

PANJSHIR WATERSHED HYDROLOGIC MODEL USING INTEGRATED GIS AND ARCSWAT INTERFACE

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ABSTRACT

Hydrological models have developed for design of the complex hydrological process and management of water resource in the watersheds. Also these models study the direct relation of the weather, topography, soil and land use in the basin. The research has been focused on the hydrology of the Ghurband and Panjshir watershed, located in the Kabul river basin at the southeast of Afghanistan using Arc SWAT model. Its aims were to evaluate the SWAT interface which implemented in ArcGIS software for simulation of monthly stream flow and establish water balance in Panjshir watershed in order to use effectively the freshwaters, as well as water conservation for irrigations in rural area and Recharge of ground water for water supply for densely populated cities. This model is using the hydro-meteorological data, digital elevation model (DEM), Soil layer and land cover data. Based on DEM, the watershed and 29 sub watershed delineated by the Arc SWAT and Geographic information system (GIS). The predicted discharge result was monthly calibrated from 2010 to 2012 and evaluated for 2013 using in SWAT-CUP interface in 3 stations namely (Omerz, Pul Ashwa and Shukhi). The coefficient of determination R^2 was (0.82, 0.77, and 0.90) for Omerz, Pul-Ashwa and Shukhi gage stations respectively in calibration periods and (0.85, 0.91 and 0.93) for validation. Efficiency of the model, NS is (0.72, 0.73 and 0.86) for the above stations respectively in calibration and (0.60, 0.86 and 0.86) for validation. The output will help the water resource managers for water conservation and efficient use of stream flow and water resources in the mentioned watershed.

Keywords: *Ghurband and Panjshir Watershed, Arc GIS, Arc SWAT, Calibration, Water Resources*

INTRODUCTION

Water is a basic and an essential element for survival of living things. It is vital factor for economic development and augmenting growth of agriculture and industry especially in the perspective of rapidly increasing population and urbanization.

Afghanistan is a landlocked country which has a land area of about 652,000 km², over 75% of which is mountainous. Afghanistan is divided into five major basin, Amu Darya River Basin, Northern River Basin, Harirod-Murghab River Basin, Hilmand River Basin, and Kabul (Indus) River Basin which all these river basins are international basins. Although Afghanistan provides headwaters of four major rivers that flow to neighboring countries, but itself uses only small portion (1/3th) of its waters that originate here.

The most important rivers in Afghanistan originates from Hindu Kush Mountains in all directions. The precipitation occurs in winter as rainfall and snowfall. The snow in high elevations play a key role in water storage especially in mountains and recharge the rivers during the snow melt. The climate is semi-arid and strongly continental.

The average annual precipitation during the period of observation is 330 mm, while the average annual temperature between 10°C to 13°C (George *et al.*, 2009). The ground water aquifers also recharge from snow melting and small streams getting dry when the snow has completely thawed, this has very much effect on discharge of large rivers. Ghurband and Panjshir watershed with an area of (12,753Km²) is located in the Kabul river basin which includes the two important tributaries of Kabul River basin

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Ghurband River and Panjshir River. The Panjshir watershed together with lower Kabul basin and its tributaries provides 14% average flow of the country. In deed the Panjshir watershed has a crucial rule in water resources in the Kabul river basin. Population growth, more exploitation of water especially ground water, urbanization, pollution of surface and ground water, traditional irrigations and flash floods causes serious problems in Afghanistan. Especially in Kabul city the population had risen from just 300,000 some 30 years ago to more than ten times that level, and because of this the water supply shortage was becoming serious issue (JICA-RI, 2012).

Therefore, the management of water resources for eradicating the scarcity and effective use, is the most important issue. The goal of this research is to design the SWAT model which implemented in ArcGIS for estimation of monthly discharge and establish water balance in Panjshir watershed in order to use effectively the freshwaters as well as water conservation for irrigations in rural area. GIS is the best and suitable tool for effectual management of complex databases and to provide the digital visualization of watershed characteristics used in the hydrologic modelling. Also the development of Remote Sensing techniques improved and expanded the use of watershed models in the world (Shimaa and Ghoraba, 2015).

In this paper the SWAT watershed based model which integrated with GIS was applied. SWAT is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Wincheel *et al.*, 2013). Many researches in different places of the world showed that SWAT model is computationally efficient in its prediction (Neitsch *et al.*, 2005).

MATERIALS AND METHODS

Methodology

Soil and Water Assessment Tool is applied in Panjshir Watershed to estimate the river flow and sediment yield. The methodology used for this study includes the hydrological model of SWAT and the spatial dataset that used for simulation and are given in the following sections with details.

Study Area: The Ghurband and Panjshir watershed (Figure 1) located 150 kilometers north of Kabul province in a mountainous range of Hindu Kush in North Part of the Kabul River basin. The watershed covers an area of 12,752.942 km². The main rivers in the watershed are Panjshir River and Ghowrband River. When the Panjshir River reaches Gulbahar, it gently irrigates the wide Shomali plain through a network of irrigation canals. There are two canal networks in the watershed, the Panjshir Canal Network and the Ghorband Canal Network which is mainly use for crop irrigation in Parwan province. The Ghurband and Panjshir watershed ends at the Naghlu dam in Surobi district in Kabul Province. The catchment area is defined by all the water collected in that dam and contains 4 provinces (Panjshir, Parwan, Kapisa and Kabul).

Ghurband and Panjshir watershed is absolute water stressed region of Afghanistan. This watershed is located in mountainous area with some of the highest peaks covered in snow. In spring and summer, rivers that originate in glaciers have sharp water level fluctuation during the day. Most rivers can be forded in the morning, but by afternoon the heavy melting of snow and ice raises the water level 0.5-1 meter above low water. Low water stage occurs from October to February (US Army Corps of Engineers, 2009). Topography of the study area is alpine with the highest elevation 5669m and lowest 1053m above mean sea level (A.M.S.L) based on DEM. The mountains are rocky with sharp peaks, and steep slopes (40-60%). Some of the peaks have permanent snow caps and glaciers. The central region of the study area is relatively flat, and dissected by the Panjshir River, its tributaries, and irrigation canals (US Army Corps of Engineers, 2009). As the potential runoff analysis shows that, significant water depth is generating during the year.

The Geo-morphology of the study area is steeply. Therefore, the rainfall immediately flows into River. So, management of Water Harvesting in the selected area is needed to sustain crop production of communities as an effective way.

