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Surface Runoff and Soil erosion Dynamics: A Case study on Bakreshwar river basin, eastern India

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Abstract

Runoff and soil erosion are two major hydro-morphological entities operating in a watershed. In the present paper Bakreshwar river basin draining through the Rarh regions of Eastern India, having 714.56 sq. km. area has been selected for the estimation of runoff using curve number (CN)method of the US Soil Conservation Service (SCS) and soil surface lowering using Revised Universal Soil Loss Equation (RUSLE) and 4 years' field based pegging operation. Several secondary and field based data have been assembled and processed using statistical and advanced application GIS techniques. The result shows that, an average of 55% of total annual rainfall flowing out as surface runoff with a associated removal of about 6.99 tons/ha/year of eroded soil in the Bakreshwar watershed. Seasonal runoff coefficient varies from 0.688 in monsoon to 0.185 in pre-monsoon. Surface lowering rate ranges from 0-17mm/year. The statistical relationship indicates that runoff positively controls soil loss. However, the resulting coefficient of determination (R^2) values (0.267) invokes that runoff is not the prime vectors for soil loss. Information provide in the present study for the un-gauged river basin is reasonably essential for planning, designing and evaluation of soil conservation projects, water pollution control measures and flood or drought control programs.

Keywords: Surface runoff, soil erosion, spatial analysis, GIS mapping, correlation analysis.

Introduction

A drainage basin or watershed is an area of land area where precipitation flows into streams or rivers or lakes or reservoirs. Relief, soil and rainfall are the key determinants of runoff operating at the basin scale[1]. One of the basic requirements in hydrologic problems analysis and soil and water resources management is the prediction and evaluation of runoff[2]. However, reliable prophecies of the amount and magnitude runoff have been a difficult and time taking task, particularly for an un-gauged watershed[3]. Various models have been developed and used by a plenty of researchers of scientific organizations throughout the world for the estimation of runoff such as, the Sacramento model[4], Tank model[5], HBV model[6], MIKE 11/NAM model[7], SCS-CN model[8] etc. Several empirical formulae, curves and tables, infiltration method, some rational method, hydrograph/time-discharge method, coaxial graphical correlation etc. are also notable in this regard. These models for the estimation of runoff require substantial hydrological, pedological and meteorological data. Moreover, the accuracy and efficiency of the models is needed to be tested[9, 10]. However, the model developed by USA Soil Conservation Service (SCS) which is now known as Natural Resource Conservation Service (NRCS)-curve number (CN) method is a well accepted method and particularly useful in hydrologic engineering and environmental impact analyses[11]. Remote Sensing and Geographical Information System (RSGIS) can supplement this method to a great extent in rainfall-runoff-erosion studies[12-14].

Soil erosion is the combined result of numerous hydro-geomorphic processes whereby soil, debris and rock materials are loosened or dissolved, removed and deposited in a distant place[15]. Erosion by running water has been recognized as one of the severe hazard intimidating the protection of soil as it reduces soil productivity by removing the most fertile topsoil[16]. The current rate of land degradation world-wide by soil erosion is about 6 million hectares of fertile land a year[17]. Asia has the highest soil erosion rate of 74 ton/acre/yr[18]. In India about 38 % out of the total reported geographical area is subject to serious soil erosion[19]. In the present Bakreshwar river basin of Eastern India is truly susceptible to erosion due to high erodibility of lateritic soil, bare soil cover, additional erosivity of the monsoonal rainfall, low clay, moisture and organic matter content of soil[20]. Simple methods namely the Universal Soil Loss Equation (USLE)[21] and the Revised Universal Soil Loss Equation (RUSLE)[22] are frequently used for the estimation of surface erosion from catchment areas[23, 24]. Estimates from these methods pertaining to basin-oriented or catchment oriented approach[25] are found to have good predictability. However, in real circumstances, predictions from these equations are found to vary to a great extent in different morpho-climatic region hence empirical estimates are more realistic[26].

During the last few decades the need for precise information on watershed runoff and soil erosion has been grown rapidly to assist watershed management programs for preservation, progress and advantageous use of all natural resources, including soil and water. Precondition for any watershed management plan is to understand the hydrology of the drainage basin and to determine runoff and soil erosion. In the present piece of writing (1) runoff character of the watershed has been assessed based on SCS-CN method, (2) soil surface lowering have been estimated by means of RUSLE equation[22] and four years' empirical observation and (3) Finally correlations are also measured to detect the nature and kind of associations between different morphological, hydrological and soil loss parameters. The need does not lie in the mere process of quantifying but such results can be the core of any decision making and supportive in policy formulation for sustaining the environment as a whole coupled with the land productivity.

Geographical Location and Regional Settings of the Study Area: Bakreshwar River draining through the Rarh regions of Eastern India is a 5^{th} order tributary of the river Kuya and a part of Mayurakshi river system (figure-1). Total length of the main water course is 86.385 km. The entire river catchment (enclosed between 23º43′23.28″ N. to 23º56′31.16″ N. latitudes and 87º17′1.59" E. to 87º47′16.07″ E. longitudes) counting an area of about 714.56 sq km, is consisting of three 4^{th} order, thirteen 3^{rd} order, fifty four 2^{nd} order and three hundred eighteen 1^{st} order rain fed streams and respective sub-catchment.

