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Sediment yield estimating from three micro-watersheds by integrated KW-GIUH and MUSLE models

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ABSTRACT

Accurate estimation of water and soil losses from agro-ecologically diverse areas is extremely important for designing appropriate resource management or soil/ water conservation measures. The developed KW-GIUH-MUSLE(Kinematic wave-Geomorphlogical Instantaneous Unit Hydrograph-Modified universal Soil loss equation) model is tested for its sediment yield estimation potential on three agro-ecologically diverse micro-watersheds in Almora district of Uttranchal. It is observed that estimates are associated with about 49% mean relative errors and mean DV value of about 0.51 in Salla Rautella and Naula micro-watersheds. This showed that point predictions of annual sediment yields are of moderate quality. However, root mean square error estimates and comparison of mean and standard deviation values for the observed and simulated sediment yields showed that long term sediment yields could be estimated quite realistically. This is also observed in Deolikhan micro-watershed that storm wise sediment yield estimates are associated with about 6% mean relative error and 0.94 mean DV value. The analysis thus clearly showed that the developed KW-GIUH-MUSLE model could indeed be utilized for obtaining reasonable sediment yield estimates for un-gauged/ inadequately gauged micro-watersheds.

Introduction

Soil erosion is an important item of consideration in the planning of watershed development works. It not only reduces the storage capacity of the downstream reservoirs, built for storing the runoff but also deteriorates the productivity of the watershed. Accurate estimation of sediment-transport rates, in general, depends on an accurate a-prior estimation of overland flows. Thus, any errors in the estimation of overland flows would be magnified through grossly inaccurate erosion estimations (Clarke, 1994). Globally more than 50% of pasturelands and about 80% of agricultural lands suffer from soil erosion (Pimentel et al., 1995). It is reported (Dudal, 1981) that worldwide about six million ha of fertile land is being lost every year, due to just soil erosion and related factors. At this rate, it is estimated that currently about 1,964.4 Mha of total land area has already been degraded (UNEP, 1997). Of this, about 1,903 and 548.3 Mha are affected with water and wind erosion problems, respectively. In India, out of a total geographic area of 328 Mha, about 187 Mha land area is subjected to varying degrees of water erosion problems (National Commission on Agriculture, 1976). It is estimated that of 5,333 MT of annual soil lost from Indian sub-continent (Dhruvarayan and Babu, 1983), about 70% gets deposited at various locations in the lower reaches; 20% reaches rivers and seas and remaining 10% gets deposited in surface reservoirs created for irrigation. Further, it has been assessed that annually about 8.4 metric tones of soil nutrients lost due to soil erosion problem and these are much greater than the quantity used at present in Indian agriculture (Singh and Poonia, 2003). Due to this, in terms of annual food grain production, soil erosion accounts for a total productivity loss of about 40 Mt. Thus, accurate estimation of soil loses from agro-ecologically diverse areas is extremely important for designing appropriate resource management or soil/ water conservation measures. Appropriate designing of soil/water conservation measures requires long-term records of rainfall and flow characteristics of test area (Ajward, 1996).

Well-validated watershed scale hydrologic models are excellent predictive tools for obtaining accurate estimates of sediment yield from agro-ecologically diverse watersheds. Physical and empirical models are the two widely used approaches for soil erosion assessment. Although physical-soil erosion models are more detailed yet sometimes even these models have been found to be relying on the same empirically derived geology and vegetation factors (Foster, 1982) as in many empirical USLE (Wischmeier and Smith, 1978), MUSLE (Williams, 1975) and RUSLE (Renard et al., 1997) models. Further, application of physically based models to large watersheds, for which insufficient sediment yield and runoff data are available, is not of practical interest and the subdivision of a large watershed into rills and interrill areas is practically impossible. Besides, physical models contain equations whose constants and exponents need to be determined through calibration exercises on each test watershed. Thus if data on sediment yield and runoff from a watershed do not exist, calibration and application of even these models are impossible.
Hikaru et al. (2000) demonstrated successful application of USLE to mountainous forests in Japan. However, studies have shown that USLE and RUSLE models can be used for predicting only long-term average annual soil losses and they could produce misleading soil loss values when applied to a seasonal or single storm situation (Wischmier and Smith, 1978). Besides this, it has been repeatedly observed that USLE contains no such

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term to specifically account for the effects of overland flow, the major transport mechanism by which soil erosion occurs. To account for the above limitations in USLE, Williams (1975) suggested the Modified Universal Soil Loss Equation (MUSLE). However, scanning of literature showed no integration of KW-GIUH theory based run-off simulating model with a soil loss estimating MUSLE model for storm based total sediment loss estimations from especially un-gauged / in-adequately gauged micro-watersheds.

