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Not really!

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~~Optimizing~~ micro watershed management for soil erosion control under various slope gradient and vegetation cover conditions using SWAT modeling

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Abstract. This study evaluated parameters of soil erosion and optimization of micro watersheds by applying a semidistributed basin-scale Soil and Water Assessment Tool (SWAT) model in various small watersheds of the Chakwal and Attock districts of Pothwar, Pakistan. The model was calibrated and validated on a daily basis for a small catchment (Catchment-25) of the Dhrabi watershed without any soil conservation structures. Statistical measures (R^2 and EN-S) were used to evaluate model performance; the model performed satisfactorily ~~well~~ for both surface runoff and sediment yield estimations, with the R^2 and EN-S values both being greater than 0.75, during calibration (2009–2010) and validation (2011). The model was applied to various small watershed sites in the Chakwal and Attock districts after successful calibration and validation. Soil erosion estimation was performed at these sites having loose stone soil and water conservation structures and being under various slope gradient and vegetation cover conditions. The structures had significant effects, and the average sediment yield reduction engendered by the loose stone structures at the various sites varied from 54 to 98 %. The sediment yield and erosion reductions were also compared under conditions involving vegetation cover change. Agricultural land with winter wheat crops had a higher sediment yield level than ~~did~~ fallow land with crop residue, which facilitated sediment yield reduction along with the soil conservation structures. Analyzing various slope gradients revealed that all selected sites had a maximum slope area of less than 5 %; stone structures were installed at these sites to reduce sediment yield. Based on slope classification analysis, the model was upscaled for the whole districts of Chakwal and Attock. The results indicated that 60 % of Chakwal (4095 km^2) and Attock (3918 km^2) by area lies in a slope range of 0–4 %; this thus implies that considerable potential exists for implementing soil conservation measures by installing stone structures. Estimates revealed that minimum sediment yield reductions of 122,850 t year^{-1} in Chakwal District and 117,540 t year^{-1} in Attock District could be achieved by installing

may be earlier?

Not your result!

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loose stone structures in 60 % of the agricultural areas of both districts having a slope of 0–4 %; these findings can serve as a reference for policymakers and planners. The overarching findings of this study show that the SWAT model provides reliable tool for planning results ~~for sediment yield and soil erosion estimation~~, which can be used in rocky mountainous watersheds for erosion control and watershed management.

Keywords: SWAT Modeling, Soil Erosion, Land Management, Soil Conservation Structures, Model Upscaling

1 Introduction

Water and soil are the most crucial natural resources for agriculture and livestock production, playing key roles in the economic growth of any region. ~~Studies have shown that agricultural soils are the alluvial deposits formed through the weathering of mountains and transported through wind and water.~~ However, when anthropogenic activities disturb fertile soil formation, this can lead to soil ~~physiognomy~~ degradation, soil productivity reduction, and crop production loss; this ultimately instigates problems in agroecological farming systems and environment watershed plans (Panomtaranichagul and Nareuban, 2005). Considerable increases in sediment yield at the expense of soil renewal pose a major threat to soil and water resources development. Although water erosion is a function of many environmental factors, its assessment and mitigation at the watershed level are complex phenomena; this is because of the unpredictable nature of rainfall along with topographic heterogeneities, ~~and~~ climate and land use–land cover variability, as well as soil properties themselves other catchment features for the specified areas under study (Moore and Burch, 1986). In addition, inappropriate land management practices and human activities increase the dynamics of these factors (Wischmeier and Smith, 1978). Modern tools used for soil erosion estimation are based on physical, empirical, or conceptual models at the watershed level; however, the current models have some limitations. For example, the Universal Soil Loss Equation (USLE) is the empirical model used because it is easy to apply and has low data requirements; nevertheless, it exhibits deficiencies in simulating physical processes in a watershed. By contrast, the Water Erosion Prediction Project model is a physically based hydrological model that provides a complete understanding and quantification of physical processes; however, it is typically used on small watersheds (between 10 and 100 km^2) and requires a large amount of data (Kliment et al., 2008). A conceptual model such as the Soil and Water Assessment Tool (SWAT) is an empirically derived physically based model that exemplifies a compromise between empirical and physical model algorithms (Borah and Bera, 2003); furthermore, it is considered a more suitable tool for agricultural management practices in watersheds, compared with other models. ?? !? — a reference please!

Agricultural land degradation in rainfed mountainous areas is a major onsite problem that also causes offsite effects such as downstream sediment deposition in fields, floodplains, and water bodies. Globally, water resources deterioration caused by soil erosion is a growing concern; an estimated productivity loss of US$13–28 billion annually in drylands can be attributed to soil erosion (Scherr and Yadav, 1996). Urbanization, deforestation, overgrazing, and improper tillage practices that leave the land ~~fallow~~ bare with low organic matter are the major causes of soil erosion and produce serious economic loss for the nation (Ashraf et al., 2002). ~~Soil erosion is a direct function of slope length and steepness, because of direct increases in flow velocity~~

or cover?

Which one?

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lots of repetition with previous paragraph

(van Vliet and Hall, 1995). Vegetation cover on sloped ground helps reduce soil loss; however, during field preparation and cultivation, the surface soil becomes pulverized and easily eroded, causing acute topsoil erosion because of vegetation cover removal. Therefore, during the cultivation of sloping land, measures should be adopted to stop fertile surface soil erosion caused by substantial rainfall runoff. If such measures are not applied, the agricultural land may turn barren in only a few years (Itani, 1998). Vegetation cover is a key measure for soil protection against water erosion (Uhlirova and Podhrazska, 2007; Gordon et al., 2008; Saco et al., 2007); it reduces the flow velocity of surface runoff by increasing surface roughness, in addition to increasing the infiltration rate (Hejduk and Kasprzak, 2004, 2005) of soil.

Soil erosion and water loss are extreme hazards in rainfed areas of Pakistan because of the uneven topography in such areas, in which agriculture is directly dependent on rainfall. According to Rafiq (1984), 76 % of Pakistan's area is affected by various types of erosion; for example, 36 % is affected by water erosion and 40 % by wind erosion.

Study area?

