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Simulation of Sediment Concentration, Nitrogen and Phosphorus Loads: Case Study of Landzu River Watershed, Nigeria

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Abstract
Pollution of water bodies has been known over the years to have detrimental effect on human being, aquatic life, as well as the reduction in the quality and quantity of the irrigated crops. Different land management practices from agriculture, urbanization and waste disposal on the water ways through surface runoff has led many rivers to be excessively rich in nutrient and consequently resulting into water pollution. Therefore, simulation of hydrological processes of the watershed is critical to providing insight into the level of nutrients in water for better management of the watershed. This study utilized Soil and Water Assessment Tool (SWAT), a hydrological modelling tool interfaced with Geographical Information System (GIS) to predict sediment concentration, phosphorus and nitrogen loads downstream of Landzu River watershed, Niger state, Nigeria. The simulation was carried out for 30 hydrological years using relevant spatial and temporal data available for the watershed. Uncaliberated results generated by the model showed that the annual average sediment concentration of the watershed was predicted as 5055.28 mg/l/yr. Annual average organic phosphorus (PO_4-P) was predicted as 75820 mg/ha/yr and organic nitrogen as 741379 Mg/ha/yr. Prioritization of the sediment concentration and Nutrients load revealed that Landzu River watershed was located in subbasin 93 of the entire watershed within the zone of low sediment concentration, severe zone of phosphorus load and moderate zone of nitrogen load. The outcome of this study could be adopted by appropriate stakeholders and relevant authorities for sustainable management of sediment and nutrient loadings in the watershed.

Keywords: *SWAT, Hydrologic modeling, Sediment, Phosphorus, Nitrogen, Nigeria*

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1. Introduction

Water pollution generally emanates from point and non-point source has been a global problem in the management of available water resources. Due to the advent of improvement in technology and its application in solving human problems, the point source (PS) pollution has been drastically reduced and the major pollutants of water bodies are predominantly from non- point source (NPS). The direct effects of water pollution are suffered by microorganism and vegetation that survive in water. On the other hand human health is at a risk globally due to drinking of contaminated water and consumption of infected aquatic habitats (Briggs, 2003).

Public concern regarding water quality degradation due to PS and NPS pollution has driven researchers and policymakers to concentrate on land management practices and examine how water quality conditions can be improved (Green and van Griensven, 2008). PS pollution mainly includes municipal sewage discharge (from urban or highly residential areas) and industrial wastewater (from a variety of factories). Although pollutant loadings from PS are slightly influenced by stochastic forcing functions such as precipitation and temperature and thus can usually be determined with reasonable accuracy, while the NPS are difficult to determine accurately due to stochastic hydro-chemical processes, heterogeneous soil and vegetation properties (Nikolaidis et al., 1998). Sediment and nutrients load of a specific watershed are therefore a global research focus to address the inherent problems associated with water pollution and environmental degradation of the watershed (Ndomba and Griensven, 2011).

Most of the studies used various physically based hydrological models to simulate hydrological processes for different scenarios in predicting sediment and nutrients loads for sustainable management of watersheds. For instance, Wu and Chen (2009) tested the performance of the Soil and Water Assessment Tool (SWAT) model and the feasibility of using the model to simulate streamflow, nitrogen and phosphorus yields over the Dongjiang River basin in South China. Layers of spatial data, land slope, soil type and land use were combined with Geographic Information System (GIS) to create the model inputs. The study shows that SWAT is able to predict streamflow, sediment generation and nutrients transport with satisfactory results.

Gurung et al. (2013) assessed the nitrogen and phosphorus loading in the Alabama River basin in USA using pollutant loading (PLOAD) model. The model results were compared with the field sampling data. The model results were in agreement with analytical results and the model provides a relatively faster and cheaper method of assessing impairment of watersheds. Kirsch et al. (2002) predicted sediment and phosphorus loads in the Rock River basin, in USA using SWAT model. The model was used to quantify phosphorus sources throughout the basin and quantify impacts from the application of basin-wide best management practices (BMPs). Modelling results indicated that implementation of improved tillage practices (predominantly conservation tillage) can reduce sediment yields by almost 20%.

Omani et al. (2012) estimated sediment and nutrient loads of Texas coastal watersheds. Hydrologic simulation was performed in the first phase, while the second phase focused on the estimation of sediment and nutrient loads. Results revealed that the modeled monthly sediment and nutrient (nitrogen and phosphorus) loads are strongly correlated with the observed data.

