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GIS based Distributed Process oriented Soil Erosion Modelling using Modified Morgan-Morgan Finney Model in Indian Region

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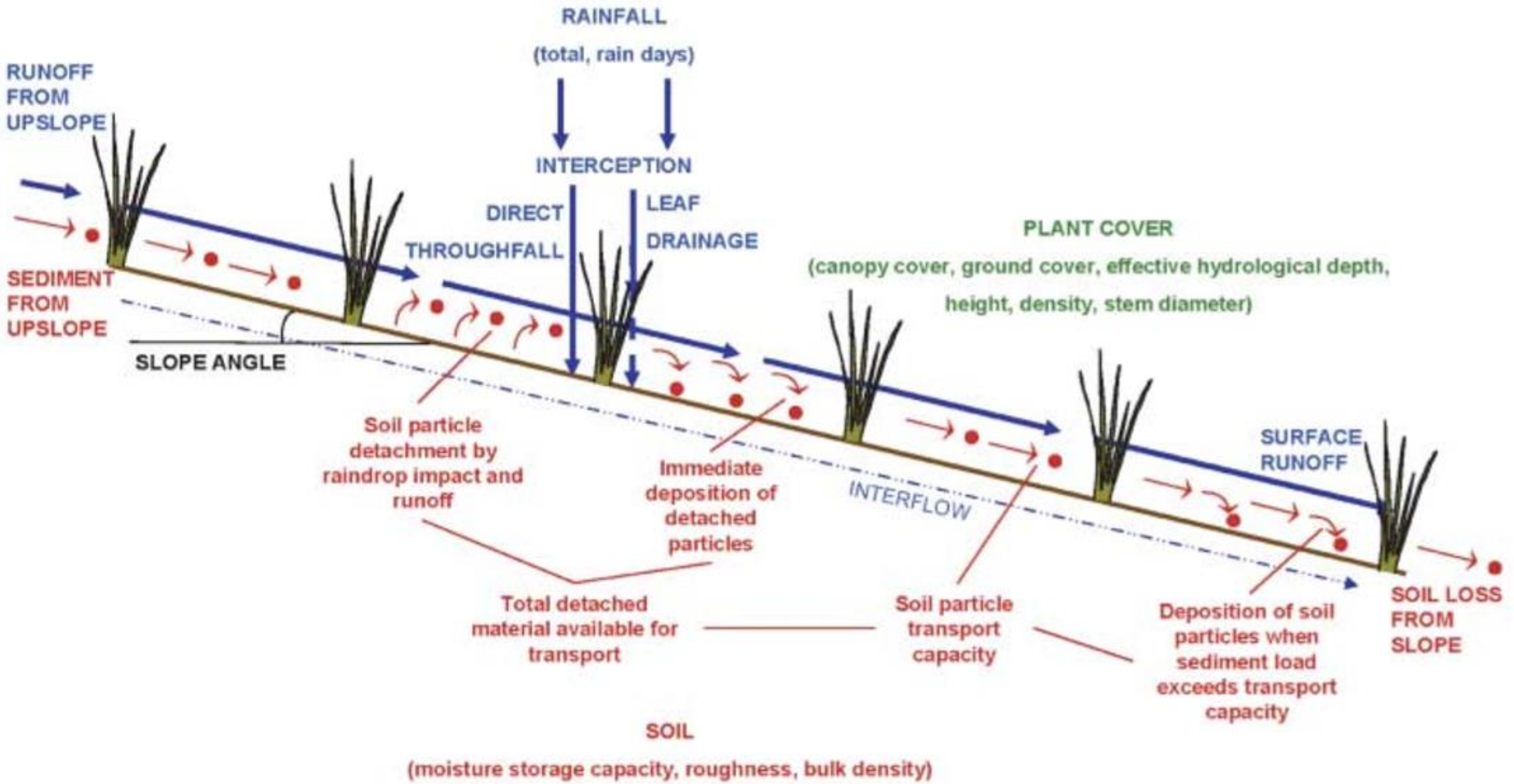
Motivation

- Soil erosion is a very complex phenomenon, there are various model available for modelling soil erosion from simple (such as USLE, RUSLE, USLE-m, etc.) to complex (such as ANSWERS, WEPP, EUROSEM, etc.)
- Complexity of a model increases the data requirements and if the data are not readily available, the complexity of the model may be a serious disadvantage.
- Modified MMF model (Morgan and Duzant, 2008) is a simple process based empirical annual soil erosion model, having distinguishing features such as it incorporates effects of vegetation cover on erosion estimates and simulates processes of detachment, transport and deposition separately for clay, silt and sand.

Modified MMF Model

Schematic representation of Morgan–Morgan–Finney model (Morgan–Duzant version)

