

Modelling Daily Surface Runoff, Sediment and Nutrient Loss at Watershed Scale Employing APEX Model Interfaced with GIS – A Case Study in Himalayan Landscape

Suresh Kumar (✉ suresh_kumar@iirs.gov.in)

Indian Institute of Remote Sensing <https://orcid.org/0000-0001-6460-6253>

Ravinder Pal Singh

Indian Institute of Remote Sensing

Justin George Kalambukattu

Indian Institute of Remote Sensing

Research Article

Keywords: Erosion modelling, APEX, Runoff, Sediment loss, Nutrient loss, Watershed, Himalaya landscape

Posted Date: February 24th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-232906/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Environmental Earth Sciences on July 30th, 2021. See the published version at <https://doi.org/10.1007/s12665-021-09791-4>.

Title:

Modelling Daily Surface Runoff, Sediment and Nutrient Loss at watershed scale employing APEX Model interfaced with GIS – A case study in Himalayan landscape

Authors:

Suresh Kumar*, Ravinder Pal Singh and Justin George K

Agriculture and Soils Department,
Indian Institute of Remote Sensing, ISRO
4 Kalidas Road, Dehradun, Uttarakhand, India – 248001

*Corresponding author: suresh_kumar@iirs.gov.in

Submitted to: Environmental Earth Sciences

Total Pages: 13

Number of words: 5378

**Modeling Daily Surface Runoff, Sediment and Nutrient Loss at watershed scale employing APEX Model
interfaced with GIS – A case study in Himalayan landscape**

Suresh Kumar*, Ravinder Pal Singh and Justin George K

Indian Institute of Remote Sensing, Indian Space Research Organization,

4 Kalidas Road, Dehradun 248001, India.

*Corresponding author: suresh_kumar@iirs.gov.in

Abstract:

Daily surface runoff, sediment and nutrient loss data collected from a watershed located in Uttarakhand state of Indian Himalayan region, in year 2010-2011 and of which half of the events data were used for calibration and remaining for validation. Model was calibrated for surface runoff, sediment loss and nutrient loss to optimize the input given to the model to predict the sediment loss, erosion and nutrient loss. The calibration was done by changing the sensitive parameters. Analysis showed that SCS CN number was found most sensitive to runoff, followed by saturated hydraulic conductivity, available water-holding capacity, CN retention parameter and C factor whereas erosion control practice (P) factor was found to be most sensitive, followed by C factor, sediment routing coefficient, average upland slope and soil erodibility (K) factor for the sediment and nutrient loss. APEX model calibrated for the watershed and it predicted quite well for the surface runoff ($r=0.92$, $NSE=0.50$), sediment loss ($r=0.88$, $NSE=0.61$) and nutrients of total carbon ($r=0.78$, $NSE=0.59$) and fairly for total nitrogen ($r=0.77$, $NSE=0.19$). Surface runoff was predicted well for low and medium rainfall; however, it was over predicted for high rainfall events. Over prediction may be attributed to the unaccountable conservation measures and practices which were not accounted by the model. Similarly, sediment loss was estimated on daily basis at the watershed scale and was well predicted for low and medium rainfalls but under-estimated for high rainfall events. The area is prone to landslips occurred at high rainfall events was not accounted by the model that may be a reason for under prediction of sediment loss by the model.

Keywords: Erosion modelling, APEX, Runoff, Sediment loss, Nutrient loss, Watershed, Himalaya landscape

1.0 Introduction

Soil erosion due to water is a major process that degrades land resources in the Himalayan region. It has been estimated that nearly 120.7 M ha land of India is degraded and of which 70% of land degradation is caused due to water erosion (ICAR, 2010). It has been estimated that nearly 39% area of the Indian Himalayas has potential erosion rates of $>40 \text{ t ha}^{-1} \text{ year}^{-1}$, which is alarmingly high (Singh et al, 1992; Mandal et al, 2011; Bhattacharyya et al., 2015). Soil erosion process is largely governed by surface runoff generation where soil particles are detached and carried away as sediments to another place or deposited in water resources. It causes two major impacts of on-site soil loss and off-site effects of sediment loss resulting environmental impact in the landscape. It removes fertile soil layer resulting in deterioration of soil quality, loss of crop productivity (Lal, 1995; Pimentel et al., 1995) as well as sediment loss affecting environmental safety (Matson et al., 1997).

The major causes of soil erosion in the Himalayan region is attributed to high and erosive rainfall, weak geological formation, active geotectonic activities, vegetal degradation and poor farm management practices. Degradation of natural forest cover, increasing anthropogenic activity and poor cultivation practices on steep sloping terrain coupled with fragile and immature soils leads to severe soil erosion (CSWCRTI, 2011). Cultivation on sloping lands and inappropriate land management enhances water-induced soil erosion in the hilly landscape. Garde and Kothyari (1987) reported that the soil erosion rate in the Northern Himalayan region is high ($20 \text{ to } 25 \text{ t ha}^{-1} \text{ yr}^{-1}$). Runoff generation and soil erosion are two important hydrological processes responsible for deterioration of soil and water quality in the region. Soil erosion removes top nutrient rich surface layer resulting in reduction of soil quality. It results in significant amount of nutrients loss from landscape adversely affecting soil quality and threatening sustainability of agriculture in mountainous landscape (Pimentel and Burgess, 2013; Lal, 2015).

Soil erosion is primarily governed by five factors of rainfall erosivity, soil erodibility, vegetation cover types, management practices and the terrain slope (Wischmeier and Smith, 1978). These factors are accounted by various soil erosion models. These models are primarily based on an understanding of the physical laws and landscape processes such as runoff and soil loss occurring in the natural environment. Comprehensive watershed management requires detailed understanding of hydrological and erosion processes at the watershed scale (Daniel et al., 2011). There are several erosion models for soil erosion estimation which are based on physical, empirical, or conceptual models are in use ranging from long term soil erosion rate estimation to simulating daily runoff and sediment loss from the landscape or watershed level (Merritt et al, 2003). They can simulate various land use / land cover types, combination of cropping systems and conservation practices and to assist appropriate / suitable conservation measures to arrest soil erosion in the landscape. Presently, several models are being used to simulate runoff, sediment and nutrients loss at watershed scale on daily and event based such as WEPP, SWAT, AGNPS, EPIC and APEX etc. (Pandey et al., 2016). Development of computer science, geospatial technologies with understanding of soil hydrological and erosion processes in recent years lead to development of several simulation models at watershed scale (Merritt et al, 2003; Gassman et al., 2007). These models are very well interfaced with Geographic Information Systems (GIS) and emerged as powerful tool in spatial handling of model input parameters and spatial prediction. A

GIS interfaced with these model provides a tool to run a simulation and to interpret results in spatial context. Performance of the watershed models are evaluated with prediction of sediment and nutrient loss at watershed scale. Prediction with reasonable accuracy is essential for its wider applications and in preparing watershed development plans. Information of sensitivity analysis, calibration, and validation are key factors in ascertaining efficiency of model for wider applicability to users and planners ([Wang et al., 2012](#); [Bhandari et al., 2017](#)).

APEX is an extended and expanded version of the Environmental Policy Impact Climate (EPIC) model ([Williams, 1990](#); [Chung et al., 1999](#); [Izaurrealde et al., 2006](#)). EPIC, a field scale model has been extensively tested for various conditions globally ([Gassman et al., 2005](#); [Liu et al., 2007](#)). In addition to the EPIC functions, APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to a watershed outlet. APEX model as state of art developed as field/watershed scale that provides opportunities to define daily weather, land use, soils, topography and management practices such as tillage, crop rotation, and agriculture inputs. The model can also consider the impact of management practices on soil erosion and water quality while allowing for routing processes for runoff, sediments, nutrients and herbicides/pesticides within and from fields at watershed level ([Saleh et al., 2004](#); [Wang et al., 2006](#)). APEX performs all these processes across complex landscapes through the channel to small watershed or field outlets ([Srivastava et al., 2007](#)). Several studies used APEX models for different environments and varying agricultural management practices to simulate runoff, nutrients and herbicides successfully at field and at the outlet of the watersheds ([Gassman et al., 2010](#)). [Lin et al. \(2016\)](#) used agricultural policy environmental extender (APEX) model to study the relationship between long-term erosion and farmland productivity losses. It also allows convenient assessment of various systems including terraces, grass waterways, strip cropping etc. ([Williams et al, 2008](#)). [Wang et al., \(2008\)](#) used APEX model to assess the benefits of ridge-till over conventional-tillage on monthly surface runoff and sediment yield in two watersheds cropped with continuous corn (*Zea mays L.*) and managed with conventional-tillage, respectively.

Sediment and nutrients from agriculture areas are usually considered as major NPS to aquatic ecosystems and are known to have major impacts on water quality. Excessive amount of nutrients such as Nitrogen (N) and phosphorus (P) can cause problems such eutrophication, oxygen deficiency and loss of biodiversity, among others. NPSs of nutrients and sediments are always difficult to assess and control as they originate from dispersed areas and are variable in time due to climatic variations. It is extremely important to identify these sources of pollution for the effective management of water and the entire watershed. Fragile soil with steep terrain, high rainfall and poor land management practices lying in the Watersheds of Himalayan landscape triggers / enhances high soil erosion and sediment loss. Thus, Soil and water conservation planning requires information on soil and nutrient loss from the watershed. The overall objective of the study is to evaluate surface runoff, sediment loss and nutrient losses (total carbon and total nitrogen) from typical watershed using APEX model interfaced with GIS. The typical watershed comprises of dominant land use / land cover types of forest, scrub and crop land having subsistence farming represented in lesser Himalayan landscape.