Over the years, Landzu River in Niger State, Nigeria has served the communities in some capacities such as drinking, washing and irrigation of farmland. However, agriculture practices, urbanization and population growth might have imparted on the water quality parameters of the river through increased sediment load and also, nitrogen and phosphorus contents. Measuring these parameters using direct method may be cumbersome, time consuming and expensive. Therefore, simulation of the hydrological processes along the river basin is necessary for the prediction of the aforementioned parameters which can be of use in decision making for sustainable watershed management by the water managers in the area. Therefore, this study focused on the modelling of the watershed upstream of Landzu River in Niger state, Nigeria using a selected hydrological modeling tool. The specific objective of study is to predict the sediment and nutrient loads at the downstream of the river and categorize them into zones for better management of the watershed.

2. Materials and methods

2.1. Description of case study area

The study area is located in Bida town, a Local Government Area of Niger State. Bida is located on the coordinates $9^{\circ}05'$ N and $6^{\circ}01'$ E with an area of 51 km^2. The watershed is characterized with several rivers and tributaries which are interconnected together and finally discharged into River Niger downstream of the watershed. The soil at the location is predominantly sandy-clay, loam soil and the type of vegetation is mainly savannah. The inhabitants of the watershed are Nupe tribe. These people are mostly farmers engaging in the planting of food crops such as groundnut, rice, maize and millet. The town is known for its production of traditional crafts, notably glass, bronze art crafts and brass wares. Fig. 1 presents the map of Nigeria showing location of the study area and stream networks within the catchment.

2.2. Model selection and description

The model selected for this study is SWAT due to its accuracy and efficiency in handling sediment and nutrient loading problems was developed by the United States Department of Agriculture Agricultural Research Service (Arnold et al., 1995). The model was coupled with a GIS-based, Map window GIS as interface for the model. The GIS component of the model is responsible for the processing of spatial data used in the modeling exercise. A full description of SWAT model is given by Arnold et al. (2011, 2012).

2.3. Model input data

2.3.1. Spatial data requirements

The data requirements for modelling the water quality parameters are broadly divided into two categories. These are the spatial data and the temporal data. The spatial data consist of the Digital Elevation Model (DEM), soil and land use map of the study area and the point location of the weather stations. The DEM of 90 x 90m resolution was used for this study. The DEM as shown in Figure 2 was obtained from the Shuttle Radar Topography Mission (SRTM) final version developed by CGIAR (2012). Figure 3 shows the land use map obtained from the database of the Global Land Cover Characterization (GLCC, 2012). Digital soil (See Table 1) data for the study was extracted from harmonized digital soil map of the world produced by Food and Agriculture Organization (FAO) of the United Nations (Nachtergaele et al., 2009; Birhanu, 2009). The onsite information, such as the type of vegetation and soil characteristics, obtained at the study area was used to complement the online database of land use and soil maps.

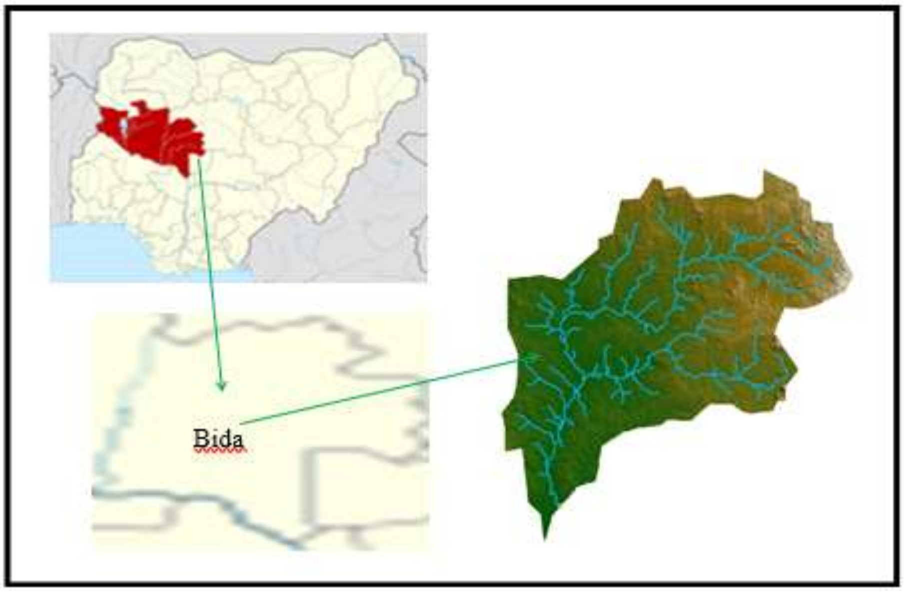

Fig. 1: Map of Nigeria showing location of the study area and stream networks within the catchment