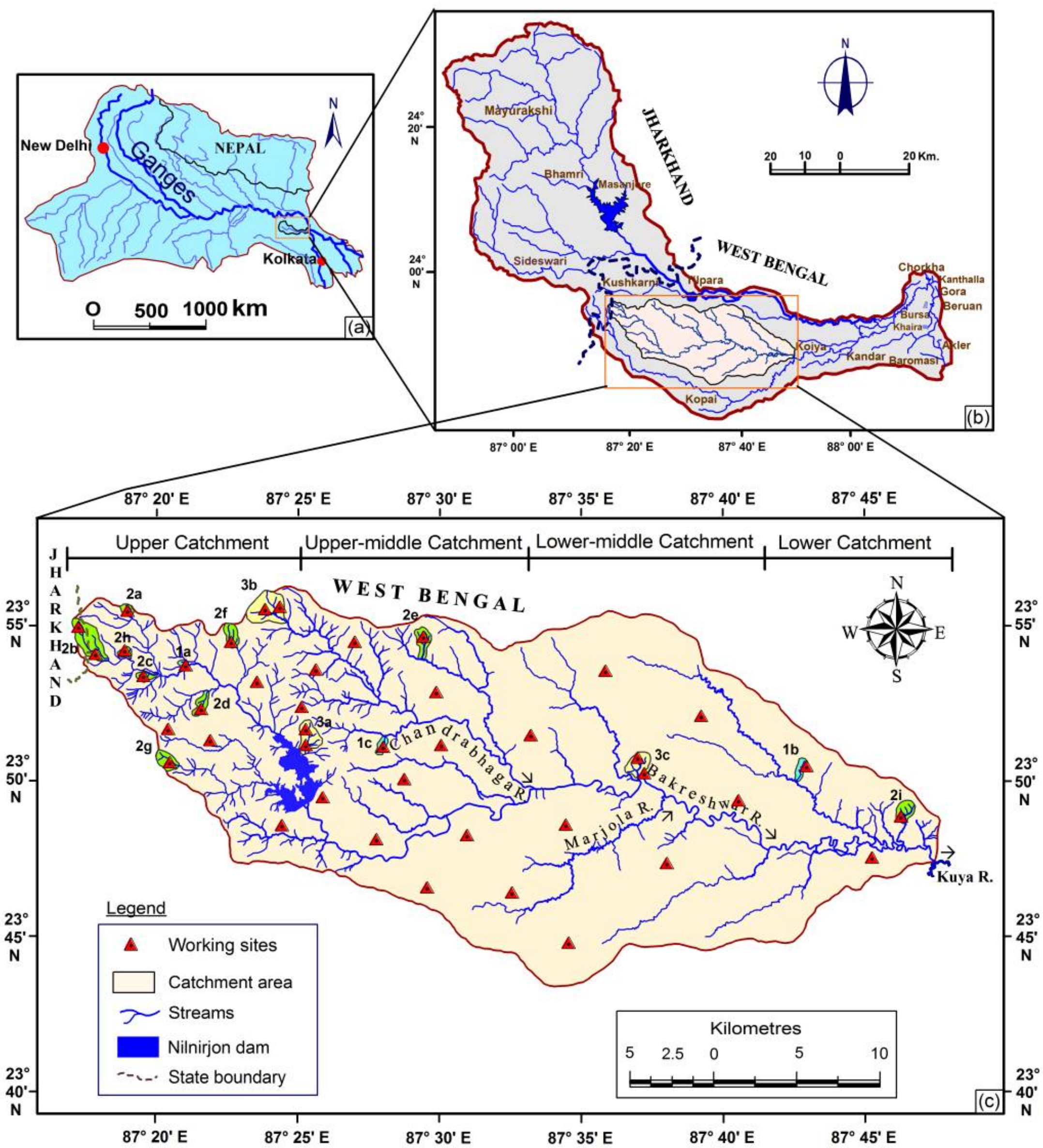

Figure-1

Reference maps (a) the Ganga Catchment, (b) the Mayurakshi river basin, (c) the Bakreshwar river basin (study area)

The catchment area is characterized by subtropical monsoonal type climate with alternate wet and dry spell. Rainfall varies between 828.8 mm to 1917.1 mm (1980-2013)[27]. South-West Monsoon (June to September) carries more than 80% rainfall in this area. Hard basalt of Jurassic to Cretaceous age, soft and medium hard laterite of Cenozoic age and china clay of late Pleistocene to early Eocene age are found in different parts of the basin and in different depths[28, 29]. The area covered mostly with the reddish, loose and friable sterile with ferruginous concretion called laterite soil (local name 'kankara'. Due to infertile soil and very bare productivity this region is named 'Rarh' meaning thereby sterile land[30]. The soil catenas consist of plateau fringe and high plains with laterite soil (Ultisols) and adjacent slopes with sandy and loamy soils and small valley floors with older alluvial soils (Ulfisols)[20]. The laterites are generally underlain by lithomergic clays which is prone to tunnel erosion[31]. Moderate physical weathering, moderate-maximum chemical weathering, moderate-maximum mass wasting, moderate-maximum fluvial processes (namely, rain splash, sheet wash, rill and gully erosion), laterisation etc. are some major pedo-geomorphic processes. Undulating lateritic uplands, broad planation surface, deep red weathered zone, duricrust of Feroxides (Ferrucrete), badlands in the upper part and low lying flat land in the lower part of the basin characterize the morphological features. On consideration of topography, the western part of the basin is the eastern extension of the Chotonagpur plateau complex and the eastern lower segment of the basin is a part of the moribundh (decayed) Ganges delta. Relief variations are considerable in this part of lateritic alluvium (figure-2). Almost throughout the entire area of the basin, the surface is broken by succession of undulations, the general trend of which is from North-West to South-East. Upper catchment of the basin is claded with sparse Sal (Shoria Robusta) forest but the large part of the forest is decaying with very fast rate. Soil erosion is one of the major regions behind such degradation.

Methodological: Experimental design and dataset: This current study engrosses three basic route surveillance, recording and interpretation. In the pre-field session topographical maps of the Survey of India (SOI), geological maps of the Geological Survey of India (GSI), climatic data of the Indian Meteorological Department (IMD), district planning series of the DST (NATMO), soil texture data of the National Informatics Centre (NIC), Birbhum District Unit and National Bureau of Soil Survey and Land Use Planning (NBSS), satellite images (IRS P6 LISS III), SRTM data of NASA and some cognitive books and articles have been consulted. The IRS LISS III satellite imageries of two seasons namely cropping season (6th Nov 2013) and non cropping season (8th April 2014) have been obtained from the NRSC, Hyderabad. The geomorphological features have been calculated using standard formulae. The land use/land cover (LULC) map for the watershed has been prepared using satellite imageries. Supervised classification method has been successfully used and the accuracy assessment of LULC has been done. In this regard, study of Phukan, Thakuriah and Saikia[32] have been consulted. Slope map have been prepared using SRTM DEM. The land slopes have been classified in to six classes as adopted by the USDA Soil Survey Manual[33].

Emphasis has been laid on field work. Surface lowering rate has been measured on 42 sites over the basin through wooden pegging operation since February, 2011 to February, 2014. Figure-3 shows some field photographs for pegging operation. Vide figure-1(c) for location of the working sites (pegging stations). Average surface lowering rate have been calculated based on the field data collected.

