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Hydrological Modeling of Tubo Watershed, Kaduna State using ArcSWAT Model

[1]Salami, I.A., [2]Adeogun, B.K, [3]Ajibike, M.A.

[1]Department of Research and Technical Services, National Water Resources Institute, Kaduna, Nigeria
[2]Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria
[3]Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria

Abstract

Hydrological models have been used to model the processes of the watershed which could serve as a decision framework for harnessing alternative water supply source. The simulation was carried out, for the most important hydrology parameters such as precipitation, evaporation, runoff, infiltration, percolation and evapotranspiration respectively, using Soil and Water Assessment Tools (SWAT) model which is integrated with ArcGIS software. The study location was Tubo Watershed along Tubo river, a sub-basin of Kaduna basin in Igabi local government area which is about 42km away from Kaduna metropolis towards the northern part of Kaduna state, Nigeria. The model was run for the period from 1979 to 2014 with calibration using field measured discharge data of watershed for four years (1983-1986) and validation performed for two years (1987-1988) respectively. Moreover, the monthly simulated runoff of Tubo watershed for the calibration and validation periods were found to match with their measured discharge value of coefficient of correlation (R^2) for both which are 0.80 and 0.73 respectively. Furthermore, the model simulated daily runoff is collaborated by reasonably high Nash-Sutcliffe simulation coefficients (ENS) of 0.81 and 0.50. Based on the recommended statistical coefficients, the model evaluation indicated a very good performance for both calibration and validation periods with (R^2) and ENS to be 94% and 83% for calibration and 96% and 88% for validation periods respectively. It can be concluded that there is good agreement between measured and simulated values of monthly scale discharge. The average annual inflow volume at the watershed outlet was estimated and predicted to be 2.78575MCM in line with other predicted parameters during this study. Also, the total water yield was estimated at 576.44 mm, Evapotranspiration (592mm), Potential evapotranspiration (2217.7mm), surface runoff (311.70mm), Lateral flow (7.03mm), Groundwater flow (257.71mm) and Transmission loss (0.0mm) respectively.

Key Words*:* Calibration, Hydrology, Modeling, Runoff, Simulation, SWAT Model, Tubo Watershed, Validation

Corresponding author's e-mail: adedokun.salami@gmail.com
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1.0 INTRODUCTION

Drainage Basin is a basin through which all flows originating from the area is discharged through a single outlet. It is also known as Watershed, Catchment etc. Streamflow is also important when studying the hydrological modeling of watershed and usually expressed in cubic metre per second (m^3/s). Therefore, the predictions and assessments of Streamflow are very fundamental. Moreover, Water is very imperative for sustaining life and the accessibility of water can be input determinant of wealth, assets and possessions. In Nigeria, there are eight main river basins and these include; Niger North, Niger Central, Upper Benue, Lower Benue, Niger South, Western Littoral, Eastern Littoral, Lake Chad and many of them are unexploited for water supply, flood control, irrigation and hydropower generation. According to Federal Ministry of Water Resources Master Plan Review (*FMWR, 2014*), it was noted that only 978,465 hectares of the potential irrigable land are developed, so the existing irrigation development in Nigeria, as compared to the resources the country has, is negligible. This might be above and beyond financial constraints; the uncertainties of the rivers discharge data are the major problem for the improvement within the sector and this may help to attaining food security and get more water for dams and irrigation activities respectively have been done.

In addition to this fact recently, although there is a great trend of utilizing available resources like water etc., and the efficiency of using this major factor is limited due to uncertainties in Streamflow modeling and inaccurate in model outputs that may arise due to model efficiencies.

Tubo Dan Mari catchment is part of sub-basin of Rigasa, Mashi, Romi and this watershed is under great pressure because of growing population and increasing demand of water mainly for irrigation, which is not well practiced at the moment in the catchment, and also a great demand of water for domestic and livestock consumption purposes. In some catchment areas particularly that of River Romi due to petrochemical effluents effect from the Kaduna Refinery Petroleum Corporation (KRPC).

