JOURNAL OF SCIENCE AND SUSTAINABLE TECHNOLOGY

E-mail: jsae@mouau.edu.ng. Website: www.mouau.edu.ng.

Modelling of Tubo Sub- Watershed Hydrological Processes Using GIS and SWAT Model

Salami, I.A
National Water Resources Institute, Kaduna, Nigeria

Adeogun, B.K
Ahmadu Bello University, Zaria, Nigeria
Corresponding e-mail: adedotun.salami@gmail.com

Abstract

This study modeled streamflow at the outlet of the gauged Tubo Dan Mari Watershed and also analyzed the associated uncertainty which could affect the accuracy in estimation of the streamflow. The Soil and Water Assessment Tool (SWAT) model was applied to estimate the streamflow of the Tubo Dan Mari catchment and associated uncertainty with the simulated outputs to that effect. The SWAT model was calibrated for the period of 1983 to 1986 and validated for the period of 1987-1988 based on the six parameters identified during sensitivity analysis. The uncertainty analysis was done by using Sequential Uncertainty Fittings Version 2(SUFI-2) and Generalized Likelihood Uncertainty Estimation (GLUE) was used to check parameter uncertainty, SWAT CUP was used to establish the uncertainty bounds of the model. The calibration and validation of the model were found acceptable as performance rating criteria value of coefficient of correlation (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) was found to be 0.80 and 0.73 for calibration and 0.81 and 0.50 for validation respectively. In the same order from the model uncertainties analysis the percentage of the simulated data within the uncertainty bound was only 33% for calibration and 29% for validation, which showed that there was uncertainty in the process. After that, SWAT CUP parameter uncertainty was tested and found with E_{NS} value of 0.75 for calibration and 0.71 for validation and this showed that the overall associated uncertainty was from either conceptual or input or a combination of both but not from parameter identification. The average annual inflow volume at the watershed outlet was estimated and predicted to be 2.78575MCM which was in line with other predicted parameters during this study.

Keywords: Hydrological Modeling; Tubo Dan Mari Watershed; Calibration; Validation; SWAT; ArcSWAT

Introduction

Water is very important for sustaining life, development and the environment. The availability of water is the key determinant of economic growth, development and social wealth, assets and possessions. Competing water needs trigger conflicts between desperate water users such as the rich and the poor, or between different sectors and regions, such as domestic and agriculture, agriculture and industry, agriculture and fisheries, upstream and downstream, rural and urban areas, Aquaculture and fisheries and flood control.

Moreover, Watershed is an area drained by a stream in such a way that all flows originating in that area is discharge through a single outlet. Watershed is also known as drainage basin or catchment or drainage area. Watershed is also a hydrologic unit which receives water as an end-product of the interaction of atmosphere, land surface and ocean systems. Streamflow is also the volume of water which pass a fixed point over a unit of time and it is usually expressed in cubic metre per second (m^3/s). Streamflow reflects the amount of water moving off the watershed and into the channel and the amount being removed from the stream. It can be affected by many factors and can vary rapidly as those factors change. Streamflow is also affected by both natural and human factors and can respond rapidly to changes in flow parameters (Van Liew et al., 2003). Evaporation and water use by plants significantly affect streamflow. Vegetation has the largest impact on flow during dry season when temperatures are high and streamside vegetation uses the most water. It is also being influenced by subsurface water flow which responds to the same factors, but at a delayed or slower rate. Seasonal variations in streamflow, coupled with increased and competing demands for water by a growing population, place considerable pressure upon efficient management of available water resources.

This is especially true for the management of reservoir storage and water release during and at the end of the dry season when water demand is highest and streamflow supply is low. Adequate streamflow allows for erosion, transport and deposition of sediment or stream-bed load. Fast-moving streams will keep sediments suspended longer. Therefore, the predictions and assessments of streamflow are essential for agricultural watershed management as well as sustainable development in the water resources sector. Water is the most important natural resource especially in the arid or semi-arid zones that face high population growth, scarcity of freshwater, irregularity of rainfall, excessive land use change and increasing vulnerability to risks such as drought, desertification and pollution. Thus, the availability and the sustainable use of this resource become the core of the local and national strategies and politics in these regions. Managing water resources is mostly required at watershed scale given that it is the basic hydrologic unit which studies the heterogeneity and complexity of processes and interactions linking land surface climatic factors and human activities. This adopted approach for assessing water quantity and quality was then expressed as various hydrologic models and tools that try to simulate and predict the watershed response at different spatial and time scales respectively.

