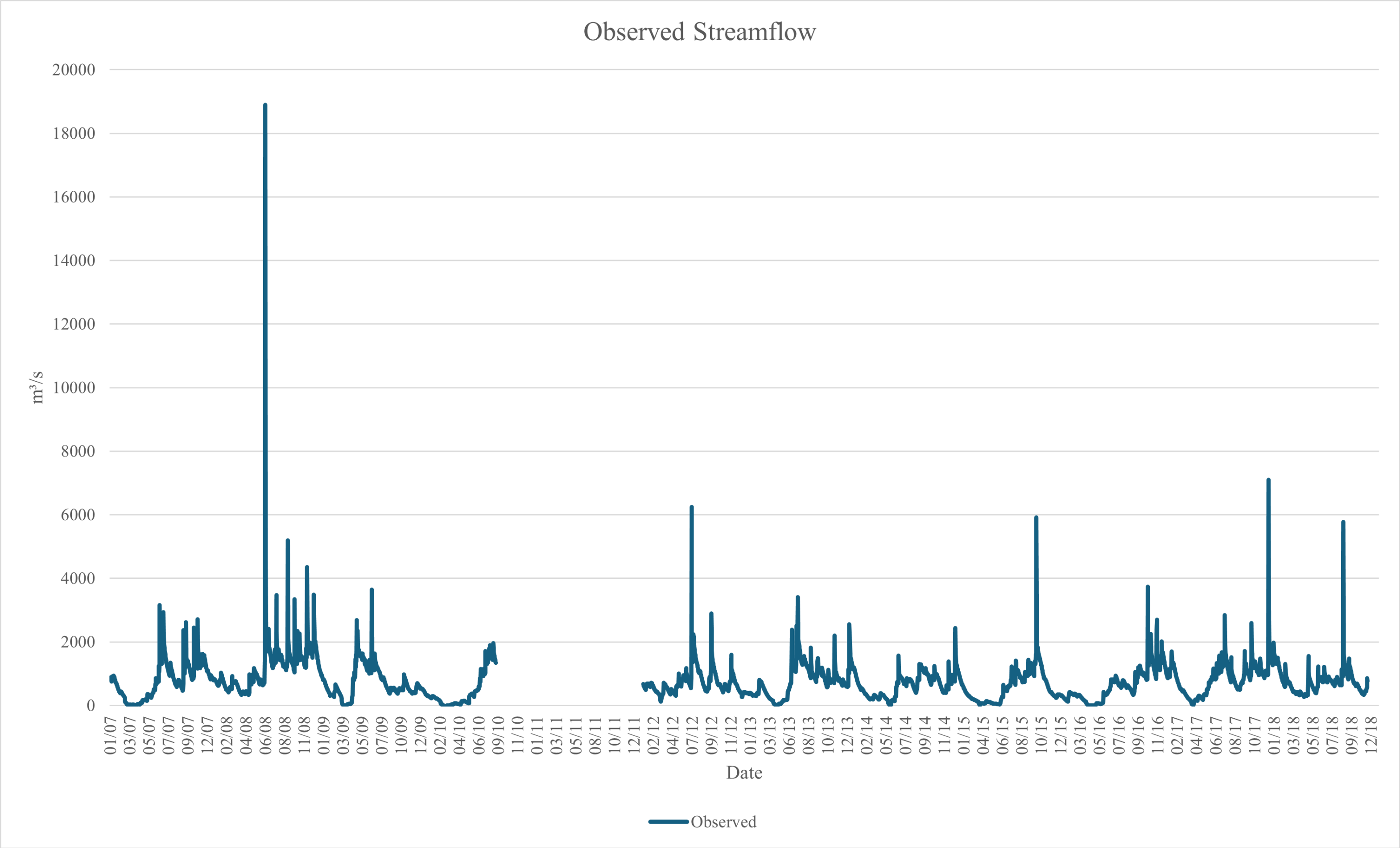




HRU Definition

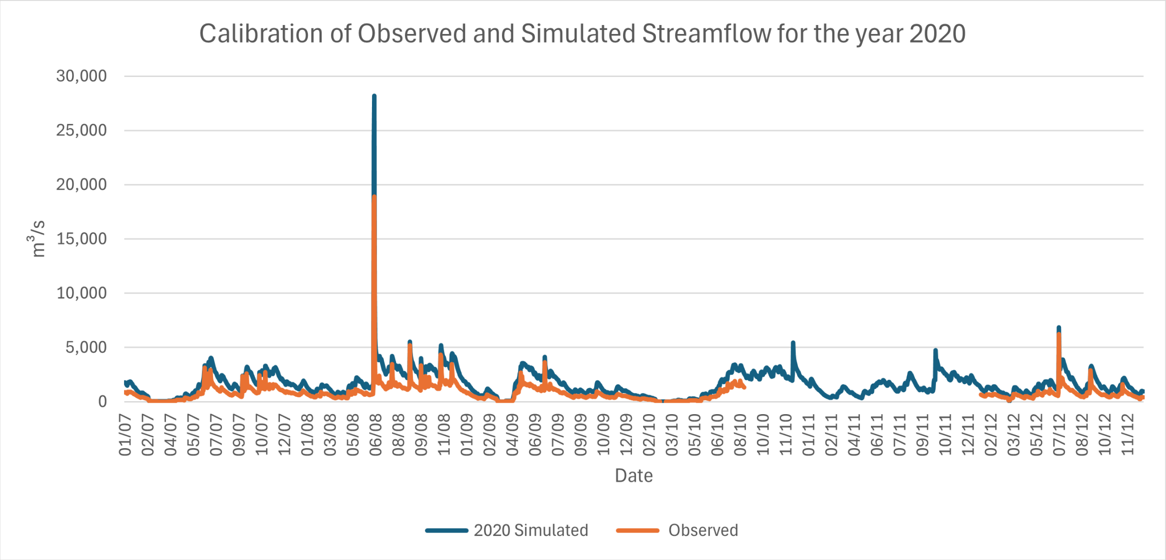
- Number of Channels: 240
- Number of LSUs: 240
- Number of HRUs: 4343