2.0 Study area

The watershed named as Sitla Rao watershed located in the lesser Himalayan landscape in Dehra Dun district Uttarakhand state, India ([Fig. 1](#)). A micro-watershed, part of the Sitlarao watershed lies between latitudes of 30° 24' 39" to 30° 29' 05" N and longitude 77° 45' 33" to 77° 57' 46" E. identified for establishing watershed observatory. The watershed represents moderately steep to very steep sloping hills where elevation ranges from 960 to 1480m. The elevation in the watershed ranges from 920 to 1480 m. The watershed is characterized by moderately steep to very steep sloping hills which drains by an ephemeral channel that runs from north-west to south-west. The mean annual rainfall received is 2051 mm (1983 - 2008) and 70% of rain is received during monsoon season (June to September), July and August being the雨iest months. The mean annual temperature ranges from 15.8° C in winter to 33.3° C in summer seasons. The soils in the watershed are mainly sandy loam, sandy clay loam, silty loam and loamy skeletal (coarse fragments in top soil > 35%) in textural class. Soils are moderately deep to deep and drainage being excessive to moderately well. Surface soils have < 10-15 % coarse fragments whereas sub-surface soils contain >15 % coarse fragments comprising gravels, pebbles, cobbles and stones. The pH of soil ranges from 5.0- 6.5, characterized as slightly acidic in nature. The soils are taxonomically classified as Loamy skeletal Typic Udothents, Coarse loamy and Fine loamy Typic Hapludepts. Major crops grown are paddy, maize and wheat in the watershed. Farmers use organic manures in agricultural field. The natural vegetation cover comprises of Sal forest (*Shorea robusta*), shrubs (*Lantana camera*, *Ipomoea batata*) and grasses (*Saccharum spontaneum*) in the watershed.

3.0 Materials and methods

3.1 APEX model description

APEX is a distributed hydrologic and water quality model that runs typically on a daily time-step ([Radcliffe et al., 2015](#)). It was developed as an extension of the Environmental Policy Integrated Climate (EPIC) model and can be used to simulate hydrology, erosion/sedimentation, weather, soil temperature, crop growth/plant competition, nutrients, pesticides, and agricultural management such as nutrient management, tillage operations, alternative cropping systems and irrigation ([Steglich and Williams, 2013](#)). It is applicable to wide range of soils, climate, cropping system and management practices. It has been well tested for terrace fields and steep sloping area ([Gassman et al, 2006](#)) with high rainfall and runoff as an erosivity factor. It can be implemented for more detailed simulations of small watersheds with complex agronomic systems ([Tuppad et. al., 2009](#)). There are various databases of soils, crops, tillage, fertilizer, and pesticides have been built to facilitate simulation in the model. The detailed theoretical and technical documentation of the APEX model (Version 0806) is available ([Steglich and Williams, 2013](#)).

3.1.1 Modeling surface runoff

SCS curve number method was used to simulate surface runoff volumes and peak runoff rates, given daily rainfall amounts. It uses the following formula

$$Q = \frac{(RFV - 0.2s)^2}{(RFV + 0.8s)} \quad RFV > 0.2*s \quad \dots \dots \dots \quad (1)$$

$$Q = 0.0; \quad RFV < 0.2*s \quad \dots \dots \dots \quad (2)$$

Where, Q is the daily runoff, RFV is the daily rainfall, and s is a retention parameter. The retention parameter, s, varies (a) among watersheds because soils, land use, management, and slope all vary and (b) with time because of changes in soil water content. The parameter s is related to curve number (CN) by the SCS equation ([U.S. Department of Agriculture, Soil Conservation Service \(1972\)](#))

$$s = 254 * \left(\frac{100}{CN} - 1.0 \right) \quad \dots \dots \dots \quad (3)$$

The CN is curve number and can be obtained easily for any area by using the APEX model user manual (William et al., 2008)

Rainfall arrives on the soil surface RFV (mm) can be estimated by:

$$RFV = RF - RFI \quad \dots \dots \dots \quad (4)$$

$$RFI = RIMX * (1.0 - \exp(-0.1 * \sqrt{TAGP * SMLA})) \quad \dots \dots \dots \quad (5)$$

Where, RFI is the intercepted rainfall in mm, RIMX is the maximum possible intercepted rainfall for an event in mm, TAGP is the above ground plant material in t ha⁻¹, and SMLA is the leaf-area-index of the plant stand. Eq. 1.15 is constructed for general operation on a variety of land uses including cropland, pastureland, range, and forestland. When rainfall exceeds interception, the excess falls to the soil surface.

3.1.2 Modeling sediment loss

This module estimates the total sediment loss at the outlet and from each subarea / HRUs on daily basis. The model component for water-induced erosion simulates erosion caused by rainfall and runoff. For Estimation of Soil loss, equation developed by [Onstad and Foster \(1975\)](#) is used in the model which considers both rainfall and runoff both as energy factor. It uses an equation of :

$$Y = X * EK * CVF * PE * SL * ROKF \quad \dots \dots \dots \quad (6)$$

Where, Y is the sediment yield in t ha⁻¹, EK is the soil erodibility factor, CVF is the crop management factor, PE is the erosion control practice factor, SL is the slope length and steepness factor, ROKF is the coarse fragment factor,

X is erosivity factor which accounts both rainfall and runoff as energy factor and can be calculated as:

$$X = 0.65 * EI + 0.45 * (Q * q_p)^{0.33} \quad \dots \dots \dots \quad (7)$$

Where, Q is the runoff volume in mm, q_p is the peak runoff rate in mm h⁻¹, and WSA is the watershed area in ha. Peak runoff rate was computed using rational equation method defined in the APEX model.

The soil erodibility factor, K, is evaluated for the topsoil layer. It depends upon the soil texture and organic carbon content of the top soil. The slope length and steepness factor (SL) is calculated using RUSLE method. The coarse fragment factor was estimated with the equation ([Simanton et al., 1984](#))

$$ROKF = \exp(-0.03 * ROK) \quad \dots \dots \dots \quad (8)$$

Where, ROK is the percent of coarse fragment in the surface soil layer.

3.1.3 Modeling Nutrient Loss

The APEX model deals with attached and dissolved nutrients individually. The part of APEX model is used to estimate the transportation of nutrients mainly sediment attached soil Carbon and Nitrogen.

Total Carbon lost by sediment: Similarly Losses of carbon from soil are usually estimated using an enrichment ratio. The equation is described below:

$$YC = 0.001 * Y * CC * ER \quad \dots \dots \dots \quad (9)$$

Where, YC is the C loss in kg ha⁻¹, Y is the sediment yield in t ha⁻¹, CC is the concentration of C in the top soil layer in g t⁻¹, and ER is the enrichment ratio.

N transported by sediments: A loading function developed by McElroy et al., (1976) and modified by Williams and Hann (1978) for application to individual runoff events is used to estimate N loss. The loading function is:

$$YN = 0.001 * Y * CN * ER \quad \dots \dots \dots \quad (10)$$

Where, YN is the N loss in kg ha⁻¹, Y is the sediment yield in t ha⁻¹, CON is the concentration of N in the top soil layer in g t⁻¹, and ER is the enrichment ratio.

The enrichment ratio is the concentration of N in the sediment divided by that in the soil. Enrichment ratios are logarithmically related to sediment concentration. The logarithmic equation for estimating enrichment ratio is:

$$\begin{aligned} ER &= a * CY^b \quad \dots \dots \dots \quad (11) \\ a &= \frac{1.0}{0.1b} \quad \text{and} \quad b = \frac{\log(DR)}{2.699} \end{aligned}$$

Where, CY is the sediment concentration in g m⁻³ and DR is sediment delivery ratio (sediment yield divided by gross sheet erosion).

3.2 Implementing APEX model in GIS environment

ArcAPEX a GIS-based user interface of APEX model that integrates enhanced GIS capabilities and algorithms with input and output management within a single interface. The ArcAPEX interface will generate a set of initial parameters based upon the subarea delineation, subarea land use/soils/slope analysis and the weather data. The model was implemented for the micro-watershed. As a first step, DEM of the area generated from stereo cartosat-1 data was taken for terrain for slope, stream network and sub-basin delineation by defining outlet of the basin/ watershed delineated with an area of 57 ha.

The HRUs were delineated based on homogeneity of dominant land use, soil types and slope. The land use/cover map ([Fig. 2a](#)) of the watershed was prepared from LISS-IV (5.8m resolution) satellite data. Soil map ([Fig. 2b](#)) was generated and relevant physical and chemical characteristics of each soil types were stored through lookup table. Slope map was generated from DEM and classified into slope classes. Subsequently, land use, soil map and classified slope map were overlaid to delineate and generate Hydrologic Response Units (HRUs) in the watershed. Soil attributes were initially stored to the APEX soil database, land use parameters (such as crop height, seeding rate etc.) was redefined in lookup table based on field observations was provided to the model for hydrological modeling and soil erosion modeling. ArcAPEX HRU definition assigns single land use, soil and slope class to each HRU based on its dominant types.

Daily weather data of precipitation, temperature, relative humidity, solar radiation and wind speed was provided in weather database of the model. Weather data was obtained from automatic weather station (AWS) installed in the watershed. The spatial location of AWS was provided with the data file prepared for year 2009-2011.