Thus with this in background the present investigation is mainly aimed at:

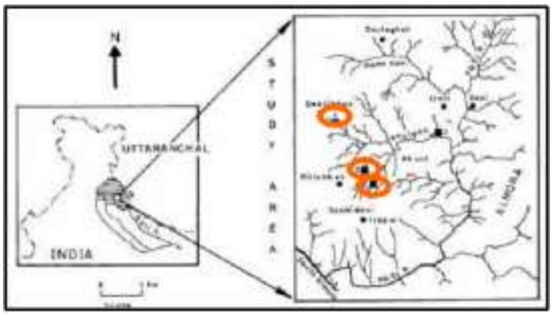
1. Developing an integrated KW-GIUH (conceptual) and MUSLE (empirical) model for obtaining storm based sediment yield estimates for un-gauged/ in-adequately gauged watersheds, and
2. Testing the application potential of the so developed KW-GIUH and MUSLE based event scale hybrid model on 3-ecologically diverse micro watersheds in Almora district of Uttaranchal.

Material and methods

Description of Study area

The test area is situated about 32-38 Km northwest of Almora town of Uttaranchal (Fig.1). It comprises of three agro-ecologically diverse micro-watersheds viz. Deolikhan (agricultural), Salla Rautella (pine forest) and Naula (oak forest).Deolikhan (agricultural) micro-watershed (near Deolikhan village), of about 0.40 km2 size extends between 29º38′10″ N to 29º38′20″ N latitudes and 79º32′15″ E to 79º32′35″ E longitudes (Fig.1). Its absolute relief and average slope are about 1700 m above m.s.l. and 28□, respectively. In contrast to this, Salla Rautela micro-watershed (near village Salla Rautela), with 0.47 Km2 area extending between 29º35′5″ N to 29º 35′ 20″ N latitudes and 79º33′10″ E to 79º 33′ 32″ E longitudes is predominantly a pine forest watershed. Its absolute relief and average slope are about 1650 m above m.s.l. and 24□, respectively. Similarly, Naula micro-watershed (near village Naula), with oak forest eco-system and about 0.42 km2 size, extends between 29º34′5″ N to 29º35′30″ N latitudes and 79º33′30″ E to 79º 33′ 33″ E longitudes. It has an absolute relief and average slope of about 2190 m above m.s.l. and 25º, respectively. It is important to notice here that all 3-test micro-watersheds are of almost comparable area, slope and altitude with Naula micro-watershed located at slightly higher altitudes than the rest. Soils of Deolikhan micro-watershed have an average organic matter content of 1.1%, saturated hydraulic conductivity of 85.95 mm/hr and volumetric soil moisture content at field capacity and saturation as 15 and 30%, respectively . In Salla micro-watershed,the soils also have an average organic matter content of 0.74%, saturated hydraulic conductivity of 133.75 mm/hr and volumetric soil moisture contents at field capacity and saturation as 15 and 30%, respectively . Similarly, in Naula micro-watershed , the soils have an average organic matter content of 1.4%, saturated hydraulic conductivity of 235 mm/hr and volumetric soil moisture at field capacity and saturation as 15 and 30%, respectively (Kaur et al., 2002a, b).About 72% of Deolikhan micro-watershed is under agriculture, thereby classifying it under agricultural micro-watershed class. Of remaining area, about 22% is barren and 6% is abandoned (now an afforested land) .Five per cent of Salla Rautella watershed is under horticulture while remaining 95% is under dense (reserved) pine forest. These forest areas are mainly occupied by Chir pine (Pinus roxburghii). Other associates (such as Quercus leucotriphora, Mrrica esculanta and Lyonia ovolifolia) contribute only 17% of the total tree density in the watershed.Naula micro-watershed is also primarily a reserved forest. However, this watershed mainly comprises of oak and pine trees (about 88%). About 8% of its total area, on top of the watershed, is under horticulture. While remaining 4% near watershed outlet, on either sides of the channel, is barren. In general, the climate of this region is sub-temperate with moderate summers (average temperatures ranging between 18 - 22□C), a short spell (about 2 months) of chilling winter and general dryness, except during southwest monsoon season. Based on the hydro-metrological records for 1990-2002. average annual rainfall for the test region varies from 874mm (for Deolikhan) to 927mm (for Salla Rautella) and 981mm (for Naula).Annual sediment yields from the test region range from 18-21 tons (from Salla Rautella and Naula, respectively) to 34 tons (from Deolikhan).