The application of SWAT model and its parameterization using SWAT CUP (SUFI- 2 and GLUE) under GIS platform provides advance option in hydrological modeling which create control environment between large amounts of data sets during parameter sensitivity analysis. The long time-series real data of rainfall, minimum and maximum temperature, relative humidity, wind speed, solar radiation and discharge were available at the gauging station and these were applied to simulate the model parameters and calibrate streamflow correlation between simulated and observed data. Higher standards of living, demographic changes, land and water use policies, and other external forces are increasing pressure on local, national and regional water supplies needed for irrigation, energy production, industrial uses, domestic purposes, and the environment. Hydrological models are important tools for planning sustainable use of water resources to meet various demands. Sustainable watershed management requires thorough knowledge of water resources, including streamflow. Therefore, understanding the hydrologic processes in a watershed and their prediction are challenging tasks of hydrologists *(*Srinivasan, M.S 2005*).* Distributed hydrologic models have significant applications in the interpretation and prediction of the effects of land use change and climate variability on parameters pertaining directly to physically observable land surface characteristics. In particular, physically based distributed hydrological models, whose input parameters have a physical interpretation and explicit representation of spatial variability, which are used to solve complex problems in water resource management *(Beven 1989; 2002;* Srinivasan, M.S *2005).* Initial parameters for distributed datasets describe soils, vegetation, and Landuse; however, these so-called physically based parameter values are often adjusted through subsequent calibration to improve streamflow simulations. In other words, some model parameters are physically based and can be measured while in some models parameters can only be estimated by calibration *(Beven, 2006; Beven, Binley 1992; Beven, Freer 2001; Boyle et al., 2000).*

The Soil and Water Assessment Tool (SWAT) *(Arnold et al., 1998)* has been applied as a physically based hydrologic model to manage and assess water resources, including arid regions of some African countries *(Veith et al., 2005).* The SWAT program is a comprehensive, semi-distributed, continuous-time, processed-based model *(Arnold et al., 2012).* The program can be used to build models to evaluate the effects of alternative management decisions on water resources and the non-point source pollution in large river basins.

2.0 Materials and Methods

2.1 Description of the Study Area

Tubo Dan Mari Catchment Area consists of the main river; River Tubo and the three major tributaries; Chidawaki, Gora, and Kajuru Rivers and also serve as a tributary of River Kaduna in Kaduna town and the land area delivering runoff water, sediment and dissolved substances into the rivers. The basin is a sub-hydrological area in the Hydrological Area II in Nigeria hydrological areas which catching, storing, and releasing water through networks of streams into the main river draining into Kaduna River. It stretched from Birnin Gwari to Kwona Mutua to Kufara Kan Hauwa to Buruku at the northern part of Kaduna metropolis in Igabi Local Government Area to Romi in Chikun Local Government Area towards the southern part of the Kaduna metropolis. It covers about 23,325.27ha of land area within latitude $10^{0}30'$N to $11^{0}00'$N and longitude $7^{0}00'$E to $7^{0}30'$E.

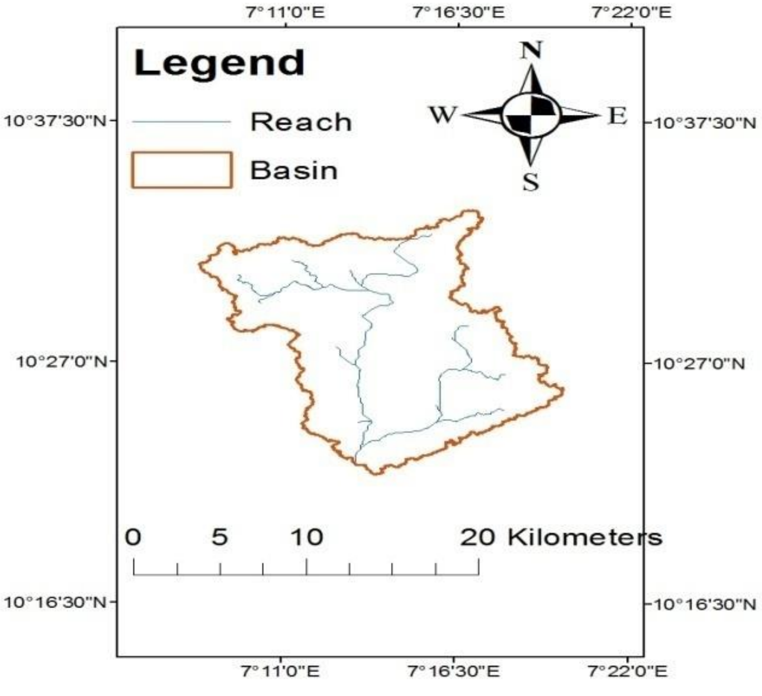


Figure 2.0 Map of Tubo Dan Mari Catchment

2.2 Materials used

The following materials were used during this research;

(i) Temporal (Hydro-meteorological) Dataset
   (a) Hydro-Streamflow data (1983-1988)
   (b) Meteorological data (1979-2014) such as Precipitation, Minimum and Maximum Temperature, Solar radiation, Relative humidity and Wind speed

(ii) Spatial (Physiographical) Dataset such as SRTM Digital Elevation Model (DEM), Land use/Land cover and Soil data

(iii) Software such as Geographic Information System (ArcGIS 10.4), ArcSWAT 2.3.4, SWATpad/graph, Microsoft Excel 2013, Microsoft Access 2013

2.3 Methodology adopted

2.3.1 Creation and collection of databases

The simulation of the water balance of an area by ArcSWAT model requires a large amount of spatial and time series datasets in order to establish the water balance equation. The main sets of data used are briefly explained below:

2.3.1.1 Physiographical datasets

The topography, land use/land cover and soil characteristics are physiographical datasets which defines the land features of any area that is the most requirement of the hydrological model. Then, the input part of SWAT model includes a section from land features in form of DEM, land use and soil.

