

Application of Soil and Water Assessment Tool Model to Estimate Runoff and Sediment Yield from Mojo Watershed

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ABSTRACT: Available water and sediment yield from Mojo watershed (2017.21 km²), Ethiopia was estimated using Soil and Water Assessment Tool (SWAT) model. The estimated available water from the watershed is 530.8 M m³ per year out of this 115.248 M m³ is required for domestic and livestock use. According to the class assigned to the annual sediment yield, map of the study area reclassified into five major categories of soil erosion hazard area namely none to slight (2 - 9 t/ha/yr), slight (10 - 21 t/ha/yr), moderate (22 - 61 t/ha/yr), high/severe (62 - 109 t/ha/yr) and very severe (110 - 204 t/ha/yr). Based on this classification about 55.03 % of the watershed area is under none to slight, 17.46% under slight, 20.90% under moderate and 6.53 % under severe degree of erosion. Areas with higher runoff condition and higher erodibility characteristics due to poor soil physical properties contributed for a higher sediment yield than others. Among all sub-watershed SW13, SW22, SW23, SW24, and SW25 need immediate intervention to minimize soil losses from the watershed.

KEYWORDS: Mojo watershed; Calibration and Validation; Distributed Watershed Model; Runoff; Sediment Yield.

I. INTRODUCTION

To tackle the problem of land degradation in Ethiopia, Government and Non-Governments (NGO's) launched massive afforestation and soil conservation schemes during the past few decades. However, despite its relatively long history, and the considerable investments made by the Government and NGO's very little achievement had been recorded in terms of output, impact, and sustainability Azene, [1]. Failures of previous attempts of Soil and Water Conservation (SWC), or land rehabilitation activities in general, were largely due to misguided nature of interventions; it disregarded local level biophysical and socio-economic realities. The first step in effective soil erosion control is assessing specially and temporal variability of the magnitude and intensity of runoff and soil erosion is very important for recommendation and designs of appropriate soil and water conservation measures. To predict reliable quantity and rate of sediment transport from land surface and to identify erosion prone areas within a watershed models are often used. Fortunately, over the last few decades, advances in hydrological science and engineering, as well as computer capabilities, have stimulated the development of wide varieties of mathematical simulation models for such assessments Merritt et al. [2]. The applicability of some of the models had been evaluated under different condition by different researcher in different parts of the world. Matamoros et al. [3] tested SWAT and AGNPS model to evaluate their potential applicability under data scarcity. The result of their study reveal that the SWAT model with less basin subdivision showed to be more accurate than AGNPS model. Mishra et al. [4] made a comparison of SWAT with HSPF model in predicting hydrologic processes of a Small multi-vegetated Watershed. Although both SWAT and HSPF models showed high capability of simulating runoff and sediment yield within the acceptable level of accuracy, the SWAT model being more responsive to the seasonal variations of precipitation, predicted monthly runoff and sediment yield more accurately than HSPF model. Ogwo et al. [5] compared the performances of AGNPS, WEPP and SWAT model

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for application in the Humid Tropics. WEPP applications were found to provide good capability to simulate sediment yield followed by SWAT while AGNPS applications were found satisfactory.

Thus, among all hydrological models SWAT is selected for this study being it is a promising model for simulations in predominantly agricultural watershed Borah and Bera, [6]. Moreover, the model is better in assessing both spatial and temporal variability of the hydrological processes under very large watershed (Rossi et al. [7]. SWAT is one of the process-based and distributed models that replaced traditional lumped and empirical models Arnold & Fohrer, [8]. Empirical models are still used because of their simple structure and ease of application. Since they are based on coefficients computed or calibrated from measurements, they cannot describe or simulate the erosion process as a set of physical phenomena. On the other hand SWAT, physically based, can describe with detail the physical mechanism of sediment yield and can simulate the individual components of the entire erosion process by solving the corresponding equations. As the result SWAT model exhibits elements of robustness in estimating hydrologic responses across a range in topographic, soils, and land use condition Michael et al. [9]. Therefore, the main objective of this study was to determine the magnitude and extent soil erosion from Mojo watershed using SWAT model.