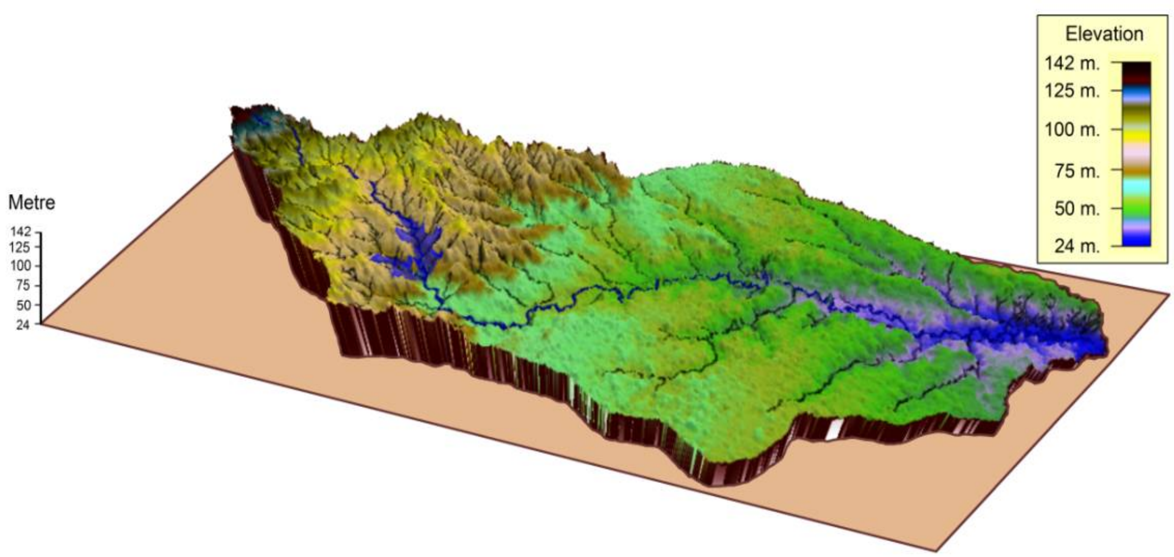

Figure-2
3D model based relief classes of Bakreshwar river basin.

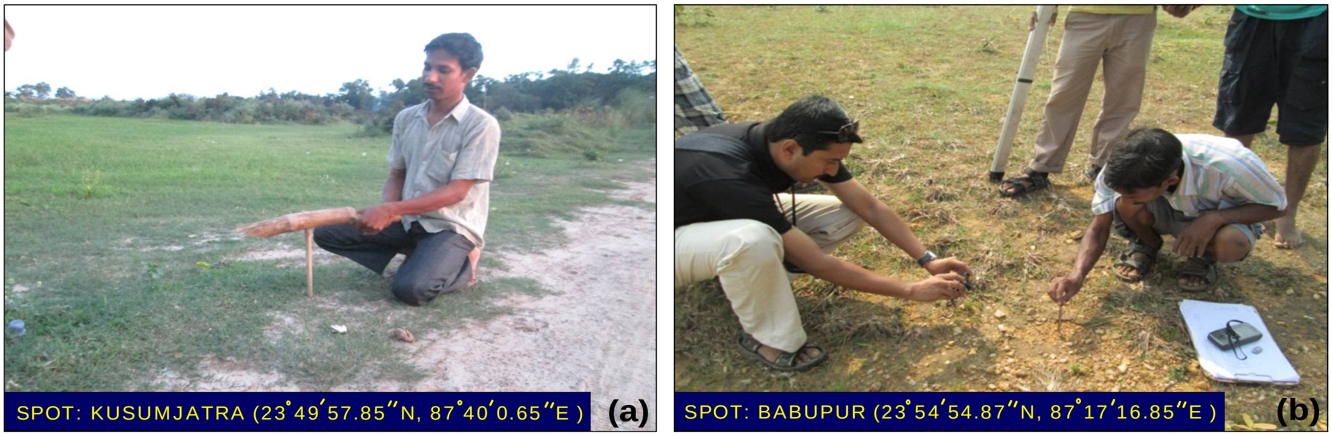

Figure-3
Field photographs (a) during planting peg (b) during the measurements of surface lowering.

In the post-field session analysis have been worked out to represent and understand the ground reality. SPSS 14.0 and MSO Excel 2007 have used for large calculations and statistical analysis. The cartographic works, starting from demarcation of basin area to the thematic mapping have been done in ArcGIS 10 and Surfer 8. Processing of SRTM data, satellite images have been finished in ERDAS 9.1 imagine software.

Methodology

Runoff Estimation Methodology: The annual, monthly and season specific runoff and runoff co-efficient have estimated based on the SCS-CN model[34] and Chow's Equation[35] respectively. As the selected river basin is having no gauge station so, this method has applied to get usable results.

The SCS-CN model[34] computes direct runoff through a pragmatic equation that necessitate rainfall data and a watershed co-efficient or Curve Number (CN) as input. CN essentially represents the runoff potential of a hydrologic soil cover complexes.

The Surface Runoff Equation[36]

$$\mathbf{R} = (\mathbf{P} - \mathbf{Ia})^2 / (\mathbf{P} - \mathbf{Ia} + \mathbf{S}) \tag{1}$$

Where, R is actual surface runoff (in mm). P is rainfall (in mm), Ia is Initial abstraction or loss of water by soil and vegetation before runoff begins and is taken as 0.4S and S is the possible maximum retention of water by soil (in mm.)

The Potential Retention Equation for 30 day Month[37]

$$\mathbf{S} = (\mathbf{25400} / \mathbf{CN}) - \mathbf{254} \tag{2}$$

Where, **CN** is the Runoff Curve Number. Note: CN is a function of LULC, soil type and antecedent moisture condition (AMC). Runoff CN in a given Soil-Vegetation-Land (SVL) complex in specific antecedent moisture condition (AMC) is attributed the values ranging from 0 to 100. When CN equals to 100, potential maximum retention becomes zero (in waterlogged areas or in wet paddy field). This leads to Runoff = Precipitation. In other cases, when potential maximum retention 100, CN will be 0, this gives Runoff = 0.

