Hydrological Analysis of Loko Watershed Using Arc SWAT and HEC-HMS: A Tool for Vital Geospatial Information

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***Abstract*— This study analyzes Loko watershed from the hydrological point of view using Arc SWAT and HEC_HMS. The Arc SWAT, an Arc Map extension interface was used to delineate and simulate the watershed to extract spatial parameters useful for the hydrological simulation and soil-water relationship analysis. The objective is to simulate the hydrologic behaviour of flow discharge with respect to, land use, soil, slope, and water movement from the upstream areas in order to analyze its effect on the Loko settlement. The Arc SWAT was used to provide the needed hydrologic flow parameters from ASTER DEM, while simulation of flow discharge was done in the HEC_HMS. Weather data for SWAT simulation were downloaded from the National Centers for Environmental Prediction's Climate Forecast System Reanalysis (CFSR) website. Land use and soil data were downloaded from the NASA Reverb/ECHO and the Harmonized World Soil Data (HWSD) web sites respectively. Results from the study show that the location of Loko settlement at the junction of clustered pour points and a strategic transition slope of the uppermost trough of the Benue River, is identified as one of the major factors for persistent flooding. The second factor identified is that the volume discharge per cubic meter seconds (cms), is high at this junction and thirdly, the porosity index of the upstream and low stream soils which encourages high flooding. It has also proven that the study is useful for organic minerals analysis. This information is a useful and vital hydrological data for planning mitigation measures against flood: through adequate engineering design and standard, and for soil analysis, useful for agricultural purposes.**

***Keywords*— Loko Watershed, Hydrology, Arc SWAT, HEC-HMS and Geospatial Information**

I. INTRODUCTION

Loko settlement has increasingly become an area of ecological study in the recent past, not because of its size or political importance, but because of the persistent flood in the area. None the less, it is an important vegetables layover point for travelers along the Mubi/Yola axis of Adamawa state in Nigeria. Its spatial location with respect to its vertical coordinates plays no small role in the hydrological behaviour of its watershed. A watershed is an area of land bounded by boundaries in which all the water that falls in it goes into the same place and is discharged from a common outlet. The analysis of a watershed therefore, refers to the process of delineating the morphology of a watershed using digital elevation model (DEM). The morphology gives a physical visualization of the hydrologic features such as the channels, flow direction, the basin and the sub basins in the entire watershed. These hydrologic features are useful inputs for delineating flood prone areas and stream flow analysis (Tumba and Amusuk, 2017) in the basin and sub basins. The flow of water in the basin and sub basins in conjunction with land use, soil, slope and weather data provide useful hydrologic data for the analysis of organic nutrients of the soil useful for agriculture and water quality management.

The soil and water assessment tool (SWAT) developed by the United States Department of Agriculture (USDA) has been at the fore front of providing hydrological models for the management of useful watersheds and river basins across the world (Tuppad *et al.*, 2011). However, the case of lack of readily available spatial data and or conventional weather data in most developing economies (Tumba and Ahmad, 2014; Dile and Srinivasan, 2014) is an impediment to SWAT modelling, especially data for calibration and validation. This is because most of the rivers or water channels are ungauged. In such instances, the option readily available is to use the United States' hydrologic engineering center (HEC) hydrologic modelling system (HMS) for flow discharge simulation. However, aside from flood simulation, this study limits itself to the derivation of hydrologic parameters that could be used by environmentalists, soil and agricultural managers, and researchers in the study area for calibration, claims and validation.

II. HYDROLOGICAL ANALYSIS

USGS, 2016 defines hydrology as the occurrence, movement, distribution, and quality of the water and their environmental watershed sustainability. The knowledge of the hydrology of a watershed has been identified to be an economically viable and ecologically safe method for planning in water resources management (Tumba and Amusuk, 2017; Mockler *et al.*, 2016; USGS, 2016). In order to analyze the hydrology of a watershed, spatial information depicting the flow of water through the channels identifying the direction of flow, drainage lines, flow accumulation, and defining the streams must be known. The segmentation of the streams defining the catchments and or sub basins help to analyze sedimentation in the reaches and soil water interaction from downward flowing water from upstream catchments into the lower drainage channels. These relationships provide enough spatial hydrological evidence to delineate potential flood areas and enable identification of chemicals and nutrients in the soil for agricultural purposes.

