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Modeling Diffuse Nutrient and Sediment Pollution affecting Lake Palakpakin, Laguna using QSWAT

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Abstract **-** Lake Palakpakin is vulnerable to nutrient and sediment pollution, leading to eutrophication and siltation. Despite existing studies identifying the pollutants and detecting their concentration within the lake, their sources were generally attributed to agricultural activities, considered a nonpoint source. This research modelled the diffuse sediment and nutrient pollution affecting Lake Palakpakin, San Pablo City, Laguna using Soil and Water Analysis Tool (SWAT). This model is physically based, requiring DEM, soil map, LULC map, slope map, and meteorological data as inputs to model physical processes associated with water movement, sediment movement, nutrient cycling, etc. Due to the unsatisfactory statistical results of the calibrated model caused by insufficient hydrological data, the uncalibrated simulation was used. It revealed that the critical source areas for NO_3-N and PO_4 are found in agricultural lands and areas that are underlain by clay and clay loam. Critical source areas were also found along the stream connecting Palakpakin lake to Laguna de Bay. Meanwhile, higher sediment yields were distinct around Sampaloc Lake and the outlet of the other lakes and in agricultural and urban areas. Moreover, the model exhibited that an increase in precipitation coincides with an increase in sediment, NO_3-N and PO_4 loading.

Keywords**:** Soil and Water Analysis Tool, diffuse pollution, critical source areas, sedimentation, eutrophication

1. Introduction

Lakes are essential for humans as it is a source of food, water, and livelihood since it can be utilized for aquaculture, agricultural irrigation, flood control, and hydroelectric power [1]. It also has a role in the ecosystem, which includes regulating water flow and quality, promoting biodiversity, mitigating climate change, purifying contaminated downstream water through sediment and nutrient retention and processing, etc. [2]. Regardless of their importance, lakes in the Philippines are at risk of ecological deterioration, as acknowledged by the first and second National Congress on Philippine Lakes held in 2003 and 2011 [3] due to anthropogenic causes like food production, increasing population, rapid urbanization, and industrialization [4]. In comparison to big lakes, only 9% of studies are focused on small lakes (with a surface area less than 2,000,000 sq. m.) despite small lakes being more fragile and vulnerable to ecological deterioration [1].

The City of San Pablo boasts its seven monogenetic maar lakes, exploiting it for tourism and aquaculture. However, its lakes are threatened due to the proliferation of floating fish cages and pollution from illegal lake dwellers [5]. Lake Palakpakin, one of the seven crater lakes, suffers from eutrophication due to nutrient runoff like phosphorus from fertilizers [6] [7] [8] and siltation [4] [9]. This is expected since the current general land use map of San Pablo is mainly agricultural with 72.41% or 14,305 hectares used for farming and plantations [10], which can be a significant source of diffuse or nonpoint pollution [11]. Unlike point sources which originate from a single site, diffuse sources are indirectly discharged to receiving water bodies through runoff, subsurface flows, and soil leaching, making monitoring more challenging because of high spatial and temporal variability and attribution of diffuse sources more complex [12].

Therefore, this study intends to model diffuse nutrient and sediment pollution affecting Lake Palakpakin using the Soil and Water Analysis Tool (SWAT+). Lake Palakpakin will be focused on since it is often overlooked by the Laguna Lake Development Authority (LLDA) whose involvement is mainly limited to water quality monitoring and the City Government to Lake Sampaloc and Pandin, leaving lake Palakpakin with insufficient development initiatives from its main stakeholders [4]. Thus, the model will help in identifying the sources of diffuse sediment and nutrient pollution, which assists in knowing which areas need interventions, and in understanding the pollutants' relationship with the given various land use, soil, and climate conditions.

2. METHODOLOGY

2.1. Study Area

The City of San Pablo lies at the southern tip of Laguna province with geographic coordinates of 14° 4' N and 121° 19' E (**Fig. 1**). Situated on a plateau, it has an elevation of 485 feet above sea level with a terrain generally sloping from east to west. The ground surface elevation within the city ranges from approximately 50 meters to over 600 meters. The soil type map from BSWM shows that Lipa loam covers 65.41% of the total land area which is characterized as having moderate permeability, acidic, and friable with good drainage that supplies nutrients like phosphorus, potassium, and organic matter. Most of the soils of San Pablo are highly suitable for agriculture.

San Pablo City has Type III climate with not very pronounced seasons usually dry from November to April and wet during the rest of the year. The City has a cool climate due to its location at the foothills of Mount Banahaw, Mount Makiling, and the Sierra Madre Mountain Ranges. The wet or rainy season in San Pablo City can be observed from June to November while dry season during December to May. The average daily wind speed is around 5 km/hr. (maximum sustained winds) and has reached an average of 63 km/hr.

Lake Palakpakin is one of San Pablo's seven monogenetic maar lakes, which is a product of phreatomagmatic eruptions later filled with water. Structurally, these monogenetic, basaltic cones are part of the northeast-trending lineament known as the Macolod Corridor. The crater lakes are also mainly made up of tephra deposits overlain by fluvial deposits. Palakpakin lake has an area of 54.39 hectares, traversing Brgy. Dolores, Brgy. San Buenaventura, and Brgy. San Lorenzo. It has a maximum depth of 7.7 meters [10] and an average elevation of 100 m above the ground surface. It rests on a plateau with gentle slopes covered by Lipa Loam. The lake consists of first-order streams with a mean water residence time of 4.4 days and water inflow coming from lakes Calibato and Pandin.