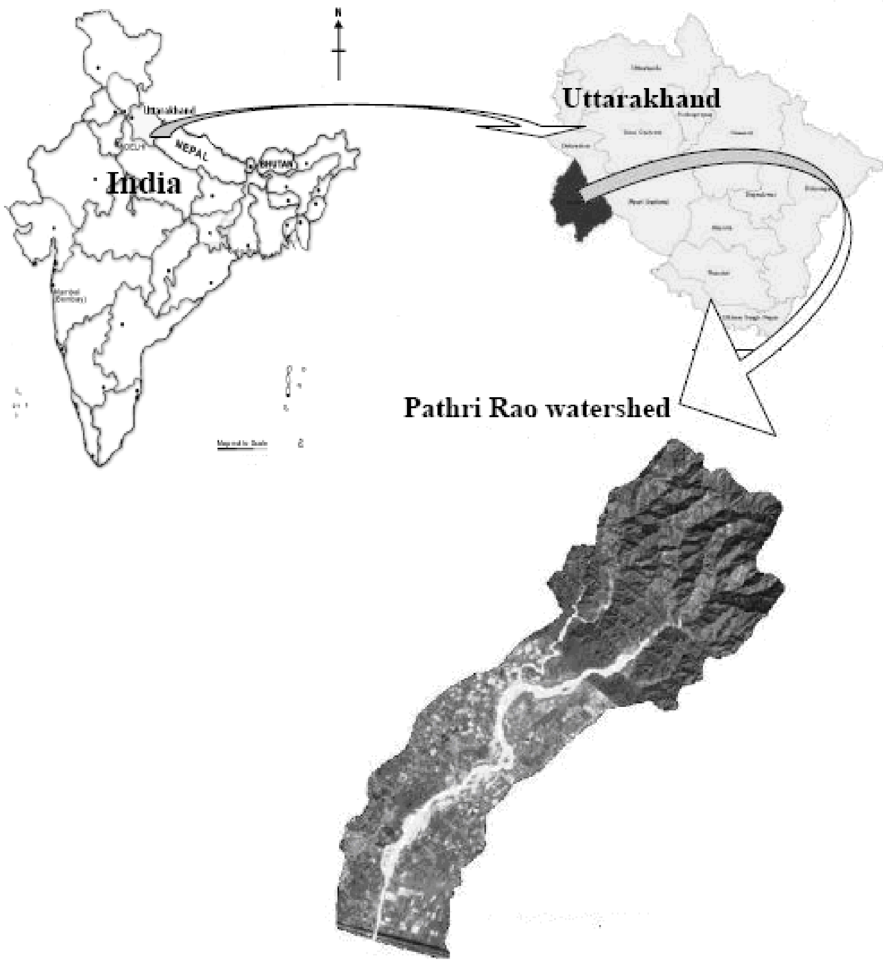


(Morgan and Duzant, 2008)

Implementation

- The model coupled with GIS has been applied in a distributed manner by discretising the watershed into number of homogenous elements.
- Implementation is done using python language and Quantum GIS
- In this study, for simulation of runoff and soil erosion, all the input parameters related to landuse/landcover, soil texture has been estimated from the guide values proposed by Morgan and Duzant, 2008.

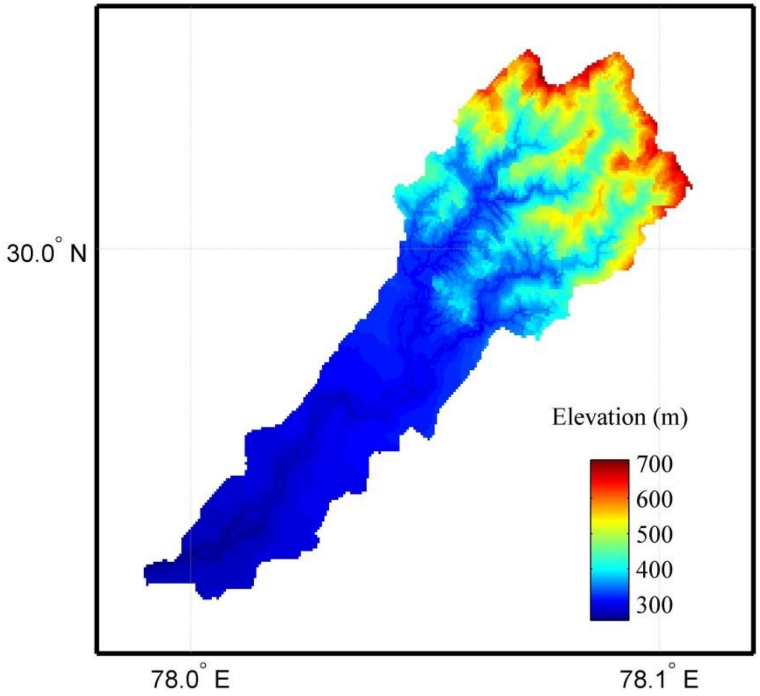
STUDY AREA



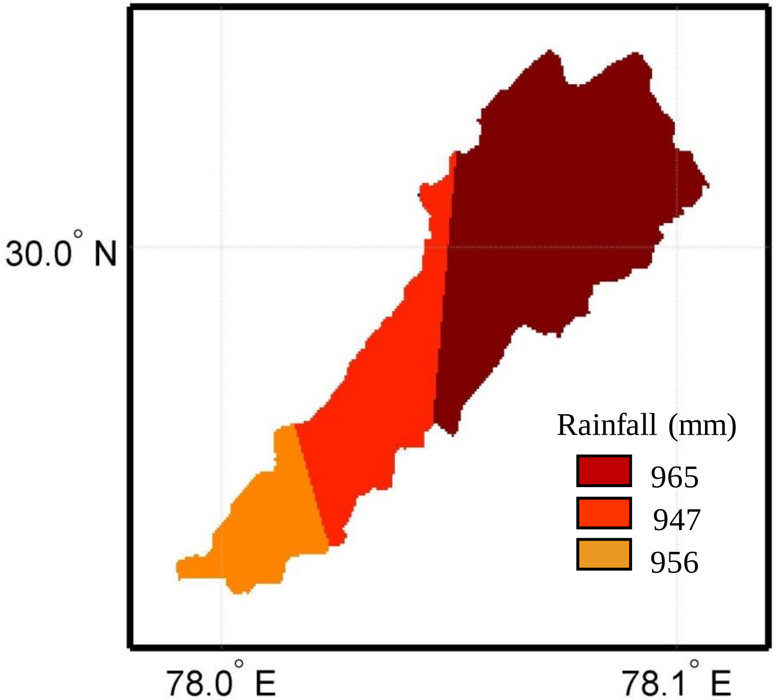
Location map of the Pathri Rao Watershed

Watershed	Pathri Rao
Location	Garhwal Himalayas, Uttarakhand, India
Area (km^2)	37.23
Watershed classification	Medium Sized
Climate	Semi-arid to sub-humid
Average minimum temperature (°C)	3
Average maximum temperature (°C)	42
Average annual precipitation (mm)	1100