The Runoff Coefficient Equation[35]-

$$\mathbf{RC} = \frac{\mathbf{F}}{\mathbf{S}} = \frac{\mathbf{R}}{\mathbf{P}} \tag{3}$$

Where, F is Actual retention after runoff begins; S is Potential maximum retention after runoff begins; R is Actual runoff/ runoff depth (mm.); P is Rainfall (in mm.) and RC is the runoff coefficient (fraction).

The steps followed for runoff calculation are-

Step-I: The watershed has demarcated and LULC classification has done from SOI maps and IRS LISS III imageries,

Step-II: Soil textural dataset have prepared from NIC in GIS environment.

Step-III: Antecedent Moisture Condition (AMC) has assessed from the past 34 years rainfall based on the seasonal rainfall limits for AMC of NEH-IV[8].

Step-IV: Soil Hydrologic conditions are appraised by investigating LULC and soil texture following the guidelines of NEH-IV[8] and drainage manual of USBR[38] with the help of empirical tables of Maidment[39].

Step-V: Curve Number in AMC II condition for each land use category under different hydrologic soil group (HSG) has applied for estimating Weighted Curve Number (CNs) following Ragan and Jackson[40].

Step-VI: The CNs ware converted to AMC III condition following Schwab *et al.*[41].

Step-VII: The potential maximum retention (S) in mm. has calculated following SCD[36].

Step-VIII: The runoff has calculated using runoff equation following Chandra *et al.*[42].

Soil Loss Estimation Methodology: Revised Universal Soil Loss Equation, RUSLE[22] has been used for calculating soil loss. The RUSLE equation is-

$$A = R \times K \times LS \times C \times P \tag{4}$$

Where, A is the potential long term average annual soil loss (in tons/acre/year).

R is the rainfall- runoff factor by geographic location which is calculated using the subsequent equation-

$$R = 38.5 + 0.35 \times Pr \quad (5)$$

Where, Pr is average annual precipitation.

K is the soil erodibility factor which is calculated according to the soil texture type of the area[43]. For example: 0.38 for silty loam, 0.32 for silty clay loam, 0.30 for loam, 0.26 for silty clay, 0.24 for sandy clay, 0.20 for sandy clay loam and 0.13 for sandy loam.

LS is the slope-length-gradient factor and calculated by Robert'sequation[43] –

$$LS = \left[0.065 + 0.0456\left(slope\right) + 0.006541\left(slope\right)2\right] \times \left(slope - length\ f\ \ const\right)^{NN} \quad (6)$$

Where, slope is percent of steepness (%), slope-length is length of slope (m), constant is 22.1 and NN is 0.5 as in the present river basin slope is more than 1%.

C is the crop or vegetation and management factor. C is obtained by multiplying crop type factor and tillage method factor. For example: 0.5 for barren land, 0.125 for agriculture, 0.050 for shrub land and grass cover land, 0.004 for forest area, 0.002 for settlement and 0 for water.

P is the support-practice factor, measured as according to the up and down slope of an area For example: the value is 0.60 for 0-7% , 0.70 for 7-14% , 0.80 for 14-21% , 0.90 for 21-28% and 1.0 for more than 28% of slope.

For spatial mapping of runoff and soil loss the entire basin area has been divided into 189 grids of 4 sq km. Then, land use/land cover, soil textural class, slope character etc. has been identified and calculations are carried out for each individual grid.

Preparatory Steps for Runoff and Soil loss Calculation
Preparation of Land Use/Land Cover and Soil Data Set*:*

Table-1
Land use/land cover statistics

Land use/Land cover	Area (sq km)	% of Total Area
Dense forest	116.91	16.36
Low Dense Forest/Scattered Trees	53.09	7.43
Build Up Area	50.88	7.12
Barren/Waste land	55.45	7.76
Permanent Agriculture/Crop land	249.09	34.86
Seasonal Agricultural Land/Seasonal fallow	158.7	22.21
Reservoir and pond	20.44	2.86
River/marshy land	10	1.4
Total	714.56	100

Table-2
Textural characteristics of soil

Textural Class	Area (sq km)	% of Total Area
Loam	149.24	20.886
Clay Loam	132.25	18.508
Loam	59.04	8.262
Sandy Loam	305.78	42.793
Sandy	56.43	7.897
Undefined	11.82	1.654
Total	714.56	100

Based on: Soil Texture Map of NIC, Birbhum District Centre

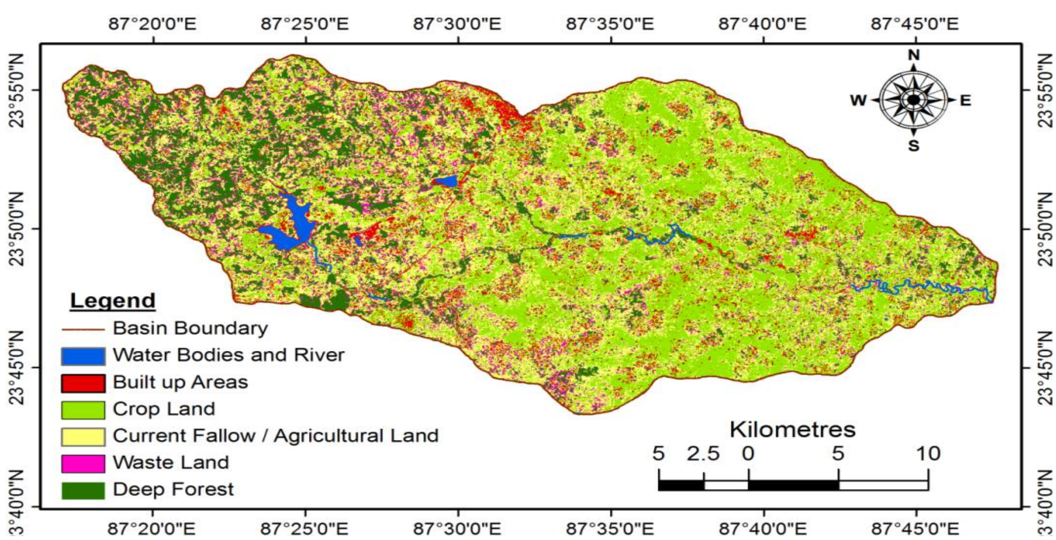

Figure-4
LULC map of Bakreshwar river basin (based on: supervised image classification of IRS P6 LISS III image, 2013-11-06)