2.2. SWAT Model Input

The data were obtained from government institutions and available open-source data. **Table 1** summarizes the dataset used in the SWAT+ model and where the researchers acquired such data. The data included the Digital Elevation Model, land use map derived from Landsat 08 OLI, soil type, administrative boundaries, meteorological data, and water quality.

Table 1: SWAT dataset and its sources

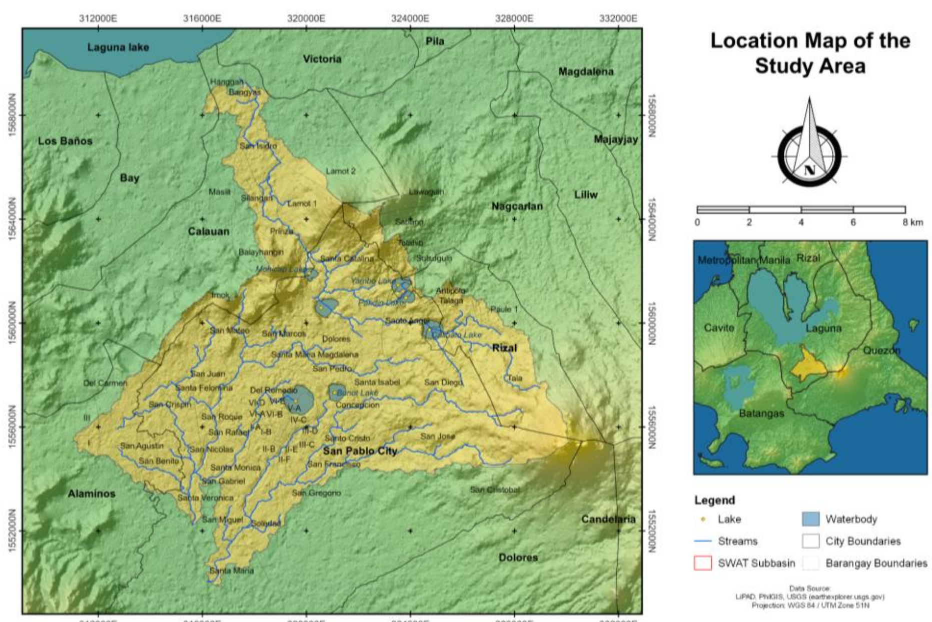

Fig. 1: Location map of the study area.

Data	Description	Format	Data Source
Digital Elevation Model (DEM)	For delineation of cells and generation of stream network, elevation, slope	ESRI GRID	SAR-DEM from LiDAR Portal for Archiving and Distribution (LiPAD)
Land use map	Land use classification	ESRI GRID	Landsat 08 OLI from United States Geological Survey (USGS)
Soil map	Soil types	ESRI GRID	Digital soil data of Food and Agricultural Organization (FAO) and Philippine Soil Map of Bureau of Soil and Water Management (BSWM)
Administrative region	Boundary of towns covered by the SWAT-delineated watershed	Shapefile	PhilGIS
Meteorological data	Precipitation, minimum and maximum temperature, relative humidity, wind speed, solar radiation (Daily data from 2001-2020)		NASA POWER (Prediction Of Worldwide Energy Resources) Project (power.larc.nasa.gov)
Water Quality Data	Inorganic Phosphate and Nitrate Concentration (Monthly data from 2006-2020)		Laguna Lake Development Authority

2.3. SWAT Modelling

SWAT+ is a small watershed to river basin-scale model mainly used for simulating the quality and quantity of surface and groundwater and predicting the environmental impact of land use, land management practices, and climate change. It is physically based, which means that it requires input data such as weather, soil properties, topography, vegetation, and land management practices to model the physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc.

Watershed Delineation

Watershed delineation was first done to segment the watershed into several "hydrologically" connected subbasins using the digital elevation model (**Fig. 2a**). Beforehand, it was made sure that its projection of UTM 51N WGS 84 is similar to the whole project. Streams were then created from the DEM with a channel threshold of 9 hectares and stream threshold of 90 hectares. Then, the outlets were defined and the shapefiles of the seven lakes were added. Afterwards, the watershed and its 85 subbasins were outlined. Masking was then done manually, tracing the delineated watershed.

Creating the Hydrologic Response Unit (HRU)

The Hydrologic Response Unit (HRU) analysis was then performed wherein land use, soil, and slope were characterized for the watershed. These determined the area and hydrologic parameters of each land-soil category, reflecting differences in evapotranspiration and hydrologic conditions.

The preprocessed land use/land classification map (**Fig. 2b**) and soil map (**Fig. 2c**) in raster format were loaded into the project, with their corresponding lookup tables. The agricultural land uses were equally split into BANA (banana), COCO (coconut), CORN (corn), PAPA (papaya), and SUGC (sugar cane) plantations with 20 % land use each. The urban land uses were split into 85% URBN (residential), 9 % UTRN (transportation), 3 % UCOM (commercial), 2 % UINS (institutional), and 1 % UIDU (industrial). The slope bands of 5, 10, 50, and 100 percent were selected (**Fig. 2d**). The land use, soil, slope threshold for defining the HRUs were 0%-0%-0% to ensure that all areas will be preserved and evaluated in the study [13].