II. BACKGROUND

The selected watershed, Mojo watershed, is one of the sub-watersheds of Awash Basin. As the result of rapid soil degradation and massive soil erosion from this watershed the lower part of this watershed is already taken out of cultivation due to an area is desiccated by gully. Land degradation due to soil erosion by water not only reduced the productivity of the land in this watershed, but also causes severe siltation of hydraulic structure existing at the downstream, mainly Koka hydroelectric power reservoir and Wonji sugar plants irrigation structure. Annual sedimentation of Koka hydropower reservoir, supplied by the Awash and Mojo rivers has been estimated 13-20 Mm³ Musa et al. [10]. Eyasu [11] pointed out that 481 Mm³ sediment, already accumulated in Koka dam, which is a loss of 30% of the total storage volume of the reservoir, with an estimated economic loss of 60 million birr. Moreover, accelerated wearing of hydropower equipment due to siltation and removal of siltation from the irrigation channel increases operation cost every year. It is believed that if it continues with the present rate of sedimentation the reservoir will not be able to function effectively after some decades in the future. Other impact of siltation is the reduction of the active storage volume resulting in loss of reservoir capacity to regulate water supply for irrigation and flood control service at the downstream. This in turn resulted in breakage of dikes and flooding of Wonji sugar plants and downstream villages that have become common phenomena every year in the downstream of Awash basin. The above mentioned facts and the relatively availability of consistent data required for the proposed study are some of the reason for selecting Mojo watershed for this study.

III. SCOPE OF RESEARCH

Effective management strategies and policies, and implementation of best management practices with an active involvement of all stakeholders to combat soil erosion problem are the call of the time. However, even before the adoption of soil conservation can be attempted, the extent and rate of soil erosion hazard and the causes of land degradation have to be assessed. Thus, the results obtained from this paper will help:

1. To provide information on runoff and soil erosion temporal and spatial variability at watershed level that will help in identifying and designing conservation measures for controlling water and soil losses from the study area;
2. To improve agricultural productivity, water quality, reservoir life and storage for its long-term use for irrigation, hydropower generation, and flood control purposes;
3. To increase storm water management use thus avoiding expensive flood control and remediation measures;
4. To integrate water resource management across sub-watershed;
5. To provide a more comprehensive approach than the piecemeal approach of traditional site specific planning and development approvals processes.
6. To reduce the plan preparation time, infrastructure capital and maintenance costs;
7. To improve mechanisms and opportunities for public consultation throughout the watershed management planning process;

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Generally, the output of this study will support planners and decision makers in prioritizing time and limited available resource to control soil erosion from the watershed.

IV. MATERIALS AND METHODS

Study Area Description

Mojo watershed having a total area of 2017.21 km² is situated in Central Oromia Regional State, Ethiopia, (Figure 1). Geographically it is located between latitudes of 8° 16' N and 9° 18' N and longitude of 37° 57' E and 39° 17' E. The watershed drains to Mojo river and finally into Awash River. The majority of the watershed particularly the central and lower part of the watershed has monomodal rainfall pattern whereas the upper part of the watershed characterized as bimodal. The mean annual rainfall of the watershed is 930.33mm. More than 85% of the annual rainfall occurs during June to September with peak in July to August. The mean maximum temperature of the watershed is ranging from 21⁰C to 27⁰C the highest being recorded in the month of May and the lowest in July. The altitude of the watershed ranges from 1592 msl at the river bed to 3065 msl at the upper part the watershed. The major dominant soil types of the watershed are Vitric Andosols (60.11 %) followed by Chromic Luvisols (29.73 %), Chromic Cambisols (7.59 %), and Umbric Leptosols (1.3%). The major farming system of the watershed is mixed farming mode of production. Agriculture is the dominant land use, about 97 % of the total land used for agricultural activities; mostly for the production of cereals crop like Teff, Wheat, Lentils, Haricot beans and Chickpea. Close to 1.16 % of the total land area is considered as degraded land and about 0.68 % of the land area is covered by shrubs and forest. The rest of the area is occupied by settlement, flower farm and water body.