Input Data

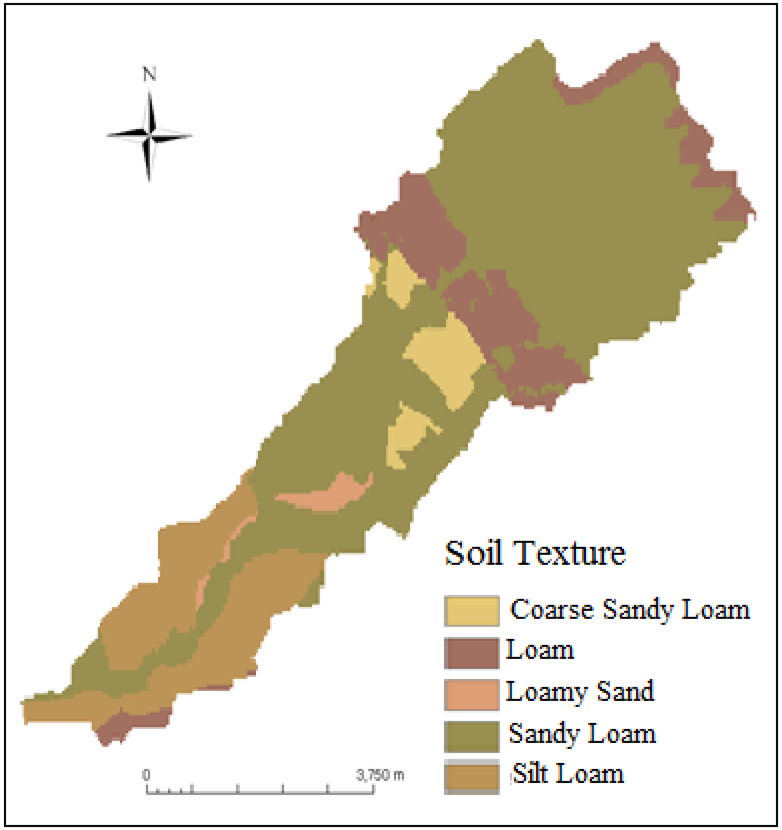


DEM of Pathri Rao Watershed (Kothyari *et al*., 2010)

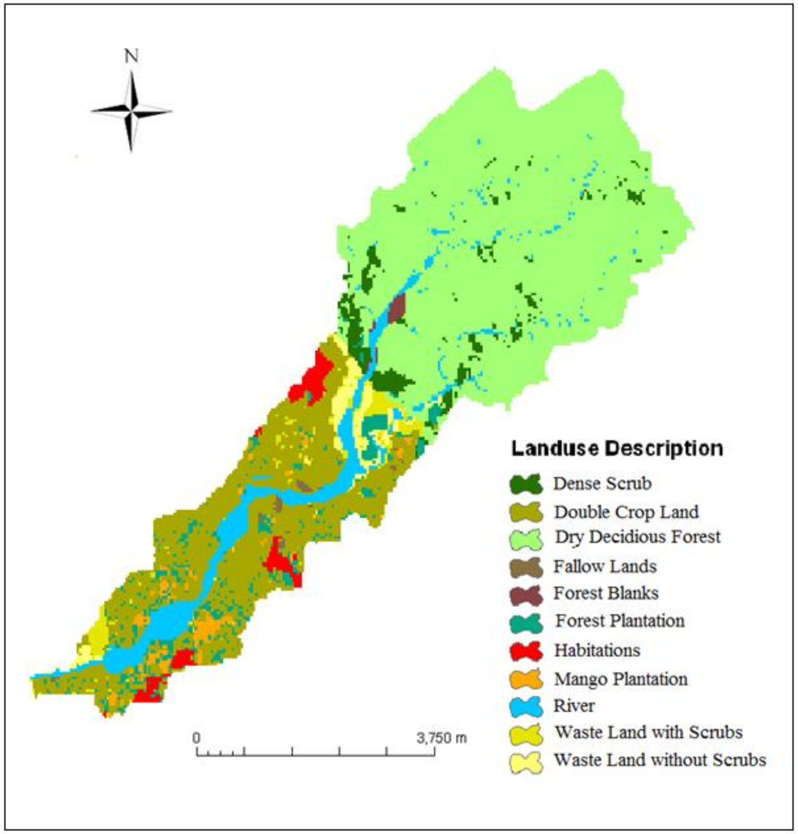


Rainfall Map Pathri Rao Watershed (Kothyari *et al*., 2010)

