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Estimation of erosivity index and soil loss under different land uses in the tropical foothills of Eastern Himalaya (India)

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Abstract: The capacity of rainfall and runoff to detach soil particles is represented by "erosivity index" (EI_{30}). In the present study EI_{30} was estimated for a small slash-and-burn (jhum) affected watershed in the tropical foothills of Eastern Himalaya, Arunachal Pradesh (India). The annual EI_{30} was estimated at 974.77 MJ cm ha^{-1} h^{-1}, which fluctuates highly over the year, with standard deviation of 160.16. The lowest EI_{30} was observed during January, whereas highest value was observed during June constituting 22.96 % of annual value. Actual soil loss was also observed through experimental plots (5 x 3 m) under barren surface, forest canopy and jhum cultivation. The average annual soil loss of all plots was 2378 ton ha^{-1}, with highest annual soil loss from jhum plot and the lowest from forest plot. The results show that the area experiences high magnitude annual EI_{30} which is more concentrated during monsoon and summer than post-monsoon and winter. This high EI_{30} roughly coincides with jhum burning and cleaning activities and thereby causes heavy soil loss.

Resumen: La capacidad de la lluvia y la escorrentía para desprender partículas del suelo está representada por el "índice de erodabilidad" (EI_{30}). En el presente estudio se estimó el EI_{30}en una cuenca pequeña afectada por agricultura de roza, tumba y quema (jhum) en las estribaciones tropicales del oriente de los Himalayas, Arunachal Pradesh (India). El EI_{30} anual estimado fue de 974.77 MJ cm ha^{-1} h^{-1}y éste fluctúa fuertemente a lo largo del año, con una desviación estándar de 160.16. El EI_{30}más bajo se observó durante enero, mientras que el valor más alto correspondióa junio, equivalente a 22.96 % del valor anual. También se observó una pérdida real de suelo por medio de parcelas experimentales (5 × 3 m) en condiciones de suelo desnudo, con dosel de bosque y en cultivocon el sistema jhum. En promedio, la pérdida de suelo anual de todas las parcelas fue de 2378 t ha^{-1}, con la mayor pérdida anual de suelo en la parcela de jhum y la más baja de la parcela de bosque. Los resultados muestran que la zona experimenta un EI_{30} anual de gran magnitud, el cualse concentra más durante el monzón y el verano que en la temporada post-monzón y el invierno. Este EI_{30}coincide aproximadamente con las actividades de quema y limpieza como parte del jhumy con ello provoca unagran pérdida de suelo.

Resumo: A capacidade da chuva e do escoamento para desagregar as partículas do solo é representada pelo "índice de erodibilidade" (EI_{30}). No presente estudo o EI_{30} foi estimado para um pequeno corte e queima (jhum) numa bacia hidrográfica localizada no sopé de colinas tropicais do leste do Himalaia, Arunachal Pradesh (Índia). O EI_{30} anual foi estimado em 974,77 MJ cm ha^{-1} h^{-1}, que oscila muito durante o ano, com um desvio padrão de 160,16. O menor EI_{30} foi observado durante janeiro, enquanto que maior valor foi observado em junho constituindo

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22,96 % do valor anual. Perda real de solo também foi observada por meio de parcelas experimentais (5 x 3 m) sob a superfície estéril, dossel da floresta e cultivo jhum. A perda média anual de solo de todas as parcelas foi 2.378 ton ha^{-1}, com maior perda de solo anual a verificada com o cultivo sob a forma de jhum e a menor parcela de floresta. Os resultados mostram que a área evidência uma magnitude alta anual quando ao EI_{30} e que este é mais concentrado durante a monção de verão do que na pós-monção e inverno. Este valor de EI_{30} alto coincide, aproximadamente, com as atividade de queima e limpeza praticadas na jhum, e que por isso, são uma causa de forte perda de solo.

Key words: Erosivity index, eastern Himalaya, Jhum, soil loss, USLE.

Introduction

Soil loss refers to that material actually removed from the particular hillslope or slope segment which may be less than erosion due to on-site deposition in micro-topographic depressions (Toy & Renard 1998). On the other hand, sediment yield from the surface is the sum of the soil losses minus deposition in micro-topographic depressions, at the toe of the hillslope, along field boundaries, or in the terraces and channels sculpted into the hillslope. More than 50 % of the world's pastureland and about 80 % of agricultural land suffer from significant erosion (Pimental *et al.* 1995). The entire Himalayan region is afflicted with a serious problem of soil loss (Jain *et al.* 2001). The Himalayan and Tibetan regions cover only about 5 % of the earth's land surface; however, they supply about 25 % of the suspended load to the world's oceans (Raymo & Rudiman 1992). According to Maithani (1978), the river Ganga carries about 3.5×10^6 m^3 of sediments annually to Farraka Barrage (a dam across River Ganga in the Indian State of West Bengal). Further, rivers like Sutlej, Beas and Yamuna are reported to have erosion rates to the tune of 1.8×10^5 m^3, 3.0×10^5 m^3 and 4.9×10^5 m^3 $year^{-1}$ 100^{-1} km^2 of catchment areas respectively, whereas this rate for rivers Columbia, Mississippi and Colorado (comparable in hydrological characteristics) is reportedly about 1.2×10^3 m^3, 7.4×10^3 m^3 and 3.7×10^4 m^3 $year^{-1}$ 100^{-1} km^2.

