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Estimation of Soil Loss in Chhatra II Micro Watershed under Semi-Arid Agro-Climatic Conditions in Raichur District

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A B S T R A C T

The detailed land resource inventorization of Chhatra II micro-watershed was carried out to a scale of 1:8000 using IRS imagery and cadastral map of the area as base map aided by ground truth delineation. The contiguous surface soil sampling was done from the grid, each of the size of 6 ha and profile sampling was done at identified sites considering the factors of slope, topography, physiography and land forms. The results which depicted the variability as well as distribution of the aforesaid physical factors within the micro watershed revealed that slope is (gently sloping, 3-5%) about 293 ha, depth (shallow, 25-50 cm) about 369 ha, texture (sandy loam, 48.2%) about 313 ha and gravelliness (gravelly, 39.63%) about 257 ha, hence resulting in 23 soil phase units. The spatial weighted annual average soil loss rate of Chhatra II micro watershed was 290.1 Mg $ha^{-1}yr^{-1}$ contrary to 343.6 Mg $ha^{-1}yr^{-1}$ when considering temporal variation under the prevailing agro-climatic conditions. Several soil and water conservation measures such as contour bunding and graded bunding were then proposed.

Introduction

Knowledge on soil as a component of land and soil loss in particular is essential to help understand the ability and capacity to sustenance the ecosystem as in which land management decisions should be adopted also assisting in the planning for future land use, particularly agriculture as in its potential for long term productivity of the soil. Soil loss is the function of both the soil physical characteristics (K-factor), topography and the land management practices. It is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff which in turn is responsible for soil transport. Factors which influences erosivity of rainfall (that ultimately affect the erodibility of soil) include quantity of rainfall as more rain goes with more erosion but in statistical terms the correlation between the two is poor considering the effectiveness of rain as in how it is distributed through the year. Rainfall intensity also comes into play as there is considerable evidence of close association between erosion and intensity, and intensity is particularly important as a parameter of erosivity because it is the only feature of rainfall which, in addition to amount, is frequently recorded at conventional meteorological stations.

There is also raindrop size as the energy released by thousands of raindrops during impact over the bare surface (that ultimately causes detachment) is affected by the size of the raindrops i.e. the larger the diameter drops the greater the detachment and subsequent rainfall erosion. Steep land is more vulnerable to water erosion than flat land for the obvious reason that erosive forces, splash, scour and transport all have greater effect on steep slope. The difference in erosion caused by different management on the same soil is very much greater than the difference in erosion from different soils given the same management. Therefore the best management may be defined as the most intensive and productive use of which land is capable without causing any degradation hence an attempt was made aimed at identification and prioritization of the potential risks posed by erosion to both the environment and the farming community in Chhatra II by identifying the areas that are likely to be affected by erosion and the extent to which they are affected.

Materials and Methods

Chhatra II micro-watershed (4D3A7I1f) is part of Kalarhatti sub-watershed, Lingasuguru taluk of Raichur district, Karnataka State and it lies between 76˚23´ to 76˚26´ East longitudes and 15˚52´ to 15˚54´ North latitudes covering a total area of 648.43 hectares bounded by Hegapur, Hadagalli and Todki villages (Fig. 1). Chhatra II micro watershed forms part of the North-Eastern dry zone of agro-climatic region of Karnataka hence "fairly" displaying conditions of a Subtropical climate. Geology of the study area is solely contributed to by granite rocks. The long term average annual rainfall for Chhatra II is 584.80 mm most of which is experienced during *kharif* (June to October) about 81.4 per cent. December is the coldest month with the mean daily maximum and minimum temperatures of 29.3˚C and 17.7˚C respectively, while May is the hottest month with a mean daily maximum temperature of 39.8˚C.

Land Resource Inventory

The detailed land resource study of Chhatra II micro-watershed was carried out to a scale of 1:8000 using IRS imagery and cadastral map of the area as base map aided by ground truth delineation. The survey was carried out by the standard soil survey procedures as described in the soil survey manual (IARI, 1971). At first instance, the traversing of the study area was done to have a resource inventory of physiography, streamlines, geology, vegetation, and land use. Based on soil surface heterogeneity locations were fixed to study pedons. Pedons were studied in the field out of several mapping units for their morphological features. A soil sample from identified horizons of each pedon was collected for analysis of Physico-chemical properties. The contiguous surface soil sampling was done from the grid, each of the size of 6 ha and profile sampling was done at identified sites considering the factors of slope, topography, physiography and land forms. The horizons were identified and designated according to revisions in Soil Taxonomy. Horizon wise soil samples were collected from pedons. The derived soil phase units are referred from Sujala-III project (Satish Kumar and Rajesh, 2018) as given in Table 1.

Estimation of soil loss

The Universal Soil Loss Equation (USLE)-Based model, having been one of the most widely accepted methods of soil loss prediction was adopted. It is regarded as the standard method for estimating soil loss. This model was designed to predict the average annual interill and rill erosion from a field slope with specific land use conditions by conservationists (Wischmeier and Smith, 1965) in the United States.

The average annual soil loss (A), is calculated as:

A = R x K x L x S x C x P(1)

Where, A = the soil loss (Mg ha^{-1})

R = the rainfall erosivity factor (MJ ha^{-1} mm h^{-1})

K = the soil erodibility factor (Mg h^{-1} MJ mm^{-1})

L = the slope length factor

S = the slope gradient factor

C = the crop management factor

P = the erosion control practice factor

Rainfall erosivity factor (R)

Rainfall erosivity of each event was derived from the product of summed up Total Kinetic Energies and maximum 30 min intensity of each rainfall event. The rainfall erosivity factor (R) indicates the soil loss potential of a given storm event. The rainfall erosivity factor (R) was calculated using the 15 min interval rainfall data for period (2010–2018). Attempts have also been made to derive EI_{15} parallel to EI_{30}. Based on the work of (Wischmeier and Smith, 1958) the following equations were used:

$KE = 0.119 + 0.0873 \log_{10} I$......(2)

$EI_{30} = KE \times I_{30}$......(3)

Where,

I = rainfall intensity in mm h^{-1}

I_{30} = maximum 30 minutes rainfall intensity of the rainfall

KE = Kinetic Energy (MJ ha^{-1} mm.h^{-1})

To carry out the calculation for EI_{30}, 30 min intensity of each rainfall event was determined from their corresponding depth. Then the logarithm of the 30 min intensity was calculated for use in the Kinetic Energy equation. Kinetic Energy was multiplied with depth to calculate Total Kinetic Energy for each rainfall event. Then EI_{30} of each event is calculated from product of summed up Total Kinetic Energies and maximum 30 min intensity of each rainfall event.

Annual R-factor was calculated from product of summed up "Total kinetic energies" of each rainfall event and maximum 30 min intensity for the year.

Rainfall erosivity was also related to the corresponding intensity as well as depth to understand how it relates between them. The calculations were carried out for all the years (2010-2018) then results were presented for combined plot of the same parameters to understand the spectrum of the variability of the energy with intensity as well as depth. The values pertaining to outliers have been omitted due to lack of consistency.

Soil erodibility factor (K)

Soil erodibility factor is an estimate of the ability of soils to resist erosion based on the physical characteristics of each soil. The K-factor was computed using the soil-erodibility Nomograph. Five soil parameters are needed to use a Nomograph:

Percent silt (0.002 – 0.05 mm) + very fine sand (0.05 – 0.10 mm)

Percent sand (0.10 – 2.0 mm)

Percent organic matter content

Soil structure code (very fine granular 1, fine granular 2, medium or coarse granular 3, blocky, platy or massive, 4)

Profile permeability class (rapid 1, moderate rapid 2, moderate 3, slow to moderate 4, slow 5 and very slow 6)

Slope length and gradient factors (LS)

The L and S factors are combined as a single topographic factor which affects the soil erosion by water and wind in a landscape. The length and slope were taken from the computed contour map. Wischmeier and Smith (1971) used the following formula for determination of the slope length (L):

$$L=\left(\frac{X}{22.1}\right)^{m} \text{........(4)}$$

$$m = \frac{\sin\Theta}{\sin\Theta + 0.269\ (\sin\Theta)^{0.8} + 0.05} \text{.......(5)}$$

$$\Theta = \tan^{-1}\left(\frac{s}{100}\right) \text{........(6)}$$

Where,

L = slope length factor

X = slope length (m)

m = an exponent

Θ = field slope gradient in degrees

The slope gradient factor (S) expresses the ratio of soil loss from a plot of a known slope to soil loss from a unit plot under identical conditions. Wischmeier and Smith (1971) used the following formula for determination of slope gradient (S):

$$S = \frac{0.43+0.30+0.043s^2}{6.613} \text{.........(7)}$$

Where,

S = slope gradient factor

s= the gradient (%)

Therefore,

$$LS = \left(\frac{X}{22.1}\right)^{m} \text{x}\ (0.065 + 0.045s + 0.0065s^2) \text{........(8)}$$

Crop management and conservation practices factor (CP)

Data regarding land conservation practice (P) was taken concerning land use/land cover map in that the wide area of land was identified to be under agriculture, wasteland and social forest land uses hence the selection of (P) under these cover managing were deliberated. The value of (P) in use is 0.6, 0.5, and 0.4 for agriculture, wasteland, and forest separately based on prevalent tillage practices followed in the watershed.