Figure .1.Location map of Deolikhan,Salla and Naula micro-watersheds



Methodology

GIS Based Digital Delineation of Test Watersheds and Drainage Networks

Digital delineation of watershed boundaries avoids subjectivity and thus results in watersheds with more accurate shapes/ sizes. Research over past one decade has demonstrated feasibility of extracting topographic information (such as slope properties, drainage areas, drainage divides, drainage network, etc.) of any area directly from its digital elevation model (Mark, 1984).

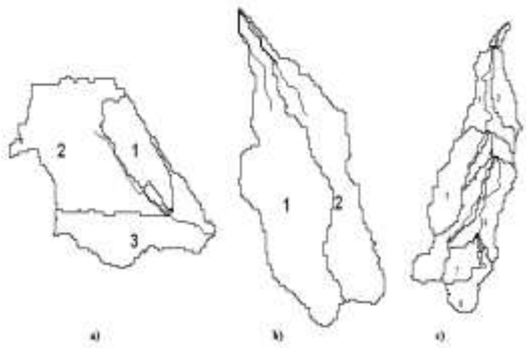


Fig.2 Delineated watershed boundaries, sub-watersheds and drainage networks for (a) Deolikhan, (b)Salla Rautella and (c) Naula micro watersheds

Figure 2(a,b,c) gives a pictorial depiction of the digitally delineated test watershed,subwatersheds and streams in the three micro-watersheds .In the present study, this sub-watershed scale topographic data is obtained through the application of a standard avenue script (named Hydrologic) of Arc-View Spatial Analyst GIS software (ESRI, 1999) on the digital elevation models (DEM) for 3-test micro-watersheds. While doing so, each (DEM-delineated) sub-watershed within any test watershed is identified by the order of the (DEM-delineated) stream flowing through it. The ordering of these streams/ channels in each test micro-watershed is based on the Strahler (1952) stream ordering method. Channel/overland roughness coefficients are derived through standard look-up table values (Engman, 1986) for specific channel / overland conditions prevailing in each test watershed area. Channel conditions are assessed (subjectively) through actual ground surveys while overland conditions are determined through actual land use maps (Rawat and Kaur, 2001) for the test watershed.

Soil Loss Prediction Using Modified Universal Soil Loss Equation (MUSLE)

Modified Universal Soil Loss Equation (MUSLE) is the most widely used sediment yield prediction model proposed by Williams and Berndt (1977). It can be used to obtain accurate sediment yield estimates (Y, in metric tons) on both single storm and annual basis and is generally expressed as :

Y=11.8(Qqp)0.56(K)(L)(S)(C)(P) (1)

where, Q is total runoff volume (in m3), qp is peak runoff rate in (m3/s), K is soil erodibility factor, LS is slope length and gradient factor; C is cropping management factor and P is erosion control practice factor. These input parameters, required for predicting sediment yield (Y) through eq.1, are estimated as per the following procedures:

Run-off Prediction through Kinematic Wave Theory Based Geomorphic Instantaneous Unit Hydrograph (KW-GIUH) Model

Based on the Strahler stream-ordering scheme, a watershed of order Ω (where is the highest order stream in the watershed) can be divided into 2Ω-1 flow paths. Every raindrop falling on an overland area moves from lower order to higher order channels, in succession, to finally reach the watershed outlet. According to Rodriguez – Iturbe and Valdes (1979), if ‘w’ represents a particular flow path: Xoi Xi Xj X, then the probability of a raindrop adopting this flow path can be expressed as:

P (w) = POAi *PXoiXi*PXiXj…………....*PXkX (2)

where, Xoi represents ith-order overland region and Xi, Xj , Xk or X denotes ith, jth, kth or highest-order channels, respectively. POAi (i.e. initial state probability) is the probability of a raindrop to (initially) fall on an ith order overland region and is equal to the ratio of the total area of ith order overland region to the total watershed area. PXoiXi (i.e. transitional state probability) is the probability of a raindrop to move from an ith order overland area to ith order channel. By definition, this is always equal to one. while, PXiXj is the transitional state probability of a raindrop to move from an ith (i.e. lower) order channel to a jth (i.e. higher) order channel and is generally expressed as:

$$P_{x_i x_j} = \frac{N_{i,j}}{N_i} \quad (3)$$

where, is number of ith order channels flowing into jth order channels and is number of ith order channels.