Soil is an important ecosystem component on which depends all primary productions. It has been identified by the International Soil Science Society as a 'limited and irreplaceable resource', with natural soil formation processes requiring 200 - 400 years to build up 1 cm of top soil (Singh & Phadke 2006). The anthropogenic pressures on this important resource have increased to such an extent that the relationship between living beings and soil has become critical (Chaudhary *et al.* 2006). It has been reported that during the last 40 years 33 % of the arable land of the world is lost by erosion and it continues to be lost at the rate of 10 million ha yr^{-1} (Gupta *et al.* 2010 ; Pimental *et al.* 1995).

Soil loss models generally attempt to translate physical laws and landscape processes into mathematical relationships in order to estimate and describe the erosion in terms of factors that include rainfall erosivity index, soil erodibility, topography and management practices, among others (Merrit *et al.* 2003). The Universal Soil Loss Equation (USLE) and its revised versions combine soil erosion from all processes in the catchments into one equation which makes use of empirical coefficients to represent rainfall characteristics, soil properties and ground surface conditions (Kothiyari *et al.* 2002). Researchers worldwide have attempted soil loss assessment using different procedures and models. Oyarzum (1995) uses stratified sampling in 12 selected sites under different landuse and establishes that soil loss increases with progressive soil degradation due to losses of physio-chemical properties of the surface soil. Tran (2001) apply fuzzy logic on revised USLE (RUSLE) and conclude that RUSLE performance improves significantly with this approach. Jain & Kothiyari (2000) obtain USLE parameters through GIS to calculate gross surface erosion and finally identify sediment source areas. Jha (2002) uses RUSLE on GRASS GIS, similarly Singh & Phadke (2006) also use USLE on advance GIS to prepare erosion potential and erosion intensity maps respectively which according to them could be used to identify priority areas for integrated watershed management. Cambazoglu & Gogus (2004) predict soil loss by USLE and Modified Universal Soil Loss (MUSLE) and finally emphasize regression model as much easier method of prediction. Lee & Lee (2006) present a method for estimating soil loss using remotely sensed geospatial data which improves soil loss prediction in a basin scale.

The soil loss by and large depends on rainfall energy known as erosivity index (EI_{30}) which is represented by R factor in USLE. The R factor of USLE is the numerical descriptor of the ability of rainfall to erode soil (Wischmeier & Smith 1959). EI_{30} is, therefore, a function of total rainfall, rainfall distribution, storm intensity, storm frequency and terminal velocity of the rainfall. Soil particles are detached from the soil surface by the beating action of raindrops and shearing force of flowing water (Jain & Kothiyari 2000). Rainfall is thus the main source of energy for detachment and transport of soil particles from the soil profile. According to Poesen *et al.* (2003) in hillslope areas, overland water flow is conceptually divided into rill flow and inter-rill flow mechanisms. The concentrated overland flow with sufficient force to form a shallow channel is referred as rills. In inter-rill areas runoff occurs as a thin and broad sheet, referred as sheet-flow. As erosive power increases, small rills may converge to form large surface channels, called gullies. The rainfall-runoff EI_{30} (expressed in MJ mm ha^{-1} h^{-1} y^{-1}) is an important determinant of soil loss, especially in the humid tropics and high rainfall areas. Wischmeier & Smith (1958) report that, when factors other than rainfall are held constant, soil loss is directly proportional to R factor of USLE, which is calculated by multiplying total storm kinetic energy (E) by the maximum 30-minute intensity (I_{30}). The numerical value of R is the average annual sum of EI_{30} for storm events during a rainfall record of at least 22 years (Renard & Foster 1998). There are several methods adopted to calculate erosive energy of rainfall: Dabral *et al.* (2008); Deore (2005) use Modified Fournier's Index; Patriche *et al.* (2006) use the EI regression equation of Brown & Foster (1987); Jain & Kothiyari (2000) use EI_{30}; Lee & Lee (2006) calculate EI_{30} on Toxopeus Equation; and Singh & Phadke (2006); Raghunath (2002) use average annual rainfall, the maximum 24 hour rainfall and maximum 1 hour rainfall with recurrence of 2 years. According to Wischmeier & Smith (1978) rainfall erosive energy indicates the volume of rainfall and runoff, but a long and slow rain may have same erosive energy value as a shorter rain at much higher intensity as erosion increases with intensity (I_{30}), which indicates prolonged-peak rates of detachment and runoff. Therefore, the product term, EI_{30}, combines both total energy and peak intensity. However, most of the other methods mentioned above used total amount of rainfall, therefore, fail to encapsulate intensity component in calculating erosive energy of rainfall.