River discharge is an imperative issue to be monitored because of its significant influence on agricultural systems and on human lives for water resources exploitation and hazards related to floods and landslides. Thus, in order to increase any water resources development work knowing the Streamflow

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with a greater certainty is a must. Therefore, assessment of water resources potential with great certainty within the basin has become important to manage and to make optimal use of water resources development alternatives *(Arnold, J.G and N.Fohrer)*. Lastly, the similar understanding is applied in this research of Tubo Dan Mari Watershed because the goal of present research is to comprehend the rainfall-runoff relationship of the watershed and SWAT CUP model and sculpt to determine associated uncertainty simultaneously. *(Neitsch et al., 2011)*

2.0 Methods

The methodology adopted for this research include hydrological modeling, temporal and spatial datasets used in the simulation and they are technically explained in details below:

2.1 Creation and collection of databases

For the creation and collection of databases, the simulation of the water balance of an area by ArcSWAT model entails a large amount of spatial and time series datasets in order to establish the water balance equation and focus on the main sets of data used.

2.2 Physiographical datasets

The physiographical datasets comprise of topography, land use/land cover and soil characteristics of the area which defines the land features of any region and it 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. *(Neitsch et al., 2002)*

2.2.1 Digital Elevation Model (DEM)

The SRTM (Shuttle Radar Topography Mission) 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 also depends on the topographic characteristics to that effect.

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2.2.2 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 influences are 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 during the data analysis.

2.2.3 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 were analyzed in soil mechanics laboratory of National Water Resources institute, Mando Kaduna and used to validate the model parameters.

2.3 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 hydrologic cycle. Moreover the rivers in the hydrological regimes may differ extensively in their runoff response to changes in the dynamic variables of temperature and precipitation in that regard.

2.3.1 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. Moreover for SWAT model, the records of precipitation and temperature were the least mandatory inputs and the other parameters were elective, voluntary and optional. Furthermore, the observation data for Tubo Dan Mari site weather station within the study area for thirty-six years (1979-2014) were obtained

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from Kaduna State Water Corporation (KADWAC) together with three additional neighboring stations; the databases were downloaded and processed with respect to the model input format to that effect.

2.3.2 Hydrological Data

Under calibration and validation, the hydrological datasets of Tubo river flow were required and the data was collected from the concerned agency i.e. Kaduna State Water Corporation (KADWAC). Moreover, a long term flow data were gauged at Buruku (located in 10.6195500˚ N, 7.2315770˚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 in that regard.

2.3.3 Projected Coordinate System

For projected coordinate system, the requisite spatial datasets were processed from the Geographic Coordinate Systems (WGS 1984) to project and anticipated 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 Tubo Dan Mari Watershed.

2.4 Key Procedures Used during the Modeling process

- Loading the ArcSWAT extension
- Delineation of the watershed and defining the Hydrologic Response Units (HRUs)
- Editing SWAT databases (Compulsory or Optional)
- Defining the weather data
- Applying the default input files writer
- Editing the default input files (Compulsory or Optional)
- Setting up (which requires specification of simulation period, PET calculation method, etc.) and run SWAT
- Applying a calibration tool (Compulsory or Optional)
- Analyzing, plot and graph SWAT output (Compulsory or Optional)

2.4.1 Digital Elevation Model for Watershed Delineation

Under Digital elevation model for watershed delineation, Hydrologic modeling of Tubo Dan Mari watershed was carried out using the ArcSWAT version 2.3.4. In addition, the workflow used for this cram is given in Figure 3.3 above. Thus, the ArcSWAT interface mark the Automatic Watershed

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Delineation (AWD) and was done and also enabled the second step as everything was okay and accepted to that effect.

2.4.2 Creating the Hydrological Response Units (HRUs)

The slope of each sub-basin was created by an intermediate point for slopes to divide Hydrological Response Units (HRUs) and this Hydrological Response Unit (HRU) feature class button was checked and the overlay command added the landuse, soil and slope layers to project file in that regard. In addition, after these operations, the HRU definition specifies criteria for landuse, soil and slope to be used in determining the Curve Number Grid Values (CNGVs).

3.0 Results and Discussion

3.1 Landuse

As shown in Table 3.1 and Figure 3.1 the Tubo 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 (AGRL) has the largest portion (47.44%) and Agricultural Land-Row Crops (AGRR) has the smallest portion (1.35%) of it respectively. The Land use of the area was defined according to SWAT's system of nomenclature to that effect.