For the crop cover (C) as well, land use/land cover data was employed and with a modest method of determining the (C) factor having been substantiated before in relation to referencing studies that have reported values for similar land cover, hence C-factor values from the literature were assumed by first taking average of land with cover (0.255 – 0.525), stated from Land Development Department (2002) as cited in (Nontananandh and Changnoi, 2012) while from (Morgan, 2005), he took bare land to be (1) thereafter getting (0.8) assuming 20 percent allowance for nature.

The major crops observed in the study region are bajra, sesamum, cotton, sunflower, sorghum, redgram, jowar and vegetables like onion and chilli. Out of these, Bajra and sesamum are grown in a larger area compared to other crops.

Preparation of Development plan for sustainable usage of land natural resource

The study carried out in respect of physiography, soil loss estimation, soil texture, soil depth, land slope, type of land use within the micro-watershed was used in modelling the plan of developmental actions. Soil and water conservation measures are broadly classified under two types, firstly the agronomical and vegetative measures. Biological/vegetative measures are effective only up to 2 per cent of land slope and where the problem of erosion is not severe.

Secondly is the engineering/mechanical structures which can be constructed either in-situ such as contour bunding, contour trenches, contour terracing or ex-situ such as percolation tanks, nala bunding, etc.

Soil and water conservation plan may be established by providing engineering measures/structures along with the recommended agronomical/vegetative practices viz., contour cultivation, strip cropping, inter-cropping, crop rotations, contour vegetative bunds, etc.

Results and Discussion

Land Resource Inventorization

The land resource inventorization is an important process which takes into account soil characteristics, topographical upheavals and delineation of extensivity of similar characteristics of soil as a unit.

The increase in slope (2.5-15.2 %) has been observed to have some ramifications in decreasing infiltration rate also at the same time the agricultural cropping situation during *Kharif* season has enhanced “opportunity time” for infiltration rate.

The texture with sizeable clay proportion (10 units with 265 ha) and with less clay (13 units with 346 ha) will have a clear influence on two dominant groups with infiltration rate. The gravelliness which generally largely occupies with (15-35%) indicating moderate susceptibility for erosion.

Out of total area of 648.43 ha, (369 ha) has a depth limitation (less than 25-50 cm) indicating careful selection of crop and in developing better strategy of soil and water conservation through appropriate measures and/or structures.

Estimation of Soil loss

Rainfall Erosivity

Fig. 6 and 7, analysis focused on rainfall intensity as one parameter which must be considered within rainfall analysis, because the soil may not be able to absorb all the water during a heavy rainfall hence lost away by runoff. Likewise, the water from a rain of low intensity can be lost due to evaporation, particularly if it falls on a dry surface. Rainfall intensity mostly measured as the amount of rain per hour or per day. Rainfall intensity also relates to the risk of soil erosion. It is known that individual raindrops carry energy capable of removing soil, particularly topsoil. The erosion caused by falling drops of water, called splash erosion, also can degrade or destroy the soil structure. It has been found that, as the rainfall intensity approaches 35 millimetres per hour, there is a steep rise in the erosive power of the rain. A large percentage of rainfall in the tropics occurs above this value (the so-called "erosion threshold"), (Salem, 1989).

Fig. 6 which was aimed at establishing the relationship between rainfall kinetic energy and intensity at 15 min interval, it is indicated that through the adoption of the power-law function which shows > 95 % consistency, a comparison between rainfall kinetic energy and intensity was recognized as it can be noted in the curve that there is a positive correlation between the two hence beginning with rainfall intensities in the range as low as 2 mm h^{-1} having rainfall kinetic energy of 0.1 MJ ha^{-1}. mm h^{-1}, followed by 10 mm h^{-1}, 20 mm h^{-1} with energies of 5.2 MJ ha^{-1}. mm h^{-1} and 23.2 MJ ha^{-1}. mm h^{-1} respectively a uniform trend develops after which a sudden shoot from intensities of 30 mm hr^{-1},40 mm h^{-}1, and 50 mm h^{-1} with their energies of 55.7 MJ ha^{-1}. mm h^{-1}, 103.4 MJ ha^{-1}.mm h^{-1}, 181.4 MJ ha^{-1}. mm h^{-1} respectively and moving up the curve the same was observed suggesting that there is a specific threshold intensity upon which any increment will cause a significant rainfall erosive energy rise thus more soil erosion vulnerability.

Table.1 Soil Phase units and their characteristics in Chhatra II micro watershed

Soil Phase	Soil Series*	Texture	Slope (%)	Erosion	Gravelliness (%)	Stoniness (%)	Rockiness (%)	Depth (cm)
BHGhF3g2S2R1	BHG	h (Sandy clay loam)	F(15.2)	3 (Severe)	g2 (Very gravelly);35-60	S2 (Very strong stony);0.1-3	R1 (Fairly rocky);2-10	(Very shallow); <25
CHRbC2g1S1	CHR	b (Loamy sand)	C(4.0)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony);0.01-0.1		(Shallow); 25-50
CHRcB2g1S1	CHR	c (Sandy loam)	B(3.0)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRcC2g1S1	CHR	c (Sandy loam)	C(3.5)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRcC3g1S1	CHR	c (Sandy loam)	C(2.5)	3 (Severe)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRhB2g1S1	CHR	h (Sandy clay loam)	B(3.3)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRhC2g1S1	CHR	h (Sandy clay loam)	C(2.6)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRhD3g1S1	CHR	h (Sandy clay loam)	D(5.0)	3 (Severe)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
CHRiC2g1S1	CHR	I (Sandy clay)	C(3.6)	2 (Moderate)	g1 (Gravelly); 15-35	S1 (Strong stony); 0.01-0.1		(Shallow); 25-50
HEGmC2	HEG	m (Clay)	C(3.4)	2 (Moderate)	(Non-gravelly); <15			(Moderately shallow); 50-75
KALbC2g1	KAL	b (Loamy sand)	C(3.6)	2 (Moderate)	g1 (Gravelly); 15-35			(Very shallow); <25
KALcC2g1	KAL	c (Sandy loam)	C(2.6)	2 (Moderate)	g1 (Gravelly); 15-35			(Very shallow); <25
KMTcD3g1	KMT	c (Sandy loam)	D(6.0)	3 (Severe)	g1 (Gravelly); 15-35			(Shallow); 25-50
THDcB2	THD	c (Sandy loam)	B(3.1)	2 (Moderate)	(Non-gravelly); <15			(Moderately shallow); 50-75
THDcC2	THD	c (Sandy loam)	C(3.8)	2 (Moderate)	(Non-gravelly); <15			(Moderately shallow); 50-75

THDhB2	THD	h (Sandy clay loam)	B(3.2)	2 (Moderate)	(Non-gravelly); <15			(Moderately shallow); 50-75
THDiC2	THD	I (Sandy clay)	C(4.1)	2 (Moderate)	(Non-gravelly); <15			(Moderately shallow); 50-75
VKRbC3g2S 2	VKR	b (Loamy sand)	C(3.4)	2 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3		(Shallow); 25-50
VKRcC3g2S 2R1	VKR	c (Sandy loam)	C(4.1)	3 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3	R1 (Fairly rocky);2-10	(Shallow); 25-50
VKRcD3g2S 2	VKR	c (Sandy loam)	D(8.8)	3 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3		(Shallow); 25-50
VKRcD3g2S 2R1	VKR	c (Sandy loam)	D(3.6)	3 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3	R1 (Fairly rocky);2-10	(Shallow); 25-50
VKRhC3g2S 2R1	VKR	h (Sandy clay loam)	C(2.9)	3 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3	R1 (Fairly rocky);2-10	(Shallow); 25-50
VKRhD3g2S 2R2	VKR	h (Sandy clay loam)	D(5.1)	3 (Severe)	g2 (Very gravelly); 35-60	S2 (Very strong stony); 0.1-3	R2 (Rocky)10-25	(Shallow); 25-50