Input Data

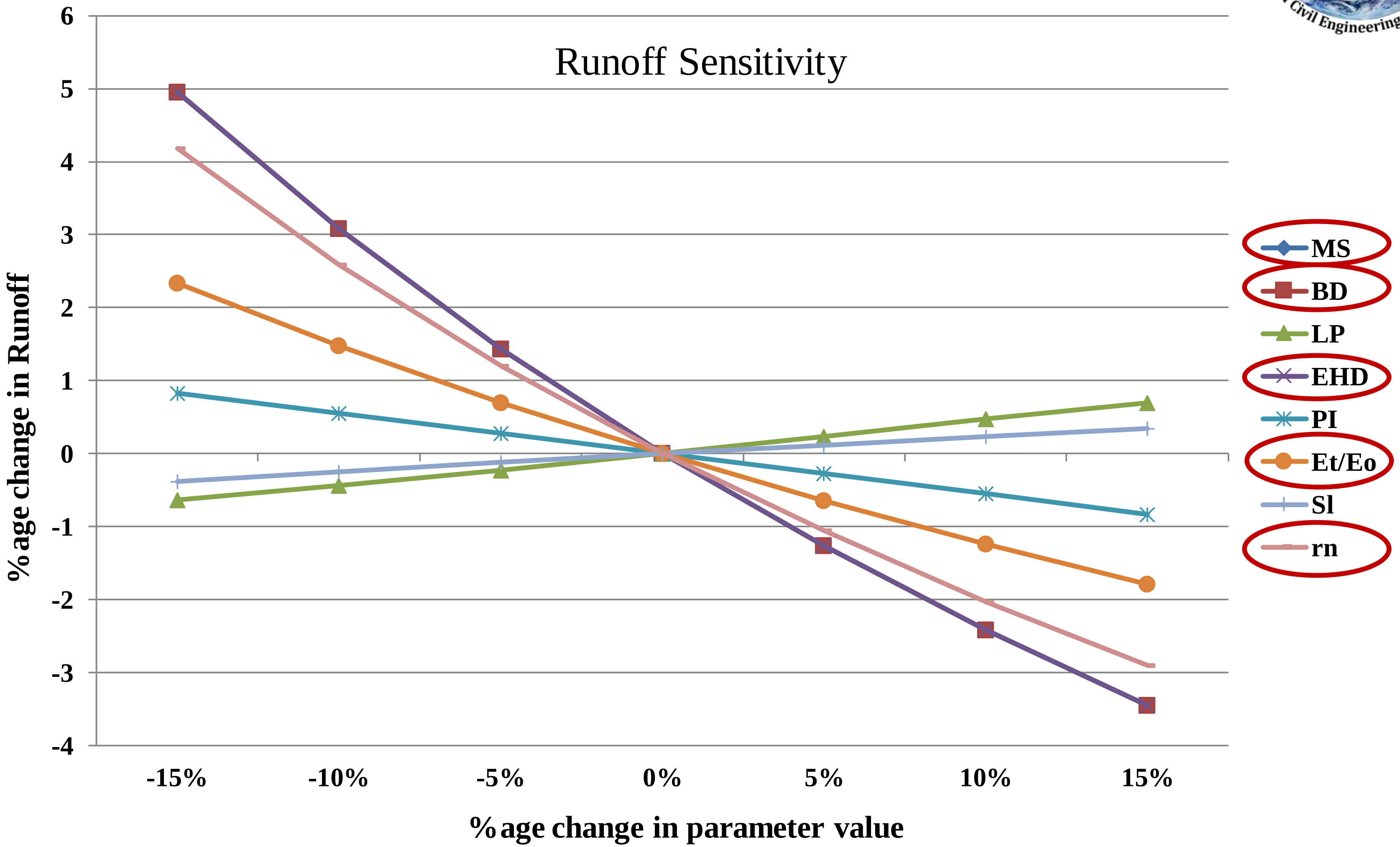


Soil Texture Map of Pathri Rao Watershed (Kothyari *et al*., 2010)



Landuse Map of Pathri Rao Watershed (Kothyari *et al*., 2010)

Sensitivity Analysis



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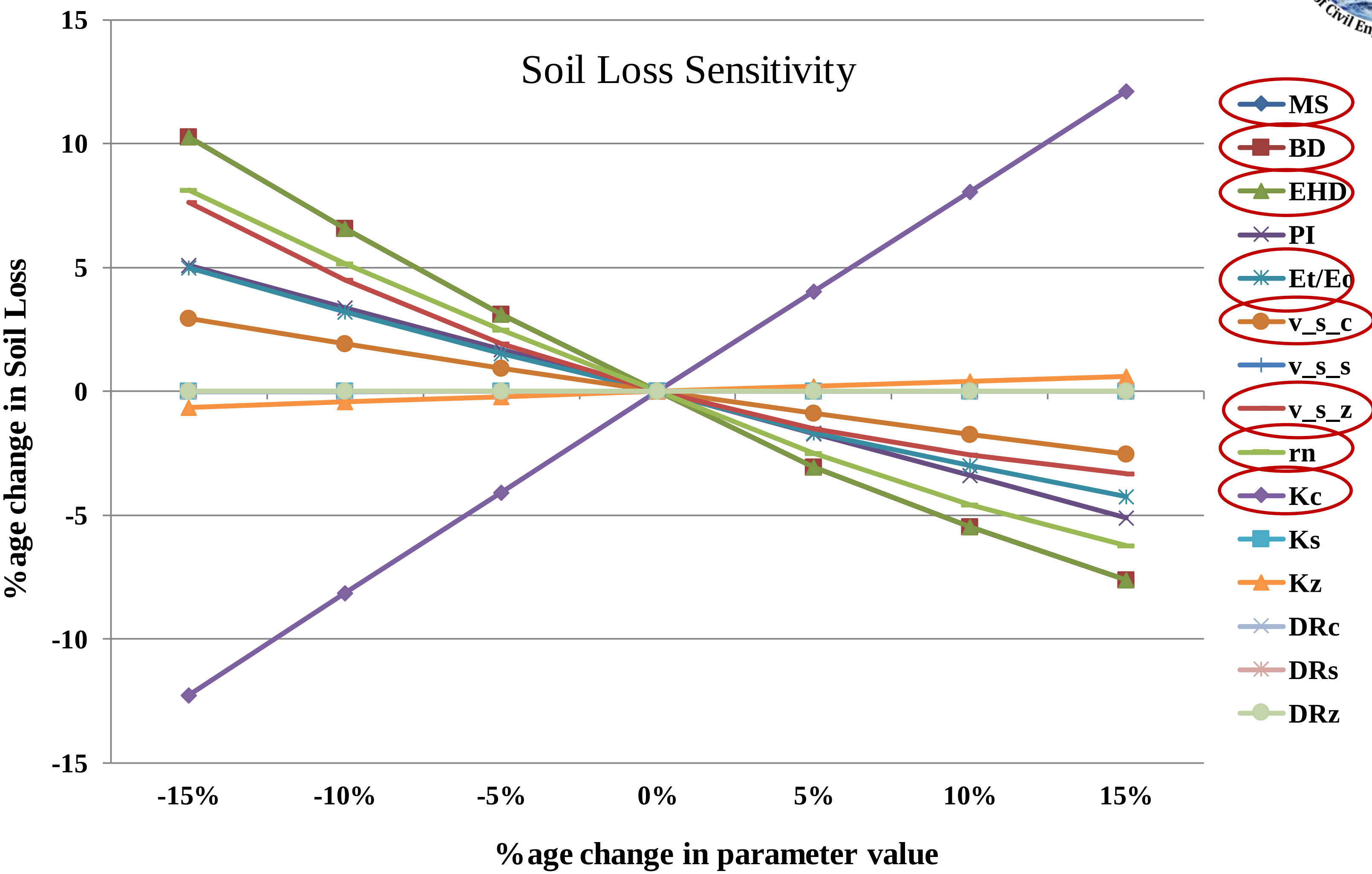
Sensitivity Analysis



