Evaluating the Role of Sediment Transport in Flood Formation Along Sections of River Kaduna

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Abstract

The pattern and amount of sediment production are regulated predominant by upstream land-use land cover (LULC) types, precipitation volume, and intensity. The Soil and Water Assessment Tool (SWAT) was employed in this study to assess the contribution of sediment to flood development. For the simulation of hydrological features and the prediction of sediment yields, the SWAT standard procedures were utilized. The SWAT model was calibrated using rainfall data for 29 years (1992-2021) and validated using data observed flow data for ten years (2011-2021). The Nash-Sutcliffe (NS), the coefficient of determination (r^2), and the proportion of observed data (p-factor), showed that the model function was statistically significant. The SWAT model evaluation produced NS, r^2, and p-factor values of 0.2447, 0.1131, and 0.1719, respectively. Two-factor or two-way ANOVA was applied to validate the Hypothesis H_0; sediment concentration contribute to the river flooding, while H_1: Sediment do not contribute to the river flooding. Using excel window X_{10}pro. The stated hypothesis H_0, stands to be adapted since $F_{crit} < F_{cal}$ i.e 3.44 < 3.05 in the excel calculation, it is seen that Fcrit = 3.44 which show that sediment concentration is contributing factor for river flooding. Results indicate that the model's estimates of stream flow and sediment output were accurate. The results indicate that flooding caused an increase in evapotranspiration, sediment output, and surface runoff.

Keywords: *Flood, Sediment, Soil Water Assessment Tool (SWAT), Digital Elevation Model (DEM) resolution.*

1.0 Introduction

Flood risk is influenced locally by changes in river channel stage, which may be influenced by variations in both flow magnitude and river channel conveyance (Lane *et al.,* 2007 ;), flood risk according to (Guan *et al.,* 2016) is influenced by series of repeated floods rather than on single event A flood occurs when the water level in the main channels exceeds the bank height. Flood frequency is influenced by geomorphological changes and sediment movement in rivers, both of which can increase it. Bed aggradation and erosion according to (Walter and Merritts 2008; Maselli et al. 2018); is caused by damming and backwater impacts channel capacity reduction (Slater *et* *al.,* 2015); and morphological changes caused by a changing sediment supply from upstream. Studies on flood risk are typically associated with major hydrological events and assume only clear water and non-erodible channels when using two-dimensional (2-D) hydraulic models to develop flood risk management plan (FRMP) (Moel *et al., 2*009; Alfieri et al. 2014; Nied et al. 2017).

River systems according to (Merz *et al.,* 2014; Liu *et al.,* 2018) exhibit significant spatial interactivity, building flood defence upstream can change the sedimentary load at the watershed scale, causing a variety of problems for people and infrastructures downstream, such as increasing siltation in hydropower reservoirs or altering river geometry, which raises local water level. Interactions between river systems (flood defence and sediment loads) may be represented in numerical models for the purpose of analyzing probable future circumstances, but an engineering knowledge of the important processes, such as long-term morphological changes, is highly limited and difficult to schematize (Sayers *et al.,* 2002), typical flood risk models do not account for sediment-related processes, potentially leading to underestimation of flooded areas and associated depths (Nones and Pescaroli 2016), as well as a lack of detailed sediment logical data on both bed load and suspended load that should be used to accurately calibrate these modelling tools.

Flooding cause's structural damage, erosion, pollution of food and water, interruption of socioeconomic activity, including transportation and communication, and loss of life and property (Hewitt and Burton, 1971). Land flooding from high rainfall, climate change, garbage obstruction in drains, building development that clogs drains, inadequate drainage networks, and population increase in urban areas are all contributing reasons to flood catastrophes in Nigeria. Flood catastrophes are often caused by a combination of multiple of these components since they do not operate independently (Adeoye *et al*., 2009). As a result of urbanizations, the population of people living in flood-prone areas, such as flood plains and river beds, the conversion of agricultural land, natural vegetation, and wetlands to built-up settings. According to Alaghland (2010), urbanization and hydrological features such as reduced infiltration, increased runoff, increased frequency, and higher flood height are connected.

Recent flood disasters along River Kaduna in Nigeria have claimed many lives and properties, and threatened the ecological biodiversity. Evaluating the role of sediment in flood formation, by using modeling techniques to simulate and predict the yield of sediment concentration in River Kaduna, is the main thrust of the study.