HRUs and weather data were stored in tables within the ArcAPEX Project geo-database. The structure of the APEX Project geo-database contains one table that shows each of the main APEX input files. These files are HRU file, Operation Schedules, Crop, Tillage, Fertilizer, Management practices, Monthly Weather data. Crop file was redefined based on field observations and measurements include crop height (m), plant population (plants/sq.m), seeding rate (kg/ha), maximum rooting depth (m), cover percentage, surface roughness factor. Fertilizer file was generated based on information obtained from farmers. FYM was used as manure in the field and no other fertilizer was used by majority of farmer. Concentration of C, N, and P in manure was defined from literature ([Verma and Sharma, 2000](#)). Operation schedule file helped to define the type of operation used in each HRU. Land use types, time of sowing to time of harvest and management practices applied like terraces, contouring etc.

Based on land use types and soil hydrologic group of soils of each subarea, CN number was calculated automatically. CN changes daily based on soil moisture retention in the soil, so soil moisture index variable was used in the modelling. It computes CN based on the wet-dry day probabilities for each day. Model was run for given inputs on the daily basis. The model was calibrated and validated for daily runoff, sediment and nutrients loading at watershed outlet. Calibration was done for low to medium and high rainfall events.

Calibration was carried out by adjusting the sensitive parameters such as CN, SAT C, USLE_K etc. ([Table 2](#)).

The Sensitivity analysis was conducted on the effects of watershed parameters on runoff rate and sediment loss considering realistic ranges of values under field conditions where the parameter values were uniformly altered by – 15 per cent to + 15 per cent with assumption that the variations in the estimation of these parameters will vary uniformly.

$$\% \text{ change in runoff(sediment)loss} = \frac{x-y}{x} * 100 \quad \dots \quad (12)$$

Simulated and measured values of runoff and sediment loss, total carbon and nitrogen were compared using correlation coefficient and coefficient of determination, including a Student T test was performed to get the behavior of simulated results over measured values in terms of over or under prediction.

3.3 *Measurement of surface runoff and sediment at Watershed outlet*

An experimental micro-watershed ([Fig.1d](#)) covering an area of 57 hectare was instrumented with measurement of weather parameters, runoff and soil hydrologic characteristics. The sub-watershed comprises of forest cover, scrub and terraced crop land. A trapezoidal weir civil structure with stage-level recorder (self-recording) was constructed ([Fig. 3a](#)) at second order stream to record surface run-off and sediment measurements. A automatic weather stations (AWS) was installed ([Fig. 3b](#)) in the watershed to record weather data viz., rainfall, temperature, relative humidity, wind velocity, wind direction and solar radiation data. Sediment loss from watershed was estimated by collecting sampled surface runoff water from sediment tank constructed at the outlet on daily basis. The samples were brought to the laboratory and filtered using high pressure filter unit. Thereafter, sediments kept in oven for drying at 104°C. Sediment weight was measured with electronic balance and sediment stored for analysis. The sediments were analyzed afterwards for total soil carbon and nitrogen using CHNS analyzer. A total of 40 rainy days runoff and sediment data collected out of which 20 of the events data was used for calibration and remaining 20 events for validation. Total carbon (TC) and total nitrogen (TN) was analyzed of the sediments collected from 30 rainy days in the watershed. Out of these, 15 measurements were used for calibration and validation each.

Surface soil samples from each soil units were collected and air-dried for soil analysis. Soil samples were analysed for soil texture (Hydrometer method), total carbon (TC), total Nitrogen (TN) using (CHNS analyzer), soil pH (1:2) and soil bulk density) Clod's method using ([Blake, 1965](#)).

3.4 *Evaluation of performance of model*

The model generates output file in ‘ascii’ format and can be converted to Microsoft Excel for further analysis. The results were evaluated by comparing the predicted and measured values graphically, and by using the statistical measures: student – test, coefficient of determination (R²), Nash-Sutcliffe efficiency (NSE) ([Nash and Sutcliffe, 1970](#)). Model performance was assumed as satisfactory with statistical criteria of R² > 0.5 and NSE > 0.3 as described by [Chung et al. \(1999, 2002\)](#). Student T-test was performed using Statistica. Negative t-calculated shows the over-

prediction whereas positive t-values reveals under prediction by the model. T-value closer to zero indicates better prediction by the model. The over prediction of the model was calibrated by changing the desired parameters,

4.0 Results and Discussion

4.1 *Generation of spatial database of soils, land use / land cover and slope map for modeling*

Soils in the watershed were characterized by identifying six soil-landscape units such as hilltop with scrub (H1-S), upper hillslope with agriculture (H2A), mid-hillslope with forest (H3F) and agriculture (H3A) and lower hillslope with upper paddy (H4A1) and lower paddy crop (H4A2). Hilltop (H1-S) soils characterized as gravelly sandy loam, shallow (20 cm) in depth with 40–45% coarse fragment in the surface. Soils in upper hillslope and mid-hillslope characterized as moderately deep and deep, respectively. These soils contain large amount of coarse fragments in sub-surface and are well drained. The soils at lower hillslope (H4) are deep (80–110 cm), 10–15% graves/pebbles in surface and are moderately well drained. These soils occupy by the paddy fields and remain saturated during rainy season. Soils in the watershed are dominantly sandy loam whereas soils in paddy field in lower hillslope were characterized as sandy clay loam. Hydrological soil groups (HSG) characterized as A, B and C classes and total carbon (TC) and total nitrogen (TN) in surface soils ([Table 1](#)). Total carbon (TC) in mid hillslope with dense forest (1.71%) followed by cropland (1.56%) and total N of 0.17 and 0.20 percent, respectively. Scrub land was found lowest in soil carbon (0.3%), total N (0.09%). This is attributed to the FYM use in Cropland areas and litter fall in case of dense forest area. Land use / land cover analysis reveals area under forest cover (dense and moderately dense) of 28.8 percent with open forest and open scrub land of 21.8 percent area in the watershed. It has cropland area under maize and paddy crops of 28.3 and 21.1 percent, respectively. CartoDEM generated from Stereo-cartosat 1 data was used to prepare slope map of the watershed. It was further classified into five slope classes and used as input parameter in the model.

HRUs (Hydrological Response Units): ArcAPEX model integrates thematic layers of land use / land cover, soil types and slope map to generate Hydrologic Response Units (HRUs)/subareas representing unique hydrology in the watershed. A total of 14 HRUs were delineated in the watershed based on homogeneity of dominant land use, soil and slope classes.

4.2 Modelling surface runoff, sediment and nutrient loss at watershed outlet

APEX model was evaluated by comparing simulated surface runoff, sediment and nutrient loss (total carbon and nitrogen) against field measurements obtained from the watershed during 2010-2011. The validation and performance of the model was evaluated by estimating correlation coefficient, coefficient of determination and student t-test. A total of 40 rainy days surface runoff and sediment data were collected and out of which 20 rain events data were used for calibration and 20 events data for validation. Sediment loss was validated based on sediment data collected from sediment tank constructed at the outlet on daily basis.

4.2.1 Sensitivity analysis of the model

The sensitive parameters of APEX model was initially identified through the sensitivity analysis using One-factor-At-a-Time (OAT) method (Morris, 1991). It was performed before calibrating the model. The parameters that affect erosion, sediment loss, carbon (C) and nitrogen (N) losses were identified through a detailed literature review (Wang et al., 2012). 14 parameters were chosen and analysed by changing the specified parameter by $\pm 5\%$, $\pm 10\%$ and $\pm 15\%$ to obtain the most sensitive parameters. It was observed that altering most of the parameters with 5% do not show much change in the output results. Analysis showed that SCS-CN number was found as the most sensitive to runoff, followed by saturated hydraulic conductivity, available water-holding capacity, CN retention parameter and C factor, being the top five sensitive to runoff (Table 2). As far as sediment is concerned, erosion control practice was found to be the most sensitive, followed by C factor, sediment routing coefficient, average upland slope and soil erodibility (K) factor (Table 2).

4.3 Model Calibration

4.3.1 Surface runoff and sediment loss

The model was calibrated for each sensitive parameter based on a trial and error basis by adjusting the selected parameters to match the predicted values with the observed value for the target variables. The calibration was done by changing the sensitive parameters for surface runoff, sediment loss and nutrient loss of carbon (C) and nitrogen (N) loss. Sediment yield was calibrated following runoff calibration. The calibrated model parameters values for surface runoff estimation are given in Table 3. The model was calibrated to simulate surface runoff for 20 rainy days. The model predicted quite well ($r=0.89$) for surface runoff. The scatterplot (Fig. 4a) indicates very well prediction for surface runoff at low to medium rainfall events whereas over prediction for high rainfall events. The t-value was found negative indicating over prediction of the surface runoff. The overall prediction of the model was quite well and the T-Test revealed that means of observed and predicted runoff were not significantly different at 95 percent. Over prediction of surface runoff was observed at high rainfall events may be attributed to the coarse fragments and stony surfaces in the watershed whereas its impact was marginal at low to medium rainfall events due to time lag and not accounted by model (Sauer and Logsdon, 2002; Kumar et al., 2016; Park et al., 2017).

The model was calibrated for sediment loss for the same 20 rainy days observed for surface runoff. The calibrated model parameters value for sediment estimation at watershed outlet is given in Table 3. The model predicted average 1.19-ton ha^{-1} of sediment loss at the watershed outlet. It was observed that model was predicting significantly good at low to medium rainfalls, while it was under-predicting at high rainfall events. Model prediction was found quite well ($r^2 = 0.89$) for sediments loss at watershed level (Fig. 4b). Scatterplot depicts the results for the rainy days. Student t-test value was estimated positive revealing under prediction of sediment loss by the model.

