BMP Implementations in Himalayan Context*: Can a Locally-Calibrated SWAT Assessment Direct Efforts?*

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Abstract
Soil erosion due to accelerating runoff in various land cover types pose a serious threat to the long term sustainability of the fragile Himalayan landscape characterized by subsistence farming. Delimitation of high runoff zones, fostering soil erosion in the agricultural dominated watersheds is thus a necessity for watershed managers, NGO's, urban planners, policy makers, and municipal administrations. The approach is practical, SWAT is a straightforward modeling system using GIS information. The BMP is also a very practical approach to mitigation of runoff accumulation on sub basin. A set of interviews with people familiar to the issues locally strengthened the confidence in the results. Results from this research show that terraces can reduce storm water runoff very effectively. There is a huge difference in amount of runoff after terraces are added to the simulation. Results showed a reduction of 57% in runoff volume during August 2004. If the area near the river is preserved as a buffer strip and a tree cover is maintained around it then it minimizes the effect surface runoff. The effect of riparian buffer is modeled in SWAT and the results show about 6% decrease in surface runoff when a buffer of 500 m is applied around the main river only. This study has drawn a location map of BMP implementations of most meaningful impact for the rehabilitation and safeguard of rivers, streams, lakes and wetlands around the river Siran in the Mansehra Tehsil, Pakistan.

1. Introduction

Himalayas are one of the most ecologically fragile and economically underdeveloped regions of the world (Tiwari, 2000). Land degradation due to erosion by water is a prominent issue in Himalayan landscape. Terrain steepness, deforestation, overgrazing, intensive and subsistence farming which originated in population pressure has led to severe soil erosion in the region (Shrestha et al., 2004). Soil is an important resource for the economy of the people living in the mountainous areas and food security of the region. Predicting the spatial extent of soil erosion is of direct impact to their livelihood. A watershed might have limited critical areas of soil loss, Best Management Practices (BMPs) can be applied to those. Effective control of non-point source pollution transported by runoff requires information about the source areas of runoff (Frankenberger et al., 1999). Investigation of the main mechanism for runoff generation (infiltration excess or saturation excess) is vital for identifying the runoff zones. Infiltration excess or Hortonian flow occur when precipitation intensities exceed the rate at which water can penetrate the soil, in contrast the saturation excess runoff is generated when rain encounters soils that are nearly or fully saturated. Saturation excess is considered main mechanism for runoff in areas having humid climate coupled with thick vegetation and permeable soils (Beven and Kirkby, 1979 and Steenhuis et al., 1995). In such areas, analyzing the saturated hydraulic conductivity of the soil in relation to observed rainfall intensities can help in delimitation of the zones of infiltration and saturation excess runoff (Dunne et al., 1975). The effects of agriculture land use practices on downstream flood risk were evaluated by Schilling in 2013. They used Soil and Water assessment Tool to assess flood risk under different land use for a large agricultural watershed. They found out that by converting all or part of agriculture land to perennial vegetation (Schilling et al., 2014). Spatial characteristics of land use, vegetative cover, soil, topography and precipitation of the concerned watershed requires a tool that can effectively manage spatial data. GIS can address the problem of the spatial data management, it has the ability to interpret data automatically, processing the data and overlaying map for solving complex decision making problems with Remote Sensing emerging as a very important tool for generating biophysical information necessary for the GIS operations (Huang et al., 2003 and Kumar et al., 2002).

The effects of landscape pattern change on hydrological processes, daily runoff, low flow was studied by Lin using SWAT model and Pearson correlation analysis. The results show a good performance by SWAT model (Linbing et al., 2014). It should be noted that methods for converting several land use and land cover features into distributed hydrologic model parameters are not well established for a wide range of circumstances. For the purpose of watershed management, many methods rely mainly on empirical studies of small plots and watersheds to relate land use and land cover to hydrologic model parameters. An example of this type of methodology is curve number method (USDA-SCS 1972) which relates land use and land cover to hydrologic model parameters. SWAT was selected to model the hydrological processes and estimate the soil loss from the Mansehra watershed as it uses Soil Conservation Services (SCS) Curve Number (CN) equation to forecast water runoff which assumes an infiltration excess response to rainfall. Best Management Practices (BMPs) require knowledge of these critical zones of soil erosion. Runoff is major factor for delimiting these zones. Mausbach in his research states that preservation practices are intended to decrease soil loss, pathogens, pesticides, nutrients and other biological and chemical materials from agricultural lands, preserve natural resources, enhance the quality of the agro-ecosystem, and enhance wildlife habitat (Mausbach and Dedrick, 2004). According to Hunt storm water Best Management Practices (BMPs) are employed to mitigate high peak flow, flow volumes, and transport of pollutants from urbanized areas (Hunt et al., 2009). Surface runoff occurs when the soil is saturated and unable to absorb rainwater, or eliminating it through the processes of infiltration, subsurface runoff and transpiration.