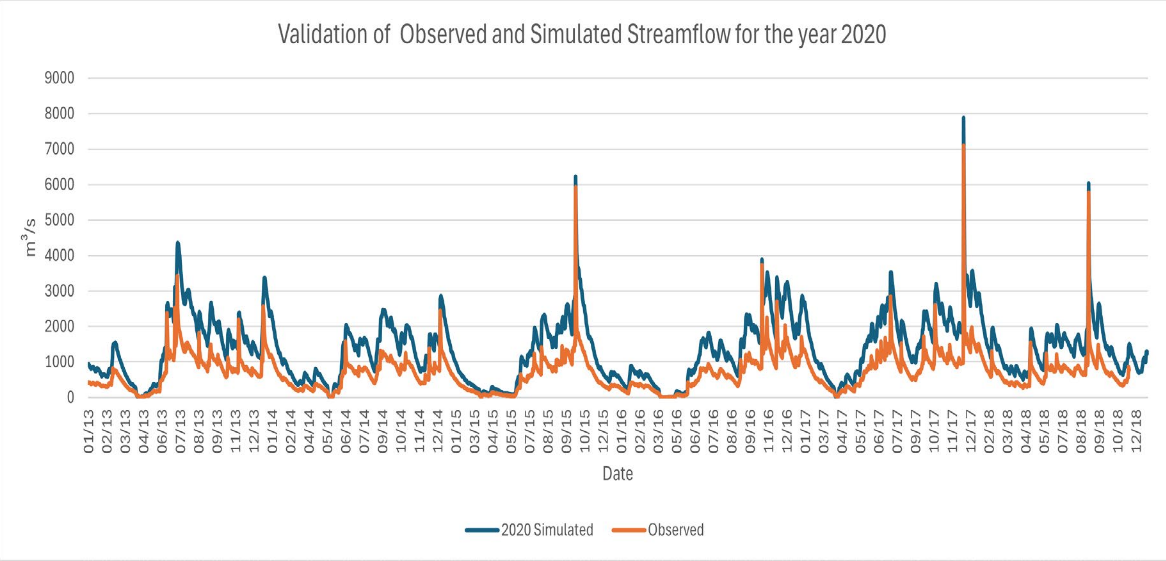
Observed Streamflow of Aklan River Watershed



- Most of the increase in streamflow was from the month of June to August where rainy seasons occur in the Philippines (DOST-PAGASA).
- Low streamflow was from the month of March to May where hot dry seasons occur (DOST-PAGASA)
- There were no observations from November 2010 to April 2012, as well as November 2018 to December 2018.
- Based on historical data, there was a typhoon that hit Panay island in June 2008, and the rainfall exceeds 300mm (dark area)
- More rain in 2012-2013 (Prado, 2015), and normal rainfall condition on the year 2014

