



Hydrological modeling of chaqchaq ungauged watershed using Arcswatmodel

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Abstract

In this study sediment and rainfall-runoff models have been developed for the Chaqchaq ungauged watershed using Arc SWAT and remotely sensed satellite image. The model aims at simulating the sediment and the runoff into the proposed Chaqchaq dam reservoir near Sulaimani governorate. Field data about the soil cover are collected using 32 soil samples from different locations within the watershed. Five major types of land covers were recognized and represented in the form of raster images of 30*30m resolution namely; Agricultural Land Cropland and pasture (RNGE), Mixed Rangeland (RNGB), Agricultural Orchards (ORCD), Barren Land Exposed Rock Land cover and Mixed Forest Land cover. The predicted annual sediment volume was 5.33 t/ha and the annual runoff depth predicted by this model was 99.17 mm.

Introduction

The rapid growth of Sulaimani population has caused great stresses on water resources in the area. It is also expected to continue even more in the future. Moreover, life style has improved which has increased the demand for alternative water sources. Dam construction is a powerful option to mitigate the impact of shortage in water resources given the favorable topography and relatively high rate of rainfall in this region. In the study and design of dams, sediment and Rainfall-runoff modelling are major parts. Therefore, they are considered as standard tool routinely used today for the investigation and application in catchment hydrology and select proper site for dams. In this study Soil and Water Assessment Tool (SWAT) is used as sediment and rainfall-runoff modelling. SWAT is one of the widely used river basin scale conceptual hydrologic models, it is developed by the United States Department of Agriculture (USDA) [1].

Literature Review

Many researchers have attempted to develop hydrological models to predict the runoff and the soil erosion generated from rainfall events. Below are a brief review of some of these attempts: Al-Dulaimy developed a hydrological model for evaluation of rainfall-runoff relationship for Darbendekhan basin with the aid of Remote Sensing & GIS techniques. The excess rainfall depth is based on SCS Curve Number (CN) method [2]. Taffese [3] developed a rainfall-runoff modelling for Mizewa Watershed located in North Western part of Ethiopia using SWAT 2005 model. Both SWAT soil conservation service curve number (SWAT-CN) and water balance (SWAT-WB) method were used. The result of the two models was compared in three ways and the result shows fair prediction for SWAT-CN approach than SWAT-WB. Ijam and Tarawnah [4] have developed a SWAT model to simulate the soil erosion and sediment for Wala dam catchment (2000 km²) in Jordan. They calibrated and verified their model using flow rate and sediment yield data observed at Wala flow station. The study suggested sediment control measures at some tributaries of high sediment rate to keep the storage at Wala dam reservoir. Dhawale [5] investigated the ability of SCS-CN model to estimate surface runoff depth for ungauged watershed. The study reveals that the SCS-CN model integrated with RS and GIS can be used accurately to estimate runoff depth when adequate hydrological information is not available.

Materials and methods

A. Study area

The Study Area is a sub basin of Sharazoor-Piramaqroon basin located in northeastern Iraq (Kurdistan Region), and (Northwest) of the Sulaimani Governorate. It extends between the latitude ($35^{\circ}36' 0''$ - $36^{\circ} 46' 0''$) to the north and the longitude ($45^{\circ} 15' 0''$ - $45^{\circ} 28' 0''$) to the east as shown in Figure:1. It covers around 138 km² area. Most of the valley surface consists of gently sloping plain to the west and south of Sulaimani city. The elevation changes very dramatically from (756-2088 amsl) with an average of 1127.63 m and standard deviation 237.47 as shown in Figure:2. Most of the land is left without treatment. The river in the watershed is of ephemeral type and it is about 23 km long.

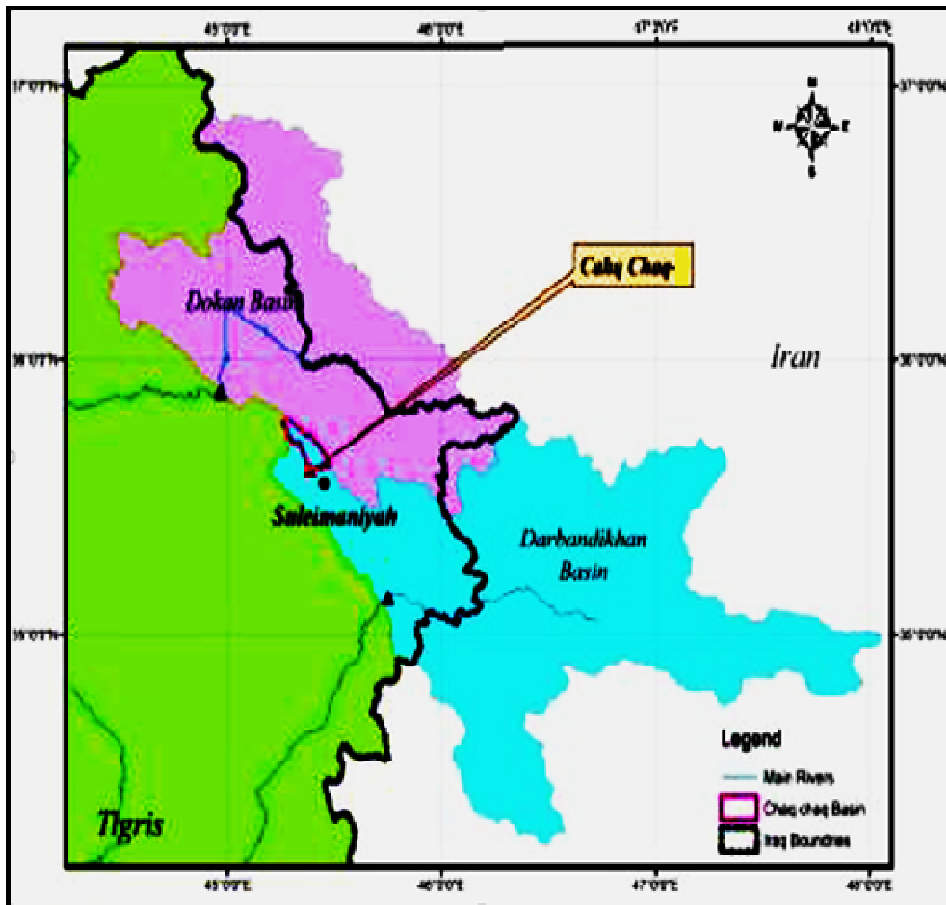


Figure-1: Location of the study area.