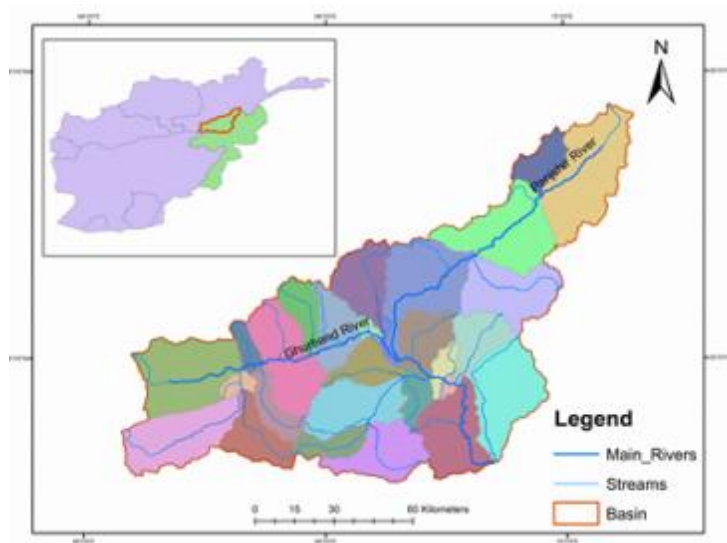


Figure 1: Location, River Network and Sub Basin in Ghurband and Panjshir Watershed

SWAT Model

SWAT is the acronym for Soil and Water Assessment Tool, a river basin or watershed, scale model developed by Dr. Jeff Arnold for the United State Department of Agriculture (USDA) and agriculture research services to predict the impact of land management practices on water, sediment, and agriculture chemical yields in large and complex watersheds with varying soil, land use, and management conditions over long periods of time (Arnold *et al.*, 1998). SWAT model is a comprehensive, semi-distributed, continuous-time, processed-base model (Arnold *et al.*, 2012; Neitsch *et al.*, 2005; Gassman *et al.*, 2007; Abbaspour *et al.*, 2015). We used Arc SWAT for ArcGIS 10.2 in the Panjshir watershed which is the latest available version of model for watershed management. The hydrological component of SWAT allows explicit calculation of different water balance components, and subsequently water resources (e.g., blue and green waters) at a sub basin level (Abbaspour *et al.*, 2015). Figure 2 illustrate the conceptual water balance model in SWAT. Two types of data (spatial and temporal) were used in the model to simulate the watershed. Spatial data including DEM, Land use and Soil are used in the preprocessing step and then fed the SWAT model via GIS program. Land use/cover type and soil texture are very important components which have much effect on the surface runoff. The DEM define the topography of watershed and used to define the stream network and calculate sub-basin parameters such as slope.

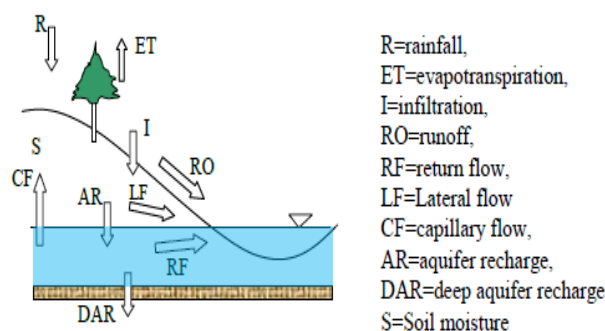


Figure 2: Schematic Illustration of the Conceptual Water Balance Model in SWAT

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SWAT use daily time series data including climate, precipitation and stream flow which prepared according to SWAT input requirements. Figure 3 shows all the process of input, output, spatial datasets and GIS parts and summarizes the methodology. The hydrological cycle which simulated by SWAT is based on the water balance equation, which considers the shallow aquifer and unsaturated zone above the impermeable layer as a unit. Equation 1, calculate the hydrologic cycle by SWAT.

$$SW_t = SW_0 + (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \dots \dots \dots (1)$$

Where, SW_t and SW_0 are the final and initial soil water contents (mm H_2O), t is time in days, R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water percolation or amount of water entering the Vadose zone from soil profile on day i (mm H_2O), Q_{gw} is the amount of return flow on day i (mm H_2O).

Water balance is the driving force behind everything that happens in a watershed to accurately predict the hydrological cycle, sediment or nutrient movement. Simulation of hydrology of a watershed is divided into two categories: (1) Land phase of the hydrological cycle, (2) The water, or routing phase of the hydrologic cycle. The first one controls the amount of water, sediment to the main channel in each sub-basin and the second shows movement of water, sediments through the channel network of the watershed to the outlet (Vikash *et al.*, 2014). SWAT model use two method for calculating of surface runoff, the Soil Conservation Service (SCS) curve number method (Arnold *et al.*, 1998), which is based on daily weather data (precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed), soil properties and land cover condition. The other is Green & Ampt infiltration method that is based on sub daily (hourly) weather data. In this method, the important factors are rainfall intensity and soil properties.

This study used SCS Curve Number (CN) method based on available daily data for estimation of stream flow. The SCS general equation is.

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a) + S}, \{I_a = 0.2s\} \dots \dots \dots (2)$$

$$Q_{surf} = \frac{(R_{day} - 0.2s)^2}{(R_{day} + 0.8s)} \dots \dots \dots (3)$$

Where Q_{surf} is daily accumulated runoff (mm H_2O), R_{day} is the amount or depth of rainfall for the day (mm H_2O), S is potential maximum retention parameter after runoff begins and I_a is initial abstraction which include surface storage, interception and infiltration prior to runoff (mm H_2O). The initial abstraction I_a is estimated 0.2s and thus the equation becomes like equation 3. Runoff will occur when rainfall is more than initial abstraction, equation 4.

$$R_{day} > 0.2s \dots \dots \dots (4)$$

The potential retention parameter S and the prediction of lateral flow by SWAT model are defined in equation 5. In the below equation S is drainable volume of soil water per unit area of saturated thickness (mm/day) and CN is the curve number.

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \dots \dots \dots (5)$$

In Addition to land cover and soil properties, antecedent soil moisture condition also effect on the curve number, SCS defines three types of antecedent moisture condition: I – Dry (wilting point), II – average moisture condition and III – wet (field capacity).

The curve number for moisture condition II (CN2) is provided to the model; subsequently it adjust the CN according to the antecedent moisture condition calculated from daily rainfall data (Amarinder, 2009). The curve numbers for moisture conditions I and III are calculated with the following equations 6 and 7 (Shimaa and Ghoraba, 2015).

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$$CN1 = CN2 \frac{20(100 - CN2)}{(100 - CN2 + e^{[2.533 - 0.0636 * (100 - CN2)]})} \dots \dots \dots (6)$$

$$CN3 = CN2 * e^{[0.00673(100 - CN2)]} \dots \dots \dots (7)$$

Where CN1 is the curve number for moisture condition I, CN2 is the moisture condition II curve number, and CN3 is the curve number for moisture condition III.



Figure 3: SWAT Model Components and Methodology Used

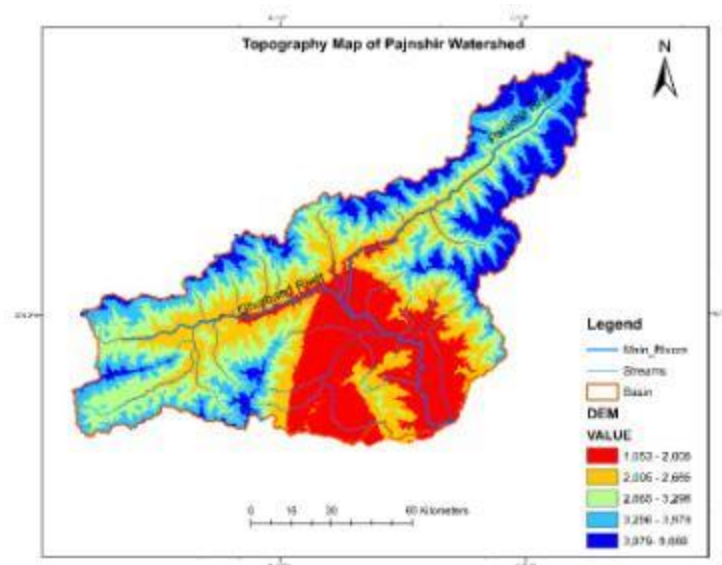


Figure 4: DEM of Ghurband and Panjshir Watershed

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Collecting and Processing Data

SWAT model requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. For this study, data input was collected from local and global sources which including DEM, land use/cover, soil properties and weather data.