4.3.2. Soil Nutrient loss

Soil nutrient loss bound with sediment loss was also predicted for total carbon (TC), total nitrogen (TN) from the watershed. The APEX model calculates sediment bound nutrients enrichment ratio, nutrients in the soil and soil erosion. It calculates transported nutrients at the outlet of the watershed and estimates the nutrients in two parts, one part was given the output for soluble nitrogen and phosphorus and the other part was about sediment attached nutrients

(C and N). A total of 15 nos. of sediment samples were collected and analyzed for total carbon and total nitrogen for calibration of soil nutrients (TC and TN). The result shows that a good correlation was found between observed and predicted total carbon ($r^2= 0.88$; [Fig. 4c](#)) and total nitrogen ($r^2=0.72$; [Fig. 4d](#)). Model NSE value indicated that model was calibrated quite well (NSE=0.68) for total carbon (TC) and fairly for total nitrogen (TN) (NSE=0.11). Student t-test revealed the means of observed and predicted nutrients was not significantly different at 95 percent. A positive value of t-calculated: 1.25 and 0.89 shows under prediction by the model ([Table 3](#)).

4.4 Model validation

The validation and performance of the model was evaluated for surface runoff and sediment loss on the basis of correlation coefficient, coefficient of determination and student t-test for 20 rainfall days of year 2010 and 2011.

4.4.1 Surface runoff and sediment loss: The model was validated to simulate surface runoff and sediment loss with the calibrated parameters for 20 rainy day events. The model predicted quite well ($r = 0.92$) for surface runoff ([Table 4](#)). The scatterplot ([Fig.5a](#)) indicates very well prediction for surface runoff at low to medium rainfall events whereas over prediction for high rainfall events. The t-value was found negative indicating over prediction of the surface runoff.

A total of 20 nos. of rainy days of sediment loss data was used to validate the model output. The model predicted satisfactory well for sediment loss with correlation coefficient (r) of 0.88 ([Fig. 5b; Table 4](#)). A positive t-calculated value shows that model were still under predicted the sediment loss. The model predicted quite well for low to medium rainfall events, while the model over predicted the runoff at high rainfall events. The model performed quite well in predicting surface runoff (NSE=0.50) and sediment loss (NSE=0.61). The t-test revealed that means of observed and predicted runoff were not significantly different at 95 per cent. Sediment loss was under-estimated for high rainfall events.

At high rainfall events area witness few landslips, collapsing of filed bunds and terraced riser due to over saturation of side slope particularly in lower hill slopes, contributing in higher sediments production which model fail to simulate as these factor were not accounted in the models, therefore model under predicted the sediments loss for the watershed. [Nearing et al \(1999\)](#) remarked that field- and plot-scale erosion models have difficulty predicting small-scale events. As noted earlier, it is difficult to predict erosion accurately when sediment losses are small ([Saleh et al., 2004](#)). [Kumar et al. \(2011\)](#) reported poor calibration performance of APEX (NSE < 0.19) when it was evaluated on grazed pasture watersheds.

4.4.2 Soil Nutrient loss: The sediment bound nutrient loss (TC and TN) was validated for the watershed. The model predicted well for the nutrient losses. Coefficient of correlation (r) for total carbon (TC) and total nitrogen (TN) was found to be 0.78 and 0.77, respectively. Model performed quite well in predicting TC (NSE= 0.59) whereas poorly for TN (NSE=0.19). Positive value of t-calculated for TC and TN were indicated for under-prediction by the model. The study revealed that APEX model performed quite well for surface runoff and sediment loss and performed satisfactorily for nutrient loss. The model was well calibrated and performed significantly well of the watershed located in the Lesser Himalayan region of Doon valley.

5.0 Conclusions

APEX, a process based model, was used for simulating surface runoff, sediment and nutrient loss at watershed scale. Analysis showed that SCS-CN parameter was found most sensitive to surface runoff, followed by saturated hydraulic conductivity, available water-holding capacity, CN retention parameter and C factor whereas erosion control practice (P) factor was found to be most sensitive, followed by C factor, sediment routing coefficient, average upland slope and soil erodibility (K) factor for the sediment and nutrient loss for the watershed. All of the identified sensitive parameters were statistically significant, and the two most sensitive parameters among them were related to runoff (CN index coefficient and runoff CN initial abstraction).

APEX model was calibrated for the watershed and it predicted quite well for the surface runoff ($r=0.92$, $NSE=0.50$), sediment loss ($r=0.88$, $NSE=0.61$) and various soil nutrients; TC ($r=0.78$, $NSE=0.59$) and fairly for TN ($r=0.77$, $NSE=0.19$) for the watershed. APEX model was calibrated for the watershed and it predicted quite well for the surface runoff ($r=0.92$), sediment loss ($r=0.88$) and various soil nutrients; TC ($r=0.78$) and TN ($r=0.77$) for the watershed. Runoff was quite well predicted for low and medium rainfall; however it was over predicted for high rainfall events. Over prediction may be attributed to the unaccountable conservation measures and practices which were not accounted by the model that may have resulted higher prediction. Similarly, sediment loss was estimated on daily basis at the watershed scale and was well predicted for low and medium rainfalls but under-estimated for high rainfall events. The area is prone to landslips at high rainfalls which were not accounted by the model. This may be the reason for under prediction of sediment loss by APEX model. The hydrological assessment of this model will facilitate future modelling applications using APEX to the Himalayan watersheds for watershed analysis including water quality management, impacts of alternates land management practices etc.

Acknowledgement

Authors are thankful to Indian Space Research Organization (ISRO) for providing financial support under Earth Observation Applications Mission (EOAM) Project (ISRO/DOS) on “Mountain Ecosystem Processes and Services” to carry out the research work. We are thankful to the Director, Indian Institute of Remote Sensing (IIRS) for providing necessary facilities to carry out the research work. Authors sincerely acknowledge the technical support of Shri R. K. Arya Sr. Technical Officer from ICAR-IISWC and Ex. Head, CMD IIRS for developing watershed observatory at the site.

Compliance with ethical standards

Conflict of interest The authors declare that they do not have any conflict of interest.

References

- Bhandari AB, Nelson NO, Sweeney DW, Baffaut C, Lory JA, Senaviratne GMMMA. et al. (2017). Calibration of the APEX model to simulate management practice effects on runoff, sediment, and phosphorus loss. *J. Environ. Qual.* doi:10.2134/jeq2016.07.0272
- Bhattacharyya R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, Das K, Anil KS, Lalitha M, Hati KM et al (2015) Soil degradation in India: Challenges and potential. *Sustainability* 7, 3528–3570.
- Blake GR, (1965) Bulk density. In : Methods of Soil Analysis, Part I, pp. 374-390, Am. Soc. Agronomy, Inc.
- Chung SW, Gassman PW, Kramer LA, Williams JR, Gu R, (1999). Validation of EPIC for two watersheds in southwest Iowa. *J. Environ. Qual.* 28(3): 971- 979
- Chung SW, Gassman PW, Gu R, Kanwar RS (2002) Evaluation of epic for assessing tile flow and nitrogen losses for alternative agricultural management systems. *Trans. ASAE* 45:1135
- CSWCR&TI (2011) Vision, 2030: Vision Document of the Central Soil and Water Conservation Research and Training Institute; Allied Publisher: Dehradun, India, 2011; pp. 1–46.
- Daniel EB, Camp JV, LeBoeuf, EJ, Penrod JR, Dobbins JP, Abkowitz MD (2011). Watershed Modeling and its Applications: A State-of-the-Art Review, *The Open Hydrology Journal*, 5, 26-50.
- Degen Lin , Hao Guo, Fang Lian , Yuan Gao, Yaojie Yue and Jing'ai (2016). Wang A Quantitative Method for Long-Term Water Erosion Impacts on Productivity with a Lack of Field Experiments: A Case Study in Huaihe Watershed, China. *Sustainability* 2016, 8, 675-693.
- Garde RJ and Kothyari UC (1986). Erosion in Indian catchments, 3rd Int. Symposium on River Sedimentation, Jackson (Miss), U.S.A.
- Gassman PW, Reyes M, Green CH, Arnold JG (2007). The soil and water assessment tool: historical development applications and future directions. *Trans ASABE*, 50(4):1211–1250.
- Gassman PW, Williams JR, Benson VW, Izaurralde RC, Flowers JD (2005). Historical development and applications of the EPIC and APEX models working paper 05-WP 397. Centre for agricultural and rural development, Iowa State University, Ames, Iowa.
- Gassman, P W, Osei E, Saleh A, Rodecap J, Norvell S, Williams JR (2006). Alternative practices for sediment and nutrient loss control on livestock farms in northeast Iowa. *Agric. Ecosystems and Environ.* 117(2-3): 135-144
- Gassman, PW, Williams JR, Wang X, Saleh A, Osei E, Hauck L, Izaurralde C, Flowers J (2010) The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses. *Trans. ASABE* 53(3): 711-740.
- ICAR (2010), Degraded and Wastelands of India-Status and Spatial Distribution. Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research New Delhi
- Izaurralde RC, Williams JR, MacGill WB, Rosenberg NJ (2006). Simulating soil-C dynamics with EPIC: Model description and testing against long-term data. *Eco. Model.* 192 (3-4), 362-384.

Kumar S, Udawatta RP, Anderson SH, Mugdal A (2011) APEX model simulation of runoff and sediment losses for grazed pasture watersheds with agroforestry buffers. *Agroforestry Systems* 83(1): 51-62.

Kumar S, Singh A, Shrestha DP, (2016). Modelling spatially distributed surface runoff generation using SWAT-VSA: a case study in a watershed of the north-west Himalayan landscape. *Modeling earth systems and environment*, 2(4), pp.1-11

Lal R (1995) Erosion-crop productivity relationships for soils of Africa. *Soil Science Society of America Journal* 59, 661–667

Lal R (2015). Restoring Soil Quality to Mitigate Soil Degradation, *Sustainability* 2015, 7, 5875-5895; doi:10.3390/su7055875

Liu J, Williams JR, Zehnder AJB, Yang H (2007). GEPIC- modelling wheat yield and crop water productivity with high resolution on a global scale. *Agric. Syst.* 94 (2); 478-493.