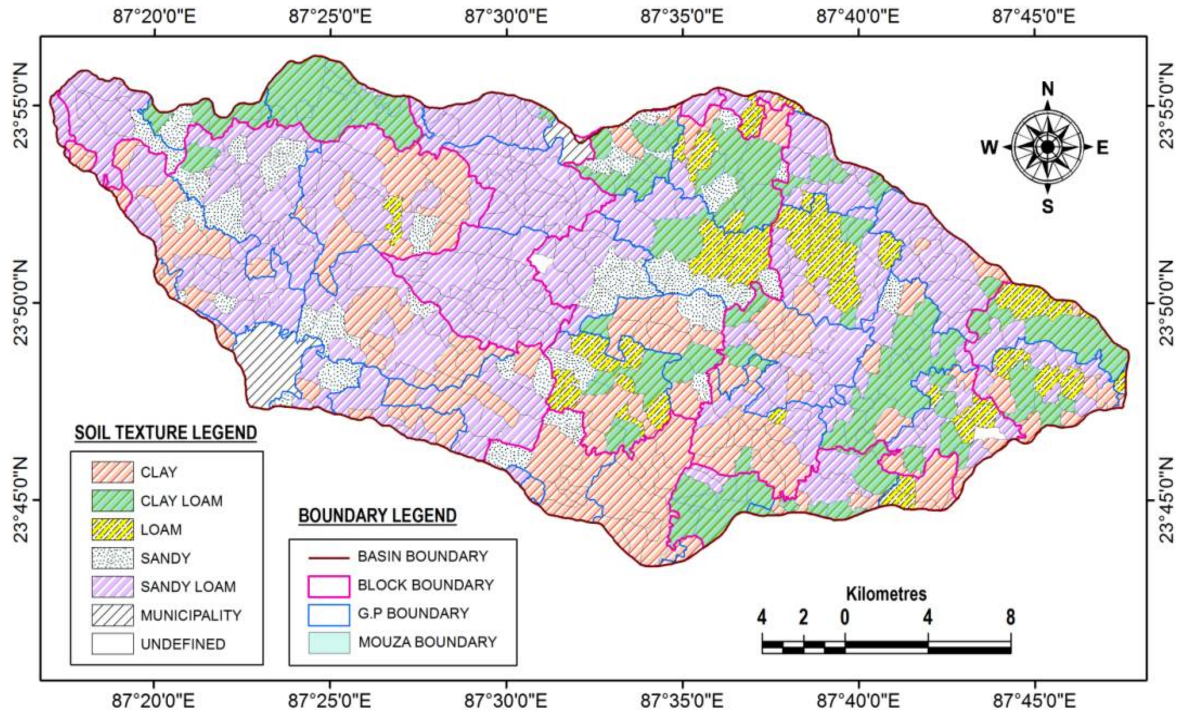

Figure-5
Soil texture map of Bakreshwar river basin (based on: mouza wise soil texture map of NIC Birbhum district)

The Antecedent Soil Moisture Condition (AMC): AMC refers to an index of wetness in an area. In the present article the soil moisture condition is classified in three AMC based on the seasonal rainfall limits for AMC of NEH-4[8].

The Hydrologic Soil Group (HSG): Hydrological soil group and their respective statistics have estimated considering the soil infiltration and drainage characteristics of different soil textural classes and soil moisture condition of the river basin following the guidelines of NEH-IV[8] and Drainage manual of USBR[38].

Table-3
Hydrological soil group statistics

Hydrological Soil Group	Area (sq. km.)	Area (%)
Group A	23.24	3.25
Group C	421.65	59.01
Group D	31.21	4.37
Total	714.56	100

Slope Classes: Five classes of slope may be mentioned here namely, i. flat (<1%), ii. slightly sloping (1-5%), iii. highly slopping (5-10%), iv. steep (10-20%) and v. very steep (>20%) after Sprenger[44].

Estimation of Curve Number (CN): To estimate Curve Number for each land use classes under different slope classes and hydrological soil group curve number table of Sprenger[44] have used as reference. In table-4 CN for different kinds of LULC and soil classes in Bakreshwar river basin has given.

Results and Discussion

Estimation and assessment of Runoff for Bakreshwar Watershed: Estimated average annual (1980-2013) runoff volume in Bakreshwar watershed is 773.201 mm which is 752.817 mm in 2013 (table-5 and 6). As most of the periods of the year are usually not receive rain, the AMC has not supportive to prompt runoff after rain. It has found that a storm rainfall having total rainfall input 335.1 mm. have produced 317.15 mm runoff (table-7). This figure may seem to be quite greater. Actually, it is possible because AMC on that period (late monsoon) supported large scale surface runoff and least abstractions. Considering seasonal variation of runoff (table 8) it has found that during monsoon period soil moisture availability is so good, that it able to react steadily and quickly. So, abstraction is only 0.2S on that period. But in pre monsoon season runoff has counted too low. Actually, after a long dry spell, this period abstracted huge rain and hence possibility of runoff became very less. Season wise runoff calculation using different rain abstractions has produced quite different result of runoff from annual average (table-5 and table-8). Total estimated volume of runoff including monsoon and pre monsoon periods was 805.15 mm. More than 90% runoff of the annual total concentrates on monsoon period when the rainfall was maximum. The runoff coefficient in monsoon is as high as 0.688; in pre monsoon it is 0.246 and the annual average condition is 0.55. Monsoon rainfall concentration, post monsoon dry spell and occasional pre monsoonal rainfall is the prime cause for such variation.