A. Swat Modeling

As earlier stated in the previous section, the SWAT is a soil and water modelling tool developed by the USDA for soil-water interaction from DEM. It is designed to predict the effect of land use and management on sediment, and agricultural chemical yields in ungauged watersheds with respect to soil-water interaction (Arnold *et al.*, 2012). SWAT modelling involves a continuous computational process of simulation using DEM, land use, soil and weather data of the same spatial reference coordinate system. The model is capable of delineating the basin, sub basins, longest flow parts, monitoring points at any designated or chosen outlet. SWAT model divides a watershed into various sub watersheds, which are additionally segmented into hydrologic response units (HRU). The HRUs consist of areas having similar land use, soil, and slope characteristics, and are defined in terms of percentage of the sub watershed area. These land use, soil and topography relationship is useful for studying the soil-water interaction for agricultural purposes, and also in the response of the soil type to excessive rain, so that areas susceptible to flooding can be identified.

B. Soil and Water Interaction

The soil-water interaction is an important reaction that helps to analyze the geochemical content of the soils. Soil-water prompted by seasonal wetting-drying cycle has been adjudged as a complex phenomenon (Zhan, 2007). Rain water infiltration into soil cracks allow disintegration of soil mass and provide easy path ways for soil-water reaction as it flows from region of high slopes to low ones. This flow movement allows for the assessment of the soil chemistry, soil physics and erosion mechanics of the soil.

The soil Chemistry gives aggregate stability, solidity and salinity of the soil based on the wetting effect of the type of soil. The soil physics on the other hand gives the hydraulic characteristics of the soil surface layer which defines its infiltration and runoff capabilities. The erosion mechanics on the other hand provides the sediment concentration of the soil organic parameters like organic nitrogen and phosphorus vital for plant needs (Greene and Hairsine, 2004). In most agricultural settings, land managers and agriculturists require this spatial information for decision making for sustainable agriculture and erosion mitigation measures (Lark *et al.*, 2016). The inability to control erosion leads to flood the effect of which can damage both human, plants and other species' lives in an ecosystem.

C. Flood

The occurrence of flood after any torrential rainfall has been a continuous re-occurrence decimal in many areas around the globe. In simple term, flooding occurs when stream or river channels are not able to contain the volume of flowing water leading to overflow of the channels or river banks (Tumba and Amusuk, 2017). In most cases, the flooded areas are places of low elevation which receive fast flowing water from elevated points. However, the delineation of flood potential areas may not hinge on the water channels alone, but also on the type of hydrologic soil group. In spite of the damages which come along with flooding, Loko enjoys rich alluvial deposits from the flood which is useful for agriculture.

III. STUDY AREA, MATERIALS AND METHODS

A. Study Area

Loko, the study area, is in Song local govern area of Adamawa state in Nigeria. Its geographical location is between latitude 9˚ 30' N and 9˚ 55' N and longitude 12˚ 18'E and 12˚ 45'E as shown in Fig. 1. As earlier stated in section 1, it is a vegetables layover point for travelers along the Mubi/Yola axis whose activities have been increasing over the years.

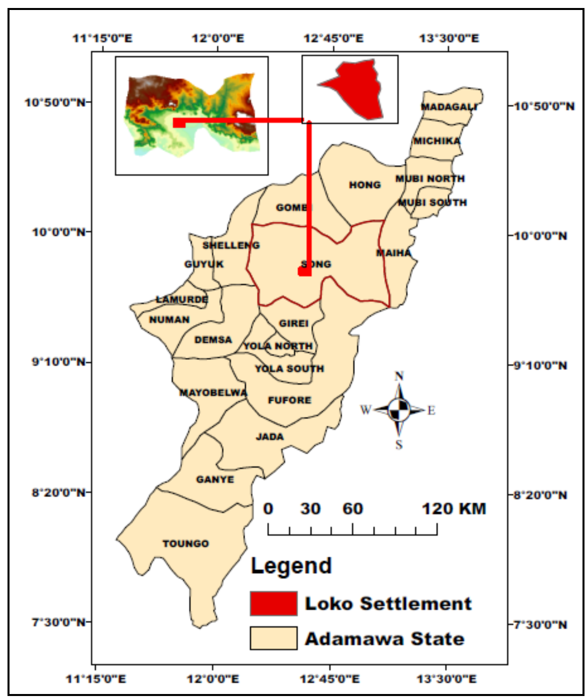

Fig. 1: Map of Adamawa state showing the study area

B. Materials and Methods

The thermal Emission and Reflection Radiometer (ASTER) digital elevation model (DEM) was used as the base map. Weather data which includes temperature, relative humidity, solar radiation, rainfall and wind speed for SWAT simulation were downloaded from the National Centers for Environmental Prediction's Climate Forecast System