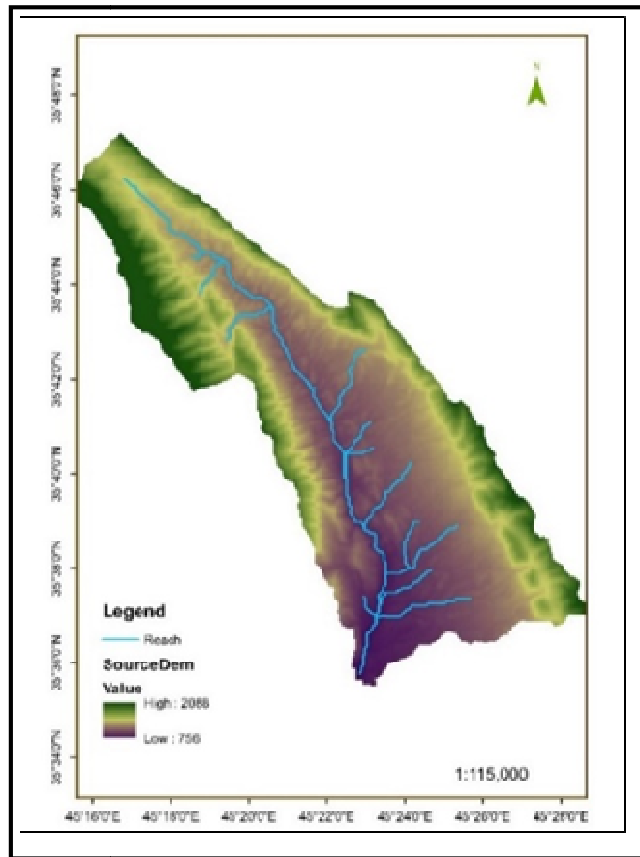


Figure 2: DEM Map of Study Area.

B. The used softwares

In order to estimate sediment and runoff quantity some Software's are used as shown below:

- Geospatial analysis by ArcGIS -10.0 and Google Mapper 12.
- Physical Soil data analysis by SPAW (Soil-Plant-Air-Water).
- Arc SWAT 2012.
- ENVI Classic 5.1 Classic supports band combination.
- Microsoft word Notepad ++ and excel.

C. Attribute and spatial data

Spatial data required in this study were collected from different sources:

- Digital Elevation Model 30 m resolution.
- Meteorological stations and their locations (Latitude, Longitude).
- Soil map using field samples and appropriate laboratory tests.
- Satellite image Landsat 8 OLI of the study area from USGS.
- Regional climate data on weather parameters.

D. Experimental and laboratory works

The experimental works were carried out through collecting 32 soil samples at different locations within the watershed under study. Proper laboratory works were conducted on the collected soil samples to determine the soil textures and the particle size distribution as well as Soil organic matter content (SOM).

E. Soil-Plant-Air-Water (SPAW)

From textural property of each soil's profile, organic matter; the soil properties were estimated using Soil-Plant-Air-Water (SPAW) hydrology program-version 6.1.52 [6], a graphical program developed by Saxton and Walter Rawls for estimating soil water tension, saturated hydraulic

conductivity and water holding capability based on soil texture, organic matter, gravel content, and compaction. The estimated properties were soil wilting point (WP), field capacity (FC), saturation (STU), soil available water content (SOLAWC), and bulk density (SOLBD) based on soil texture, organic matter, and gravel content.

F. Satellite image and DEMmodel

The satellite image of Chaqchaq basin was extracted from Landsat 8 OLI, at September 15, 2014, with 30m resolution free downloads in website <http://earthexplorer.usgs.gov/> [7]. ENVI software has been used to make radiometric correction and atmospheric correction which converts the satellite image to original digital number (DN) reflectance. The TIFF Raster was then converted to GRID format for easier Geoprocessing activities. Arc Scene 10 can be used to create accurate topographic elevation models and generate precise 3D data layers as shown in Figure:3.

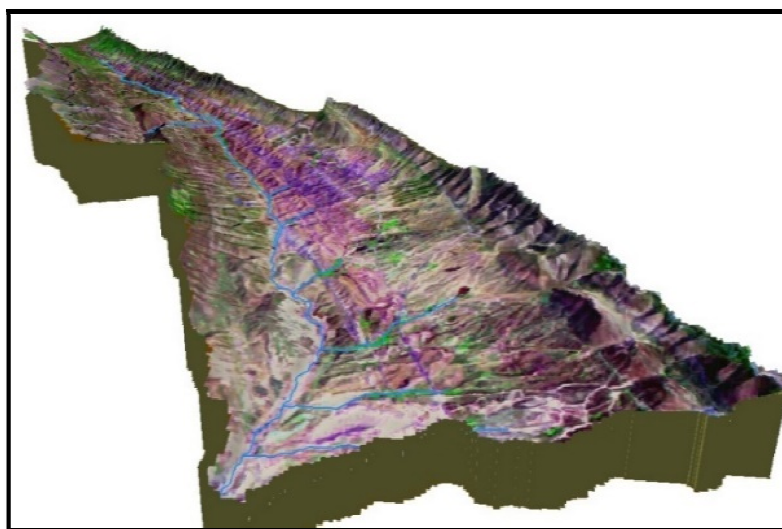


Figure-3: Three Dimension of Chaqchaq Basin Model.

G. Weather Data:

SWAT requires daily values for precipitation (mm), maximum and minimum temperature (°C), solar radiation (MJ/m²/day), relative humidity (fraction) and wind speed (m/s). Meteorological data for Sulaimaniyah weather station (15 km from study area) has been used and locational tables were provided. These locational tables were linked with the data table, which contained the daily values for the rainfall, temperature, humidity, sunshine, and wind speed. The weather generator input file contains the statistical data needed to generate representative daily climate data for the sub-basins. Due to intervention and missing of sum data, fourteen years (2000-2013) of data is used in this study.

Hydrological modelling by soil and water assessment tool based Arc GIS (Arc SWAT):

Arc SWAT 2012 has been used to model the annual rainfall-runoff and the annual sediment volumes for Chaqchaq watershed. The procedure adopted to develop the Arc SWAT model is illustrated below:

A. Supervised classification

In supervised classification, the identity and location of some of land cover types, such as urban, agriculture, wetland are specified through a combination of fieldwork, analysis of aerial photography, maps, and personal experience [8]. Supervised classification technique has been used to produce digital Land use/Land cover map as shown Figure: 4.

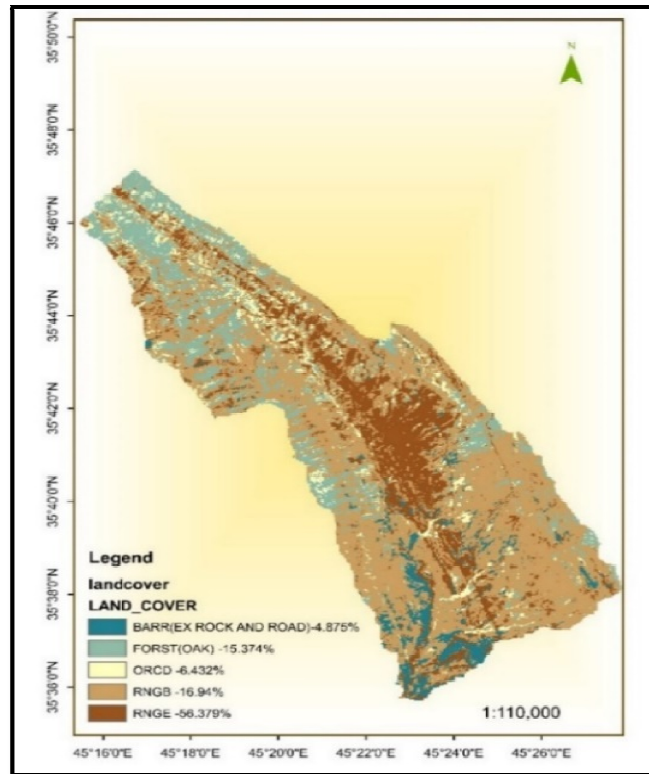


Figure-4: Land Cover Supervised classification.