* -BHG (Bhogapur), CHR (Chhatra), HEG (Hegapur), KAL (Kalmali), KMT (Kamarkhedtanda), THD (Thodki) and VKR (Vyakarnal), *Source*: Sujala-III Project

Table.2 Year-wise rainfall erosive factor (R)

Year	Max 30 min Intensity (mm h^{-1})	Rainfall for EI_{30} event (mm)	Total kinetic energy (J m^{-2})	EI_{30} index (J m^{-2} mm h^{-1})	R-factor (MJ ha^{-1} mm h^{-1})	Annual rainfall (mm)
2010	18	9.0	396.8	7142.0	71.4	503.5
2011	55	27.5	3350.6	184283.0	1842.8	420.0
2012	40	20.0	11736.5	469460.0	4694.6	414.0
2013	59	29.5	24011.6	1416684.0	14166.8	788.5
2014	67	33.5	16484.1	1104435.0	11044.3	560.0
2015	60	30.0	14249.3	854958.0	8549.6	446.0
2016	55	27.5	6866.0	377630.0	3776.3	274.5
2017	56	28.0	22950.1	1285206.0	12852.1	698.0
2018	89	44.5	10798.6	961071.0	9610.7	323.5

Table.3 Parameters of soil erodibility, K-factor

Sl. No.	Soil Phase	Soil texture	Clay %	Silt %	Sand %	Organic matter %	Structure code	Permeability code	K-factor (Mg h^{-1} MJ mm^{-1})
1	BHGhF3g2S2R1	Sandy clay loam	25	15	60	0.74	4	3	0.15
2	CHRbC2g1S1	Loamy sand	5	15	80	0.72	3	2	0.14
3	CHRcB2g1S1	Sandy loam	10	30	60	0.76	3	2	0.22
4	CHRcC2g1S1	Sandy loam	10	30	60	0.46	3	2	0.22
5	CHRcC3g1S1	Sandy loam	10	30	60	0.92	3	2	0.22
6	CHRhB2g1S1	Sandy clay loam	25	15	60	0.74	4	3	0.15
7	CHRhC2g1S1	Sandy clay loam	25	15	60	0.74	4	3	0.15
8	CHRhD3g1S1	Sandy clay loam	25	15	60	0.72	4	3	0.15
9	CHRiC2g1S1	Sandy clay	43	7	50	0.96	4	4	0.12
10	HEGmC2	Clay	67	18	15	0.72	4	5	0.18
11	KALbC2g1	Loamy sand	5	15	80	0.72	3	2	0.15
12	KALcC2g1	Sandy loam	10	30	60	0.76	3	2	0.22
13	KMTcD3g1	Sandy loam	10	30	60	0.76	3	2	0.22
14	THDcB2	Sandy loam	10	30	60	0.94	3	2	0.22
15	THDcC2	Sandy loam	10	30	60	0.72	3	2	0.22
16	THDhB2	Sandy clay loam	25	15	60	0.84	3	3	0.12
17	THDiC2	Sandy clay	43	7	50	0.96	4	4	0.12
18	VKRbC3g2S2	Loamy sand	5	15	80	0.72	3	2	0.14
19	VKRcC3g2S2R1	Sandy loam	10	30	60	0.72	3	2	0.22
20	VKRcD3g2S2	Sandy loam	10	30	60	0.64	3	2	0.22
21	VKRcD3g2S2R1	Sandy loam	10	30	60	0.64	3	2	0.22
22	VKRhC3g2S2R1	Sandy clay loam	25	15	60	0.96	4	3	0.15
23	VKRhD3g2S2R2	Sandy clay loam	25	15	60	0.88	4	3	0.15

Table.4 Annual Average Soil Loss rate, A (Mg ha^{-1}) during the year 2010-2018 of Chhatra II micro-watershed

Soil Phase	Area (ha)	Annual Average Soil Loss, A (Mg ha^{-1})									Annual Average (Mg ha^{-1})
		2010	2011	2012	2013	2014	2015	2016	2017	2018	
BHGhF3g2S2R1	17	6.7	172.5	439.4	1326.0	1033.8	800.2	353.5	1203.0	899.6	692.7
CHRbC2g1S1	1	1.6	42.3	107.7	324.9	253.3	196.1	86.6	294.7	220.4	169.7
CHRcB2g1S1	39	2.8	71.2	181.3	547.0	426.4	330.1	145.8	496.2	371.1	285.8
CHRcC2g1S1	36	2.1	55.3	141.0	425.4	331.7	256.7	113.4	385.9	288.6	222.3
CHRcC3g1S1	9	5.0	129.7	330.5	997.3	777.5	601.9	265.9	904.8	676.6	521.0
CHRhB2g1S1	17	2.0	51.7	131.8	397.8	310.1	240.1	106.0	360.9	269.9	207.8
CHRhC2g1S1	81	1.5	38.8	98.9	298.4	232.6	180.1	79.5	270.7	202.4	155.9
CHRhD3g1S1	28	2.7	70.1	178.5	538.7	420.0	325.1	143.6	488.7	365.4	281.4
CHRiC2g1S1	10	2.4	61.9	157.7	476.0	371.1	287.3	126.9	431.8	322.9	248.7
HEGmC2	13	1.8	46.6	118.6	358.0	279.1	216.1	95.4	324.8	242.9	187.0
KALbC2g1	25	3.9	99.5	253.5	765.0	596.4	461.7	203.9	694.0	519.0	399.7
KALcC2g1	5	3.8	97.3	247.9	748.0	583.1	451.4	199.4	678.6	507.4	390.8
KMTcD3g1	5	11.3	291.9	743.6	2244.0	1749.4	1354.3	598.2	2035.8	1522.3	1172.3
THDcB2	100	2.1	55.3	141.0	425.4	331.7	256.7	113.4	385.9	288.6	222.3
THDcC2	42	3.1	79.1	201.4	607.8	473.8	366.8	162.0	551.4	412.3	317.5
THDhB2	18	1.2	31.0	79.1	238.7	186.1	144.0	63.6	216.5	161.9	124.7
THDiC2	22	2.2	56.9	145.0	437.6	341.1	264.1	116.6	397.0	296.9	228.6
VKRbC3g2S2	8	1.4	35.2	89.7	270.7	211.1	163.4	72.2	245.6	183.7	141.4
VKRcC3g2S2R1	23	2.9	75.9	193.3	583.4	454.9	352.1	155.5	529.3	395.8	304.8
VKRcD3g2S2	10	5.8	150.2	382.7	1154.7	900.2	696.9	307.8	1047.6	783.4	603.3
VKRcD3g2S2R1	43	2.5	63.2	161.1	486.2	379.0	293.4	129.6	441.1	329.8	254.0
VKRhC3g2S2R1	19	1.9	48.5	123.6	372.9	290.7	225.1	99.4	338.3	253.0	194.8
VKRhD3g2S2R2	40	5.6	143.7	366.2	1105.0	861.5	666.9	294.6	1002.5	749.6	577.3
Total	**611**										-
Weighted average (Mg ha^{-1})		**2.8**	**72.2**	**184.0**	**555.4**	**433.0**	**335.2**	**148.0**	**503.8**	**376.7**	-
Annual rainfall (mm)		**503.5**	**420.0**	**414.0**	**788.5**	**560.0**	**446.0**	**274.5**	**698**	**323.5**	-

Table.5 Proposed Contour Bunding System for Soil Phase Units having texture with clay (≤ 25 %)

Sl. No.	Soil Phase Unit	Area	Slope (%)	Texture	Clay (%)	Silt (%)	Sand (%)	Proposed specifications of contour bunding			Runoff conserved at present (mm)	Expected with intervention (mm)	Average rainfall (2010-2018), (mm)
								Section (m^2)	Length (per ha)				
									Straight	Lateral			
1	CHRbC2g1S1	1	4.0	Loamy sand	5	15	80	0.79	150	50	4.6	13.8	492
2	CHRcB2g1S1	39	3.0	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
3	CHRcC2g1S1	36	3.5	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
4	CHRcC3g1S1	9	2.5	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
5	KALbC2g1	25	3.6	Loamy sand	5	15	80	0.79	150	50	4.6	13.8	492
6	KALcC2g1	5	2.6	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
7	KMTcD3g1	5	6.0	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
8	THDcB2	100	3.1	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
9	THDcC2	42	3.8	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
10	VKRbC3g2S2	8	3.4	Loamy sand	5	15	80	0.79	150	50	4.6	13.8	492
11	VKRcC3g2S2R1	23	4.1	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
12	VKRcD3g2S2R1	43	3.6	Sandy loam	10	30	60	0.79	150	50	4.6	13.8	492
13	**Total**	**336**	-	-	-	-	-	-	-	-	-	-	-

