World Journal of Engineering and Technology, 2018, 6, 98-115
http://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Spatial-Temporal Sediment Hydrodynamics and Nutrient Loads in Nyanza Gulf, Characterizing Variation in Water Quality

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How to cite this paper: Misigo, A.W.S. and Suzuki, S. (2018) Spatial-Temporal Sediment Hydrodynamics and Nutrient Loads in Nyanza Gulf, Characterizing Variation in Water Quality. *World Journal of Engineering and Technology*, **6**, 98-115.
https://doi.org/10.4236/wjet.2018.62B009

Received: April 11, 2018
Accepted: May 19, 2018
Published: May 22, 2018

Abstract

Accelerated aging and eutrophication of water resources is a world menace attributed to influx of nutrient rich sediment from its catchment, resulting in poor water quality and shifts in ecological dynamism. Nyanza Gulf is a paramount source of livelihood, portable water, and of service to the rich biodiversity making it indispensable to the entire Lake Victoria watershed ecosystem. This water resource has been deteriorating over the past decades as a consequent of anthropogenic socio-economical activities. This has effectuated an increase in phytoplankton and hydrophyte colonies. The objective of this study was to track the quality and quantity of sediment inundation into the gulf considering the catchment micro-basins processes and influence of human socio-economical activities. Using Quantum Geographic Information System (QGIS) as an interface to Soil and Water Assessment Tool (SWAT) with input of satellite digital elevation model (DEM), local rainfall, soil and land use data sets were utilized to determine the daily variability in sediment and nutrient loads from five major river basins. The SWAT model was successfully calibrated, and the performance validated with observed hydrological and water quality data. The model achieved identification of seasonal water quality budget filling in knowledge gaps about the catchment. River Nyando, Sondu-Miriu, Awach-Kibuon, Awach-Tende and Kibos discharge sediment loads of 3.91, 1.6, 1.18, 1.06 and 0.78 tons/ha respectively. Total suspended solids (TSS) concentration of up to 578mg/L on average daily is discharged by River Awach-Kibuon. This was associated with intense agricultural activities (>54% of the entire basin) on steep slopes (average 12.97) with Acrisols (15%of the basin) soils that is prone erosion. Poorly managed range-bush land that covers about 10% of this basin also contribute significantly to the TSS yield. River Kibos discharge least TSS concentration of 144.43 mg/L in comparison with other rivers mainly due gentle slope falling into a plain, low erodible Cambisols (covers 20% of the basin) and Ferralsols (10%) as well as Nanga forest effect at its exit. River Awach-Tende and Awach-Kibuon on average discharge 1.67 mg/L and 1.58 mg/L respectively of Total Nitrogen (TN) daily. This was linked to intensive farming on poorly managed dominant Phaeozems and Acrisols that are susceptible to leaching. River Sondu-Miriu is the least contributor with a daily average of 1.1101 mg/L dominated with low leached Nitisols. The bay receives highest Total Phosphorus (TP) loads from River Nyando with daily average of 0.3699 mg/L alluded to high biomass production in the basin and Sondu-Miriu least with 0.0288 mg/L. The fluctuation of nutrients and sediment fluxes correlated positively with rainfall events. The long rainfall season with average regular storm events in March to June yield highest monthly loads as compared to short rainfall season (September to November) with isolated intense storm events over a shorter time. The study depicted poor water quality discharged into the gulf throughout the year by the 5 major basins to be above average of conventional ecological healthy basins.

Keywords

Micro-Basin, Spatial, Sediment, Nutrient, SWAT, Anthropogenic

1. Introduction

Nyanza (also known as Winam or Kavirondo) gulf forms a cardinal part of larger Lake Victoria basin ecosystem that has been degrading at an alarming rate. Signs of degradation of its water resource were first visible in early 1980s [1]. Consequences of this eutrophication have been seasonal occurrence of algal bloom and intensive proliferation of water hyacinths which dates to 1990 [2] [3]. The weed colonies have a huge threat to the productivity of the gulf negatively affecting socioeconomic wellbeing of the population that depends on it for livelihood. Rapid urbanization along the lake shores and poor land use management under intensive farming have negatively impacted the gulf. Influx of nutrient rich sediment into the lake has increased from both diffuse and point-sources exerting considerable negative effect particularly on the near-shore regions [4] [5]. Between January and March 2004, the persistence of massive phytoplankton blooms in the Nyanza Gulf resulted in a temporary shutdown of the drinking water supply from the lake [6].

Nyanza Gulf has an area of 1400 km^2, mean depth 7 m, max. depth 30 m and a 550 km shoreline that is located entirely in Kenya (**Figure 1**) on the northeast of Lake Victoria [7]. The gulf is river-fed embayment by multiple rivers largely arising from the Kenya highlands on East and South East. The water inputs from the catchment combined with the shallow depths of the gulf yield a freshwater renewal time of 3 years in comparison with the 100 years for the larger Lake Victoria [8]. Shallow mean depth, strong winds and a bottleneck opening to the