Results and Discussion



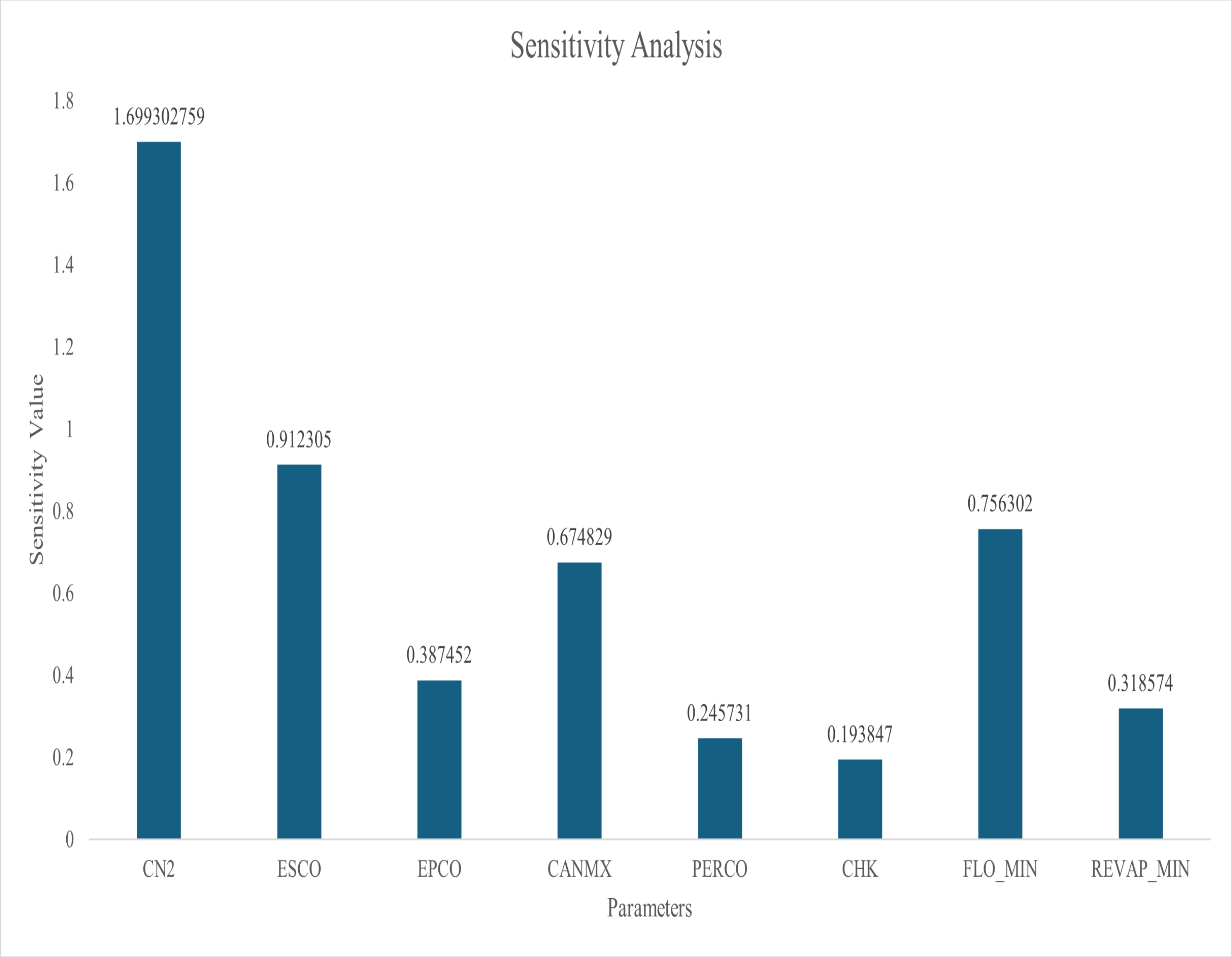


Performance measures using SWAT+ toolbox for the year 2020

Performance Measures	Calibration		Validation	
	Value	Remarks	Value	Remarks
R^2	0.75	Satisfactory	0.83	Good
NSE	0.76	Good	0.78	Good
PBIAS	24.63	Satisfactory	18.89	Satisfactory
RSR	0.64	Satisfactory	0.51	Good

- During calibration, the R^2 value was 0.75, and during validation, it increased to 0.83, indicating a strong positive correlation with the observations.
- The Nash-Sutcliffe Efficiency (NSE) recorded 0.76 during the calibration and 0.78 during the validation, thus supporting credibility with absolute accuracy, as a value higher than 0.70 is considered indicative of good model performance.
- The Percent Bias (PBIAS) remained well within acceptable limits, suggesting that, in general, the model was not significantly overestimating or underestimating streamflow results.
- The Root Mean Square Error Standard Deviation Ratio (RSR) across the essentially altered conditions of 2020 remained very low, indicating that the overall effect of prediction error was indeed less compared to an equal reduction in variability across the observed data at hand.

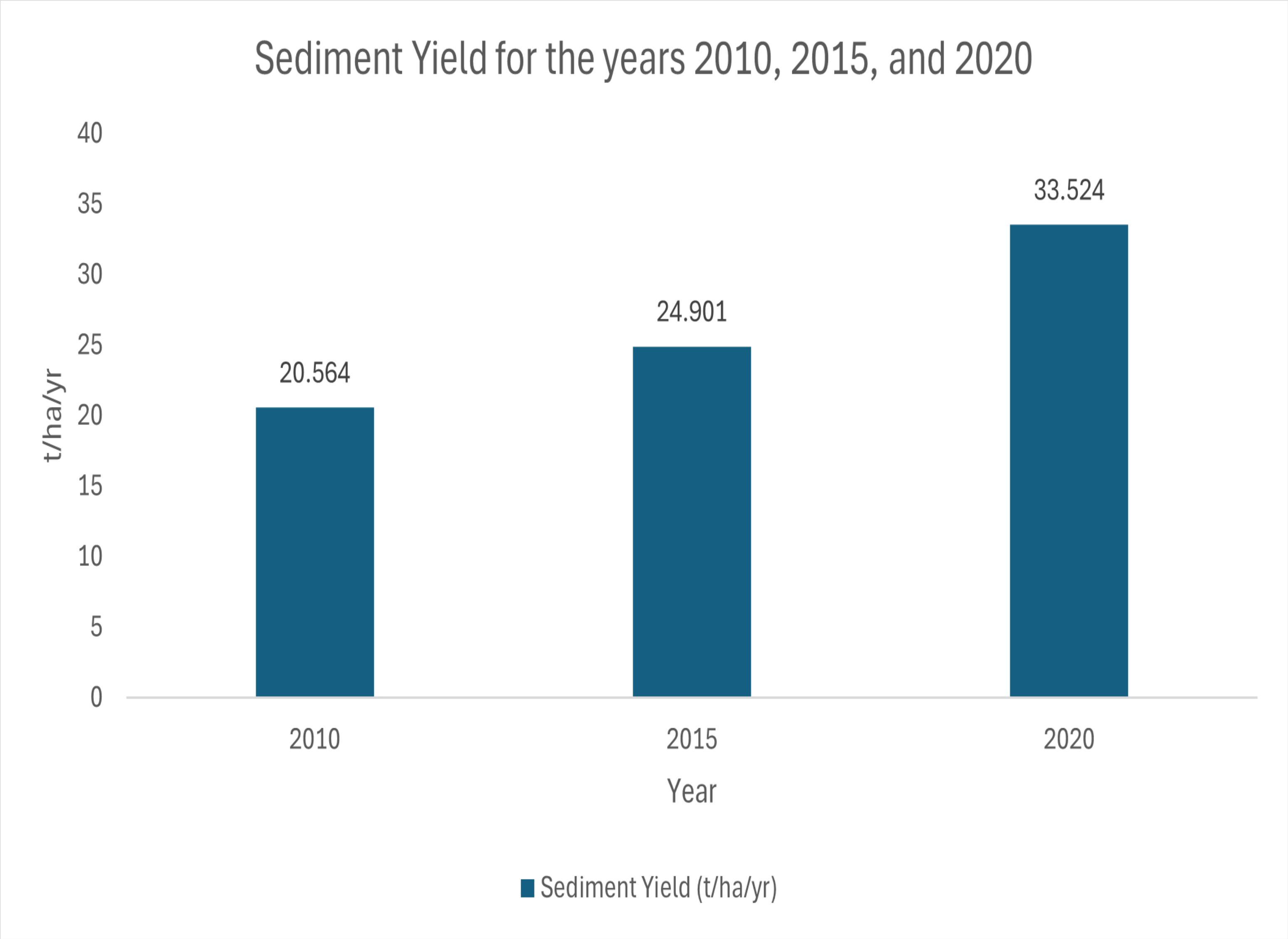
Sensitivity Analysis



- Sobol's method of Global Sensitivity Analysis is a variance base methods of sensitivity analysis method which is capable in computing "first order indices or first order effects' and the 'Total Sensitivity Indices (TSI) or Total Effects' (Bilal, 2014).