Table-4
CN for different kinds of LULC and soil (AMC II and Ia = 0.4S)

Land use/land cover (LULC)	Hydrologic soil group	Curve number (CN)	Area (sq km)
Water body (reservoir, pond, river and marshy land)	A	74	7.28
	B	85	4.46
	C	92	4.55
	D	95	14.15
Dense forest	A	55	29.31
	B	60	63.88
	C	81	21.86
	D	87	1.86
Low dense forest/Scattered trees	A	46	9.64
	B	66	29.19
	C	77	13.08
	D	83	1.18
Agriculture/Crop Land	A	72	1.1
	B	81	33.44
	C	88	135.21
	D	91	79.34
Waste land/Barren land	A	68	16.16
	B	79	13.65
	C	86	18.21
	D	89	7.43
Build up area	A	57	1.12
	B	72	2.41
	C	81	27.30
	D	86	20.05
Seasonal agriculture/seasonal fallow land and others	A	54	8.37
	B	64	55.58
	C	73	78.39
	D	78	16.36
Total area (in sq. km.)			714.56
Weighted Curve Number			75.23

Table-5
Estimation of annual average runoff (average of the period 1980-2013)

Month	P	S	Ia	(P-Ia)	$(P-Ia)^2$	(P-Ia)+S	R	RC
Jan	13.276	84.66	33.864				0	0
Feb	21.359	84.66	33.864				0	0
Mar	33.032	84.66	33.864				0	0
Apr	48.497	84.66	33.864	14.633	214.126	99.29	2.157	0.044
May	104.915	84.66	33.864	71.051	5048.203	155.71	32.420	0.309
June	235.856	84.66	33.864	201.992	40800.72	286.65	142.335	0.603
July	302.365	84.66	33.864	268.501	72092.63	353.16	204.136	0.675
Aug	289.964	84.66	33.864	256.100	65587.42	340.76	192.474	0.664
Sept	264.150	84.66	33.864	230.286	53031.64	314.95	168.383	0.637
Oct	103.312	84.66	33.864	69.448	4822.992	154.11	31.296	0.303
Nov	18.238	84.66	33.864				0	0
Dec	9.468	84.66	33.864				0	0
Annual	1444.432						773.201	0.535

Table-6
Estimation of annual runoff of the year 2013

Month	P	S	Ia	(P-Ia)	$(P\text{-}Ia)^2$	(P-Ia)+S	R	RC
Jan	2.7	84.66	33.864				0	0
Feb	7.1	84.66	33.864				0	0
Mar	9.2	84.66	33.864				0	0
Apr	45.3	84.66	33.864	11.436	130.782	96.10	1.361	0.030
May	79	84.66	33.864	45.136	2037.258	129.80	15.696	0.199
June	155.6	84.66	33.864	121.736	14819.65	206.40	71.802	0.461
July	177.9	84.66	33.864	144.036	20746.37	228.70	90.716	0.509
Aug	291.59	84.66	33.864	257.726	66422.69	342.39	193.999	0.665
Sept	157.6	84.66	33.864	123.736	15310.6	208.40	73.469	0.466
Oct	408.7	84.66	33.864	374.836	140502	459.50	305.774	0.748
Nov	22.8	84.66	33.864				0	0
Dec	0	84.66	33.864				0	0
Annual	1357.49						752.817	0.555

Table-7
Estimated runoff volumes in connection with a storm ("Pilen") in the year 2013

Month/date	Rainfall, P (in mm.)	S (84.66/30= 2.82)	Ia=0.4S in Initial and End Phase and Ia=.2S in Peak Rainfall Phase	(P-Ia)	$(P\text{-}Ia)^2$	(P-Ia)+S	R	RC
11 Oct, 2013	41	2.82	1.128	39.872	1589.776	42.692	37.238	0.908
12-Oct	57	2.82	1.128	55.872	3121.68	58.692	53.187	0.933
13-Oct	111.8	2.82	0.564	111.236	12373.45	114.056	108.486	0.970
14-Oct	83.2	2.82	0.564	82.636	6828.708	85.456	79.909	0.960
15-Oct	42.1	2.82	1.128	40.972	1678.705	43.792	38.334	0.911
Total	335.1	---	---	---	---	---	317.154	0.946

Table-8
Season specific runoff estimation

Season	Month	Rainfall (mm.)	S	Ia	(P-Ia)	$(P\text{-}Ia)^2$	(P-Ia)+S	R	∑R	RC
Pre Monsoon	Mar	33.032	84.66	33.864	-0.83	P-Ia<0		0	34.576	0.185
	Apr	48.497	84.66	33.864	14.63	214.125	99.29	2.156		
	May	104.914	84.66	33.864	71.05	5048.10	155.71	32.419		
Monsoon	Jun	235.855	84.66	16.932	218.92	47927.28	303.58	157.872	770.574	0.705
	Jul	302.364	84.66	16.932	285.43	81471.43	370.09	220.138		
	Aug	289.964	84.66	16.932	273.03	74546.47	357.69	208.41		
	Sep	264.15	84.66	16.932	247.22	61116.74	331.88	184.154		
Post Monsoon	Oct	103.311	84.66	25.398	77.91	6070.44	162.57	37.339	37.339	0.225
	Nov	18.238	84.66	25.398	-7.16	P-Ia<0		0		
	Dec	9.467	84.66	25.398	-15.93			0		
	Jan	13.276	84.66	25.398	-12.122			0		
	Feb	21.358	84.66	25.398	-4.04			0		
Annual Average = 1444.432									842.49	0.583

Spatial pattern of runoff (figure-6a to 6d) shows maximum runoff near the confluence segment due to higher soil saturation level, more swelling potential clay loam soils, clay pan or layer at or near the surface with a permanently high water table. Runoff is also more in the upper catchment due to steep slope and barren land. In the lower middle catchment although the curve number is little more but runoff is quite less as rainfall is quite less in this counterpart and water used regularly for brick kiln, irrigation and domestic purpose. Moreover, stagnant water in the low lying agricultural land infiltrates through moderately fine to coarse textures sandy to sandy loam soil resulting relatively less surface runoff. In monsoon season runoff is high throughout the basin and in the pre-monsoon season runoff counts marginal and highly occasional which mostly occurs due to pre-monsoon shower by the thunderstorm Norwester.

Estimation of Soil Erosion for Bakreshwar River Catchment: The average annual surface lowering status of the entire basin has been shown in figure-7a. From this isoerodent plotting, catchment specific surface lowering rate and volume can roughly be calculated. The annual surface lowering rate ranges from 8 mm to 17 mm/year in the upper catchment, 6-10 mm/year in the upper-middle catchment and 3-6 mm/year in the lower-middle catchment. Average rate of lowering for the entire catchment is 6.63 mm/year. The catchment specific surface lowering rate and respective erosion volume have furnished in the table-9.

Erosion volume per unit area is excessively high in the upper catchment. Areas especially in the lateritic tract, lowering rates are exceptionally high. In spite of good coverage of forested land in the upper part of the basin, soil loss volume is heavier there because other soil erosion vectors are accelerating the lowering rate. The low-lying undulating surface in the lower catchment shows negligible surface lowering rate. Total estimated volume of erosion due to surface lowering in Bakreshwar basin is 4737532.8 m^3/year and the rate is 6630 m^3/sq km/year.