The aim of this research is evaluation of sediment transport in flood formation in sections of river Kaduna using SWAT Analysis, with objectives which include: To analyze the influence of the hydrological process and human activities on runoff within the study area, to develop a relationship between sediments and runoff within hydrological response unit and to calibrate and validate, the potential use of the SWAT model

2.0 Materials and methods

2.1 Materials

2.1.1 Data Collection

The research data includes a 30 m resolution digital elevation model (DEM) of the study area. Land-use and land cover data obtained from the conducted reconnaissance survey in the watershed were integrated with a 2 km resolution land cover classification map of Western Africa and an extracted soil map of Nigeria with 1 km resolution from the FAO Soil database. Meteorological datasets of precipitation, relative humidity, wind, and solar radiation, as well as minimum and maximum temperature datasets obtained from the weather data and water board Kaduna state Water Board also formed part of the input parameters. Data types, description resolution and sources are presented in Table 1

Table 1. Data Source, Description and type

S/N	Data Type	Description	Resolution	Source
1	Weather	Precipitation, Min. and Max. Temperature, Relative Humidity, Wind and Solar Radiation	Daily	Kaduna Waterboard
2	Topography	Digital Elevation Model (DEM)	30 m	Shuttle Radar Topography Mission (SRTM)
3	Land Cover Map	Land cover classification	20 m	The European Space Agency (ESA) Sentinel-2 Satellite Observations
4	Land Cover Map	Land cover classification	2km	U.S. Geological Survey Earth Resources Observation and Science (USGS EROS)
5	Soil Map	Soil types and texture	1km	FAO Digital Soil database map of the World
				African Flood and Drought Monitor

2.1 .2 Tools for Analysis

The following tools were used for the analysis Soil and Water Assessment Tool (SWAT), QGIS and hand held GPS,

2.2 Methods

2.2.1 The SWAT model requires input data on the terrain, land use, soil and climate, and its setup involves two components: a GIS system for storage and display of maps, performance of terrain analysis to delineate watersheds and identify associated sub-basins, and a component that can generate all the files needed by SWAT, partly from the input maps and analyses, and partly by manual editing. SWAT model simulation of the hydrologic cycle today is centered on water balance equation (Equation 1). The stream power equation embedded in the current version of the SWAT model was used for sediment routing in the derived channel. All spatial data used were projected to the Universal Transverse Mercator Zone 32 Northern Hemisphere (UTM Zone 32N) that corresponds to the study location, and all input files were in meters. Automatic watershed delineation (AWD), hydrologic response unit creation, and SWAT input tables were generated following standard modeling procedures. The input DEM at 30m resolution (Fig 1), The GUI of QGIS (Fig 2) and the process of creating the QSWAT 3 is depicted in Figure 3.

$$P = ET + Q + \Delta S \quad (1)$$

Where P is precipitation, ET is evapotranspiration, Q is runoff and ΔS is change in storage (ground water and soil moisture).