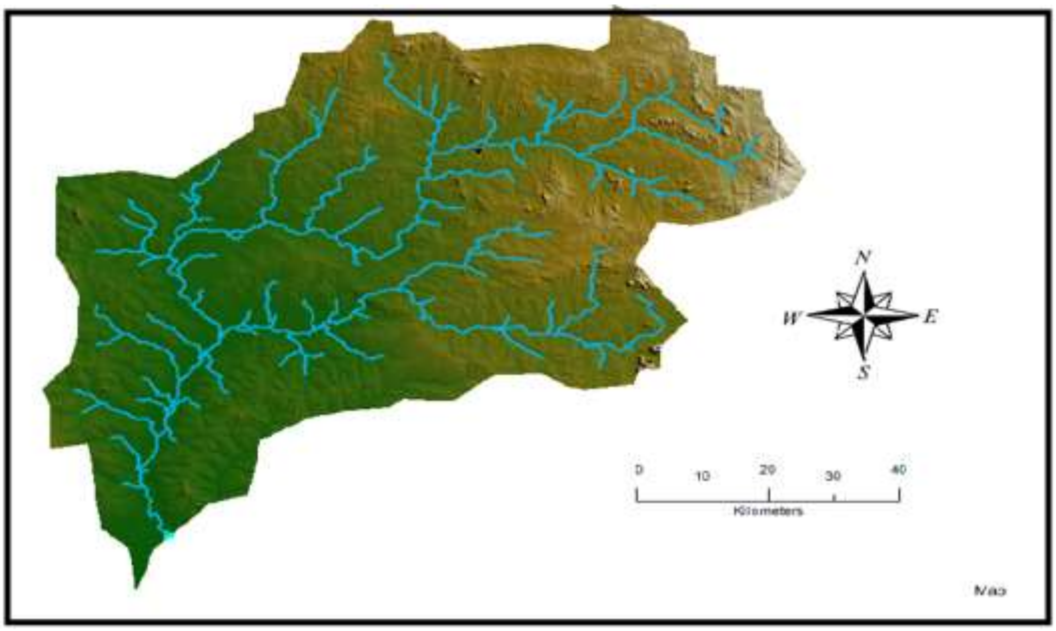

Fig. 2: Digital elevation model of the study area attributed with stream networks

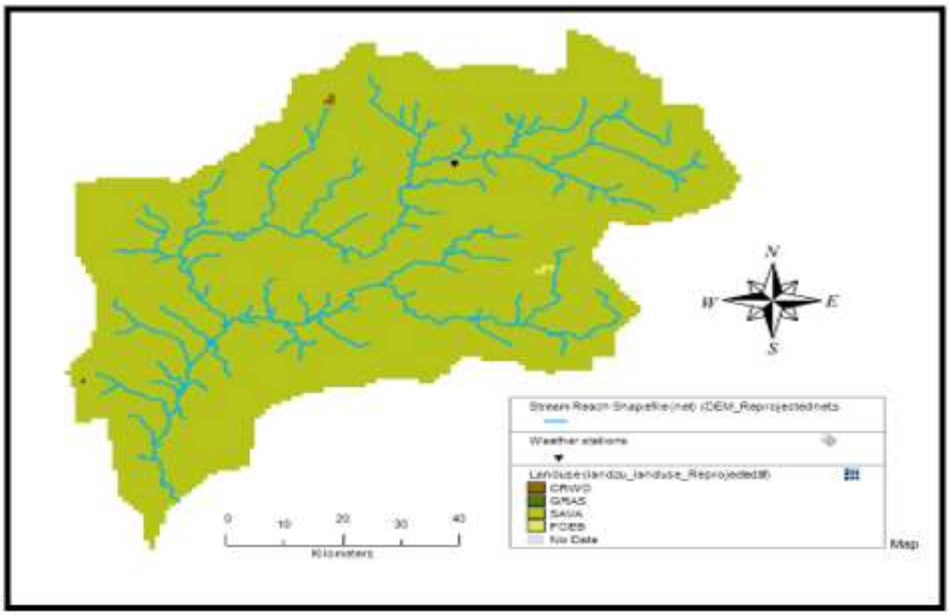

Fig. 3: Digital land use map of the study area with stream network

Table 1: Summary description of the soil type in the watershed

S/No.	SWAT Code	Description	Area(ha)	% of watershed
1	Lf1-1420	Sandy clay loam	9937.42	1.77
2	Lp6-1537	Sandy clay loam	209009.89	37.14
3	I-Lf-1255	Sandy clay loam	86571.81	15.38
4	Nd8-1a-1572	Sandy loam	183668.40	32.64
5	Lp2-1528	Sandy clay loam	44039.11	7.83
6	J2-1-2a-1326	Sandy loam	26935.63	4.79