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. Moreover, Lithosols-Chromic LuvisolsI has 8.63% and the smallest portion of the area was covered with Plinthic Ferralsols (0.36%) and Calcaric Fluvisol (0.36%) respectively.

3.3 Slope

The slope of Tubo Dan Mari Watershed was found to have multiple types of slopes and the dominant one is steep slope of 0.5-15% over which covers about 86.69% of the total area coverage 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 4.3 and Figure 4.3 respectively. Moreover it shows that the

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area is steeped in nature which might lead to erosive action of water erosion since most the area is used for agricultural cultivation purpose in that regards.

3.4 Sensitivity analysis

The sensitivity analysis for Tubo Dan Mari Watershed was carried out for a period of four years, which included the calibration period from January 1st, 1983 to December 31st, 1986 respectively. 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. Moreover 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) and Soil Evaporation Compensation Factor (ESCO). Therefore, with respect to the baseflow, the threshold water depth in the shallow aquifer for flow (GWQMN), and the groundwater recession factor (ALPHA_Bf) has the premier influence in controlling the baseflow for Tubo Dan Mari Watershed. The six relative sensitivity analyses of all the twelve parameters indicated in SWAT is presented in the Table 3.4 below.

3.5 Flow Calibration

For the flow calibration, after the sensitive parameters identification, then calibration followed by validation and in this study it was executed for the significant parameters, moreover, the calibration of the model was also executed to evaluate the performance of the model simulation using automatic calibration tools embedded in SWAT in addition to manual calibration technique for previous studies on other catchments.

Therefore, the 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 during the research. 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. As earlier discussed in Chapter three under materials and methods, the flow was calibrated via automatic calibration method by means of the observed flow gauged at the outlet of the sub-watershed.

Initially, the surface runoff component of the gauged flow was unprejudiced with that of the simulated flow. At this juncture, the model was attuned to calculate the potential

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evapotranspiration of this sub-watershed by using the Hargreaves Method. Then the manipulations of the parameter values were carried out within the allowable ranges recommended by SWAT developers to that effect. Hence, the performance test result of the model is presented in the Table 4.5a and Table 4.5b respectively.

Based on the calibration results in Table 4.5a it then shows and signifies that we have a satisfactory agreement between the simulated and gauged monthly flows. Then, this is established through correlation coefficient (R^2=0.80) and the Nash-Suttcliffe simulation efficiency (ENS= 0.73) values for the Tubo watershed. Therefore, the results fulfilled the requirements recommended by Moriasi, et al., (2007) in Table 3.2 which stated that R^2 >0.6 and ENS > 0.5 respectively.

PBIAS value which is 27.1 is a very satisfactory performance and in addition to this, 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 acceptable and suitable range as recommended by Moriasi, et al., (2007) in Table 3.2

By and large, the overall performance of the prediction capacity of the model is under satisfactory range to that effect rather than lies under very good to good performance range for best result. This shows that there are some uncertainties on prediction of the simulated flow and the calibration graph of the watershed is shown in Figure 4.5.

3.6 Flow validation

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

As made known in Table 3.6, the recital value of RSR, R^2, and ENS lies under good performance, it means that despite the fact that they lie under good performance, there is only satisfactory prediction performance values which were recorded under calibration, and the capability of this prediction was very good enough to exploit the calibrated model to evaluating the flow for the imminent effective possible running

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practices. The validation graph is presented in Figure 3.6.

The Tubo Dan Mari watershed has been technically and critically studied in this present research and so far the estimation of average annual inflow is 2.78575MCM, where Federal Ministry of Water Resources, Abuja or Kaduna State Government can plan to build small earth dam across the River Tubo and conserve more water inside the reservoir for irrigation purpose.

3.7 Uncertainty analysis

During 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. Moreover, 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.

Furthermore after the flow calibration 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 results were obtained as shown in Table 3.8 and Figure 3.5 for calibration and Figure 3.6 for validation.

3.8. Parameter Uncertainty Analysis

In veracity for this parameter uncertainty analysis, there is overall great uncertainty, so in order to check parameter uncertainty independently SWAT CUP interface GLUE (GENERALIZED LIKELIHOOD UNCERTAINTY ESTIMATION) method of uncertainty and ambiguity analysis was implemented and the following results were obtained and they are made known in Table 3.8

From Table 3.8 above, it shows that there are small values of P and R factors but not

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included for E_{NS} value based on the literature read and studied, the most habitually used likelihood measure for Generalized Likelihood Uncertainty Estimation (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 correspondingly which represents the good parameter identification to that effect.