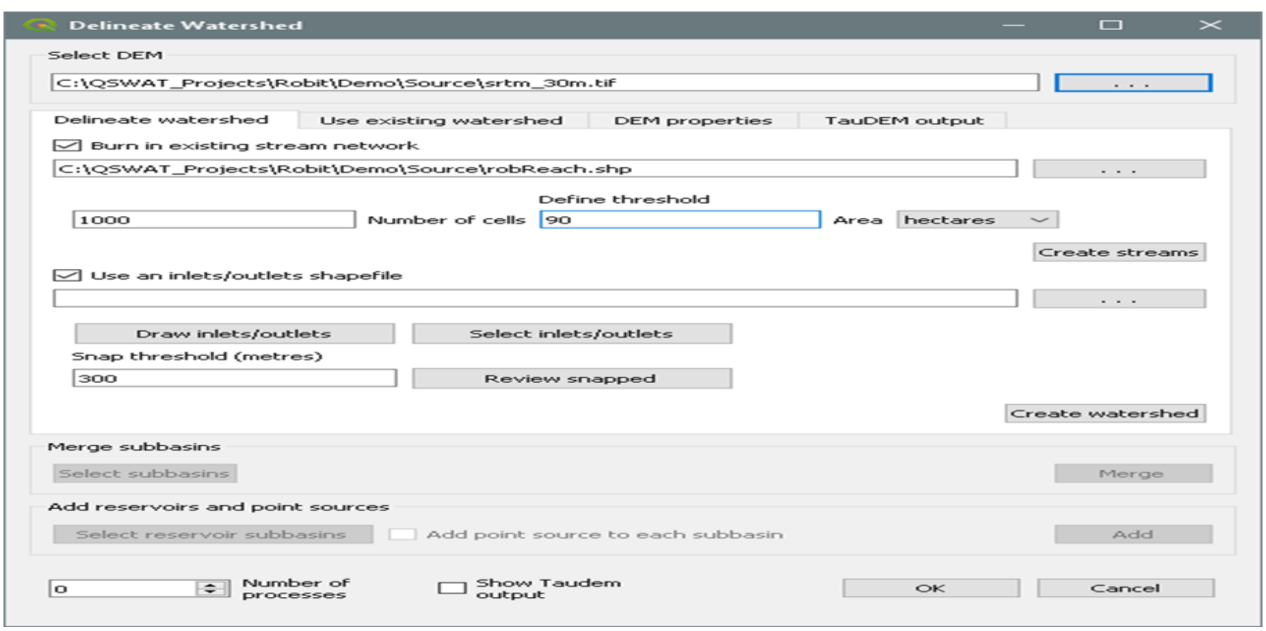


Figure 1: Input DEM at 30m resolution

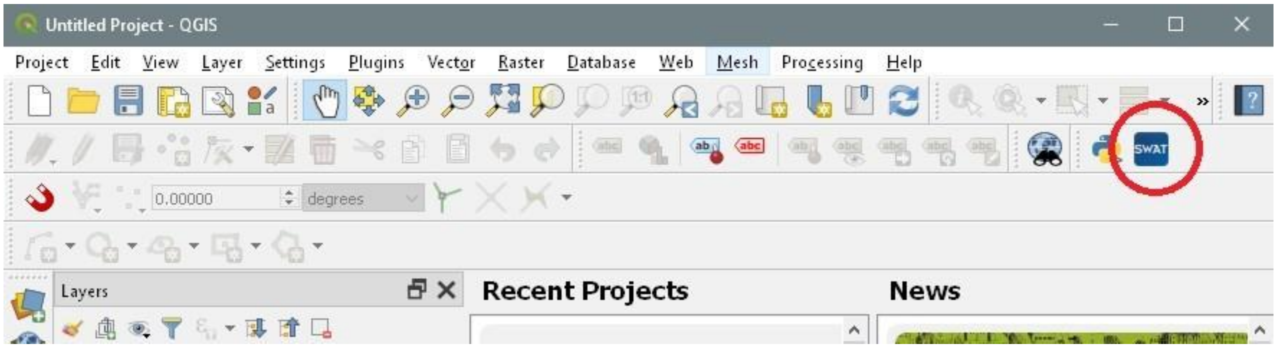


Figure 2: GUI of the QGIS

The **SWAT** icon is buildup from the GIS interface as new project and applied to start the QSWAT.

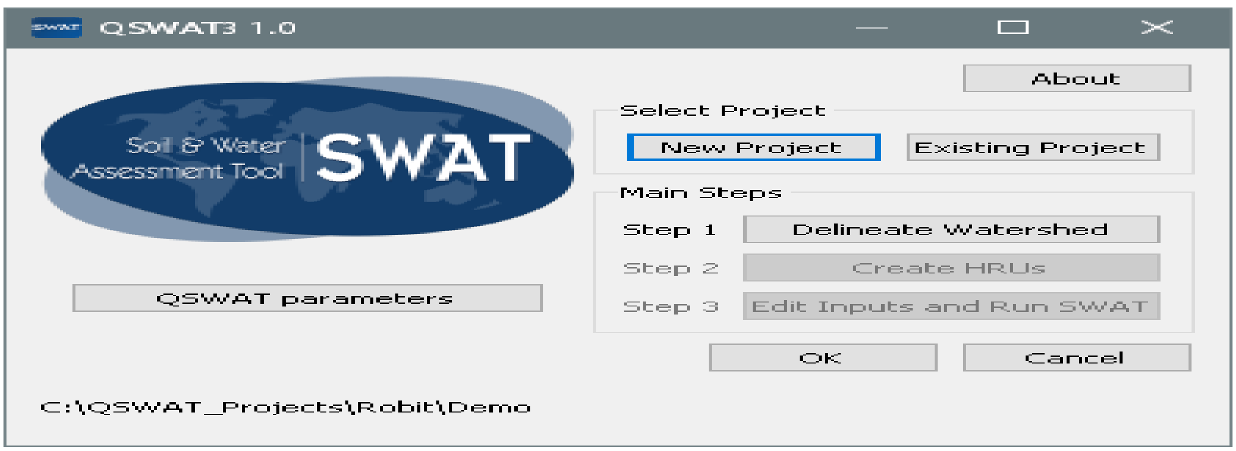
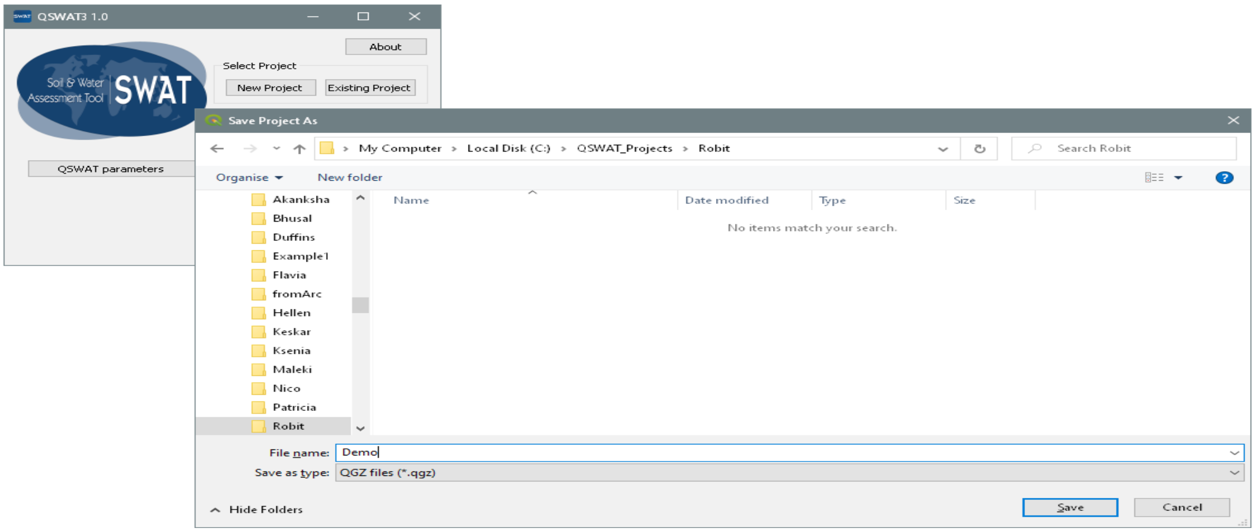