Determining the relationship between rainfall, runoff and soil erosion is imperative in the Pothwar rainfed region for creating applicable soil and water conservation mechanisms, as well as for enhancing crop productivity. Considering the long-term sustainability and productivity of eroded land, the present study focused on the Pothwar plateau (Chakwal and Attock districts) having an arid to semiarid climate, according to a soil survey report (Ali, 1967). Generally, the plateau land comprises broken gullies, low hill ranges, and a flat to gently undulating topography. ~~The~~ soil textural classification varies from sandy to silt and clay loam, and the land consists of poor to fertile soil derived from sandstone and loess parent material (Nizami et al., 2004). The rainfall pattern is unpredictable with high intensity; 60–70 % of the total rainfall occurs during the monsoon season (from mid-June to mid-September). After the rains, soil crusting decreases the infiltration rate and aeration and increases soil strength, which reduces plant emergence and exposes the soil surface to erosion (Shafiq et al., 2005). The soil loss rate becomes more deleterious with higher intensity rainfall ~~runoff~~ over greater slope lengths and steepness levels (Rai and Mathur, 2007). The highest estimated record of soil erosion was 150–165 t ha^{-1} year^{-1} in the Dhrabi watershed in part of the Pothwar region (Ashraf et al., 2002). Without adequate protection, the effects of erosion on this highly erodible soil are extensive fertile soil and vegetation loss, endangered soil and water conservation structures, and reservoir depletion through sedimentation. Moreover, it causes doubts about the viability of existing and future soil and water conservation schemes. If ignored, untimely soil erosion and sedimentation can reduce benefits and may lead to prohibitively expensive remedial measures. The Pothwar region consists of cultivated highland slopes where timely soil and water conservation strategies and remedial measures are the basic requirements for sustainable crop productivity. In this study, the SWAT model was applied to assess sediment yield in small watersheds of the Pothwar region, as well as to evaluate the effect of loose stone soil conservation structures.

soil depth?

how measured?

Geography?

need to understand which ones are existing?

1.1 SWAT model description

The SWAT is a comprehensive, semidistributed, conceptual ~~physically based,~~ basin-scale hydrological model that assesses land–soil–water–plant systems (Arnold et al., 1998; Neitsch et al. 2001). It is commonly used to simulate water and soil loss in small agricultural watersheds (Tripathi et al., 2003). Neitsch et al. (2001) discussed the model's development, operation, assumptions,

then end
state objective

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and limitations in the SWAT theoretical documentation and user's manual available on the SWAT website (USDA-ARS, 2002). Srinivasan et al. (1998) reviewed the SWAT model simulation and application for streamflow, sediment, and nutrient transport along with the effects of management practices. The model simulates hydrology parameters and sediment yield in each hydrologic response unit (HRU). The surface runoff computation is performed using a modified USDA-SCS Curve Number method (USDA-SCS, 1972) or the Green and Ampt infiltration method (Green and Ampt, 1911). Sediment yield levels from each HRU are estimated using the Modified Universal Soil Loss Equation written as a mass balance equation as follows (Williams, 1975; Williams and Berndt, 1977):

$$S.Y = 11.8\left(Q_{surf} \times q_{peak} \times area_{hru}\right)^{0.56} . K_{USLE} . C_{USLE} . P_{USLE} . LS_{USLE} . CFRG \tag{1}$$

where S.Y = sediment yield (t ha^{-1}); Q_{surf} = surface runoff (mm ha^{-1}); q_{peak} = peak discharge (m^3 s^{-1}); and $area_{hru}$ = area of hydrological response unit (ha). lower KUSLE, CUSLE, PUSLE, and LSUSLE are USLE parameters and are presented in Table1. The sediment yield level at a watershed outlet is affected by two principal channel processes: sediment aggradation and degradation. The sediment transport capacity is a direct function of the channel peak velocity, which is used in the SWAT model as shown in Eq. (2):

$$T_{ch} = \alpha v^{b} \tag{2}$$

where T_{ch} (t m^{-3}) = transport capacity of a channel; v (m s^{-1}) = channel peak velocity; and α and b = constant coefficients. The channel peak velocity is calculated using Manning's formula in a reach segment as presented in Eq. (3):

$$v = \frac{1}{n} R_{ch}{}^{2/3} S_{ch}{}^{1/2} \tag{3}$$

where n = Manning's roughness coefficient; R_{ch} (m) = hydraulic radius; and S_{ch} (m m^{-1}) = channel bed slope. Channel aggradation (Sed_{agg}) and channel degradation (Sed_{deg}) in tons are computed in the channel segment using the criteria presented in Eqs. (4) and (5):

$$if\ sed_i > T_{ch}:\ \ Sed_{agg} = (sed_i - T_{ch}) \times V_{ch}\ \&\ Sed_{deg} = 0 \tag{4}$$

$$if\ T_{ch} < sed_i:\ \ Sed_{deg} = (T_{ch} - sed_i) \times V_{ch} \times K_{ch} \times C_{ch}\ \&\ Sed_{agg} = 0 \tag{5}$$

where sed_i (t m^{-3}) = initial concentration of sediment; C_{ch} = channel cover factor; K_{ch} (cm h^{-1} Pa^{-1}) = channel erodibility factor; and V_{ch} (m^3) = channel segment water volume.

(Sed_{out}) in tons is the total sediment transported out of the channel segment, which is computed using Eq. (6):

$$Sed_{out} = \left(sed_i + Sed_{deg} - Sed_{agg}\right) \times \frac{V_{out}}{V_{ch}} \tag{6}$$

where V_{out} (m^3) = volume of water leaving the channel segment at each time step.

how defined?

1.2.1 Portrayal of study area

This study was conducted in subcatchments of Chakwal and Attock districts to optimize the micro watersheds for soil erosion estimation using the SWAT model. First, the model was calibrated and validated in ~~the~~ one subcatchment (Catchment-25) of the Dhrabi Watershed, Chakwal District, Pothwar. Catchment-25 is an agricultural watershed consisting of deep gullies and having

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an area of 2 ha and elevation ranging from 527.15 to 539.78 m above sea level. It has well-defined boundaries and wide gully beds that mimic the full representation of the study area. The soil texture class is sandy loam and rainfall ranges from 450 to 630 mm. The watershed outlet as the measuring point has the coordinates 32.8946380 N and 72.7094070 E, as shown in Fig. 1.

The SWAT model was applied to the following sites for estimating the soil erosion in watersheds with water conservation structures:

1. Kohkar Bala — ha?
2. Khandoya
3. Dhoke Mori (Khaliq Gulli, Ashraf Gulli)
4. Chak Khushi
5. Dhoke Dhamal
6. Dhoke Hafiz Abad

Table?

for each of them?