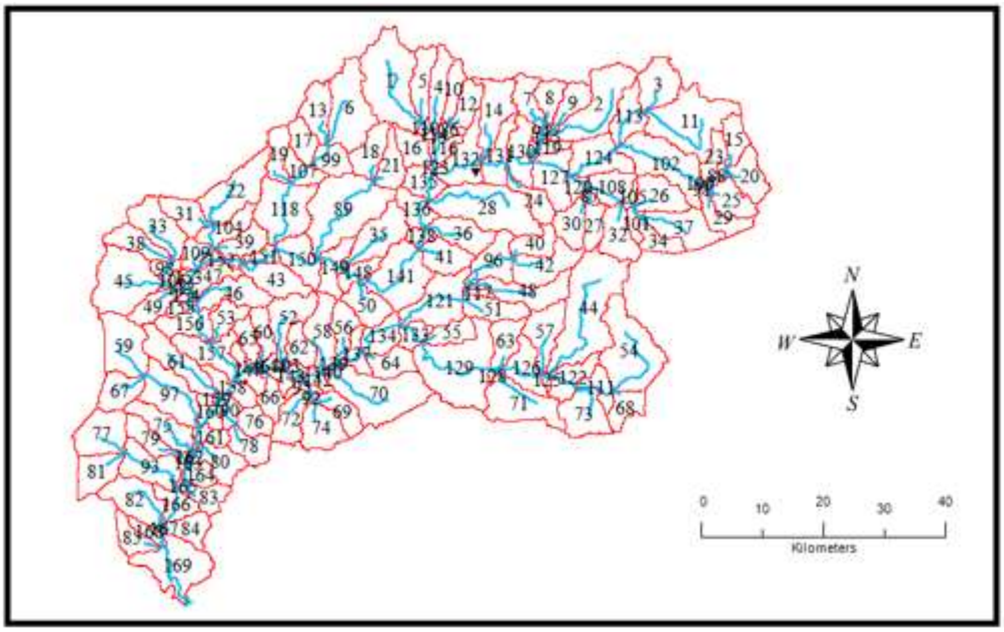

Fig. 4: Delineation of study area into 169 sub-basins and 190 HRUs

2.3.2. Temporal data requirements

Weather variables, such as precipitation, temperature (minimum and maximum), solar radiation, relative humidity and wind speed were used for driving hydrological balance of sediment and nutrient loads within the watershed from January, 1986 to December, 2016. These data were obtained from Nigeria Metrological Agency, Lagos and applied in the simulation using SWAT model. In the case of missing data, a weather generator embedded within the SWAT model, developed by Schuol and Abbaspour (2007) was employed to generate the required data to fill the gap.

2.4. Pre-processing of spatial data and delineation of watershed

The GIS component of the model was used to delineate the watershed into 169 sub-basins and 190 Hydrological Response Units (HRUs) with unique combination of landuse, slope and soil (Fig. 4). As reported by Setegn et al. (2008), the process of further delineation of subbasins into areas with unique land use, soil and slope combinations makes it possible to study the difference in evapo-transpiration and other hydrologic conditions for different land covers, soils and slopes.

2.5. Model setup and run

SWAT was executed using the runoff Curve Number method for estimating surface runoff from precipitation, Penman Monteith method for estimating potential evapo-transpiration generation as recommended for semi-arid zone like Nigeria (Adeogun et al., 2015). The variable storage method was selected to simulate channel water routing. The model was run yearly for a period of 30 hydrological years and the simulation period was from 01 January, 1985 to 31 December, 2015. Each of the model run output was visualized using the GIS component of the model and the results obtained in database file (dbf) were further processed in Microsoft Excel to obtain the required model output.

2.6. Prediction and categorization of sediment concentration and nutrient loads

SWAT model was used to simulate hydrological processes using temporal data for 30 years and spatial data of the study area being the input data required for prediction of the level of sediment concentration, nitrogen and phosphorus loads of the watershed. The watershed was categorized into four zones namely: low, moderate, severe and extreme. The reason for categorization is to enhance the spatial distribution of the modelled parameters across the Landzu River watershed for better planning and management.

3.Results and discussion

3.1. Model calibration and validation

SWAT model developed for the case study area cannot be independently calibrated due to lack of observed stream flow data for Landzu River in the study area. However, the results of the SWAT model previously calibrated and validated in a similar watershed in North-Central Nigeria where the case study is located were adopted for the study. Details of the validation and calibration can be obtained in (Adeogun et al., 2014). The performance evaluation of the model in the area showed a good correlation between the simulated and observed streamflow. Values of 0.76 and 0.72 were obtained for coefficient of R^2 and Nash Sutcliffe Efficiency (NSE) respectively during calibration period. Also, 0.71 and 0.78 were estimated for coefficient of R^2 and Nash Sutcliffe Efficiency (NSE) respectively during validation period.