Reanalysis (CFSR) website. Land use and soil data were downloaded from the NASA Reverb/ECHO and the Harmonized World Soil Data (HWSD) web sites respectively. The ArcGIS 10.3 software, with Arc SWAT extension installed, and the United States' hydrologic engineering center (HEC) hydrologic modelling system (HMS) software were used for the processing of the spatial information. Watershed delineation in the SWAT model was carried on based on the DEM as against pre-defined streams and watersheds. The outlet for the entire basins of the watershed was defined from DEM delineated streams. This enabled the calculation of the watershed parameters by the SWAT software. The HRU analysis was done based on the added user-defined land use and soil maps in conjunction with the processed slope parameters from the DEM. Weather data downloaded from NASA web site which includes; temperature, rainfall, solar radiation, wind speed and relative humidity enabled running of final simulation for the SWAT model. Modelling was done based on a non-United States (US) jurisdiction, since it is outside the US. Simulation period of 20 years (1990-2010) with a skip period of three (3) years was applied. The HEC-HMS tool in conjunction with the curve numbers (CN) and precipitation parameters obtained from the SWAT was used for simulating flow discharge from the upstream channels to the lower ones out into the outlet.

The operation in the HEC-HMS involves creating a basin model for the entire catchment, in which the 17 sub basins were identified and marked. Stream junctions, reach elements (used to convey stream flow) and outlets were marked, based on the combination of the drainage lines and the sub basin divides or adjoint catchments (Tumba and Amusuk, 2017). A 24hour ungauged simulation was applied to simulate the behaviour of flow from the sub basin channels. An initial abstraction of zero, meaning; water droplet to start from zero, was used for the sub basin and the Muskingum method was used for routing the flow of water.

IV. RESULT AND ANALYSIS

Result from the SWAT model (Fig. 2) shows the delineated watershed which forms the area known as Loko watershed. This watershed constitute areas from which runoffs flow into Loko and is made up of seventeen (17) sub basins as shown in Fig. 3 and 96 HRU as show in Table I.

A. Delineated Watershed

Fig. 2 shows the delineated watershed of Loko with the reaches (water connecting stretches) and their pour points (water meeting points). Loko settlement is located at the elbow of clustered points as shown in Fig. 3. The longest flow paths indicating uninterrupted down stream flows are also shown. The contributing sub basins which form the entire watershed are clearly delineated from the DEM.

Each of the 17 sub basins have their own characteristic chemical response patterns to the flow of water, based on the type of vegetation and soil type inherent in the area with respect to slope as shown in Table I. For instance the curve number (CN) of a type of vegetation determines its response to erosion, and is a function of the hydrologic soil group. Soils in group C have high infiltration rate of 1.3-3.8 with high