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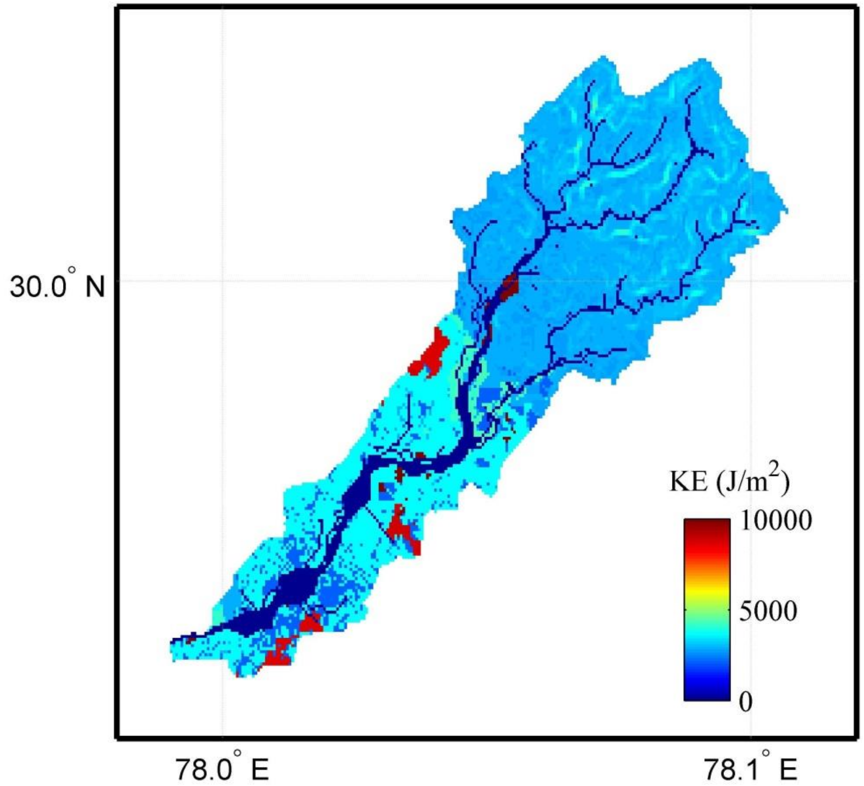
Results

- Simulations were carried out for the year 2005 and found that the model estimated surface runoff and soil erosion compares well with the observed data

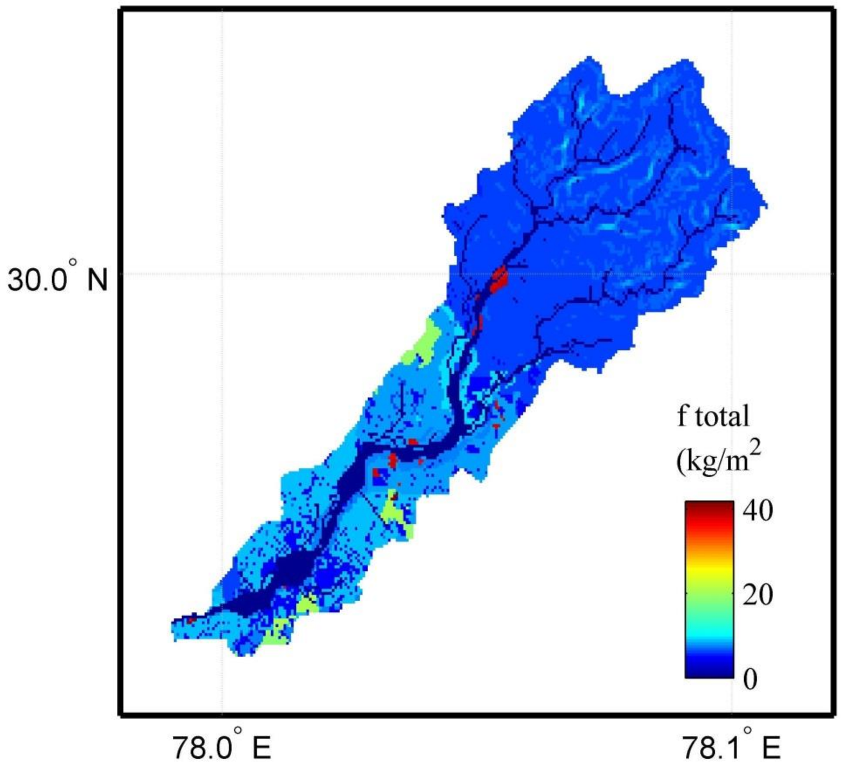
Variable	Observed	Estimated	% Error
Total volume of runoff from catchment (m^3/year)	6.55 * 10^6	6.493 * 10^6	0.88
Soil Loss (tonnes/year)	15.8 * 10^3	15.045 *10^3	4.86

Output Maps

Kinetic Energy (J/m^2)

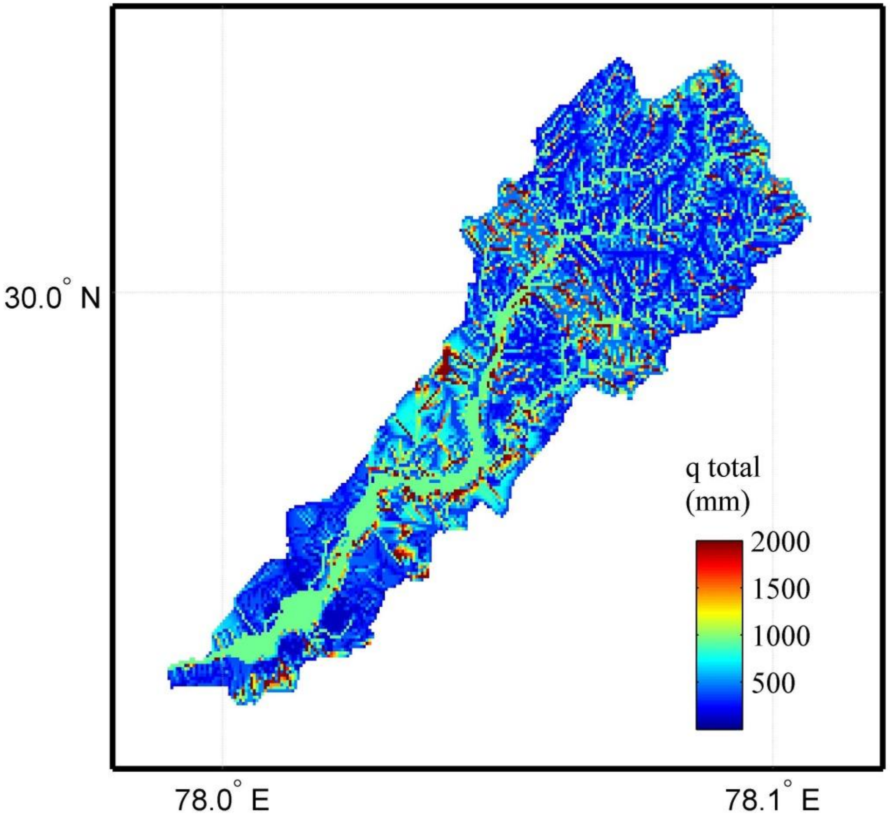


Total Detachment due to Raindrop (kg/m^2)