2.3.1.2 Digital Elevation Model (DEM)

The SRTM DEM of 90 m resolution (HTML: CGIARCSI) was downloaded from the International Centre for Tropical Agriculture (CIAT) website (http://srtm.csi.cgiar.org/) and processed for the extraction of flow direction,flow accumulation, stream network generation, watershed delineation and sub-basins. Moreover the topographic parameters such as terrain slope, channel slope or reach length were also derived from the DEM. Furthermore, from the present cram of ArcSWAT model, the Tubo Dan Mari watershed covers an area of 233.253 km^2 with an elevation ranging from 482m to 690 m. The whole watershed was segmented in a total number of 23 sub-basins as it depends on the topographic characteristics.

2.3.1.3 Land Use/Land Cover Data

Most of the time in watershed management, changes in land use and vegetation really affect the hydrological processes and its influence is a function of the density of plant cover and morphology of plant species. Land-use data (West Africa Land Use Land Cover Time Series two-kilometer (2-km) resolution land use land cover (LULC) 2013) with 26 classes of land-use representation was constructed by USGS Earth Resources Observation and Science (EROS) and was downloaded from https://eros.usgs.gov/westafrica. The land use classes were converted from original land use classes to SWAT classes and defined using a lookup table.

2.3.1.4 Soil Data

The Soil map was obtained mainly from the United Nation Food and Agriculture Organization (HTMAL: FAO-AGL, 2003) and extracted from harmonized digital soil map of the world (HWSD v1.1) which can be downloaded from the link http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/. The database provides for 16,000 different soil mapping units containing two layers (0 - 30 cm and 30 - 100 cm depth). For this study soil samples from different locations within Tubo watershed area were collected from two different layers (0 - 30 cm and 30 - 100 cm depth) and analyzed in soil mechanics laboratory of National Water Resources institute, Mando Kaduna and used to validate the model parameters.

2.3.2 Temporal Datasets

For temporal datasets, the climatic data were required by ArcSWAT to provide the moisture and energy inputs which controlled the water balance and determine the relative significance of the different components of the water cycle. Moreover the rivers in the hydrological regimes may differ significantly in their runoff response to changes in the driving variables of temperature and precipitation to that effect.

2.3.2.1 Meteorological Data

Basically, the long term meteorological datasets of precipitation, temperature, wind speed, solar radiation and relative humidity were required for the hydrological modeling of Tubo Dan Mari Watershed. For SWAT model, the records of precipitation and temperature are the minimum mandatory inputs and the other parameters are optional. The observation data for Tubo Dan Mari site weather station within the study area for thirty-five years (1979-2014) were obtained, from Kaduna State Water Corporation (KADWAC) together with three additional stations; the databases were downloaded and processed with respect to the model input format in that regard.

2.3.2.2 Hydrological Data

For calibration and validation, hydrological datasets of Tubo river flow were required. The data was collected from the concerned agency, Kaduna State Water Corporation (KADWAC). Moreover, a long term flow data were gauged at Buruku (located in $10^{0}32'31.1272''$N, $7^{0}26'09.2047''$E) which is a very close control point Upstream of the Tubo River. The historic daily flow data were available for the period 1983–1988 for both calibration and validation of flow simulation.

2.3.3 Projected Coordinate System

In any projected coordinate system, the requisite spatial datasets were processed from the Geographic Coordinate Systems (WGS 1984) to projected coordinate system WGS 1984 UTM Zone 32N, the Transverse Mercator Projection, the project area falls between Zone 32 of Northern Hemisphere. The GIS data was masked by a "Focus Mask" which was clipped to the study area.

2.3.4 Digital Elevation Model for Watershed Delineation

Hydrologic modeling of Tubo Dan Mari watershed was carried out using the ArcSWAT version 2.3.4. Then, to start the ArcSWAT Interface, ArcMap was started and an empty document was opened, On the Tools menu, Extensions was clicked and three extensions were checked for ArcSWAT to run: Spatial Analyst, SWAT Project Manager and SWAT Watershed Delineator. Then to start the Automatic Watershed Delineation (AWD), the Automatic Watershed Delineation item from the Watershed Delineation menu was clicked and the Watershed Delineation dialog opens the DEM after a few minutes. Moreover, the name of the elevation map grid was displayed in the DEM text box on the Automatic Watershed Delineation (AWD) dialog box. Moreover, it is very important for the 'Elevation Units' to be in meters, as it was set in meters earlier and the 'Mask' may be manually selected from the file if there is a shape file that was already demarcating the area of interest. Therefore, the mask was selected as a shape file and the first part of the watershed delineation icon was then run which took some few minutes. Then the threshold size for sub-basins was set next by area in hectares but it can be set by area in various units such as sq.km or hectares, or by number of cells available. Furthermore, the second run button to delineate the stream network was clicked in order to complete the whole process to that effect and it is very important to know that there is a need to define the outlet of the watershed and also a prepared shape file could be used or manually done in that regard. Thus, the ArcSWAT interface mark the Automatic Watershed Delineation (AWD) was done and enabled the second step as everything was okay and accepted to that effect.