Figure 3: Creating a **QSWAT3** project

Figure 4: Step 1 interface

The project database is created in the project folder, and a copy of the SWAT reference database *QSWATRef2012.mdb* is also created there in text file.



The maps are prepared in an equal area projection (probably, but not necessarily, UTM1). All the maps are in the same projection coordinate system. The interface now presents a step-by-step configuration that was followed in order to prepare the SWAT simulation.

2.3 Calibration and Validation

The Digital Elevation Model (DEM) and land-use and soil data (for watershed delineation), daily weather data (e.g., precipitation, minimum and maximum temperature, relative humidity, wind, and solar radiation), and stream flow and suspended sediment concentration are the input data used for validation and calibration using SWAT CUP. Within the watershed region, the best possible criterion for site selection and water sampling were used. Calibration and validation were performed to reduce the disparity between observed and simulated values. The former entailed parameterization of the model and sensitivity analysis. The Soil and Water Assessment Tool Calibration/Uncertainty or sensitivity programmed (SWAT-CUP SUFI 2) was used to realize model parameters. The DEM was used to generate the stream flow network, while the land use, soil, and slope definitions were used to generate the HRU, coefficient of determination (r^2) and Nash-Sutcliffe Efficiency (NS) to determine the model's performance. To assess the quality of calibration and uncertainty analysis, the 95% Prediction Uncertainty (95PPU). The results of the validation performance assessment were utilized to update the SWAT model for final model simulation of sediment and hydrological impacts such as evapotranspiration, water yield, surface runoff, stream flow, and lateral flow, and groundwater flow.

3.0 RESULTS AND DISCUSSION

3.1 Watershed outputs

The sensitivity analysis of the observed and simulated data (watershed out put0 along the (x,y) coordinates represented by out flow 1 and out flow 3 are presented in Figures 5 and 6.