Table.6 Proposed Graded Bunding System for Soil Phase Units with clay (≥ 25 %)

Sl. No.	Soil Phase Unit	Area	Slope (%)	Texture	Clay (%)	Silt (%)	Sand (%)	Proposed specifications of contour bunding			Grade (%)	Runoff conserved at present (mm)	Expected with intervention (mm)	Average rainfall (2010-2018), (mm)
								Section (m^2)	Length (per ha)					
									Straight	Lateral				
1	CHRhB2g1S1	17	3.3	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
2	CHRhC2g1S1	81	2.6	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
3	CHRhD3g1S1	28	5.0	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
4	CHRiC2g1S1	10	3.6	Sandy clay	43	7	50	1.09	200	50	0.2	4.6	18.5	492
5	HEGmC2	13	3.4	Clay	67	18	15	1.09	200	50	0.2	4.6	18.5	492
6	THDhB2	18	3.2	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
7	THDiC2	22	4.1	Sandy clay	43	7	50	1.09	200	50	0.2	4.6	18.5	492
8	VKRhC3g2S2R1	19	2.9	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
9	VKRhD3g2S2R2	40	5.1	Sandy clay loam	25	15	60	1.09	200	50	0.2	4.6	18.5	492
10	**Total**	**248**	-	-	-	-	-	-	-	-	-	-	-	-

Fig.1 Location map of Chhatra II micro watershed

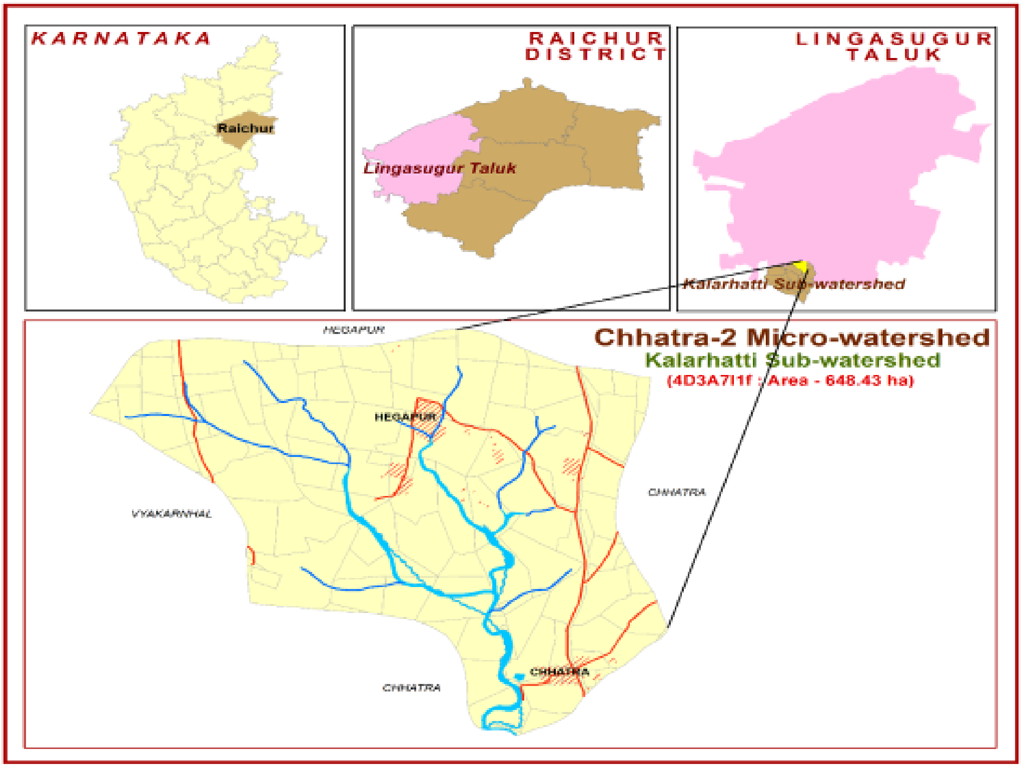

Fig.2 Nomograph for estimating soil erodibility factor (Wischmeier *et al.*, 1971)

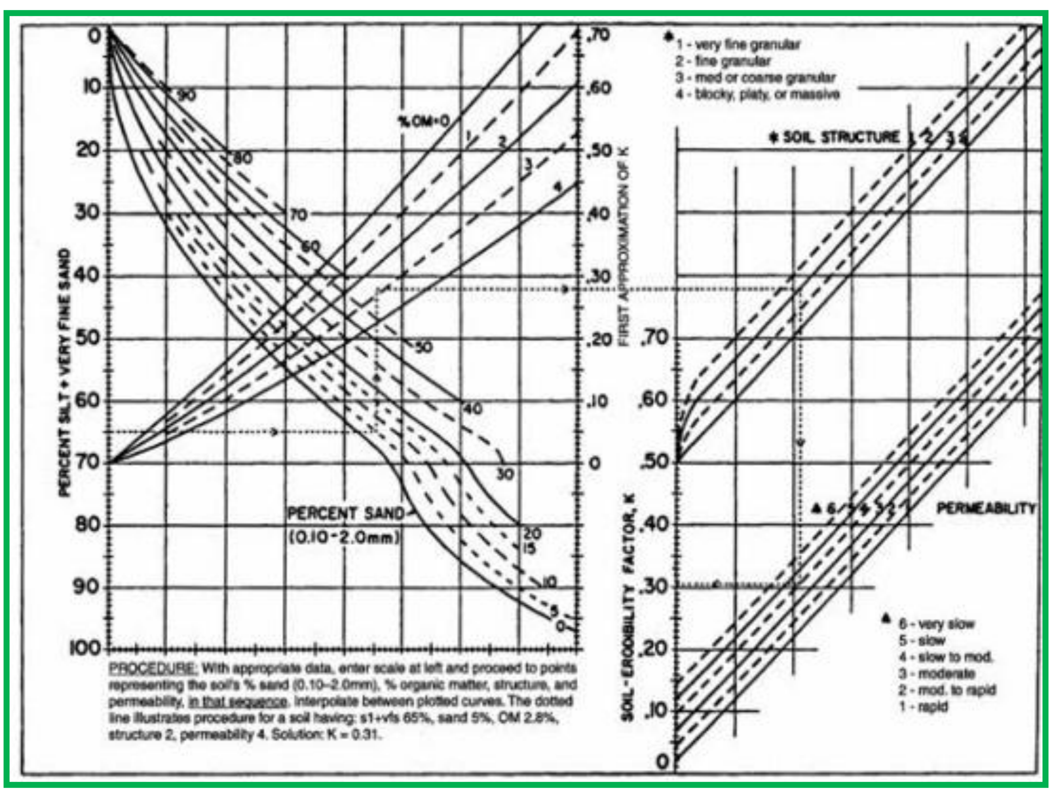

Fig.3 Variability and distribution of Slope in Chhatra II micro watershed

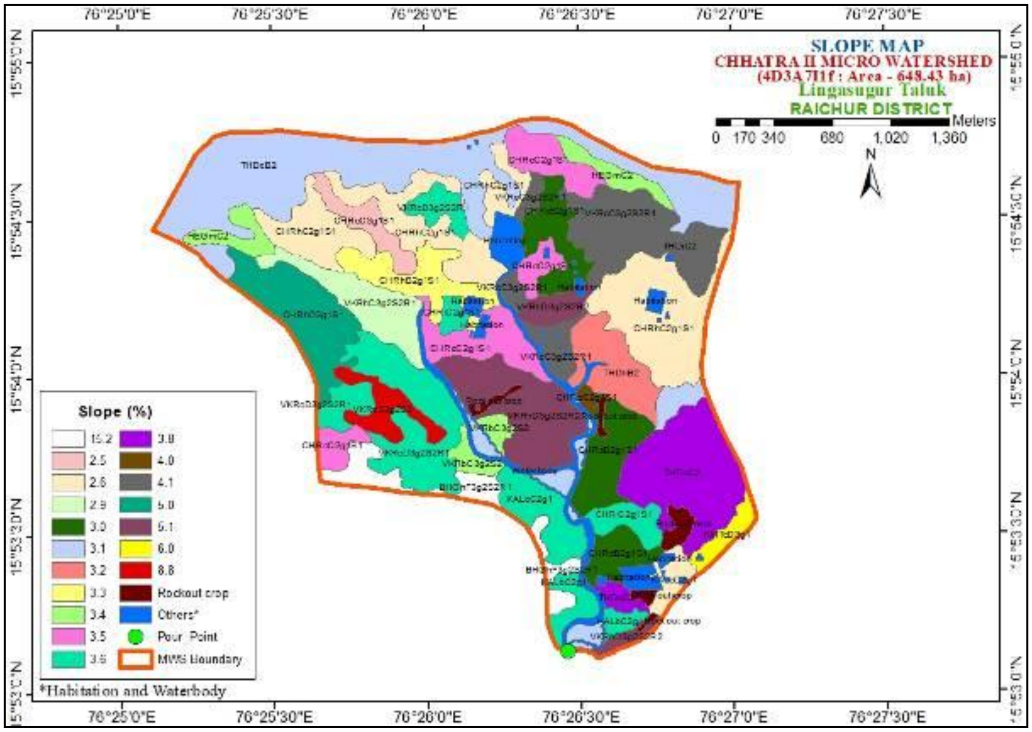

Fig.4 Variability and distribution of Topographic factor (LS)