B. Geostatistical interpolations used in creating soil map

In this study Kriging method has been used to perform the geostatistical interpolation. The raster soil map are constructed using five class textures as shown in Figure: 5. The Root-Mean-Square Standardized was equal 0.67, Average Standard Error was equal 10.8.

The HSGs have been assigned based on the saturated hydraulic conductivity. For each soil texture the saturated hydraulic conductivity is determined according to Table 1 [9]. The range of soil group is specified by (SCS, 1986) as shown in Table 2.

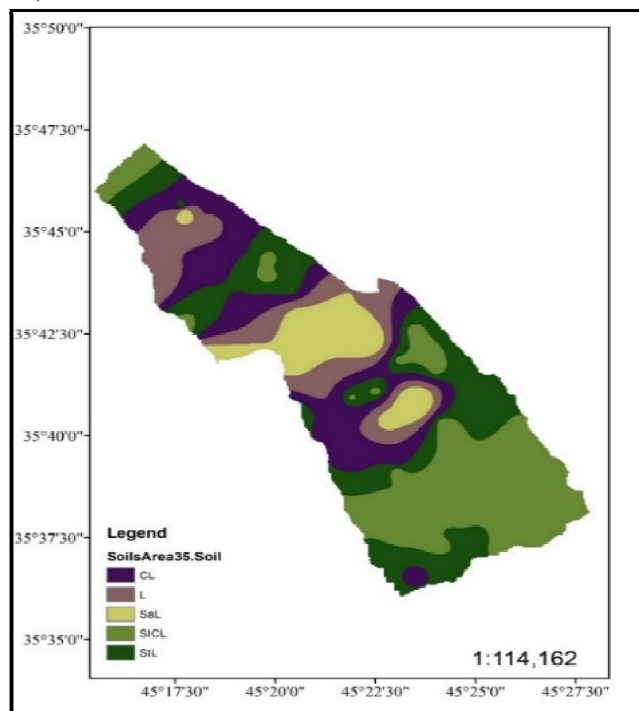


Figure 5: Land Soil Distribution across Study Area.

Table 1: Typical Soil Properties for Different Soil Texture [9].

Texture class	Sample size	Total porosity (θ), cm^3/cm^3	Residual saturation (θ_r), cm^3/cm^3	Effective porosity (θ_e), cm^3/cm^3	Bubbling pressure (ψ_b)		Pore size distribution (λ)		Water retained at -0.33 bar tension, cm^3/cm^3	Water retained at -15 bar tension, cm^3/cm^3	Saturated Hydraulic Conductivity † (K_s) cm/hr
					Arithmetic, cm	Geometric, cm	Arithmetic	Geometric			
Sand	762	0.437** (0.374-0.500)	0.020 (0.001-0.039)	0.417 (0.354-0.480)	15.98 (0.24-31.72)	7.26 (1.36-38.74)	0.694 (0.298-1.090)	0.592 (0.334-1.051)	0.091 (0.018-0.164)	0.033 (0.007-0.059)	21.00
Loamy sand	338	0.437 (0.368-0.506)	0.035 (0.003-0.067)	0.401 (0.329-0.473)	20.58 (0.0-45.20)	8.69 (1.80-41.85)	0.553 (0.234-0.872)	0.474 (0.271-0.827)	0.125 (0.060-0.190)	0.055 (0.019-0.091)	6.11
Sandy loam	666	0.453 (0.351-0.555)	0.041 (0.0-0.106)	0.412 (0.283-0.541)	30.20 (0.0-64.01)	14.66 (3.45-62.24)	0.378 (0.140-0.616)	0.322 (0.186-0.558)	0.207 (0.126-0.288)	0.095 (0.031-0.159)	2.59
Loam	383	0.463 (0.375-0.551)	0.027 (0.0-0.074)	0.434 (0.334-0.534)	40.12 (0.0-100.3)	11.15 (1.63-76.40)	0.252 (0.086-0.418)	0.220 (0.137-0.355)	0.270 (0.195-0.345)	0.117 (0.069-0.165)	1.32
Silt loam	1206	0.501 (0.420-0.582)	0.015 (0.0-0.058)	0.486 (0.394-0.578)	50.87 (0.0-109.4)	20.76 (3.58-120.4)	0.234 (0.105-0.363)	0.211 (0.136-0.326)	0.330 (0.258-0.402)	0.133 (0.078-0.188)	0.68
Sandy clay loam	498	0.398 (0.332-0.464)	0.068 (0.0-0.137)	0.330 (0.235-0.425)	59.41 (0.0-123.4)	28.08 (5.57-141.5)	0.319 (0.079-0.559)	0.250 (0.125-0.502)	0.255 (0.186-0.324)	0.148 (0.085-0.211)	0.43
Clay loam	366	0.464 (0.409-0.519)	0.075 (0.0-0.174)	0.390 (0.279-0.501)	56.43 (0.0-124.3)	25.89 (5.80-115.7)	0.242 (0.070-0.414)	0.194 (0.100-0.377)	0.318 (0.250-0.386)	0.197 (0.115-0.279)	0.23
Silty clay loam	689	0.471 (0.418-0.524)	0.040 (0.0-0.118)	0.432 (0.347-0.517)	70.33 (0.0-143.9)	32.56 (6.68-158.7)	0.177 (0.039-0.315)	0.151 (0.090-0.253)	0.366 (0.304-0.428)	0.208 (0.138-0.278)	0.15
Sandy clay	45	0.430 (0.370-0.490)	0.109 (0.0-0.205)	0.321 (0.207-0.435)	79.48 (0.0-179.1)	29.17 (4.96-171.6)	0.223 (0.048-0.398)	0.168 (0.078-0.364)	0.339 (0.245-0.433)	0.239 (0.162-0.316)	0.12
Silty clay	127	0.479 (0.425-0.533)	0.056 (0.0-0.136)	0.423 (0.334-0.512)	76.54 (0.0-159.6)	34.19 (7.04-166.2)	0.150 (0.040-0.260)	0.127 (0.074-0.219)	0.387 (0.332-0.442)	0.250 (0.193-0.307)	0.09
Clay	291	0.475 (0.427-0.523)	0.090 (0.0-0.195)	0.385 (0.269-0.501)	85.60 (0.0-176.1)	37.30 (7.43-187.2)	0.165 (0.037-0.293)	0.131 (0.068-0.253)	0.396 (0.326-0.466)	0.272 (0.208-0.336)	0.06

Table2: Definitions of Hydrologic Soil Groups in SCS (adapted from [10]).