3.9 Sensitivity analysis after uncertainty analysis

Sequel to the sensitivity analysis after uncertainty analysis, the sensitivity ranges of parameters which were found under auto-calibration and sensitivity analysis as earlier explained has gotten reshuffled after uncertainty analysis. From Table 3.9 shown above, the most sensitive parameter is Groundwater re-evaporation (Gw_Revap) but the most perceptive parameter in the case of sensitivity analysis prior to uncertainty analysis is Alpha base flow (Alpha_Bf). Thus, there is little difference between the results before and after uncertainty and this represents that there is great uncertainty in the estimation of simulated flow as sensitivity affects calibration and validation again which determined simulation of flow amount. Moreover, the very good ENS values under GLUE test shows that the parameter uncertainty is insignificant and the GLUE values measure the overall parameter uncertainty than the explicit individual parameter values to that effect.

Finally, as the most sensitive parameter is more liable to uncertainty, GW_Revap remains the most liable parameter to uncertainty than other parameters deduced from the results of t-test, p-value and sensitivity ranking gotten from the analysis to that effect.

4.0 Conclusion or Summary

In conclusion, runoff contribution was estimated for Tubo Dan Mari watershed using semi-distributed model also known as SWAT in combination with the GIS crossing point ArcSWAT was successfully applied to enumerate the amount of flow for the Tubo Dan Mari catchment in order to administer the available water resources properly with good water management strategy at a meticulous and painstaking sub-basin level on a monthly basis with uncertainty analysis using SWAT CUP to that effect. Then the model was calibrated against river discharge data and SUFI-2, GLUE which are component of SWAT CUP were also used to calculate 95PPU band for the outputs to

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characterize model uncertainty and based on SWAT watershed delineation at outlet of the catchment, the catchment area was estimated as $233.2527km^2$ and subsequently the mean annual inflow was also estimated as 2.78575MCM.

More importantly the estimation of runoff has become more significant for future development and in this regards, the performance rating criteria shows that the model in the catchment was satisfactory and fall within an acceptable performance. In addition, the intend of the research is to determine the flow at the outlet of Tubo Dan Mari watershed in order to use it for planning purpose using SWAT model to a great certainty by using SWAT CUP model. Thus, as the performance rating and sensitivity value is different from the results prior to uncertainty analysis, and then there is uncertainty in the estimation of replicated runoff.

At this juncture, these uncertainties may come either due to conceptual model uncertainty or input uncertainty or parameter uncertainty or combination of three uncertainties.

These uncertainties may occur due to the following reasons:

(1) Difficulties in simulating the outflow from wetland (i.e. the river drains to marshy area during rainy season around local area and most of them remain there as the level is lower in elevation).

(2) A larger uncertainty range for the watershed might be due to higher conceptual model uncertainty as water management projects but may not be included in the model and this could alter natural hydrology as earlier discussed in this study.

(3) The effect of smaller lakes, reservoirs, wetlands, and irrigation projects which was not inclusive.

Respect to the results attain from this research, the subsequent values were estimated for watershed parameters such as water yield (576.44mm), Groundwater recharge (257.71mm), Lateral flow(7.03mm), Precipitation (1185.2mm), Evapotranspiration (592.2mm),Potential Evapotranspiration (2217.7mm) As the value of E_{NS} during GLUE analysis is very good, parameter uncertainty is insignificant.

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5.0 Acknowledgement

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APPENDICES

Appendix A: Location of Meteorological Station in Study Area.