2.3.5 Creating the Hydrological Response Units (HRUs)

For creating the hydrological response units (HRUs), this step determines the details of the Hydrological Response Units (HRUs) that are used by SWAT. Moreover, this is basically dividing the watersheds into smaller pieces and each of which has a particular soil/landuse (crop)/slope range combination. The Landuse and soil maps were imported and look-up tables for the Landuse classes (from the global Landuse classes) and for the soil (from global soils) were reclassified respectively. The slope of each sub-basin is created by an intermediate point for slopes to divide Hydrological Response Units (HRUs). This Hydrological Response Unit (HRU) feature class button was checked and the overlay command added the land-use, soil and slope layers to project file. After these operations, the HRU definition specifies criteria for land use, soil and slope to be used in determining the Curve Number Grid values (CNGVs). One or more unique combinations can be created for each sub-basin where runoff was simulated separately for each HRU and routed to the stream channel. Hydrological Response Units distribution command access the dialog box used to define the number of HRUs created within each sub-basin in the Tubo Dan Mari Watershed. Then this Step is now reportedly done and now available as various reports concerning the sub-basin, topographic and hydrological response unit properties to that effect.

2.3.6 Write Input Weather Data Table

On the perspective of Write input weather data table, Weather data time series for precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed (i.e. those five basic climatic or weather parameters) were used to update the global weather data for weather generator file prepared from the local climatic condition of the area and the SWAT manual gives the procedure to follow in providing the weather generator file. Moreover, these datasets serve as input to Write SWAT Input Table and this Input menu contains the commands which generate the ArcSWAT geo-database files used by the interface to store input values for the SWAT model. Furthermore, the Weather Stations command was checked to load weather station locations and data for use as earlier displayed on the Write Input menu during the data analysis in that regard.

2.3.7 ArcSWAT Setup and Run

This step involves the setting of the simulation period (start and finish date) and the selection of the weather sources from the SWAT data base. Moreover, the option to choose the methods for the estimation of surface runoff (Curve

Number or Green and Ampt Method), channel water routing (variable or Muskingum method), potential Evapo-transpiration (Priestley, Penman-Monteith, Hargreaves) are available. Furthermore, SWAT was executed using the Runoff Curve Number method for estimating surface runoff from precipitation, the Hargreaves method for estimating potential evapo-transpiration generation, and the Variable-storage method to simulate channel water routing to that effect.

The model was simulated for three Landuse and Land cover types - LULC types (1975, 2000 and 2013) from 01 January 1979 to 31 December 2014 which is the period of availability of climate data, it was also projected with the recent (2013LULC) type to Year 2020 to determine the impacts on the water balance components. Then, Modeling data for the first three years were used to warm up the model while those from 1983 to 1986 were used for the calibration and 1987 to 1988 for validation of the model. At the same time, all the necessary files needed to run SWAT were written at this point in time and the appropriate selection of weather sources done before running the ArcSWAT executables in that regard.

2.3.8 SWAT Output, Streamflow Calibration, Validation and Sensitivity Analysis Using SWATCUP

SWAT output is the result achieved from the simulation and saved it in Microsoft access database and afterward statistically used by other software like SWATCUP and Excel for analysis. Moreover, The SUFI-2 Algorithm (Abbaspour *et al.*, 2004, 2007) in the SWAT-CUP software package (Abbaspour, 2011) was used for model calibration, validation and sensitivity analysis. This algorithm maps all uncertainties (parameter, conceptual model, input, etc.) on the parameters (expressed as uniform distributions or ranges) and tries to capture most of the measured data within the 95% prediction uncertainty (95PPU) of the model in an iterative process.

After setting up the model within ArcSWAT 2012, the model was calibrated and validated using the SUFI-2 algorithm in SWAT-CUP (version 5.1.6.2), basically following the guidelines of (Abbaspour *et al.*, 2007), as the SUFI-2 program within the SWAT-CUP software was utilized for parameter optimization, then, the uncertainty band represented by the 95PPU was used to account for the modeling uncertainty, and is quantified as the p-factor, which measures the ability of the model to bracket the observed hydrograph with the 95PPU.

Finally, the p-factor is simply the fraction enveloped by the 95PPU, thus, the p-factor can be between 0 and 1, where 1 means a 100% bracketing of the measured data. The width of the 95PPU is calculated by the r-factor. The r-factor divides the average distance between the lower and upper percentile with the standard deviation of the measured data. The r-factor ranges from 0 to infinity, and should be below 1, implying a small uncertainty band. The final parameter ranges are estimated and a detailed description of the single parameters is given in Arnold *et al*., (1998).

3.0 Results and Discussion

3.1 Land use

As shown in Table 3.1 and Figure 3.1 the watershed was found to compose of six land use types: Settlement (FRSD), Agricultural Land-Generic (AGRL), Water land (WATR), Forest-Mixed (FRST), Agricultural Land-Row Crops (AGRR) and Forest-Evergreen land (FRSE). Agricultural land-generic close grown (AGRL) and Agricultural land-Row Crops (AGRR) covering the largest (47.44%) and smallest (1.35%) portion of it respectively. The landuse of the area was defined according to SWAT’s system of nomenclature.