2. Study Area

Mansehra Tehsil (Figure 1) is one of the three Tehsil Municipal Administrations (TMAs) of District Mansehra. The Tehsil contains 244 villages, including the large village of MANSEHRA, its headquarters and the town of BAFFA. According to 1998 census report the population of MANSEHRA Tehsil is 574,975. Siran River flows through the center of Mansehra Tehsil. It originates from the MandaGucha Glacier and merges into the Indus River. The climate of Mansehra is characterized by warm summers and cold winters with snowfall in the neighboring mountains. January/February are the coldest months as winter starts in November/December. At higher altitudes the temperature drops below -20°C. March through April is spring season and summer starts in May up to September with June and July being the warmest months with temperatures up to 40°C in the lower areas.

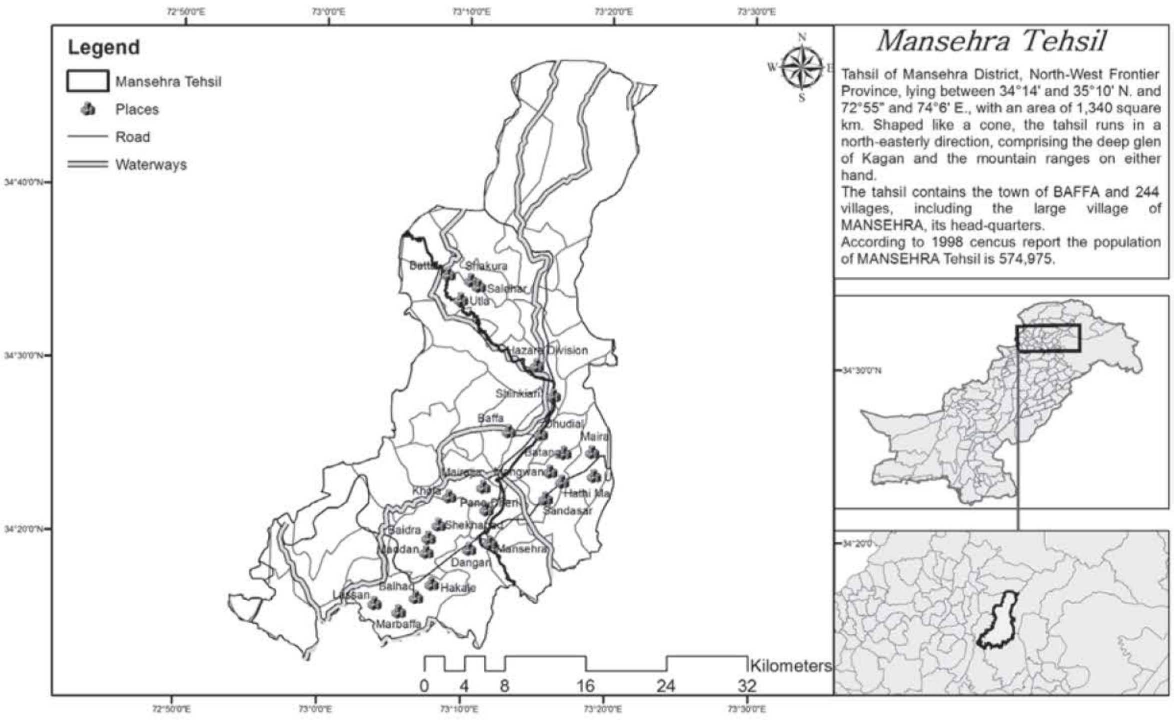

Figure 1: Mansehra Tehsil map

3. Data and Tools

SWAT is an all-inclusive model that requires data provided by the user to simulate runoff and soil erosion. The first step is to divide the watershed into sub basins. The user can provide pre-defined sub basins or allowing SWAT to automatically delineate the sub basins using the Digital Elevation Model (DEM). The sub basin is then divided into hydrologic response units (HRUs). Hydrologic response units (HRUs) are parts of sub basin having unique land use, slope range, and soil attributes (Neitsch et al., 2005). The databases required for the ArcSWAT-2012 include Digital Elevation Model, stream network, weather parameters, land use, and soil type. River discharge data were also used for calibration and validation purpose but it is not used as a model input. A brief explanation of each dataset is given below. Watershed boundaries and drainage network can either be given to the model manually or the model can automatically delineate the watershed and sub basins. SWAT uses the digital representation of the topographic surface to delineate watershed and sub basins. DEM is the basic input of spatial analysis and runoff simulation. Aster DEM with spatial resolution of 30m is used for this purpose. Sub basin parameters such as aspect, slope gradient, slope length of terrain and the stream network properties such as channel width, length and slope were calculated and used by the model.