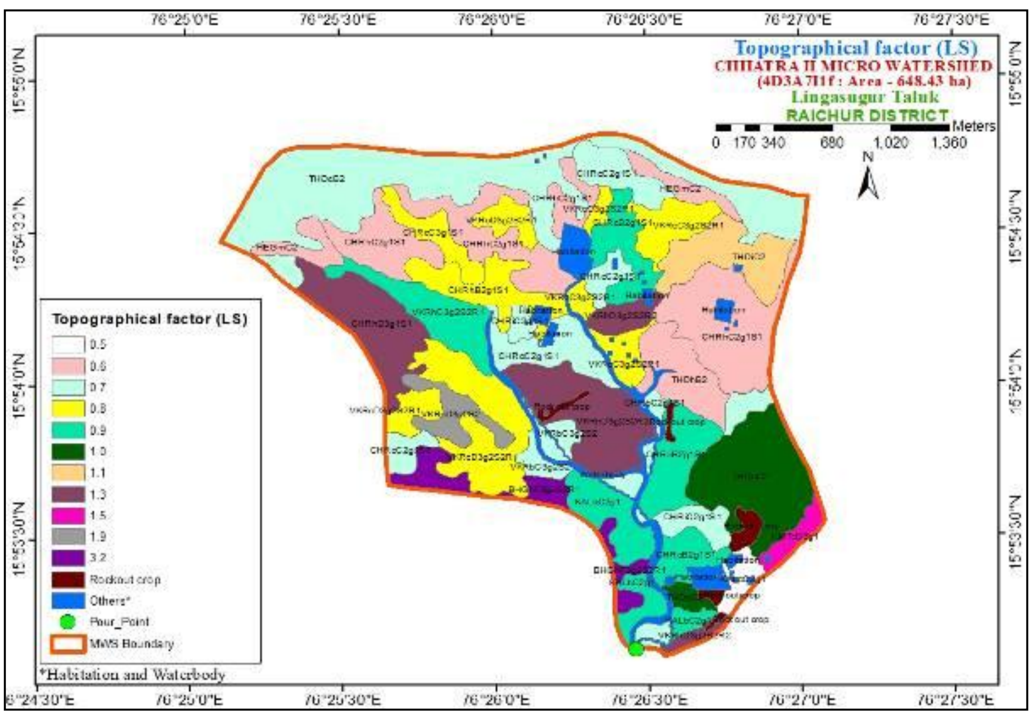

Fig.5 Variability and distribution of land use/land cover

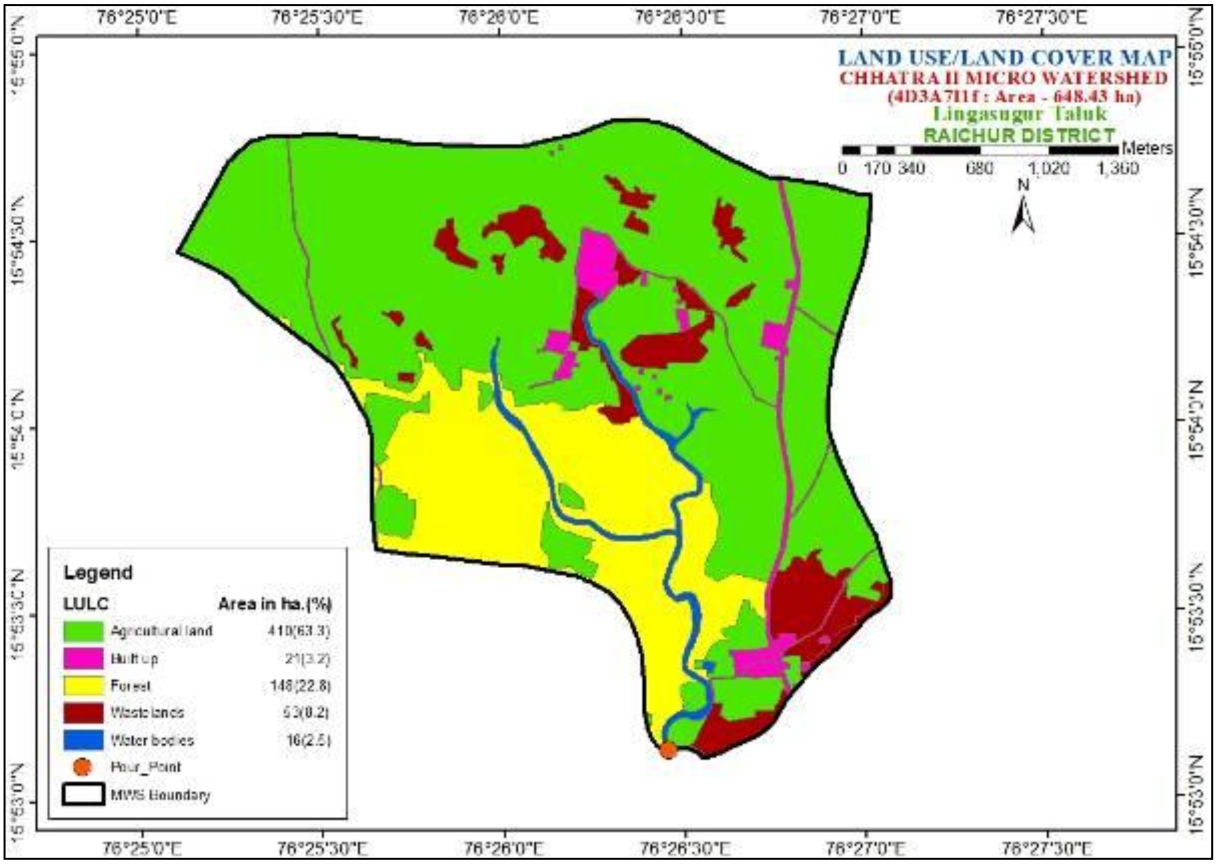

Fig.6 Plot of Kinetic Energy vs. Intensity during period (2010-2018) at 15 minutes interval

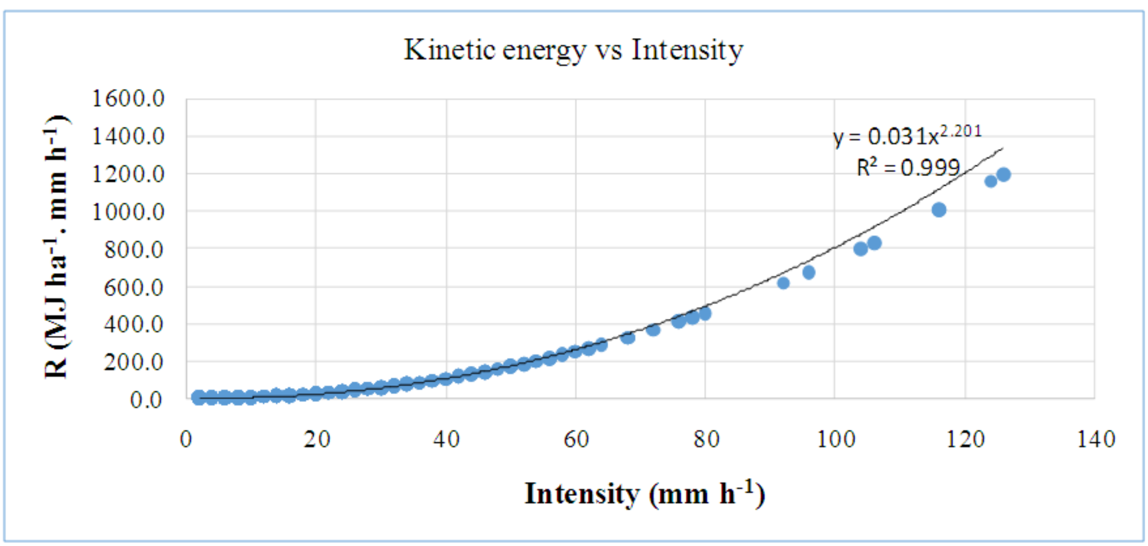

Fig.7 Plot of Kinetic Energy vs. Intensity during period (2010-2018) at 30 minutes interval