Soil Types	Definitions	Saturated Hydraulic Conductivity in/hr
A	Soils having high infiltration rate, low runoff capacity, and consist chiefly of deep sand, deep losses, aggregated silt.	≥ 0.45
B	Soils having moderate infiltration rates, and consisting chiefly of moderately deep to deep, moderately well to well drained, moderately fine to moderately coarse textures. E.g., shallow losses, sandy loam.	0.3-0.15
C	Soils having low infiltration rates, and consisting chiefly of soils with layers that impedes downward movement of water or soils with moderately fine to fine textures. E.g., clay loam shallow sandy loam.	0.15-0.05
D	Soils having very low infiltration rates, and consisting chiefly of clay with a high swelling potential, soils with permanent high water table, soils with clay layer at or near the surface, shallow soils with nearly impervious materials.	0.05-0.0

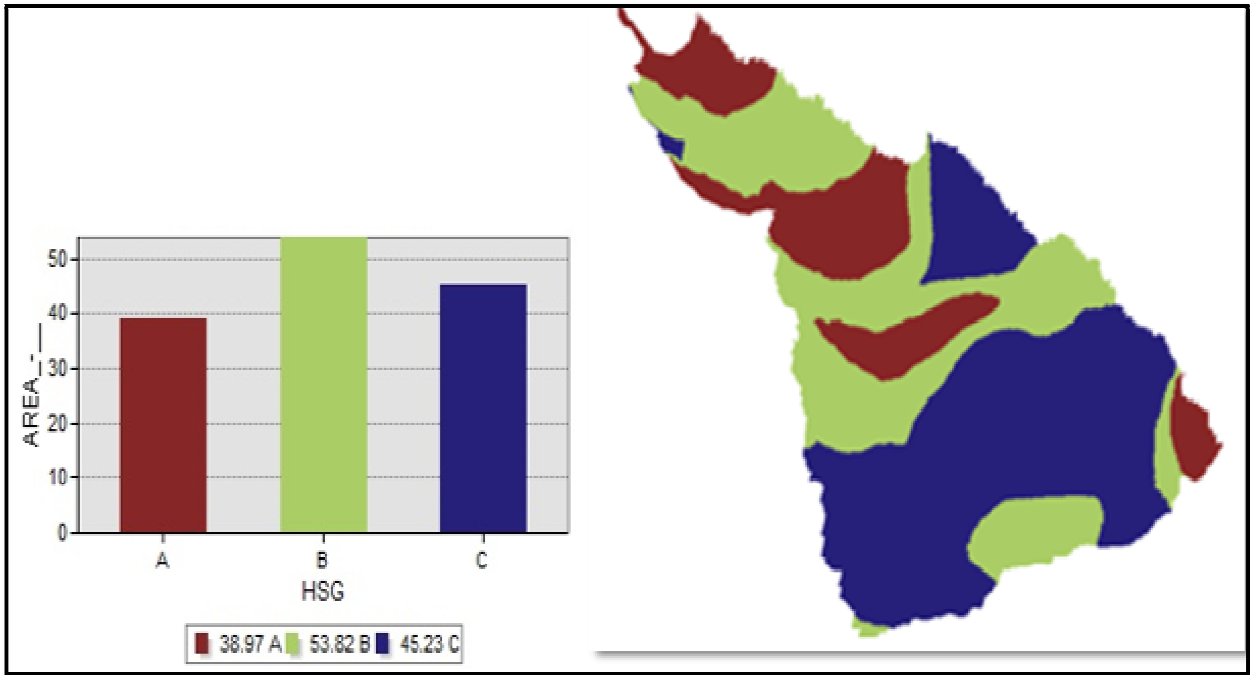


Figure-6: Final Result for HSG for Chaqchaq.

Figure 6 shows that there are three types of soil groups in Chaqchaq catchment area; namely A, B and C. Type "A" represents about 28% of the total area and it is of high infiltration. Type "B" can be found in the middle and near the Chaqchaq lake and forms around 39% of the total area, while Type "C" constitute of 33% of basin area and it is found often in the part that land cover exposed rock and it represents low infiltration soil rate.

C. *Runoff modeling*

SWAT simulates surface runoff volumes for each HRU using two methods namely, the SCS Curve Number (CN) procedure and the Green & Ampt infiltration method [11]. The Green and Ampt method needs sub-daily time step rainfall which made it difficult to be used for this study due to the absence of sub daily rainfall data. Therefore, the SCS curve number method was adopted for this study. The HSG was defined for each HRUs in the soil database. The SWAT model calculates the CN automatically from arrangement the land use, soil and slope as shown Figure:7. These curve numbers are then adjusted for the slope effects as shown in Table:3. As a final result, the average curve number for the watershed was 68.46.

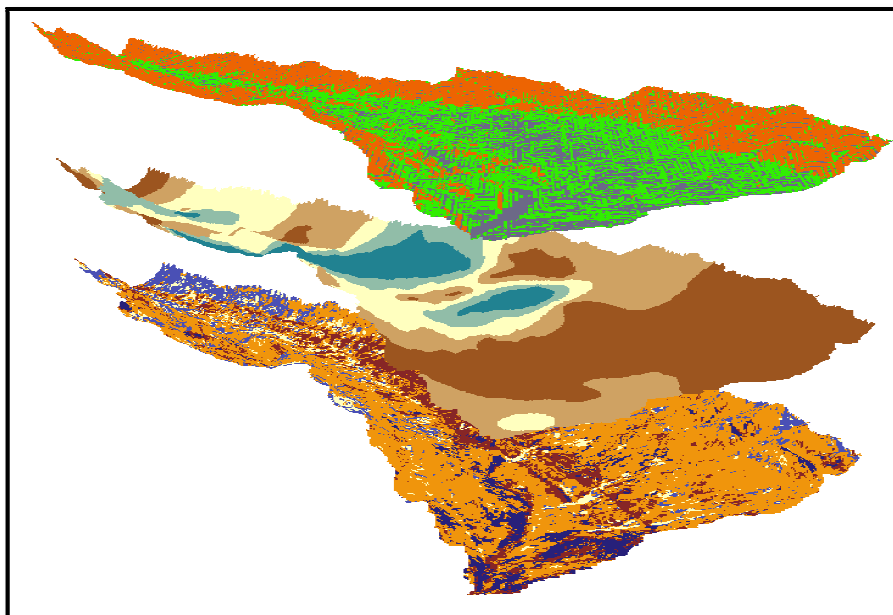


Figure-6: Land Use/Soil/Slope Respectively (Up To Down) are overlaid to Create HURs for Each Sub Basin.