Station	X-Coordinate	Y-Coordinate	Elevation
Tubo Dan Mari Watershed	10.460	7.500	608.000

Appendix B:Summary of the Meteorological data collected from NIMET

APPENDIX-B: SUMMARY OF METEOROLOGICAL DATA COLLECTED FROM NIMET									
DAILY METEOROLOGICAL DATA COLLECTED									
STATION NAME	PRECIPITATION(mm)		TEMPERATURE(Oc)		RELATIVE HUMIDITY (%)		SUNSHINE DURATION	WIND SPEED	
TUBO DAN MARI WATERSHED	FROM	TO	FROM	TO	FROM	TO	FROM	FROM	TO
	1979	2014	1979	2014	1979	2014	1979	1979	2014

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Appendix C: Tables

Table 3.1: Land use classification of Tubo Dan Mari Catchment using ArcSWAT Model

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

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

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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

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

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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	

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	

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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

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

Table 3.9: Results of sensitivity analysis using GLUE after uncertainty analysis

Parameter Name	t-test	p-value	Sensitivity rank
Canmx	-0.17	0.99	9
ALPHA_BF	0.64	0.85	8
Gwqmn	-0.69	0.72	7
SOL_Z	0.75	0.68	6
Esco	-0.82	0.57	5
Revapmn	0.95	0.52	4
SOL_AWC	-1.46	0.36	3
CN2	-1.91	0.27	2
GW_Revap	-1.95	0.12	1