DEM of 30m resolution achieved from global digital elevation model ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer), (HTML: ASTER GDEM). DEM used to extract the flow direction, flow accumulation, stream network, sub watersheds and watershed delineation. The topographic parameters such as elevation and terrain slope, stream slope and reach length were also derived from DEM in study area (Figure 4). The elevation ranged from 5669m, in north and northeast (Hindu Kush Mountains) to 1053m in Naghlu dam, the outlet of Panjshir watershed.

Land use is based on Afghanistan land use map 2010. In this study land use data collected from MAIL/AFG (Ministry of Agriculture and Life Stock in Afghanistan) and have been used in SWAT model (Figure 5). A lookup table used to reclassify the original land use classes to SWAT model classes and as SWAT code it reclassified into 9 classes. RNGE 70.96%, AGRL 9.58% and BARR 6.01% are the dominant land cover respectively. The percentage of classification showed in (Table 1).

Soil is very important factor in hydrological modelling and in various process plays the main role. In the SWAT model the soil properties like, soil texture, hydraulic conductivity, bulk density, available water content in the soil layer are essential. The soil vector data downloaded from global soil map of the world and is based on FAO-UNESCO soil map (FAO/UNESCO, 2015). For soil layer also a lookup table created and input to the model. Figure 6 shows the reclassification of the soil by SWAT model. As can be seen from the (Figure 6), the soil divided to four major classes. After the specification of land use/cover map and soil types, the threshold area defined for slope into five classes. Slopes are defined based on topographic condition of the area and divide as (0-10%, 10-20%, 20-30%, 30-50% and < 50%). The dominant slope class is more than 50 percent in the study area (Figure 7).

The land use, soil and slope then overlaid to define the Hydrologic Response Unite (HRU) for each sub basin in the watershed. A watershed is the area of land where all of the water that falls in it and drains in it goes to a common outlet. In SWAT model, a watershed is subdivided in to sub basin. HRU is the smallest subdivision in a watershed having unique land use, soil and slope.

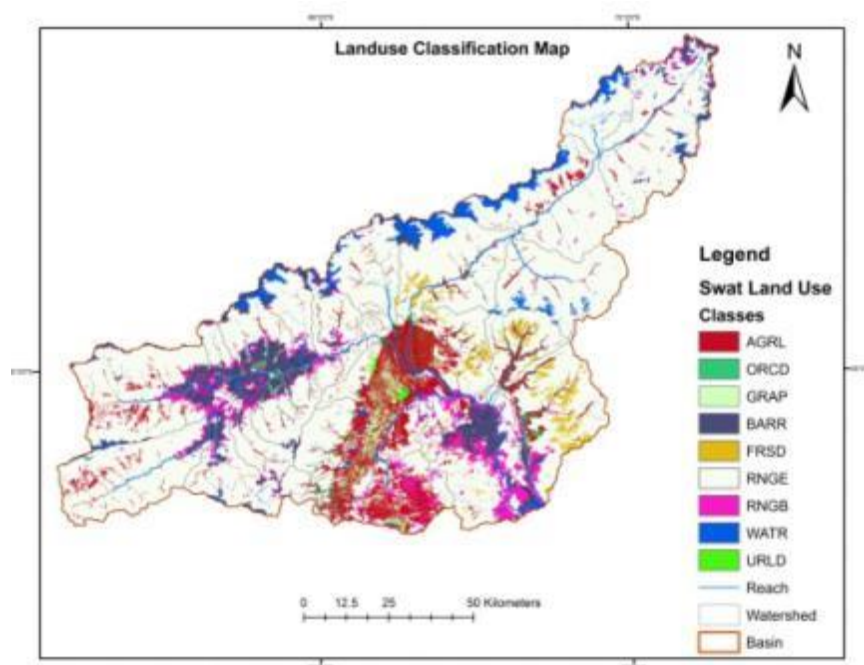


Figure 5: Land Use Map Classification

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Table 1: Shows Land Use/Land Cover Classes Used for Arc SWAT for Panjshir Watershed

Id	Land use	LU/LC-Code	Area
1	Agriculture land	AGRL	9.58
2	Orchard	ORCD	1.19
3	Grape	GRAP	1.37
4	Barren land	BARR	6.01
5	Forest-Deciduous	FRSD	1.51
6	Rangeland-grasses	RNGE	70.96
7	Range-Brushes	RNGB	4.59
8	Water	WATR	3.83
9	Urban Area	URLD	0.96
Total Area			100

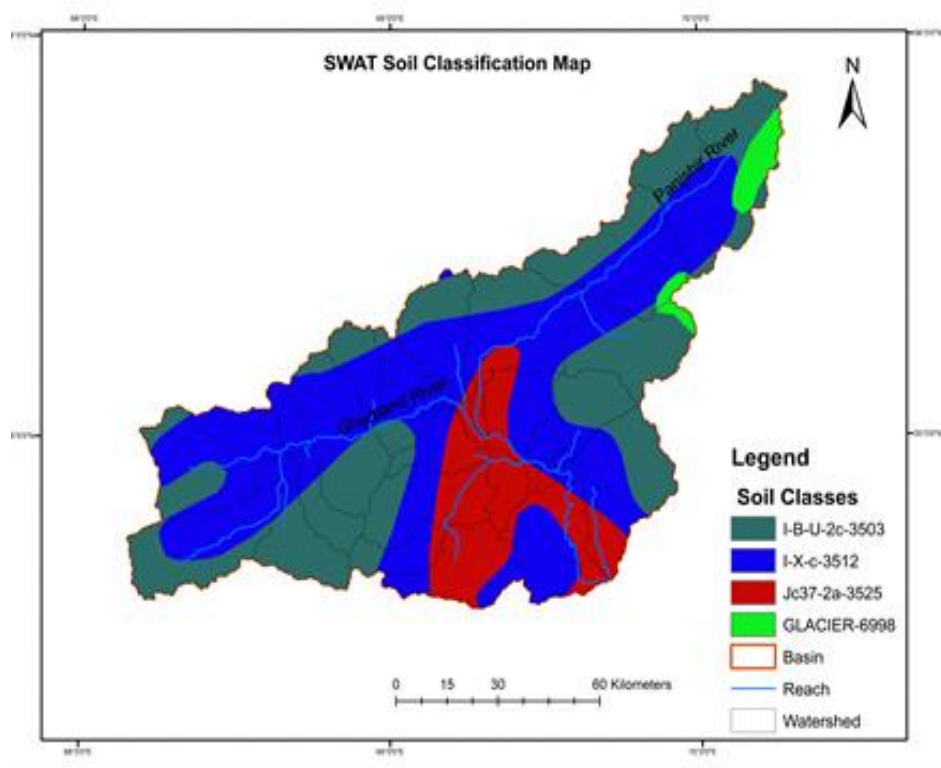


Figure 6: Soil Map Classification

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Climate data are necessary input by SWAT to provide the hydrologic condition (moisture and energy inputs) that control the water balance and determine the relative importance of the different component of the hydrology cycle (Shimaa and Ghoraba, 2015). The observation data of 9 weather stations inside the study area collected from the Ministry of Energy and Water in Afghanistan (MEW/AF). Daily time series weather data included precipitation, maximum and minimum temperature data from 2010 to 2013 was available and used in SWAT model. The watershed area (12,753Km²) was very large compared to existing stations, because of this, the data of 13 stations which downloaded from global weather data used in the model (Global Weather Data, 2015). These stations consist the daily precipitation (mm), temperature (°C), wind speed (m/sec), relative humidity (fraction) and solar radiation (MJ/m²). The mentioned data and location of each station are provided in text code format which are actually required in Arc SWAT 2012. (Figure 8) shows the location of all stations in the study area.