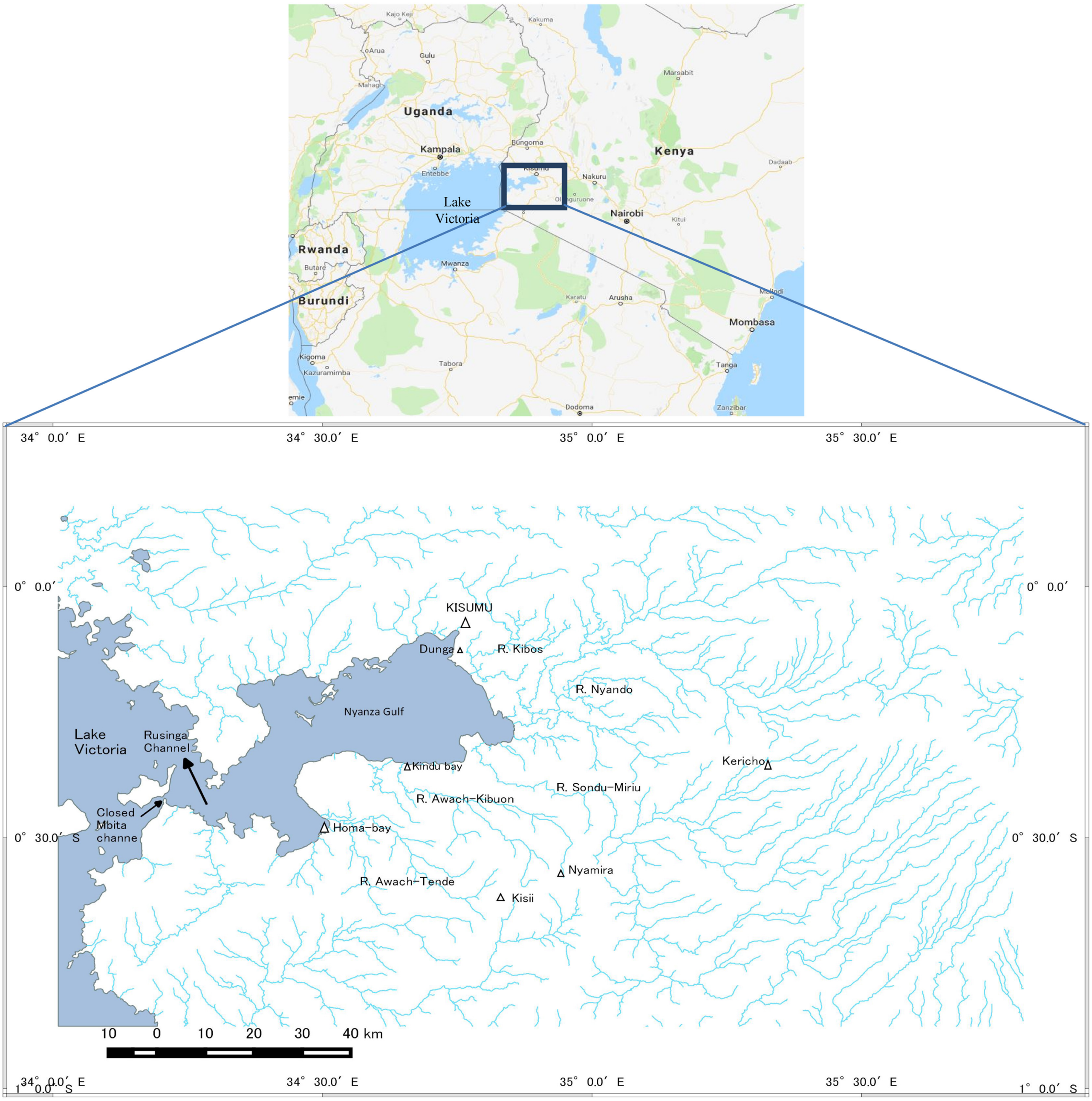

Figure 1. Nyanza Gulf catchment information.

larger lake governs hydrodynamics in the gulf. The nutrient dynamics of Nyanza Gulf are driven by strong currents, eroding the apatite-rich residual rock and remobilizing the buried/store nutrients back into the water column. This result into a eutrophic gulf throughout the annual cycle, with a probable algal peak observed between June and August during complete perturbation [9]. The gulf is semi-enclosed restricting mixing with larger lake consequently responsive to fluvial inputs from its own watershed [10]. An increase in sedimentation and nutrient content in the gulf due to land degradation, surface run-off and soil erosion has been observed throughout the past decades, while a proposed increase of atmospheric deposition remains disputed [3].

Spatial temporal estimation of sediment and nutrient loads is of crucial interest for a good assessment of water pollution of such vital water resource in identification and mitigation of water quality and biodiversity [11]. Assessing runoff, soil and nutrient loss in a catchment is important for investigation of soil erosion hazards, aquatic shifts and for determining suitable land uses and soil conservation measures. Such information would be key in optimizing benefit from the use of the land whilst minimizing the negative impacts of land degradation. Physical based SWAT model [12] was developed for analyzing effects of naturogenic process and anthropogenic activities on a water resource. The tool quantifies the sediment loss in space and time basing on runoff, soil characteristics, land use and slope to predict water quality, sediment yield and pollution loading in the catchment. SWAT model can be taken as a potential tool for simulation of the hydrology of gauged/ungauged watershed in mountainous areas to address the issues related to water quality and evaluate best watershed management practices [13]. Spatial temporal quantification of the water quality parameters in Nyanza bay was studied by application of this promising physical based distributed SWAT model interfaced in QGIS [12] [14] [15]. The objective was to determine daily discharge of the five (5) major rivers, sediments and nutrients loading to fill in the knowledge gap of understanding the influence of major basins on the water quality in Nyanza gulf (Calibration period 2005-2014 and Validation period 2014-2015).

2. Methodology

2.1. Study Area

Nyanza gulf is in Western Kenya whose watershed lies between 0.25N - 1.00S latitudes and 34.0E - 36.0E longitudes as shown in **Figure 1**. It covers an approximate total drainage area of 12,300 km^2. The Rivers originate from East and south East highlands. They flow from up to 3005 m elevation to the outlet at the lake which is 1134 m below East-west and South East to North direction. The average areal annual rainfall distribution of up to 1400 mm on the Eastern side-1600 mm on South Eastern-South and the annual maximum and minimum temperature of the watershed area is about 30˚C and 8˚C, respectively. The catchment experience equatorial climate with two rainfall seasons; March to June (long rain season), September to November (short rain season), followed by a relatively dry season in December to February and July to August respectively. Land preparation mostly starts in January to February and cereal cropping done with onset of long rainfall seasonal apart from the plains in Nyando and Kibos River basin that benefit largely from established irrigation scheme. Land is also prepared in August-September for short rain season cereal/vegetable crops. The catchment is considerably covered with Nitisols, Fluvisols and Cambisols that are stable to erosion and leaching under minimum management. Awach-Tende and Awach-Kibuon basins are an exception dominated with phaeozems that are susceptible to leaching and Acrisols that are prone to erosion. The fishing industry and favorable weather condition have catalyzed rapid urbanization extending to the shore of the lake and uncontrolled farming practices encroaching riparian zones.

2.2. Data Acquisition

The region is covered with three weather stations but only two (2) at Kisii (−00667, +034783) and Kisumu Airport (−00100, +034750) were utilized. Kericho (−00367, +035350) station had a lot of inconsistence data. Daily climate data (rainfall, maximum and minimum temperatures, relative humidity and solar radiation was used as model input and monthly data for the Weather Generator (WGN) Parameters. There are no hydrometric stations in this region. Local detailed Soil data map derived from KENSOTER for studies of carbon stocks [16] was used. The soil data (**Figure 2**) contains detailed information of the 2-soil depth: top soil (0 - 30 cm) and subsoil (30 - 100 cm). Land use statistics was obtained from World resource institute-WRI (**Figure 3**). It contains different classes; Agricultural land use (cereals, sugar, paddy rice/sugar under irrigation, perennial crops like tea), forests (Protected forest, evergreen, deciduous and mixed), Wetland and urban residential. Agriculture is dominant in the region covering more than 60% of the total land use. Crop management was scheduled as; long season I (January-Land preparation, March-planting and fertilization, August-harvesting) and Short Season II (September-land preparation, October-planting and fertilization, December harvesting). Digital Elevation model