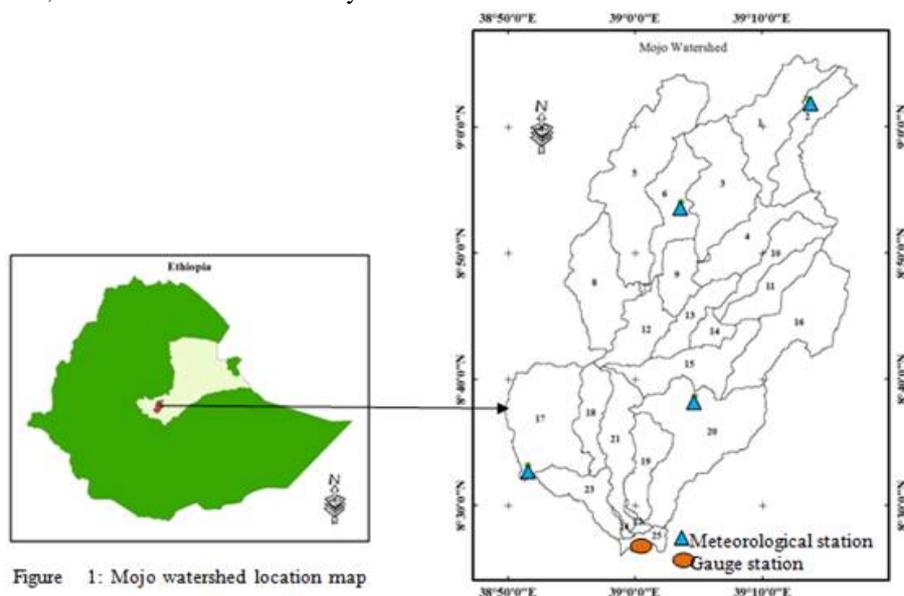


Figure 1: Mojo watershed location map

Input data preparation for SWAT model

The meteorological data elements such as daily precipitation, maximum and minimum temperature, daily wind speed, daily sunshine hours, daily relative humidity and soil physical properties such as texture, hydrologic conductivity, bulk density, erodibility, organic matter content etc were the basic data used to set up the ArcSWAT2009 model. The weather elements daily data for 30 years (1980-2009) obtained from four meteorological stations that are available within the study area were prepared as per the model requirement and added to the SWAT database, user weather generator. Daily precipitation data used by the weather generator of the SWAT model (Userwgn.dbf) are calculated using pcpSTAT.exe computer program for each station using daily precipitation data. The other weather parameter, average daily dew-point temperature per month of each station was calculated using another computer program, dew02.exe from daily temperature and humidity of each station. Apart from the properties of the soils obtained from FAO [12] soil map, additional soil characteristics required to set up SWAT2009 model such as soil saturated hydraulic conductivity, bulk density, soil available water and texture class at different soil depths were computed using the Soil

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Plant Air Water (SPAW) model. The model used soil water characteristics, soil texture and percentage of organic carbon content as an input and computes the soil characteristics such as texture class, wilting point, field capacity and saturation in percent by volume, available soil water, saturated hydraulic conductivity and bulk density.

SWAT model setup

The first step in SWAT model setup for particular area is defining watershed boundaries. These boundaries normally fall along the ridges in a watershed. Cotter et al. [13] and Santosh et al. [14] indicated that GIS data resolution has significant impact on model output uncertainty. So, in order to minimize model uncertainty associated with input data the watershed is delineated and subdivided into 25 sub-basins based on the minimum threshold area of 5000 ha Gong et al. [15] from DEM 90 m X 90 m resolution of Awash basin were processed using Arc SWAT2009. Further, Land use and soil map along with their respective look up tables prepared were uploaded to the model for reclassification according to SWAT coding convention. Moreover, Veith et al. [16] suggest that the HRU threshold value has to be based on a land use and soil type covering an area of at least 5% and 20%, respectively, within any given subbasin. Accordingly, multiple HRUs were defined based on the minimum threshold level that accounts for 5 % Land use, 20 % soil and 10 % slope threshold combination to have a better estimation of stream flow and sediment yield for Mojo watershed. At last the whole watershed slopes were categorized into five slope classes, ie 0-3, 3-8, 8-15, 15-30 and greater than 30 % slope, based on FAO slope classification for soil and water conservation using the existing model interface. Then, Land use, soil and slope maps were overlaid to create HRU's that is having similar hydrologic condition. Finally, location table of weather data, Daily precipitation, Maximum and Minimum Temperatures, Wind speed, Relative Humidity, Solar Radiation location data file were loaded to link them up with the corresponding files already created for the purpose. After loading all the necessary input data and generating all the required database files, SWAT model was initially run on monthly bases.