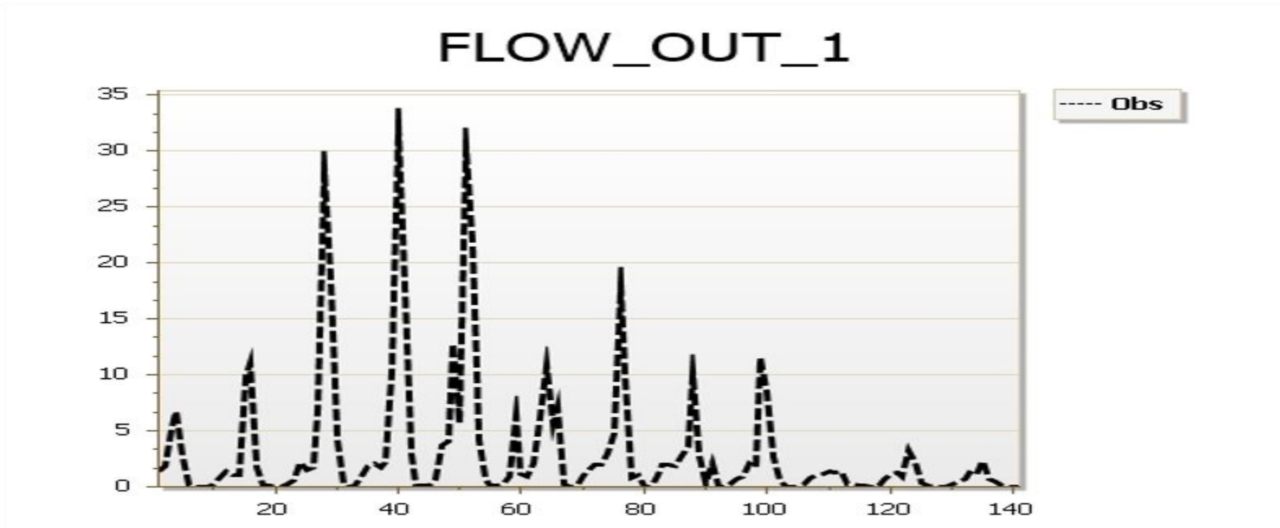


Figure 5 sensitivity data of flow-out 1

Sensitivity data in the figure 5 highlight the compatibility output data in flowout-1.The above graph in figure 5, shows the sensitivity of both observed and simulated data. The sensitivity of the parameter data on the coordinate (x,y) shows the active data at 34.5 on y-axis, and 40 on x-axis for both observe and simulated data while the inactive data shows the following value on the coordinate (x,y) as 1on y-axis and 110 on x-axis for both observed and simulated in flow-out-1.

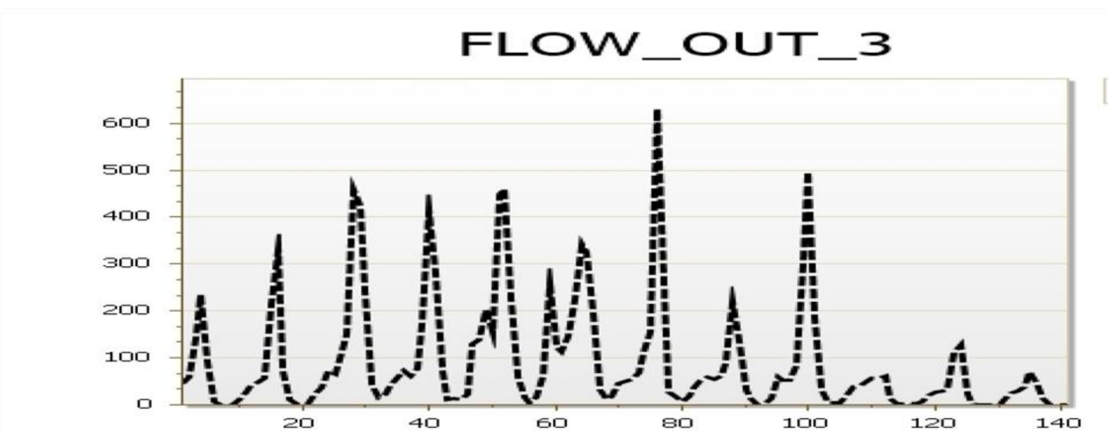


Figure 6: flow-out sensitivity data

This is also applicable in flow out-3 in the above figure 6, both the observed and simulated data on the x,y coordinate were observe to be that the most active data was 602on y-axis while the simulated value 80 on x-axis as the sensitivity data of flow-out-3.

Table 2: Result of trends analysis rainfall (1990-2021).

Months, annual	First year	Last year	N	M-K	P VALUE	SENSITIVITY OF SEDIMENT	DOWN STREAM (%)	UPPER STREAM (%)
January	1992	2021	30	-	-	-	-	-
February	1992	2021	30	0.171	0.280	0.000	0.000	0.000
March	1992	2021	30	-0.106	0.468	0.000	0.000	0.000
April	1992	2021	30	-0.226	0.083	-1.000	-2.413	0.092
May	1992	2021	30	0.182	0.164	2.239	-0.600	4.317
June	1992	2021	30	0.094	0.475	0.804	-2.250	3.062
July	1992	2021	30	0.113	0.392	2.530	-2.780	6.292
August	1992	2021	30	0.126s	0.335	1.746	-1.468	5.482
September	1992	2021	30	-0.030	0.830	-0.867	-6.129	4.983
October	1992	2021	30	-0.168	0.199	-1.122	-3.159	0.696
November	1992	2021	30	-0.258	0.106	0.000	0.000	0.000
December	1992	2021	30	-	-	-	-	-
Annual	1992	2021	30	0.094	0.475	5.130	-9.100	-18.500

Table 2, shows the trend analysis of rainfall from 1990-2021.The year of observation showing the highest percentage level of sediment concentration as 6.2% upstream and 0% downstream with a p-value 0.113 respectively.