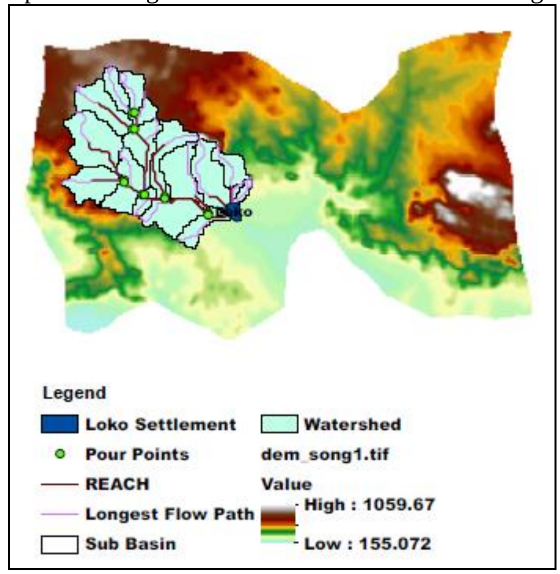

Fig. 2: Song Local Government Showing Delineated Loko Watershed

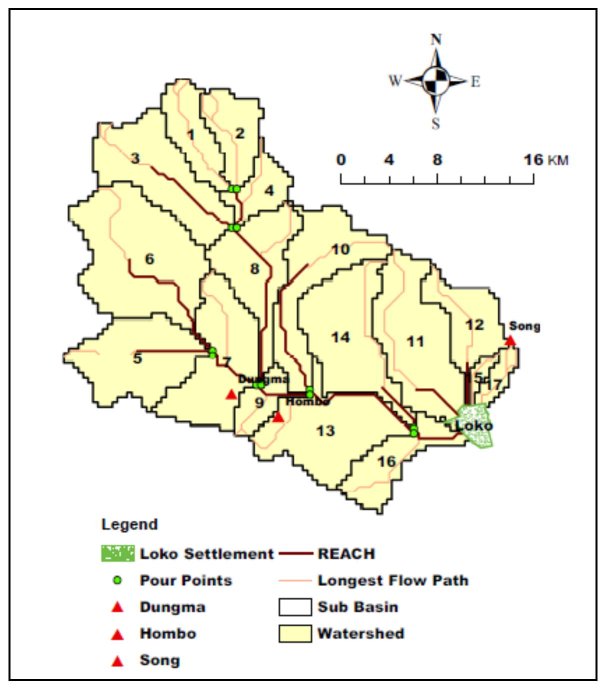

Fig. 3: Loko Watershed showing the 17 Sub basins

erosion K factor of 0.28, while soils in group D have low infiltration rate of between 0-1.3 and low erosion K of 0.24. Invariably it is expected that soils in group D can resist erosion more than that of group C. These are important spatial information useful for agriculture and engineering designs.

B. Hydrologic Response Units

As earlier stated, HRUs consist of areas having similar land use, soil, and slope characteristics, defined in terms of percentage of the sub watershed area. From Table II, the watershed is about 75599 hectares. Cropland/grassland mosaic (CRGR) has the largest land use of about 48580.1408 hectares, which is about 64.26% of the total watershed. The second largest land use is the savannah (SAVA) which is about 32.11%. Obviously, there is less presence of cropland/woodland mosaic (CRWO) indicated by the 0.98%, and the near absence of deciduous broadleaf forest (FODB) having 0.09%. This distribution is further highlighted in Fig. 4.

Table I: Soil Response Parameters of the 17 Sub basins

Sub Basin	**CN (SCS)**	**Soil Hydro Group**	**Erosion K**
1	81	C	0.28
2	81	C	0.28
3	81	C	0.28
4	81	C	0.28
5	81	C	0.28
6	81	C	0.28
7	81	C	0.28
8	81	C	0.28
9	85.50	D	0.24
10	81	C	0.28
11	85.50	D	0.24
12	85.50	D	0.24
13	85.50	D	0.24
14	81.00	C	0.28
15	85.50	D	0.24
16	85.50	D	0.24
17	85.50	D	0.24

Table II: Land use, Soil and Slope

SWAT model simulation Date: 8/31/2017 12:00:00 AM Time: 00:00:00			
MULTIPLE HRUs Land Use/Soil/Slope OPTION		THRESHOLDS: 0 / 0 / 0 [%]	
Number of HRUs: 96			
Number of Sub basins: 17			
	Area [ha]	Area [acres]	
Watershed	75599.0540	186809.0425	
	Area [ha]	Area [acres]	%Wat.Area
LANDUSE:			
CROPLAND/GRASSLAND MOSAIC → CRGR	48580.1408	120043.956	64.26
SHRUBLAND → SHRB	1937.1415	4786.7736	2.56
SAVANNA → SAVA	24273.2257	59980.3543	32.11
CROPLAND/WOODLAND MOSAIC → CRWO	741.1672	1831.4612	0.98
DECIDUOUS BROADLEAF FOREST → FODB	67.3788	166.4965	0.09
SOILS:			
I-Re-a-1292	3992.1960	9864.9160	5.28
I-Re-b-1294	37715.3035	93196.4006	49.89
Lf48-1a-1473	33891.5545	83747.7258	44.83
SLOPE:			
0-10	72567.0064	179316.701	95.99
10-20	2829.9111	6992.8519	3.74
20-30	202.1365	499.4894	0.27