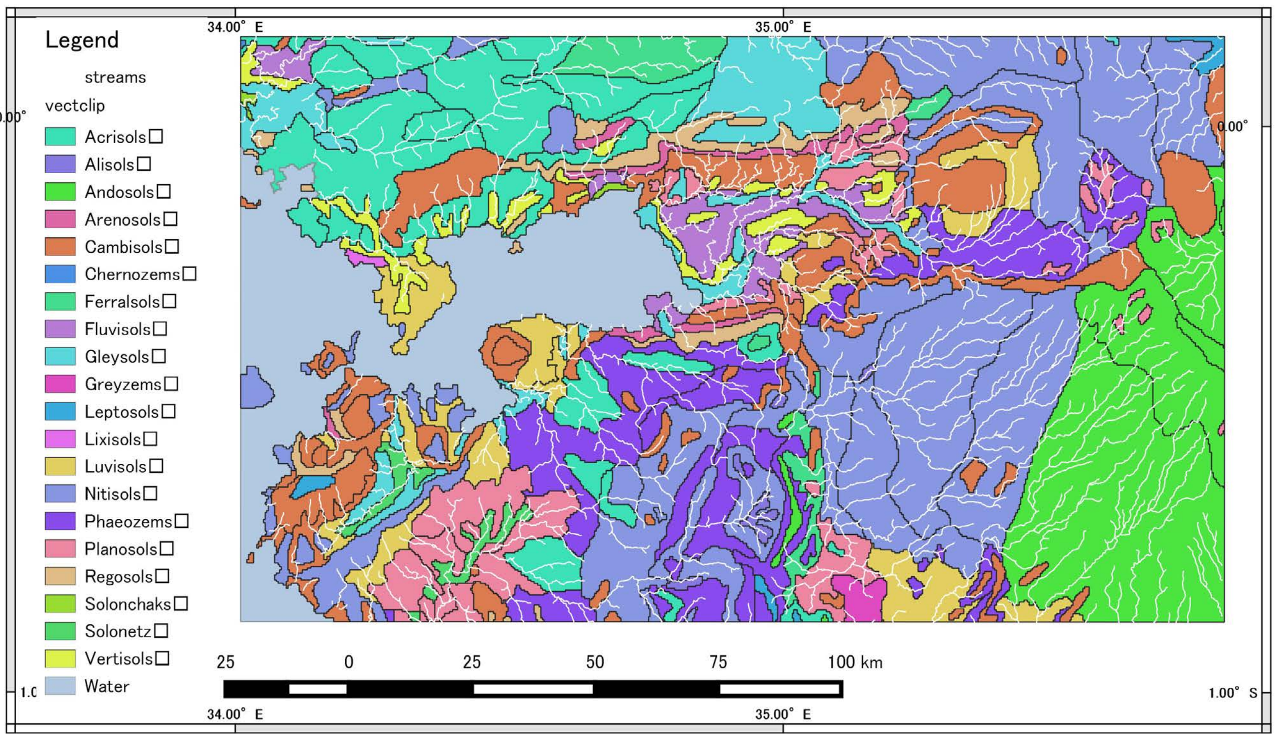

Figure 2. Local detailed Soil data map derived from KENSOTER.

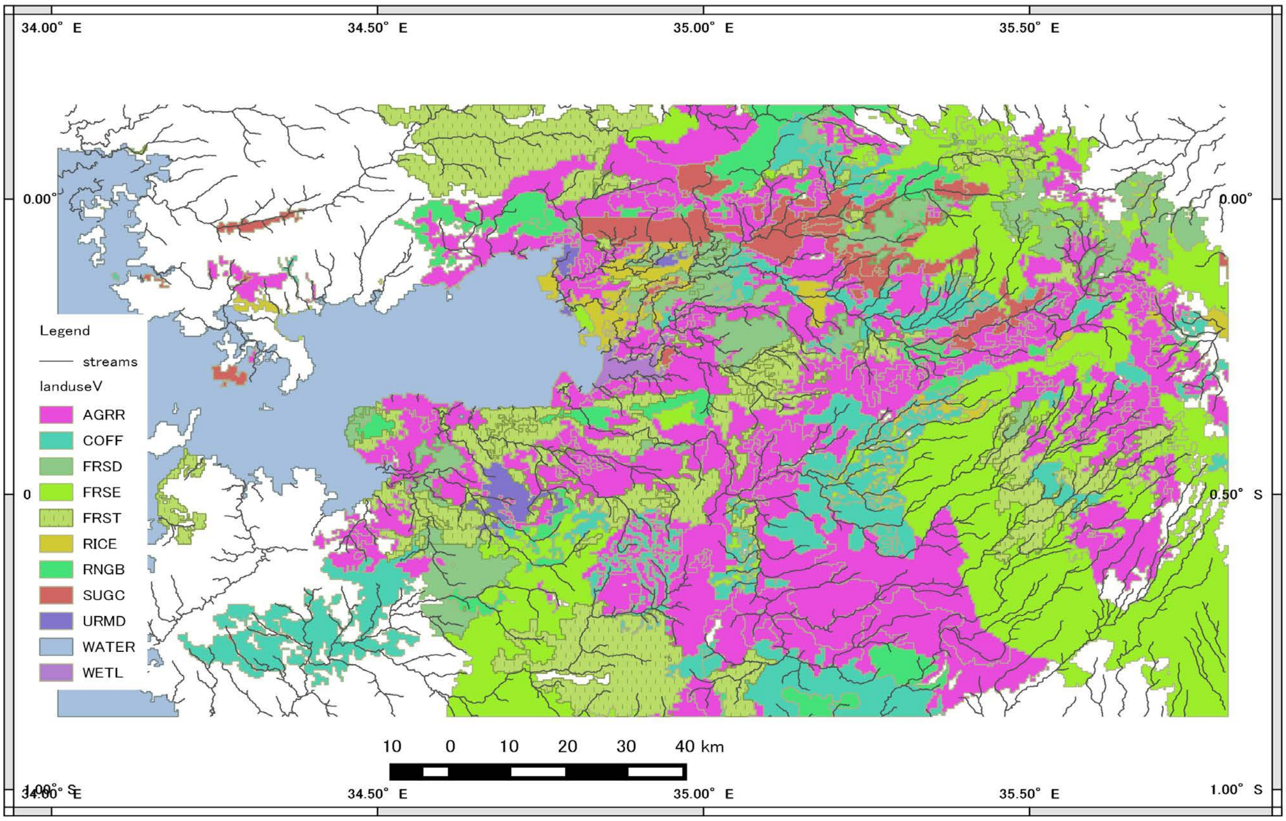

Figure 3. Detailed map of Land uses in the modeled river basins (COFF = TEA).

(DEM) was derived from Shuttle Radar Topography Mission (SRTM) at 30 m resolution.

2.3. SWAT Model

SWAT is a river or watershed, spatial model developed to predict the impact of land management practices on water, sediment hydrodynamics, and agricultural chemical yields in large complex watersheds with varying soils, land use, management conditions and weather conditions. The model consists of the following main components: Weather, hydrology, plant growth, nutrients (Nitrogen and Phosphorous based), pesticide, bacteria and land management-SWAT version 2012 [17]. The Model is run in QGIS interface enabling integration of spatial distributed characteristics of the watershed into calculations.

This study focuses mainly on hydrologic component coupled with effects of land use management to determine sediment and nutrient concentration in water of specific rivers discharging into the Gulf. In SWAT, watershed is portioned into sub-basins with a given threshold using DEM, which is further subdivided into Hydrological Response Units (HRUs) with homogeneous soil type, land use and slope [18]. HRUs form basis for water balance calculation utilizing nearest weather station data. Watershed hydrology is calculated in two separate components: land phase and routing phase. The land phase determines the amount of water (surface and base flow), sediment, nutrient and pesticide loading into the route channel in each sub-basin [19]. These hydrologic processes are based on infiltration, percolation, evaporation, plant uptake, lateral flows and groundwater flows including snowfall and snowmelt [14]. Sediment yield is estimated based on Modified Universal Soil Loss Equation (MUSLE) which factors in the surface runoff volume, the peak runoff rate, the area of the HRU, the Universal Soil Loss Equation (USLE) soil erodibility factor, the USLE cover and management factor, the USLE support practice factor, the USLE topographic factor, and a coarse fragment factor. On other hand routing phase defines movement of water, sediments and nutrient loads from each channel network to the outlet. Channel transmission losses, evaporation, return flow etc., are adjusted for estimation of outflow from a channel which is predicted by the Muskingum method [20]. The hydrological balance is simulated by SWAT model according to the equation below [21].