Arunachal Pradesh, in the Eastern Himalaya, forms the upper catchments of Brahmaputra basin in north-east India. People in this state and other northeastern states largely practice slash-and-burn cultivation, locally known as jhum. The growing human population and increasing anthropogenic pressure on land has reduced the jhum cycle from 10 to 2 - 3 years, resulting degradation of ecosystems and environmental quality in the hilly regions (Pangging & Arunachalam 2008). In addition, the entire northeast region falls under highest rainfall zone of the country with a tropical monsoon climate. Twenty five percent of rain showers occur during the pre-monsoon period (March - May), with the bulk of the rainfall (67 %) occurring during the monsoon period (June - September) (Samuel & Satapathy 2008). The high rainfall, jhum cultivation along slopes, and deforestation are responsible for large - scale soil losses, which is transported to rivers by run-off. The whole Arunachal Pradesh (Eastern Himalaya) region has been placed in the "high to very high" water erosion vulnerability category, and "very high" human-induced water erosion category by United States Department of Agriculture, Natural Resource Conservation Services (USDA-NRCS) due to physiographic conditions, coupled with a low-input and least farming conservation-technology (Reich & Eswaran 2001). Rivers in this area flow in highly braided channels characterized by numerous mid-channel bars and islands in plain areas. The Brahmaputra, which together with its tributaries drains entire Arunachal Pradesh, is the fourth largest river in the world in terms of average discharge, but second in terms of sediment transport per unit drainage area (Kotoky *et al.* 2005). Keeping the preceding facts in mind, this communication aims to estimate rainfall EI_{30} in a small jhum-affected watershed of the tropical foothills in the Eastern Himalaya, Arunachal Pradesh, using rainfall data recorded by digital event logger. In addition, we determined soil loss under different land use practices common in the foothills, and examined relationships between soil loss, erosion index and rainfall regimes.

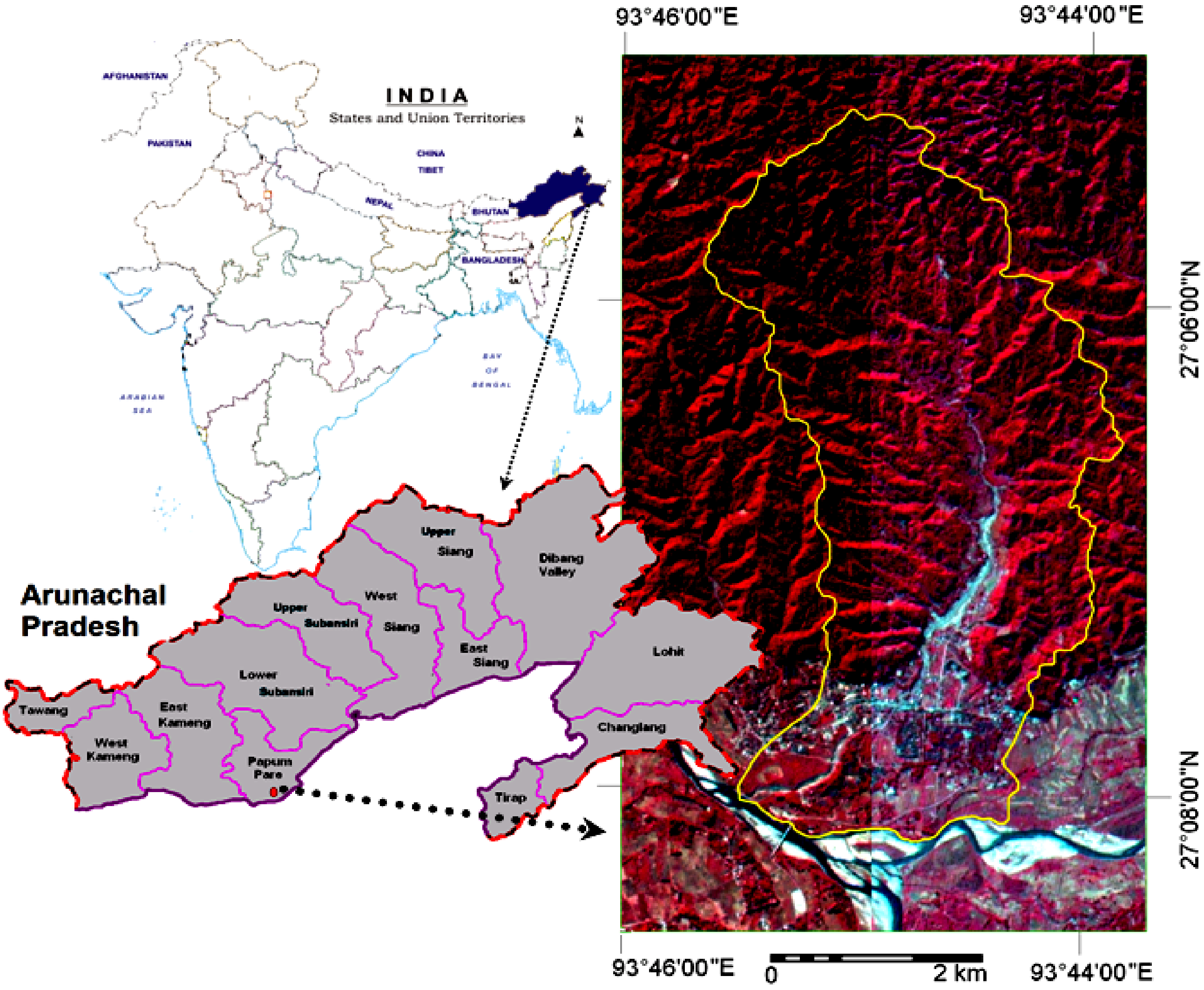

Fig. 1. Location map of study area.