According to the RUSLE, average rate of soil loss in the study area is 6.9947 tons/ha/year. Of course there is large scale spatial variation of soil loss. In the upper catchment, this rate is more than 15 tons and in the lower catchment it is less than 4 tons (figure-7b). Total volume of soil loss in this watershed is 499813.2832 tons/year (table-10).

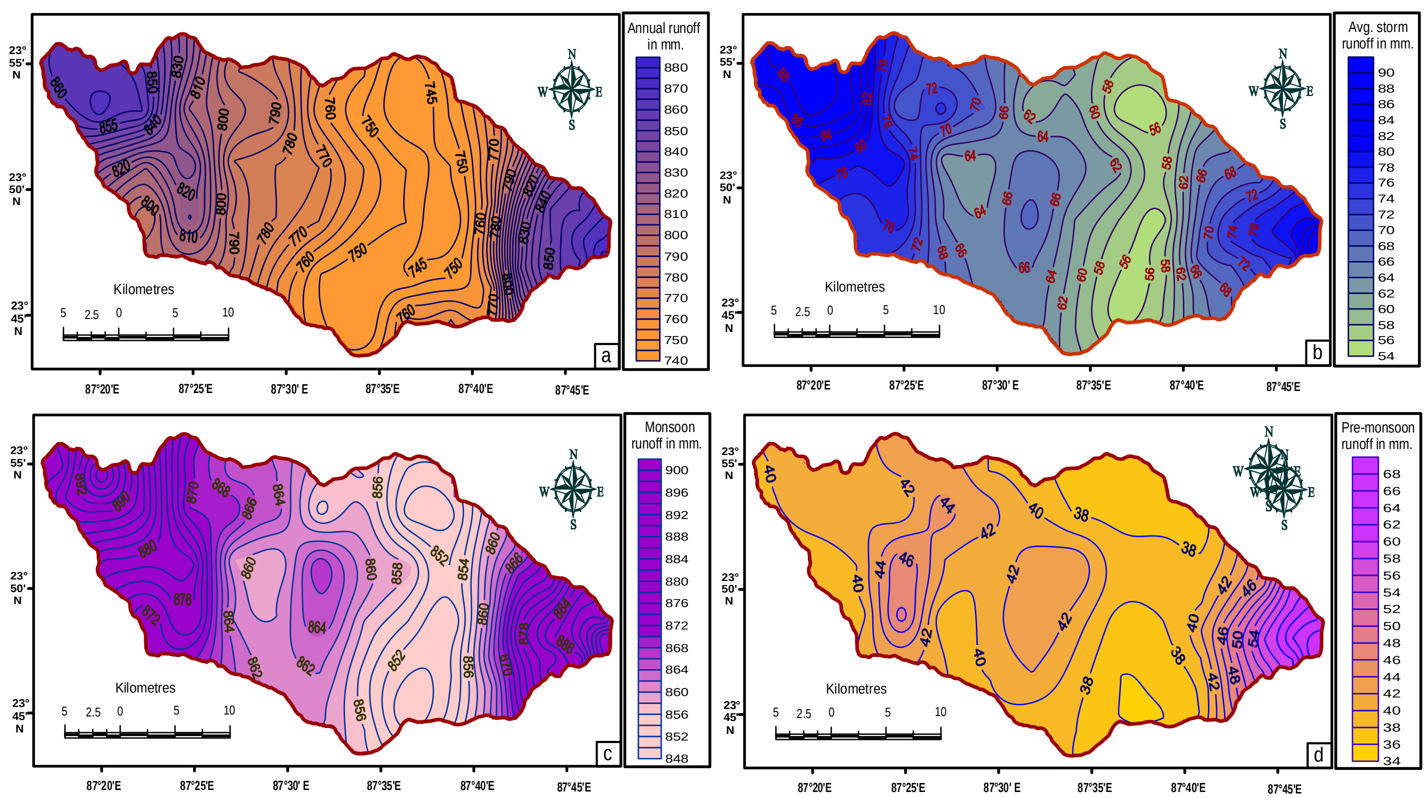

Figure-6
(a) Spatial Annual Surface Runoff, (b) Storm Runoff during the 'Pilen' event of 2013, (c) Monsoon Runoff and (d) Pre-monsoon Runoff of Bakreshwar River Basin (based on SCS-CN Method).

Table-9
Catchment specific annual surface lowering rate and total estimated erosion volume.

Catchment	Area (sq km)	Average lowering rate (mm/year)	Volume of eroded material in m^3/year
Upper	78.03	12.5 (8-17)	$78.03\times10^6\times12.5\times10^{-3}$ = 975,375
Upper-middle	216.69	8 (6-10)	$216.69\times10^6\times8\times10^{-3}$ = 1,733,520
Lower-middle	341.44	4.5 (3-6)	$341.44\times10^6\times4.5\times10^{-3}$ = 1,536,480
Lower	79.4	1.5 (negligible)	$79.4\times10^6\times1.5\times10^{-3}$ = 119,100
Whole basin	714.56	6.63	$714.56\times10^6\times6.3\times10^{-3}$ = 4,737,532.8