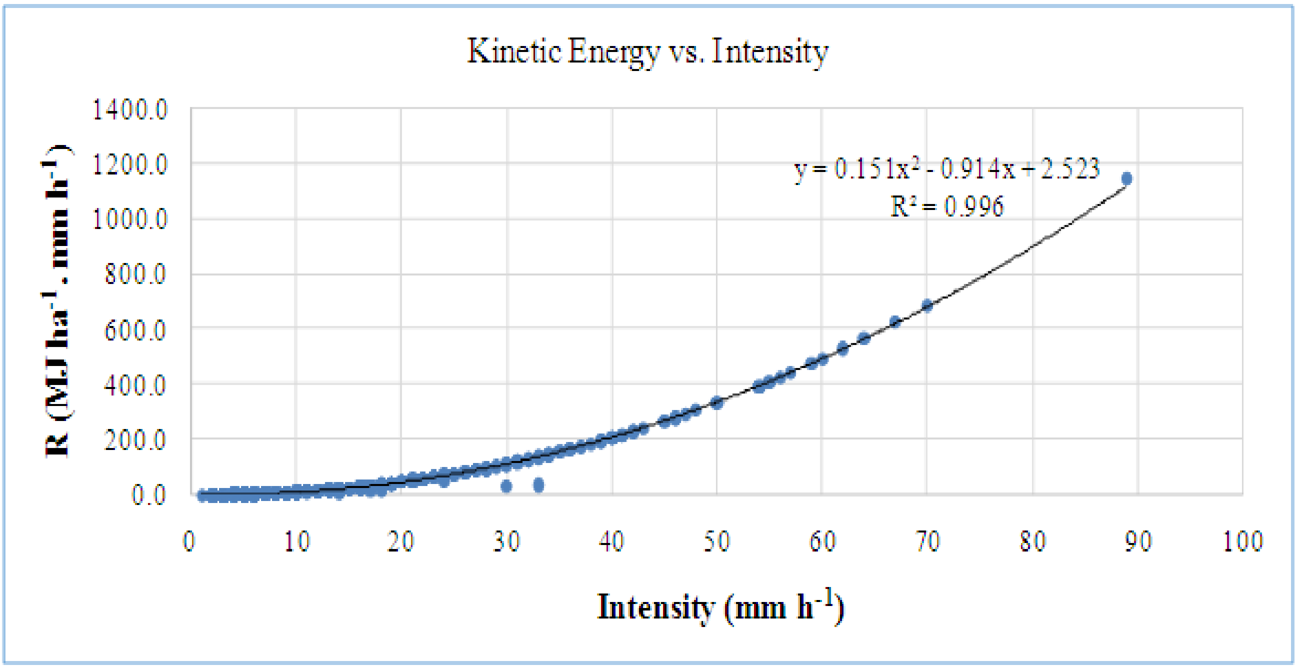

Fig.8 Plot of Kinetic energy vs. Depth during period (2010-2018) at 15 minutes interval

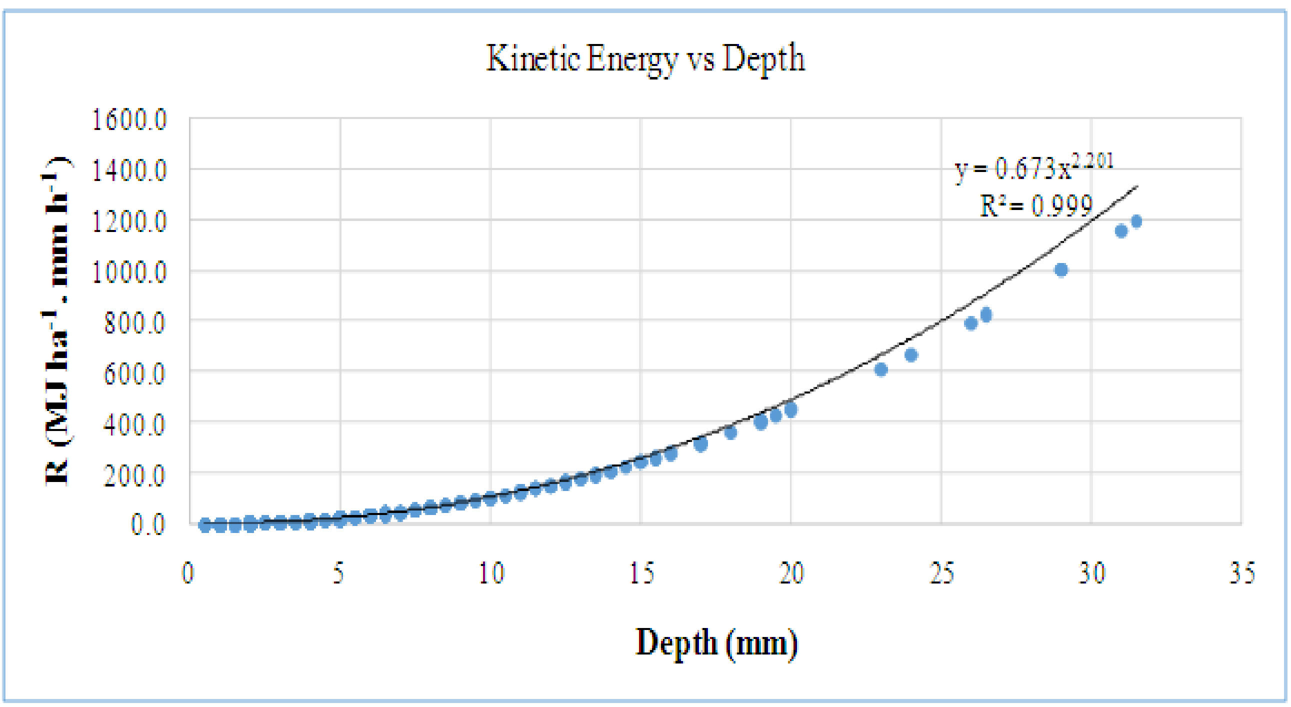

Fig. 7 which was aimed at establishing the relationship between rainfall kinetic energy and intensity at 30 min interval, it is indicated that through the adoption of the polynomial function a comparison between rainfall kinetic energy and intensity was realized as it can be noted in the curve that there is a positive correlation between the two hence beginning with rainfall intensities in the range as low as 2 mm h^{-1} having rainfall kinetic energy of 0.3 MJ ha^{-1}. mm h^{-1}, followed by 10 mm h^{-1}, 20 mm h^{-1} with energies of 10.3 MJ ha^{-1}. mm h^{-1} and 46.4 MJ ha^{-1}. mm h^{-1} respectively, a constant trend develops after which a sudden shoot from intensities of 30 mm h^{-1},40 mm h^{-}1, and 50 mm h^{-1} with their energies of 111.4 MJ ha^{-1}. mm h^{-1}, 206.7 MJ ha^{-1}. mm h^{-1}, 333.5 MJ ha^{-1}. mm h^{-1} respectively and going up the curve, the same was observed suggesting that there is a specific threshold intensity upon which any increment will cause a significant rainfall erosive energy rise thus more soil erosion vulnerability.

Garollina *et al.*, (2007) showed that it is arithmetically possible to express EI_{30} in terms of the rainfall depth. The very high coefficient of determination between rainfall depth and erosivity (R^2 =0.99; P < 0.0001) suggests that nearly 99% of the variation in erosivity is accounted for by rainfall depth.

Fig. 8 which was intended to establish the relationship between 15 min interval rainfall kinetic energy and accumulated depth, through the adoption of the power-law function which shows > 95 % consistency, indicates in the curve that there is a positive correlation between the two as observed at depth of 10 mm, pose a potential 103.4 MJ ha^{-1}. mm h^{-1} of rainfall kinetic energy and the rainfall erosive power continues to increase as the depth expands with values of 455.3 MJ ha^{-1}. mm h^{-1}, 796.3 MJ ha^{-1}. mm h^{-1}, 1197.6 MJ ha^{-1}. mm h^{-1} for depths of 20, 26, and 31.5 mm respectively as one moves up the curve is witnessed.