Materials and methods

Study area

A small watershed of the Nirjuli stream in the tropical foothills of Eastern Himalaya extending between 27° 04' 46.78" N to 27° 07' 47.06" N latitudes and 93° 43' 58.25" E to 93° 46' 0.26" E longitudes and covering an area of 10.06 km^2 was studied. The majority of the study area towards the south consists of undulating hillocks criss-crossed by several streamlets feeding the Nirjuli (Fig. 1), whereas the northern margin is skirted by plains, mainly river terraces and piedmont plains. The hilly area consists of conglomerate, soft sandstone and clay beds in gradational contact with the underlying Subansiri formation of Outer Himalaya unconformably overlain by sub-recent terraces and flood plain deposits (Joshi & Rawat 2004). The soil texture calculated from soil samples collected at different sites are slightly gravelly sand, sand, loamy sand, slightly loamy sand and loam, where pH value ranges from 4.2 to 7 and organic matter varies from 0.33 % to 3.89 %. The terraces and piedmonts are composed of recent deposits (sand, pebbles and boulders) with pebble sizes ranging between 10 cm to 25 cm (Joshi *et al.* 2002). The forest cover includes a mosaic of dense, moderately dense, open and scrub forest. Traditional jhum cultivation is predominant along the slopes, degenerating tropical dense forest into open forest and scrub vegetation.

Methodology

The kinetic energy of rainfall (E) and the maximum 30 minute intensity of the event (I_{30})

methodology of USLE (as suggested by Wischmeier & Smith 1978) were adopted for computing the erosive index. The kinetic energy of a rainstorm depends on the size and terminal velocity of the raindrops, which are related to intensity. Hence, the energy of a rainstorm is a function of the amount and intensity of rainfall. Both number and size of raindrops increase with rain intensity and velocity of rainfall. Since the energy of a given mass in motion is proportional to mass and velocity-squared ($E \propto mv^2$), the rainfall energy is directly related to rain intensity. This relationship is expressed by the equation:

$$E = 210 + 89 \log_{10} I \quad (1)$$

where, E is kinetic energy in MJ ha^{-1} cm rain; and I is rainfall intensity in cm h^{-1}.

$$\text{Rainfall Erosivity Index} = E \times I_{30} \quad (2)$$

where, I_{30} is the maximum 30-min rainfall intensity.

A digital event logger was installed in the study area to record rainfall depth with respect to time during August 2007 to July 2008. The event logger records rainfall data into the inbuilt memory with a resolution of 0.254 mm within a given time. Windows - compatible software enables downloading logger data, which is then imported into Microsoft Excel for calculation. The peak 30-minute rainfall of each storm event was used to calculate the EI_{30}. Storms less than 12.7 mm (0.5 inches) and separated from other rain periods by more than 6 h were not considered to be sufficiently erosive, and hence were not included in computation of the erosion index, unless the maximum 15-min intensity exceeded 2.413 cm h^{-1} (0.95 inch h^{-1}) (Wischmeier & Smith 1978).

A sample EI_{30} computation is presented in Table 1 using data for a storm event on 6 November 2008 between 09:14:30 to 09:46:11.5 hours. The clock time and date are shown in the first column, with the second column containing rainfall depth (mm) as recorded by event logger. The duration (seconds) and amount of rainfall (mm) were calculated from time and depth and are shown in columns three and four, respectively. The rainfall intensity (I) (cm h^{-1}) was calculated by dividing the rainfall amount by the duration and multiplying by 60 minutes. The energy (cm^{-1}) was obtained using the intensity (I) from Equation 1. Finally, the energy for increment was calculated as the product of energy (cm^{-1}) and the amount of rainfall (cm).

The total energy of the 33.32 min storm event, with a depth of 1.17 cm, is 284.76 MJ ha^{-1}. However, a constant factor of 10^{-2} is applied to convert the storm kinetic energy to the dimension in which EI are commonly expressed (Wischmeier & Smith 1959). Thus, the kinetic energy (E) is 284.76 x 10^{-2} = 2.85 MJ ha^{-1}. Since the maximum rainfall in consecutive 30-min periods is 1.12 cm, the maximum 30-min intensity (I_{30}) = 2 x 1.12 = 2.24 cm h^{-1}. Hence, the Erosion Index (EI_{30}) is 2.85 MJ ha^{-1} x 2.24 cm h^{-1} = 6.36 MJ cm ha^{-1} h^{-1}. The relationship between soil loss and EI_{30} is assumed to be linear, and the parameter's individual storm values are directly added to find out the total EI_{30} of the period of study or averaged for annual estimation (Renard *et al.* 1996). Thus, the annual total of all significant storms in a particular locality is the annual EI_{30} or R factor of that locality. It is calculated using the equation of Wischmeier & Smith (1959):

$$R = \frac{1}{n} \sum_{j=1}^{n} \left[\sum_{k=1}^{m} (E)(I_{30}) \right]$$

where, R is the average annual rainfall EI_{30} (MJ cm ha^{-1} h^{-1}), E is the kinetic energy (MJ ha^{-1}), I_{30} is maximum 30-min rainfall intensity (cm h^{-1}), j is the index of number of years used to produce the average; k is the index of number of storms in a year; n is the number of years used to obtain the average; and m is the number of storms in each year.