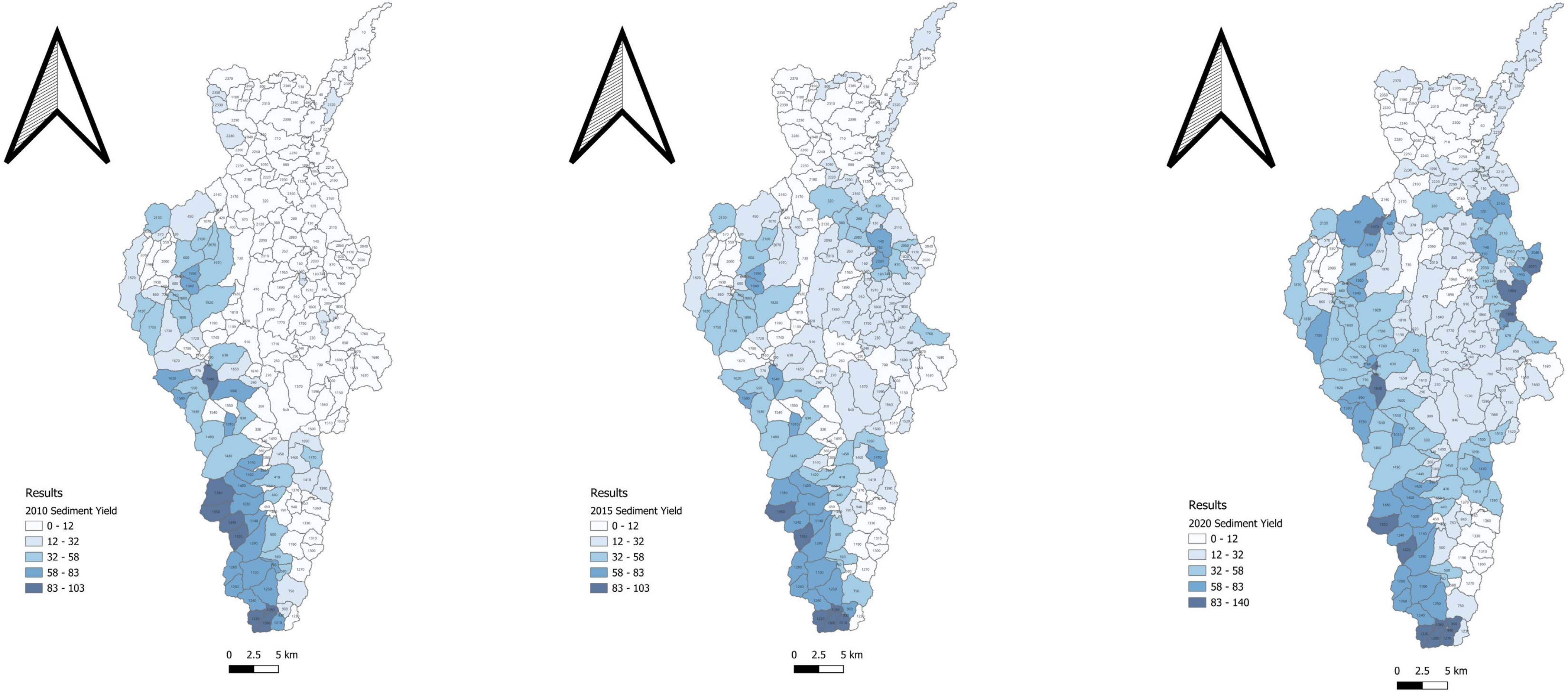
- The SCS runoff number for moisture condition II (CN2) was identified to be the most sensitive parameters for estimating the surface runoff, consistent with the findings of Puno et al. (2019) and Briones et al. (2016).