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Appendix D: Figures

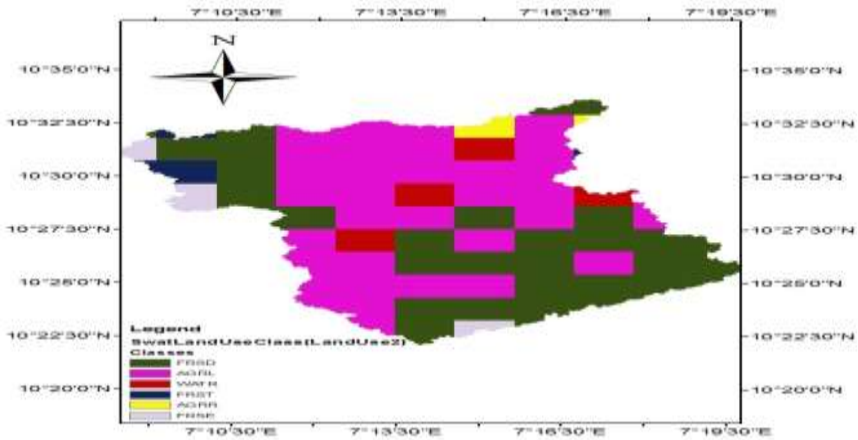

Figure 3.1: Landuse map of Tubo Dan Mari watershed

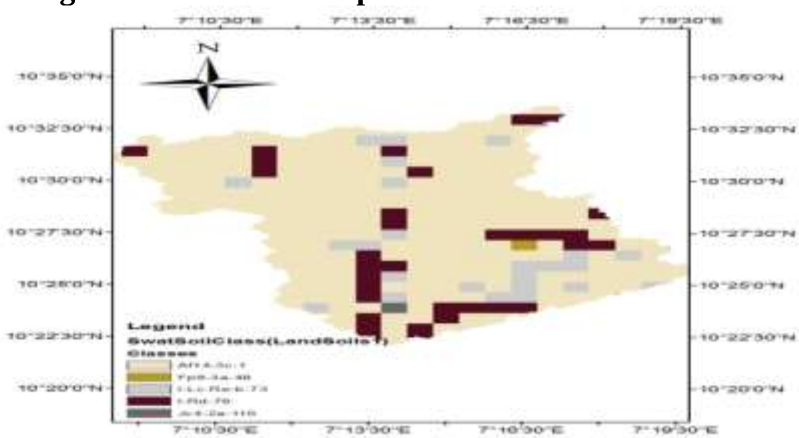

Figure 3.2 Soil map of Tubo Dan Mari Watershed

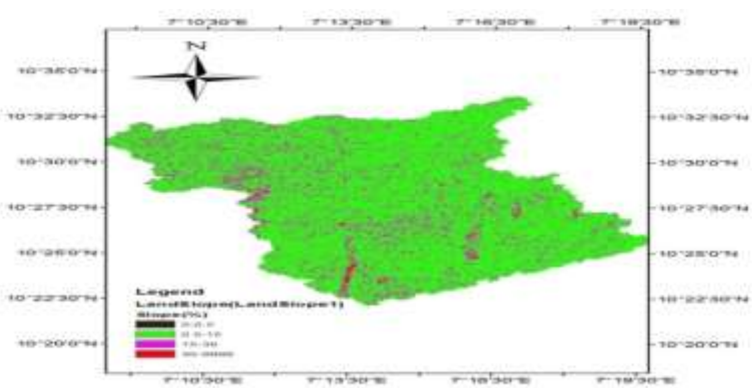

Figure 3.3: Slope map of Tubo Dan Mari Watershed

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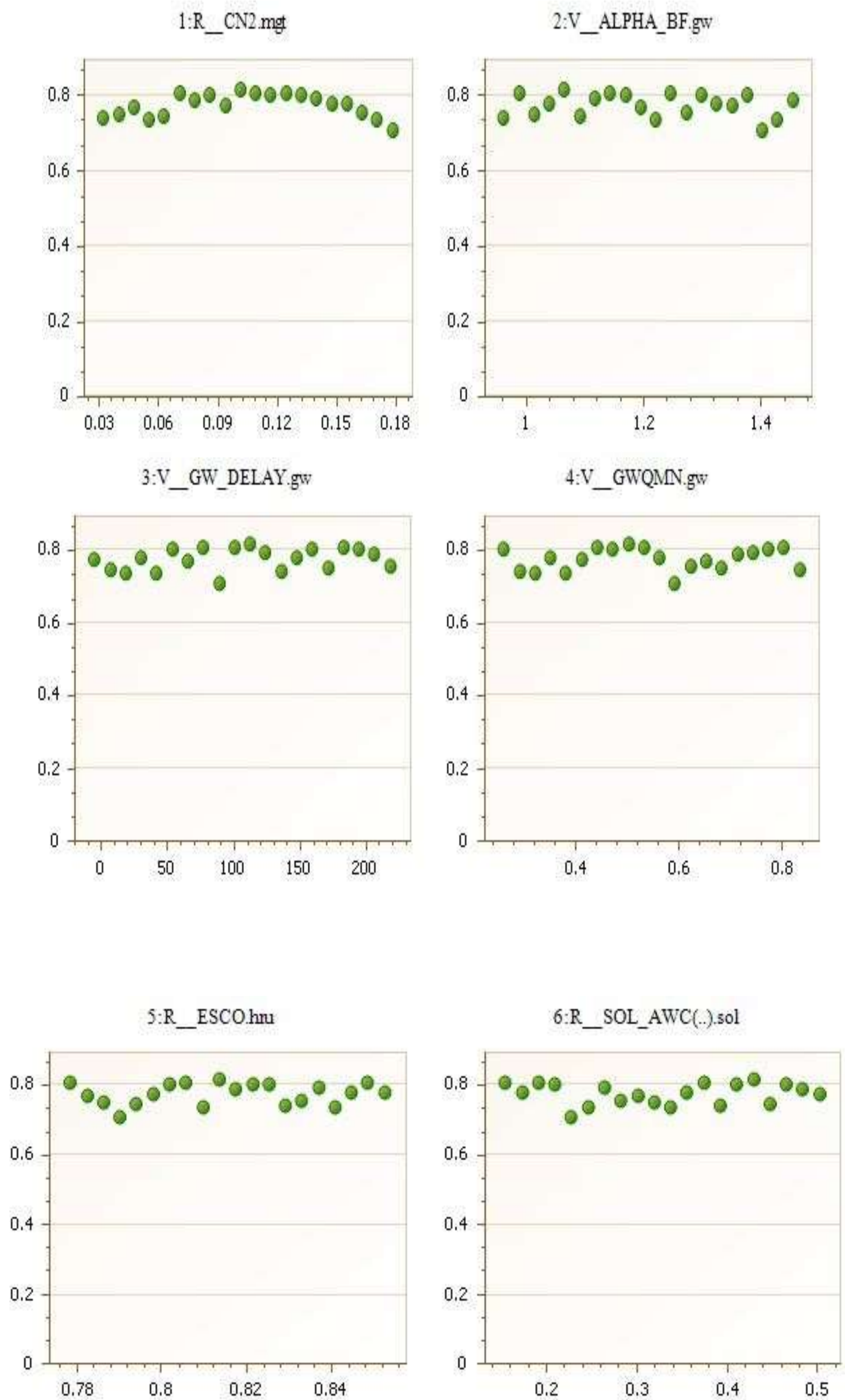