Actual soil loss was also measured during the period over which the EI_{30} was calculated. For this 3 experimental plots of rectangular shape, each having length of 5 m and breadth of 3 m, were laid down along the slope direction with average slope of 27°. The plots were set up under different surface conditions i.e. each under barren surface, forest canopy and shifting cultivation with soil texture varying from loamy sand to loam. In order to reduce variation is soil properties, plots were deliberately set up within 5 m distance from each other. The surface of barren plot was left undisturbed and was covered with grasses. Forest plot was set up under bamboo mixed canopy, a dominant forest cover type in the area, while its surface was covered with twigs, litter and undergrowth. In the jhum plot, forest plants were cut down, cleaned and seeds were sown. The local jhum cultivators slash forest for jhum during November to January; set fire on slashed forest and thereafter clean the surface during March to April; sow mixed seeds through dibbling method during May; and finally, harvest their mixed crops from September to November. Similar timings and conditions were followed under the jhum plot in

Table 1. Calculation of EI_{30} from digital logger data for a storm event.

Date/Time	Depth (mm)	Duration (second)	Amount (mm)	Intensity (cm h-1)	Energy	
					cm-1	For increment
06/11/08 09:14:30.0	0.000	0	0	0.00	0	0.00
06/11/08 09:14:51.5	0.254	21	0.254	4.35	267	6.78
06/11/08 09:15:09.5	0.508	18	0.254	5.08	273	6.93
06/11/08 09:15:32.5	0.762	23	0.254	3.98	263	6.68
06/11/08 09:16:02.0	1.016	30	0.254	3.05	253	6.43
06/11/08 09:16:35.5	1.270	33	0.254	2.77	249	6.32
06/11/08 09:17:16.5	1.524	41	0.254	2.23	241	6.12
06/11/08 09:17:59.5	1.778	43	0.254	2.13	239	6.07
06/11/08 09:19:03.5	2.032	64	0.254	1.43	224	5.69
06/11/08 09:19:27.5	2.286	24	0.254	3.81	262	6.65
06/11/08 09:19:50.0	2.540	22	0.254	4.16	265	6.73
06/11/08 09:20:07.5	2.794	17	0.254	5.38	275	6.99
06/11/08 09:20:32.5	3.048	25	0.254	3.66	260	6.60
06/11/08 09:20:52.0	3.302	19	0.254	4.81	271	6.88
06/11/08 09:21:23.0	3.556	31	0.254	2.95	252	6.40
06/11/08 09:21:56.0	3.810	33	0.254	2.77	249	6.32
06/11/08 09:22:27.0	4.064	31	0.254	2.95	252	6.40
06/11/08 09:22:46.0	4.318	19	0.254	4.81	271	6.88
06/11/08 09:23:11.5	4.572	25	0.254	3.66	260	6.60
06/11/08 09:23:38.0	4.826	27	0.254	3.39	257	6.53
06/11/08 09:24:10.0	5.080	32	0.254	2.86	251	6.38
06/11/08 09:24:39.0	5.334	29	0.254	3.15	254	6.45
06/11/08 09:25:33.0	5.588	54	0.254	1.69	230	5.84
06/11/08 09:26:20.0	5.842	47	0.254	1.95	236	5.99
06/11/08 09:26:48.0	6.096	28	0.254	3.27	256	6.50
06/11/08 09:27:29.0	6.350	41	0.254	2.23	241	6.12
06/11/08 09:28:09.5	6.604	41	0.254	2.23	241	6.12
06/11/08 09:28:35.0	6.858	26	0.254	3.52	259	6.58
06/11/08 09:29:17.0	7.112	42	0.254	2.18	240	6.10
06/11/08 09:29:51.5	7.366	34	0.254	2.69	248	6.30
06/11/08 09:30:46.0	7.620	55	0.254	1.66	230	5.84
06/11/08 09:31:33.5	7.874	47	0.254	1.95	236	5.99
06/11/08 09:33:08.0	8.128	94	0.254	0.97	209	5.31
06/11/08 09:34:32.5	8.382	85	0.254	1.08	213	5.41
06/11/08 09:36:09.0	8.636	96	0.254	0.95	208	5.28
06/11/08 09:37:03.0	8.890	54	0.254	1.69	230	5.84
06/11/08 09:37:36.5	9.144	34	0.254	2.69	248	6.30
06/11/08 09:38:06.5	9.398	30	0.254	3.05	253	6.43
06/11/08 09:38:36.5	9.652	30	0.254	3.05	253	6.43
06/11/08 09:39:00.5	9.906	84	0.254	1.09	213	5.41
06/11/08 09:39:42.0	10.160	81	0.254	1.13	215	5.46
06/11/08 09:40:17.5	10.414	35	0.254	2.61	247	6.27
06/11/08 09:41:04.5	10.668	47	0.254	1.95	236	5.99
06/11/08 09:41:50.5	10.922	46	0.254	1.99	237	6.02
06/11/08 09:42:45.0	11.176	55	0.254	1.66	230	5.84
06/11/08 09:44:02.5	11.430	77	0.254	1.19	217	5.51
06/11/08 09:46:11.5	11.684	129	0.254	0.71	197	5.00
Totals		1999	11.684			284.76

Note: Date is in month/day/year and time in hour/minute/second formats as recorded by event logger.