The hydrological data also collected from same department of Ministry of Energy and Water in Afghanistan (MEW/AF). Daily observed discharge data was available for three stations including Omerz station on Panjshir River, Pul-Ashawa station on Ghurband River and Shukhi station in lower sub basin, after these two rives joins. These data used to compare with simulated discharge by SWAT in calibration and validation process. The location of discharge outlets showed in Table (2) and Figure (8).

Table 2: Shows the Position of Discharge Stations in Panjshir Watershed

No	Name	Xpr	Ypr	Lat	Long	Elev	Type
1	Omerz	558,131.14	3,914,769.92	35.37456303	69.63996762	2042	O
2	Pul-Ashwa	513,793.55	3,883,285.62	35.0922665	69.15132947	1624	O
3	Shukhi	544,501.26	3,865,784.79	34.93357139	69.48728071	1374	O

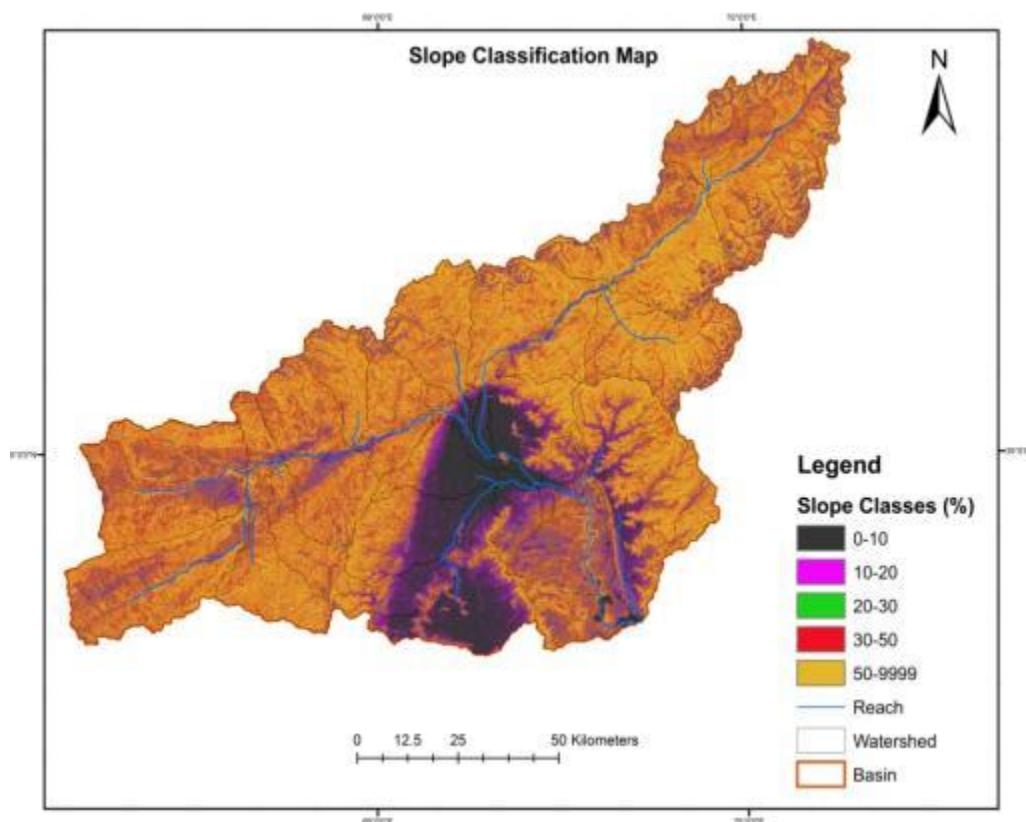


Figure 7: Slope Map Classification

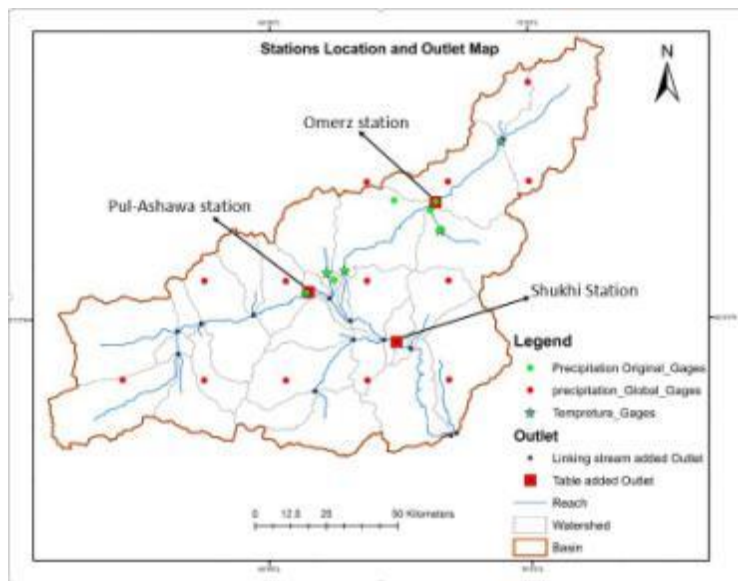


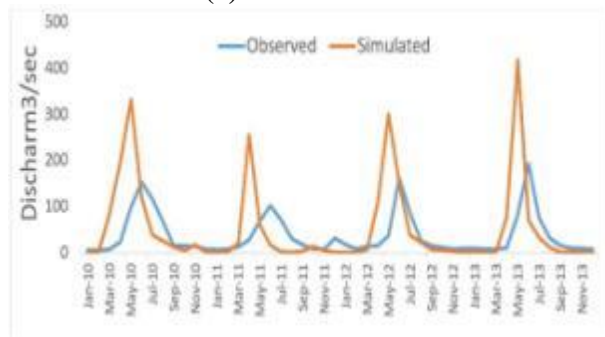
Figure 8: Location of Weather Stations and Outlets

RESULTS AND DISCUSSION

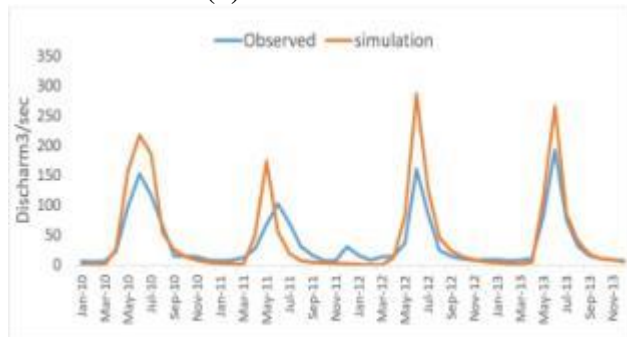
Arc SWAT Estimation

Monthly discharge simulation was carried out in Ghurband and Panjshir watershed, using SWAT model that was appropriate for ArcGIS 10.2.2. The simulation performed after all the above mentioned data prepared and input to SWAT model. Based on data access to climate, the simulation is done for 4 years from 2010 to 2013. Several simulations performed to get good results of matching the simulated and observed discharge by changing of some parameters in SWAT.