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

where: SW_t is the final soil water content (mm); SW_0 is the initial soil water content on day i (mm); R_{day} is the amount of precipitation on day i (mm); Q_{surf} is the amount of surface runoff on day i (mm); E_a is the amount of evapotranspiration (ET) on day i (mm); W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm); Q_{gw} is the amount of return flow on day i (mm).

2.4. Calibration and Uncertainty Analysis

SWAT-Calibration Uncertainty Programs version 2012 (SWAT-CUP) was utilized for Calibration/validation, uncertainty and sensitivity analysis of the model. Investigation of sensitivity and uncertainty in stream flow and sediment concentration was done by Sequential Uncertainty fitting (SUFI-2) algorithm. Several objective functions were used to gauge model performance by: coefficient of linear correlation R^2, Nash-Sutcliffe Efficiency (NSE) and the coefficient of percentage biasness (PBIAS). NSE (Equation (2)) is a normalized statistic that determines the relative magnitude of the residual variance in comparison to the measured data variance indicating how well the plot of observed fits the simulated data; 1:1 [22] [23]. NSE = 1 is the optimal value, values between 0.0 and 1.0 regarded as acceptable levels of performance of the model, whereas values ≤ 0.0 indicating that mean observed value is a better predictor than simulated value (unacceptable performance of the model).

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n} (X_i^{obs} - X_i^{sim})^2}{\sum_{i=1}^{n} (X_i^{obs} - X^{avg})^2} \quad (2)$$

where X_i^{obs} is the ith observation for the constituent being evaluated, X_i^{sim} is the ith simulated value for the constituent being evaluated, X^{avg} is the average/mean of observed data for the constituent being evaluated, and n is the total number of observations.

PBIAS (Equation (3)) is a deviation term used to evaluate the accumulation of differences in streamflow/sediment concentration between simulated and measured data for the period of analysis. PBIAS = 0 is optimal indicating unbiasedness and larger value show more variance between simulated value and observed information. Positive value indicates model overestimation bias, and negative value indicates model underestimation bias.

$$\text{PBIAS} = \frac{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right)*100}{\sum_{i=1}^{n}\left(X_i^{obs}\right)} \tag{3}$$

In this study, model performance for a monthly time and specific day data was judged as satisfactory if NSE > 0.50 and PBIAS = ±25% and graphical analysis that reveals a good agreement between predicted and measured hydrographs (R^2 = 0.6).

3. Results and Discussion

The capability of a hydrological model to adequately simulate streamflow, sediment and nutrient concentration rely on the precise calibration of its parameters as well as quality input of baseline data sets [24]. Model calibration and validation are indispensable for simulation process in estimating characteristics of a phenomenon that would rather be either impossible or uneconomical for actual study and analysis.

3.1. Model Calibration

The calibration of a conceptual model necessitates setting the input variables to correspond optimally in mimicking measured observations thus representing the reality on of studied phenomenon. It is deliberately carried out with the purpose of defining the values or desirable ranges of the model parameters that depend broadly on the nature and specific properties of the study area. Preliminary analyses, subsequent simulation of databases combination of DEM, precipitation, crop and soil, yielded a fair default performance (NSE = 0.0922) before calibration. The impact of soil data set was most significant in the modeling of the basins for discharge and water quality. Calibration of SWAT model in the Nyanza through semi-automated approach (SUFI-2) method was performed over a period of 9 years by comparing the mean monthly measured flow rates (stream flow estimated done by floating method) and sediment concentration to simulated rates. This was performed to the 5 study rivers with monthly mean estimates of the flow rates and water quality regarding TSS concentration from 2005-2014. The following represents one of the major basins (**Figure 4**) in Gulf's catchment during calibration and validation period basing on monthly discharge and concentration of sediments loads.

These figures exhibit successful model simulation of the river flow and sediment concentration variations. The model meets the performance assessment criteria as recommended for a monthly time step [23]. The calibration of individual river basins attained good model performance for flow rates with a

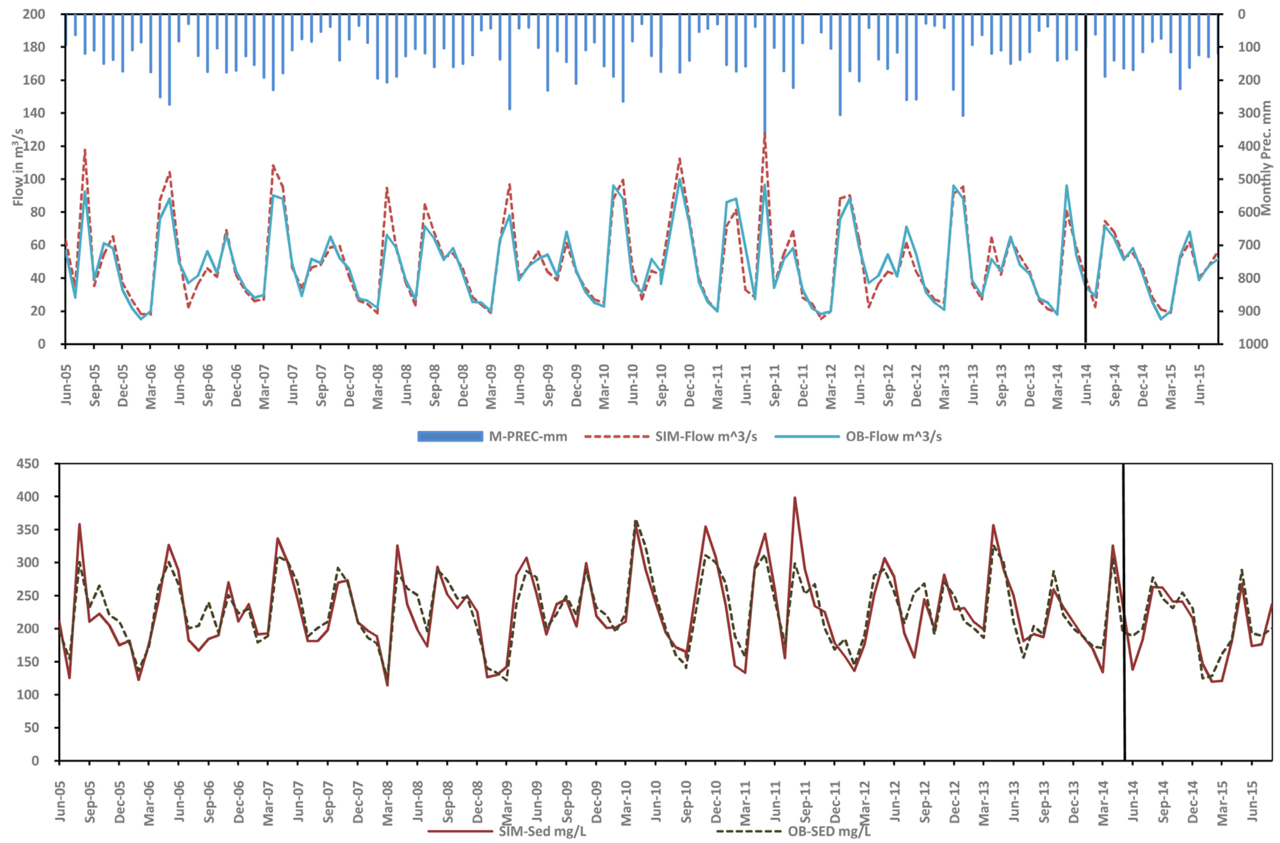

Figure 4. River Sondu simulated and observed monthly mean flow discharge and Sediment concentration.