Table 2. Erosivity index (EI_{30}), rainfall and observed soil loss.

Months	EI_{30}	EI_{30} Concen-tration	Rainfall (mm)		Soil Loss (ton ha^{-1})			
			Recorded	Average	Barren	Forest	Jhum	Average
January	3.24	0.16	45.47	33.39	10.93	5.21	59.81	25.32
February	6.41	0.32	36.32	69.57	4.25	1.60	35.07	13.64
March	118.07	5.98	196.09	113.40	73.10	12.61	499.05	194.92
April	73.99	3.75	215.39	240.08	2.93	22.49	239.29	88.24
May	130.99	6.63	309.37	503.68	140.47	132.64	538.90	270.67
June	453.35	22.96	734.82	720.64	759.90	271.57	1098.61	710.03
July	235.89	11.95	521.72	552.87	577.48	159.79	831.40	522.89
August	298.56	15.12	318.01	420.04	132.71	37.02	534.22	234.65
September	382.66	19.38	563.88	398.98	222.57	60.72	598.00	293.76
October	271.61	13.75	211.07	168.50	20.58	14.26	37.85	24.23
November	0	0	0	33.09	0.00	0	0	0
December	0	0	0	16.66	0.00	0	0	0
Total	1974.77	100	3152.14	3270.88	1944.92	717.91	4472.20	2378.34

order to have insight of soil loss during the various crop phases and rainfall regimes. Galvanized steel sheets were placed 15 cm below the surface and remaining 35 cm above the surface to fence the plots all around. In each plot an outlet was made from the galvanized sheets at lower side in which a plastic pipe of 5 cm diameter was fitted to convey runoff into a tin container of 15 liters capacity. Water in the container is measured weekly or sometime (during heavy rainfall) in higher frequency using a graduated scale thereby depth of rainfall and water volume is calculated. The sample water collected weekly from each plot is filtered in the laboratory through tissue papers thereafter the tissue papers containing filtered soils were oven-dried and weighed through digital balance to calculate soil loss.

Results and discussion

Table 2 shows the monthly EI_{30} in the study area calculated based on rainfall data using a digital event logger. It is evident that EI_{30} fluctuates substantially over the months largely depending on the variable magnitudes and intensities of rainfall. The highest EI30 (453.35 MJ cm ha^{-1} h^{-1}) was observed in June (Table 2), whereas, the EI was zero in November and December, due to low rainfall. During January and February the EI_{30} was 3.24 and 6.41 MJ cm ha^{-1} h^{-1}, respectively, and in April it was 73.99 MJ cm ha^{-1} h^{-1}. In the remaining months the EI_{30} was generally above 100, with values in June and September above 300, fluctuating from 200 to 300 MJ cm ha^{-1} h^{-1} during July, August and October. Thus 22.96 % of the annual EI_{30} was accounted for in June alone, with July, August, September and October it accounting for 11.95 %, 15.12 %,19.38 % and 13.75 %, respectively. By contrast, between January to May each month accounted for less than 7 %, with the lowest value (0.16 %) observed in January.

Table 2 also presents measured soil loss against the corresponding period over which the EI_{30} was measured for different surface conditions. The average annual soil loss of all plots was 2378 ton ha^{-1}. The highest annual soil loss was generated from the jhum plot (4472.2 ton ha^{-1}), with maximum soil loss measured in June and the minimum in November and December. The annual soil loss from the barren field plot was 1944.92 ton ha^{-1}, with values fluctuating from 0 in November and December to 760 ton ha^{-1} in June. The plot under forest canopy yielded the lowest annual soil loss (718 ton ha^{-1}), with monthly values ranging from 1.6 to 271 ton ha^{-1}. Dabral *et al.* (2001) attempts to determine soil erosion ratio or soil erodibility following Middleton (1930) based on soil dispersion ratio, soil moisture content and soil colloid content. He derives erosion ratios under prominent landuses viz. land under jhum, forest cover, forest fire, natural grasses (virgin soil) and settled agriculture from the micro-watersheds of Dikrong river basin which is adjacent to present study area. He establishes low erosion ratios in the forest soil compared to other landuses. Jain *et al.* (2001) use two models viz. Morgan *et al.* (1984) and USLE to estimate soil loss from Himalayan watershed in the Western Dun Valley, Dehra Dun i.e. watershed of Asan river system, a tributary of river Yamuna. Both Morgan model and USLE model show very less soil loss from the forested