Sediment Yield of Aklan River Watershed



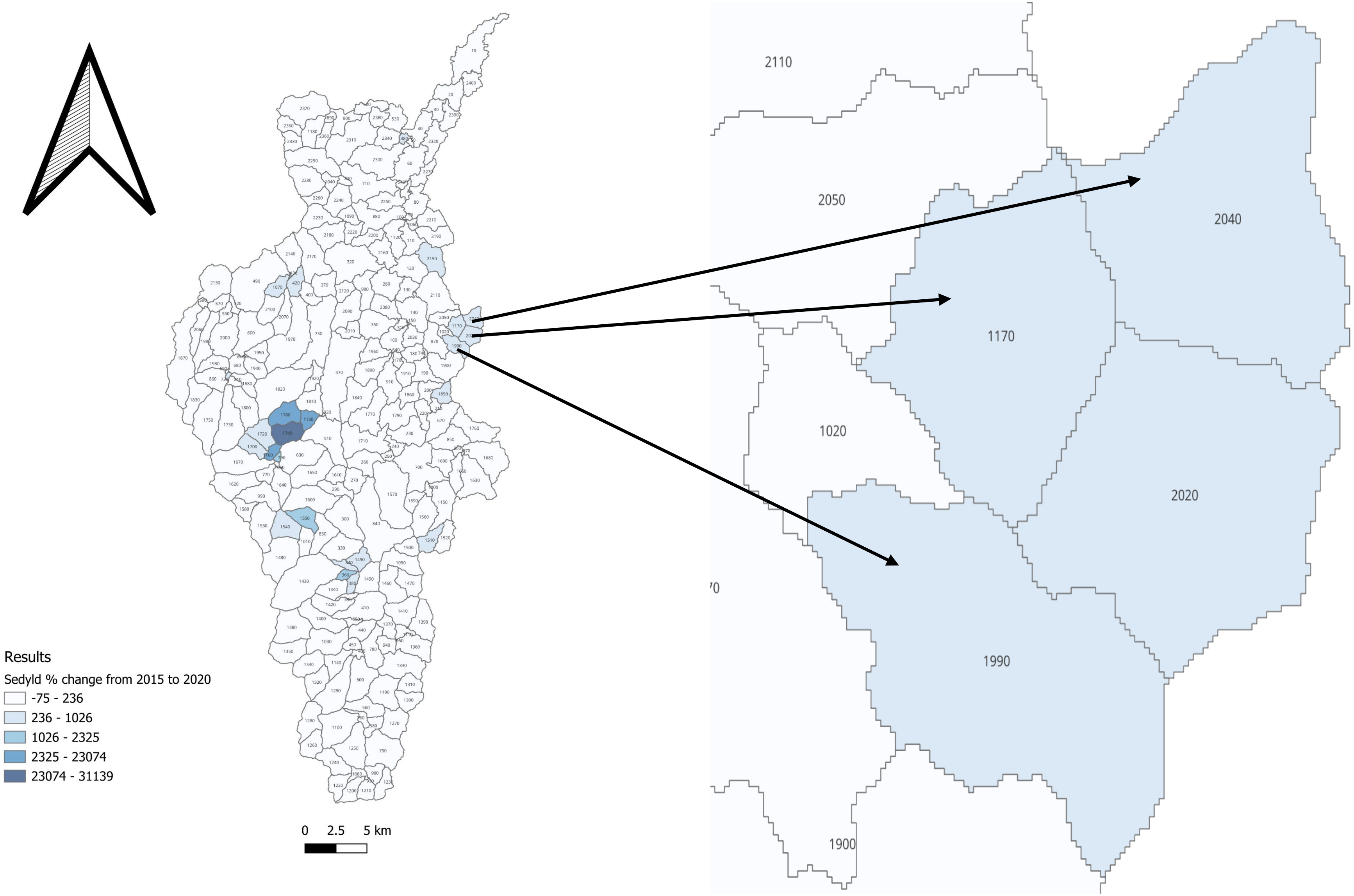
- Sediment yield consistently increased from 20.546 t/ha/yr in 2010 , 24.901 t/ha/yr in 2015 to 33.524 t/ha/yr in 2020.

- This ten-year increase highlights a notable escalation of erosion in the watershed.



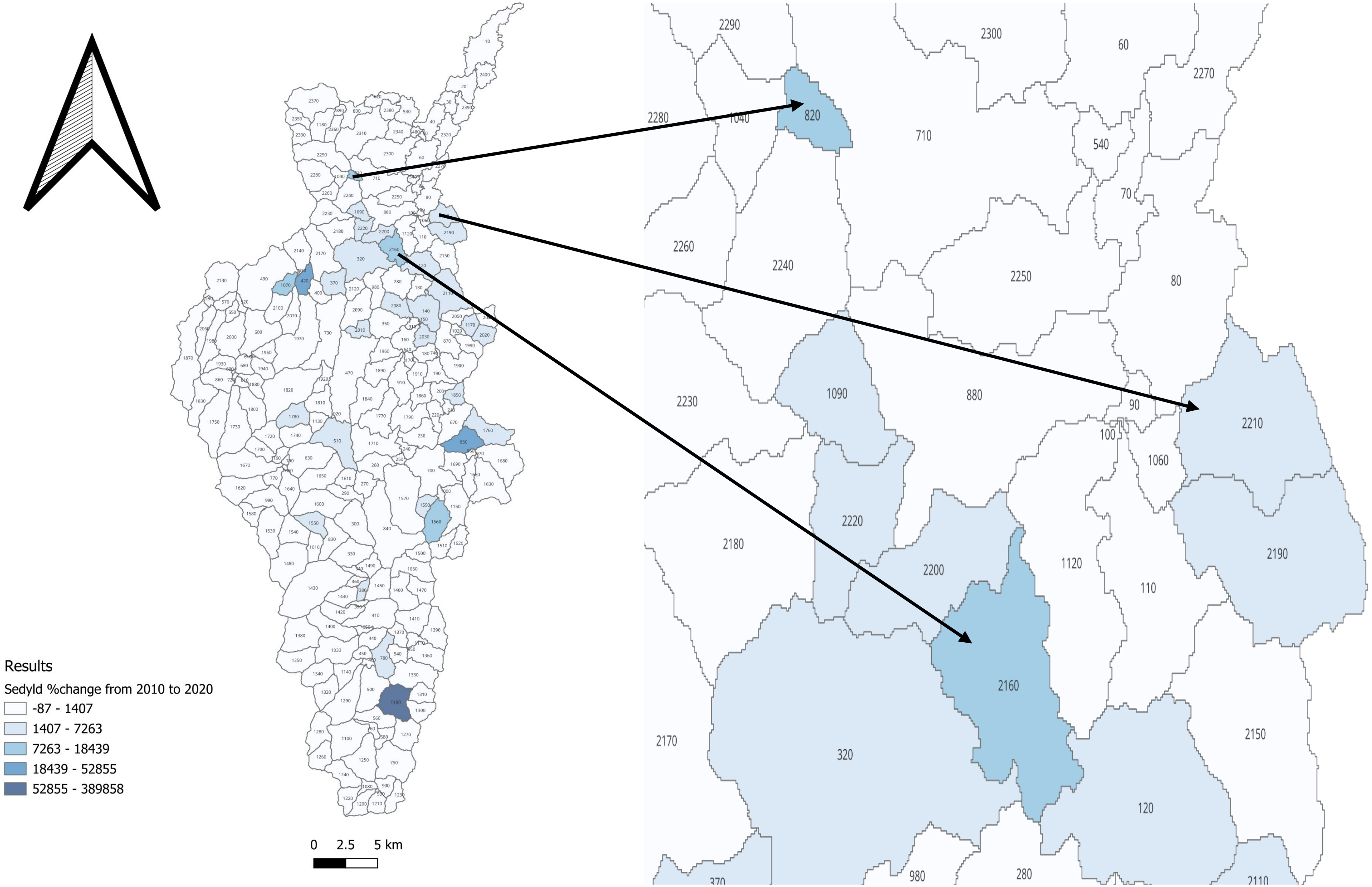
Spatial Distribution of Sediment Yield for the year 2010, 2015, and 2020