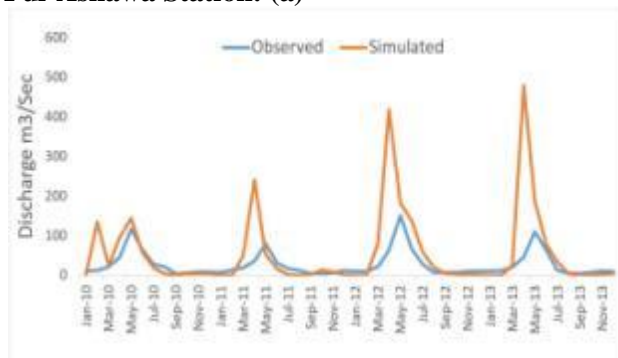
Omerz Station: (a)



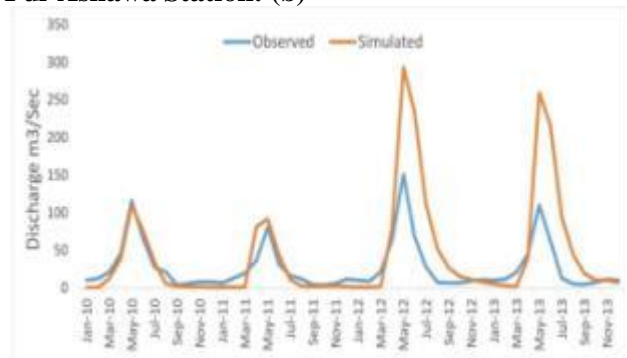
Omerz Station: (b)



Pul-Ashawa Station: (a)

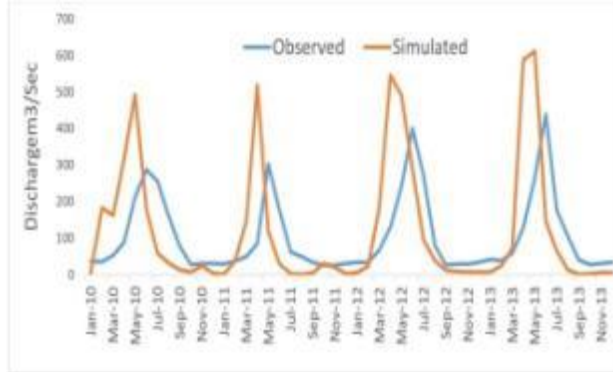


Pul-Ashawa Station: (b)



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Shukhi Station: (a)



Shukhi Station: (b)

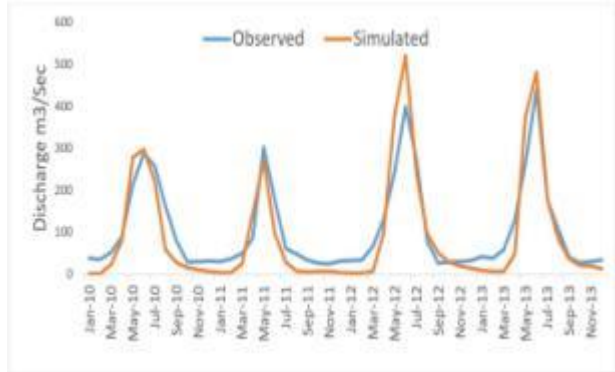


Figure 9: Simulated Discharge Compared with Observed for 3 Outlets, (a) Shows before and (b) Shows after the Parametrization in SWAT Model

These parameters are snow fall temperature (SFTMP), snow melt base temperature (SMTMP), snow pack temperature lag factor (TIMP), curve number (CN2), soil evaporation compensation factor (ESCO), ground water-evaporation (GW_REVP), available water capacity of the soil layer (Sol_Awc), ground water delay (GW_DELAY). In the optimization process in the SWAT model the CN2 and GW_DELAY had much effect on the peaks. Also the snow factors (SMTMP and SFTMP) had very much effect on delay time of peaks. The hydrographs (Figure 9) shows the discharge before and after changing of the parameters in SWAT model.

To evaluate the accuracy simulation result of SWAT, three statistic coefficient by SWAT-CUP (Calibration and Uncertainty Procedures) model, SUFI-2 method used (Abbaspour *et al.*, 2007). SWAT-CUP is a computer software that operates independently for SWAT model which contains five different calibration procedures including Particle Swarm Optimization (PSO), Sequential Uncertainty Fitting (SUFI-2), Markov Chain Monte Carlo (MCMC), Parameter Solution (Para-Sol), Generalized Likelihood Uncertainty Estimation (GLUE) and has the functionality for validation, uncertainty analysis as well as visualization of study area using Bing Map (Abbaspour *et al.*, 2015). For time consuming large-scale model, Sufi-2 was quite efficient (Yang *et al.*, 2008; Abbaspour *et al.*, 2015).

The coefficient of determination (R^2) which indicates the correlation between observed and simulated value, Nash-Sutcliffe efficiency (NS) and Percent Bias (PBIAS) used as objective function. The coefficient of determination ranges between (Zero to 1.0), the value equal or less than zero indicating no correlation and 1 indicating best fit estimation or less error variance equation 8. The Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970) is used to predict the efficiency of the SWAT model. NS can ranges from $-\infty$ to 1, with an efficiency of 1 ($E=1$) shows a perfect match, an efficiency of zero ($E=0$) indicating that the predictions as accurate as the mean of the observed and an efficiency of less than zero ($E<0$) shows the model weak predictions. Moriasi *et al.*, (2007) stated that simulation efficiency by Nash Sutcliffe Index (NSI) of model defines with four levels. With values of $0.75 < NSI \leq 1$ indicate very well, $0.65 < NSI \leq 0.75$ indicate well, $0.50 < NSI \leq 0.65$ judged as satisfactory and $NSI < 0.50$ indicate dissatisfaction. NS is calculated from equation 9.

$$R^2 = \frac{\sum_i [(Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)]^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2} \dots\dots\dots (8)$$

$$NS = 1 - \frac{\sum_i (Q_{m,i} - Q_{s,i})^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \dots\dots\dots (9)$$

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Where, R^2 is the coefficient of determination, NS is Nash-Sutcliffe efficiency, Q is discharge, m and s stand for measured and simulated respectively, and the bar stands for average, it is the i^{th} measured or simulated data.

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed (Gupta *et al.*, 1999). The optimal value of PBIAS is Zero (0). Generally, the model simulation can be judged as satisfactory if PBIAS between (-25% to +25%) for stream flow, PBIAS (-55% to +55%) for sediment, and PBIAS (-70% to +70%) for Nitrogen and Phosphorus (Table 3), (Moriassi *et al.*, 2007). Low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values Indicate model overestimation bias (Gupta *et al.*, 1999). PBIAS is calculated with equation 10:

$$PBIAS = \frac{\sum_{i=1}^n (Q_{m,i} - Q_{s,i}) * 100}{\sum_{i=1}^n (Q_{m,i})} \quad \dots\dots\dots (10)$$

Where, PBIAS is the deviation of data being evaluated, expressed as a percentage. PBIAS has the ability to clearly indicate poor model performance (Gupta *et al.*, 1999). PBIAS values for stream flow tend to vary more, among different auto-calibration methods, during dry years than during wet years.