Model calibration and validation

Automatic calibration and uncertainty analysis incorporated in SWAT2009 via the SWAT-CUP (SWAT Calibration and Uncertainty Procedures) software developed and tested by Abbaspour [17] with the semi-automated program SUFI2 (Sequential Uncertainty Fitting ver. 2) was used for this study. Prior to model calibration parameter sensitivity analysis was done using the SUFI2 global sensitivity methods, for the whole catchment area. Generally, twenty three hydrological parameters related to stream flow and sixteen hydrological parameters related to sediment yield simulation were considered for sensitivity analysis in the study area. The parameters selected for sensitivity analysis were based on a review of calibration parameters used in past studies Zhang et al. [18] and [19], Margaret and Chaubey [20], Jajarmizadeh et al. [21], Mengistu and Sorteberg [22]. The relevant model parameter based on their sensitivity analysis the top thirteen ranking parameters were selected as starting points for model calibration on monthly bases first for surface runoff and followed by sediment yield, being sediment outflow from each HRU and sub-basin is primarily governed by soil physical properties, surface runoff, stream discharge and stream flow velocity. Then, calibration of the model were done by changing the parameter value within the range until the predicted value was reasonably in line with that of observed value and its accuracy was evaluated with Nash-Sutcliffe coefficient (NSE) and Coefficient of determination (R^2). After the model was calibrated, the accuracy of the model was evaluated during the validation process with the help of the data, which were not used during the calibration of the model. Thus, for this purpose monthly simulated stream flow and sediment yield for 2000 to 2009 were compared with observed monthly stream flow and sediment yield data of the same period. All the model evaluation parameters used for calibration were also used in the validation process

Model performance evaluation

Coffey et al. (2004) as cited by Arnold et al. [23] describe nearly twenty potential statistical tests that can be used to judge SWAT predictions, including R^2 , NSE, root mean square error (RMSE), nonparametric tests, t-test, objective functions, autocorrelation, and cross-correlation. For the present model performance evaluation techniques the recommendation given by Moriasi et al. [24], Nash Sutcliffe Efficiency (NSE), Percent bias (PBIAS), and Coefficient of Determination (R^2), were considered. To decide the accuracy of the model the value of each index obtained by the model were compared with the value of hydrologic model performance ratings given by Moriasi et al. [24].

Identifying Erosion Prone Area

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Erosion prone area of the watershed were identified based on the estimated values of soil erosion from each HRU erosion prone area of the watershed was categorized according to FAO degree of erosion classification as none to slight (0-11 t/ha/year), slight (11-20 t/ha/year), Moderate (20-50 t/ha/year), high/severe (50-106 t/ha/year), and very severe (>106 t/ha/year). For this study, sub-watersheds, which produced more than 11 t/ha/year were identified as erosion critical areas.

V. RESULTS AND DISCUSSEDION

Sensitivity analysis

According to global sensitivity analysis the most sensitive parameters identified in Mojo river flow simulation are those representing surface runoff, groundwater recharge, soil water and channel process. Generally, the selected sensitive parameters are within the range of parameters used by Mutenyo et al. [25] for the evaluation of SWAT performance on a mountainous watershed in Tropical Africa. In this study, the response of the model towards parameter involves evaporation (EPCO and ESCO), surface runoff (CANMX), and groundwater (GW_DELAY, ALPHA_BF, and GWQMN) are very low. On the other hand parameters involving surface runoff (CN₂) and ground water (ALPHA_BNK) are found the most sensitive parameter in flow simulation. In addition, parameters involve channel processes (CH_N₂ and CH_K) groundwater (REVAPMN), soil water (SOL_K) and surface runoff (HRU_SLP, SURLAG and OV_N) are also showed considerable sensitivity in water yield simulation. In case of sediment yield sensitivity analysis the model did not show any response towards parameters related to channel processes (CH_S₂, CH_WDR and PRF). On the other hand the following parameters were found to be more sensitive through sensitivity analysis mainly those representing soil (USLE_K), sediment (CH_COV₂, CH_COV₁, LAT_SED, and USLE_C), and Channel processes (CH_D, SPCON, SPEXP and ADJ_PKP). It is also found that some of the selected parameters are inter-related; an increase in one parameter will result in decreasing the other parameter and vice versa, which help in counterbalancing over-prediction and under-prediction of the model.

Model calibration and validation

To improve the efficiency of the model during calibration the top thirteen ranking parameters were considered to account for the over and under prediction responses of the model as suggested by Neitsch et al. [26]. The final fitted value of the most sensitive parameters for steam flow and sediment yield for the watershed is given in Table 1 and Table 2 respectively according to its rank. The over prediction nature of the model is controlled by decreasing CN₂ from the initial value 73 to 63.4. On the other hand under prediction of the model were adjusted by increasing REVAPMN from 1 to 6.43. Moreover, the simulated flow patterns with observed flow pattern were adjusted with HRU_SLP and OV_N value. For sediment yield performance efficiency of the model were improved by adjusting the parameters related to sediment, soil and channel process. Accordingly, increasing the values related to sediment (CH_COV₁, CH_COV₂, LAT_SED and USLE_C) and decreasing soil parameter (USLE_K) gives a better result of the model. Increasing the value of a parameter related to channel process (CH_D, SPCON and SPEXP) is also improving the performance of the model in simulating sediment yield form the watershed.