If Tw represents total time taken by a raindrop to reach the watershed outlet, after traversing through path ‘w’ and TXk are raindrop-travel times in states Xk then Tw can be expressed as:

Tw = TXoi + TXi + TXj + …….. + TX (4)

The raindrop travel times for different states in the watershed, in the above equation, are assumed to be statistically independent and represented as probability density functions of type fXk(t), with TXk as mean travel times value for each state Xk . With this, the above eq. (4) reduced to:

Tw = fxoi (t) + fxi (t) + fxj (t) +…….+ fX (t) (5)

Assuming these probability density functions to be of exponential type (Gupta et al., 1980), the above eq. (5) is re-written as:

Tw = aoiexp (-t/TXoi) + biexp (-t/Txi) + bjexp (-t/Txj) …+bexp (-t/Tx) (6)

where, aoi, bi, bj, ……, b are the coefficients determined through Laplacian transformation. Combining equations (2) and (6) in the following manner yielded a geomorphologic unit hydrograph-uw (t), for flow path (w) of a watershed:

uw(t) = {aoiexp (-t/TXoi) + biexp (-t/Txi) + bjexp (-t/Txj) …+bexp(-t/Tx)}*P(w) (7)

The so generated individual geomorphic instantaneous unit hydrographs, uw (t), for each flow path (w) in the total path space (W) are then summed up to generate total geomorphic instantaneous unit hydrograph, U(t), at the watershed outlet:

U (t) = u1 (t) + u2 (t) + u3 (t) + …….uw (t)

where, w = (1, 2, 3, ……., 2Ω-1) flow path in a watershed.

As test watersheds of this study are of second order (i.e. = 2) therefore they had following (2(2-1) =) 2 - flow paths:

Flow Path-1 (i.e. w1): Xo1 X1 X2 while

Flow Path-2 (i.e. w2): Xo2 X2

The probability of raindrops or rainfall excess to follow these flow paths are expressed as:

P (w1) = POA1.PXo1X1.PX1X2 and

P (w2) = POA2.PXo2X2

While their travel times, along flow paths 1 and 2, are expressed as:

Tw1 = TXo1 + TX1 + TX2 and

Tw2 = TXo2 + TX2

Where,

Tw1 = {Txo1/(Txo1-Tx1)*(Txo1-Tx2)}*{exp (-t/Txo1)-exp (-t/Tx2)} +{Tx1/(Tx1-Txo1)*(Tx1- Tx2)}*{exp (-t/Tx1)-exp. (-t/Tx2)} and

Tw2 = {1/(Txo2-Tx2)}*{exp (-t/Txo2)-exp (-t/Tx2)}

Following above procedure, total hydrologic response (or GIUH) of the test watersheds is thus expressed as:

U (t) = u1 (t) + u2 (t)

where,

u1 (t) = [{Txo1/(Txo1-Tx1)*(Txo1-Tx2)}*{exp.(-t/Txo1)-exp.(-t/Tx2)} + {Tx1/(Tx1-Txo1)*(Tx1-Tx2)}*{exp. (-t/Tx1)-exp. (-t/Tx2)}]*P (1) and

u2 (t) = [{1/(Txo2-Tx2)}*{exp (-t/Txo2)-exp (-t/Tx2)}]*P (2) (8)

Direct run-off hydrograph {Q(t)} at the test-watershed outlet, determined as convolution integral of watershed-specific excess rainfall hyetograph {Ie(t)} and hydrologic response function U(t), can be expressed hence finally as:

$$Q(t) = \int_0^t Ie(\tau)\, U(t - r)\, dr \quad : (8)$$

where, r is a dummy variable.

Estimating Channel/ Overland Flow Travel Times

Estimation of watershed-geomorphology based excess rainfall-travel times for overland/ channel areas in un-gauged/ in adequately gauged watersheds is the most challenging task in geomorphic run-off simulation. Lee and Yen (1997) applied the concepts of Kinematic Wave (KW) theory to estimate these travel times. Thus, based on KW-approximations (Wooding, 1965), time taken by excess rainfall to travel through an ith order sub-watershed (Txoi) is obtained as:

$$\text{Txoi}=\left(\frac{n_o L_{oi}}{S_{oi}^{1/2}\, i_{e_i}^{m-1}}\right)^{1/m} \qquad (10)$$

where, no is overland roughness coefficient, Soi is mean ith-order overland slope (in fractions), m is an exponent (= 5/3 from Manning's equation); ie is excess rainfall intensity (m/min) and Loi is mean overland flow length (m). The mean overland flow length (Loi) in above equation is expressed as:

Loi = (A *PoAi)/(2* Ni * Lci) (11)

where, Ni is number of ith order streams, Lci is mean ith order channel length (m) and A is total area of watershed (m2). However, time taken by excess rainfall to travel through an ith-order channel is expressed as:

$$\text{Tx}=\frac{B_i}{2 i_e L_{oi}}\left[\left(h_{coi}^{m}+\frac{2 i_e n_c L_{oi} L_{ci}}{S_{ci}^{1/2} B_i}\right)^{1/m}-h_{coi}\right] \qquad (12)$$

where, nc is channel roughness coefficient, Sci is mean ith order channel slope; Bi is width of ith order channel and hcoi is in-flow depth of ith order channel due to water transported from upstream reaches. As no channel flow is transported from upstream reaches for a (i =) 1st order channel, therefore

hcoi = 0 for i =1 (13a)

and

hcoi = for (1< i < r) (13b)

where Ai is mean of drainage areas of ith - order.