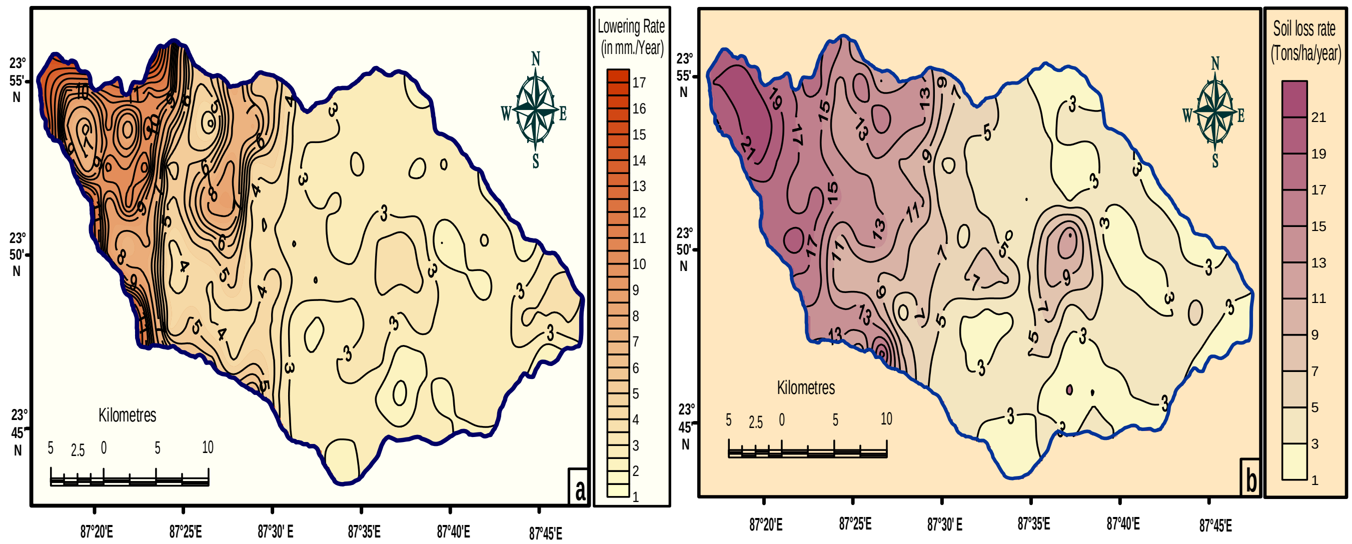

Figure-7
(a) Annual average surface lowering of Bakreshwar river basin (based on: pegging operation, 2011-15), (b) Spatial status of annual average soil loss for Bakreshwar river basin (based on RUSLE).

Table-10
Estimated yearly soil loss based on RUSLE.

Basin Area	R	K	LS	C	P	A (tons/ha/year)	Yearly soil loss for the basin
714.56 Sq km	89.06	0.28	5.5	0.1	0.51	6.9947	$714.56\times10^{6}\times6.9947\times10^{-4}$ = 499813.2832

In general vegetation cover for a large proportion of geographical lands registers marginal volume of soil loss but for the present river basin particularly in the upper catchment in spite of having forest cover soil erosion rate in considerably high. As per the study of Sarkar *et al.*[20] high erodibility of lateritic soil, bare soil cover due to deforestation, more erosivity of the monsoonal rainfall, low clay with less moisture and organic matter content of the soil, the region is prone to soil erosion. Moreover, sparseness of vegetation coverage over, greater slope and association of numerous lower order streams cumulatively strengthen surface runoff and erosion power in this counterpart. The field based surface lowering rates in the three basic geomorphic units (namely lateritic region, bare lateritic region and forested region) have differed considerably. In lateritic region the rate of lowering (>15 mm/year) is more than the non lateritic capped region (3-16) and forested region (2-13 mm/year). These lateritic patches contain coarse and fragile, incohesive moram soil, greater association of rills and gullies etc. encouraging soil erosion more aggressively.

Runoff Erosion Relations: Certainly, surface runoff is one of the major vectors of soil erosion in association with multivariate factors. As the other factors like resistivity of the rock, slope of the land, vegetation coverage etc. are operate in quite reverse direction the control of runoff is less significant on soil loss. R^2 value and trend curve indicate runoff positively controls soil loss but with marginal intensity (figure-8). The direction of influence of runoff to soil erosion in most of the cases are positive (table-11)

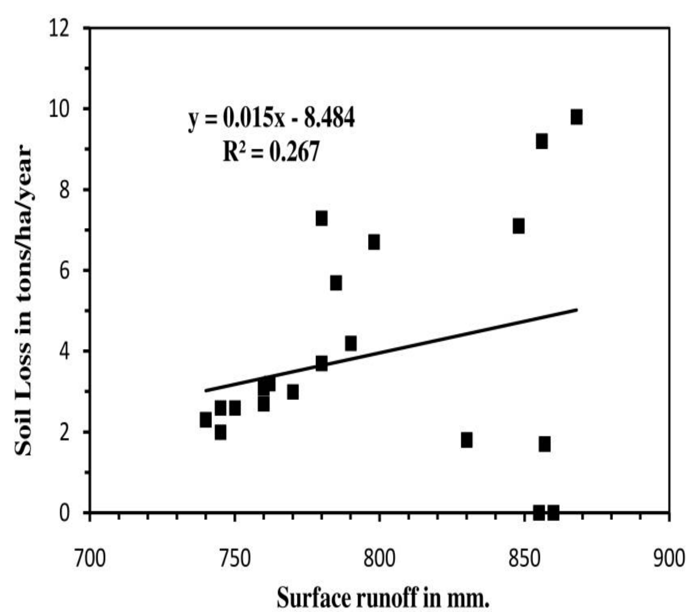

Figure-8
Scatter plot of the co-relation between surface runoff and soil loss

Table-11
Correlation matrix between runoff and soil erosion

	a	b	c	d	e	f	g	h	i	j
a	1	-.717(**	-.635(**)	-.709(**)	-0.021	0.141	.823(**)	.823(**)	0.045	0.1
b		1	.906(**)	.952(**)	0.086	-0.071	-.783(**)	-.783(**)	0.048	-0.025
c			1	.971(**)	0.342	0.207	-.608(**)	-.608(**)	0.328	0.26
d				1	0.293	0.134	-.653(**)	-.653(**)	0.254	0.182
e					1	.978(**)	0.339	0.339	.951(**)	.945(**)
f						1	.467(*)	.467(*)	.957(**)	.964(**)
g							1	1.000(**)	0.368	0.426
h								1	0.368	0.426
I									1	.997(**)
j										1

Note: a. Curve Number, b. Surface Lowering, c. Soil Loss, d. Length-Gradient, e. Monsoon Runoff-Coefficient, f. Monsoon Runoff, g. Pre-Monsson Runoff coefficient, h. Pre-Monsoon Runoff, i. Avg. Runoff Coefficient, j. Avg. Runoff.
** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Conclusions

The present study of runoff and soil erosion of the basin can be used for outlining efficient water use and crop management practice and conservation measures to "tolerable soil loss" rates. Vulnerable soil erosion zonation, alternative water resource use, crop management and seasonal crop systems may also be evaluated by the study. Statistical relationship rationale invokes the positive relationship between runoff and erosion. Hence SCS-CN method has potential workability for crude estimation of soil loss for the present study region.

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