The land of the area is used for various purposes depending upon elevation, physiographic position, climatic conditions, soil conditions, perennial and seasonal irrigation water availability. Socio-economic conditions have also influence the land use considerably. Major land use types in the area are agricultural, forest and arable cropping (Figure 2). For recent investigation old soil mapping units delineated on topographic sheets (1:50,000) were digitized with major infrastructure and the soil map layer so produced was superimposed on SPOT image. Information regarding land use, vegetation, cropping patterns and yields on different soils were collected by questioning farmers and taking notes of standing crops. The variation in yields provided estimates of the effects of different level of management on identical soils on one hand and crop performance and soil behavior of different soils on the other hand. The SWAT model needs data about a range of physical and hydrological attributes of soils which include layer depth, available water content, texture, bulk density, organic matter and hydraulic conductivity for all layers of each soil type (Figure 2). Soils in the watershed should be categorized and prepared as a map in a shape file format and then linked to a customized soil database designed by the user if the soils are not included in the existing SWAT soil database.

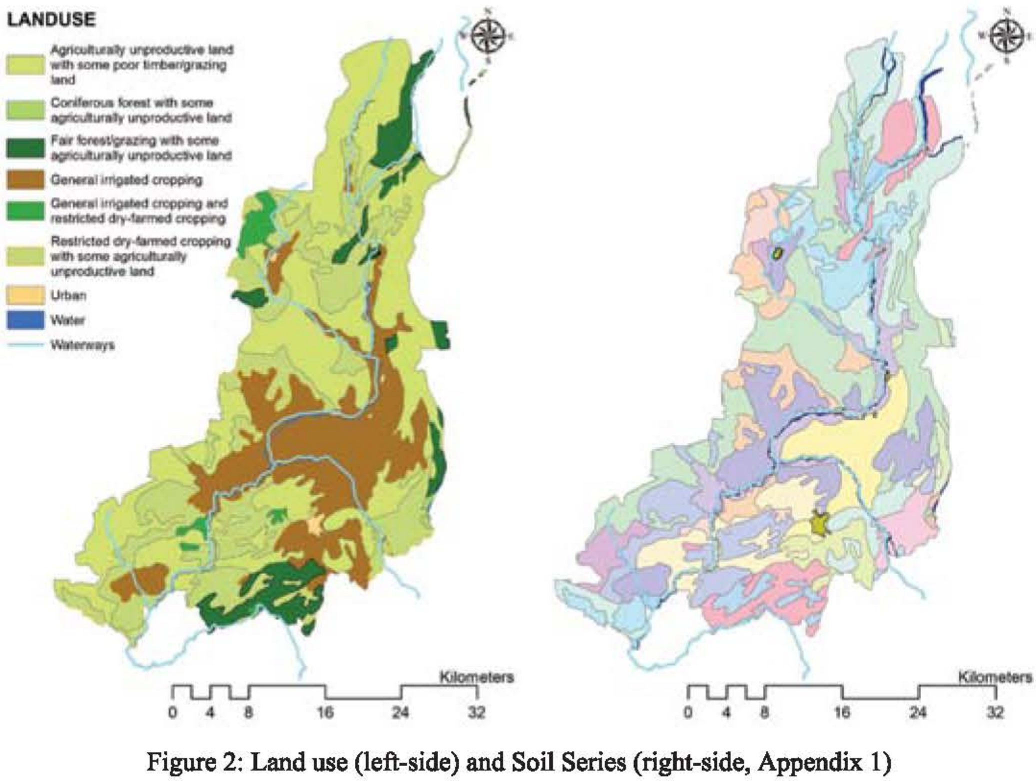

Figure 2: Land use (left-side) and Soil Series (right-side, Appendix 1)