Table 3: General Performance Rating for Recommended Statistics for a Monthly Time Step

Performance Rating	RSR	NSE	PBIAS (%)		
			Streamflow	Sediment	N, P
Very good	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$	$PBIAS < \pm 10$	$PBIAS < \pm 15$	$PBIAS < \pm 25$
Good	$0.50 < RSR \leq 0.60$	$0.65 < NSE \leq 0.75$	$\pm 10 \leq PBIAS < \pm 15$	$\pm 15 \leq PBIAS < \pm 30$	$\pm 25 \leq PBIAS < \pm 40$
Satisfactory	$0.60 < RSR \leq 0.70$	$0.50 < NSE \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$	$\pm 30 \leq PBIAS < \pm 55$	$\pm 40 \leq PBIAS < \pm 70$
Unsatisfactory	$RSR > 0.70$	$NSE \leq 0.50$	$PBIAS \geq \pm 25$	$PBIAS \geq \pm 55$	$PBIAS \geq \pm 70$

Calibration and Validation of the Model

SWAT model used to simulate the monthly water discharge in 3 outlet gages, in Ghurband and Panjshir watershed. In the first step, it delineated the watershed with 29 sub basin according to the terrain and river channels based on available climate data for the period of 2010 to 2013. Further division of multiple hydrological response units (HRUs) including of unique land use, soil, and slope management was based on user-defined threshold percentages (Arnold *et al.*, 1998).

The threshold area percentage selected 15% for land use, 15% for soil and 15% for slope respectively. The penman monteith method was selected during the parametrization in SWAT model to estimate the Potential Evapotranspiration (PET) for adjusted water balance parameters and SCS method for surface runoff estimation.

Calibration is the model inputs adjusting with the purpose of achieving the best simulation match with observation which includes parameters, structure of the model and variables. Model calibration and validation is necessity for processing of hydrological simulations to evaluate the prediction result. SWAT is physically based, distributed watershed model, so need for calibration and validation before it's used for water processing in watersheds.

Firstly, the calibration performed for the purpose of comparing the simulated discharge result with available measurements. The monthly calibration is done for the period 2010 to 2012 based on the available climatic data and validation has been done in another period 2013 thereafter to evaluate the model performance with calibrated parameters. The calibration performed separately for 3 outlet stations namely (Omerz, Pul-Ashawwa and Shukhi).

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In SWAT-CUP in calibration process 8 parameters used for outlet number 3(Omerz station). These are snowfall temperature (SFTMP), snow melt base temperature (SMTMP), melt factor for snow on warm period December 21(SMFMN), melt factor for snow on cold period June 21(SMFMX), snow pack temperature lag factor (TIMP), curve number for soil moisture condition 2 (CN2), available water capacity in soil (SOL_AWC) and soil evaporation compensation factor (ESCO). In the sensitivity evaluation process, the parameters SMFMX, SMTMP and SOL_AWC were more sensitive.

For outlet number 9 (Pul-Ashawa station) we used 13 parameters, which are snow melt base temperature (SMTMP), snowfall temperature (SFTMP), curve number (CN2), soil available capacity (SOL_AWC), soil evaporation compensation factor (ESCO), saturated hydraulic conductivity (SOL_K), moist bulk density (SOL_BD), Threshold water depth in the shallow aquifer for flow (GWQMN), groundwater re-evaporation coefficient (GW_REVAP), Threshold water depth in the shallow aquifer for “revap” (REVAPMN), average slope steepness (HRU_SLP), manning’s n value for overland flow (OV_N) and average slope length (SLSUBBSN). Based on sensitivity analysis, the parameters (SOL_BD, CN2, GW_REVAP, HRU_SLP, SOL_AWC, SFTMP, and SMTMP) were more sensitive.

For outlet number 17 (Shukhi station) 8 parameters used in calibration, these are curve number (CN2), base flow alpha factor (ALPHA_BF), groundwater delay (GW_DELAY), threshold water depth in the shallow aquifer for flow (GWQMN), threshold water depth in the shallow aquifer for “revap” (REVAPMN), groundwater re-evaporation coefficient (GW_REVAP), Snow melt base temperature (SMTMP) and snowfall temperature (SFTMP). In this outlet the most sensitive parameters are (GW_DELAY, SFTMP, SMTMP and CN2) respectively.

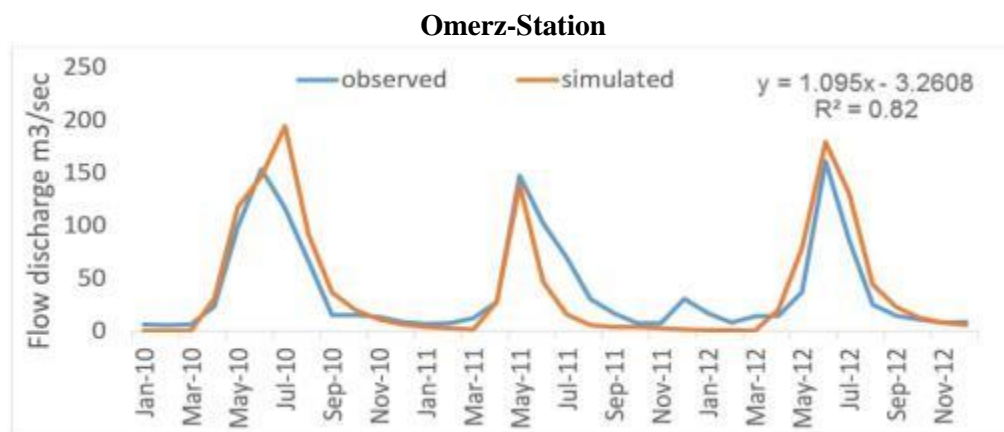


Figure 10: Monthly Observed and Simulated Flow Comparison for Calibration Period (2010-2012)

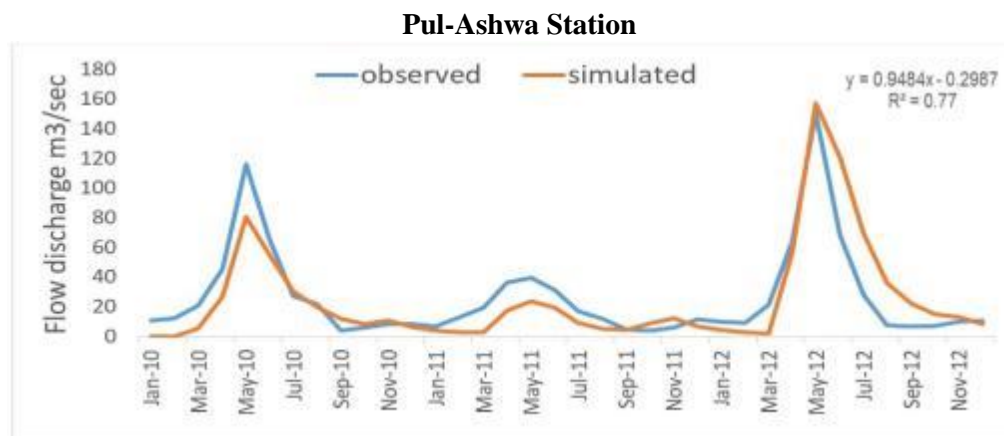


Figure 11: Monthly Observed and Simulated Flow Comparison for Calibration Period (2010-2012)