3.2. Prediction of sediment concentration

The spatial distribution of sediment concentration along Landzu River is as shown in Figure 5. The result showed that a total sediment concentration of 156713.57 mg/l was produced. This translates to an annual average sediment production of 5055.28 mg/l/yr. The maximum annual average sediment concentration was predicted in 2009 within the watershed with sediment concentration of 15451.24 mg/l and the minimum production of sediment concentration was predicted in the year 2000 with sediment concentration as 1047.41mg/l.

3.3 Prediction of phosphorus and nitrogen load

The model result indicated that the total organic phosphorus (PO_4-P) was 2350429 mg/ha and annual average production of phosphorus (PO_4-P) load within the Landzu River watershed was predicted as 75820 mg/ha/yr for thirty years simulation period. The minimum production of organic phosphorus was predicted in 2003 having the value of 12751 mg/ha while maximum production was predicted to occur in 2006 with the value of 147593 mg/ha. The variation pattern of the phosphorus production over the simulation period of thirty years is shown in Figure 6. Model result predicted that annual average organic nitrogen production in Landzu River watershed was 741379 mg/ha/yr for thirty years simulation period out of the total value of 22982740 mg/ha of nitrogen produced over the years. The minimum production of organic nitrogen was predicted in 2003 as 120817 mg/ha and maximum production was predicted to occur in 2006 having the value of 1484931 mg/ha as shown in Fig. 7.