Not really!

Sites 1 to 4 are located in Chakwal District, whereas sites 5 and 6 are in Attock District, as shown in Fig. 2a and b. The topography of the area made it difficult to assess the selected site. The structures were installed in the gullies and small fields. Considerable effort was required to accurately delineate the watershed for estimating the HRU and subbasins.

2 Materials and methods

2.1 Required data and their collection

To model sediment yield, two types of input data were required: (1) spatial raster data, including digital elevation model (DEM), mask DEM, land use, and soil and slope data; and (2) daily meteorological and climatic data in a lookup table and observed runoff and sediment data. For this study, Catchment-25 was used for sediment yield evaluation because of the similar characteristics of its selected small watersheds. A physical topographical survey of the catchment was conducted using a global positioning system (GPS), and a DEM was then generated using point-source elevation data in a geographic information system by applying the inverse distance weighting method. The soil, sandy loam, is composed of 67% sand, 19% silt, and 14% clay. The catchment features deep gullies with scrub trees, bushes, and grasses on top. The vegetation cover consists of the saroot (*Saccharum bengalense*) shrubs, phulahi (*Acacia modesta*) trees, dab (*Desmostachya bipinnata*) and khavi grass, and khabbal (*Cynodon dactylon*). appropriate

Meteorological, [illegible] ~~measured~~ runoff, and sediment data for the period 2009–2011 were collected from the Soil and Water Conservation Research Institute (SAWCRI), Chakwal District Department. The department installed an automatic weather station, water-level recorder for runoff, and stilling basin for sediment (~~see~~ Oweis and Ashraf ~~(eds.)~~ (2012)).

a table

units not elevation Area Precipitation etc should be added

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Hev Areas?

2.2 Model setup and simulation

After the SWAT model established, the first step in measuring the catchment's topography was physiographic analysis. ArcSWAT was used to delineate subwatersheds automatically and generate a stream network based on the DEM. An appropriate database of subbasin parameters and comprehensive topographic reports of the watershed were generated. SWAT coding conventions were used to reclassify land use and soil maps. The model's predictions are highly sensitive to HRU distribution levels (Mamillapalli, 1998); therefore, the distribution levels were set to 0 %, and the watershed was classified into HRUs based on the unique land use and soil and slope class in the overlaying section. The weather station location table and lookup tables of daily precipitation and temperature (maximum and minimum) data were loaded to link them with the required files. The model was initially simulated using default parameter values for surface runoff and sediment yield. Event base model calibration (2009–2010) and validation (2011) were performed using the parameters in Table.1

?

Warm-up?

3 Results and discussion

3.1 Model calibration and validation

Calibration involves the adjustment of parameters in watershed modeling; model predictions obtained without calibration may differ substantially from observed data. ~~Various options and techniques are available for SWAT model calibration.~~ In this study, the SWAT calibration procedure of Santhi et al. (2001a) was adopted. The statistical measures used in the model evaluation were the coefficient of efficiency (EN-S) (Nash and Sutcliffe, 1970) and coefficient of determination (R^2). The EN-S value ranges from $-\infty$ to 1; the simulation results are considered good if the EN-S value is >0.75 and satisfactory if the EN-S is in the range 0.36–0.75 (Motovilov et al., 1999). The model prediction is considered unacceptable if the EN-S value is negative or nearly 0 (Santhi et al., 2001a). The R^2 value ranges from 0 to 1, with higher values representing stronger predication and agreement. An R^2 value of 1 indicates a perfect correlation between observed data and model simulations.

Both calibration (2009–2010) and validation (2011) processes were performed manually on an event basis by using the soil erosion parameter values provided in Table 2. For the calibration process, the parameter ranges were referenced from Neitsch et al. (2001) and the calibration criteria followed those of Santhi et al. (2001a).

Table 3 presents the model performance in terms of surface runoff and sediment yield, as evaluated using statistical indicators (R^2, EN-S). This table indicates that the model performed reasonably well for the small watershed (Catchment-25) in the Pothwar region. Furthermore, high R^2 values were observed, indicating a strong correlation between the observed and simulated runoff and sediment yield. EN-S values signifying the observed and predicted runoff and sediment yield plots fit the 1:1 line well. The calibration and validation results for surface runoff are illustrated in Fig. 3a and b, respectively, and those for sediment yield are illustrated in Fig. 4a and b, respectively.

In 2009, a total rainfall of 400 mm was observed to accumulate from 11 erosive rainstorms. The maximum rainstorm (108 mm) occurred on July 29, producing a 46.2 mm runoff and a 6.86 t ha^{-1} sediment yield. The total measured runoff was 95.5

Water??

2007

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mm, and the runoff values ranged between 0.24 and 46.2 mm (Fig. 3a). The total sediment yield was 13.2 t ha^{-1}, and the yield values ranged between 0.003 and 6.86 t ha^{-1} against the corresponding events (Fig. 4a).

From February to September 2010, 13 erosive storms occurred with a total rainfall of 528.3 mm. The observed overall runoff during the 2010 measuring period was 129.53 mm, with runoff events ranging from 0.31 to 31.5 mm (Fig. 3a). The maximum rainstorm (122.3 mm) occurred on the same date as the previous year, generating a 25.9 mm surface runoff and 7.75 t ha^{-1} sediment yield. The rainfall event on July 29 (122.3 mm) and August 24 (62.8 mm) produced relatively low runoff values of 25.9 and 20.3 mm, as well as low erosion rates of 7.75 and 5.15 t ha^{-1}, respectively. By contrast, the rainfall event on July 20 (59.9 mm) produced a maximum amount of runoff (31.5 mm) and sediment yield (9.04 t ha^{-1}), although the soil was not wet from a prior rainfall event, whereas for the other two storms, the soil was wet from prior rainfall events (Fig. 3a and Fig. 4a). The total soil loss during the 2010 investigation period was 31.13 t ha^{-1}, with the loss values ranging between 0.016 and 9.041 t ha^{-1}.

a water plot would tell us more

During the validation period, 12 erosive rainfall events occurred with a total rainfall amount of 262 mm, which produced an overall runoff of 28.34 mm and sediment yield of 2.59 t ha^{-1}. The maximum rainstorm (39.6 mm) occurred on August 12, causing a 7.48 mm runoff and 0.598 t ha^{-1} soil loss, as illustrated in Fig. 3b and Fig. 4b. The observed runoff and soil loss during the validation period were lower because of light rainstorms.