Different kinds of soils were identified during the course of reconnaissance soil survey carried out in the area. Based on their similarity in certain basic characteristics, the soils were recognized, described, classified and named as 'soil series'. Each soil series occurs in close association with some others which, though identifiable individually, cannot be separated from each other for mapping on the standard reconnaissance scale, i.e. 1:250,000. For that purpose, such soil series are closely associated and occur in certain regular geographic patterns, with known proportions, are mapped together in the form of defined groups called as 'associations /complexes'. Such groups of soil series when delineated on a map are called 'Soil Mapping Units'. 25 soil mapping units were recognized in Mansehra Tehsil. SWAT requires weather parameters on daily or monthly basis in SWAT readable format or can be generated by a weather generator already included in SWAT. The required weather parameters include minimum and maximum temperatures, solar radiation, dew point temperature, rainfall and wind speed. In this study, measured meteorological data were used and the weather generator model was set up to estimate any missing data. Daily weather parameters from 2001 to 2011 were obtained from National Tea Research Institute, Shinkiari and Pakistan Meteorological Department. SWAT used solar radiation, wind speed and relative humidity to calculate the potential evapotranspiration (PET) as the model for this particular project used Penman Monteith approach for PET calculation. The river discharge data from 1999 to 2005 was shared/acquired from People and Resource Dynamics in mountain watersheds of Hindu Kush-Himalaya (PARDYP), International center for Integrated Mountain Development for hilkot area. SWAT optimization scheme targets this set of data as reference against simulated values during calibration and validation periods. Temporal ranges of 2001-2002 were used for calibration and 2003-2004 for validation.

4. Methodology

Watershed and sub basins were delineated automatically in SWAT using a Digital Elevation Model (DEM), the ArcGIS Spatial Analyst extension is used to perform watershed delineation. Stream network was defined for the whole area by ArcSWAT using the concept of flow direction and flow accumulation, including sink filling and watershed boundary homogenization.