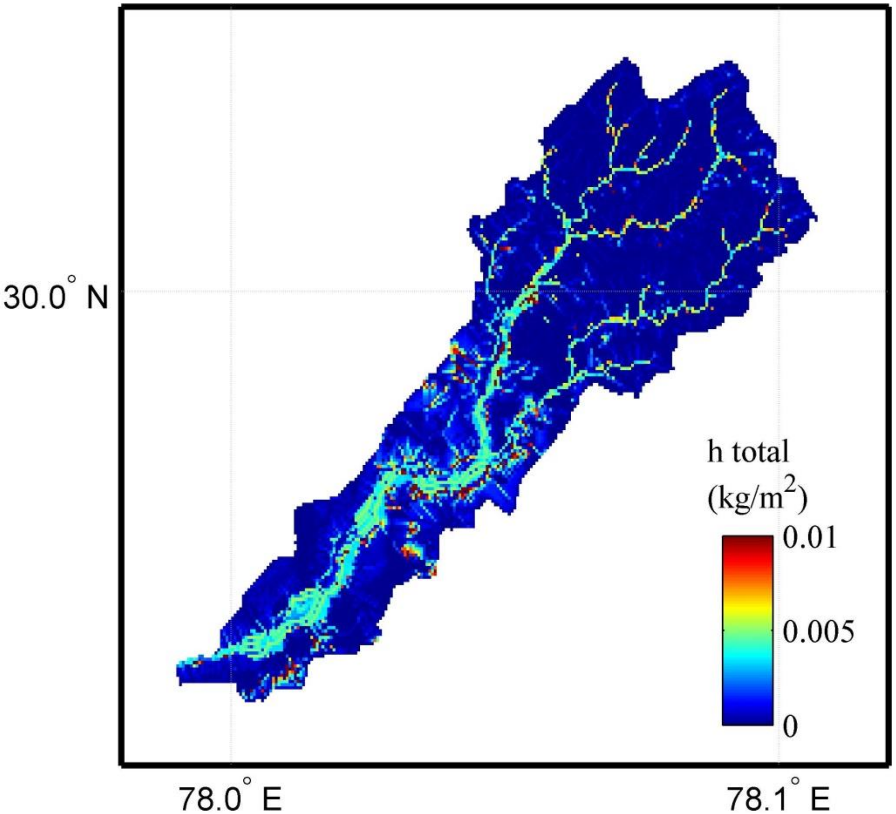


Output Maps

Total Runoff (mm)

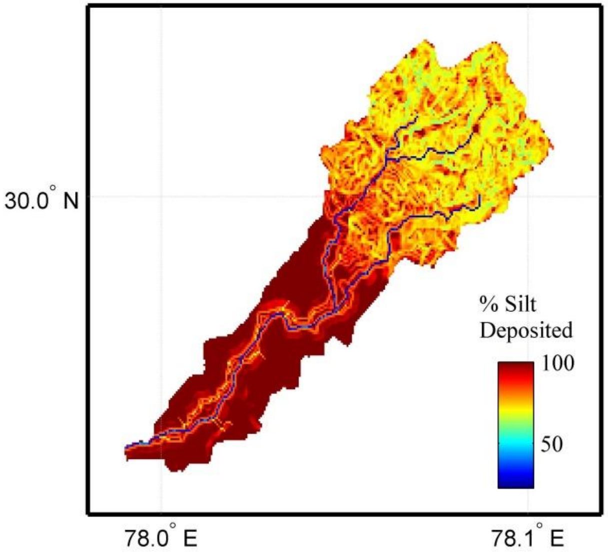


Total Detachment due to Runoff (kg/m^2)

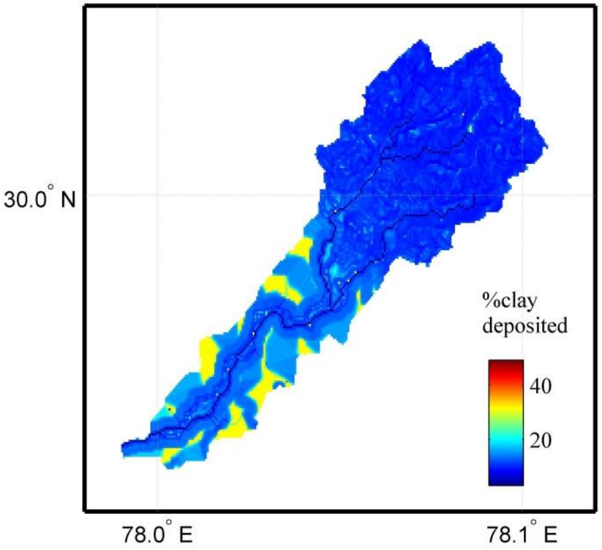


Output Maps

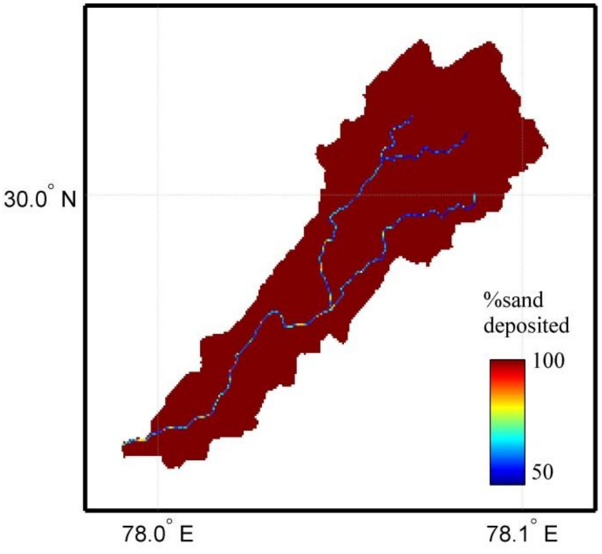
Deposition (% Silt)



Deposition (%clay)