Mandal D, Sharda VN (2011) Assessment of permissible soil loss in India employing a quantitative bio-physical model. *Curr. Sci.*, 100, 383–390.

Matson PA, Parton WJ, Power AG, Swift MJ (1997) Agricultural intensification and ecosystem properties. *Science* 277, 504–509.

McElroy AD, Chiu SY, Nebgen JW (1976). Loading functions for assessment of water pollution from nonpoint sources. *Environ. Prot. Tech. Serv.*, 600(2):76-151.

Merritt WS, Letcher RA, Jakeman AJ (2003) A review of erosion and sediment transport models. *Environmental Modelling & Software* 18(8): 761–799.

Morris, MD, 1991. Factorial sampling plans for preliminary computational experiments. *Technometrics* 33, 161–174.

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

Nearing MA, Govers G, Darrell NL (1999). Variability in Soil Erosion Data From Replicated Plots, *Soil Science Society of America Journal* 63(6): 1829-1835.

Onstad CA, Foster GR (1975). Erosion modeling on a watershed. *Trans. ASAE* 18(2):288-292.

Pandey A, Himanshu SK, Mishra SK, Singh VP (2016) Physically based soil erosion and sediment yield models revisited, *Catena*, 147 595-620.

Park JY, Ale S, Teague WR , Jeong J (2017) Evaluating the ranch and watershed scale impacts of using traditional and adaptive multi-paddock grazing on runoff, sediment and nutrient losses in North Texas, USA, *Agriculture, Ecosystem and Environment*, 240 : 32-44.

Pimentel D, Burgess M (2013). Soil erosion threatens food production. *Agriculture*, 3, 443–463.10.3390/agriculture3030443

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R, Blair R (1995) Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1123.

Radcliffe DE, Reid DK, Blomback K, Bolster CH, Collick AS, Easton ZM, Francesconi W , Fuka DR, Johnson,H, King K, Larsbo M, Youssef MA Mulkey AS , Nelson NO, Persson K, Ramirez-Avila JJ, Schmieder F, Smith DR (2015) Applicability of models to predict phosphorus losses in drainage felds: A review. *J. Environ. Qual.* 44:614–628.

Saleh A, Arnold JG, Gassman PW, Hauck LW, Rosenthal WD, Williams JR, McFarland AMS (2000). Application of SWAT for the upper North Bosque River watershed. *Trans. ASAE* 43(5): 1077-1087.

Saleh A, Williams JR Wood JC, Hauck LM, Blackburn WH (2004) Application of APEX for forestry. *Trans. ASAE* 47(3): 751- 765

Sauer TJ, Logsdon SD (2002) Hydraulic and Physical Properties of Stony Soils in a Small Watershed, *Soil Sci. Soc. Am. J.*, 66 : 1947-1956.

Simanton JR, Rawitz E Shirley ED (1984). Effects of rock fragments on erosion of semiarid rangeland soils. *Erosion and Productivity of Soils Containing Rock Fragments. Soil Sci. Soc. Am.,* 7:65-72.

Singh G, Babu R, Narain, P, Bhushan LS, Abrol IP (1992) Soil erosion rates in India. *J. Soil Water Conserv.*, 47, 97–99.

Srivastava P, Migliaccio KW, Šimůnek J (2007) Landscape Models For Simulating Water Quality, At Point, Field, And Watershed Scales, *Transactions Of The ASABE.* 50(5): 1683-1693. (Doi: 10.13031/2013.23961)

Steglich E, Williams J (2013) Agricultural Policy Environmental Extender Model user's manual. Version 0806. Blackland Res. Ext. Center, Temple, TX.

Tuppad P, Winchell MF, Wang X, Srinivasan R, and Williams JR (2009). ARCAPEX: ArcGIS Interface for Agricultural Policy Environmental Extender(APEX) Hydrology/water Quality Model. *International Agricultural Engineering Journal,* 18(1-2):59-71

U.S. Department of Agriculture, Soil Conservation Service (1972). National Engineering Handbook. Hydrology Section 4. Chapters 4-10. Washington, D.C.: USDA.

Verma TS, Sharma PK (2000). Effects of Organic Residue Management on Productivity of the Rice-Wheat Cropping System. Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems: 163.171.

Wang E, Xin C, Williams JR, Xu C (2006). Predicting soil erosion for alternative land uses. *J Environ Qual*, 35:459–467.

Wang X, Williams JR, Gassman PW, Baffaut C, Izaurrealde RC, Jeong J, Kiniry, JR (2012) EPIC and APEX: Model use, calibration, and validation. *Trans. ASABE* 55:1447–1462. doi:10.13031/2013.42253

Wang X, Williams JR, Gassman, PW, Baffaut C, Izaurrealde RC, Jeong J, Kiniry JR (2012) EPIC and APEX: Model use calibration, and validation. *Trans. ASABE* 55, 1447–1462.

Williams JR (1990) The erosion productivity impact calculator (EPIC) model: a case history. *Phil. Trans. R. Soc. Lond,* 329: 421-428.

Williams JR, Hann RW (1978). Optimal operation of large agricultural watersheds with water quality constraints. Texas Water Resources Institute, Texas A&M Univ., Tech. Rept. No. 96.

Williams JR, Izaurrealde RC, Steglich EM (2008). Agricultural policy/environmental eXtender model: theoretical documentation version 0604 (draft). BREC report # 2008-17. Texas AgriLIFE Research, Texas A&M University, Temple, TX.

Williams JR, Izaurrealde RC, Steglich, EM (2008) “Agricultural Policy/Environmental Extender model: Theoretical documentation. Version0604.” BRECRep.2008-17,Black land Research and Extension Center (BREC), Texas A&M AgriLife Research, Temple, TX.

Wishmeier WH, Smith DH (1978). Predicting rainfall erosion losses – a guide to conservation planning. *Agric. Handbook No. 537.* USDA, Washington DC.

FIGURES

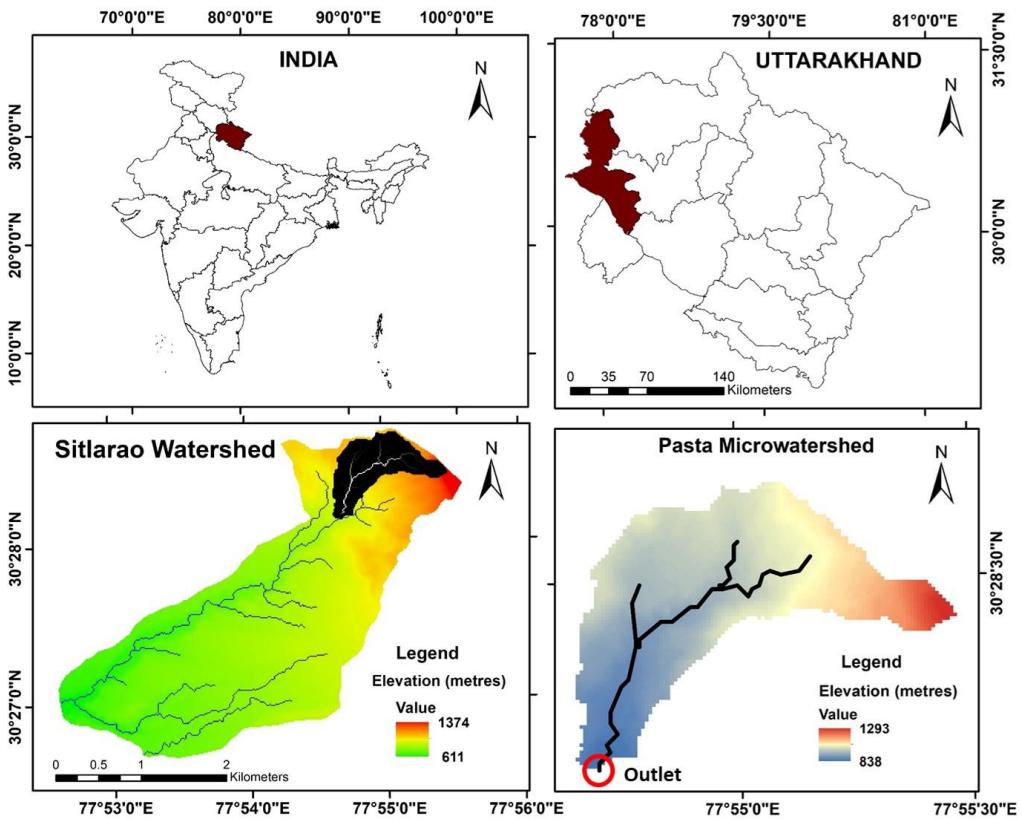


Figure 1: Location of the study area



Figure 2: Watershed Gauging site (a). Trapezoidal weir civil structure with stilling well (b) Automatic

Weather Station (AWS)