Running the Model

The weather station and weather generator were added using the meteorological data. The simulation period was set from January 2001 to December 2020 with a warm-up period of 5 years. With this, the simulation length was 13 years from 2006 to 2020.

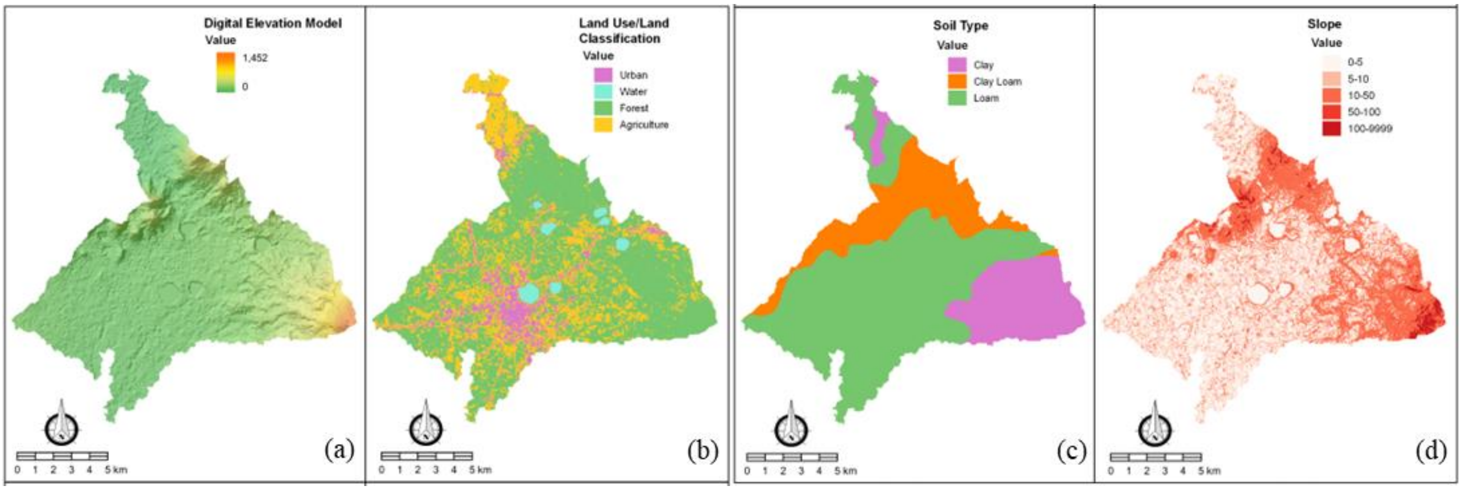

Figure 2: Input for SWAT+ model. (a) Digital elevation model. (b) LULC map. (c) Soil map. (d) Slope map.

2.4. Calibration and Validation

The simulation length was divided into two: The first half from January 2006 to December 2013 was used for model calibration, while the second half from January 2014 to December 2020 was used for model validation. Nitrate nitrogen and phosphate concentrations were the only data available for model calibration and validation, leaving sediment pollution to be uncalibrated.

Manual calibration was performed for each sensitive parameter until the results were considered satisfactory according to the statistical analyses, coefficient of determination (r^2), root mean squared error (RMSE), and Nash-Sutcliffe Efficiency (NSE).

The coefficient of determination, r^2, tests the preciseness of simulated data through the standard deviation. This determines the fitness of the simulated model in comparison to the observed data. It is calculated using the formula as seen in Equation 1 wherein r is the Pearson correlation, n is the number in given dataset, x is the observation data, and y is the simulated data.

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}} \quad (1)$$

The root mean squared error, RMSE, highlights the errors in the model and whether or not these were acceptable. This is simply the difference between the simulated and modelled values. This is computed using Equation 2 wherein $X_{obs,i}$ is the observation data, and $X_{sim,i}$ is the simulated data.

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n}\left(X_{obs,i} - X_{sim,i}\right)^2}{n}} \quad (2)$$

The Nash-Sutcliffe efficiency, NSE, determines the noise in the data and the magnitude of the residual variance in comparison to the measured data variance. This also indicates the fitness between the plot of the observed and simulated data. This is calculated using Equation 3 wherein OBS_i is the observation data, SIM_i is the simulated data, and $\overline{OBS_i}$ is the average of the observed data.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{\sum_{i=1}^{n}(OBS_i - \overline{OBS_i})^2} \quad (3)$$

Table 2 shows the acceptable performance ratings for each statistical methods.

Table 2: Performance ratings for r^2, RMSE, and NSE

Rating	Interpretation
>0.5	Acceptable variance for r^2 analysis
0.2-0.5	Acceptable variance for RMSE analysis
>0.35	Acceptable variance for NSE analysis

3. Results and Discussion

3.1. Model Performance

The model was calibrated and validated using three efficiency criteria: the NSE, r^2, and RMSE. During processing, parameters sensitive to nitrate nitrogen and phosphate concentrations were calibrated. Specifically, biological mixing efficiency (BIOMIX), nitrate percolation coefficient (NPERCO), phosphorus percolation coefficient (PPERCO), maximum canopy storage (CANMX), organic N enrichment ratio for loading with sediment (ERORGN), Universal Soil Loss Equation for support practice factor (USLE_P), and Universal Soil Loss Equation for soil erodibility (USLE_K) were adjusted to achieve the best results summarized in **Table 3** and shown in **Figure 3.1** and **Figure 3.2**. The obtained values were then compared to **Table 2** to assess model performance.