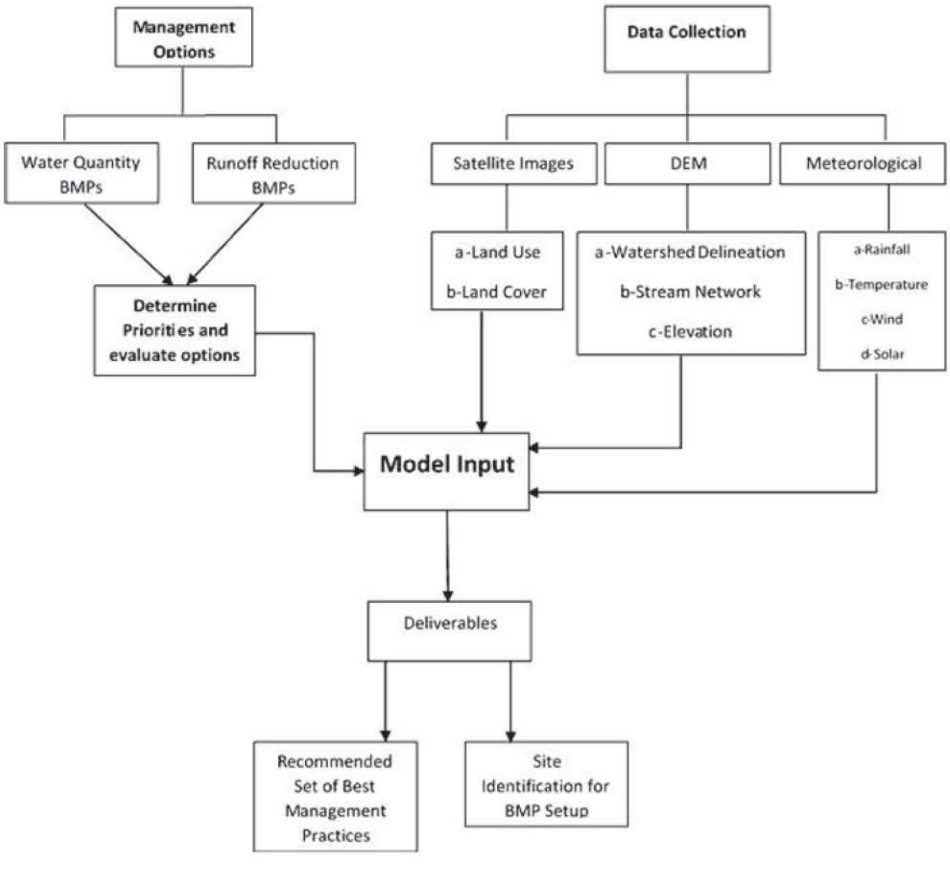

Figure 3: Processing Flow-chart

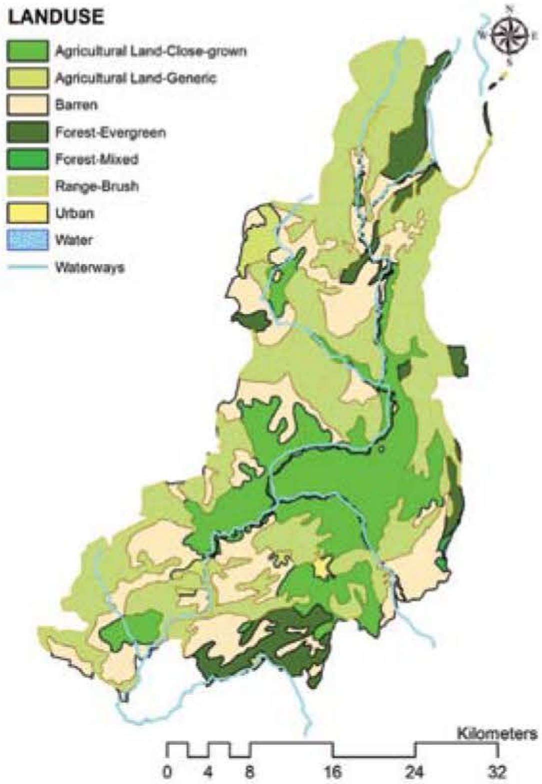

Figure 4: Reclassified Land Use map

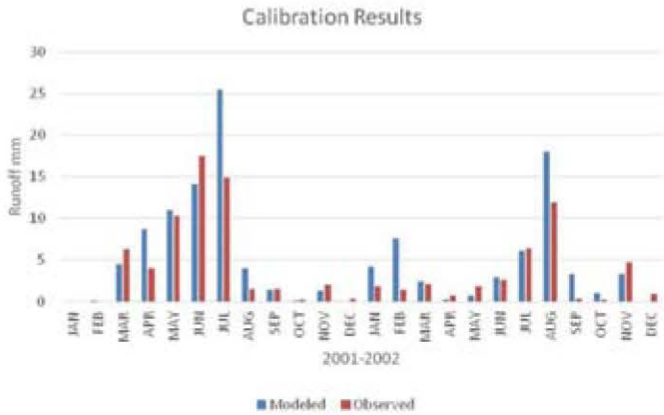

Figure 5: Calibration Results

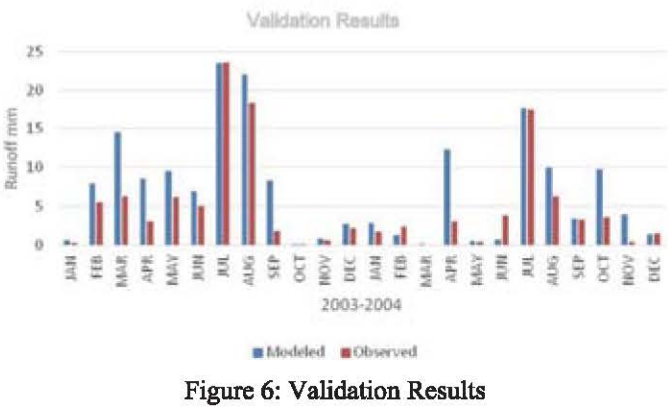

Figure 6: Validation Results

Table 1: Land Use reclassification for SWAT

Landuse	Code
Agricultural Land-Close-grown	AGRC
Agricultural Land-Generic	AGRL
Barren	BARR
Forest-Mixed	FRST
Forest-Evergreen	FRSE
Range-Brush	RNGB

Table 2: Identified parameters for calibration

Parameter	Description
ESCO	Soil evaporation compensation factor
SOL_Z	Soil depth
SOL_AWC	Available water capacity of the soil layer
CN2	SCS runoff curve number
SOL_K	Saturated hydraulic conductivity (mm/h)