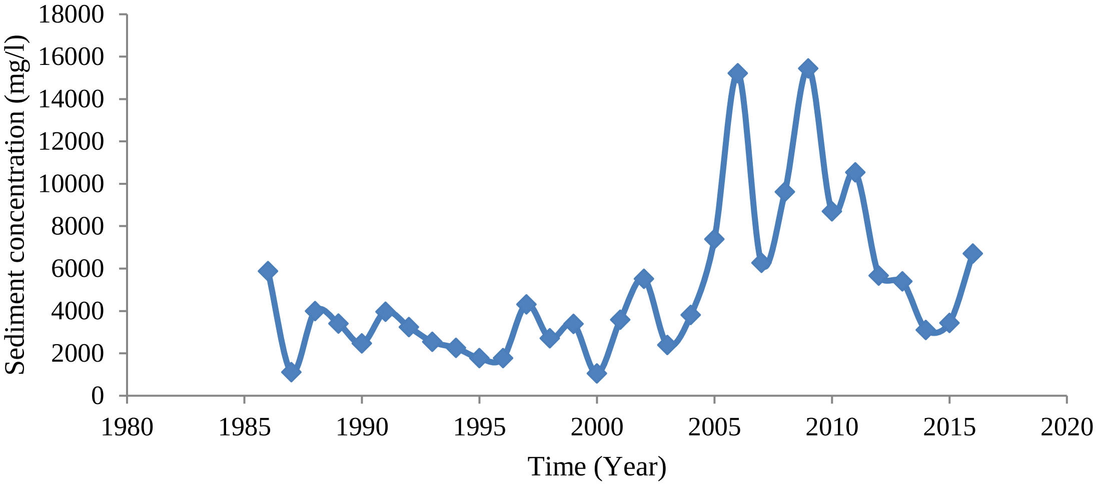

Fig. 5: Annual variation of sediment concentration in the watershed

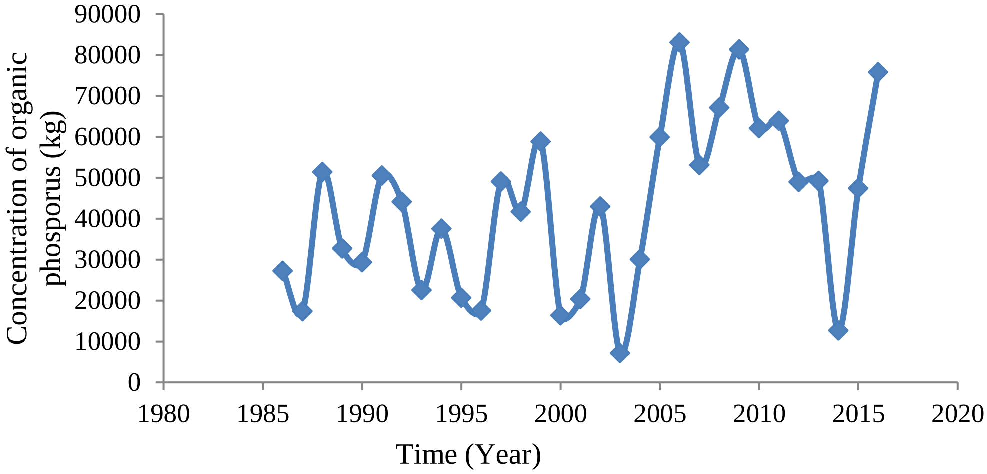

Fig. 6: Annual variation of organic phosphorus

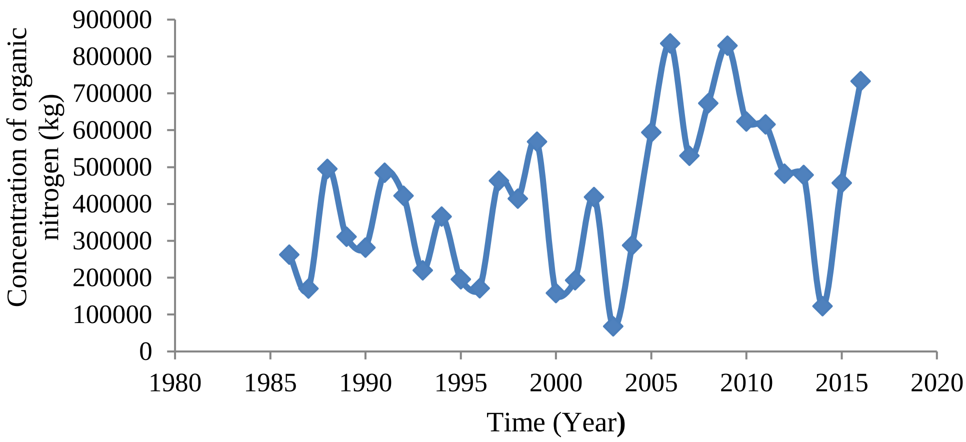

Fig. 7: Annual variation of organic nitrogen

3.4 Categorization of sediment concentration in the watershed

The model results indicated that sediment yield is predominantly high at the extreme reach especially at sub-basins 6, 11, 26, 29, 32, 37 and 68 (purple colour) of the catchment while the sub-basins with red color represent low zone of sediment concentration of which the study (subasin 93) area is located, yellow and grey colors representing moderate and severe zones respectively as shown in Fig. 8.

3.5 Categorization of nitrogen and phosphorus production

Based on categorization, the sub-basins in the extreme zones of nitrogen production are found in sub-basins 127, 129, 130, 132, 134, 135, 136, 137, 141, 150, 151, 152, 153, 161 and 169 (that is, the blue colour region). However, the study (sub-basin 93) area was in the moderate zone. Brown and grey colours are respectively in low and severe zones as shown in Fig. 9. The watershed was categorized into low, moderate, extreme and severe zones. Landzu River was found to be in the region of severe zone (sub-basin 93) which indicated a significant phosphorus load in the river as shown in Fig. 10.

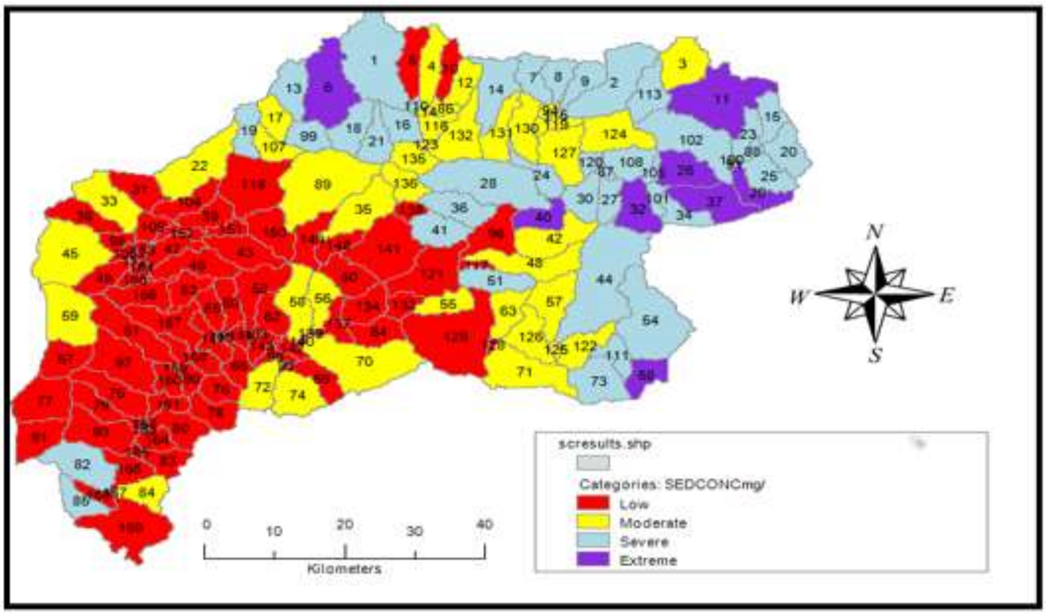

Fig. 8: Prioritization of Sediment concentration in the reach within the watershed