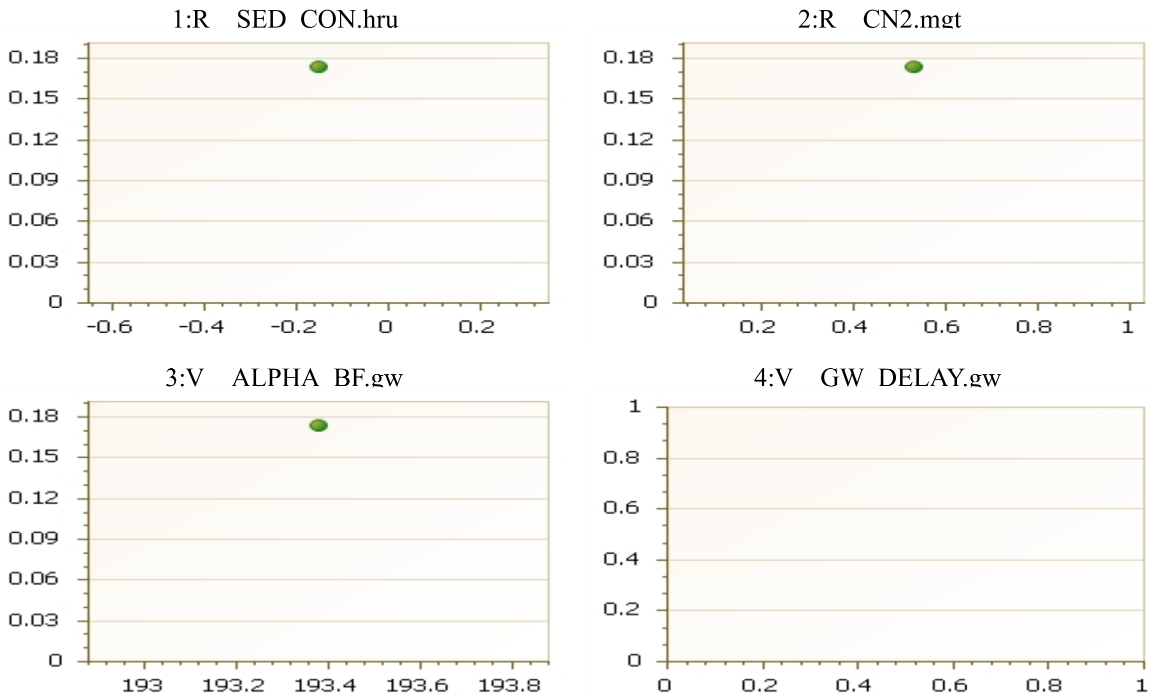


Figure 6: Highlight of parameter, sediment cont., runoff mgt., base flow and ground flow

The yield of the river in terms of sediment concentration (SED. CON.hru), runoff magnitude (R.CN2.mgt), base flow (ALFA BF.gw) and ground water delay (GW DELAY.gw) are presented in Figure 6 above. These parameters showed SED CON.hru at (x,y) of 0.1 and 0.79, R.CN2. mgt at (x,y) of 0.5 and 0.17, BF.gw at (X,Y) of 193.4 and 0.17 and GW delay shows the level of sediment concentration, has zero indication of sediment concentration.

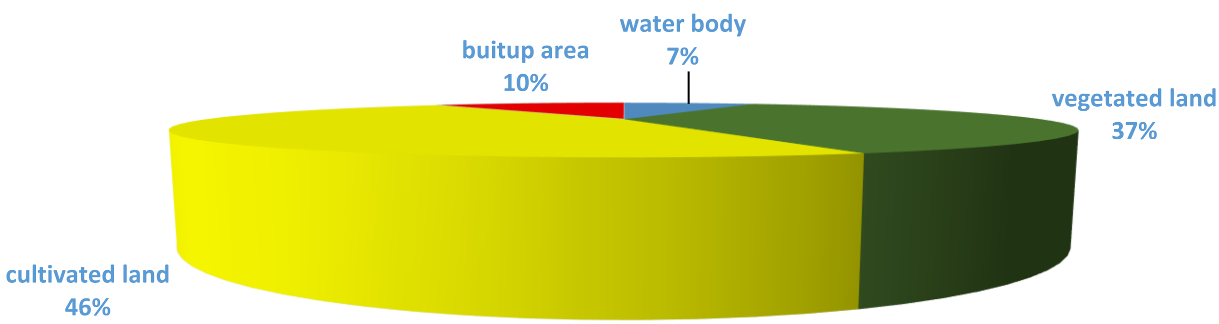


Figure: 7 Land use land cover 1991 (Area hectare in 1991)

The land use land cover of 1991 in figure 7, the analysis of the performance using geostatic parameter r^2 showed, buildup area 10%, waterbody7%,vegetation land 37% cultivatedland46%. As at 1991 the land use land cover has the cultivated land 46%.