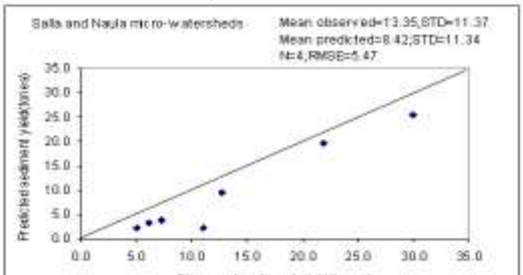


Figure 3. Observed versus predicted annual sediment yield in test microwatersheds

Estimating Excess Rainfall

In the present study, following (CN-independent) alternate analytical form of potential maximum retention equation given by (Mishra and Singh, 1999a, b) is applied, which has been expressed as:

$$S = P\left(\frac{[2\lambda + R(1-\lambda)] - \sqrt{R[R(1-\lambda)^2 + 4\lambda]}}{2\lambda^2}\right) \qquad (14)$$

where, =runoff factor of test watershed, □ = initial abstraction ratio. It has been observed through many studies on Indian watersheds that a value of □ = 0.3 gives reasonable estimates of initial abstractions (Soil Conservation Department, 1972). In the present study, average values of runoff factors for (Q/P) the test (viz. Deolikhan, Naula and Salla Rautella) watersheds, are obtained from their annual rainfall-runoff records for 1992-93, 1996-97 and 2000-01 periods (Rawat et al., 1999). Run-off factors for other Indian watersheds can be obtained through either Central Water Commission maintained actual long-term annual rainfall-runoff records or general look-up tables.

In the present study, (storm / annual) total runoff volumes (Q) and peak runoff rates (qp) for each test watershed are estimated through Kinematic Wave theory based Geomorphic Instantaneous Unit Hydrograph (KW-GIUH) model.

Estimating Soil Erodibility Factor (K)

The soil erodibility factor (K) represents average soil loss from a specific area of soil in cultivated continuous fallow with a standard plot length as 22.13 meters and a standard percentage slope as 9%. It varies from 0.70 for the most fragile soil to 0.01 for the most stable soil. The K factor is determined using a soil erodibility nomograph based on particle size, organic matter, soil structure, and permeability data (Johnson et al., 1984). The following formula is used to evaluate the nomograph readings:

K = 2.73 x10-6 x M1.14 (12-a)+3.25 x 10-2 (b -2)+2.5 x 10-2 (c- 3) (15)

where, "M" is particle size diameter = {(%silt + %very fine sand) x (100 - %clay)}, "a" is percent organic matter, "b" is soil structure code (as in Table 1) and "c" is profile permeability class (as in Table 2). The nomograph based soil erodibility estimations have proved to give accurate results (DSI, 2000). In the present study, the above % sand, %silt, %clay and %organic matter, soil structure and soil permeability data required for calculating K-factors for the test watersheds (Table 3) are obtained from Kaur et al. (2002a, b).

Estimating Slope Length (L) and Gradient (S) Factor (LS)

The slope length and gradient factor (LS) is defined as the ratio of soil loss from any slope length and gradient to soil loss from a 22.13 m plot with 9% slope and same soil type and other conditions. It varies from 0.1 to 5 in the most frequent farming contexts in West Africa, and may reach 20 in mountainous areas. This factor is defined by the multiplication of the L and S-factors (Moore and Burch, 1986),

L = (La/22.13) m (16)

Here, La is the actual (second order overland area's) slope length (in m) of the test watershed and m is a slope dependent exponent computed as (McCool et al., 1989):

m = sin□/{sin□ + 0.269(sin□)0.8 + 0.05}

where,

□ = slope of test watershed in degrees=tan-1(watershed slope in %/100)

while,

S = 3.0 (sin□)0.8 + 0.56 for slopes < 4m (17)

S = 10.8 sin□ +0.03 for slopes > 4m and s < 9%

S = 16.8 sin□ - 0.50 for slopes > 4m and s □ 9%

where, s is test watershed's (second order overland area's) slope (in %).