According to the comparisons of the simulated and measured sediment yield and runoff during the calibration and validation periods (Fig. 3a and b and Fig. 4a and b), the average simulated runoff (6.73 mm) was close to the average observed runoff (7.04 mm), whereas the average simulated sediment yield was nearly equal to the average observed sediment yield (1.30 t ha^{-1}). Furthermore, the mean values and standard deviations revealed good agreement between the simulated and observed sediment yield and surface runoff values for the calibration and validation periods. The validated model was subsequently used to assess model applicability for soil erosion estimation with conservation structures under various scenarios.

3.2 Model application with conservation structures

12-6

After the model validation with adjusted soil erosion parameters, the model was applied to the ~~aforementioned~~ small watersheds. These small watersheds already have existing soil and water conservation structures for assessing soil erosion. All of the structures are of loose stone apron type without steel wire meshing and have similar geometry to a weir-type spillway. The crests of the structures play a major role in reducing the flow velocity that creates ponding and results in sediment deposition (erosion reduction) upstream of the structures, whereas the downstream sections of the structures prevent channel or gully development. Using a GPS and total station (Fig. 5), this study marked the point elevation data and boundaries of all watersheds; because of the complex topography of the small watersheds, considerable effort was required to accurately delineate the watershed area for estimating the HRU and subbasins (for example, at the Khokar Bala site). After preparation

along the main slope?

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of the requisite data file for SWAT model input, the model was run for all the selected sites for 6 years from January 2010 to April 2015. → Rainfall data? needs to explain the choices.

3.3 Soil erosion estimation and effect of conservation structures

The validated model was run without and with conservation structures separately for each ~~selected~~ site. Sediment yield results were compared under each condition, as shown in Table 5, by modifying the SWAT parameters representing the conservation structures, as shown in Table 4. Soil and water conservation structures, such as loose stone structures and stone bunds, act as imperative measures in the reduction of flow velocity, surface runoff, soil erosion, and slope length in a watershed system (Bracmort et al., 2006). Apposite parameters that signify the effect and importance of loose stone structures are the average slope length (SLSUBBSN), land management practice parameter (USLE_P), and curve number (CN2) for rainfall runoff conversion (Betrie et al., 2011). During the establishment of the SWAT model, these three parameters were modified manually; the SLSUBBSN value was modified by editing the HRU (.hru) input table, whereas CN2 and USLE_P were altered in the management input file (.mgt). Three more parameters were modified, namely average slope steepness (HRU_SLP) of the HRU input tables and two basin parameters (SPCON and SPEXP) representing the general watershed attributes in the Basin (.bsn) input files. The six parameters were modified according to the slope characteristics of the small watersheds and field conditions, in addition to being modified according to the terraced and contoured section of the SWAT user's manual (Neitsch et al., 2005) and a literature review (Betrie et al., 2011; Herweg and Ludi, 1999; Hurni, 1985). ?

Table 5 presents a significant sediment yield reduction achieved by ~~incorporating the parameter values recommended~~ presence for stone structures. The average annual sediment yield reduction varied from 40 to 90 % ~~in the analyzed sites;~~ the Khokar Bala site showed the maximum reduction. ~~The average 5-year sediment yield reduction engendered by structures at various sites was revealed to vary from 54 to 98 %~~; these results are relatively comparable to the findings of various scientists (e.g., Betrie et al., 2011; Gebremichael et al., 2005; Herweg and Ludi, 1999). Betrie et al. (2011) indicated 6–69 % sediment reductions in the Upper Blue Nile River basin caused by stone bunds. A field-scale study in the northern part of Ethiopia by Gebremichael et al. (2005) indicated a 68 % sediment yield reduction engendered by stone bunds. In addition, Herweg and Ludi (1999) conducted a study at plot scale in the Eritrean highlands and Ethiopia and reported 72 –100 % sediment yield reductions engendered by stone bunds. INTRO

The effect of conservation structures on sediment yield reduction is elucidated in a report by Oweis and M. Ashraf (eds.) (2012): "Stone spillways as conservation measures were designed and installed in the Dhrabi Watershed of Chakwal District to reduce soil erosion; analysis results revealed that, on average, water at a height of approximately 10–15 cm was retained in the fields by the stone spillway structures, thus reducing soil erosion by reducing the kinetic energy of the runoff." Regarding the effectiveness of the soil conservation structures (stone structures) installed in the Dhrabi watershed, the average soil loss rates in 2009 without and with structures were calculated as 47 and 37.98 t ha^{-1} year^{-1}, respectively, with a 20 % reduction. However, the maximum soil loss rates without and with structures were 2716.17 and 1731 t ha^{-1} year^{-1}, respectively, with a INTRO

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37 % reduction. Similarly, a 31 % reduction in average soil loss and a 36 % reduction in maximum soil erosion were reported for the year 2010 in the same catchment (Klik et al., 2012). Nabi et al. (2008) reported that in the Soan River basin of Pothwar, the soil loss rates in barren and shrub land were 63.41 and 53.41 t ha^{-1} $year^{-1}$, respectively, whereas those in low- and high-cultivation land were 34.91 and 25.89 t ha^{-1} $year^{-1}$, respectively.

3.4 Soil erosion estimation under different scenarios

In addition to evaluating the effectiveness of the soil conservation structures as presented in Table 5, this study developed various scenarios to estimate the further reduction in soil erosion associated with various types of land use change in the studied catchment areas. The scenarios were developed according to the scientific literature of land use and vegetation cover importance to assess soil erosion. Vegetation cover increases the infiltration rate (Hejduk and Kasprzak, 2004, 2005), reduces the erosive velocity of surface runoff, and plays a key role in resisting water erosion. A trivial variation in vegetative cover ?? can produce considerable effects in overland flow (Wei et al., 2011). Vegetation cover is a key factor in controlling and reducing surface runoff and water erosion on agricultural land (Hofman et al., 1985).

The SWAT model was applied on the basis of four scenarios at the Dhoke Mori (Khaliq and Ashraf Gulli) and Khandoya catchment sites. The scenarios are described as follows:

Scenario 1 (S1): The model was applied for soil erosion estimation on land without structures under the following conditions: the land use type was determined to be winter wheat; for overland flow, Manning's n = 0.15 (for short grass), and for channel flow, Manning's n = 0.025 (for natural, earth uniform streams).

stone spillways?