Results and Discussion



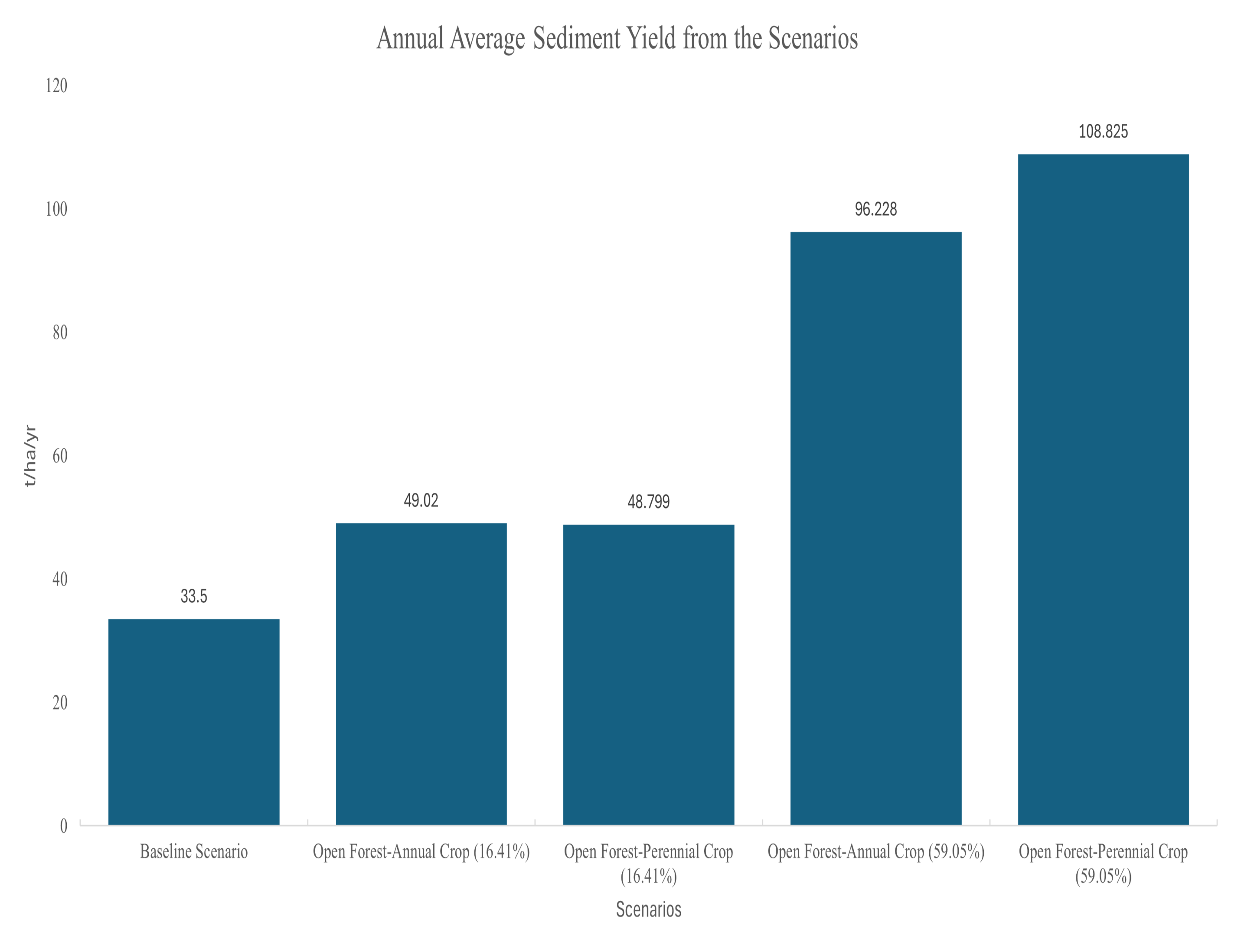
Landscape Unit (LSU) No.	Sediment Yield (t/ha/yr)	
	2015	2020
1170	14	14.2
2040	7.91	8.31
1990	15.2	15.7

Results and Discussion



Landscape Unit (LSU) No.	Sediment Yield (t/ha/yr)	
	2010	2020
820	4.33	6.49
2160	5.28	8.96
2210	12.2	17.7