Fig.9 Plot of Kinetic Energy vs. Depth during period (2010-2018) at 30 minutes interval

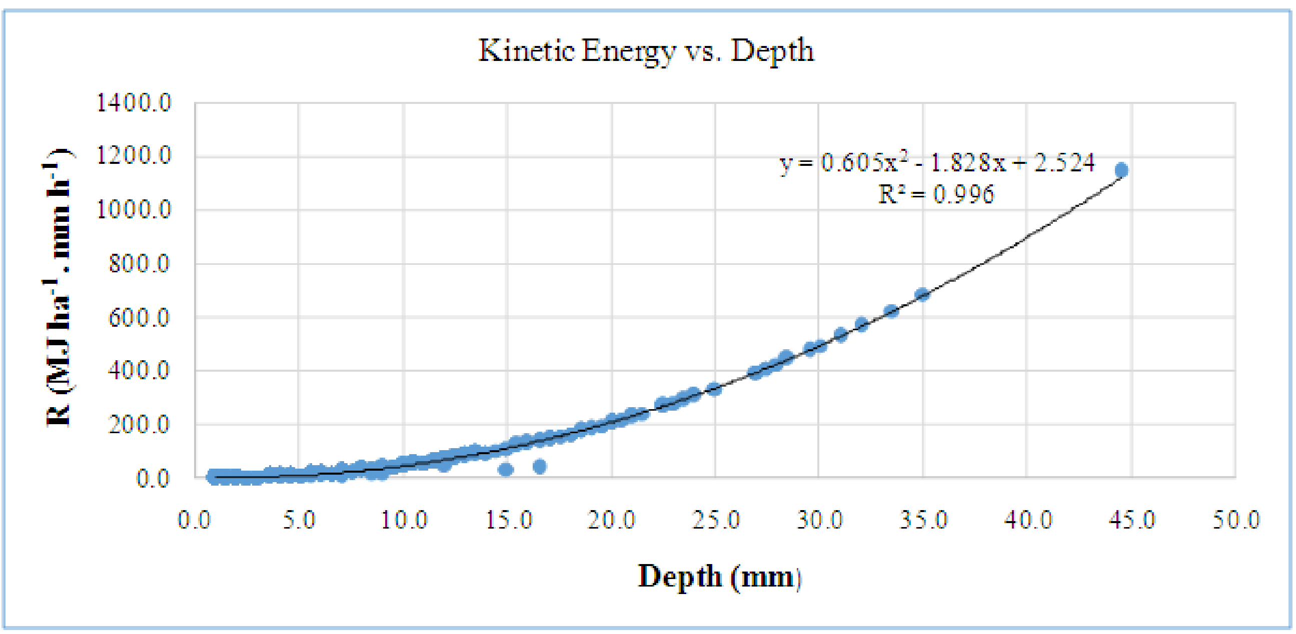

Fig.10 Spatial averages across the study period (2010-2018)

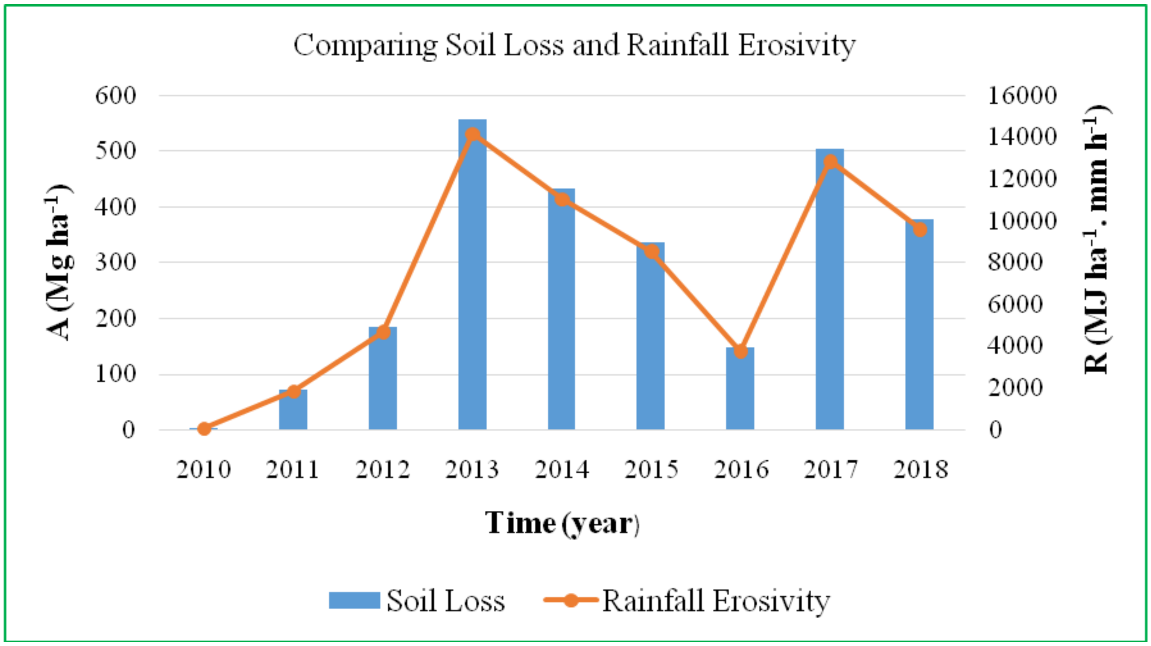

Fig.11 Distribution of annual soil loss from each soil phase unit in minimum rainfall year (2016)

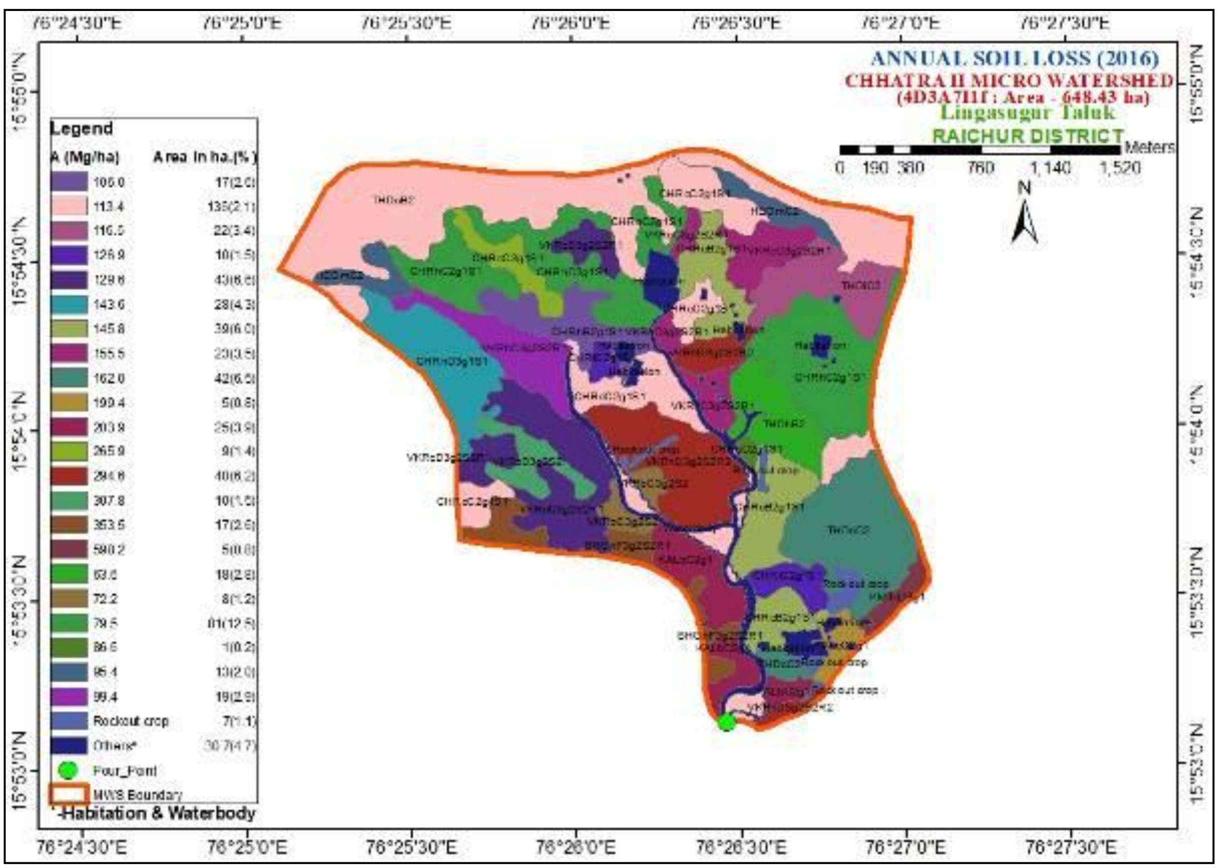

Fig.12 Distribution of annual soil loss from each soil phase unit in maximum rainfall year (2013)