The comparison made between the observed and simulated stream flow indicated that a good agreement were obtained between the observed and simulated discharge, which was verified using both graphical technique and quantitative statistics. The value of coefficient of determination ($R^2=0.83$), Nash-Sutcliffe efficiency (NSE=0.82), and percent bias (PBIAS=10.5) obtained during calibration and R^2 value 0.77, NSE value 0.75, and percent bias 9.8 obtained during validation justify that the model is very good in simulating runoff from Mojo watershed. The performance of the model for sediment yield was evaluated in the same way as for the stream flow. The computed statistical indicators $R^2 = 0.76$, NSE = 0.75, and PBIAS = 8.10 were estimated during the calibration periods. Similarly, for the validation period, the computed statistical indicators have been computed as 0.79 for R^2 , 0.71 for NSE, and 35.83 for PBIAS. The indicators have been found to be within the range of good to a very good performance level except for the validation PBIAS value which is in the range of satisfactory criteria.

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Table 1: Hydrological parameter selected for stream flow Calibration

Name	Definition	Threshold value	Initial value	Fitted value
r_CN ₂ .mgt	SCS runoff curve number for moisture condition II	-0.20-0.20	73.00	63.400
v_ALPHA_BNK.ret	Base flow alpha factor for bank storage	0.00-1.00	0.00	0.095
v_RCHARG_DP.gw	Deep aquifer percolation fraction	0.00-0.20	0.05	0.807
v_CH_K ₂ .ret	Effective hydraulic conductivity in main channel alluvium (mm/hr)	0.00-150.00	0.00	74.625
v_CH_N ₂ .ret	Manning's coefficient for channel	0.00-0.50	0.014	0.136
v_TLAPS.sub	Temperature laps rate (°C/km)	-10 - 10	0.00	3.500
r_HRU_SLP.hru	Average slope steepness (m/m)	0.00-0.20	0.011	0.016
v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur (mm)	0.00-500.00	1.00	6.430
v_SURLAG.bsn	Surface runoff lag time	0.00-10.00	4.00	0.530
r_SOL_K.sol	Soil conductivity (mm/h)	-0.50-0.50	250.00	2000
r_Ov_N.hru	Manning's value for overland flow	-0.20-0.00	0.14	0.086

X_Code indicate the type of change to be applied to the parameter, V_means the existing parameter value is to be replaced by the given value, a_ means the given value is added to the existing parameter value, and r_means the existing parameter value is multiplied by (1+a given value).

Table 2: Hydrological parameter selected for sediment yield Calibration

Name	Definition	Threshold value	Initial value	Fitted value
a_USLE_K.sol	USLE equation soil erodibility (K) factor	0 – 0.20	0.32	0.13
v_SPCON.bsn	A linear parameter used in channel sediment routing	0 - 0.01	0.0001	0.0039
a_CH_COV ₂ .rte	Channel erodibility factor	0 – 0.20	0.00	0.043
a_CH_COV ₁ .rte	Channel cover factor	0 - 0.20	0.00	0.091
a_ADJ_PKP.bsn	Peak rate adjustment factor for sediment routing in the subbasin	0 – 0.20	0.00	0.56
v_CH_D.rte	Average depth of main channel	0 - 30	2.73	19.89
v_CH_W ₂ .rte	Average width of main channel	0 - 0.20	124.02	143.47
v_LAT_SED.hru	Sediment concentration in lateral flow and ground water flow	0 – 2.00	0.00	1.32
a_USLE_C.Crop.data	Minimum value of USLE C-factor applicable to the land cover	0 – 0.20	0.03	0.173
v_SPEXP.bsn	An exponent parameter used in channel sediment routing	1.0 – 1.50	1.00	1.17

Water Balance of the Watershed

The simulated annual water balance components for the watershed indicated that 48.96 % and 17.19 % of the annual precipitation is lost by evapotranspiration and deep percolation respectively. Simulated hydrologic component also revealed that the base flow is the major contributor of total discharge of the study area. The highest contribution 53.34 % of base flow followed by surface runoff contributes 38.54 %, and groundwater contribution 8.52 % to the water yield of the watershed. This shows that on yearly basis more than half of the stream flow in the watershed is from lateral flow. Previous studies eg. Shrestha et al. [27] also show that around 60% of the total flow is contributed by base flow. Fig. 2 shows simulated temporal variability of average rainfall in relation to evapotranspiration and deep percolation loss. The

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highest rain fall occurred during summer season (June, July and August) on the other hand simulated monthly PET is very high throughout the year except during summer, tending to decrease to a certain degree. Simulated monthly ET attained its peaks in July and August, this indicated that AET in the watershed depends more in the availability of moisture through rainfall.