Resulting sub-basins are further divided into one or more Hydrologic Response Units (HRUs), which are lumped areas with unique combination of land cover, management, soil, and slope (Gassman et al., 2007 and Neitsch et al., 2005). SWAT land use requirement has 8 types of classes (Figure 4, Table 1). The soil classes in the input soil map were encoded using a lookup table so that the parameters corresponding to each soil type could be accessed from the ArcSWAT soil database. Additionally, the HRU analysis in ArcSWAT divides HRUs by slope classes (Table 2). The multiple slope option was selected at this stage, deriving four different classes according to (user-defined) quartiles (25% slices). The sub-basin HRUs are hydrologically computed independently, then summed together to determine the water, erosion, and sediment load for a given sub-basin. SWAT's HRUs are allocated by order of dominant land use, soil and slope for computing efficiency purposes. For purposes of BMPs impact detection, it is important to keep minority areas evaluated within SWAT. The inclusion threshold was set to 10% to overlay Land Use, Soil and DEM. Finally, the WXGEN weather generator model in SWAT was used to fill gaps in measured values, all the necessary statistical information from the NTRI (National Tea Research Institute) Shinkiari weather station meteorological records were included for local parameterization. Water Quantity BMPs serve to reduce the amount of water from an event by storing or routing the storm water. Sub surface drains can be used to reduce the effect of excess water on ground. A subsurface drain is installed below the ground surface to interrupt and transport water through a network of perforated pipe, tubing or tile. It increases the aeration of soils, maximize crop yield and minimize the cost of installation. But it is very difficult to install sub surface drains in large and hilly areas. To prevent soils erosion from wind, human or animal activities and uncontrolled runoff, a vegetative cover should be maintained. It decreases the runoff velocity and capture sediments before entering into the river. It also improves the capacity of soil to retain water. This can also serve as a habitat for animals and birds. Vegetative Riparian buffers can reduce non-point source (NPS) nutrients from upslope areas. They can be considered as key regions in providing natural regulation function for water quality (Zhao et al., 2013). Vegetated riparian buffers have been considered as one of the most effective tools for alleviating the effect of NPS pollution on water quality in rivers and lakes (Weller et al., 2011). Assuming that a Riparian Buffer will act to reduce the effect and velocity of surface runoff, it is evaluated as a management practice. A 500m buffer of vegetative/ tree cover is applied across the main stream (Siran River) which runs through center of study area. The resulted land cover is then evaluated in SWAT model and its effects are then studied. A second type of management practice is also selected for evaluation based on field observations. Terraces are implemented as a management practice on agriculture areas using Soil and Water Assessment Tool in the Saginaw River Watershed. Terraces proved to be very effective in reducing pollutants (Giri et al., 2014). Terracing is applied as a second management practice. Terracing can be modeled in swat as an operation by changing the parameters in .ops file. Terracing is applied for 4 years (2001-2004). To model terracing the inputs required are USLE practice (TERR_P) factor, the slope length (TERR_SL) and curve number (TERR_CN). The slope is kept at 10 percent and the curve number is taken from the project after calibration. The P factor (TERR_P) is taken from SWAT manual which is 0.12.

5. Results

Model performance is checked using different statistical methods which include coefficient of determination (R^2), Nash-Suttcliff simulation efficiency (ENS). The Nash–Sutcliffe coefficient is used to evaluate the predictive power of hydrological models. It indicates how well the observed versus simulated values fits the 1:1 line. Model outputs are considered perfect if the values of R^2 and ENS are near to one and unacceptable or poor if the values are less than or very close to zero. The correlation coefficient and Nash–Sutcliffe coefficient is high which indicates a close relationship between the two parameters. HRU based runoff map is developed which shows areas of high and low runoff.

5.1 Calibration

The SWAT model was calibrated for the hilkot sub-watershed, equipped with hydro meteorological stations. Hydro meteorological stations were installed by People and Resource Dynamics in Mountain Watersheds of the Hindu Kush-Himalayas project. During calibration, parameters estimated from model are compared with real world observations. Model was calibrated for two years of observed data. The parameters identified for calibration are defined in (Table 2). These parameters were altered and the model was run again to meet the original values. Repeated alteration of the model was performed by adjusting CN2, SOL_K, ESCO, and SOL_AWC. ESCO was the least sensitive while CN2 was the most sensitive parameter. Finally a good fit was observed between the model output and observed runoff. The adjusted parameters are shown in (Table 3). The calibration results (Figure 5) show an R^2 of 0.874 and NATSCH coefficient of 0.733 which is quite significant.

5.2 Validation

The validation process is done for a period of two years 2003 and 2004 using the actual discharge values. The simulated values from model and observed values on ground matched well. The model over predicted the runoff values at some points which may be due to the fact that the observed values are of a specific location and the model predicted the runoff for entire basin. For validation period (Figure 6) model showed R^2 of 0.868 and NATSCH coefficient of 0.767. Sub basin level runoff maps were generated from the model results (Figure 7 left side). The sub basin map shows that the sub basin 15 is sowing highest amount of runoff. It also shows that the runoff is greater at lower part of the basin. The sub basins are then further divided in HRUs. HRU level maps are then generated to better understand the effect of runoff in different areas (Figure 7 right side). This will help in locating the areas with high runoff and applying mitigation strategies. Riparian buffer is applied as a management practice to observe the effects on surface runoff. A 500m buffer is applied around the main stream and mixed vegetation/forest cover is given as land cover. The results showed that the runoff values at lower end decreased whereas the peak values remained almost the same for the fact that the peak values occur in the river. The results show that the high values occur at lower end of the area. One reason is that runoff accumulates at the lower portion of area and secondly the lower area has more population and impervious surfaces. The runoff map after BMP implementation shows the areas of high runoff generation (Figure 8 left side). It is concluded that high values were observed in the downward cells, where the water accumulated. These were located near the stream areas. Low saturation zones were mainly the hill tops and outward flow areas. Terraces are also recommended as a second management practice to observe the effect of terraces on surface runoff. Terraces are modeled in ArcSWAT as a management operation changing the values in Ops. The results showed that terraces can be very effective in reducing amount of runoff. The upper part of study area and most of the area along the river are experiencing heavy runoff although they are very less as compared to when no management practice was applied. Terracing proved to be very useful for runoff volume reduction and it is also not very expensive to built (Figure 8 right side). Terraces intercept runoff on moderate to steep slopes. They transform long slopes into a series of shorter slopes. Terraces reduce the velocity of runoff, allowing the soil particles to settle. The minimum and maximum runoff before any management practice is 24.85 mm and 535.66 whereas after applying riparian buffer it reduced to 5.49 mm and 534.25 mm and with terraces it went to 1.52 and 465.24. July and August are the months of heavy rainfall, simulations found that the amount of runoff became 13% less when terracing is applied during extreme events in July 2004 and it reduced 57 % in August 2004. Combined riparian buffer and terraces are recommended management practices to reduce storm water runoff. Riparian Buffer should be applied along the river bank.