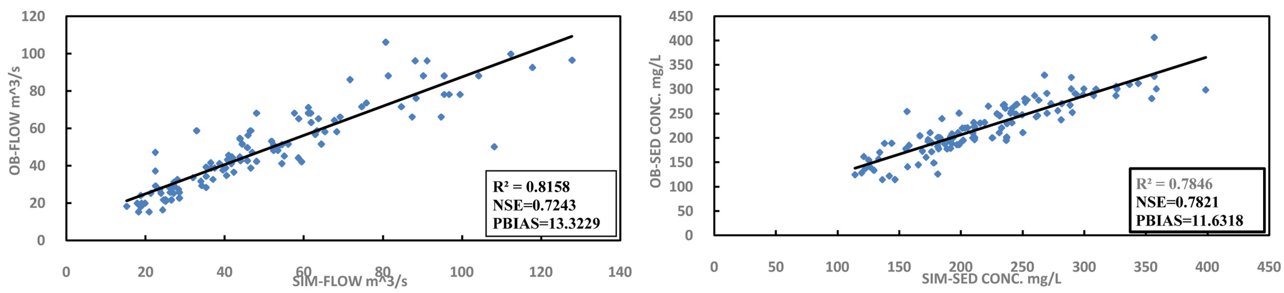

Figure 5. Scatter plot of monthly stream flow and Sediment concentration for calibration period (2005-2014).

coefficient of NSE of the order of 0.69 to 0.81 and PBIAS of the order of 9.52 to 21.45. The performance of the model for sediment concentration was within adoptable range with NSE of 0.64 to 0.79 and PBIAS of 9.09 to 19.63. The model of the largest contributing basin, Sondu River, had coefficient of NSE 0.72, R^2 of 0.82 and PBIAS of 13.32 basing on monthly mean flow rates. The sediment concentration of the same basin has a coefficient NSE of 0.78, R^2 of 0.79 and PBIAS of 11.63 as shown in **Figure 5**. Calibration decreases the uncertainties associated with modelling and provides better estimates of the studied seasonal water qualities in the catchment [25]. Due to lack of consistence in either daily or monthly data available on the concentration of nutrients in these basins, manual calibration was in cooperated to adequately estimate the daily water quality flowing into the Gulf.

3.2. Model Validation

Validity of a model is gauged on how comparable it is to the actual situation of the study area basing on the series observations done over a defined period. Any calibration procedure of a model should be put necessarily to the control of testing its reliability and performance. Validation of SWAT model of each basin was performed from 2014-2015 (1 year) over the period of calibration (2005-2014) by comparing monthly mean flow rates, specific day sediment and nutrient concentration to measured data (e.g. **Figure 6**). Sondu Miriu basin. The limnology data was obtained from selective grab samples at the mouth of the rivers and water quality analysis done on specific days during Lake Victoria Comprehensive Research for Development (LAVICORD PROJECT, 2015).

Considering daily simulated results of the model in comparison with the observations, all the modeled river basins showed high performance as indicated below (**Table 1**). Despite of few observed water quality data for Awach-Tende river, the model response was quite successful indicating both equivalence and trends in the changes (**Figure 7** and **Table 2**). Its probability of biasness was within good range though higher compared to the other models.

The results indicate high inflow of sediments with mean of 578 mg/L, 526 mg/L, 384 mg/L,198 mg/L, and 143 mg/L from Awach-Kibuon, Awach-Tende, Nyando, Sondu Miriu and Kibos respectively as (**Figure 8**). The highest loads of sediment into the gulf within the study period was found to be in April-May

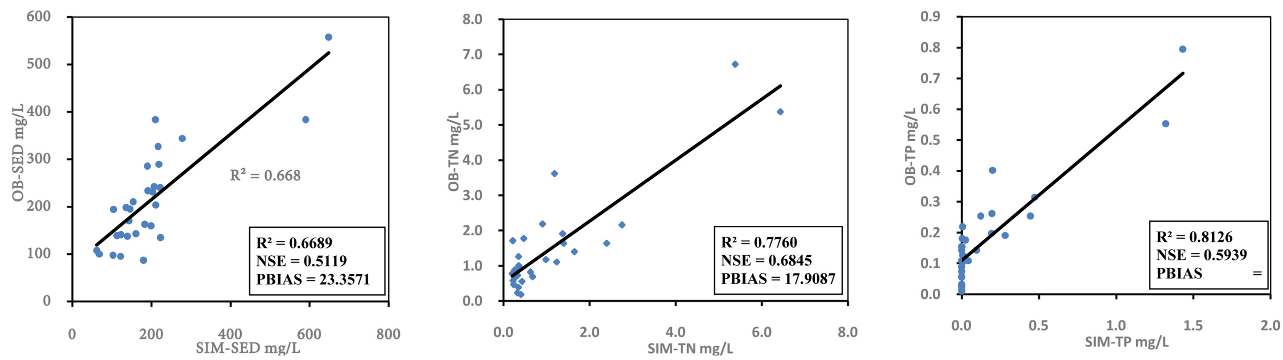

Figure 6. Sondu-Miriu River: scatter plot of specific day sediment and nutrient concentration for validation period (2014-2015).

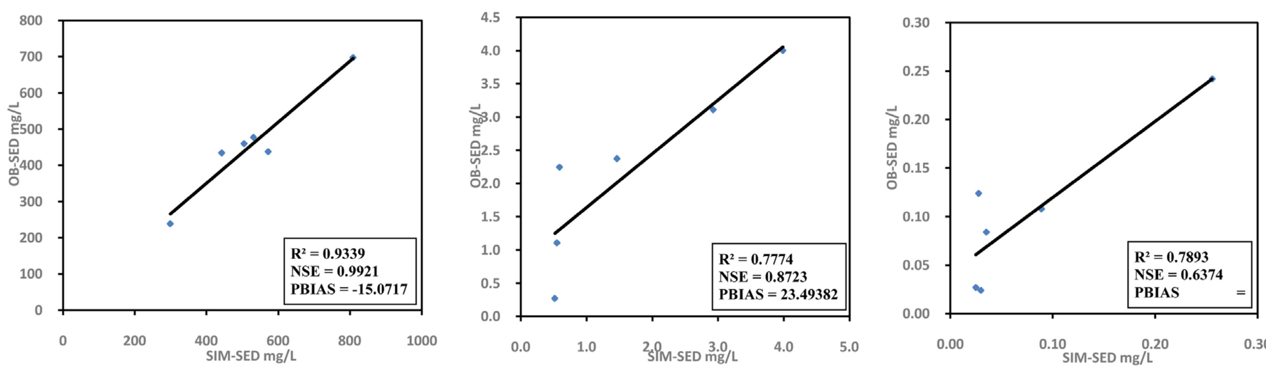

Figure 7. Awach-Tende River: scatter plot of specific day sediment and nutrient concentration for validation period (2014-2015).