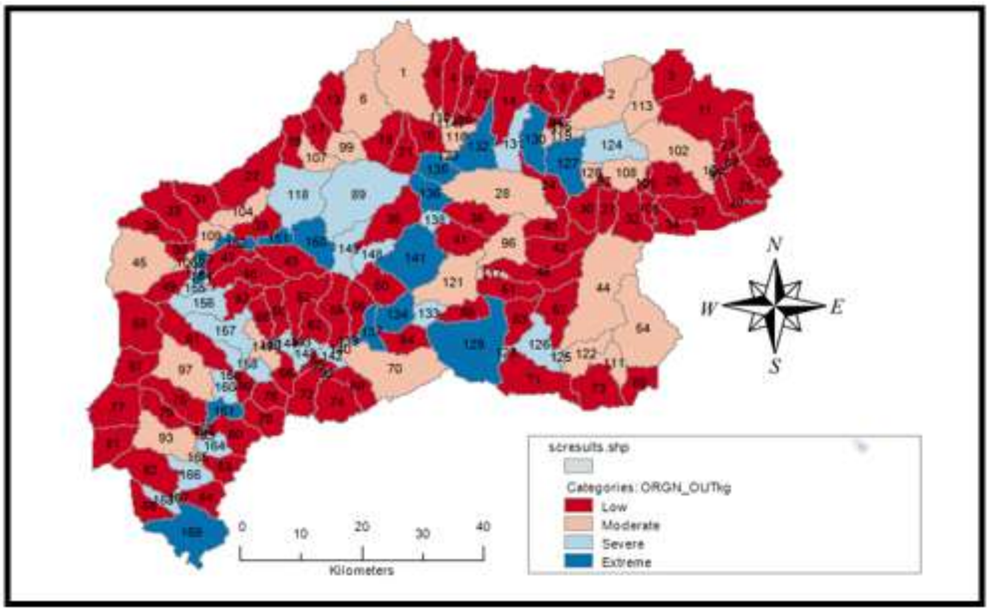

Fig. 9: Prioritization of organic nitrogen generation in the watershed

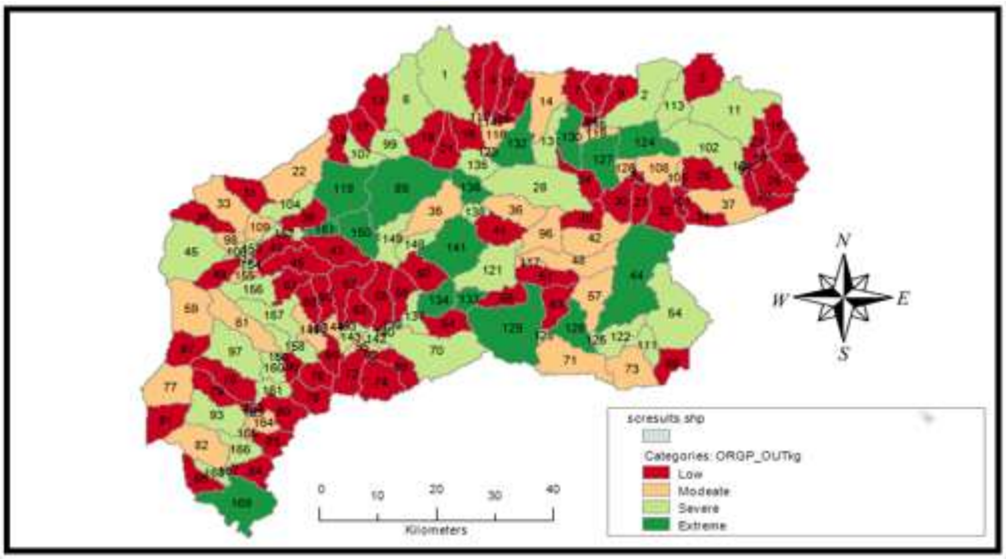

Fig. 10: Prioritization of organic phosphorus generation in the watershed

4. Conclusions

The SWAT model was used for the simulation of hydrological processes and predicted the sediment concentration, nitrogen and phosphorus loads in the watershed. Based on the outcome of the study, the following conclusions are made:

i. The annual sediment concentration in the Landzu River was predicted as 5055.28 mg/l/yr while the annual nitrogen load was predicted as 741379 mg/ha/yr between 1986 and 2015. Similarly, the annual phosphorus load was predicted as 75820 mg/ha/yr during the same period.

ii. Prioritization of the watershed indicated that Landzu River watershed was located in subbasin 93 of the entire watershed within the zone of low sediment concentration, severe zone of phosphorus load and moderate zone of nitrogen load.

iii. It was also noticed that there has been an increase in the sediment concentration, nitrogen and phosphorus loads over the years which could be attributed to different land uses emanating from diffuse sources including precipitation, discharge of waste from urban centers and runoff from agricultural field.