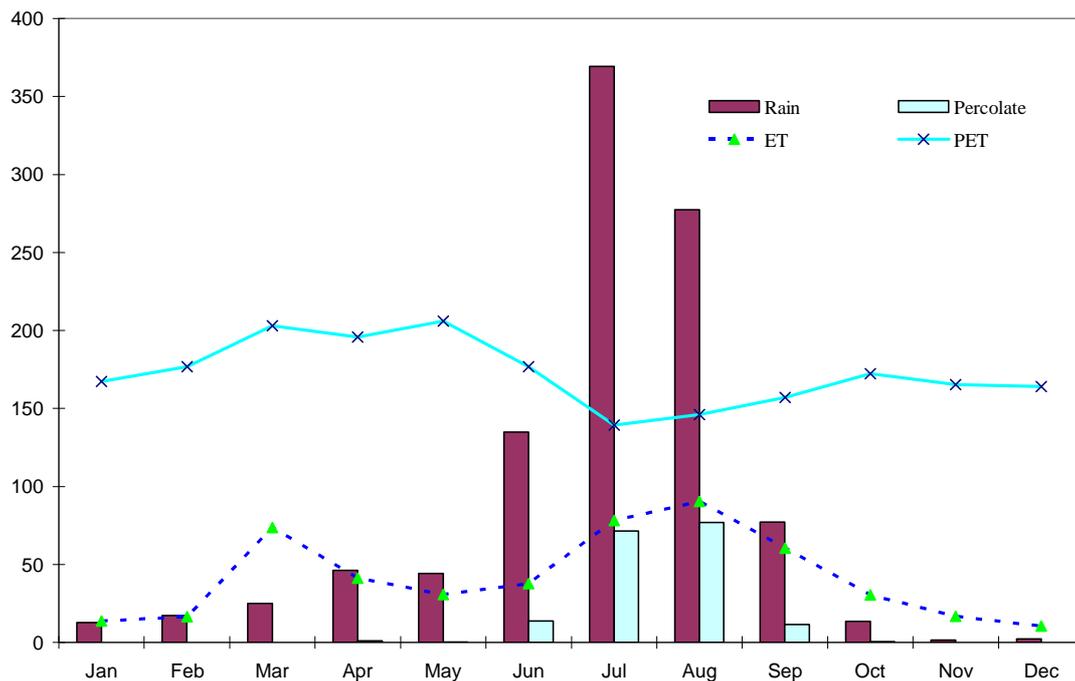


Fig..2: Average monthly rainfall, water percolation past bottom of the soil profile (PERCO LATE), Actual Evapotranspiration (AET) and Potential Evapotranspiration (PET) of the watershed (1983-2009).

Based on SWAT model output, spatial variability of each HRU's discharge rate is shown in Fig. 3(a). As it can be seen from the Fig. the highest rate of discharge rate is occurring at the South-East and central part of the watershed (at SW20, SW25, SW22, SW24, SW13 and SW15), whereas the lowest discharge rate is mainly occurring at the North-Eastern, Western and South-Western part of the watershed (at SW1, SW2, SW6, SW8, SW17, SW18, SW19, SW21, and SW23). Leptosols and Andosols are the major dominate soil type existing in the area where the highest discharge occurring. The dominant slope class in the upper part where discharge rate is high is 0-3 and 3-8. In an area where low discharge is occurring the major dominant soil type is Luvisols and Andosols with 0-3 dominant slope class.

Knowledge of the current status of water availability and trends of water demand in the watershed is very important for successful water management planning. Accordingly, the total available water estimated from the watershed is 530.8 M m³ per year out of this 115.248 M m³ is required for domestic and livestock use of which agricultural water demand takes the lion's share with about 89.61 % followed by domestic water demand 7.85 % and livestock water demand 2.29 %.. Therefore, 415.6 M m³ is available for irrigation; taking irrigation requirement as 16281 m³/ha the current available water can irrigate a total area of 25526.69 ha.