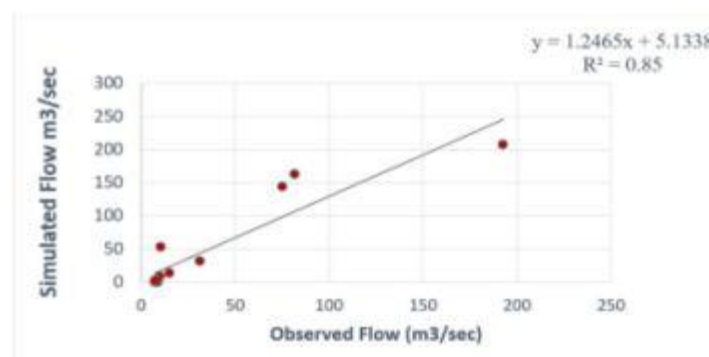
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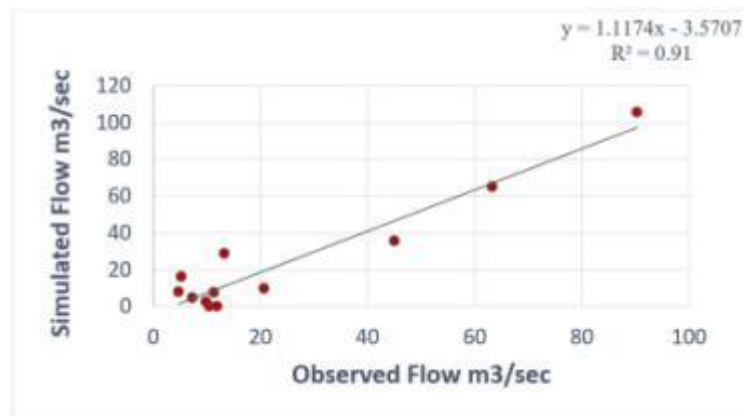
Figure 12: Comparison of Monthly Observed and Simulated Flow for Calibration Period (2010-2012)

(Figure 10) represent the monthly graphic comparison between observed and simulated flow for calibration in Omerz station (Outlet 3). In the calibration, the total average flow for the simulation period is 39.2 m³/s, while the average observed flow for the same period is 38.8 m³/s which shows 0.42 m³/s difference and this shows very close similarity. The monthly peak is in the Jun 2010, Jun 2011 and Jul 2012 respectively, in the time of calibration. In validation time, the result for the flow shows good correlation between observed and predicted values in Omarz, which demonstrated in Figure (13a). The statistic of coefficient of determination (R^2) are 0.82 and 0.85 for calibration and validation periods respectively. While in Pul-Ashawa sub basin (outlet 9), the peak flow shows under predict in calibration time (Figure 11). In this station the total average flow for the simulation is 24.46 m³/s, whereas the total average observed flow for the same period shows 26.10 m³/s. The difference of the total average water flow is 1.64 m³/s that show under estimation. The R^2 is 0.77 and 0.9 respectively that represent in the Figures (11 and 13b). The statistical evaluation showed good relationship between predicted and observed discharge.

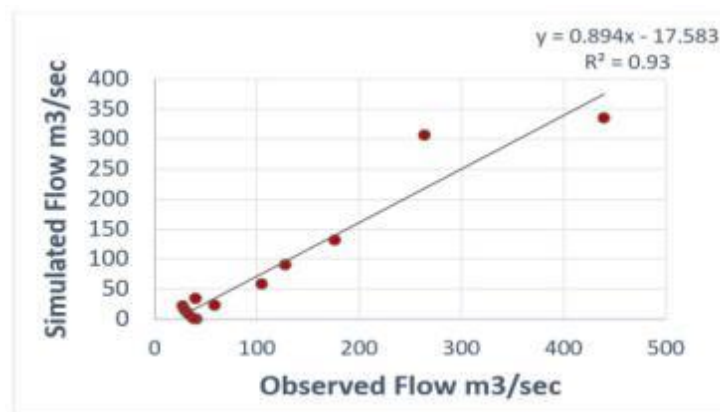
Also (Figure 12) represent the graphic comparison between observed and simulated monthly flow for calibration in Shukhi station (Outlet 17). After the calibration, the total average flow for the simulation period is 218.1 m³/s whereas the average observed flow for the same period is almost 216 m³/s. From the figure it seems that the monthly peak observed in the Jun 2010, May 2011 and Jun 2012 respectively, in the time of calibration. The simulation result showed good match in high flow periods and is less estimation in the low flow periods. For validation period, the result showed very good correlation between observed and predicted values which demonstrated in (Figure 13c). The statistics of coefficient of determination (R^2) is 0.9 and 0.93 for calibration and validation respectively, which totally showed very good correlation between monthly observed and simulated river discharge in Shukhi station. It is cleared that if more reliable precipitation and temperature datasets with accurate spatial coverage for the study area available, the results could be improved with more excellent accuracy.



(a): Validation Period for Omer Station (2013)



(b): Validation Period for Pul-Ashwa Station (2013)



(c): Validation Period for Shukhi Station (2013)

Figure 13: (a), (b) and (c) Comparison of Monthly Simulated and Observed Flow for 3 Outlets

During the calibration and validation evaluation in SWAT-CUP, the Nash-Sutcliffe Efficiency (NSE) method, as well as PBIAS considered for model efficiency. The statistics of NSE and PBIAS also showed good agreement between simulated and observed flow discharge for all stations in both periods. (Table 4) shows the all statistics evaluation for average monthly flow.

Water Balance Components

The components of water balance is important that usually considered in the water management issues and the processes which occur in watersheds. The most important elements of water balance in the basins are precipitation, surface runoff, lateral flow, base flow and evapotranspiration. Also as state by Shimaa, that among these components, all the variables, except precipitation, need prediction for quantifying as their measurement is not easy (Shimaa and Ghoraba, 2015). So in this study we also considered the Shukhi station (Outlet 17) which is located lower from the two other mentioned outlets. The average monthly values which simulated by the model for different water balance components after the calibration and validation are represented in the (Table 5). From the table we can find that the rainfall is increasing from 23.28 mm in Dec to 116.3 mm in Apr that is inflexible and it is occur during winter and early summer. With increasing of the precipitation, the snow fall also increases from Dec to Feb from 21.98 mm to 87.07mm respectively. But the surface runoff is very less during the winter period which shows it zero because of low temperature in winter and snow storage in high elevations of mountains. The more runoff occurs from Apr to Jun months during the summer season. The average annual values for different water balance components that simulated by the model and calculated as a relative percentage to average annual rainfall is shown in (Figure 14). These components are actual evapotranspiration 31%, discharge 8%, and ground water from shallow aquifer which reaches back to stream flow during the time 22%,

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water recharge from deep aquifer to stream flow 1%, lateral flow 4%, and total water yield 34% respectively. It seems that water yield (WLD) actual evapotranspiration (ET) contributed a large amount of water loss from this outlet.

Table 4: Represent the Static Evaluation of Average Monthly Flow for 3Sub-Basin in Watershed

Outlet Stations	Coefficients	Calibration Period (2010-2012)		Validation Period (2013)	
		Obs Flow (m3/sec)	Sim Flow (m3/sec)	Obs Flow (m3/sec)	Sim Flow (m3/sec)
Omerz	Mean	38.83	39.26	37.9	52.4
	P- Factor		0.64		0.67
	R- Factor		0.98		1.16
	R2		0.82		0.85
	NSE		0.72		0.60
	PBIAS		-1.1		-38.2
Pul- Ashawa	Mean	26.1	24.4	24.4	23.7
	P- Factor		0.67		0.42
	R- Factor		0.75		0.60
	R2		0.77		0.91
	NSE		0.73		0.86
	PBIAS		6.3		2.9
Shukhi-Station	Mean	215.9	218.1	114.9	85.21
	P- Factor		0.78		0.75
	R- Factor		1.18		0.77
	R2		0.90		0.93
	NSE		0.88		0.86
	PBIAS		1.9		25.9