Table 3: Modified parameters and values for calibration

Parameter	Description	Initial	Modified
ESCO	Soil evaporation compensation factor	0.95	0.8
SOL_Z	Soil rooting depth[mm]		10-1650
SOL_AWC	Available water capacity of the soil layer[mm/mm]	0.3	0.2
CN2	SCS runoff curve number	85	63
SOL_K	Saturated hydraulic conductivity (mm/h)	70	100

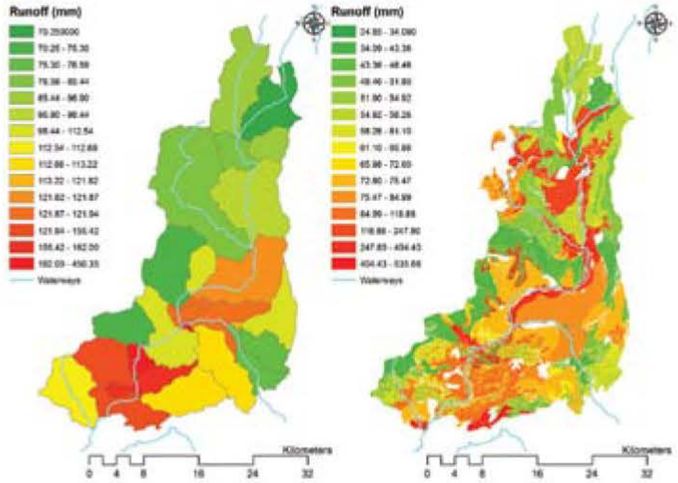

Figure 7: Sub basin Runoff (mm) Map (left side) & HRU Runoff (mm) Map (right side)

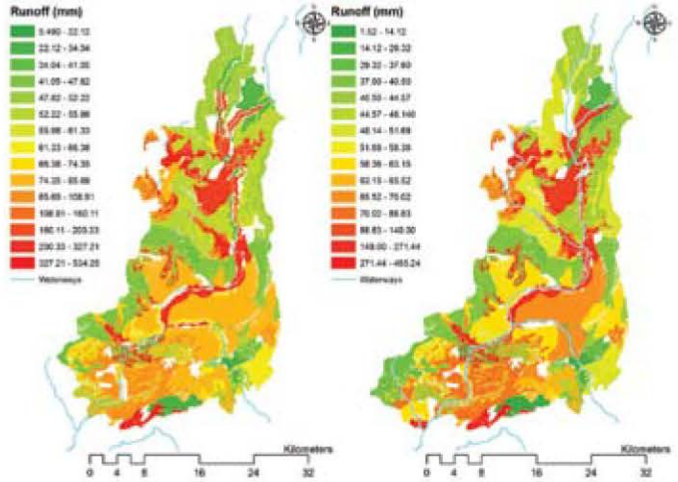

Figure 8: Runoff (mm) Map with riparian buffer (left side) and with terraces (right side) BMPs