Estimating Crop Management (C) and Conservation Practice (P) Factor (CP)

The cropping management factor (C) represents the ratio of soil loss from land with specific cropping and management to that from tilled and fallow conditions on which the K factor is evaluated. The C-factor, also called the cover and management factor, varies from 1 for bare soil to 1/1000 for forest, 1/100 for grasslands and cover plants, and 1 to 9/10 for root and tuber crops. Table 4 illustrates C-factors for varied land use types.

The erosion-control-practice factor (P) represents the effect of conservation practices. The P factor is determined as the ratio of soil loss using one of the conservation practices to the soil loss using straight row farming. The P factor for straight row farming is always equal to unity. It generally varies from 1 for bare soil with no erosion control to about 1/10 for tied ridging on a gentle slope. Table 5 illustrates P-factors for varied land use and conservation practice types. Deolikhan (agricultural) watershed is terraced. While, Salla Rautella and Naula watersheds with pine and oak forests had no conservation practices.In the present study, average CP-factor for Deolikhan (agricultural) watershed is determined through inverse modelling on seven-storms based hydrologic and sediment yield records for 1992, 1993 and 1996 years. However, due to non-availability of storm based sediment yield data for Salla Rautella (pine forest) and Naula (Oak forest) watersheds, CP factors for these watersheds are determined through inverse modelling on annual hydrologic and sediment yield records for year 1992.

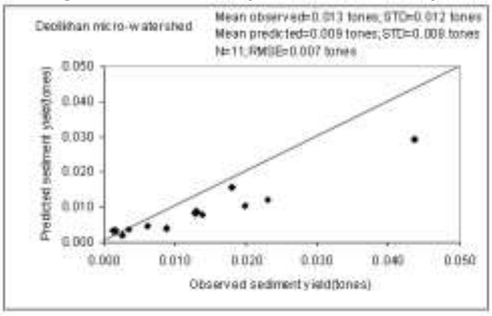


Figure 4. Observed versus predicted sediment yield in test micro-watersheds

Calibration/ Validation of Sediment Yield Predicting MUSLE Model

Due to scarcity of storm based sediment yield data for all test watersheds, composite crop management and conservation practice factor (CP) for MUSLE model are obtained through inverse modeling on 12-hydrologic and sediment yield events for Deolikhan micro-watershed and on 6 annuals (i.e.1990, 91, 92, 93, 94 and 95) hydrologic and sediment yield data for Salla Rautella (pine forest) and Naulla (oak forest) watersheds. Following these CP factor estimations, the sediment yields estimated through MUSLE model are validated on 11-storm events for Deolikhan watershed and on three (i.e.1996, 97 and 98) and four years (i.e.1999, 2000, 2001 and 2002) annual sediment yields for Naula and Salla Rautella watersheds, respectively. On obtaining reasonable sediment yield estimates through MUSLE model, storm/ event based sediment yield estimating potential of integrated KW-GIUH-MUSLE model is validated on 11- small sized storms/ events for Deolikhan watershed.

Evaluation of KW-GIUH-MUSLE Model

Both visual (graphical) and statistical comparisons between the observed and predicted sediment yields are made to evaluate the sediment yield estimating potential of KW-GIUH integrated MUSLE model. As overall measure of fit between an observed and computed hydrologic parameter cannot be assessed completely by a single statistical parameter (Green and Stephenson, 1986), the proposed model's performance is assessed through the following statistical indices (ASCE, 1993):

DV (Deviation of Volume) = (S / O) (18)

$$\text{RE (Relative error, in \%)} = \frac{S-O}{O}\times 100 \quad (19)$$

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \quad (20)$$

where, S is the simulated sediment yield, O is the observed sediment yield and N is the total number of data pairs. A good model yields DV values nearing one and is associated with lowest RE and RMSE values.

Result & Discussions

In this study, geomorphologic parameters of three test micro-watersheds are determined (Table 6) from their DEM using Arc View Spatial Analyst GIS software. These sub-watershed wise extracted geomorphologic parameters are then used for calculating geomorphologic parameters (Table 7) and initial and transitional state probabilities (Table 8) for each order of the three second order test watersheds as per the procedures detailed in section material and methods chapter. Composite overland and channel roughness coefficients are also calculated for the three test micro-watersheds as per the procedures detailed in section of material and methods. In general, the test watersheds are characterized with smooth rock cut material laden channels of occasionally/frequently alternating cross-section, negligible obstruction, low vegetation and minor degree of meandering. This gave rise to channel roughness coefficients as 0.0325, 0.0325 and 0.04025 for Deolikhan, Salla Rautella and Naula micro-watersheds, respectively. In the mean time, overland roughness coefficients for the first (with mainly agricultural land use type: 92%) and second (with mainly fallow land use type: 69%) order overland areas of Deolikhan micro-watershed are calibrated at 0.032 and 0.011, respectively. Salla Rautella and Naula micro-watersheds, with mainly pine and oak forests, are associated with overland roughness coefficient values of 0.15 and 0.07, respectively. Finally, In this study, (storm / annual) total runoff volumes (Q) and peak runoff rates (qp) for each test watershed are estimated.