Scenario 2 (S2): The model was applied for soil erosion estimation on land with structures under the same conditions as S1.

Scenario 3 (S3): The model was applied for soil erosion estimation on fallow land without structures. Manning's n = 0.09 for overland flow. Crop residue and channel flow conditions remained the same.

Scenario 4 (S4): The model was applied for soil erosion estimation on land with structures under the same conditions as S3.

The analysis of the various scenarios revealed that the sediment yield level was higher in S1 and S2 than in S3 and S4. This indicates that the sediment yield level is higher on agricultural land than on fallow land with crop residue. In the comparative analysis of S1 and S2, the average sediment yield decreased to 1.25 t ha^{-1}, whereas in S3 and S4 (fallow land with crop residue), the average sediment yield decreased to 0.85 t ha^{-1}. The results reveal that land use change facilitates sediment yield reduction, in addition to soil conservation structures.

Notably, a visual observation of the various structures revealed that the effects of the structures on soil erosion control generally extended to a 4 to 5 m radius from the center of the structure crests during high flow seasons; the water accumulated and sediment was deposited upstream of the structures.

table

INTRO?

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3.5 Model upscaling for Attock and Chakwal districts

As reported by various researchers, soil loss is minimal on sloping land with vegetation cover; however, when the available vegetation cover is removed, soil loss becomes more significant as a function of slope length and slope steepness. The stream power (ƮU) as a function of shear stress and flow velocity and the shear stress caused by flowing water are the basic criteria for assessing erosion of soil particles caused by overland flow. Shear stress and flow velocity are directly proportional to slope steepness. This means that the steeper the land slope is, the greater the shear stress becomes, consequently increasing the potential for soil erosion.

Additionally, when soil conservation structures are installed in a field, farmers focus on cultivating agricultural crops in the areas above and below such structures. Considering these factors, this study estimated the potential area that would benefit from the installation of structures in Chakwal and Attock. Accordingly, the model was upscaled and soil erosion reduction was estimated at the district level by determining suitable slopes for stone structures and agricultural practices. The areas under various slopes in the small watersheds were calculated and are shown in Table.7

All selected sites in the catchment were depicted as having a maximum slope area of less than 5 %. This is because the selected sites were used for agricultural production. Farmers have graded the land as suitable for crop production and generating less surface runoff. ~~The~~ A agriculture practices are only possible on soil that has a slope of less than 8 %; otherwise, land grading must be carried out. The same has been suggested by various authors; a USLE experiment conducted at the SAWCRI office concluded that only a slope of less than 10% is acceptable for agricultural practices under rainfed conditions.

INTRO

The total maximum and minimum sediment yield reductions are provided in Table.8 by law? reference

The maximum proportions of the areas in Attock District and Chakwal District with less than 20% slope were 94 and 94.5 %, respectively. The table shows that approximately 61 % (3918 km^2) of Attock District lies in a slope range of 0–4 %, whereas 28 % (1786 km^2) lies in a slope range of 4–10 %. This 89 % area has a potential minimum sediment yield reduction of 171,120 t year^{-1} if soil conservation structures are constructed. Similarly, 60 % (4095 km^2) of Chakwal District lies in a slope range of 0–4 %, whereas 28 % (1913 km^2) of Chakwal District lies in a slope range of 4–10 %, which means a potential minimum sediment yield reduction of 180,240 t year^{-1}. The minimum slope areas were considered according to Betrie et al. (2011), who recommended that stone bunds should be applied in low-slope areas for soil conservation. However, the effectiveness of the structures depends on the local topography and soil and land use–land cover conditions. Considering topographic conditions, considerable potential exists for implementing soil conservation measures through the installation of stone structures. However, appropriate maintenance of the structures is crucial for sustaining effectiveness.

INTRO

DON?

4 Conclusions and Recommendations

The following conclusions were reached:

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Not this study results

1. Loose stone structures are effective options for soil erosion control in rainfed areas. The model results reveal that 40–90 % sediment yield reduction could be achieved using soil conservation structures.
2. An all-inclusive interpretation of the quantitative model results may be misleading because no model can simulate all physical processes of soil and water interactions in a real sense. Some assumptions were made during modeling; however, the results suggest to policymakers and planners that more than 60 % of the area in Attock and Chakwal districts has potential for soil conservation using stone structures.

discussion

3. The conservation structures require regular maintenance because nonmeshing can cause stones to slide, which may lead to the displacement of the whole structures.
4. The structures were not designed according to the hydraulic characteristics of surface flow. Downstream damage of the structures was common because of the nonavailability of downstream energy dissipation arrangements.
5. Considering the topographic conditions, loose stone structures should be installed in areas with a slope range of 0–10 %. Not explored —
6. Wire-meshed stone structures should be installed in areas with a slope range of 6–10 %. Proper energy dissipation arrangements should be implemented to prevent downstream erosion.

??! When did you talk about this?

Acknowledgments

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Author contributions

Ghulam Nabi was in charge of designing the study and wrote the paper. Fiaz Hussain performed the analysis and produced the results. Ray-Shyan Wu helped in strengthening the quality of the work in terms of data management and result evaluation. The authors Vinay Nangia, Riffat Bibi, and Abdul Majid contributed to the preparation and review of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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Table 1. Soil erosion estimation parameters used in ArcSWAT

S. No.	Parameter	Description
1	USLE_P	USLE conservation practice factor
2	USLE_C	Cover and management factor in USLE
3	USLE_K	USLE Soil erodibility factor
4	SPCON	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing
5	SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing
6	CH_EROD	Channel Erodibility factor → sol dt ?
7	CH_COV	Channel Cover factor

why? combine

Table 2. Soil erosion parameters used during model calibration and validation

Parameter	Default Value	Value Used
USLE_P	0 to 1	0.11 ?
USLE_C	0.001 to 0.5	0.182
USLE_K 1 soil only?	0 to 0.65	0.246
SPEXP	1.0 to 2.0	1.0
SPCON	0.0001 to 0.01	0.0032

Table 3. SWAT model performance evaluation

Surface Runoff) which parameters?		
Parameter	Calibration	Validation
R^2	0.84	0.81
EN-S	0.81	0.78
Sediment Yield		
R^2	0.82	0.79
EN-S	0.79	0.76