Figure 3.4: Results of sensitivity analysis prior to uncertainty analysis

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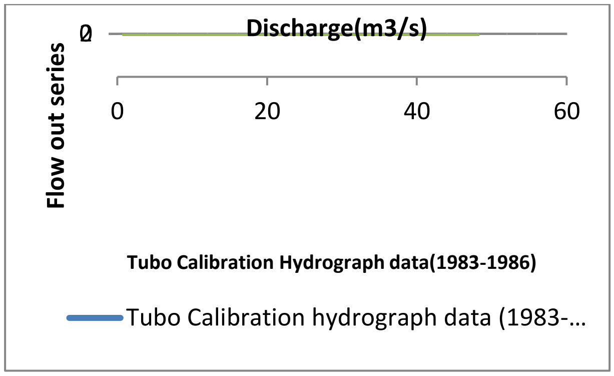

Figure 3.5: Calibration of observed and simulated flow hydrograph of Tubo River (1983-1986)

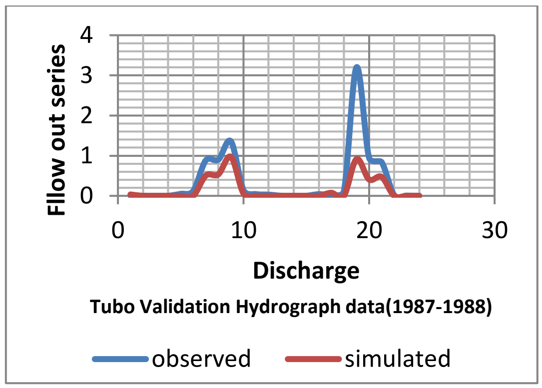

Figure 3.6: Validation of observed and simulated flow hydrograph of Tubo River