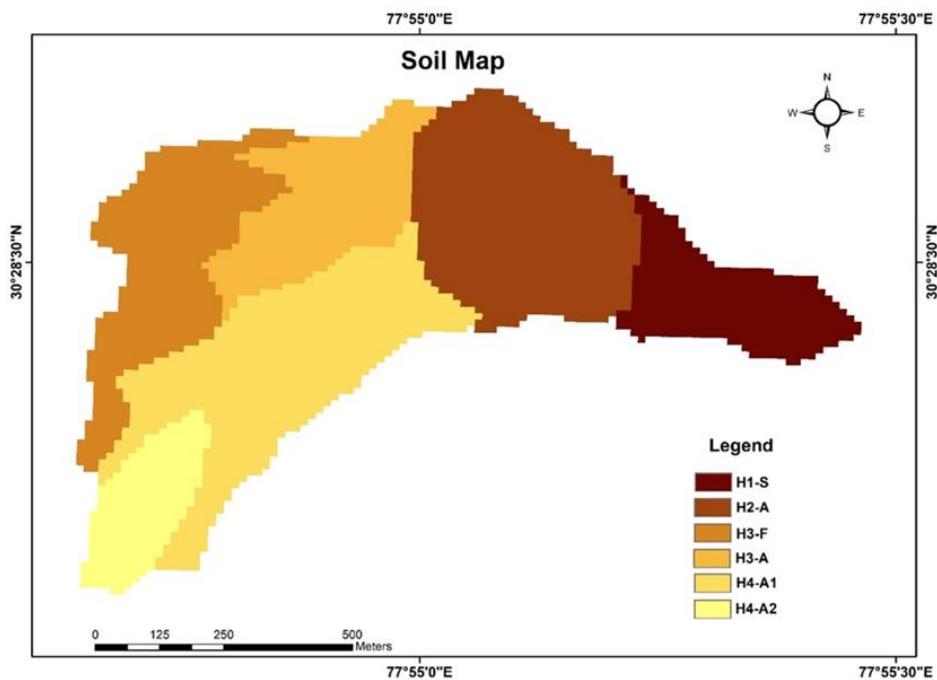


Fig. 3a Soil map units in the watershed

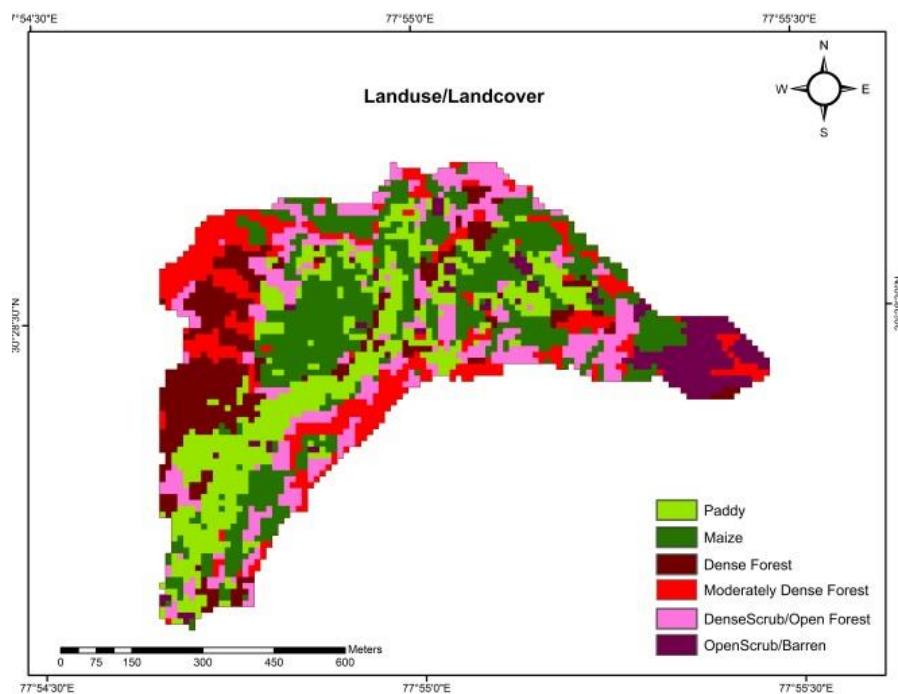


Fig 3b: Land use / land cover map

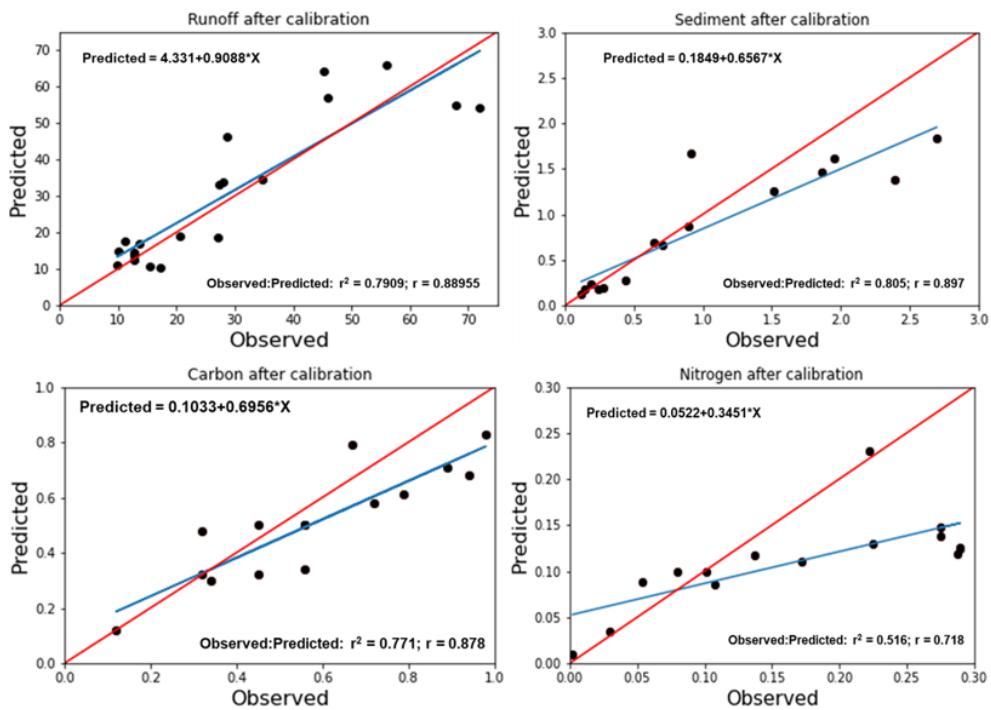


Fig 4. APEX model calibration (a). surface runoff, (b). sediment, (c) total carbon and (d) total nitrogen

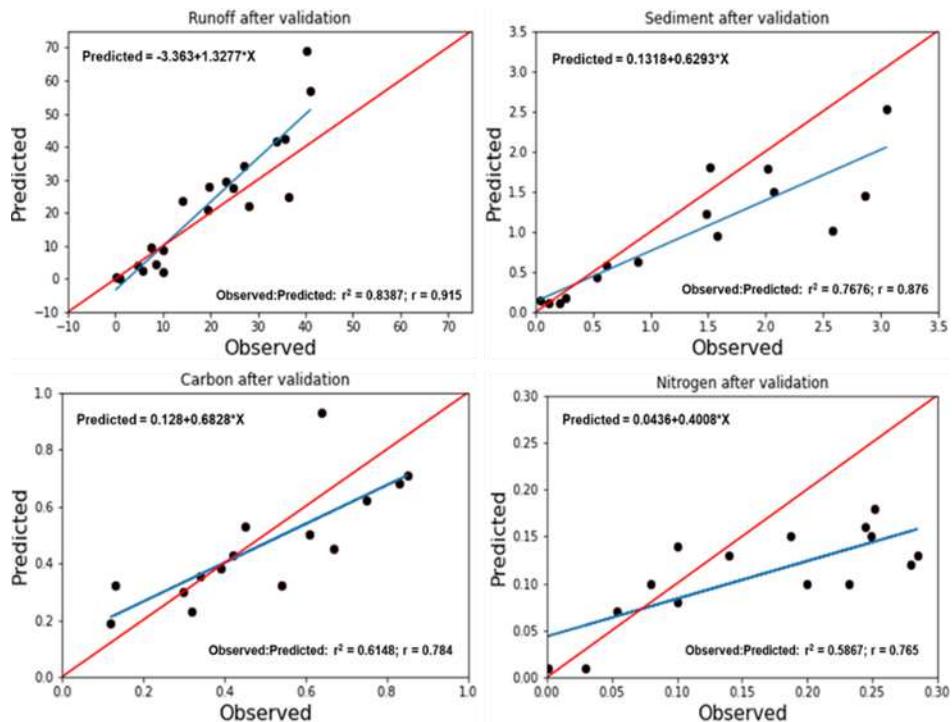


Fig 5. APEX model validation (a). surface runoff, (b). sediment, (c) total carbon and (d) total nitrogen

TABLES

Table 1. Soil characteristics of soil map units in the watershed

Soil-landscape unit	Area (%)	Soil texture	Total Carbon (TC) (%)	Total Nitrogen (TN) (%)	Hydrological Soil Groups (HSGs)
Hilltop-scrub (H1-S)	15.51	Coarse Sandy loam	0.30	0.09	A
Upper Hillslope-Agriculture (H2-A)	25.12	Sandy loam	0.82	0.11	B
Mid Hillslope – Dense Forest (H3-F)	11.87	Sandy loam	1.71	0.17	B
Mid Hillslope–Agriculture (H3-A)	13.82	Sandy loam	1.14	0.12	B
Lower Hillslope Agriculture (H4-A1)	25.89	Sandy loam	1.31	0.16	C
Lower Hillslope Agriculture (H4-A2)	7.78	Sandy clay loam	1.56	0.20	C