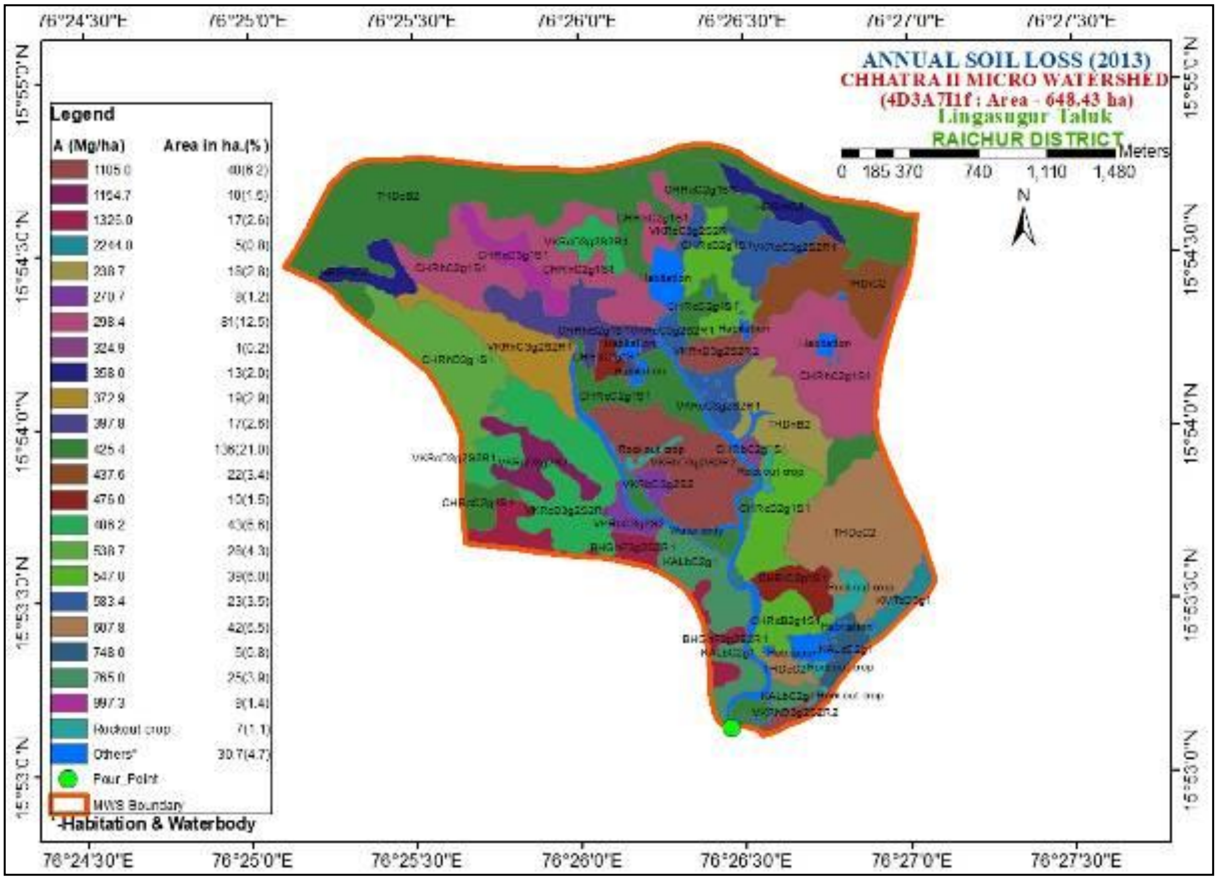

Fig. 9 which was intended to establish the relationship between 30 min interval rainfall kinetic energy and accumulated depth, through the adoption of the polynomial function, it is indicated in the curve that there is a positive correlation between the two as observed at depth of 10 mm, pose a potential 46.4 MJ ha^{-1}. mm h^{-1} of rainfall kinetic energy and the rainfall erosive power continues to increase as the depth expands with values of 206.7 MJ ha^{-1}. mm h^{-1}, 333.5 MJ ha^{-1}. mm h^{-1}, 492.7 MJ ha^{-1}. mm h^{-1} for depths of 20, 25, and 30 mm respectively as one moves up the curve are witnessed.

Average Annual Soil Loss, (A)

From Fig. 10, comparison of Soil Loss with Rainfall Erosivity proves that both processes are positively correlated as it can be learned that as the Rainfall erosivity increases, it will influence the magnitude of soil loss experienced. It is revealed that 2013 recorded the maximum Rainfall Erosivity (14166.8 MJ. mm ha^{-1} h^{-1}) hence more soil loss (555.4 Mg ha^{-1}) experienced contrary to the lowest Rainfall Erosivity (71.4 MJ. mm ha^{-1} h^{-1}) registered in 2010 henceforth resulting in about (2.8 Mg ha^{-1}). Wischmeier and Smith (1958) found that soil loss by rain splash, sheet and rill erosion is related to the product of rainfall kinetic energy (KE) and maximum 30-min rainfall intensity I_{30}, or EI_{30}.

Monthly R values are obtained from the sum of EI_{30} values of all rainfall events within a month, and similarly, annual R values are the sum of the EI_{30} values of storms in a year. From Table 4, it can be noted that mapping unit wise, KMTcD3g1 recorded maximum soil loss of 1172.3 Mg ha^{-1}, seconded by BHGhF3g2S2R1, VKRcD3g2S2 with 692.7 Mg ha^{-1} and 603.3 Mg ha^{-1} correspondingly and the least being THDhB2 with 124.7 Mg ha^{-1}. Even though R-factor enhances fairly proportional to depth of rainfall, when compared between the years, it is true that Kinetic energy accounts directly proportional to intensity. The intensive rains with intensity more than (40 mm h^{-1}) are generally less and the duration is also less. Similarly the less intensive rains (10 - 40 mm h^{-1}) are of larger number and cause moderate splash erosion.

Further, although slope has a powerful influence on erosion, the presence of erosion and heavy runoff on gentle slopes (2% in the Sahel or on European uplands) indicates that this phenomenon can occur without any need for a steep slope: the action of rain is enough (Fauck, 1956; Fournier, 1967). Roose (1967) found that erosion and runoff increase very quickly with minor variations in slope (0.5%).

Preparation of Development plan for sustainable usage of land and water resources

The appropriate soil and water conservation measures for the Chhatra II micro watershed were designed based on soil, rainfall, land use and topography of the area. It is expected that after the implementation of these measures, the rainwater will be efficiently utilized and productivity will be increased.

Conservation in this prospect means allowing dissipation of water flow energy by constructing contour or graded bund depending upon type of soil. In case of soil phase units, (12 numbers) with texture consisting clay quantity less than 25% would have more infiltration rate hence, contour bunds are proposed at the rate of (150 m ha-1) along with (50 m ha-1) of lateral bunding. Due to the contour bunding, there intend to be an increase in runoff harvested from (4.6- 13.8 mm).

In case of soil phase units (9 units) with clay texture (≥ 25%), there would have less infiltration rate (≤ 9 mm h-1) hence, graded bund are proposed with section of (1.09 m2) and length of (200 m ha-1) as a straight bund and (50 m ha-1) as a lateral length. There shall be longitudinal grade of (0.2%) to dispose off runoff accumulated behind the bunding that may continue to lodge beyond 24 hours since many times, continuous water logging in water spread area beyond 24 hours may be detrimental for crop growth. Due to the graded bunding intervention, runoff conserved would be rising from (4.6-18.5 mm).

In case of non-arable land (social forest and wasteland) that occur partially in some soil phase units (9 numbers) with total area (163 ha), contour trenches are proposed with staggered trenching having section of (0.27 m2) and length of (15 m).

From the study, it can be noted that the soil loss rate and quantity is mainly affected by rainfall erosive energy and runoff factors, out of which rainfall energy plays pivotal role that too in case of rain-fed areas prevail under semi-agro climatic conditions including Chhatra II hence, the analysis of estimation of soil loss rate and volume concentrated on rainfall erosive energy which gets assisted or controlled by the factors namely; soil erodibility, slope (steepness and aspect), crop cover conditions and tillage practices hence it is concluded that soil erosion is a result of several factors, including rainfall intensity, steepness of slope, length of slope, vegetative cover, and management practices.

Rock particles can also provide cover and decrease erodibility. Besides all this, the inherent properties of a soil play a major role in the ability of water to detach and transport its soil particles.

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