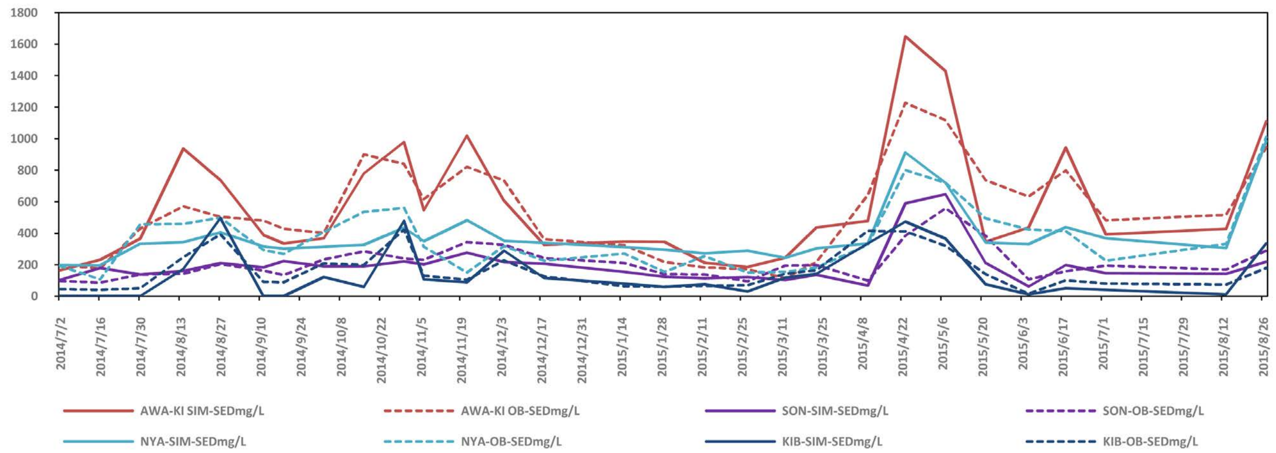

Figure 8. Simulated and observed specific day seasonal sediment loads[1].

Table 1. Model performance statistics for the 5-major river Catchment of Nyanza Gulf.

Time step description	Criterion	Calibration (2005-2014) Awach-Kibuon	Sondu Miriu	Nyando	Kibos	Awach-Tende	Validation 2014-2015 (LAVICORD, 2015) Awach-Kibuon	Sondu Miriu	Nyando	Kibos	Awach-Tende
Monthly River Discharge	R^2	0.7616	0.8158	0.7026	0.7528	0.7123	0.7826	0.8591	0.6906	0.7619	0.7336
	NSE	0.7334	0.7243	0.6905	0.6971	0.7268	0.8113	0.7324	0.7195	0.7213	0.7988
	PBIAS (%)	18.2687	13.3229	9.5242	21.4457	−10.2543	11.3781	15.3546	11.6472	17.3465	−8.5317
Monthly Sediment Concentration	R^2	0.7894	0.7846	0.684	0.7455	0.7773	0.7966	0.8133	0.7281	0.7568	0.8614
	NSE	0. 7285	0.7821	0.7149	0.6983	−0.6258	0. 6922	0.7212	0.7849	0.7268	0.5415
	PBIAS (%)	14.3382	11.631	−10.0905	−8.3829	12.7829	12.3520	19.631	−9.0905	−9.9540	6.1345
Lack monthly mean data for Nutrient concentration calibration was based on isolated studies (Lake Victoria Environmental Management Project PHASE I, 1995 and PHASE II, 2008)							**Validation 2014-2015 (LAVICORD, 2015)**				
Specific sampled Day Sediment Concentration	R^2						0.7840	0.6689	0.7093	0.8554	0.9339
	NSE						0.6149	0.5119	0.7027	0.7058	0.9921
	PBIAS (%)						−16.0905	23.3571	−24.3322	11.4173	−15.0717
Specific sampled Day Total Nitrogen Concentration	R^2						0.7554	0.7760	0.8126	0.8618	0.7774
	NSE						0.6810	0.6845	0.7046	0.6596	0.8723
	PBIAS (%)						18.0824	17.9087	13.6827	19.9562	23.49382
Specific sampled Day Total Phosphorous Concentration	R^2						0.7847	0.8126	0.7373	0.7100	0.7893
	NSE						0.7319	0.5939	0.6258	0.7642	0.6374
	PBIAS (%)						−4.1887	7.2427	−6.8782	15.7204	24.0044

during long rains followed by October-November during short rain season.

Total nitrogen and Phosphorous Loads were substantially high in April – May as modeled in **Figure 9** & **Figure 10** attributed to high precipitation and agricultural activities within the entire catchment.

[1]AWA-KI-River Awach-Kibuon, SO-River Sondu Miriu, NYA-River Nyando, KIB-River Kibos, SM-Simulated and OB-Observed.

Table 2. Awach-Tende simulated and observed specific day seasonal sediment and nutrients loads.

DATES	SIM-SED mg/L	OB-SED mg/L	SM-TN mg/L	OB-TN mg/L	SIM-TP mg/L	OB-TP mg/L
6/26/2014	299.231	338.541	0.518	0.271	0.028	0.124
9/1/2014	808.648	697.756	2.926	3.111	0.256	0.242
11/4/2014	572.284	437.750	1.463	2.375	0.089	0.108
1/13/2015	442.664	434.254	0.590	2.247	0.035	0.084
3/27/2015	504.941	459.750	3.985	4.002	0.025	0.027
6/25/2015	531.204	477.170	0.550	1.108	0.030	0.024

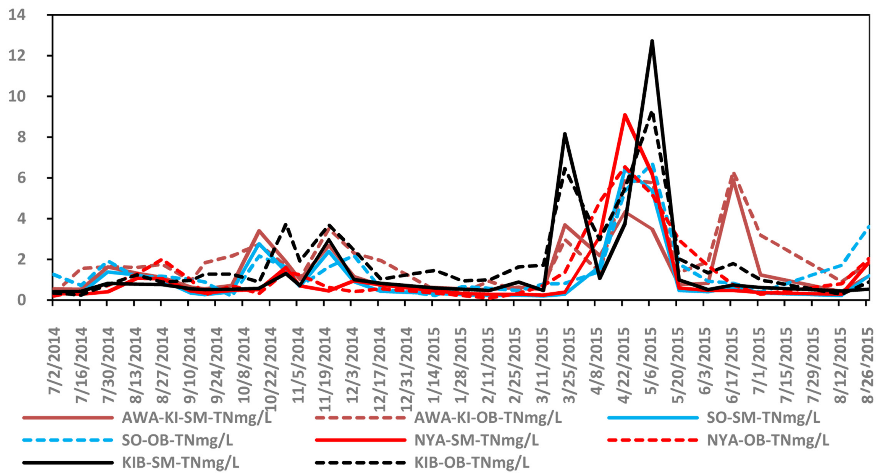

Figure 9. Simulated and observed specific day seasonal total nitrogen loads.