Table 2. Calibrated APEX model parameters for surface runoff and sediment loss

S. No.	Parameters (Symbol in APEX code)	Calibrated Value	Range value
Parameter for surface runoff			
1	SCS CN	72(Agriculture) 81(Forest)	0-98
2	SATC	10-20mm/h	-
3	AWC	0.08-0.20	0-1
4	PARM16 (CN retention Parm)	1.3	1-1.5
5	PARM42 (CN index coeff.)	1.5	0.2-2.5
Parameter for sediment loss			
1	USLE_K	0.3-0.55	0-0.65
2	PEC (Erosion Control Practice Factor)	0.15, 0.6	0.1-0.9
3	Channel Cover	0.1	0.08-0.20
4	Channel Erosion	0.32	0.0001-0.5
5	Sediment Routing Exponent (PARM18)	1.5	1-1.5
6	Sediment Routing Coeff .(PARM19)	0.03	0.01-0.05

Table 3. Model performance for calibration of surface runoff, sediment, total carbon (TC) and nitrogen (TN)

Parameter	Runoff (mm)		Sediment loss (t ha ⁻¹)		Total Carbon (kg ha ⁻¹)		Total Nitrogen (kg ha ⁻¹)	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Mean	28.46	30.20	1.00	0.84	0.58	0.51	0.170	0.111
SD	19.38	19.81	0.87	0.64	0.25	0.20	0.103	0.050
Maximum Peak	72.00	65.98	2.69	1.83	0.98	0.83	0.290	0.230
Total	569.37	604.05	14.98	12.61	8.67	7.58	2.548	1.662
Rainy days	20		15		15		15	
Corr. Coeff.(r)	0.89		0.89		0.88		0.72	
Coeff. Of Det.(r ²)	0.79		0.81		0.77		0.52	
t-calculated	-0.82		0.89		1.25		0.89	
NSE	0.76		0.74		0.68		0.11	

Table 4. Model performance for validation of surface runoff, sediment, total carbon (TC) and nitrogen (TN)

Parameter	Runoff(mm)		Sediment loss (t ha ⁻¹)		Total Carbon (kg ha ⁻¹)		Total Nitrogen (kg ha ⁻¹)	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Mean	19.58	22.63	1.32	0.96	0.49	0.46	0.162	0.109
SD	13.42	19.46	1.03	0.74	0.23	0.20	0.096	0.050
Maximum Peak	41	68.97	3.04	2.52	0.85	0.93	0.285	0.180
Total	391.55	452.61	19.82	14.45	7.36	6.946	2.436	1.630
Rainy days	20		15		15		15	
Corr. Coeff.(r)	0.92		0.88		0.78		0.77	
Coeff. Of Det.(r ²)	0.84		0.77		0.62		0.59	
t-calculated	-1.88		1.59		1.05		1.51	
NSE	0.50		0.61		0.59		0.19	

Figures

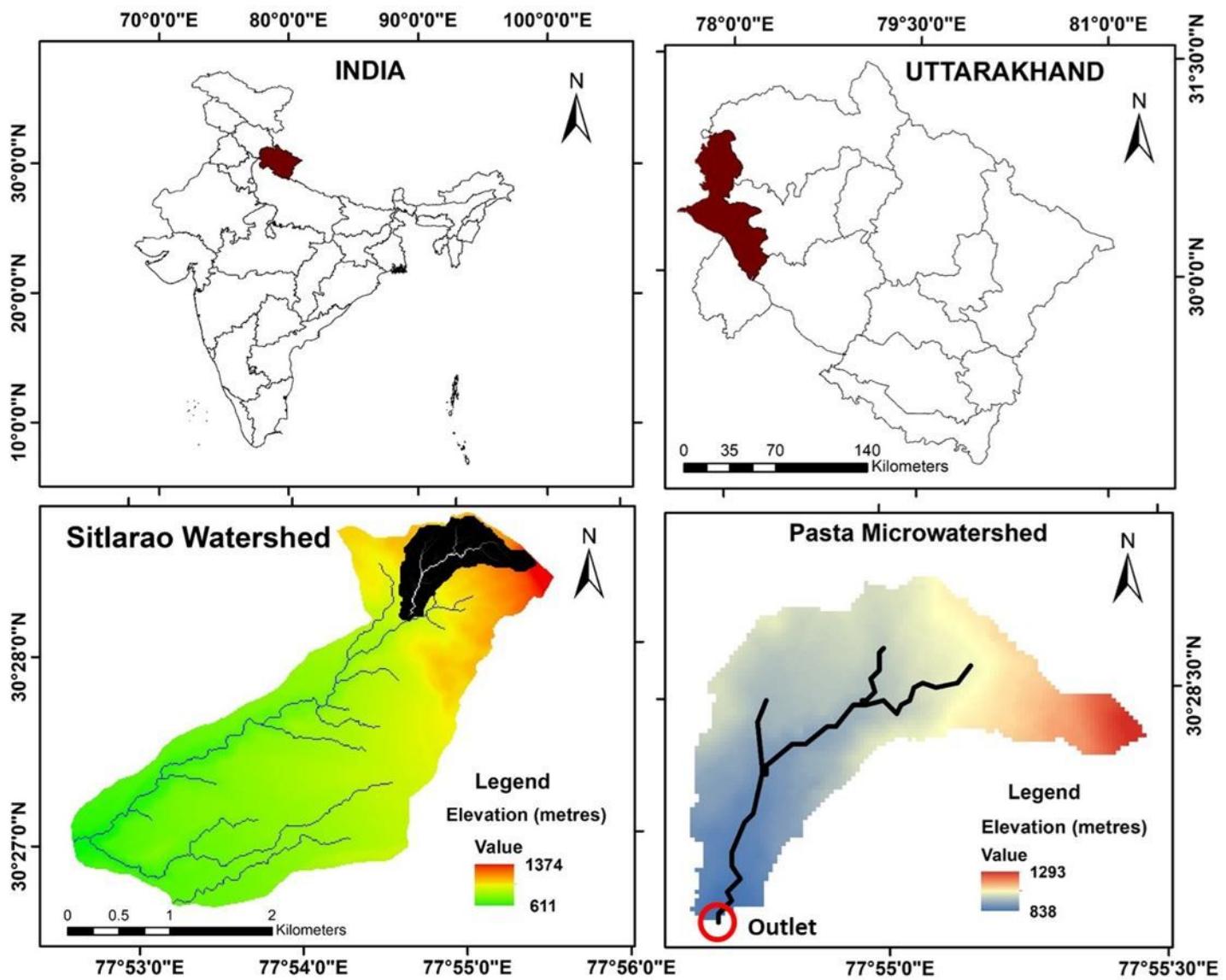


Figure 1

Location of the study area.



(a)



(b).

Figure 2

Watershed Gauging site (a). Trapezoidal weir civil structure with stilling well (b) Automatic Weather Station (AWS)

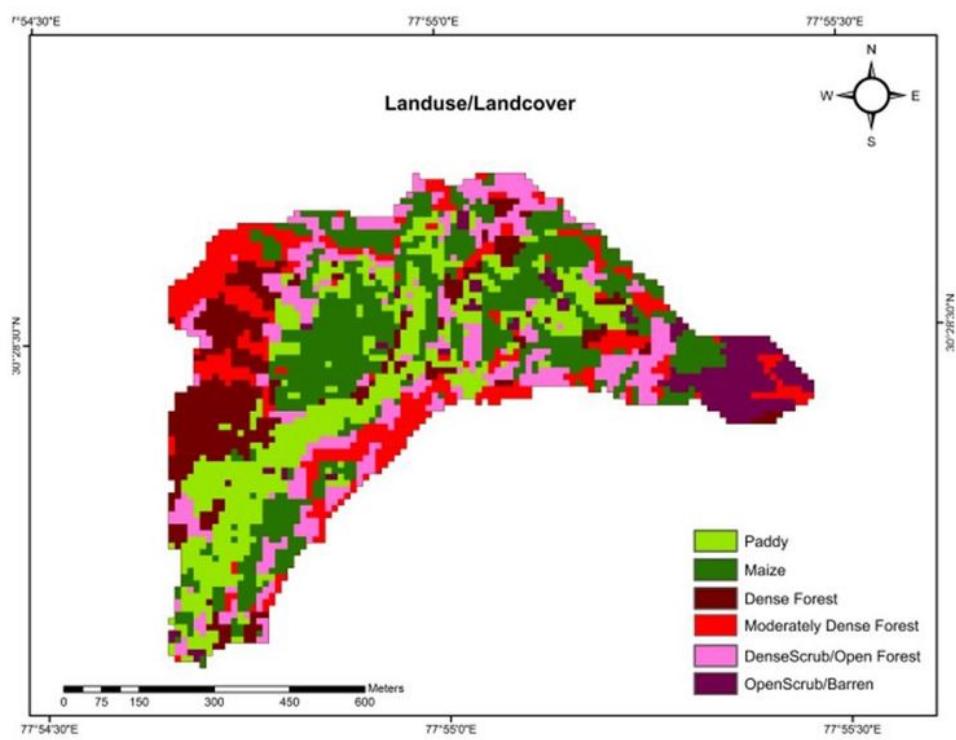
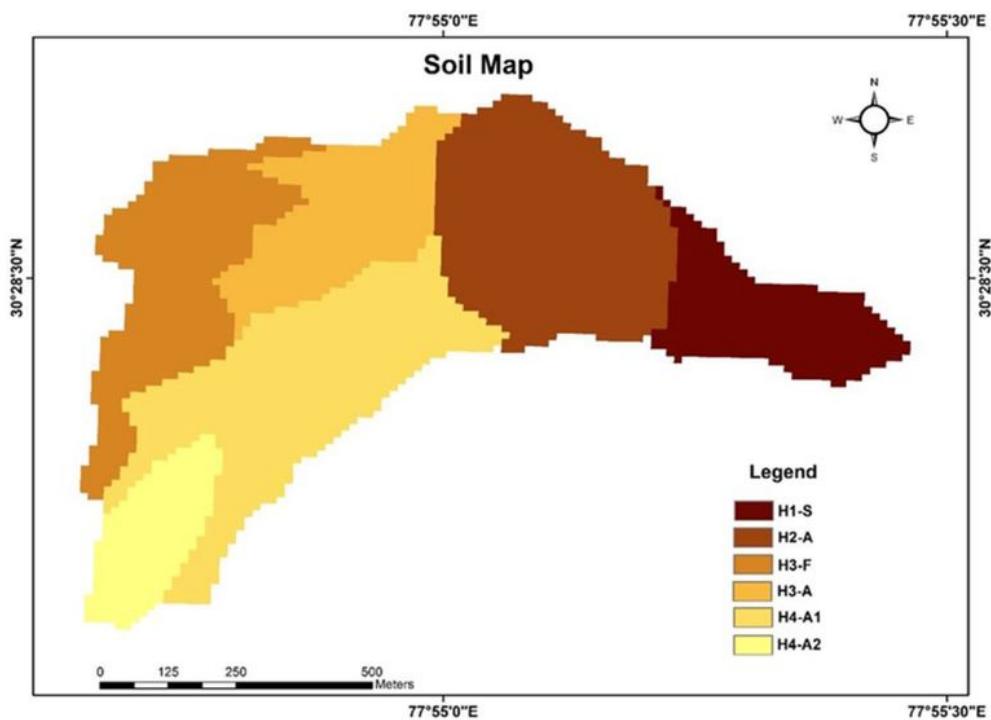