Table-3: Corrected CNs for slope effect.

lu/lc	Sum of Area (ha)	Average of CN1	Average of CN2	Average of CN3
BARR	300.28	75.60	88.50	95.60
FRST	2030.52	40.66	59.95	77.64
ORCD	406.20	55.70	73.68	87.57
RNGB	2152.84	44.53	63.47	80.23
RNGE	8911.47	50.56	69.25	84.94
<i>Total Area = 13801.31</i>				

Figure:8 shows the surface runoff depth for each subbasin. From this figure; it can be concluded that there are three levels of runoff regarding the rainfall events. High runoff depth obtained in sub-basins (14, 16, 20, 22, and 23.) mid runoff depth obtained in sub-basins (2, 5, 8, 10 and 11) and low runoff depth obtained in sub-basins 3 and 4. The resulted overall annual runoff depth has been estimated at 99.17 mm resulting in annual runoff volume of around 13.8 Mm³

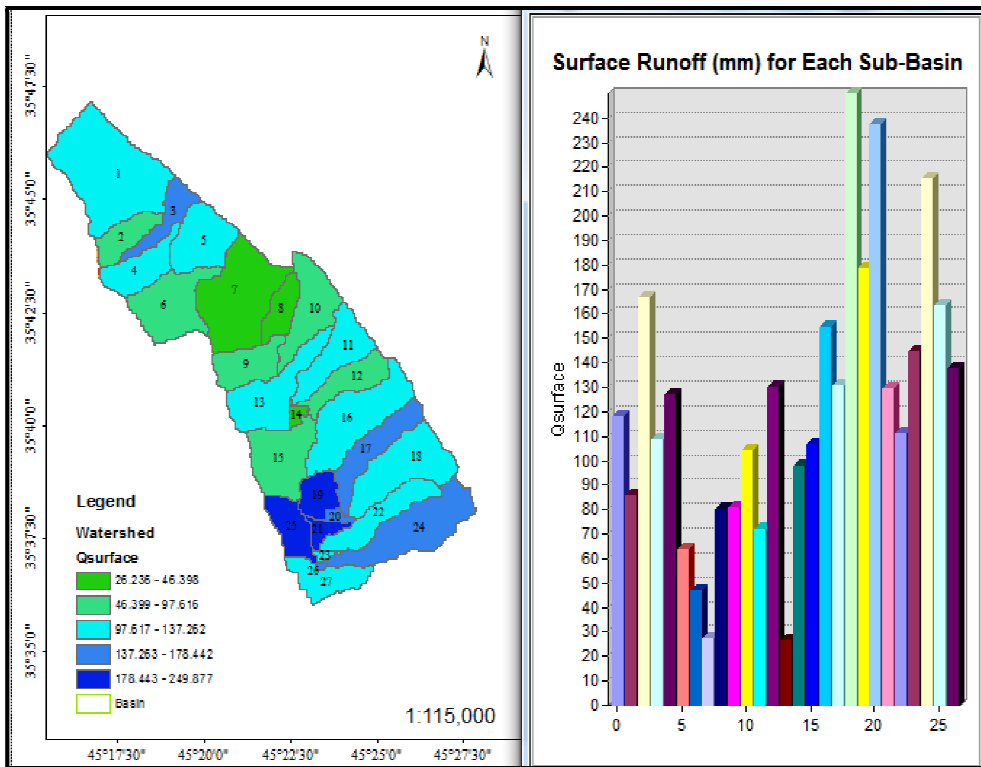


Figure 7: Surface Runoff Depth for Each Sub Basin within Chaqchaq Watershed.

Figure:9 depicts the hydrological processes for Chaqchaq watershed using Arc SWAT model. Figure:10 shows a graphical presentation of the monthly precipitation and the corresponding monthly surface runoff.

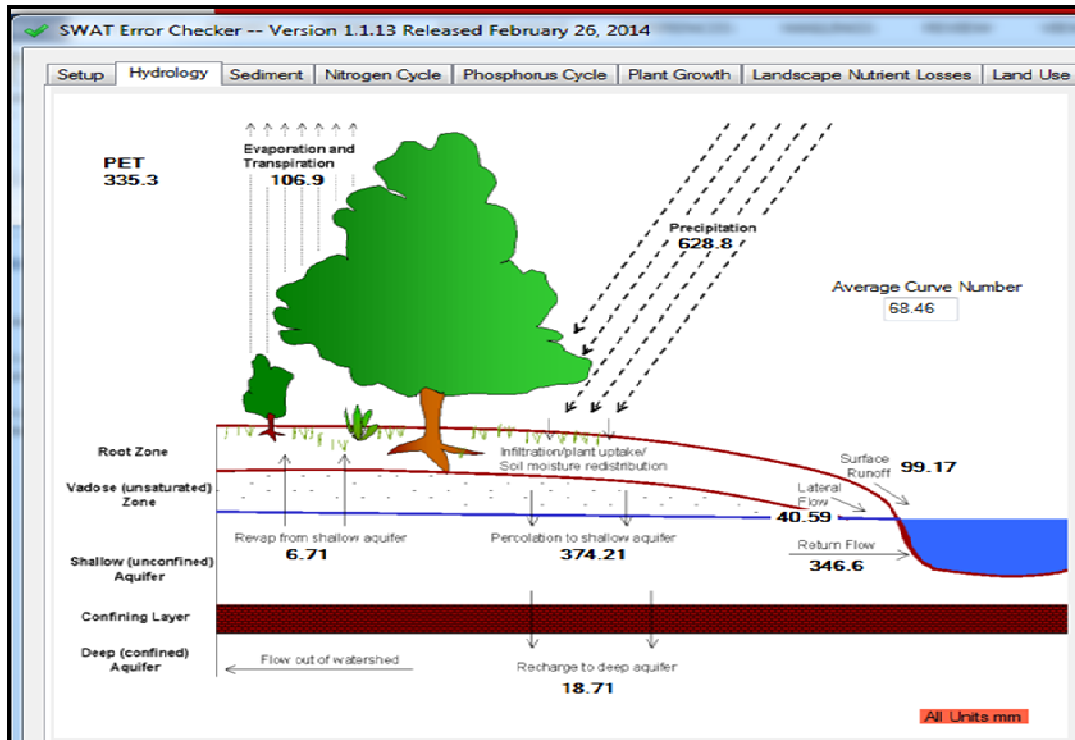


Figure-8: SWAT Model Processes For Chaqchaq Watershed.