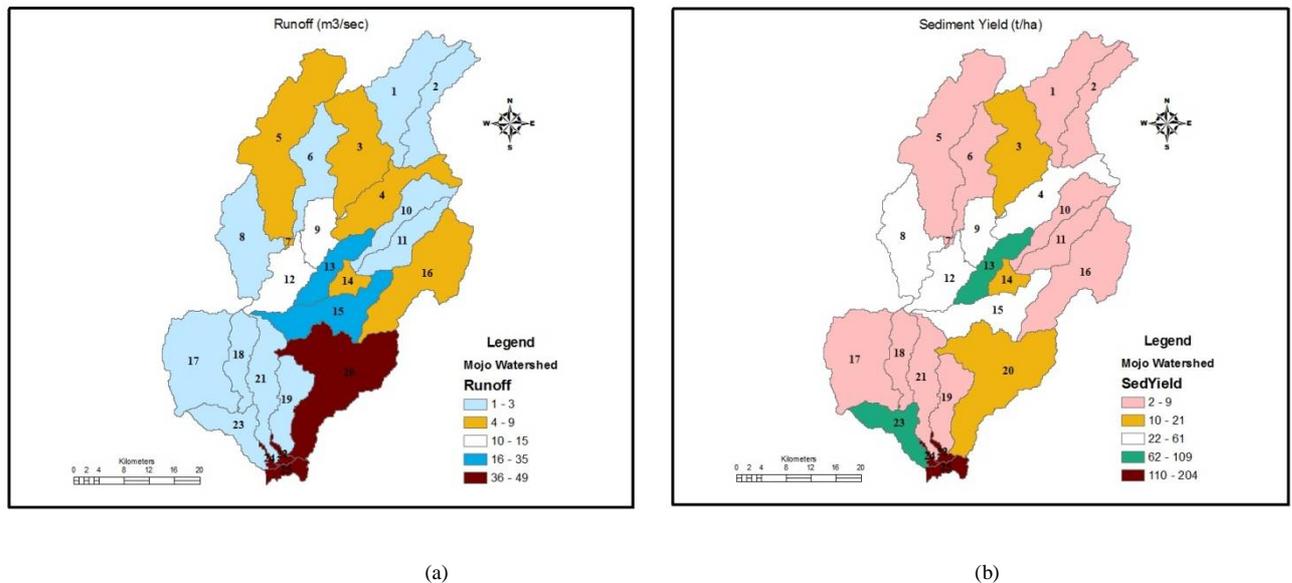


Fig.. 3: Spatial distribution (a) Runoff (b) Sediment yield from the watershed

Soil Erosion Rate Spatial Distribution

Following the successful calibration of SWAT model for sediment yield at the outlet of the watershed, the sediment outflow from each sub-basin has been simulated and delineated. The estimated soil loss rate from different sub-watershed ranges from 2 t/ha/year to 204 t/ha/year (Fig. 3b), whereas the annual weighted average soil loss rate from the watershed was estimated 21.97 t/ha. According to the class assigned to the annual sediment yield, map of the study area reclassified into five major categories of soil erosion hazard area namely none to slight (2 - 9 t/ha/yr), slight (10 - 21 t/ha/yr), moderate (22 - 61 t/ha/yr), high/severe (62 - 109 t/ha/yr) and very severe (110 - 204 t/ha/yr). Based on this classification about 55.03 % of the watershed area is under none to slight, 17.46% under slight, 20.90% under moderate and 6.53 % under sever degree of erosion. Moreover, the result indicated that the lower and central portions of the area which are known to be highly cultivated area are more vulnerable to soil erosion. Areas with higher runoff condition and higher erodibility characteristics due to poor soil physical properties contributed for a higher sediment yield than others. Among all sub-watershed SW13, SW22, SW23, SW24, and SW25 are more vulnerable to soil erosion, which need immediate intervention to minimize soil losses from the watershed. The above classification of soil erosion revealed the actual existing reality on the ground in the watershed.

The comparison between mean monthly rainfall, catchment discharge and sediment yield from the watershed shows that there is a direct relationship between rainfall, runoff and sediment yield (Fig. 4). Rainfall and runoff are responsible factors for the detachment, transport and deposition of sediment particles. At the beginning of the rainy season sediment yields increases rapidly, reaching a peak in August. Sediment yield and river discharge increases about one month later, reaching a peak in August. The average peak rainfall in the area is in July and the average peak sediment yield is in August. The higher value of sediment yield is observed during July and August when there is higher intensity of rainfall that contributes to the higher surface runoff. Easton et al. [28] in their analysis of runoff and sedimentation in Blue Nile, Ethiopia, the sediment peak occurs approximately two weeks before the flow peak. Interestingly, in this study the sediment peak occurs approximately one month later than the flow peak. This show that sediment export from the various subbasins was controlled by channel erosion rather than land scape based erosion.