Figure 3

a Soil map units in the watershed. b: Land use / land cover map.

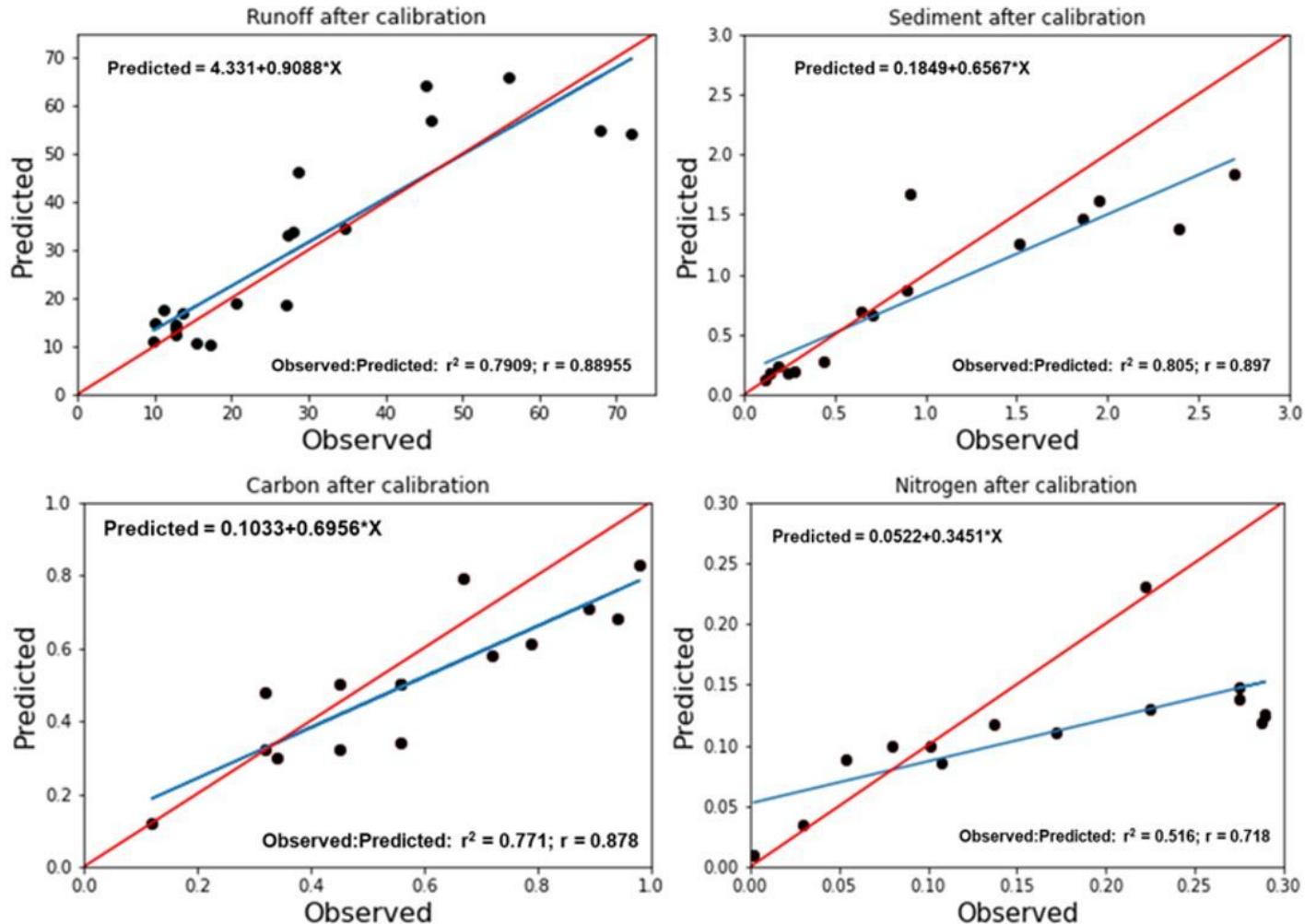


Figure 4

APEX model calibration (a). surface runoff, (b). sediment, (c) total carbon and (d) total nitrogen

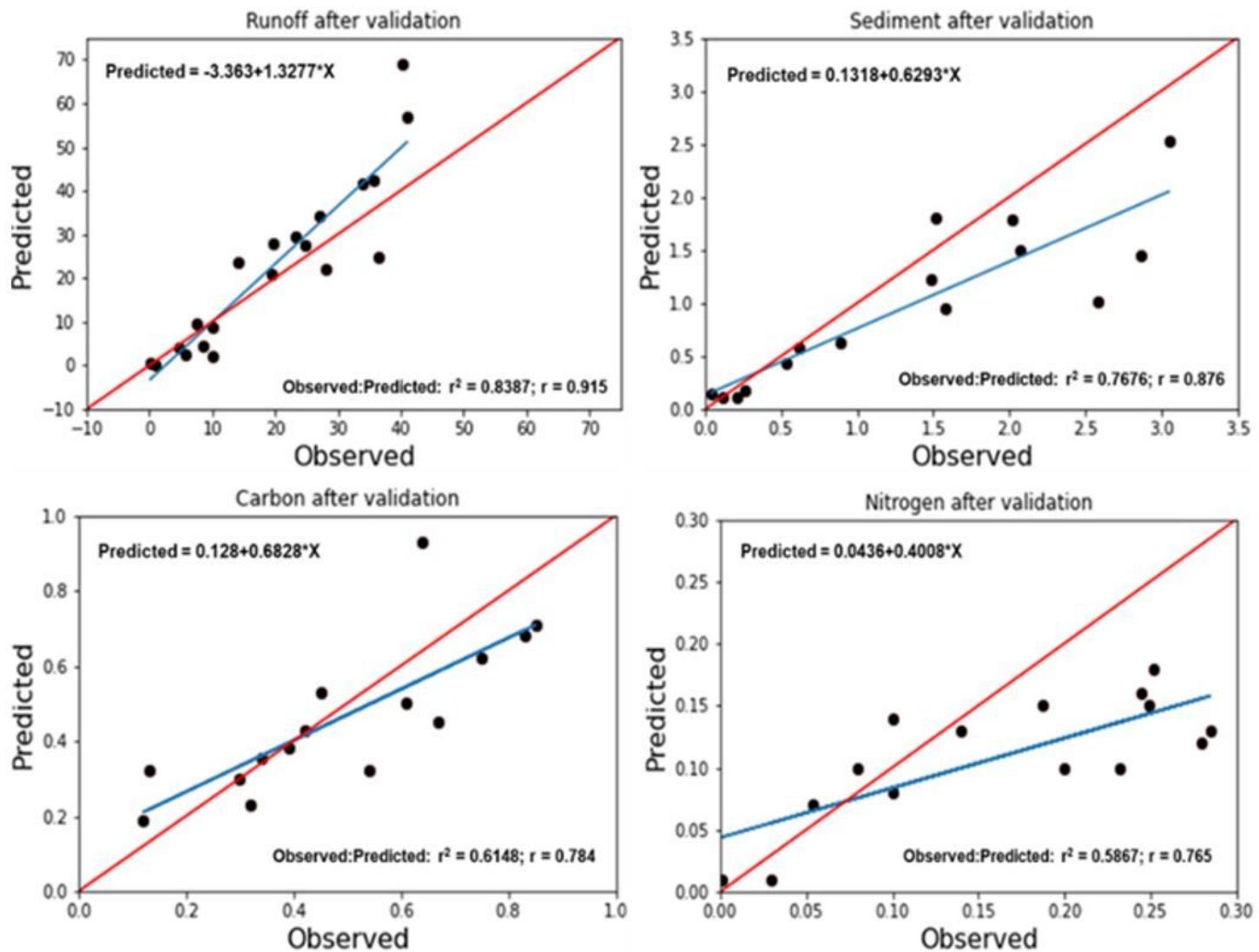


Figure 5

APEX model validation (a). surface runoff, (b). sediment, (c) total carbon and (d) total nitrogen