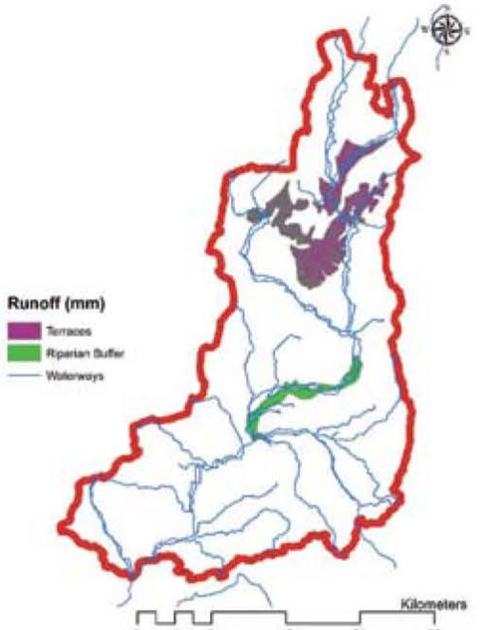

Figure 9: Site Map for recommended BMP implementation

Forest cover should be maintained along the river bank to reduce the effect of runoff. Best Management Practices should be applied upstream so that it controls runoff and non-point source pollution to effect the lower portion of area. After evaluating different management scenarios and looking at the results it is concluded that the upper portion of the study area should be carefully preserved and it should be selected as a location to apply Best Management Practices. Terraces should be applied in the upper part of area because it is hillier and riparian buffer should be applied on the lower portion of the area because it is plainer. A recommendation for BMP types action is made (Figure 9), including most feasible BMPs as per field visits and interviews.

6. Discussion

SWAT, as a modeling tool, has few advantages for managing input data and modeling rainfall-runoff processes within a GIS environment. SWAT was used to compare curve number and Green-Ampt rainfall-runoff models in agricultural watershed of San Joaquin River in California. The comparison showed that nearly equal average runoff values for both models on monthly simulation but on daily simulation the curve number model performed better than Green-Ampt model (Fickling and Zhang, 2013). Many researchers have used SWAT to simulate runoff and stream flow. The model performance was evaluated in Tao River Basin for runoff yield and the results show a close relation between simulated and observed monthly runoff, reflecting the validity and effectiveness of SWAT model (Xu and Peng, 2013). Stream flow simulations were performed in upper Rhone watershed located in the south western part of Switzerland using SWAT model. The results indicate good model performance in simulating stream flow (Rahman et al., 2013). SWAT has proven to be an effective and useful tool to simulate runoff in mountainous watersheds. The model has also performed well in this study for simulating surface runoff in a mountainous watershed. According to Hamid (2014) there are practically no management practice being implemented in Mansehra to reduce runoff from mountains on large scale. He added that some management practices can be observed in the area but they are not built to reduce runoff but for cultivation purpose. He further mentioned that a major earthquake disturbed the channels and stream network resulting in increases of landslides. BMP's like terraces are being implemented in the area but not by the authorities or on a larger scale, rather implemented by individuals and farmers and used for cultivation purpose. Terraces are also helpful in storm water management as they are not very costly and farmers can use those areas for cultivation. They can help to reduce water flow from mountains and preventing them to go downstream. Results from this research show that terraces can reduce storm water runoff very effectively. There is a huge difference in amount of runoff after terraces are added to the simulation. Results showed a reduction of 57% in runoff volume during August 2004. This is also an inexpensive way to minimize flood hazard and using the land as agriculture fields. The cost of installation includes earthwork cost associated with terrace construction the establishment of an adequate outlet such as a grassed waterway. If the area near the river is preserved as a buffer strip and a tree cover is maintained around it then it could act to minimize the effect of surface runoff. The effect of riparian buffer is modeled in SWAT and the results show about 6% decrease in surface runoff when a buffer of 500 m is applied around the main river only.

7. Conclusions

Predicting the location of runoff source areas is of utmost importance for watershed flood management. Characterization of areas on the basis of the runoff mechanism promotes a better understanding of the hydrological processes involved in flooding and its mitigation. SWAT created HRUs from the combination of land use/soil types and runoff was modeled on the basis of Curve Number (CN) defined to rainfall. In runoff calculation the model overestimated the runoff. The error for overestimation was within the limit of calibration. The reason was attributed to the model assuming normal (bell shaped) rainfall distribution contrary to the bi-modal distributions which were actually observed in case of high rainfall (daily). The model was highly sensitive to CN for the runoff, minor changes in the CN value affected the runoff amount significantly. Available Water Content (AWC) was the second sensitive parameter, adjustment of the parameter resulted into better simulation of runoff. The simulations generated by the model setup are used, within accuracy limits, as a practical tool to access the effects of different Best Management Practices in remote mountainous areas. A recommendation map was drawn for easy planning of upstream BMPs by local administrators, highlighting both terraces and riparian buffering BMPs locations found. Recently, rainwater harvesting was introduced by the local authorities who would help people store rainwater for their use and reduce the chances of flash flooding. Further field and modeling research is needed to evaluate the impact of high density rainwater harvesting technology.

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