Table 3: Performance ratings for r2, RMSE, and NSE

Simulation	**Period**	**Nitrate Nitrogen (NO3-N)**			**Phosphate (PO4**		
		r^2	RMSE	NSE	r^2	RMSE	NSE
Initial Run	2006 - 2013	0.1723	0.0892	-4.3268	0.0693	0.4564	-0.8461
	2014 - 2020	0.0235	0.0668	-8.3642	0.0438	0.4250	-9.5241
Calibration	2006 - 2013	0.1669	0.0412	-0.1355	0.0625	0.3653	-0.1825
Validation	2014 - 2020	0.0331	0.0265	-0.4310	0.0581	0.2735	-2.9881

For both nitrate nitrogen and phosphate, the obtained NSE values were negative. These indicate that the mean of the observed nutrient concentrations would be a better predictor of future and current nutrient trends than the simulated model. Notably, NSE is sensitive to extreme values due to the squared variances in its equation. Hence, in cases where the data is incomplete and the lapses in the concentration-time series must be replaced with 0, the NSE may predict over- or underestimated values. Such is the case with the study area where there are inconsistent data measurements throughout the year.

The results for r^2 were also below the acceptable range. Such values indicate that there is little correlation between the observed and simulated values. However, this correlation is not sufficient to render the model capable of predicting nutrient concentration trends for the given watershed.

Finally, the values for the root mean squared error (RMSE) fails to meet the range of acceptable values for the uncalibrated and calibrated NO_3-N results. However, the RMSE values for the calibrated PO4 model fall within the 0.2 to 0.5 range declared by previous studies employing the SWAT model.

The lack of observed runoff and sediment data, as well as the amount of missing data for the monthly phosphate and nitrate nitrogen concentration values, hindered the researchers from effectively calibrating the model, producing unsatisfactory statistical results for the calibrated and validated model. Arnold et al. [14] stated that an ideal calibration and validation should be process-based wherein each parameter affecting the process must be calibrated individually at the subwatershed level. It was also recommended to conduct calibration sequentially starting from the streamflow, sediment, then nutrient transport due to their interdependencies. However, these recommendations cannot be applied in the study due to the limited observed data making the estimation of calibrated parameters more biased. Moreover, as opposed to using SWAT-CUP for automatic calibration, the researchers manually calibrated the model due to the inaccessibility of the computer program. This made the calibrated model more user-dependent as the changes reflected the researchers' experience, knowledge, chosen parameters, and how much they will change them [15].

In some research, SWAT had still successfully simulated the water quantity and water quality even for ungauged watersheds [16] [17] [18]. Other studies have also explored not performing calibration to determine how the default parameters depicted the watershed [15]. Furthermore, the SWAT model was originally developed to be applied in ungauged watersheds with minimal calibration efforts [19]. For these reasons, the researchers opted to utilize the uncalibrated simulation with the default parameters.

3.2. Diffuse Pollution Affecting Palakpakin Lake

Through the application of SWAT, diffuse pollution models were produced displaying the sediment and nutrient loads affecting the delineated watershed. **Figure 3.3** shows the spatial distribution of the simulated monthly average sediment

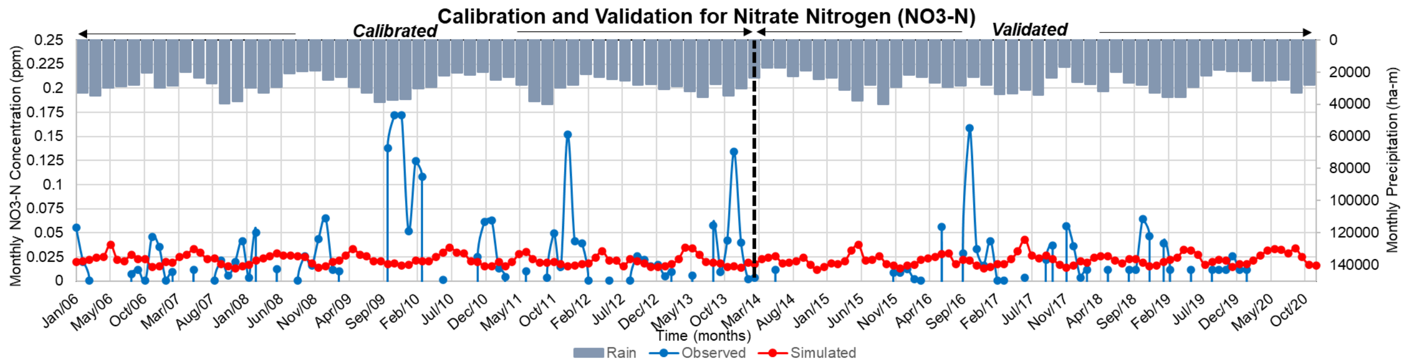

Figure 3.1: Calibrated and validated observed vs simulated monthly NO_3-N concentration.