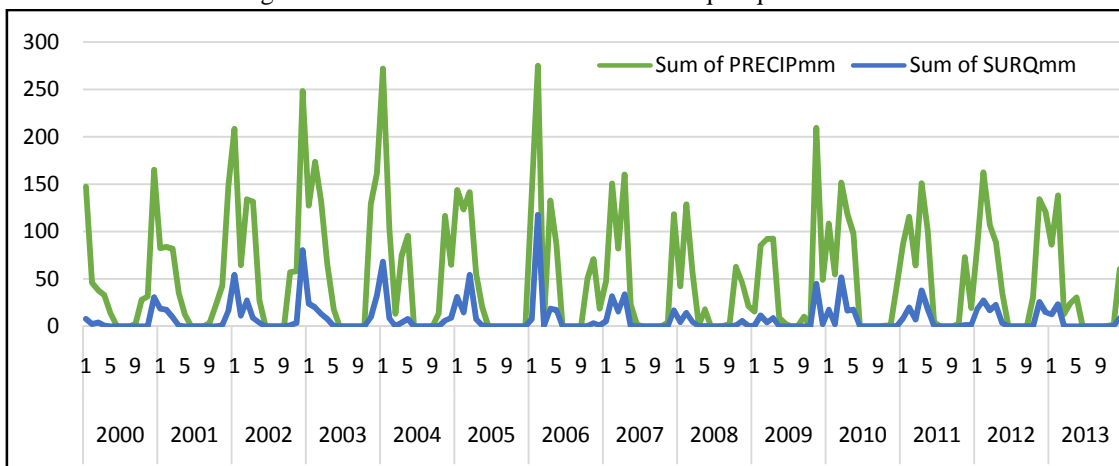


Figure-9: Simulated Daily Surface Runoff for Chaqchaq Watershed (2000 to 2013).

Sediment Yield Model:

The rate of sedimentation is one of the most important quantities that need to be known because this quantity determines the useful life of the dam. USLE provide approximation to regional assessment sediment yield for watershed planning purpose.

Soil erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith [12]. MUSLE equation is:

$$Sed = 11.8(Q_{surf} * q_{peak} * area_{hru})^{0.56} * K_{USLE} * KC_{USLE} * P_{USLE} * LS_{USLE} * CFRG \dots \dots \dots (2)$$

Where *sed* is the sediment yield on a given day (metric tons), Q_{surf} is the Surface runoff volume (mm H₂O/ha), q_{peak} is the peak runoff rate (m³/s), $Area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m²hr./m³-metric ton cm), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, L_{SUSLE} is the USLE topographic factor and CFRG is the coarse fragment factor. Standard MUSLE cover and management factors within the SWAT were used. The land use/cover classification related to the model are given in Table:4.

Table-4: Land Cover Classification and Values.

SWAT ID Landcover	Manning's Roughness Coefficient	SCS Curve Number					hydrologic condition	MUSLE Cover and Management Factor
		A	B	C	D			
BARR	0.2	77	86	91	94	-	0.200	
FRST	0.45	45	66	77	83	fair	0.001	
ORCD	0.3	57	73	82	86	poor	0.001	
RNGB	0.6	49	69	79	84	fair	0.003	
RNGE	0.6	68	79	86	89	poor	0.003	

A. Soil data input& results.

Soil physical attributes were initially stored to the SWAT's soil database through an interface, relevant information required for hydrological modeling and soil erosion modeling was provided to the model. The database was linked to soil map through the look up table which was again linked to the soil map, as shown in Table:5.

Table-5: Input Soil Database Soil.

Class texture	%Silt	%Sand	%Clay	%Organic matter	SOLBD	SOLK	SOLAWC	STU	FC	WP
CL	33.01	37.70	29.29	4.65	1.35	0.09	0.14	49.13	33.40	19.23
L	38.48	42.33	19.19	3.64	1.33	0.52	0.14	49.80	28.54	14.04
SaL	24.05	63.15	12.80	2.72	1.40	1.01	0.10	47.36	21.26	10.52
SICL	51.48	14.62	33.90	3.71	1.27	0.06	0.16	52.13	37.60	20.93
SIL	54.29	24.39	21.32	3.54	1.27	0.27	0.18	49.88	32.22	14.50

Figure: 12 shows the contribution of each sub catchment in the sediment production. Sub catchments 19 and 25 yield more sediment than other sub catchments. Chaqchaq sediment inflow rate can be reduced considerably by constructing several small check dams at the downstream end of the sub catchments having high to moderate sediment yields or at least constructing one check dam at the upstream end of the reservoir. Some of the sub catchments close to the dam axis (lower end of the catchment area) including sub catchment 25 may be completely or partially submerged by the reservoir water. The submergence of any sub catchment will prevent the soil erosion and will produce no sediment yield.

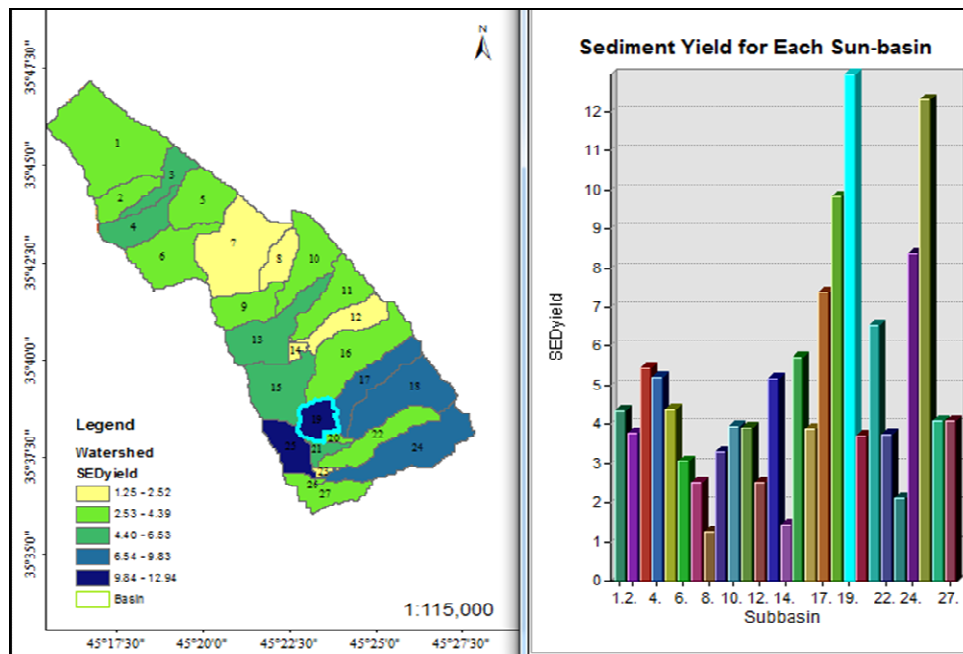


Figure 10: Sediment Yield for Each Sub catchment within Chaqchaq watershed.

Figure: 13 shows the predicted Sediment yield using the SWAT model. Figure: 14 shows a graphical presentation of the monthly Sediment yield.