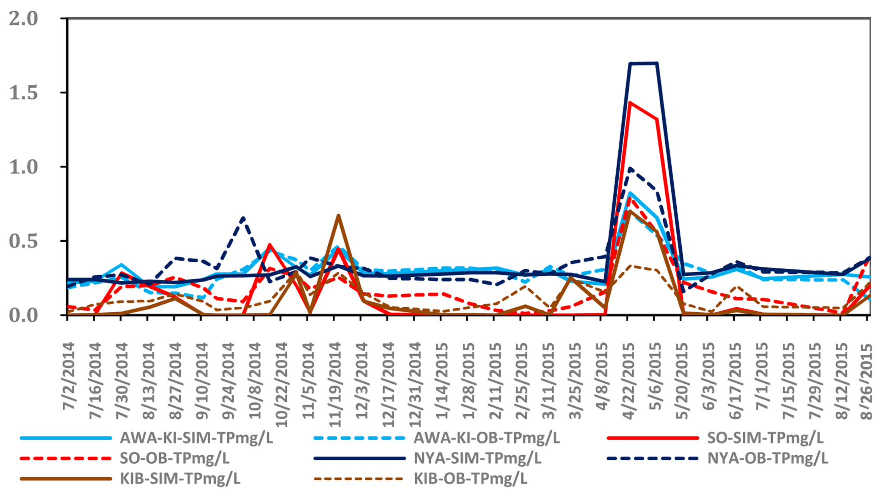

Figure 10. Simulated and observed specific day seasonal total Phosphorous loads.

3.3. Uncertainty Analysis

In modeling river discharge, sensitive values in each basin were evaluated in parameter estimation process. **Table 3** shows optimum values determined by semi-automated SUFFI-2 imbedded in SWAT-CUP for calibration of Stream

Table 3. Summary of the SWAT model Parameters calibrated on the major river basins in Nyanza gulf catchment.

Parameter	Description	Calibration Range	Fitted value [Range]	*p*-Value
CN2	SCS Run off curve number	−0.5 - 0.5	0.155 [−0.199; 0.252]	0.001
OV-N	Manning's' "n" value for overland flow	0.01 - 28	21.23 [3.061; 29.915]	0.345
SLSUBBSN	Average slope basin	10 - 110	49.808 [12.677; 49.924]	0.362
ALPHA_BF	Base flow alpha factor	−0.2 - 0.1		0.679
ESCO	Soil evaporation compensation factor	0.01 - 1	0.898 [0.768; 0.991]	0.714
SOL_AWS	Available water content of the soil	−0.35 - 0.25	0.120 [−0.0169; 0.197]	0.016
SOL_BD	Moist bulky density	0.110 - 0.139	0.116 [0.112; 0.195]	0.426
GW_DELAY	Ground water Delay	0.0 - 100	34.938 [0.487; 49.823]	0.37
SURLAG	Surface Runoff lag time	0.05 - 30	20.219 [0.076; 23.878]	0.831
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur	0 - 500	173.709 [0.636; 499.845]	0.516
GW-REVAP	Groundwater revap coefficient	−0.02 - 0.2	0.190 [0.021; 0.199	0.522
SOL-K	Saturated Hydraulic conductivity	0.17 - 0.65	0.183 [0.18; 0.265]	0.05
USLE_K	Saturated hydraulic conductivity (mm/h)	−0.173 - 0.59	0.209 [0.08; 0.227]	0.366
USLE_P	USLE equation support factor	0.35 – 0.76	0.456 [0.384; 0.6898]	0.021
ADJ_PKR	Peak Adjustment factor (sediment routing in sub-basin)	0.537 - 1.167	0.647[0.622;1.134]	0.364
CH_K2	Effective hydraulic conductivity in the main channel	−0.010 - 239.609	17.961 [16.98; 114.313]	0.012
CH_N2	Manning's "n" value for the main channel	0.027 - 0.091	0.051 [0.026; 0.059]	0.286
SPCON	Linear parameter for max am sediment that can be re-entrained	0.005 - 0.011	0.007 [0.00115 - 0.0023]	0.483
SPEXP	Exponent parameter for sediment re-entrained	0.753 - 1.151	1.001 [0.825 - 1.09]	0.064
NPERCO	Nitrate percolation Coefficient	0.265 - 0.489	0.269 [0.265; 0.385]	0.022
PHOSKD	Phosphorus soil partitioning coefficient m^3/Mg	102 - 200	178 [166; 183]	0.324
PPERCO	Phosphorous percolation Coefficient $10m^3/Mg$	10.237 - 14.368	11.67 [10.953; 14.335]	0.027

flow, Sediment and nutrient loads of the 5 basins. Based on the 22 selected SWAT parameters, globalized sensitive analysis was used for identifying sensitive and important model parameters while holding ALPHA_BF at fixed value. Several iterations and simulations of each basin independently till acceptable results were realized. Eight (8) parameters *i.e.* CN2, CH_K2, SOL_AWC, USEL_P, NPERCO, PPERCO, SOL_K and SPEXP were found to be the most sensitive for the gulf catchment in entirety. The performance of the SWAT model for the 5 basins was good during calibration with NSE > 70, thus consistency in the data sets utilized.

3.4. Sediments and Nutrient Yield

3.4.1. Discharge

The model results demonstrate responsiveness between the precipitation and river discharge with similar pattern over the entire study period. **Table 4** indicates an average total stream discharge of 87.629 m^3/s water from the five major river basins flow into Nyanza gulf constituting over 94.5%. Relatively steep topography and high rainfall in Sondu Miriu explains the significant high discharge when compared to Nyando that is largely a plateau.

3.4.2. Spatial Sediment and Nutrients Yield

SWAT model simulates loss of sediment transport in a catchment basing on MUSLE equation relating runoff, soil characteristics, land use, topography and land management practices. Quantity of sediments eroded and conveyed to the hydrographic network at each spatial unit can be adequately estimated with SWAT model [21]. Part of estimated soil eroded particles, flow into the stream leading to increase in water turbidity. Seasonal sediment concentration (**Figure 11**) in water discharged to Gulf was temporal attributed to changes precipitation and localized factors in individual HRUs.

Table 4. Annual rainfall and mean river discharge.

Name of the river	Annual rainfall (mm)	OB-Mean discharge (m^3/s)	SIM-Mean river discharge (m^3/s)	Size of the Catchment (km^2)
Sondu-Miriu	1573	44.92	44.240	3448.542
Nyando	1327	20.37	20.237	3597.808
Awach-Tende	1573	10.54	11.366	686.426
Awach-Kibuon	1573	8.18	8.464	549.149
Kibos	1327	4.67	4.322	560.745

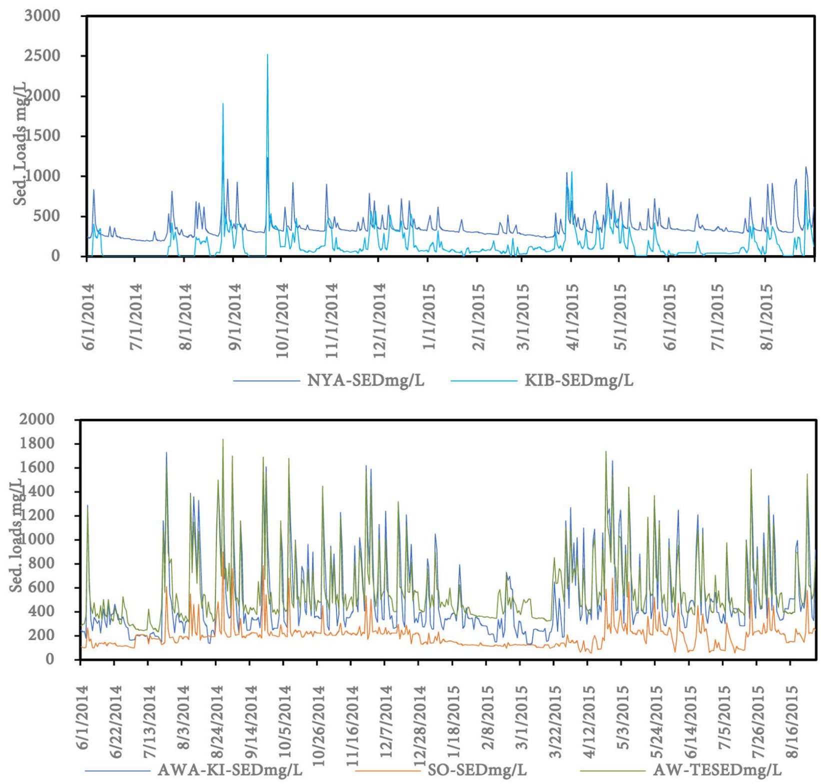

Figure 11. Sediment loads into the Nyanza Gulf.