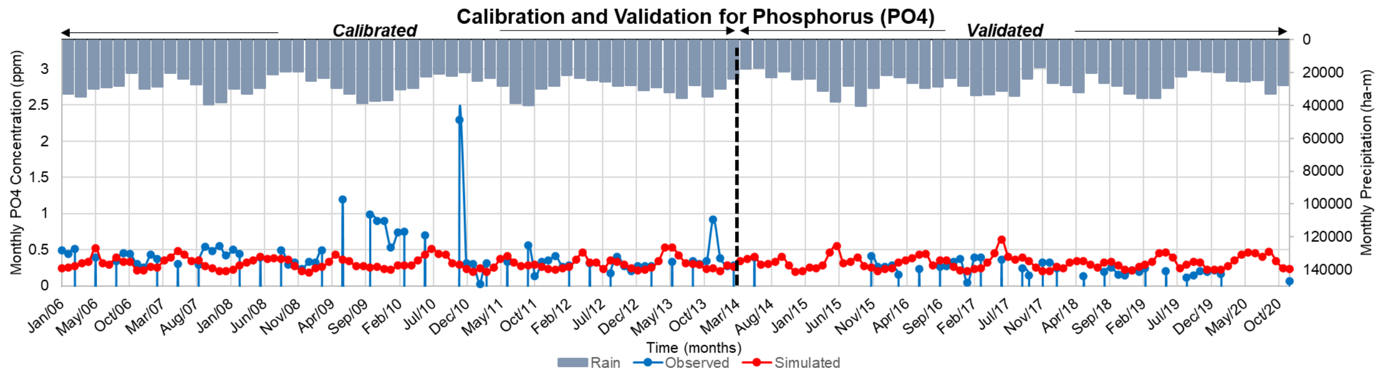

Figure 3.2: Calibrated and validated observed vs simulated monthly PO4 concentration.

yields and nutrient loadings across the watershed at the Slope Length and Steepness units (LSU) scale and the monthly average loadings of sediment and nutrients flowing into the channel. The LS unit scale divides the sub-basin based on its slope length and steepness. The sediment yield leaving the landscape caused by water erosion is more evident around Lake Sampaloc and the outflow areas of the rest of the lakes with about 0.05-0.11 tons/ha (**Fig. 3.3a**). There are also higher yields in urban and agricultural areas compared to the forest areas. The nitrate nitrogen transported in surface runoff is apparent in areas under clay loam and for agricultural purposes at 0.0021-0.0034 kg/ha (**Fig. 3.3c**). The phosphate transported in surface runoff is mainly observed in areas classified as having clay loam and loam at 0.025-0.030 kg/ha (**Fig. 3.3e**). It is also noticeable that urban areas have lesser amounts of nutrient loadings at a maximum amount of 0.0004 kg/ha for NO_3-N and 0.005 kg/ha for PO_4. In addition, the San Cristobal mountain area also had the least amount of sediment yield and nutrient loadings. An average of 1,980 to 6,830 tons of sediment (**Fig. 3.3b**), 4 to 9 kg of NO_3-N (**Fig. 3.3d**), and 27 to 63 kg of PO_4 (**Fig. 3.3f**)flow into the main channel leading to Lake Palakpakin. A monthly average of 1,980 to 488,640 tons of sediment (**Fig. 3.3b**), 9 to 27 kg of NO_3-N (**Fig. 3.3d**), and 63 to 160 kg of PO_4 (**Fig. 3.3f**) flow to the main channel going out from Lake Palakpakin into Laguna Bay.

The monthly average temporal variation in sediment yield for Lake Palakpakin within the 20-year timeframe is 12,237 kg/ha. Further, the temporal variation in sediment loading as compared to seasonal changes is presented in **Figure 3.4a**. Where there is a spike in precipitation, a spike in sediment yield follows. Similarly, low values in precipitation also produce low values of sediment loading. This suggests that as the influx of water increases, the sediment yield in Palakpakin Lake also increases. This statement agrees with the simulations conducted by Sharma & Tiwari (2019).

The same observation is true for the simulated nitrogen and phosphorus loadings transported from surface runoff into Lake Palakpakin as illustrated in **Figure 3.4b** and **3.4c**. The average concentrations for NO_3-N and PO4 within the 20-year period are 15.81 kg/ha and 53.80 kg/ha respectively. Although an influx in water by precipitation dilutes the NO_3-N and PO4 concentrations, the increase of nutrient loadings transported by surface runoff to the reservoir allows the nutrient concentration to rise and fall along with the variations in seasonal precipitation.