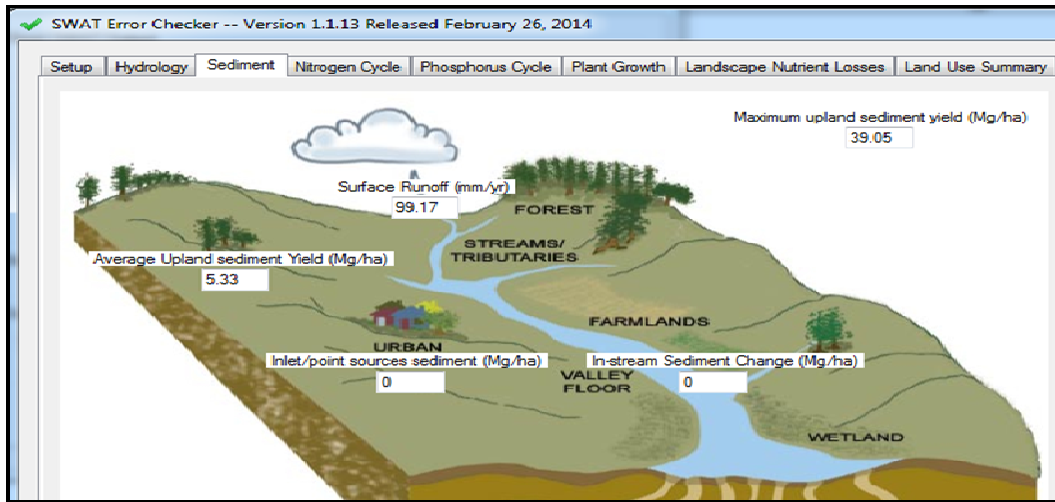


Figure-11: SWAT model processes of the sediment Yield for the Chaqchaq watershed.

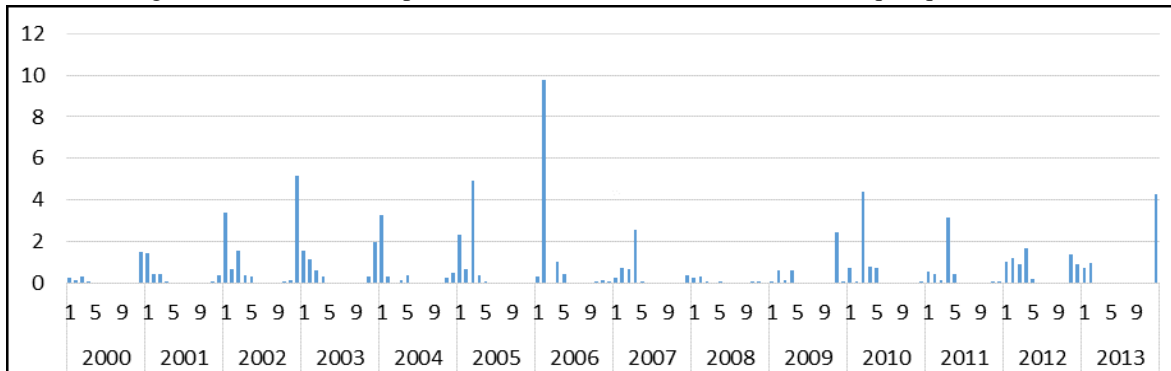


Figure-12: SWAT Output for Average Monthly Sediment.

Verification of the Sediment Yield Model

As mentioned before there are no continues measurement for Chaqchaq catchment related to runoff and sediment yield. So the verification of the sediment yield predicted by the SWAT model will be carried out using two empirical equations as below:

A. Modified PSIAC Method by using satellite data

This model estimates the soil erosion in ungauged basins located in arid and semiarid regions in 1968 [1]. In this model the sediment is estimated according to nine factors as presented mathematically in Table: 6. The following is the MPSIAC equation [14]:

$$Q_s = 0.25 * e^{0.036R} \dots \dots \dots (3)$$

$$R = X_1 + 16.6K + 0.2P_2 + 0.006R + 10Q_p + 0.33S + 0.2P_c + 0.25SSF + 1.67SSFg \dots \dots \dots (4)$$

Q_s is Total Sediment load, t/ha/year, R= Average Effective factors.

Table-6: MPSIAC Model Factors [15].

Description	Equation	Effective Factors
X_1 = Stones sensitivity to erosion (0 - 10)	$Y_1 = X_1$	Surface geology
K = Soil erodibility	$Y_2 = 16.67K$	Soil
P_2 = 6-hour rainfall with 2-year return period	$Y_3 = 0.2P_2$	Climate
R = runoff height,	$Y_4 = .006R + 10Q_p$	Runoff
Q_p =1-year specific pick discharge		
S =slope %	$Y_5 = 0.33S$	Topography
P_b = bare ground percent	$Y_6 = 0.2P_b$	Land cover

P_c = crop canopy percent

$$Y_7 = 20 - 0.2P_c$$

Land use

SSF = the score of soil surface erosion in the BLM method

$$Y_8 = 0.25SSF$$

Surface erosion

SSF_g = the score of gully erosion in the BLM method

$$Y_9 = 1.67SSF_g$$

Gully erosion

Figure: 15 shows soil erosion potential and channel erosion potential layers of study area and Figure: 16 show surface and slope layers of the study area.

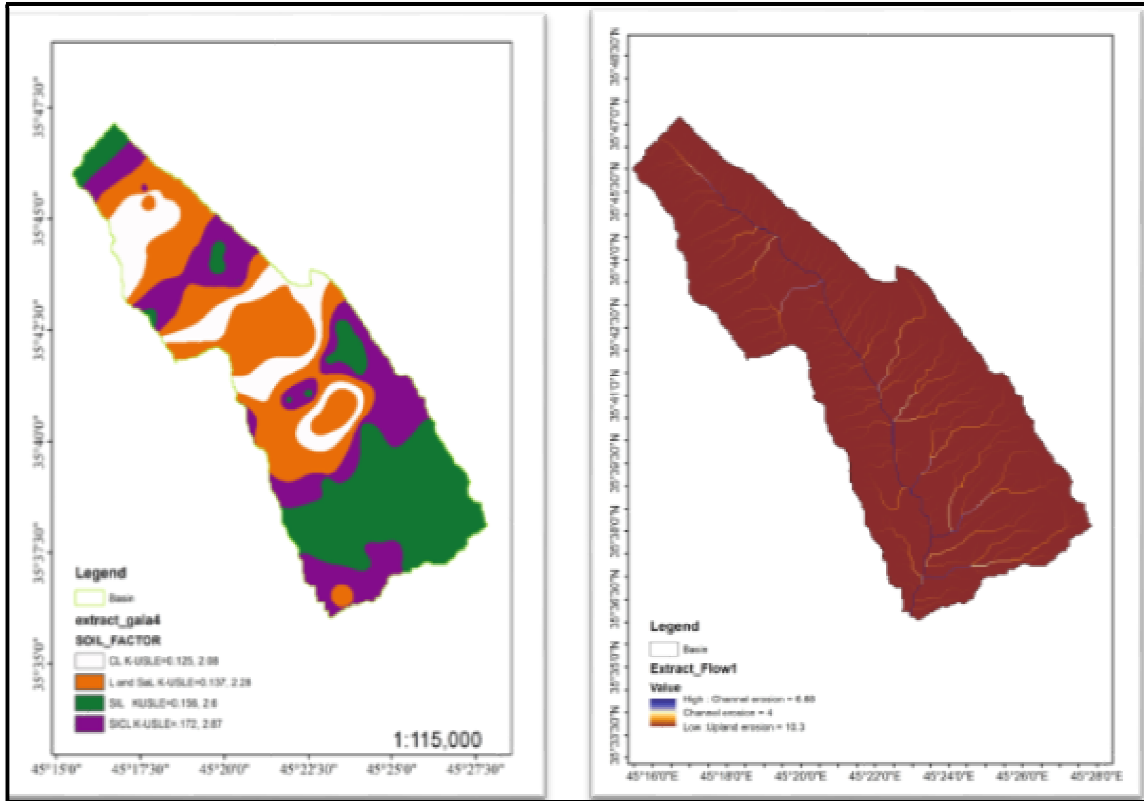


Figure-13: Soil Erosion Potential (Left) and channel Erosion Potential (Right) layers for the Study Area.