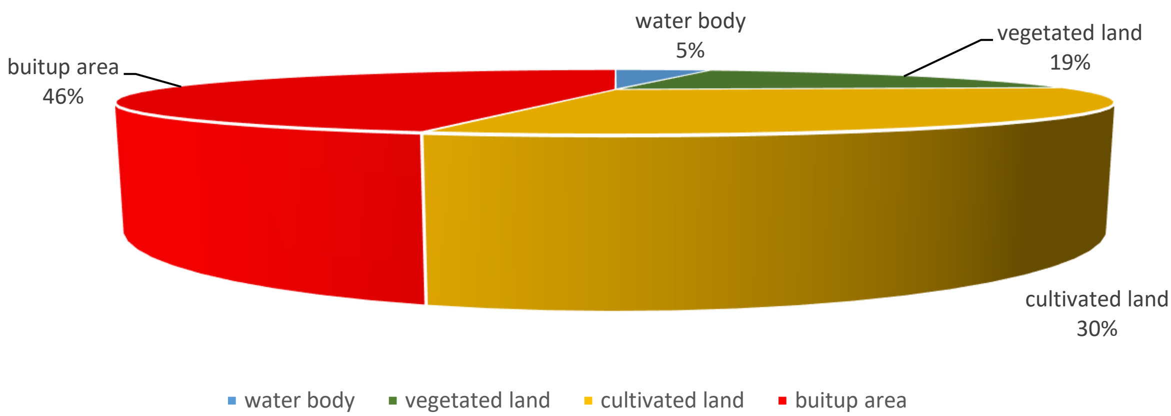


Figure 8: Land use land cover 2021 **Area in hectare in (2021)**

From figure 8, the land use land cover changes in 2021 due to buildup area has 46%, cultivated land 30%, vegetated land19% and water body 5%. The land use land cover has affected the water body by 2% to influence flooding due to the changes in the land use land cover of 1991 to 2021.

Relationship between the observed and simulated data

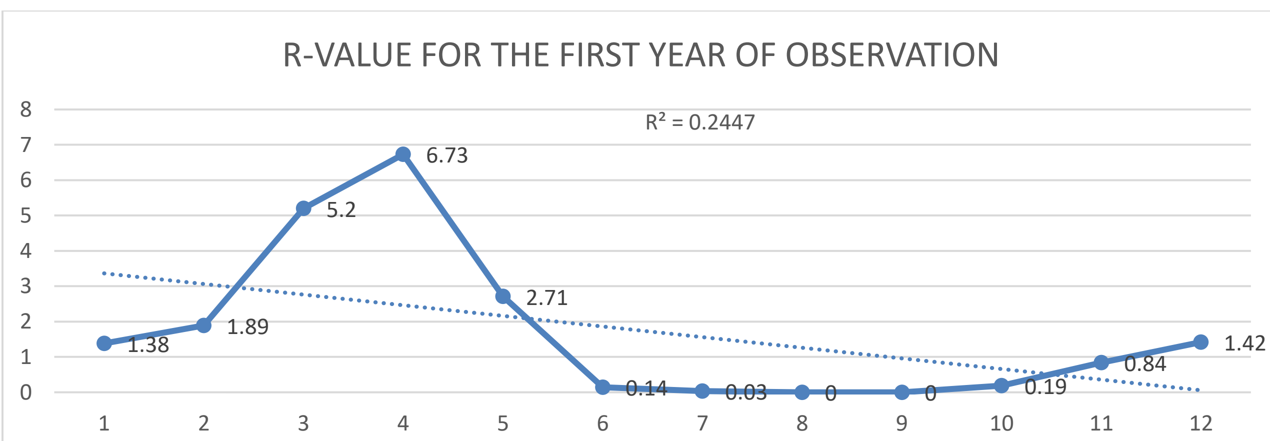


Figure9: R-value for the first year of observation

The following relationship between the observe and the simulated data are related using the coefficient of determination r^2 in figure 9, these two parameter are said to laid on the coordinate (x,y) 6.7 and 0, with a r^2value = 0.244. this shows that both observed and simulated data are related with a r^2-value = 0.244.this is also applicable to Figures 10 and 11 below showing the r^2 value, are r2=0.1519, and r2= 0.1131 respectively.