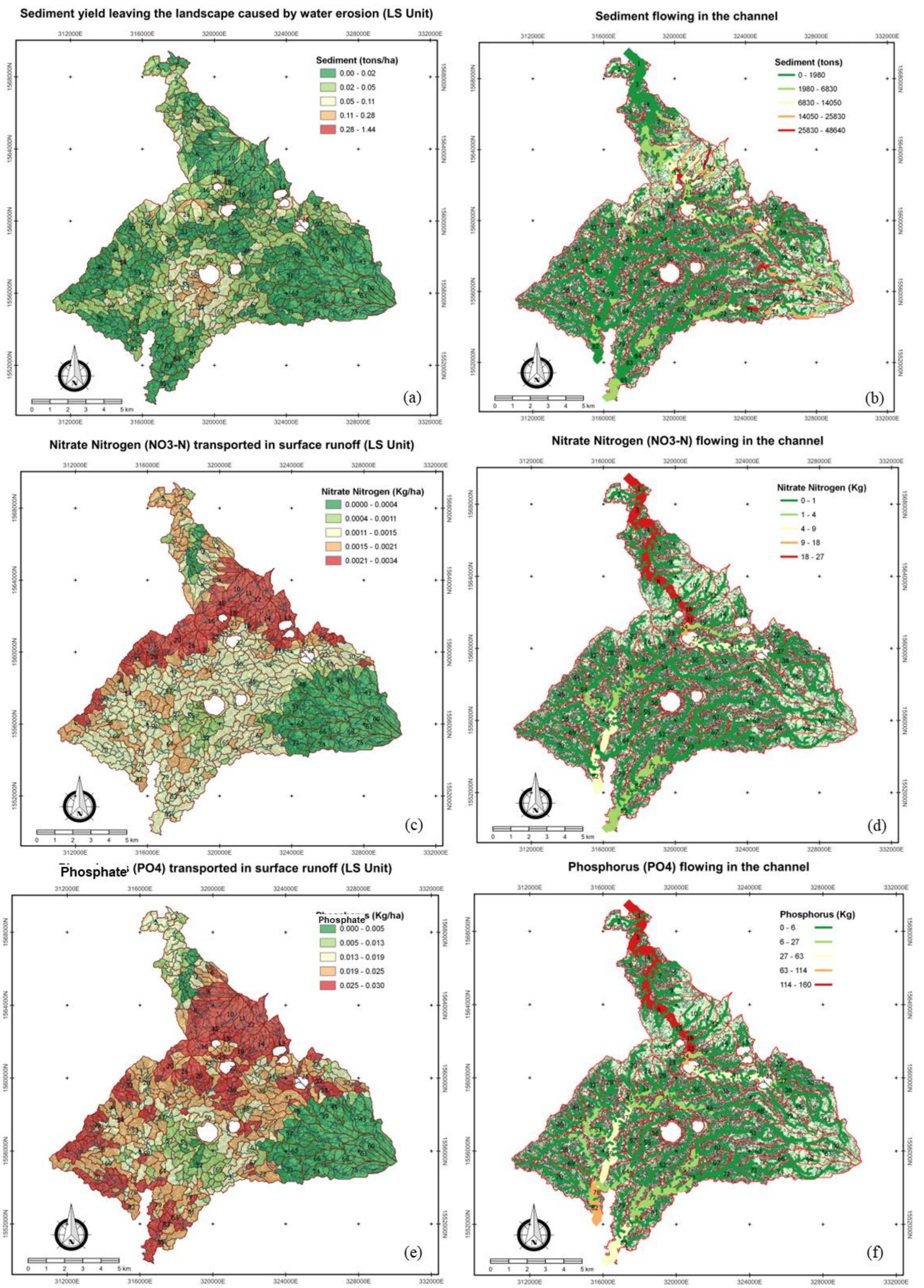

Figure 3.3: Maps showing the spatial distribution of sediment and nutrient yield within the watershed. (a) Sediment yield at LS unit. (b) Sediment loadings flowing in the channel. (c) NO_3-N transported at LS unit. (d) NO_3-N loadings flowing in the channel. (e) PO_4 transported at LS Unit. (f) PO_4 loadings flowing in the channel