Table 4. SWAT parameters used to represent conservation structures

Parameter Name (input file)	Modified Value
SLSUBBSN (.hru) L	60

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From to

HRU_SLP (.hru)	0.016	
CN2 (.mgt)	65	?
USLE_P (.mgt)	0.65	
SPCON (.bsn)	0.001	??
SPEXP (.bsn)	1.25	

Table 5. Effect of stone structures on sediment yield reduction

Sediment Yield (t/ha) Reduction due to Stone Structures

	Khaliq Gulli			Ashraf Gulli			Khokar Bala			Chak Khushi			Dhoke Dhamal		
Year	W.O.S	W.S	% Red	W.O.S	W.S	% Red	W.O.S	W.S	% Red	W.O.S	W.S	% Red	W.O.S	W.S	% Red
2010	59.3	30.3	49.0	25.0	10.4	58.5	37.6	0.9	97.6	1.6	0.8	49.4	15.3	8.3	45.7
2011	25.8	15.3	40.6	10.7	2.6	75.8	21.9	0.4	98.1	0.9	0.4	58.8	6.7	2.3	66.3
2012	2.3	0.0	100	0.9	0.0	100	3.9	0.1	98.5	0.0	0.0	100	0.6	0.0	98.2
2013	32.9	14.6	55.7	14.0	3.5	75.2	28.7	0.7	97.7	1.1	0.2	78.2	8.9	2.2	75.0
2014	27.6	11.9	57.0	11.6	2.2	81.1	13.8	0.2	98.6	0.8	0.2	69.7	7.4	1.8	75.4
2015	34.0	25.2	25.9	14.5	3.0	79.0	21.1	0.3	98.8	0.9	0.1	92.1	9.4	0.9	90.3
Ave.	-	-	54.7	-	-	78.3	-	-	98.2	-	-	74.7	-	-	75.2

Table 6. Effect of different scenarios on sediment yield reduction

Catchment Name	S1 (t/ha)	S2 (t/ha)	S.Y Reduction	S3 (t/ha)	S4 (t/ha)	S.Y Reduction
Ashraf Gulli	10.95	10.15	0.80 t/ha	7.91	7.04	0.86 t/ha
Khaliq Gulli	25.98	24.75	1.23 t/ha	17.10	16.5	0.60 t/ha
Khandoya	48.75	47.0	1.75 t/ha	42.28	41.18	1.1 t/ha

Table 7. Area under different slopes in small watersheds of Chakwal and Attock districts

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	Ashraf Gully	Khaliq Gully	Chak Khushi	Dhok Dhamal	Khokar Bala	
Slope (%)	Area (%)	Area (%)	Area (%)	Area (%)	Slope (%)	Area (%)
0-2	63	50	97	81	0-5	65
2-5	30	42	3	17	5-10	25
>5	7	8	-	1	>10	10

Table 8. Sediment yield reduction under different slopes with application of stone structures in Chakwal and Attock districts

Slope Category	Chakwal				Attock			
	Area	Area	Min S.Y Reduction	Max S.Y Reduction	Area	Area	Min S.Y Reduction	Max S.Y Reduction
(%)	km2	(%)	(t/yr)	(t/yr)	km2	(%)	(t/yr)	(t/yr)
0-4	4095	60	122850	7944300	3918	61	117540	7600920
4-10.1	1913	28	57390	3711220	1786	28	53580	3464840
10.1-20	547	8	16410	1061180	472	7	14160	915680
20.1-40	233	3	6990	452020	165	3	4950	320100
40-90	75	1	2250	145500	55	1	1650	106700

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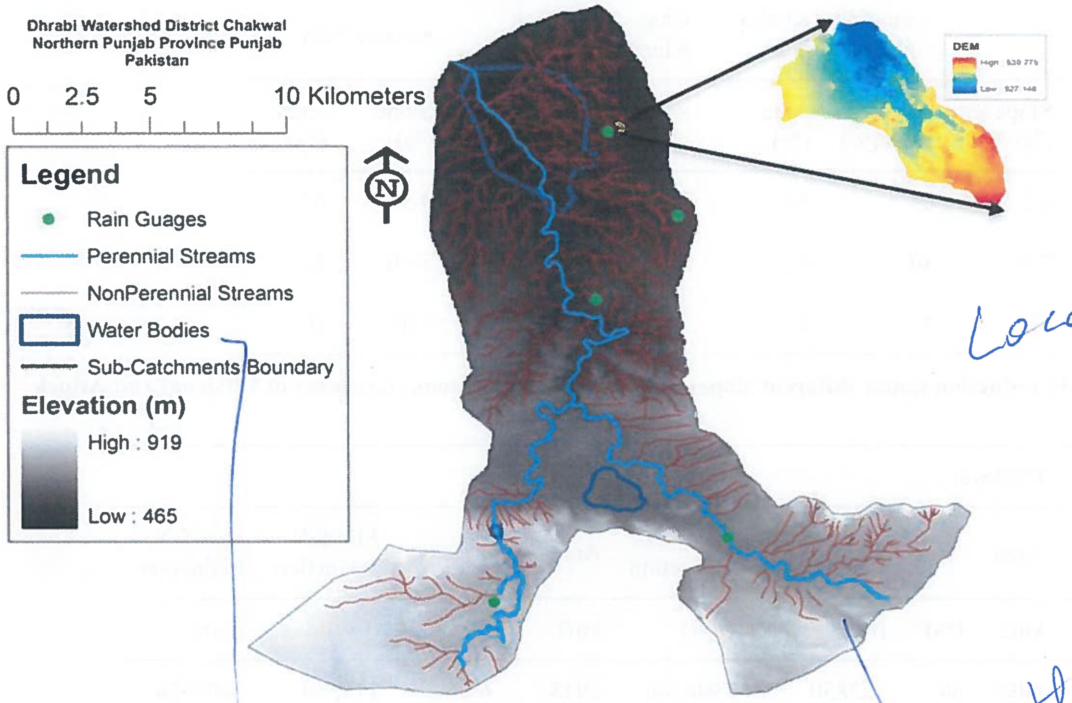

Location – PAkistan?

Figure 1. Location of Catchment-25 used for model calibration and validation.

? lakes?

and this is what?
step 2–6?