Table 3.1. Land use, SWAT of land use, and Total area

No.	Land use	SWAT Land use Class	Area (ha)	% of Total Area
1	Settlement	FRSD	9338.8231	40.04
2	Agricultural Land-Generic	AGRL	11064.4834	47.44
3	Water	WATR	1420.1002	6.09
4	Forest-Mixed	FRST	460.3207	1.97
5	Agricultural Land-Row Crops	AGRR	314.6138	1.35
6	Forest-Evergreen	FRSE	726.9313	3.12
		Total =	**23325.27**	**100**

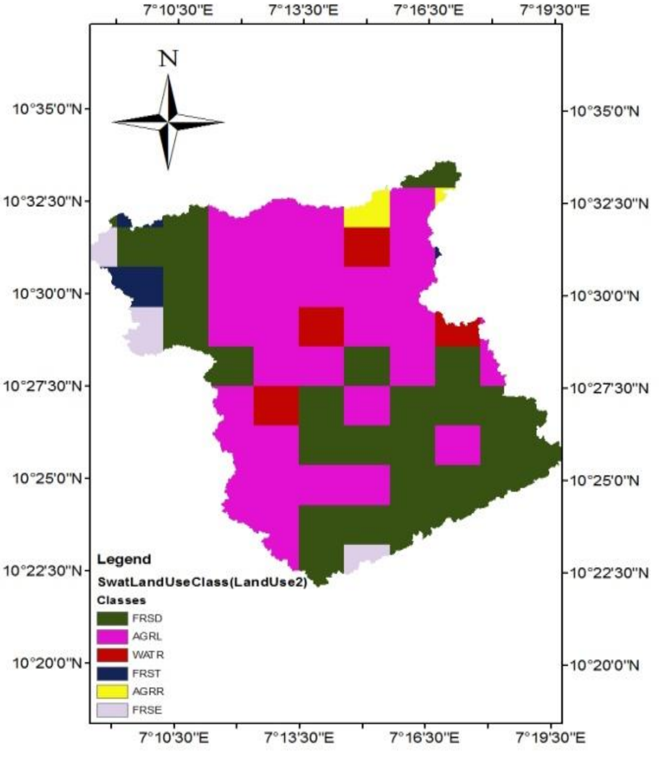


Figure 3.1 Landuse map of Tubo Dan Mari watershed

3.2 Soil

Five soil types were identified in the sub-watershed and the details are shown in Table 3.2 and Figure 3.2 respectively. The Ferric Acrisol and Lithosols-Dystric Regosoil are the major soil types in Tubo Dan Mari Watershed which covers about 79.28% and 11.36% of the overall sub-watershed area respectively. The smallest portion of the area is covered with Plinthic Ferralsols (0.36%), Calcaric Fluvisol (0.36%) and Lithosols-Chromic LuvisolsI (8.63%).

Table 3.2: Soil type classification of Tubo Dan Mari catchment as per FAO-UNESCO soil classification system

No.	Soil Type	Soil Classes defined in SWAT	Area (ha)	Total Area (%)
1	Ferric Acrisol	Af14-3c-1	18491.9524	79.28
2	Plinthic Ferralsols	Fp9-3a-48	84.8778	0.36
3	Lithosols-Chromic LuvisolsI	I-Lc-Re-b-73	2012.9245	8.63
4	Lithosols-Dystric Regosoil	I-Rd-79	2650.6399	11.36
5	Calcaric Fluvisol	Jc4-2a-116	84.8778	0.36
		Total =	**23325.27**	**100**

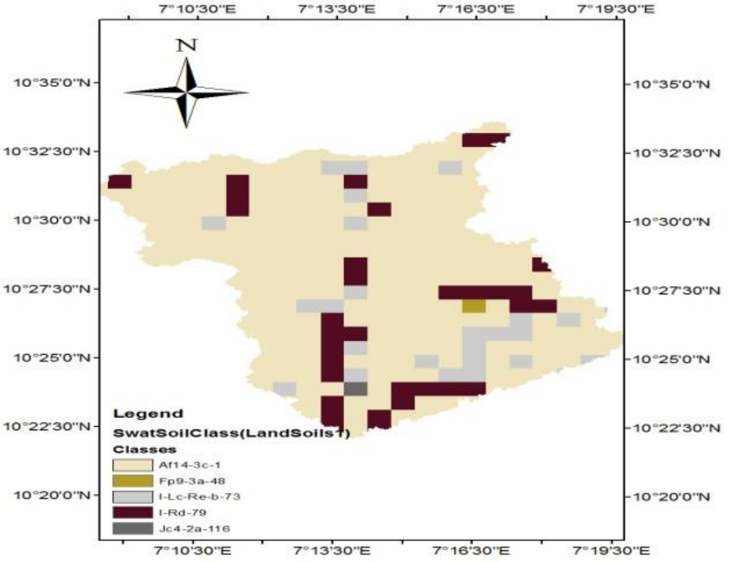


Figure 3.2 Soil map of Tubo Dan Mari Watershed

3.3 Slope

The watershed area of Tubo Dan Mari Catchment was found to have multiple types of slopes and the dominant one is steep slope of 0.5-15%-over which covers about the 86.69% of the total area and slope of 15-30% is the next dominant type of slope with total area coverage of 12.73% of the whole watershed area and slope of 0-0.5% is the less dominant type of slope with total area coverage of 0.12%. The common types of slopes which were found from SWAT analysis of the software is presented in Table 3.3 and Figure 3.3 respectively. This shows that the area is steeped in nature which might lead to erosive action of water erosion since most the area is used for agricultural cultivation purpose.