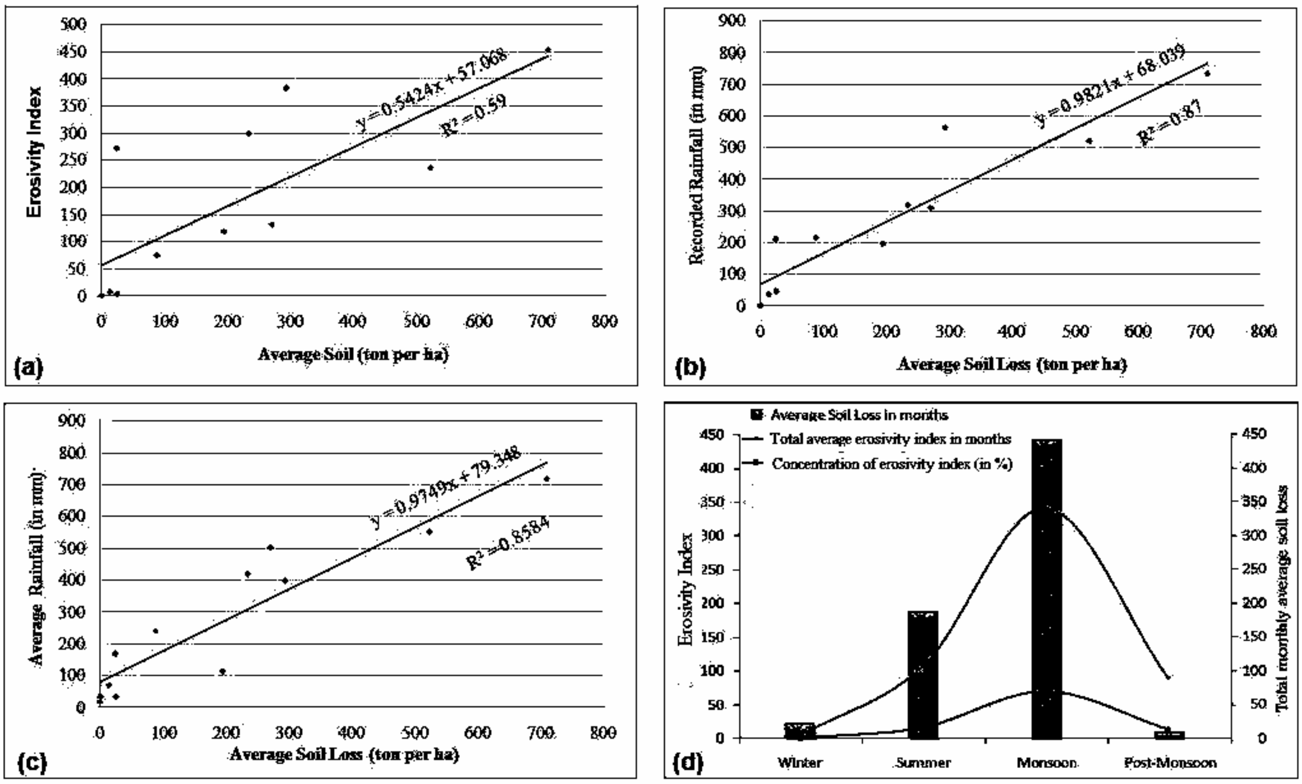

Fig. 2. Scatter diagrams of (a) EI_{30} and average observed soil loss; (b) Recorded rainfall and average observed soil loss; (c) Average rainfall and average observed soil loss; and (d) Seasonal EI_{30}, its concentration and soil loss.

Table 3. Seasonal EI_{30} and slash-and-burn (jhum) activities.

Parameters	Winter (Jan-Feb)	Summer (March-May)	Monsoon (June-Sept)	Post-Monsoon (Oct-Dec)
Jhum related activities	New jhum site selection & slashing or clear felling forest	Burning, cleaning & dibbling seeds	collecting vegetables, especially green leaves	Harvesting cereal & other crops & abandoning jhum for fallow
General surface conditions	Covered with residues of slashed forest	Clean hill slopes or jhum under seed beds	Covered with mixed crops in different growing stage	Covered with crops & crop residues (straw)
Average EI_{30} in months (MJ mm ha^{-1} h^{-1})	4.83	107.68	342.62	90.54
Standard deviation of EI_{30}	2.24	29.89	95.21	156.81
Coefficient of Variance (%)	46.46	27.75	27.79	57.74
Concentration of EI_{30} (%)	0.48	16.36	69.41	13.75
Monthly Average Soil Loss (Barren)	7.59	72.17	423.17	6.86
Monthly Average Soil Loss (Forest cover)	3.41	55.91	132.28	4.75
Monthly Average Soil Loss (Jhum)	47.44	425.75	765.56	12.62
Total Monthly Average Soil Loss (ton ha^{-1})	19.48	184.61	440.33	8.08

areas and give higher soil loss from poorly vegetated, fallow lands, open scrub and mixed forest occupying higher altitudes. The low value of soil loss from forested areas is partly because of their rooting characteristics and partly because of protection of the soil surface from raindrop impact by the plant canopy (Quansah *et al.*1990). Forest vegetation offers better ground protection than crops because their cover develops faster and forest canopy protects more surface area than the crops (Jabbar *et al.* 2005). The high humus content and thereby organic matter content of the forested soil increases its aggregation, further decreasing erodibility. Further, the soils under forest cover have higher water retention and infiltration rate, and lower dispersion and erosion ratios, relative to bare and agricultural soils (Khera & Kahlon 2005; Singh & Khera 2008).