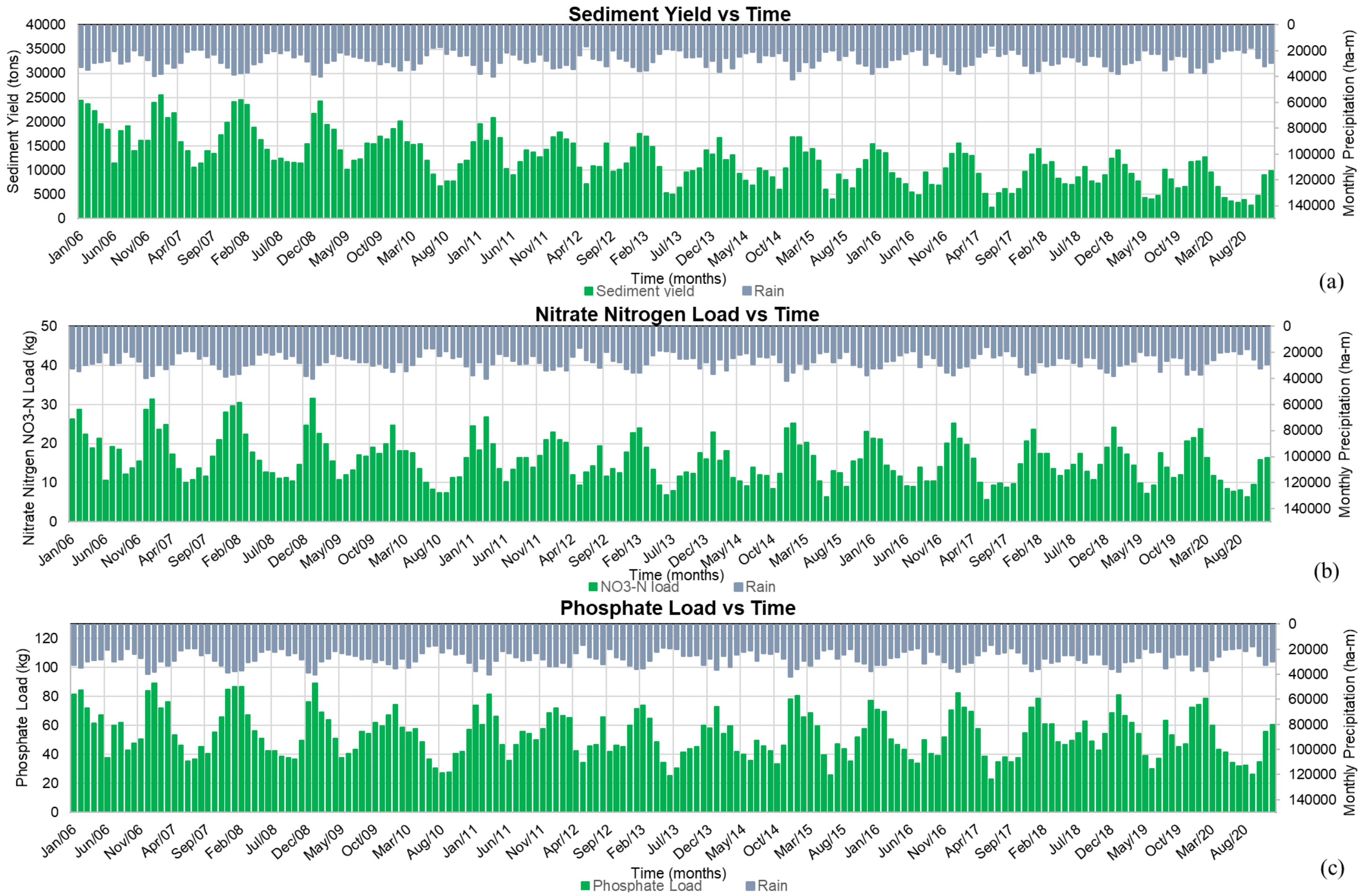

Figure 3.4: Temporal variation in (a) sediment yield, (b) nitrate nitrogen yield, (c) phosphate yield of Lake Palakpakin

4. Conclusion

A diffuse pollution model affecting Lake Palakpakin was produced by applying SWAT using altimetric, Landsat, and meteorological data. However, the model was unable to yield satisfactory efficiency results due to inconsistencies in the acquired observed water quality data. Hence, the uncalibrated model was used in this study, which revealed that the critical source areas for nitrate nitrogen and phosphate concentrations are situated along the stream connecting the monogenetic maar lakes with the Laguna de Bay. Further, the model also showed that areas underlain by clay and clay loam retain more nutrient loadings. Hence, measures to lessen point sources of nitrogen and phosphorus such as nitrate and phosphate bearing fertilizers used in agriculture are advisable in clay- and clay loam-laden sites.

The model also revealed relevance to the land use characteristics of the study area. For instance, there are higher sediment yields in agricultural and urban regions compared to forest areas. Further, nutrient concentration distinctively decreases in urban areas and increases along agricultural sites. Notably, cultural eutrophication is also influenced by sediment yield. In [20], it was cited that eutrophication is worsened by the absorption of phosphorus in sediments. The model also showed that sediment yield is more distinct around Sampaloc Lake and the outlet of the other lakes. One way to counter the adverse effects of siltation brought by increasing sediment yields is to increase riparian vegetation along the outlets of the maar lakes.

The uncalibrated model also showed variations in its monthly sediment and nutrient loadings as the season changed, whereby an increase in precipitation coincides with an increase in sediment, nitrate nitrogen, and phosphate loadings, respectively. These temporal changes in sediment and nutrient concentrations agree with the studies conducted by Sharma & Tiwari [21] and the field-based siltation analysis done by Komissarov & Ogura [22]. A method recommended by Schindler [23] focuses on lessening phosphorus content in soil and water on an ecosystem-scale to reduce the effects of cultural eutrophication.

References

[1] B. B. Brillo, “The Status of Philippine Lake Studies: Scholarly Deficit on Social Science Studies and on Small-Lake Research,” in *Asia-Pacific Social Science Review*, 2015, vol. 15, no. 1, pp. 78–101.

[2] M. Schallenberg, M.D. de Winton, P. Verburg, D.J. Kelly, K.D. Hamill, & D.P. Hamilton, “Ecosystem services of lakes,” in *Dymond JR ed. Ecosystem services in New Zealand – conditions and trends,* Manaaki Whenua Press, Lincoln, New Zealand, 2013.

[3] M. L. Cuvin-Aralar, A. Santos-Borja, A. Palma, M. Mendoza, P. Ocampo, E. Manalili, & L. Darvin, “LakeCon2011: Second national congress on Philippine lakes: Building on the pillars of integrated lake basin management,” in *SEARCA*, Los Banos, Philippines, 2011.

[4] B. B. Brillo, “Developing a small lake: The case of Palakpakin Lake, San Pablo City, Philippines,” in *Water Resources*, 2016, vol. 43, no. 4, pp. 611-620.