Table 3.3: Multiple Slope of the Tubo Dan Mari Watershed

No	Slope (%)	Area (ha)	Total Area (%)
1	0-0.5	29.1414	0.12
2	0.5-15	20219.876	86.69
3	15-30	2970.3463	12.73
4	30-99.99	105.9087	0.45
Total		**23325.27**	**100**

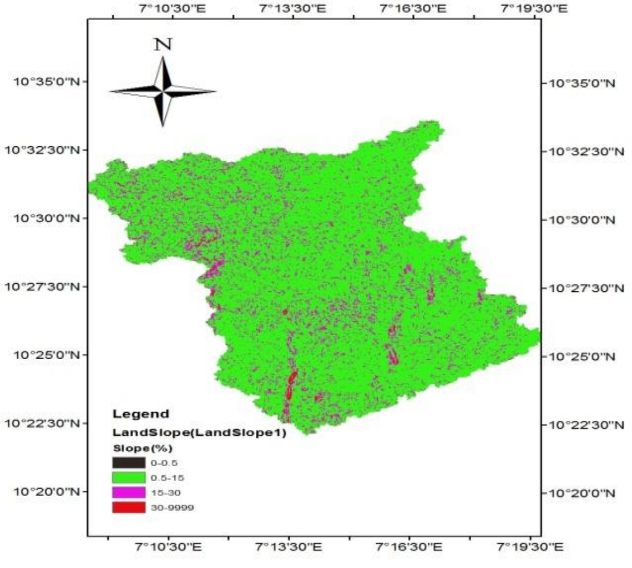


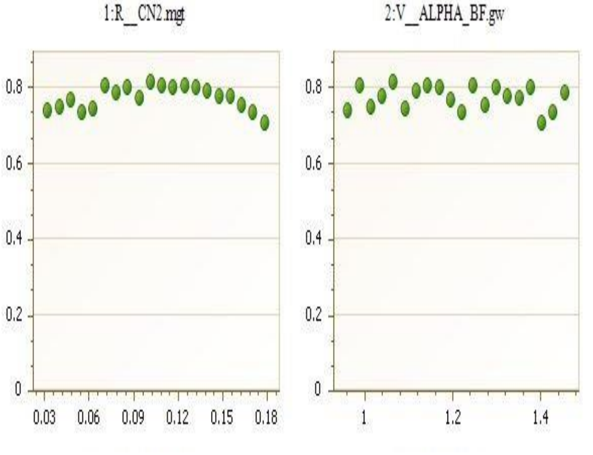
Figure 3.3 Slope map of Tubo Dan Mari Watershed

3.4 Sensitivity analysis

The sensitivity analysis was carried out for a period of four years, which included the calibration period (from January 1st, 1983 to December 31st, 1986). As shown in Table 3.4, the first six parameters showed a relatively high sensitivity, being the alpha factor (ALPHA_BF) which is the most sensitive of them all. The most sensitive parameters controlling the surface runoff in the sub watershed were found to be the curve number (CN2), the soil available water capacity (SOL_AWC), maximum canopy storage (CANMX) and soil depth (SOL_Z) and the soil evaporation compensation factor (ESCO). With respect to the baseflow, the threshold water depth in the shallow aquifer for flow (GWQMN), and the groundwater recession factor (ALPHA_Bf) have the highest influence in controlling the baseflow for all catchments. The six relative sensitivity analyses of all the twelve parameters indicated in SWAT is presented in the Table 3.4 and Figure 3.4 below.

Table 3.4 Results of sensitivity analysis prior to uncertainty analysis

No	Parameters	Description of the parameters	Sensitivity rank
1	ALPHA_BF	Base flow alpha factor (days)	2
2	CN2	Initial SCS CN II value	1
3	Gwqmn	Threshold water depth in the shallow aquifer for flow (mm)	4
4	ESCO	Soil evaporation compensation factor	5
5	Sol_Awc	Available water capacity (mm water/mm soil)	6
6	Gw_Revap mn	Groundwater "revap" coefficient	3



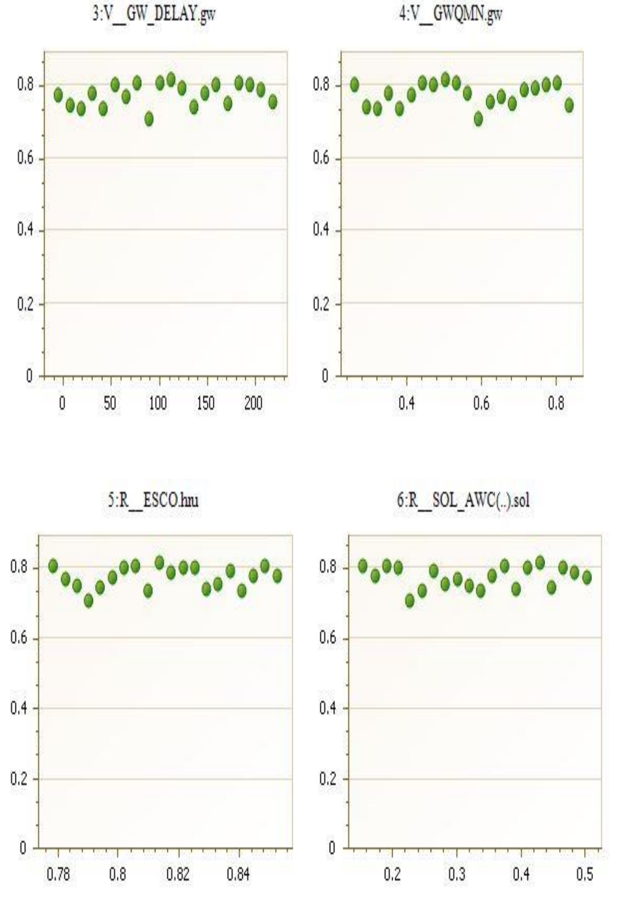


Figure 3.4 Results of sensitivity analysis prior to uncertainty analysis

3.5 Flow Calibration

After the sensitive parameters identification, then calibration followed by validation and it was executed for the significant parameters. The calibration of the model was executed to evaluate the performance of the model simulation using automatic calibration tools embedded in SWAT in addition to manual calibration technique for all catchments.