Results of the model can be adopted by local authorities and relevant stakeholders in the study area to formulate policies and strategies for planning and management of the watershed in the reduction of sediment concentration and nutrient loads in Landzu River. It can also be an eye opener to stakeholders and concerned individuals to be conscious of the effect of over fertilization of the farmland upstream of the river which may often lead to water pollution. Finally, the result may also serve as decision support tool in suggesting best land management practices to minimizing the chances of excess nutrients which is key actor of water pollution.

References

Adeogun, A.G., Sule, B.F. and Salami, A.W. (2015) Simulation of Sediment yield at the upstream watershed of Jebba lake in Nigeria using SWAT model. Malaysian Journal of Civil Engineering, 27(1): 25-40.

Adeogun, A.G., Sule, B.F., Salami, A.W. and Okeola, O.G. (2014) GIS-based hydrological modelling using SWAT: Case study of upstream watershed of Jebba reservoir in Nigeria. Nigerian Journal of Technology, 33(3): 351-359.

Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R. and Haney, E.B. (2011) Soil and water assessment tool input output file documentation. Soil and Water Research Laboratory, Agricultural Research Service, Grassland, 808 East Blackland Road, Temple, Texas.

Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J. (2012) SWAT: model use, caliberation and validation. Transactions of the American Society of Agricultural and Biological Engineers, 55(4): 1491-1508.

Arnold, J.G., Williams, J.R. and Maidment, D.R. (1995) Continuous-time water and sediment-routing model for large basins. Journal of Hydraulic Engineering, 121(2): 171-183.

Birhanu, B.Z. (2009) Hydrological modelling of the Kihansi River catchment in south central Tanzania using SWAT model. International

Journal of Water Resources and Environmental Engineering, 1(1): 1-10.

Briggs, D. (2003) Environmental pollution and the global burden of disease, British Medical Bulletin. https://doi.org/10.1093/bmb/ldg019. Assesed 1 December 2003.

CGIAR (2012) SRTM 90m digital elevation data. http://srtm.csi.cgiar.org/, Accessed 23rd December 2013.

GLCC (2012) Global land cover characterization. http://edc2.usgs.gov/glcc/glcc.php. Assessed 13 October 2013.

Green, C.H.M. and van Griensven, A. (2008) Autocalibration in hydrologic modeling: Using SWAT2005 in small-scale watersheds. Environmental Modelling and Software, 23(4): 422-434.

Gurung, D.P., Githinji, L.J.M. and Ankumah, R.O. (2013) Assessing the nitrogen and phosphorus loading in the Alabama (USA) river basin using PLOAD model. Air, Soil and Water Research, 6: 23-36.

Kirsch, K., Kirsch, A. and Arnold, J.G. (2002) Predicting sediment and phosphorus loads in the Rock river basin using SWAT. American Society of Agricultural Engineers, 45(6): 1757-1769.

Nachtergaele, F., Velthuizen, H.V. and Verelst, L. (2009) Harmonized world soil database (HWSD). Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/ fileadmin/ templates /nr/documents/HWSD/ HWSD_Documentation.pdf. Assessed 12 December 2015.

Ndomba, P.M. and Griensven, A. (2011) Suitability of SWAT model for sediment yields modelling in the eastern Africa; advances in data, methods, models and their applications in Geoscience, Dongmei Chen (Ed.), ISBN: 978-953-307-737-6. InTech, http://www.intechopen.com/articles/ show/title/suitability-of-swat-model-for-sediment-yields-modelling-in-the-eastern-africa:261-284. Assessed 25 May 2015.

Nikolaidis, N.P., Heng, H., Semagin, R. and Clausen, J.C. (1998) Non-linear response of a mixed land use watershed to nitrogen loading Agriculture, Ecosystems and Environment, 67(2–3): 251-265.

Omani, N., Srinivasan, R. and Lee, T. (2012) Estimation of Sediment and Nutrient Loads to Bays from Gauged and Ungauged Watersheds Applied Engineering in Agriculture, 30(6): 869-887.

Schuol, J. and Abbaspour, K.C. (2007) Using monthly weather statistics to generate daily data in a SWAT model application to West Africa. Ecological Modelling, 201: 301-311.

Setegn, S.G., Srinivasan, R. and Dargahi, B. (2008) Hydrological modelling in the Lake Tana basin, Ethiopia using SWAT model. Open Hydrology Journal, 2: 49-62.

Wu, Y. and Chen, J. (2009) Simulation of nitrogen and phosphorus loads in the Dongjiang River basin in South China using SWAT. Front. Earth Science. China 3, 273–278 https://doi.org/10. 1007/s11707-009-0032-6.