The overall measure of fit between the observed and simulated sediment yields is assessed through three statistical indices viz. RE (Relative Error), DV (Deviation of Volume) and RMSE (Root Mean Square Error). The results of this analysis are depicted in Figures 3 to 4. Table 9 illustrates observed vs. simulated annual sediment yields (in tons) for Salla Rautella/ Naula (pine and oak forest) micro-watersheds. It could be clearly observed from this table that these estimates are associated with about 49% mean relative errors and mean DV value of about 0.51.

It indicate that point predictions of annual sediment yields are of moderate quality. However, root mean square error estimates and comparison of mean and standard deviation values for the observed and simulated sediment yields (Fig. 2) show that long term sediment yields could be estimated quite realistically. This could also be observed from KW-GIUH-MUSLE model based sediment yield estimates for Deolikhan micro-watershed (Table 10 and Fig. 3). Table 10 shows that sediment yield estimates for Deolikhan micro-watershed are associated with about 6% mean relative error and 0.94 mean DV value.The above analysis thus clearly shows that the developed KW-GIUH-MUSLE model could indeed be utilized for obtaining reasonable sediment yield estimates for un-gauged/ inadequately gauged micro-watersheds.

Conclusions

Developed KW-GIUH-MUSLE model can be utilized for obtaining reasonable sediment yield estimates for the un-gauged/ inadequately gauged micro-watersheds.

Thies model can be used with minimum data on ungauged/inadequately gauged micro-watersheds with moderate results in different ecologically conditions

The model can also be used in solving many water and soil loss problems, including appropriate and accurate designing of various soil and water conservation plans in micro-scale levels.

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Table. 1. Soil structure classes

Class	description
1	Very fine granular
2	Fine granular
3	Medium or coarse granular
4	Blocky ,platy or massive

Table. 2. Soil permeability class

Class	description	Hydraulic conductivity(mm/hr)
1	Very rapid	>200
2	Rapid	60 to 200
3	Moderate rapid	20 to 60
4	Moderate slow	6 to 20
5	Slow	2 to 6
6	Very slow	0.6 to 2

Table 3. Characteristics of different micro-watersheds for calculation of soil erodibility factor (K factor)

Name of watershed	Soil texture			Organic matter	Soil structure	Saturated Hydraulic conductivity (Ksat, mm/hr)	K factor
	% clay	% silt	% sand				
Deolikhan	7.5	22.67	70.23	1.10	3	87.204	0.18
Salla	23.22	13.33	63.44	0.73	3	133.75	0.09
Naula	14.14	26.33	59.52	1.40	3	235	0.17

Table 4: C Factor values for different types of landuse

Landuse/land cover types	C Factor values
Row Crops	0.24
Pasture/hay	0.05
Water/wet areas	0.00
Urban, low density	0.03
Urban, high density	0.00
Deciduous Forest	0.009
Evergreen/Coniferous Forest	0.004
Mixed Forest	0.007
Forest/Woody Wetland	0.003

Jianguo, Ma (2001)

Table 5. P factor values for different landuse/land cover and practices conditions

Landuse/land cover types	P factor
Barren land	1.00
Sugar caner	0.12
Wheat	0.10
Dense forest	0.80
fallow land	1.00
Moderately dense forest	0.80
Open forest	0.80
River bed	1.00
Types of practices	P factor
Terracing and contouring on slopes 3 to 8 %	0.1
Terracing and contouring on slopes 9 to 12 %	0.12
Terracing and contouring on slopes > 17 %	0.16
Strip cropping on slopes 3 to 8 %	0.25
Strip cropping on slopes 1 to 2 % and 9 to 12	0.3
Strip cropping on slopes 17 to 20 %	0.4
Strip cropping on slopes > 21 %	0.45
Contouring on slopes 3 to 8 %	0.5
Contouring on slopes 9 to 12 %	0.6
Contouring on slopes 17 to 20 %	0.8
No practice adopted	1

Deoreb Sachin (2006)

Table 6: Sub-watershed-wise extracted geomorphologic parameters for channel and overland areas in delineated Deolikhan, Salla Rautella and Naula micro-watersheds