Flow calibration was also performed for a period of four years from January 1st, 1983 to December 31st, 1986 for monthly peak surface runoff using the sensitive parameters identified. However, flow was simulated for four years from January 1st, 1983 to December 31st, 1986, as the first two years were considered as *warm up* periods. Moreover, the flow was calibrated using automatic calibration method by using the observed flow gauged at the outlet of the sub-watershed. Firstly, the surface runoff component of the gauged flow was balanced with that of the simulated flow. At this juncture, the model was adjusted to calculate the potential evapo-transpiration of this sub-watershed by using the Hargreaves Method. Manipulation of the parameter values were carried out within the allowable ranges recommended by SWAT developers.

As a result of this, the number of performance optimization parameters modified during the calibration was kept to a minimum relative to the total number of SWAT parameters available for calibration.

Moreover, Calibration statistics of the monthly peak simulated and gauged flows at the Outlet of Tubo Dan Mari watershed was performed and the performance test result of the model based on coefficient such as mean, Pbias, P-factor, r-factor etc. is presented in the Table 3.5 above.

Table 3.5: Calibration statistics of the monthly peak simulated and gauged flows at the Outlet of Tubo Dan Mari watershed

Coefficient	Calibration period(1983-1986)	
	Obs. Flow (m^3/s)	Pre. Flow (m^3/s)
Mean	0.39	0.28
R^2	0.80	
ENS	0.73	
RSR	0.52	
PBIAS	27.1	
p- factor	0.75	
r- factor	0.70	

The calibration results in Table 3.5 show that there is a satisfactory agreement between the simulated and gauged monthly flows. This is demonstrated by the correlation coefficient (R^2=0.80) and the Nash-Sutcliffe (1983) simulation efficiency (ENS= 0.73) values for the whole watershed. The results fulfilled the requirements suggested by Moriasi, et al., (2007) in Table 3.2 which stated that R^2 >0.6 and ENS > 0.5. PBIAS value which is 27.1 is a very satisfactory performance. In addition, p-factor which is 0.75 and r-factor which is 0.70 lies under satisfactory range and RSR value of 0.52 also lies under satisfactory range as suggested by Moriasi, et al., (2007).

3.6 Flow validation

Validation proves the performance of the model for simulated flows in periods different than the calibration periods, but without any further adjustment in the calibrated parameters. Consequently, validation was performed for two years period from January 1st, 1987 to December 31st, 1988. The performance test result of the validation value is presented in Table 3.6.

Table 3.6: Validation statistics of the monthly peak simulated and gauged flows at the Outlet of Tubo watershed

Coefficient	Validation period(1987-1988)	
	Obs. Flow (m^3/s)	Pre. Flow (m^3/s)
Mean	0.36	0.17
R^2	0.81	
ENS	0.50	
RSR	0.71	
PBIAS	54.1	
p- factor	0.5	
r- factor	0.24	

As shown in Table 3.6, the performance value of RSR, R^2, and ENS lies under good performance. That means despite the fact that they lie under good performance, there is only satisfactory prediction performance values were recorded under calibration, and the capability of this prediction is very good enough to utilize the calibrated model for estimating the flow for the future effective potential management practices.

4.7 Uncertainty analysis

SWAT was calibrated based on the daily average value of monthly measured flow, at the outlet for each catchment using the automatic calibration method embedded in ArcSWAT. A split sample procedure 60 and 40 percent was used for calibration and validation respectively. For most of the selected catchment data from the period of 1983–1986 were used for calibration, and data from 1987–1988 were used to validate the model. It should be noted that a watershed model can never be fully calibrated and validated. Calibration of models at a watershed scale is a challenging task because of the possible uncertainties that may exist as earlier discussed. Sources of uncertainties in distributed models are due to inputs such as Rainfall and Temperature. Rainfall and Temperature data are measured at local stations and regionalization of these data may introduce large errors. In SWAT, climate data for every sub-basin is furnished by the station nearest to the centroid of the sub-basin. Also, it is very important to know that the direct accounting of rainfall or temperature distribution error is quite difficult as information from many stations would be required. Therefore, carrying out uncertainty analysis for the prediction of the hydrological model is crucial to decide the calibrated parameters to transfer to other homogenous catchments and also using for further predictions. In SUFI-2, parameter uncertainty accounts for all sources of uncertainty, e.g., input uncertainty, conceptual model uncertainty, and parameter uncertainty, because disaggregation of the error into its source components is difficult, particularly in cases common to hydrology where the model is non-linear and different sources of error may interact to produce the measured deviation (Abbaspour et al., 2009). After calibration of flow of the Tubo Dan Mari catchment the value of the uncertainty was determined using SUFI-2 (Sequential Uncertainty Fitting, version 2, Abbaspour et al., 2009) interface and the following result was obtained. As shown in Table 3.5 and also Figure 3.5 for calibration and Figure 3.6 for validation.