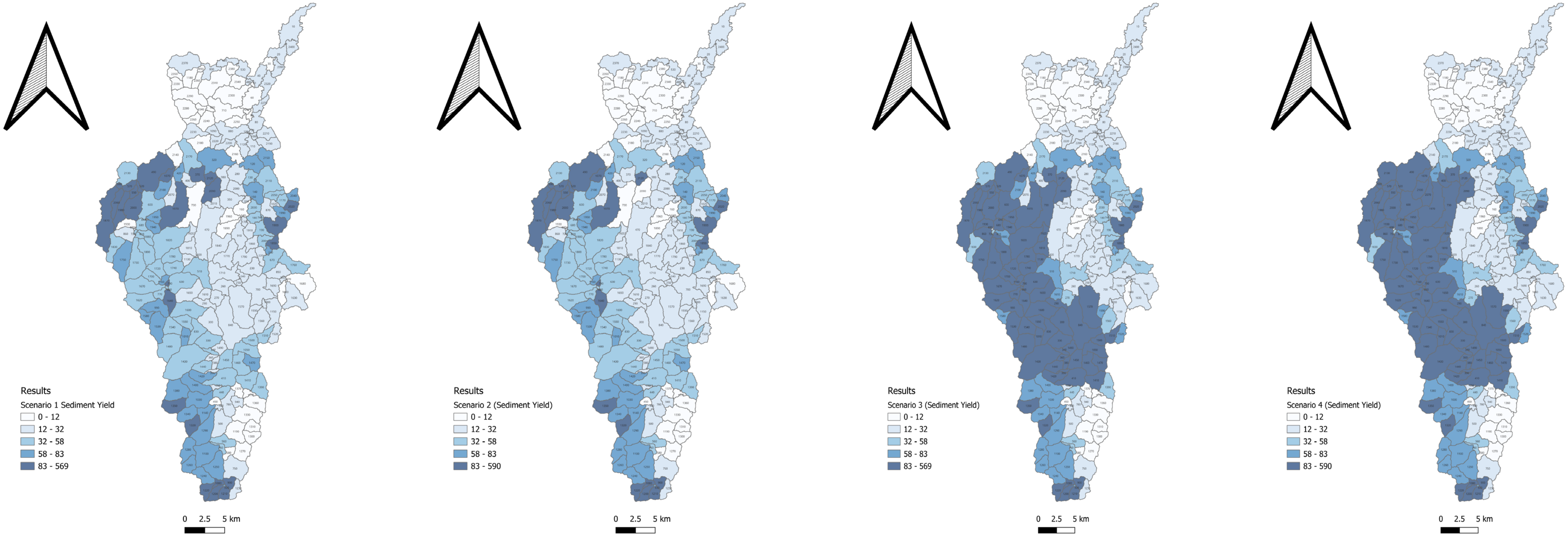
Sediment Yield of Aklan River Watershed



- Scenario 4, which entails a 59.05% reduction of open forest to perennial crops (AGRR), yields more sediment than Scenario 3, which represents the exact extent of forest conversion to annual crops (AGRL).

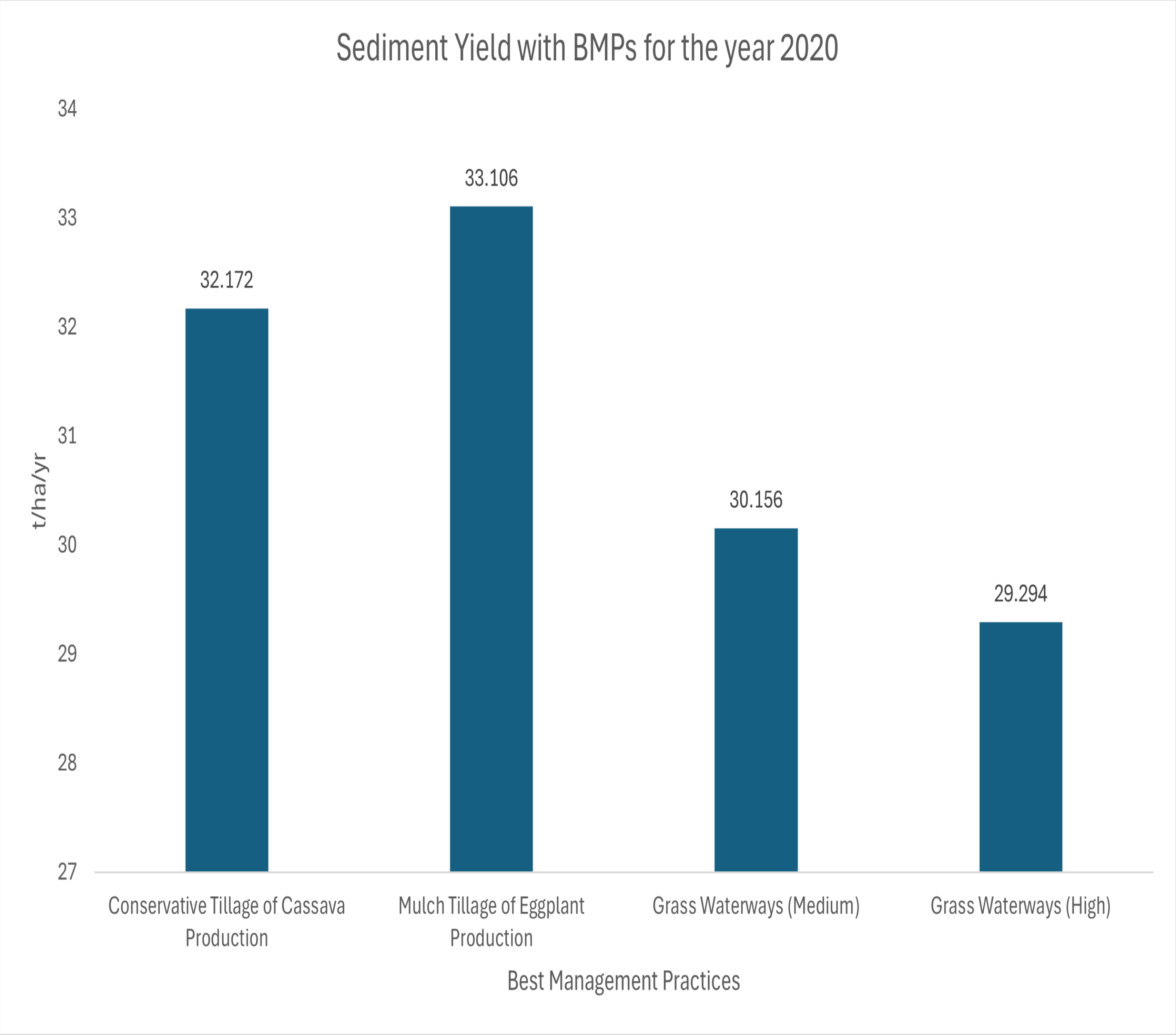
- In Scenario 4, a large number of perennial crop conversions took place in LSUs with steep slopes and highly erodible soils.