Fig. 4 shows that the areas of cropland/grass mosaic are settlements where farming activities are prevalent. These are areas around Dungma (Dumne), Hombo and Song. The higher elevated mountains consists of Savannah grass lands.Greater percent of the soil in the study area is of the C group sub-classes, having the Food and Agricultural Organization’s (FAO’s) usersoil codes I-Re-a-1292 and I-Re-b-1294. Most of the areas have average slope of 0-10. Slopes between 10-20 and 20-30 are found around song settlements. This land use, soil and slope parameters help trmenduously in the geochemical behaviour of organic sediments as the flow down the stream.

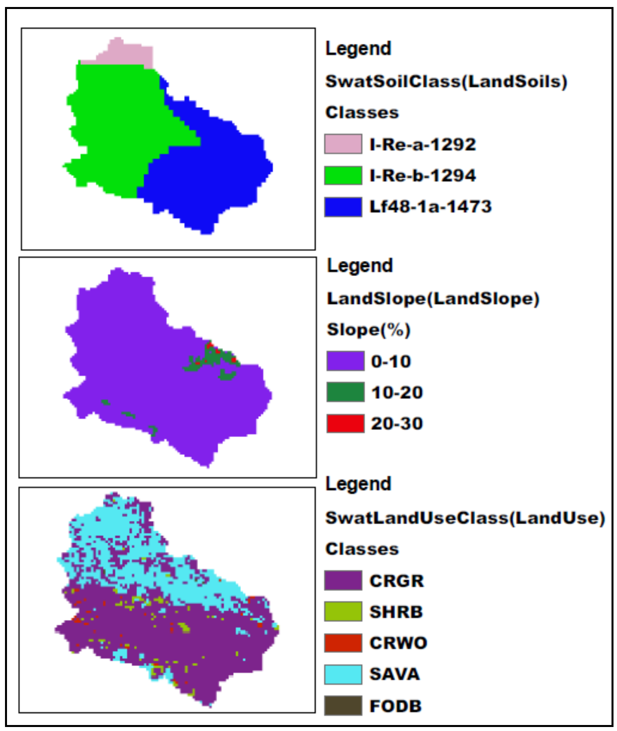

Fig. 4: Distribution of, Soil, Slope and Land use in Loko Watershed

C. Organic Content

The average organic content for sediments, nitrogen and phosphorus per hectare in the study area for each sub basin is shown below in Fig. 5 for the year 2000. It is evidenced that sub basins 9, 11 and 12 have the highest values of organic nitrogen per hectare for the year 2000. These are areas between Dungma and Hombo, and Song. This may not be unconnected with the fact that these areas are cropland/grass and mosaic (CRGR) as observed in Table I and Fig. 4. Hence, because of farming activities are likely to have high concentration of organic nitrogen, while sediment concentration along with phosphorus is low. Although sediment deposition along with nitrogen and phosphorus are used as examples in this study, the SWAT has the capability of analyzing many other geochemical minerals useful to many disciplines.

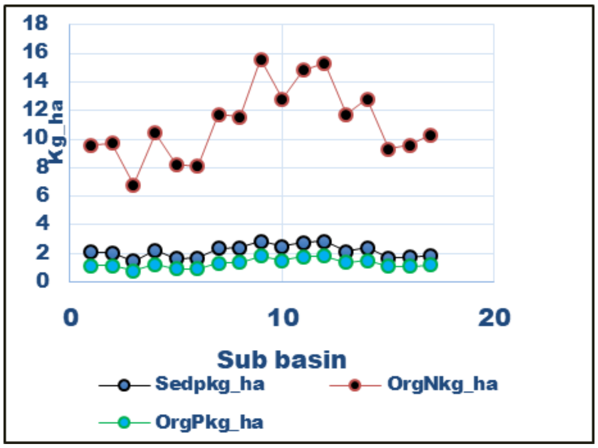

Fig. 5: Graph of Sediment, Organic Nitrogen and Phosphorus per Sub basin for the year 2000

D. Flow Discharge

The discharge for the 17 sub basins are highlighted in Table III and the flow discharge in the reaches (8 of them) shown in Fig. 6. It can be clearly seen that the discharge at the outlet is the same as reach 1, this is because the outlet finally receives the total amount of flow from all the reaches through reach 1. The highest peak discharge of 180.5 M³/s is therefore the same for the two.