Table 3.7 Performance index of Tubo Watershed after uncertainty analysis using SUFI-2

Coefficient	P factor	R factor	RSR	R^2	ENS	PBIAS	Mean
Calibration (1983-1986)	0.95	0.86	0.82	0.78	0.75	29.7	0.80
Validation (1987-1988)	0.89	0.37	0.77	0.72	0.71	59.2	0.36

3.7.1 Parameter Uncertainty Analysis

Although there is overall great uncertainty, to check parameter uncertainty independently SWAT CUP interface GLUE (generalized likelihood uncertainty estimation) method of uncertainty analysis was implemented and the following results were obtained as shown in Table 3.8

Table 3.8 Performance index of Tubo Dan Mari watershed after GLUE analysis

Coefficient	P factor	R factor	RSR	R^2	ENS	PBIAS	Mean
Calibration (1983-1986)	0.72	0.68	0.50	0.75	0.71	25.6	0.80
Validation (1987-1988)	0.52	0.21	0.70	0.79	0.53	52.8	0.36

From Table 3.8 above, it shows that there are small values of P and R factor but the E_{NS} value (from literature read and studied, the most frequently used likelihood measure for GLUE (SWAT CUP manual, 2009) and also assigned as an objective function in the model program running process) of 0.71 and 0.53 for calibration and validation respectively represents there good parameter identification.

4.0 Conclusion

Based on the findings of this research, runoff contribution was estimated for Tubo Dan Mari watershed using semi-distributed model known as SWAT, in combination with the GIS interface ArcSWAT was successfully applied to quantify the flow amount for the Tubo Dan Mari catchment in order to manage the available water resources properly with good water management strategy at a detailed sub-basin level and monthly basis with uncertainty analysis using SWAT CUP.

Extensive calibration and validation as well as sensitivity and uncertainty analyses were performed to increase the applicability and reliability of the model outputs. The model was calibrated against river discharge. SUFI-2 and GLUE which are component of SWAT CUP were used to calculate 95% prediction uncertainty band for the outputs to characterize model uncertainty and based on SWAT watershed delineation at outlet of the catchment, the catchment area was estimated as $\mathbf{233.2527km^2}$ and subsequently the mean annual inflow was also estimated as **2.78575MCM.**

Thus, estimation of runoff has become more significant for future development and in this regards, the performance rating criteria shows that the model in all catchments were satisfactory and within an acceptable performance. The result of sensitivity analysis also shows that Alpha_Bf is the most sensitive parameter in all catchments in that regard.

5.0 REFERENCES

- Abbaspour (2009). SWAT-CUP2: SWAT Calibration and Uncertainty Programs - A User Manual. Department of Systems Analysis, Integrated Assessment and Modeling (SIAM), Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland, 95pp.
- Arnold, J.G., Sirinivasan, R., R.S Muttiah, J.R. Williams, (1998).Large area hydrologic modelling and assessment, Part 1: Model development. Journal of the American water resources association, 34(1).
- Arnold, J. G., and N. Fohrer (2012). SWAT 2000: Current capabilities and research opportunities in applied watershed modeling. Hydrol. Process. 19(3): 563-572.
- Beven, K.J. and A.M. Binley (1992). The future of distributed models: model calibration and uncertainty prediction, Hydrological Processes, 6, p.279–298
- Beven and Borah, D.K (2002). Watershed-scale hydrologic and nonpoint-source pollution models: Review of applications. *Trans. ASAE* 47(3): 789-803.
- Boyle R.F and Beven, K.J. (2000). *Rainfall-Runoff Modeling: The Primer*, John Wiley & Sons, Ltd., New York, New York.
- Lenhart, T., K. Eckhardt, N. Fohrer, H.-G. Frede (2002). Comparison of two different approaches of sensitivity analysis, Physics and Chemistry of the Earth 27 (2002), Elsevier Science Ltd., 645–654pp.
- Neitsch S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams (2005). Soil and Water Assessment Tool (SWAT) Theoretical Documentation, Version 2005, Grassland Soil and Water Research Laboratory, Agricultural

Research Service, Blackland Research Center, Texas Agricultural experiment Station.

- Soil Conservation Service (1972). Section 4: Hydrology *In* National Engineering Handbook.SCS.
- Srinivasan, M.S., P. Gerald-Marchant, T.L. Veith, W.J. Gburek, and T.S. Steenhuis (2005). Watershed scale modeling of critical source areas of runoff generation and phosphorus transport. *J. Amer.Water Resour. Assoc*. 41(2): 361-375.
- Van Liew, M.W., J.G. Arnold, and J.D. Garbrecht (2003). Hydrologic simulation on agricultural watersheds: choosing between two models. *Trans. ASAE* 46(6): 1539-1551.
- Veith, T.L., A.N. Sharpley, J.L. Weld, W.J. Gburek (2005). Comparison of measured and simulated phosphorus losses with indexed site vulnerability. Trans. *ASAE* 48(2): 557-565.