[5] Global Nature Fund. (2014, February 2). Threatened Lake of the Year 2014 [Online]. Available: https://www.globalnature.org/ThreatenedLake2014

[6] R. J. R. Claveria, T. R. Perez, J. K. V. Tesorero, B. J. D. Pasaporte, & G. M. S. Bayugo, Petrographic Analysis of Rocks and Sediments around the Seven Lakes of San Pablo City, Laguna: Implications to Sulfate Distribution and Provenance," in *SEAFDEC/AQD Institutional Repository*, 2011, p. 308

[7] Laguna Lake Development Authority, “Water quality report of the seven crater lakes 2006-2008,” Rizal, Philippines: LLDA-EQRD, 2008.

[8] I. K. D. Dimzon, A. S. Morata, J. Müller, R. K. Yanela, S. Lebertz, H. Weil, T. R. Perez, J. Müller, F. M. Dayrit, & T. P. Knepper, “Trace organic chemical pollutants from the lake waters of San Pablo City, Philippines by targeted and non-targeted analysis,” in *Science of The Total Environment*, 2018, vol. 639, pp. 588–595

[9] G. A. Severino, “Morphometry and Sedimentation of Palacpaquen Lake, San Pablo City, Laguna, Philippines,” Thesis, Department of Environmental Science, School of Science and Engineering, Ateneo de Manila University, Quezon City, Philippines, 2007.

[10] City Planning and Development Office, “The Comprehensive Land Use Plan of San Pablo City 2015-2025,” 2015.

[11] V.G.V. Paller, D. Magcale-Macandog, E.R.C. de Chavez, M.G.V. Paraso, M.C.L. Tsuchiya, J.G. Campang, J.V.R. Pleto, M.Z. Bandal, Jr., Y.C.L. Cabillon, A.G. Elepaño, J.R.M. Macaraig, and S.S. Mendoza, “The Seven Lakes of San Pablo: Assessment and Monitoring Strategies Toward Sustainable Lake Ecosystems,” in *Philippine Science Letters*, 2021, vol. 14, no. 1.

[12] OECD, “Diffuse Pollution, Degraded Waters: Emerging Policy Solutions,” in *OECD Studies on Water*, OECD Publishing, Paris.

[13] Y. Her, J. R. Frankenberger, I. Chaubey, & R. Srinivasan”, Threshold Effects in HRU Definition of the Soil and Water Assessment Tool,” in *Transactions of the ASABE,* 2015, vol. 58, pp. 367-378.

[14] J. G. Arnold , D. N. Moriasi, P. W. Gassman, K. C. Abbaspour, M. J. White, R. Srinivasan, C. Santhi, R. D. Harmel, A. van Griensven, M. W. Van Liew, N. Kannan, & M. K. Jha “SWAT: Model Use, Calibration, and Validation,” in *Transactions of the ASABE,* 2012, vol. 55, no. 4, pp. 1491–1508.

[15] R. Srinivasan, X. Zhang, & J. Arnold, “SWAT Ungauged: Hydrological Budget and Crop Yield Predictions in the Upper Mississippi River Basin,” in *Transactions of the ASABE,* 2010, vol. 53, no. 5, pp. 1533–1546.

[16] K. Narula and S. Nischal, “Hydrological Modelling of Small Gauged and Ungauged Mountainous Watersheds Using SWAT—A Case of Western Ghats in India,” in *Journal of Water Resource and Protection*, 2021, vol. 13, pp. 455-477.

[17] H. Mishra, D. M. Denis, S. Suryavanshi, M. Kumar, S.K. Srivastava, A.F. Denis, & R. Kumar, “Hydrological simulation of a small ungauged agricultural watershed Semrakalwana of Northern India,” in *Appl Water* Sci, 2017, vol. 7, pp. 2803–2815.

[18] E. Sisay, A. Halefom, D. Khare, L. Singh, & T. Worku, “Hydrological modelling of ungauged urban watershed using SWAT model,” in *Modeling Earth Systems and Environment*. 2017, vol. 3.

[19] J.G. Arnold, R. Srinivasan, R.S. Muttiah, J.R. Williams, “Large area hydrologic modelling and assessment, part 1: model development,” in *JAWRA*, 1998, vol. 34, no. 1, pp. 73-90

[20] I.A. Navarrete, G.P. Dicen, T.R. Perez, S.M. Mendoza, R.V. Rallos, J.L.R. Labides, C.T. Rivera, A.V. Hallare, & R.J.R. Claveria, “Towards Integrated Management of a Shallow Tropical Lake: Assessment of Water Quality, Sediment Geochemistry, and Phytoplankton Diversity in Lake Palakpakin, Philippines,” in *Environmental Monitoring and Assessment*, 2019, vol. 191, no. 8, pp. 6.

[21] A. Sharma and K. N. Tiwari, "Predicting non-point source of pollution in Maithon reservoir using a semi-distributed hydrological model," in *Environmental Monitoring and Assessment,* 2019, vol. 191, no. 8.
[22] M. Komissarov, & S. Ogura, "Siltation and radiocesium pollution of small lakes in different catchment types far from the Fukushima Daiichi nuclear power plant accident site," in *International Soil and Water Conservation Research*, 2020, vol. 8, no. 1, pp. 56–65.
[23] D. W. Schindler, "The Dilemma of Controlling Cultural Eutrophication of Lakes," in *Proceedings of the Royal Society B: Biological Sciences*, 2012, vol. 279, no. 1746, pp. 4322–4333.