Table III: Hydrologic Elements of 17 Sub basins

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
Subbasin-1	27.37	6.3	01Jan2000, 22:00	7.97
Subbasin-2	27.7	6.3	01Jan2000, 22:00	7.97
Subbasin-3	62.98	14.4	01Jan2000, 22:00	7.97
Subbasin-4	19.13	4.4	01Jan2000, 22:00	7.97
Subbasin-5	59.19	14.1	01Jan2000, 22:00	8.31
Subbasin-6	95.63	22.8	01Jan2000, 22:00	8.31
Subbasin-7	60.18	15.3	01Jan2000, 22:00	8.68
Subbasin-8	49.46	11.8	01Jan2000, 22:00	8.31
Subbasin-9	16.16	5.6	01Jan2000, 14:00	13.07
Subbasin-10	57.21	14.5	01Jan2000, 22:00	8.68
Subbasin-11	68.59	23.4	01Jan2000, 14:00	12.82
Subbasin-12	33.47	11.9	01Jan2000, 22:00	13.31
Subbasin-13	65.79	23.4	01Jan2000, 22:00	13.31
Subbasin-14	63.64	16.2	01Jan2000, 22:00	8.68
Subbasin-15	6.9	2.8	01Jan2000, 22:00	13.69
Subbasin-16	30.99	11	01Jan2000, 22:00	13.31
Subbasin-17	11.54	4.7	01Jan2000, 22:00	13.69
Junction-6	154.82	36.9	01Jan2000, 22:00	8.31
Reach-6	154.82	34.8	01Jan2000, 16:00	7.51
Junction-8	55.07	12.6	01Jan2000, 22:00	7.97
Reach-8	55.07	12.2	01Jan2000, 19:00	7.19
Junction-7	137.18	30.3	01Jan2000, 22:00	7.66
Reach-7	137.18	30	01Jan2000, 20:00	6.89
Junction-5	401.64	88.4	01Jan2000, 22:00	7.57
Reach-5	401.64	87.4	01Jan2000, 20:00	6.8
Junction-4	475.01	105.1	01Jan2000, 18:00	7.24
Reach-4	475.01	105.3	01Jan2000, 19:00	6.46
Junction-3	673.03	164.4	01Jan2000, 22:00	7.99
Reach-3	673.03	159.1	01Jan2000, 19:00	7.14
Junction-2	33.47	11.9	01Jan2000, 22:00	13.31
Reach-2	33.47	11.6	01Jan2000, 15:00	12.21
Junction-1	755.93	182	01Jan2000, 22:00	7.78
Reach-1	755.93	180.5	01Jan2000, 20:00	6.95
OUTLET	755.93	180.5	01Jan2000, 20:00	6.95

From this simulation, it is expected that water flowing from the uplands down to Loko settlement will start to increase from about 07:00 hrs., as indicated in Fig. 6, and will reach its peak in the 22:00hrs. This situation is for a case where there are no underground water and initial simulation droplet is zero. Hence the combined accumulated hourly flow of water at the Loko outlet can be properly visualized from Fig. 7. This situation combined with the porosity index of soils in Loko settlement might probably be the reason for the incessant flooding of the area. On the positive side, this too might be the reason for the fertile soil of Loko as a result of the deposit of rich alluvial soils from the upstream.