Micro-Watershed	Sub-watershed Number	Mean overland area, A (m^2)	Cumulative Drainage area (m^2)	Mean channel length, L_c (m)	Mean overland slope, S_o (%)	Mean channel slope, S_c (%)	Mean channel width, B(m)
Deolikhan	1	66966	66966	26.45	49.06	1.05	0.25
	2	206086	206086	556.98	38.06	33.83	0.50
	3	127671	400723	268.14	42.21	22.67	0.75
Salla Rautella	1	290522	290522	485.82	26.52	17.43	0.61
	2.	189329	189329	591.82	26.18	16.97	0.48
	3	131	479982	8.08	12.46	0.10	0.83
Naula	1	58300	371700	603.74	39.83	30.18	0.71
	2	37600	37600	31.21	38.95	0.64	0.18
	3	81700	81700	259.67	31.70	24.39	0.29
	4	25400	231700	157.97	30.84	13.41	0.54
	5	66700	66700	613.39	26.18	26.90	0.25
	6	70500	139600	535.62	26.38	22.88	0.40
	7	32600	32600	83.51	38.26	7.38	0.17
	8	36500	36500	229.58	19.45	17.69	0.18
	9	5500	414800	163.94	37.65	40.54	0.76

Table 7: Sub-watershed order-wise extracted geomorphologic parameters for channel and overland areas in delineated Deolikhan, Salla Rautella and Naula micro-watersheds

Micro-Watershed name	Sub-watershed Order, i	Number of i^{th} order channels, N_i	Mean i^{th} order overland area, A_i (m^2)	Mean i^{th} order channel length L_{ci} (m)	Mean i^{th} order channel slope S_{ci} (fraction)	Mean i^{th} order overland area length L_{oi} (m)	Mean i^{th} Order overland area slope S_{oi} (fraction)	Mean i^{th} order channel width B_i (m)
Deolikhan	1	2	136526	291.72	0.17	234.00	0.44	0.39
	2	1	400723	268.14	0.23	238.06	0.42	0.75
Salla Rautella	1	2	239925	538.82	0.17	222.63	0.26	0.54
	2	1	479982	8.08	0.001	8.11	0.12	0.83
Naula	1	5	51020	243.47	0.15	104.78	0.30	0.30
	2	1	414800	365.32	0.26	218.57	0.20	0.76

Table 8: Initial and transitional state probabilities for Deolikhan, Salla Rautella and Naula micro-watersheds

Micro-watershed name	Sub-watershed Oder, i	Initial state probability of i^{th} order subwatershed, P_{OAi}	Transitional state probability of i^{th} order overland area to i^{th} order channel, P_{oaixi}	Transitional state probability of i^{th} order overland area to j^{th} order channel, P_{oaixj}
Deolikhan	1	0.68	1	1
	2	0.32	1	0
Salla Rautella	1	1.00	1	1
	2	0.00	1	0
Naula	1	0.62	1	1
	2	0.38	1	0

Table 9. Goodness of fit tests on MUSLE model Simulated annual sediment yield for Salla Rautella and Naula (forest) micro-watersheds

Storm No	Observed sediment yield (tones)	Predicted sediment yield (tones)	RE (%)	DV
1	5.10	2.20	-56.91	0.43
2	8.65	6.59	-23.81	0.75.78
3	12.34	9.46	-23.33	76.66
4	22.65	18.32	-19.18	80.82
5	7.20	3.95	-45.19	0.55
6	11.09	2.17	-80.46	0.20
7	29.99	25.39	-15.34	0.85
Mean	13.86	10.98	-49.48	0.51
STD	9.08	9.05		
RMSE		5.47		

Table 10. Goodness of fit tests on CN independent KW-GIUH-MUSLE model Simulated sediment yields for 11-test storms in Deolikhan micro-watershed

Storm No	Observed sediment yield (tones)	Predicted sediment yield (tones)	RE (%)	DV
1	0.0230	0.012	-48.13	0.52
2	0.0437	0.029	-33.49	0.67
3	0.0199	0.011	-47.01	0.53
4	0.0181	0.016	-13.01	0.87
5	0.0140	0.008	-44.01	0.56
6	0.0027	0.002	-29.92	0.70
7	0.0088	0.004	-54.58	0.45
8	0.0014	0.003	135.25	2.35
9	0.0017	0.003	92.67	1.93
10	0.0061	0.005	-26.13	0.74
11	0.0035	0.004	4.99	1.05
Mean	0.0130	0.009	-5.76	0.94
STD	0.0128	0.008	62.33	0.62
RMSE		0.007		