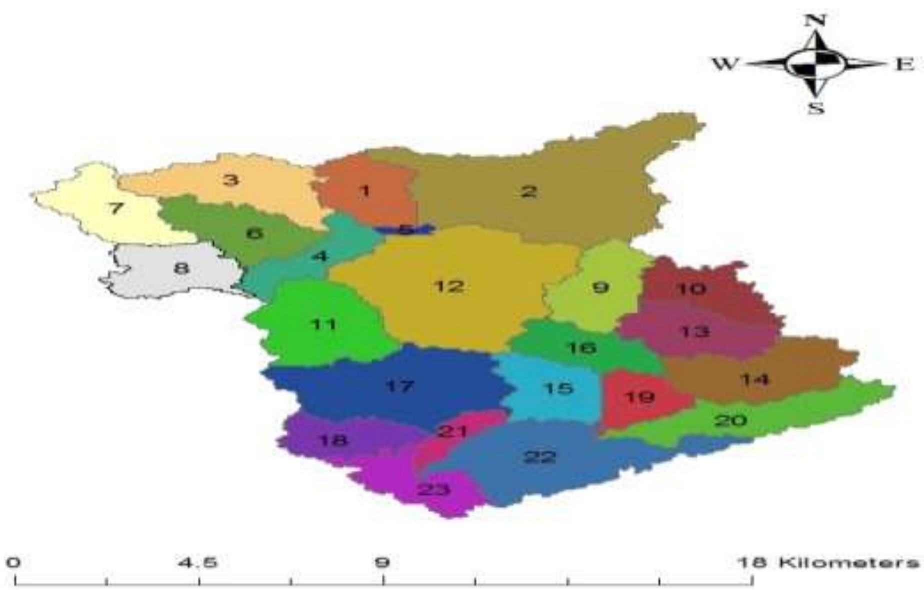

Figure 3.7: Characteristics of Tributary and Main channels

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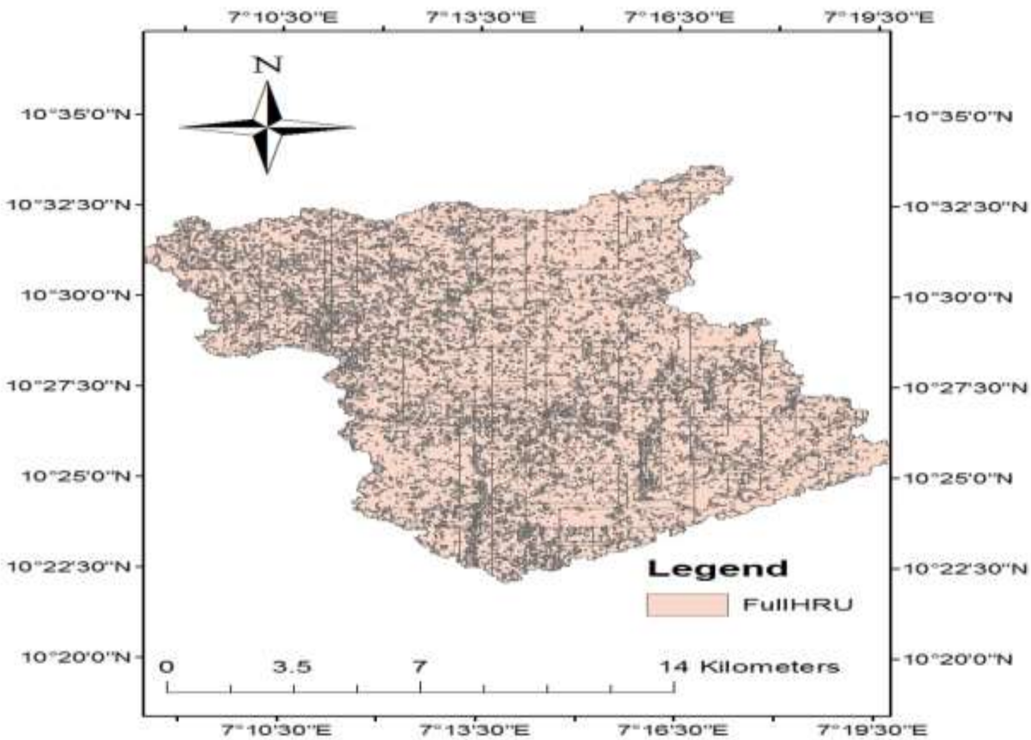

Figure 3.8: Hydrological Response Units (HRU) for Tubo Dan Mari Watershed

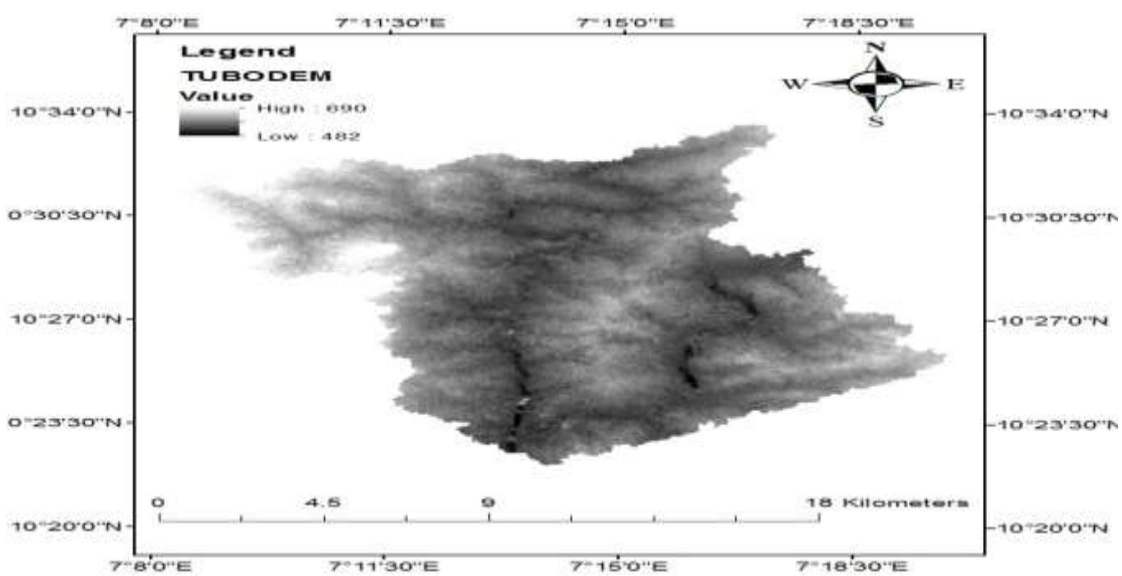

Figure 3.9: DEM of Tubo Dan Mari Watershed

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