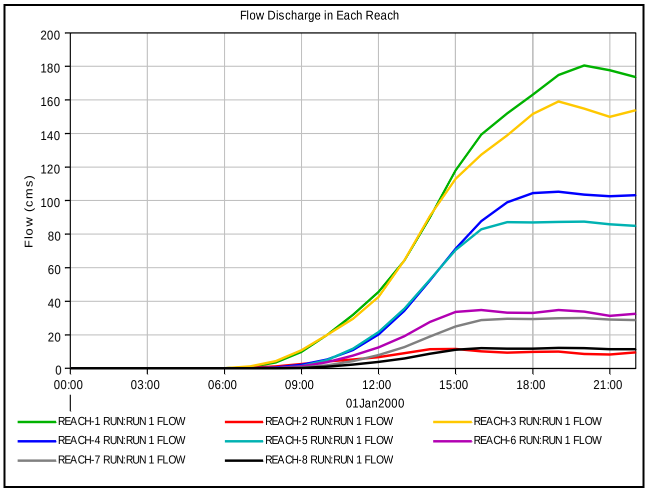

Fig. 6: Flow Discharge for the Reaches in the Sub basins

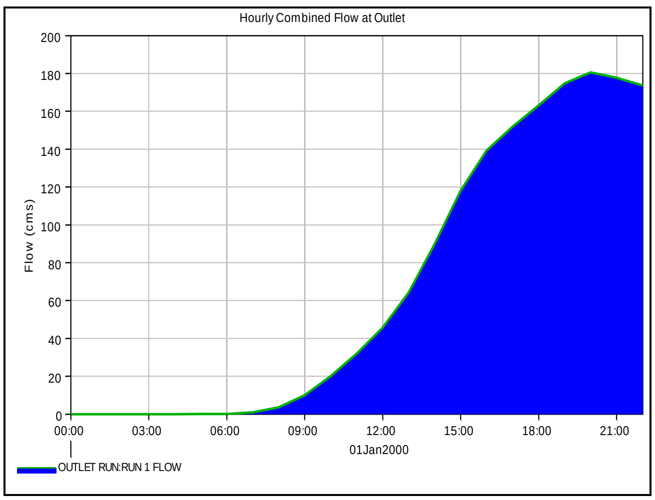

Fig. 7: Hourly Combined Flow at Loko Settlement

E. Flood Area Delineation

Delineating flood prone areas is one of the first steps to providing mitigation measures in order to curtail flood. Fig. 8 shows Loko settlement and the simulated flood levels for 230m and 240m above mean sea level. It is observed that any water level up to 240m completely submerges Loko and the areas beyond it, while water levels less than 230m is good for the settlement.

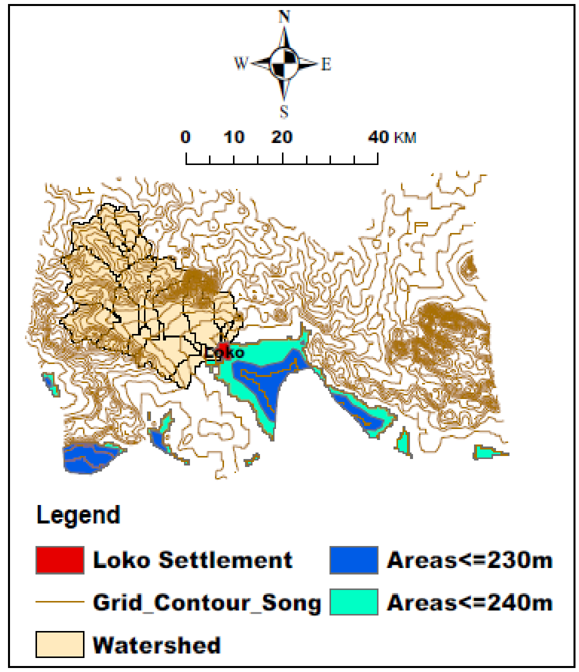

Fig. 8: Loko Settlement Flood Level Model

Hence any planning for flood mitigation must take into consideration the level beyond which flood is likely to occur. This however does not mean identifying flood prone areas solves the problem of flooding. For example, as stated in the previous sections, Loko settlement is located at the elbow of clustered pour points and the hydrologic soil is D; which does not allow easy infiltration. This makes the area prone to constant flooding.

V. CONCLUSION

SWAT simulation is complex because of its large volume of data output, hence extraction of spatial parameters of interest for a particular chosen year is necessary for any meaningful study. However, this study has been able to use the drainage characteristics of the area to provide useful hydrologic and hydraulic models that can be used for engineering and agricultural purposes. It has also identified that the location of Loko at clustered pour points, and the porosity index of the group D soil, prevalent in the area; which does not allow easy penetration is one of the causes of constant flooding. Added to this is the advantage it has from deposits of organic minerals from upstream; making it a fertile agricultural land. Although the area enjoys this advantage, it is not easy however to proffer lasting solution to the problem of flooding. However, in order to proffer mitigation measures against this constant flooding, works towards arresting the situation at the clustered pour points, at the elbow, should be done. This should be geared towards making the settlement a washland so that agricultural activities in the area can be enhanced.

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