Table 5: Average Monthly Parameters for Shukhi Outlet Station

MON	RAIN (MM)	SNOW		WATER		SED	YIELD (T/HA)	PET (MM)
		FALL (MM)	SUR_Q (MM)	LAT Q (MM)	YIELD (MM)	ET (MM)		
1	32.26	32.07	0	0.22	2.51	2.93	0	21.39
2	87.5	87.07	0	0.26	1.82	3.64	0	12.44
3	60.2	59.71	0.38	1.02	4.69	16.4	1.63	47.36
4	116.3	113.56	6.75	2.24	18.17	29.68	55.9	78.47
5	80.33	76.56	18.84	6.6	57.31	46.11	164.17	146.34
6	36.01	33.9	22.56	6.76	66.25	43.33	188.03	205.08
7	6.31	4.45	8.63	5.05	44.4	32.4	102.83	250.26
8	10.67	7.15	0	2.37	24.27	19.76	0	221.32
9	9.65	7.14	0	1.24	15.79	13.09	0	163.96
10	24.58	21.76	0	0.93	11.27	12.02	0	110.9
11	23.47	20.94	0	0.69	7.58	9.76	0	51.44
12	23.28	21.98	0	0.42	5.32	4.93	0	34.75
Total	510.56	486.29	57.16	27.8	259.38	234.05	512.56	1343.71

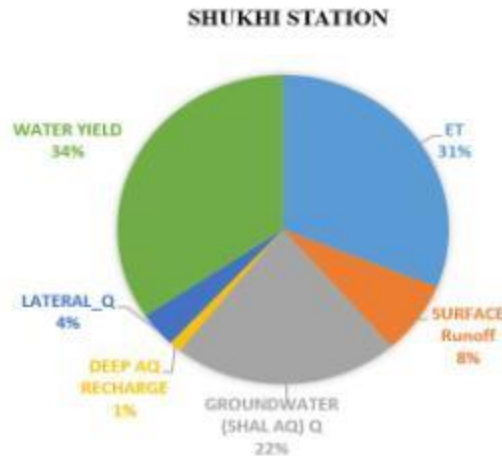


Figure 14: Represent the Average Annual Water Balance as a Relative Percentage after Calibration

Conclusion

This research conducted to study the hydrology of the Panjshir watershed which is located in the Kabul river basin at the south-east of Afghanistan. This is the first step applying SWAT model with GIS software in this study area and the main purpose was to estimate monthly discharge. Three hydrological stations was selected to evaluate the discharge result and water balance in the watershed. Arc GIS extracts the hydrologic information from spatial data. DEM used to delineates the stream network, sub basins, watershed, define HRUs. The model delineated the watershed with 29 sub basin and 184 HRUs within the sub basins. Soil Conservation Services (SCS) method used based on available daily data for estimation of stream flow. The simulation is done for 4 years from 2010 to 2013. After the simulation, the model evaluated for efficiency of predicted result by calibration and validation process. Calibration and validation has been done using Sufi-2 Algorithm SWAT-CUP model. The Sufi-2 algorithm is used outside of the Arc GIS interface and can be downloaded free. The coefficient of determination (R^2), Nash-Sutcliff efficiency (NS) and Percent Bias (PBIAS) used as an objective function. The calculated result of R^2 was 0.82, 0.77 and 0.91 in calibration and 0.85, 0.91 and 0.93 in validation period for Omerz, Pulashawa and Shukhi outlets respectively. The value for NS was 0.72, 0.73 and 0.88 in calibration and 0.60, 0.86 and 0.86 in validation. From these evaluations, it is indicated that the SWAT model had very good estimation in the Ghurband and Panjshir watershed and can be a potential monitoring tool for watersheds in mountainous area. It is highly recommended that SWAT model should be used with reliable hydro-meteorological data in the mentioned watershed for more details.

ACKNOWLEDGEMENT

The Authors would like to thank from the University of the Ryukyus, Japan International Cooperation Agency (JICA) Project for the Promotion and Enhancement of the Afghan Capacity for Effective Development (PEACE) for providing founded and giving chance for improving of knowledge scales and the government of Afghanistan for its cooperation in this study.

REFERENCES

- Abbaspour KC, Rouholahnejad E, Vaghefi S, Srinivisan R, Yang H and Kløve B (2015). A continental scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. *Journal of Hydrology* **524**(1) 733-752.
- Abbaspour KC, Yang J, Maximov I, Siber R, Bogner K Mieleitner J, Zobrist J and Srinivasan R (2007). Modelling hydrology and water quality the pre-alpine/alpine Thur watershed using SWAT, *Journal of Hydrology* **333**(2-4) 413-430.

Research Article

Singh A (2009). Characterizing runoff generation mechanism for modelling runoff and soil erosion, in small watershed of Himalayan region, Thesis of International Institute for Geo-information Science and Earth Observation, Netherland 14.

Arnold JG, Srinivasan R, Muttiah RS and Williams JR (1998). Large area hydrologic modeling and assessment, part I: Model development, *Journal of the American Water Resources Association* **34**(1) 73-89.

Advanced Space Borne Thermal Emission and Reflection Radiometer (ASTER) GDEM [Online]. California Institute of Technology. Available: <http://gdem.ersdac.jspacesystems.or.jp> [Accessed 12.04.2015].

Food and Agriculture Organization of the United Nations (FAO/UNESCO) [Online]. *Soil Map of the World*. Available: <http://www.fao.org> [Accessed 12.03.2015].

Global Weather Data for SWAT [Online]. National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR). Available: <http://globalweather.tamu.edu> [Accessed 01.23.2016].

Gupta HV, Sorooshian S and Yapo PO (1999). Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. *Journal of Hydrologic Engineering* **4**(2) 135-143.

Japan International Cooperation Agency Research Institute JICA-RI (2012). Report of Afghanistan and Japan work together on state-building and development in Afghanistan **978**(4) 119.

Moriassi D, Arnold JG, Van Liew MW, Bingner RL, Harmel RD and Veith TL (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *Transactions of the American Society of Agricultural and Biological Engineers* **50**(3) 885-900.

Nash JE and Sutcliffe JV (1970). River flow forecasting through conceptual models part I: A discussion of principles, *Journal of Hydrology* **10**(3) 282-290.

Neitsch SL, Arnold JG, Kiniry JR and Williams JR (2005). *Soil and Water Assessment Tool Theoretical Documentation Version*, Black Land Research Centre Texas Agricultural Experiment Station **720**, East Black Land, Texas 76502, (Grassland, Soil and Water Research Laboratory, Black Land Research Centre, Temple, Texas)

Shimaa M and Ghoraba (2015). Hydrological modeling of the Simly Dam watershed (Pakistan) using GIS and SWAT model, *Alexandria Engineering Journal* **54**(3) 583-594.

Houben G, Niard N, Tünnermeier T and Himmelsbach T (2009). Hydrogeology of the Kabul Basin (Afghanistan), part I: aquifers and hydrology, *Hydrogeology Journal* **17**(3) 665-677.

US Army Corps of Engineers (2009). Provincial water resource data summery of Parwan/Afghanistan, *UNCLASSIFIED//FOUO* 1-7.

Shivhare V, Goel MK and Singh CK (2014). Simulation of surface runoff for upper TAPI sub catchment area (Burhanpur watershed) using SWAT, *The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences* **XL**(8) 391-397.

Wincheel M, Srinivasan R, DiLuzio M and Arnold J (2013). *Arc SWAT Interface for SWAT 2012 User Guide*, (Grassland Soil and Water Research Laboratory USDA Agricultural Research Service 808 East Black Land Road-Temple, Texas, USA) 765021.