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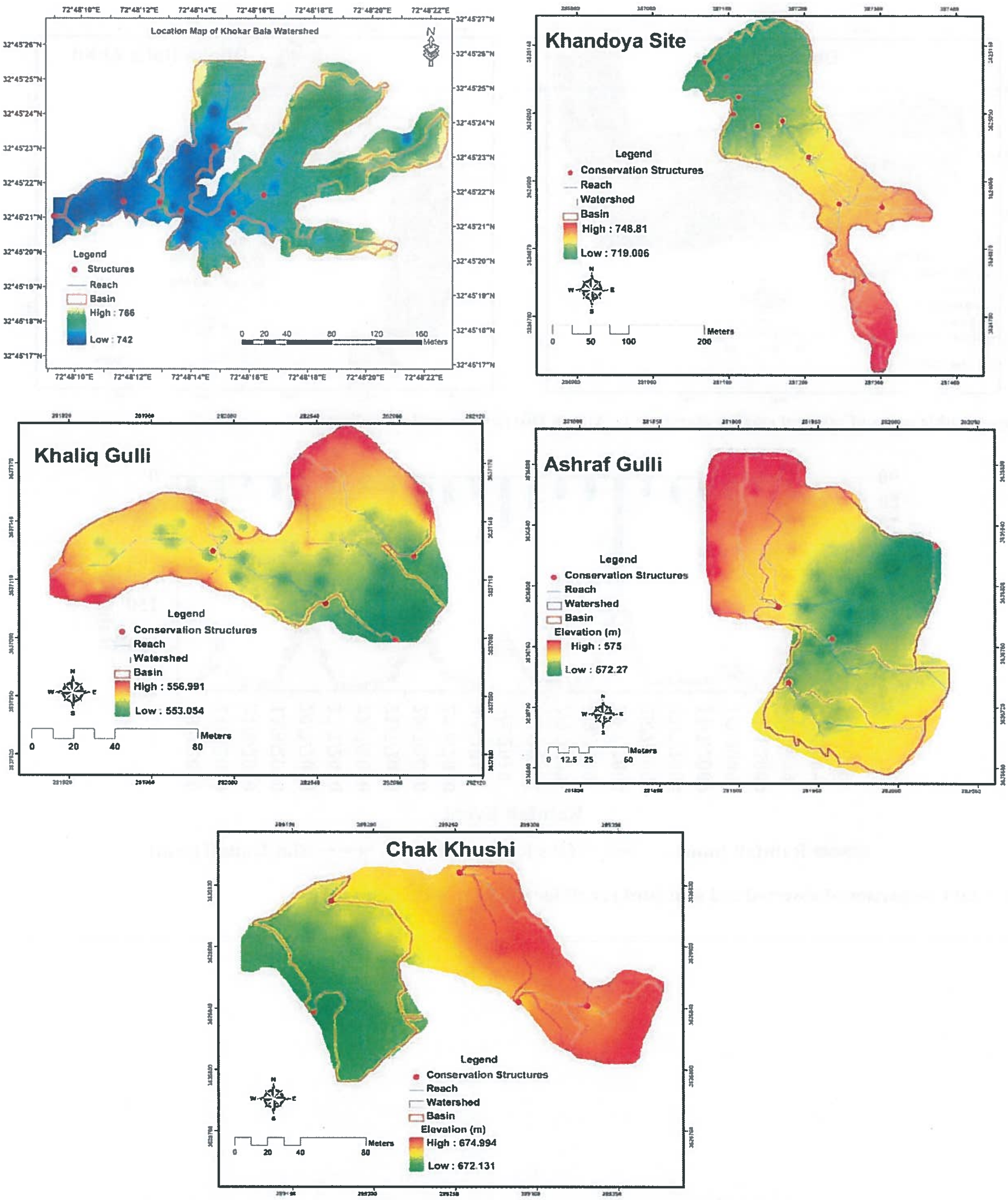
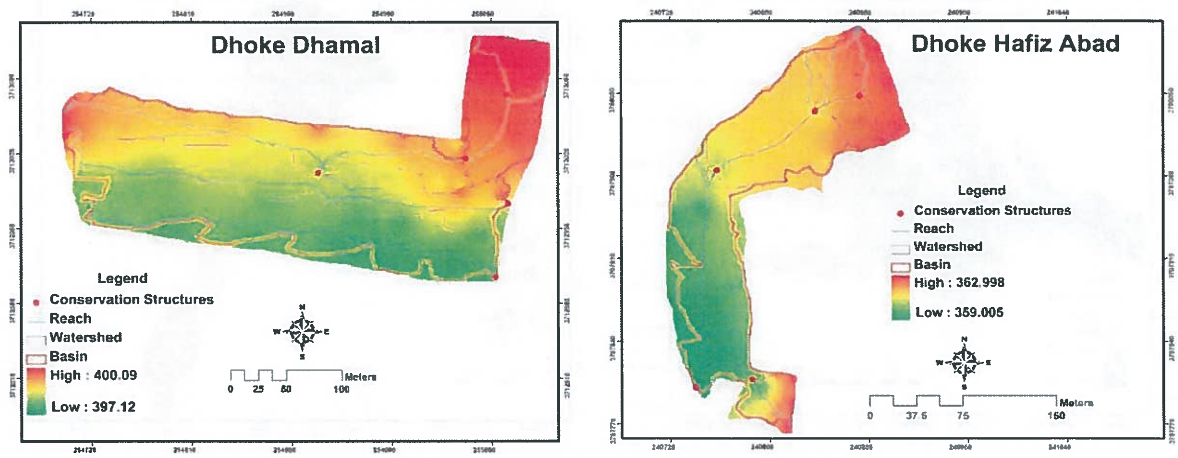


Figure 2. (a) Topographic maps of selected small watersheds in Chakwal District for model application.