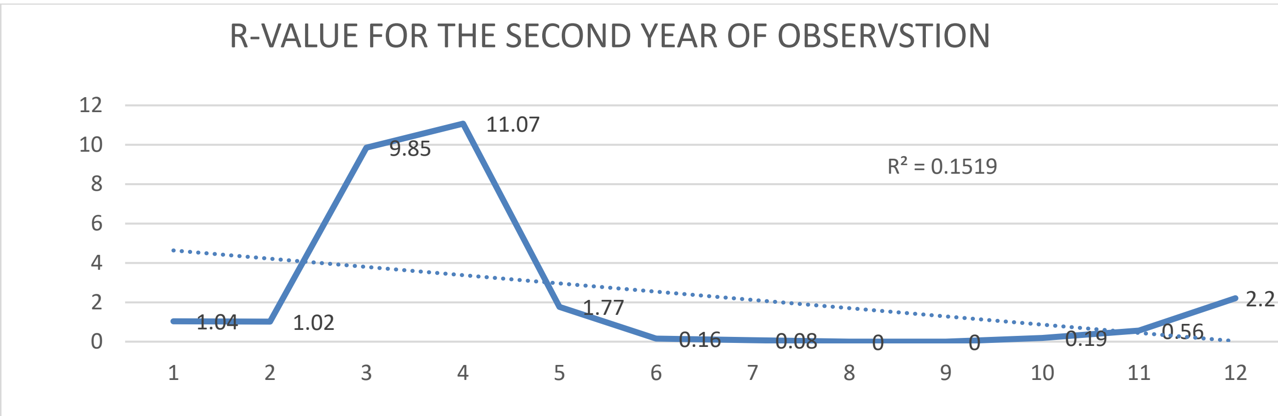


Figure 10: R-value for the second year of observation

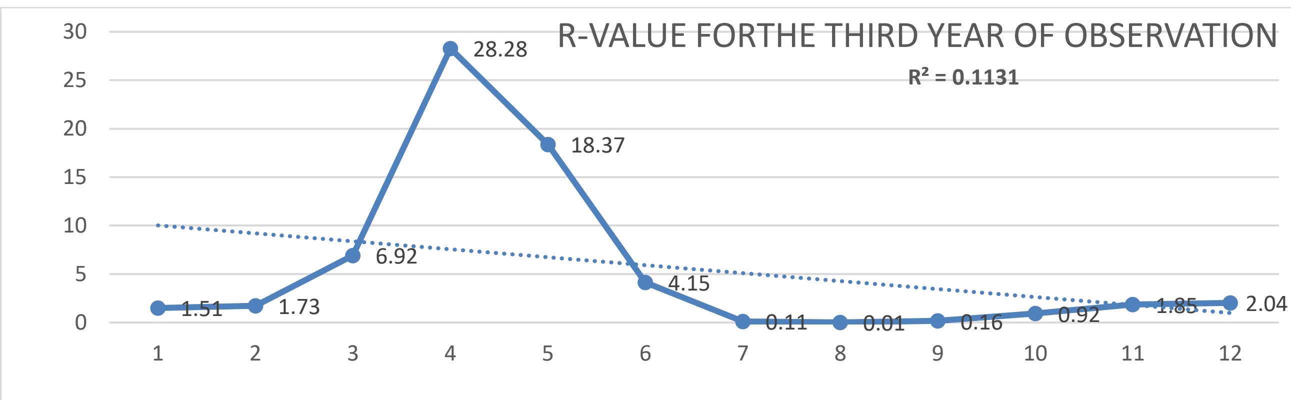


Figure 11: R-value for the third year of observation

Table 3 Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	3	3.93	1.31	0.0589
Row 2	3	4.64	1.546667	0.214433
Row 3	3	21.97	7.323333	5.527633
Row 4	3	46.08	15.36	129.9037

Row 5	3	22.85	7.616667	86.94653
Row 6	3	4.45	1.483333	5.333433
Row 7	3	0.22	0.073333	0.001633
Row 8	3	0.01	0.003333	3.33E-05
Row 9	3	0.16	0.053333	0.008533
Row 10	3	1.3	0.433333	0.177633
Row 11	3	3.25	1.083333	0.460433
Row 12	3	5.66	1.886667	0.169733
Column 1	12	20.53	1.710833	4.80079
Column 2	12	27.94	2.328333	14.99912
Column 3	12	66.05	5.504167	77.50139

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	712.1355	11	64.73959	3.976424	0.002848	2.258518
Columns	99.42641	2	49.7132	3.053476	0.067561	3.443357
Error	358.1789	22	16.28086			
Total	1169.741	35				

From the above table 3, two-factor or two-way ANOVA was applied to validate the Hypothesis H_0; sediment concentration contribute to the river flooding, while H_1: Sediment do not contribute to the river flooding. Using excel window X_{10}pro . the stated hypothesis H_0, stands to be adapted since $F_{crit} < F_{cal}$ (3.44 < 3.05) in the excel calculation, it is seen that Fcrit = 3.44 which show that sediment concentration is contributing factor for river flooding.

4.0 Conclusion

The DEM was used to produce the stream flow network, and the land use, soil, and slope definition were utilized to create the HRU. Land-use change detection analysis was performed using geostatistical parameters (coefficient of determination $r^{2)}$ and Nash-Sutcliffe Efficiency NS) to determine the model's performance evaluation. To assess the quality of calibration and uncertainty analysis, the 95% Prediction Uncertainty (95PPU) (p-factor) and r-factor (Ratio of Average Thickness of the 95PPU) were used. Validation performance assessment were utilized to update the SWAT model for final model simulation of sediment and hydrological impacts. Land erodibility, runoff intensity, and sediment accumulations downstream rely strongly on land use induced factors than on land size.

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