Spatially, Agricultural activities on steep slopes e.g. cereal and tea farming in Kisii and Nyamira resulted into substantial sediments loss in the Awach-Kibuon basin (**Figure 12** basins 6, 16, 11, 15 and 18). Phaeozems (58%), Nitisols (25%) and Acrisols (15%) are the most abundant soil in this basin. Acrisols are easily eroded while Poor land management Phaeozems and Nitisols on steep slopes showed proneness to erosion as indicated by high sediments yield from the range-bush land use (Awach-Kibuon basins 21 & 13) source of sediments. Water quality at the mouth of Kibos River had less sediment concentration that was attributed to its low average slope and riparian effect of the forest at Nanga area.

Nutrient concentrations in water resources are indispensable of sediment transport [26]. Nyando River showed notably high phosphorous concentrations; majorly organic phosphorus probably from the forest and resultant biomass in the catchment (sugar, rice and other cereals refuse). Substantial nitrogen concentration from Awach-Tende and Awach-Kibuon (dominated by Phaeozems and Acrisols that are intensively leached in wet seasons) can be linked to intense use of nitrogen fertilizers in Kisii highlands for cereal and Tea farming. Influence of Urban activities led to the high Nitrogen concentration in the Kibos basin. Discharge from the 5-basins showed poor water quality throughout the year and high concentration of nutrients (**Table 5**).

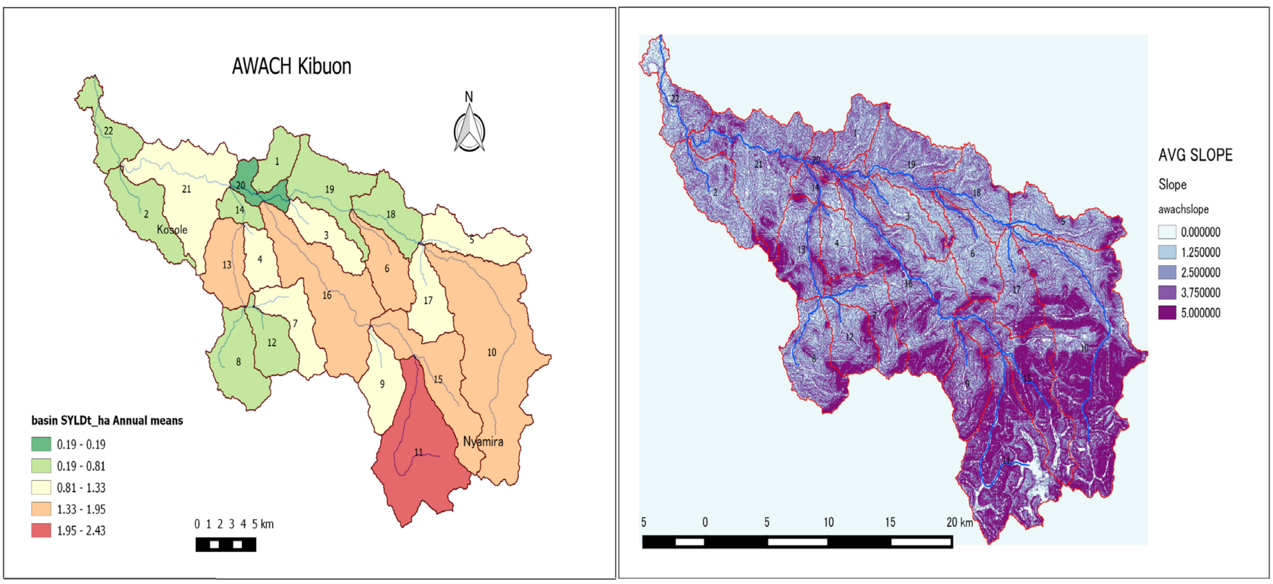

Figure 12. Spatial sediment yield in Awach-Kibuon River and average slope influence.

Table 5. Simulated water quality and sediment loads.

RIVER	AREA ha	TSS mg/L	TN mg/L	TP mg/L	SED LOAD ton/ha/yr
Awach-Kibuon	54,914.9	577.59	1.5431	0.3089	1.08
Awach-Tende	68,642.6	526.50	1.6700	0.0823	0.96
Nyando	359,780.8	384.43	1.1687	0.3699	4.07
Kibos	56,074.5	143.02	1.5561	0.1070	0.8
Sondu Miriu	344,854.2	198.14	1.1101	1.1674	1.5

4. Conclusion

Spatial-temporal SWAT model used in this study was successfully calibrated and validated for the 5 major basins generating adequate results on seasonal variation in river water quality. Spatial approach of these models integrates hydrology, vegetation, erosion and nutrient dynamics to obtain hydrological functioning of each mesoscale sub-basins units process, production and transfer of sediments and nutrients. The model herein plays a vital role in assessing different human activities in the catchment and thereafter effects on water resource with respect to time and space. For instance, intense farming on the Kisii highlands dominated with highly erosion prone Acrisols, yield highest annual sediments of up to 2.4 tons/ha while Plains dominated cambisoils resulted to lowest annual sediment yield of up to 0.089 tons/ha. Cereal, Tea farming and poor maintained range-bushland use were main contributors to poor water quality in the five-major rivers. Effect of poor urban management and disposal can be linked to high Nitrogen concentrations that couldn't be precisely modeled in Kibos River basin. The study depicted poor water quality discharged into the gulf by the 5 major basins to be above average of conventional ecological healthy basins (TP of 0.01 - 0.04 mg/L, TN of 0.1 - 0.5 mg/L, TSS of 2 - 5 mg/L). The model applicability in the five river basins was adequate for performance of monthly time and daily step satisfied NSE > 0.50, PBIAS = ±25% and graphical analysis that revealed a good agreement between predicted and measured hydrographs. Thus, can be used to evaluate impact of natural and anthropogenic activities in the catchment on water quality discharge. Detailed spatial-temporal information can be utilized in locating issues and applying mitigation for soil loss consequently improving quality of water discharged in the Gulf. Recommendation for further point pollution, offshore activities and ecohydrological studies within the gulf need to be carried out basing on daily imports of the materials into gulf to determine effects of each part of the catchment on deterioration of water quality implicated by appearance of seasonal algal bloom.

Acknowledgements

The authors wish to thank JICA (Japanese International Cooperation Agency) for their support through ABE-Initiative Scholarship and Nagasaki University fraternity for provision of facilities and resource to make this study possible.

Conflicts of Interest

The author declares no conflict of interest.

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