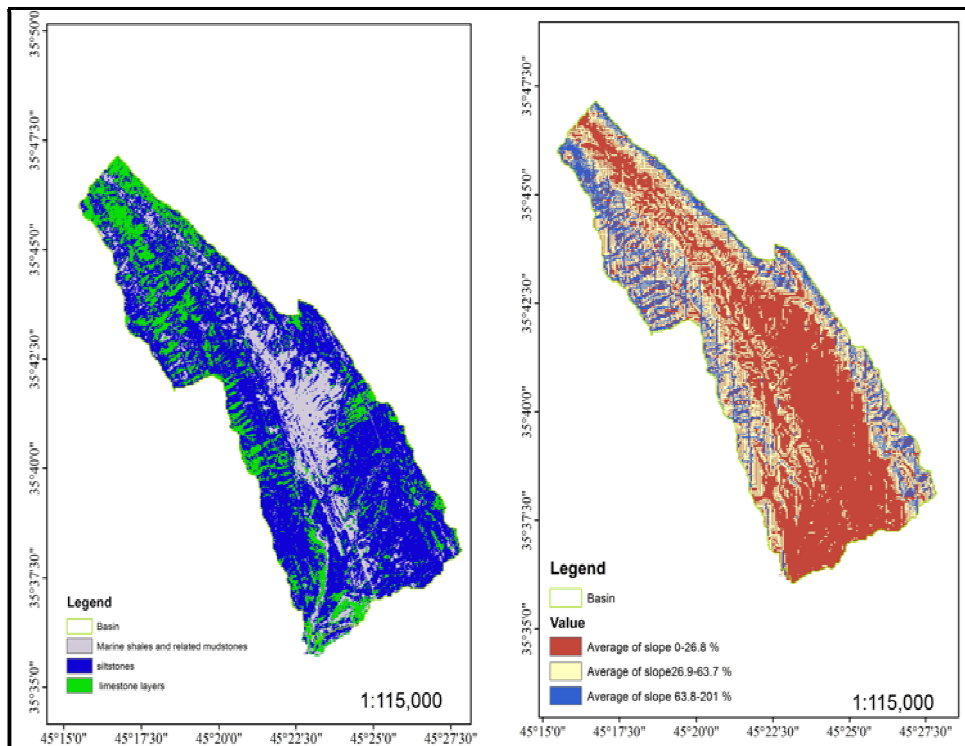


Figure-14: Surface Geology (Left) and Slope (Right) layers of Study Area.

The characteristics and sediment yield levels of Chaqchaq Basin is obtained and shown in Figure:17. The effective factor R is estimated to be 61.312 and the total sediment load is 5.39 t/ha/year.

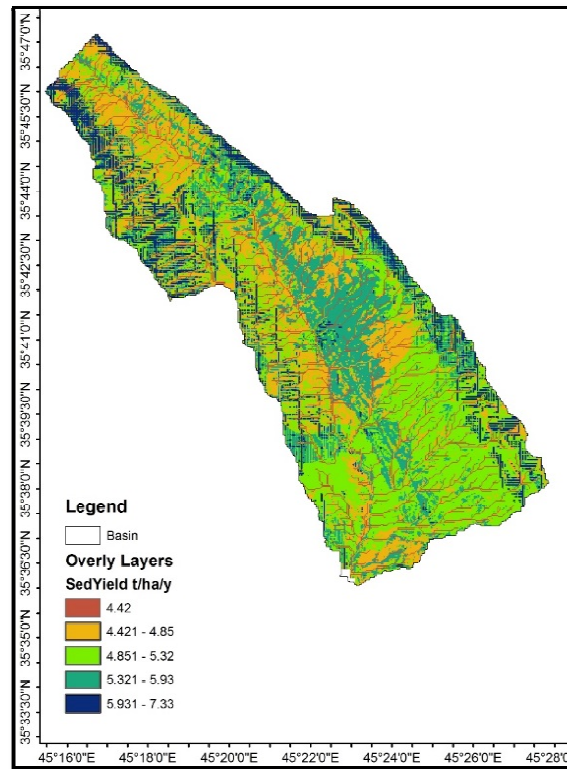


Figure 15: Sediment discharge rate Zoning Based on MPSIAC Models at the Study Area.

B. Dendy and Bolton Equation

Dendy and Bolton have developed the following equations depending on mean annual runoff depth and catchment area for estimation of the sediment yield [16].

$$T_{SS} = 1280Q^{0.46}[1.43 - 0.26 \log(a)] \dots \dots \dots (5)$$

$$T_{SS} = 1965 e^{-0.055Q}[1.43 - 0.26 \log(a)] \dots \dots \dots (6)$$

Where:

Q = annual runoff (inches)

A = area of drainage basin (mi²)

T_{SS} = total annual sediment yield in (tons/mi²/Year)

Equation 4 can be used for total annual runoff less than 2 inches, and equation 5 used for annual runoff more than 2 inches. Since the mean annual runoff depth for the catchment area under study is more than 2 inch [106.6 mm], equation 2 have to be used. The summary of the sediment results using different methods is shown in table 7.

Table-7: Summary of Arc SWAT Model and the Empirical Equation for Fourteen Year Sediment Yield.

<i>year</i>	<i>MUSLE SED-Arc SWAT Av. SYLD</i>	<i>SED-Dendy and Bolton Eq.</i>	<i>Modified PSIAC Method</i>
<i>Average Sediment yield for 14 year (t/ha/y)</i>	5.33	5.47	5.39

The above table shows that there is small difference between sediment yield predicted by the model and that estimated by the empirical equations, with maximum difference of 4%.

Conclusions

From the information collected during this study, and from the analysis of results, the following conclusions are extracted:

1. The surface soil map and the laboratory experiments have shown that there are exposed limestone rocks and five main types of surface soil in Chaqchaq basin (L, CL, SICL, SIL and SaL).
2. The Annual rainfall was 628.8 mm and the resulted annual runoff depth has been estimated at 99.17 mm resulting in annual runoff volume of around $13.8 Mm^3$.
3. Annual sediment volume estimated from the SWAT model was equal to 5.33 t/ha.
4. Annual sediment volume estimated from Dandy and Bolton Eq. was 5.47 t/ha, while Modified PSIAC Method resulted in 5.39 t/ha.
5. There was a small difference between the SWAT model and the empirical model results.

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