(b) Topographic maps of selected small watersheds in Attock District for model application

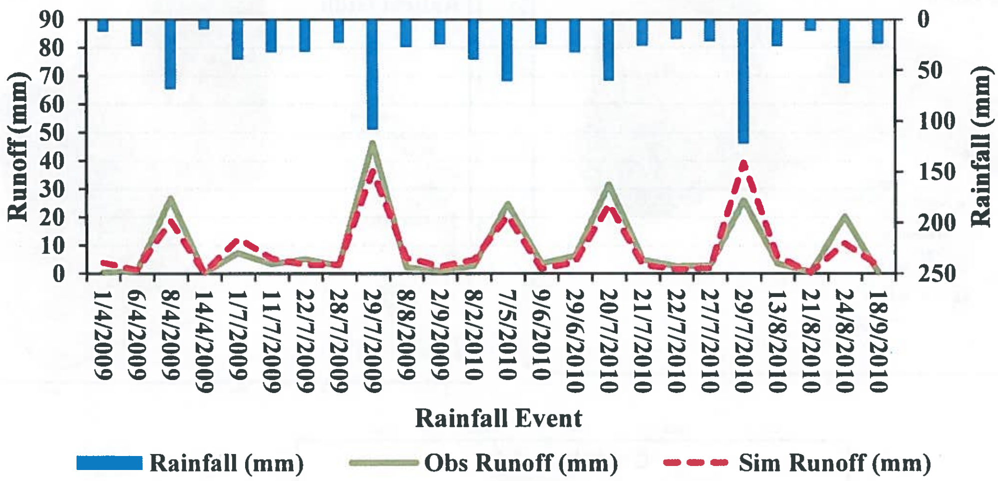


Figure 3. (a) Comparison of observed and simulated runoff for SWAT model calibration

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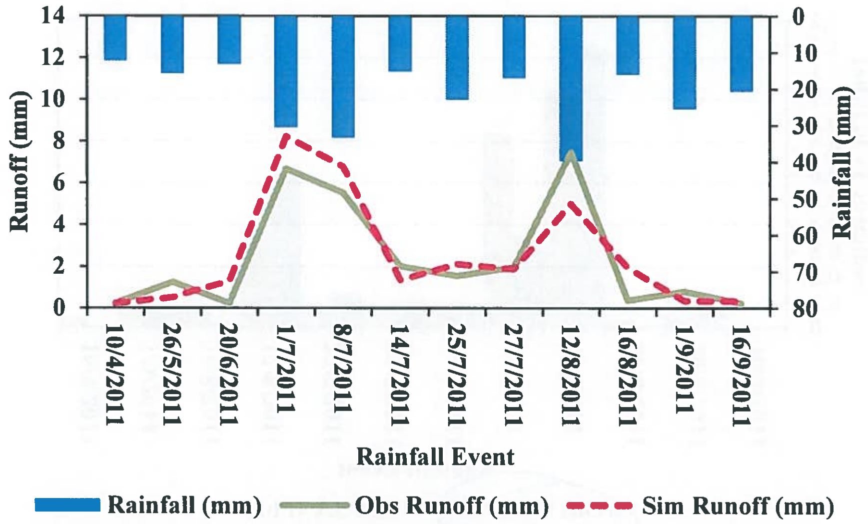

(b) Comparison of observed and simulated runoff for SWAT model validation

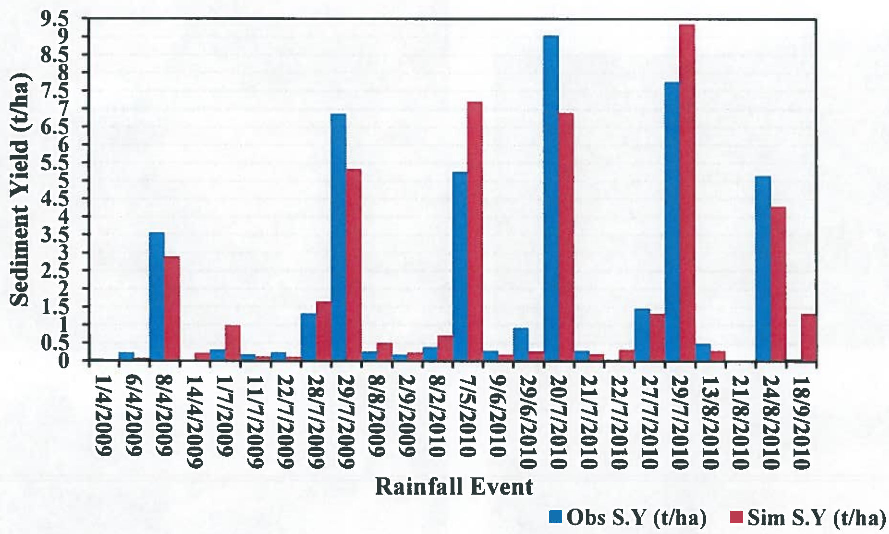

Figure 4. (a) Comparison of observed and simulated sediment yield for SWAT model calibration

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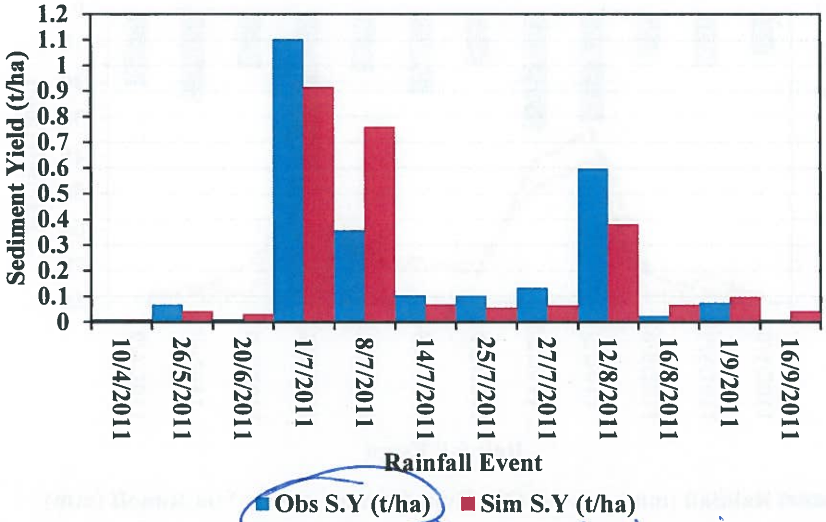
Depth of specific site(s) to clarify unclear

Need a table to see how similar sites are - what type of are - Agriculture? Precipitation?



explain in caption.

(b) Comparison of observed and simulated sediment yield for SWAT model validation

Figure 5. Pictorial view of data collection and conservation structures at different locations

objective?

MAJOR Rev -
1) A description of the area
+ the type of conservation measures -
results need to be better presented
conclusions are NOT covered by study
DATA -
restructure all the paper!