The monthly average soil loss was positively correlated with EI_{30}, average rainfall and recorded rainfall (Fig. 2 a, b & c). Dabral *et al.* (2008) carried out soil loss assessment in Dikrong river basin of Arunachal Pradesh using USLE with the R factor derived from Modified Fournier's Index that uses monthly and annual rainfall. The Nirjuli stream of the present study, in fact, is a tributary of River Dikrong. Dabral *et al.* (2008) also found a close correlation between the rainfall characteristics and soil loss, and an increase in rainfall amount is generally accompanied by an increase in soil loss. However, in present case the correlation coefficient (R^2) between soil loss and EI_{30} was 0.59, between soil loss and average rainfall was 0.86 and that of soil loss and observed rainfall was 0.87. The lower value of R^2 of soil loss with EI_{30} than that of rainfall suggests that other factors, such as soil erodibility, surface condition, antecedent moisture, and topographic conditions also affect soil loss.

The standard deviation of 160.16 MJ cm ha^{-1} h^{-1} and CV of 97.32 % for the annual EI_{30} in the study area reveals high annual variability than that of across the season. Seasonal EI_{30}, its concentration, and observed soil loss in the corresponding period (Table 3 and Fig. 2 d) shows that the maximum EI_{30} is during the monsoon season. The average monthly EI_{30} during the monsoon is 342.62 MJ cm ha^{-1} h^{-1} with low fluctuation, as indicated by the standard deviation of 95.21 MJ cm ha^{-1} h^{-1} and a CV of 27.79 %. The average EI_{30} in summer months is 107.68 MJ cm ha^{-1} h^{-1}, with a standard deviation of 29.89 MJ cm ha^{-1} h^{-1} and a CV of 27.75 %. During post-monsoon season the monthly average EI_{30} is 90.54 MJ cm ha^{-1} h^{-1}, which was highly variable, with standard deviation of 156.81 MJ cm ha^{-1} h^{-1} and a CV of 57.74 %. The minimum average monthly EI_{30} was 4.83 MJ cm ha^{-1} h^{-1} during winter season, with a standard deviation of 2.24 MJ cm ha^{-1} h^{-1} and a CV of 46.46 %. The concentration of the erosive energy was highest during monsoon and follow the order: monsoon (69.41 %) < summer (16.36 %) < post-monsoon (13.75 %) < winter (0.48 %). Thus the erosive energies are more concentrated and less variable during monsoon and summer than post-monsoon and winter seasons. The concentrated, consistent and high EI_{30} during the monsoon produces high monthly average soil loss (440.33 ton ha^{-1}) from all plots together, which is 765.56 from jhum; 427.17 from barren; and 132.28 ton ha^{-1} from forest land. During summer, the monthly average soil loss is 184.61 ton ha^{-1} from all plots, 425.75 from jhum bed; 72.17 from barren condition; and 55.91 ton ha^{-1} from forested area.

In Arunachal Pradesh the traditional jhum cultivation practices along the hill slope are a predominant agricultural practice. The selected area is clear-cut for jhum cultivation in November-January, and the vegetation is left on the soil surface for a couple of months to be complete dried. Once the slashed biomass is adequately dried, it is set on fire during March-April (Fig. 3d) for the complete incineration of plant residues. The hill slopes are then cleaned for dibbling (digging) crop seeds. Seeds are generally sown in the jhum bed during April - May. Thus, the clean jhum surface - devoid of any litter or effective cover - roughly coincides with highly concentrated, consistent and heavy erosive energy of the monsoon and summer seasons (Table 3). On the other hand, land under jhum also depends on these heavy rainfalls of summer and monsoon for distribution of moisture to the field crops because the traditional jhum fields have no provisions for irrigation. However, it is evident that such jhum burning and cleaning during summer and monsoon causes a high amount of soil loss from hillslopes annually. Further, the region along with the foothills of the Shiwaliks is comprised of undulating terrains and soils that are structurally very poor (Singh & Khera 2008). Soil is an important element of these ecosystems, playing a crucial role in biochemical and geochemical cycling, water storage and release, pH buffering, and energy partitioning, all of which are essential for supporting ecosystems (Dwivedi 2002). In addition, soil loss has both onsite and off-site effects. Onsite effects include removal of top soil, decrease in soil fertility, and low productivity, whereas siltation, river braiding,

Fig. 3. (a) Soil loss observation plot under forest canopy; (b) Soil loss plot under barren condition; (c) Soil loss plot under jhum cultivation; and (d) Clear fell forest burnt for jhum.

island or delta formation, mudflow, swelling of flood water, and spill of flood water are some of the off-site effects of soil losses.

Conclusions

The EI_{30} or R factor of USLE significantly predicts the erosive energy of storm events over time periods that are relevant for planning and management processes in multiple fields. The use of high-resolution Digital Logger rainfall data gives a better result of EI_{30} than daily, monthly and annual data, although it involves robust calculations. For precise estimation of EI_{30}, a high-resolution Digital Logger data with longer temporal duration is desirable so as to eliminate annual variations due to the sporadic nature of rainfall. The results of our study reveal that the study area experiences a high magnitude of annual erosive energy due to the heavy rainfall, with a more concentrated and consistent high EI_{30} observed during the monsoon and summer seasons. The high-energy erosive events in the study area roughly coincide with burning and cleaning of the slashed forest area under juhm. This prevailing phenomenon, in conjunction with the high magnitude annual EI_{30} of the study area, is expected to cause heavy soil loss. Therefore, additional research on EI_{30} and soil loss at broader spatio-temporal scale is needed in this jhum affected region for sensitization and prioritization of soil management strategies.

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