- This highlights that even land-use transitions thought to be sustainable may worsen erosion when implemented on sensitive terrain unless they are accompanied by technical assistance and spatial guidance.

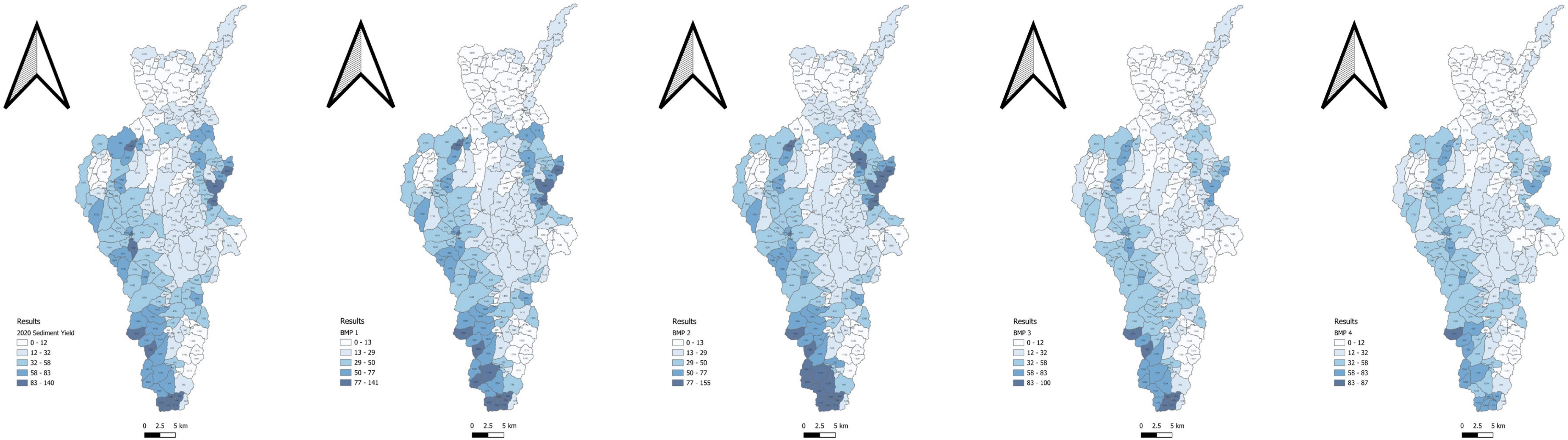


Spatial Distribution of Annual Average Sediment Yield from the Scenarios representing SWAT+ LSU

Results and Discussion



- The findings demonstrate that BMPs such as grass waterways, mulch tillage, and conservative tillage significantly lower sediment yield.
- Grass waterways offered the best erosion control among these, with dense vegetation that greatly trapped silt and slowed runoff.
- By preserving surface residue and improving infiltration, both conservative tillage and mulch tillage demonstrated excellent performance.



Spatial Distribution of Annual Average Sediment Yield from the BMPs representing SWAT+ LSU

Summary and Conclusion

Objective 1

To utilize, adapt, and calibrate the Soil and Water Assessment Tool+ (SWAT+) model to assess the streamflow of the Aklan River Watershed

- The results showed satisfactory to good performance statistics (R^2 ranging from 0.75 to 0.83; NSE from 0.76 to 0.78; PBIAS from 24.63 to 18.89; RSR from 0.64 to 0.51), indicating that the SWAT+ model can accurately describe the hydrologic processes in the Aklan River Watershed.
- Sensitivity analysis further demonstrated the importance of parameters such as CN2 (Curve Number), ESCO, and FLO_MIN in influencing model output, specifically surface runoff and streamflow.

Summary and Conclusion

Objective 2

To assess the effects of different agricultural land cover scenarios on sediment yield in the Aklan River watershed using the SWAT+ model; and

- The average sediment yield increased from 20.564 tons per hectare per year in 2010, 24.901 tons per hectare per year in 2015, to 33.524 tons per hectare per year in 2020.
- Even over a 5-year period, the gains show a steady upward trend in erosion, although they seem modest, particularly in LSUs situated on sloping terrain where forest loss has occurred.
- Continuous forest-to-crop conversion occurred in these land-use systems (LSUs), resulting in increased soil exposure and subsequent erosion over time.

Summary and Conclusion

Objective 3

Identify potential management options based on SWAT+ simulation results.

- The study presented and modeled the effects of three Best Management Practices (BMPs): grass waterways both medium and high, mulch tillage, and conservative tillage.
- The BMPs was strategically in line with regional farming practices based on the agriculture statistical performance of the Department of Agriculture-Western Visayas .
- Since grass waterways stabilize flow channels, reduce runoff, and filter particles before they enter streams, they are very efficient at lowering silt in important erosion hotspots.
- Conservative and mulch tillage methods were effective in minimizing soil disturbance, retaining surface leftovers, and reducing erosion.

Acknowledgement

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Assessment of the Impact of Agricultural Land Cover Changes in Aklan River Watershed, Philippines using SWAT+

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