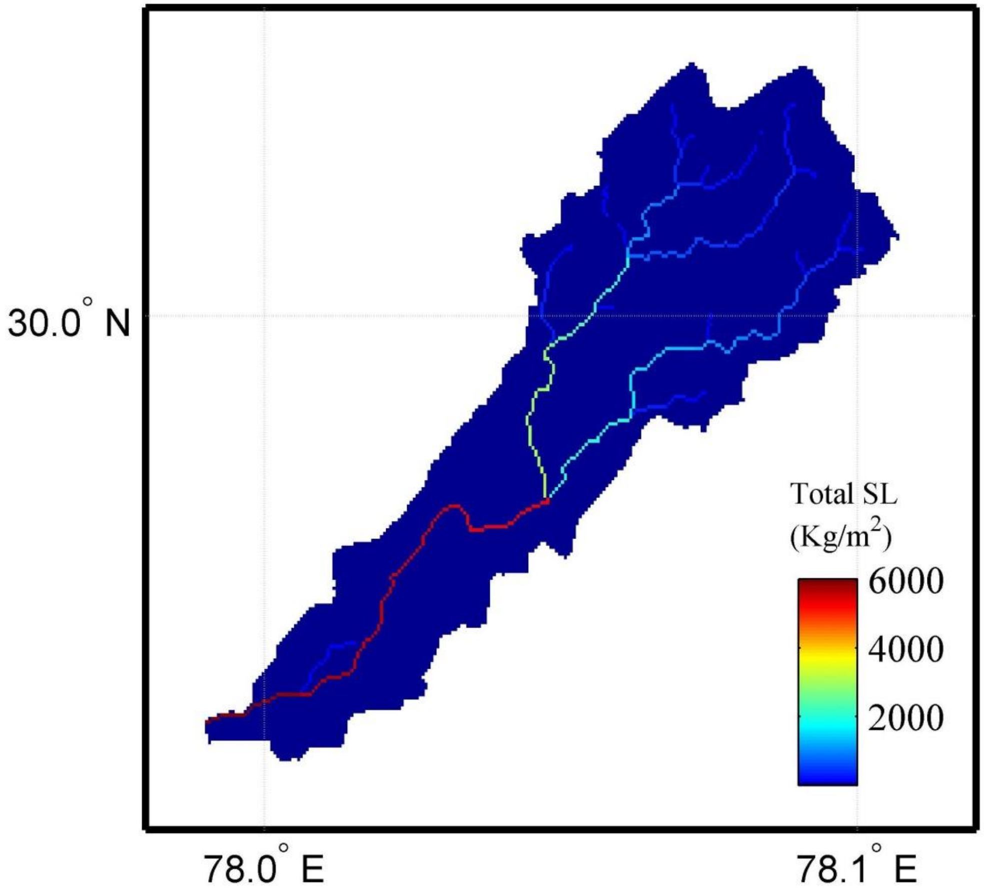


Deposition (%sand)



Output Maps

Annual Sediment Yield (kg/m^2)



Key Points

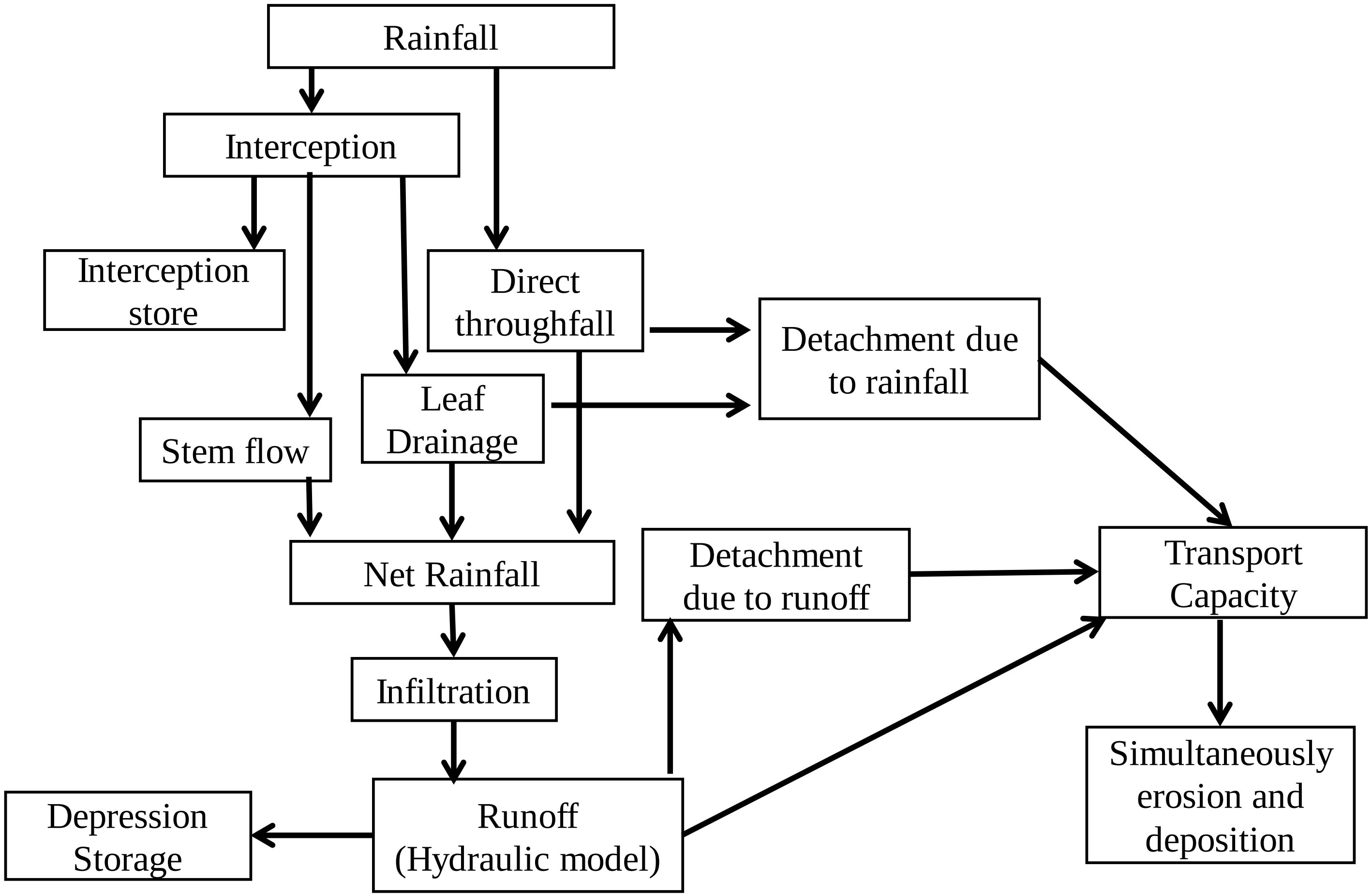
- Modified MMF model (Morgan and Duzant, 2008) is a simple process based empirical annual soil erosion model, having distinguishing features such as it incorporates effects of vegetation cover on erosion estimates and simulates processes of detachment, transport and deposition separately for clay, silt and sand.
- Based on the above obtained results, and the results of other studies like (Lilhare et al., 2014; Kothyari et. al., 2010), it can be said that the Modified MMF model can be successfully applied in small to larger watersheds.
- Likewise, based on the successful results obtained elsewhere, simplistic nature, inherent structure and its unique features mentioned above, it can be said that the modified MMF model has huge potential to be incorporated in the watershed management tools like SWAT as an alternative option for soil erosion estimation in watershed management studies.