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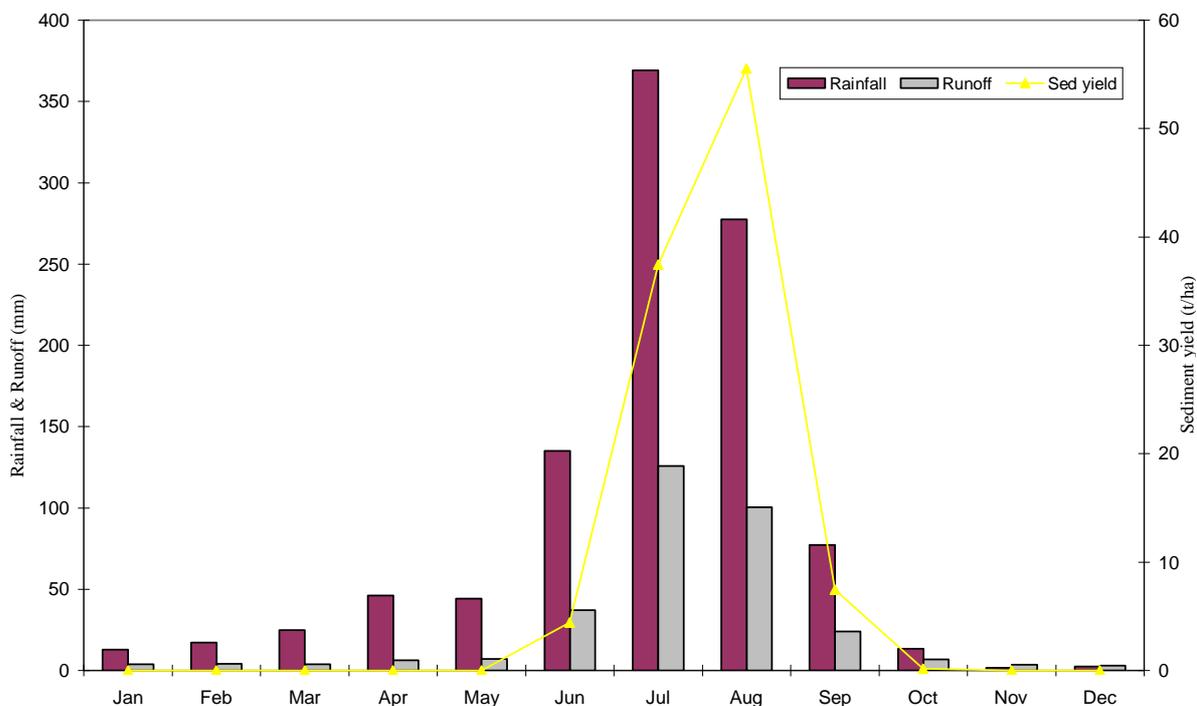


Fig. 4: Relation between rainfall, runoff and sediment yield of the watershed

VI. CONCLUSION

The total available water estimated from the watershed is 530.8 M m³ per year out of this 115.248 M m³ is required for domestic and livestock use of which agricultural water demand takes the lion's share with about 89.61 % followed by domestic water demand 7.85 % and livestock water demand 2.29 %.. Therefore, 415.6 M m³ is available for irrigation; taking irrigation requirement as 16281 m³/ha the current available water can irrigate a total area of 25526.69 ha. Moreover, the estimated annual water balance component indicate that 48.96 % and 17.19 % of the annual precipitation lost by evapotranspiration and deep percolation respectively whereas base flow 53.34%, surface runoff 38.54 % and groundwater 8.52 % contributed to the total yield of the watershed. The developed SWAT model also helped in identifying erosion prone area of the watershed. Accordingly, the sub-watershed S3, S4, S5, S7, S8, S9, S11, S12, S13, S14, S15, S20, S22, S23, S24, and S25 is highly exposed to soil erosion, so more attention has to be given to these area. The estimated soil loss rate from different sub-watershed ranges from 2 t/ha/year to 204 t/ha/year, whereas the annual weighted average soil loss rate from the watershed was estimated 21.97 t/ha. According to reclassification of SWAT model sediment yield output about 55.03 % of the watershed area is under none to slight, 17.46% under slight, 20.90% under moderate and 6.53 % under sever degree of soil erosion. Generally, the output of this study may support planners and decision makers to take relevant soil and water conservation measures and thereby reduce the alarming soil loss and land degradation problems in the watershed.

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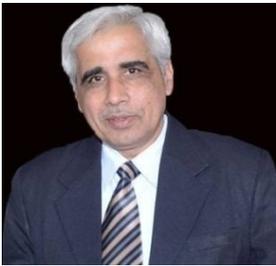
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