Important References

- Morgan, R.P.C. and Duzant, J.H. (2008) 'Modified MMF model for evaluating effects of crops and vegetation cover on soil erosion', Earth Surface Processes and Landforms, Vol. 33, No. 1, pp. 90-106.
- Kothyari, U., Ramsankaran, R., Ghosh, S. and Mendiratta, N. (2010) 'Geospatial-based automated watershed modeling in Garhwal Himalaya', Journal of Hydroinformatics, Vol. 12, No. 4, pp. 502-520.

Thank You

Process and Factors Responsible for Soil Erosion



(Source: Morgan et al., 1998)

Morgan-Morgan Finney Model

MMF model

Basic Structure-
Water phase-

Rainfall energy depends on rainfall and intensity

Runoff depends on rainfall, critical rainfall value and no. of rainy days

Sediment phase-

Splash detachment depends on soil detachability, energy, permanent interception and stem flow

Transport capacity depends on slope, runoff and crop management factor

Revised MMF model

Rainfall energy separately calculated for direct through fall and leaf drainage depending on the height of fall

Detachment due to raindrop and runoff

Splash detachment depends on soil detachability and rainfall energy

Modified MMF model

Incorporated deposition modelled through particle fall number

Considers particle size selectivity (i.e. sand, silt and clay)

Runoff also incorporates inter flow value

Considers immediate deposition of detached particles

Considers vegetation promotes deposition

Simulates the movement of water and sediments from source to outlet

Modified MMF model Equations

Estimation of rainfall energy

$Rf = R (1 - PI) (1/\cos S)$

$LD = Rf * CC$

$DT = Rf – LD$

The Kinetic energy (J m^{-2}) due to-

$KE(DT) = DT (11.9+8.7 \log I)$

$KE(LD) = 0$ for $PH < 0.5$

$KE(LD) = (15.8 * PH^{0.5}) – 5.87$ for $PH > 0.5$

The total Kinetic Energy

$KE = KE(DT) + KE(LD)$

Estimation of runoff –

The interflow of the contributing element

$IF = ((R - E - Q) * LP * \sin S) / 365$

$E = R / (0.9 + R^2 / Z^2)^{0.5}$

$Z = 300 + 25 * T + 0.05 * T^2$

$R_c = (1000 * MS * BD * EHD * (E_t/E_o)^{0.5}) – IF(CE)$

$Q = (Rf + Q(CE)) \exp(-R_c / R_o) (L/10)^{0.1}$

Detachment of soil particles (* kg m^{-2}*)-

$F = K * \%c / 100 * (1 - ST) * KE * 10^{-3}$

$H = DR * \%c / 100 * Q^{1.5} * (1 – (GC + ST)) * \sin^{0.3}S * 10^{-3}$

Notations c- clay, z - silt and s- sand
CE- contributing element

R is mean annual rainfall (mm)
Rf is effective rainfall (mm)
PI plant interception
S is slope in degrees
LD is leaf drainage (mm)
DT is direct through fall (mm)
CC is canopy cover
KE is kinetic energy (J m^{-2})
I is intensity of erosive rain
PH is plant height (m)
IF is inter flow (mm)
E is annual evapotranspiration
T is mean annual temperature (˚C)
Z is function of temperature
LP is lateral permeability (m / day))
Rc is soil moisture capacity (mm)
MS is soil moisture at field capacity
BD is bulk density of soil (Mg / m^3)
EHD is effective hydraulic depth of soil (m)
E_t/E_o is actual to potential evaporation
L is slope length (m)
Q is total runoff (mm)
F is detachment of soil particles by rain drop (kg / m^2)
H is detachment of soil particles by runoff (kg / m^2)
K is detachability of soil (J / m^2)
ST is stone cover
GC is ground cover

Modified MMF model Equations

Immediate deposition of detached particles-

$N_f = (l * v_s) / (v * d)$

$v_s = (1/18 * \delta^2 * (\rho_s - \rho) * g) / \eta$

Flow velocity (v)-

$v_b = 1/n * d^{0.6} * S^{0.5}$

$v_v = (2g / (D*NV))^{0.5} * S^{0.5}$

%age of deposited sediment

$DEP = 44.1(N_f)^{0.29}$

Delivery of detached particles to runoff–

$G = (F + H) * (1 - (DEP/100)) + SL(CE)$

Transport capacity of the runoff

$TC = ((v_a * v_v * v_t / v_b)) * (\%c / 100) * Q^2 * \sin S * 10^{-3}$

Sediment balance

If TC $\geq$ G, than	SL = G	
Else If TC < G,	than	G(1) = G * (1 - (%DEP / 100))
Else If TC $\geq$ G(1)	than	SL = TC
Else if TC < G(1)	than	SL = G

The mean annual soil loss (SL; kg m^{-2}) from the element is-

SL = SL(c) + SL(z) + SL(s)

N_f is particle fall number
v is flow velocity
v_b is flow velocity for bare soil
v_t is flow velocity considering tillage effect
v_v is flow velocity for vegetation condition
v_s is particle fall velocity
d is flow depth
NV is number of stems per unit area
n is manning's roughness coefficient
δ is diameter of the particle
ρ_s is sediment density (kg / m^3)
P is flow density (kg / m^3)
g is gravitational acceleration (m / s^2)
η fluid viscosity (kg / m / s)
l is length of element (m)
DEP is percentage of deposited sediment
G is detached particle to runoff (kg / m^2)
TC is transport capacity of runoff (kg / m^2)
SL is mean annual soil loss