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Identification of Soil Erosion Susceptible Areas in Hinglo River Basin, Eastern India Based on Geo-Statistics

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Abstract:

Reliable databases are the prime requirement for identifying vulnerable erosion zone in order to execute alleviation measures. Geo-morphometric characterizations of a watershed are commonly used and scientific approach in this connection. In the present paper un-gauged 5th order Hinglo River Basin draining through the Rarh regions of Eastern India as a tributary of the river Ajay having 444.308 sq. km. area have been selected for detection of erosion susceptible areas. A total of 15 (7 relief and 8 drainage) geo-morphometric parameters have been considered for the study with the aid of Remote Sensing (RS) and Geographical Information System (GIS). Principle Component Analysis (PCA) based Average Weighted Composite Score (AWCS) method is used to assimilate the erosion driving variables and thereby to fabricate spatial soil erosion vulnerable map. According to the result, high to severe erosion susceptibility zone counts about 34.85% (154.84 sq.km.) of the basin area, mainly concentrated in the upper catchment due to excessive drainage conditions, steep slope, high dissection and ruggedness index, surplus drainage density and stream frequency. These erosion hotspot areas of the river basin needs special attention to take up mechanical soil conservation measures, gully control structures and grass erection to protect nutrient rich topsoil loss this agriculturally conquered region.

Keywords: Soil Erosion, Drainage Morphometry, Relief Morphometry, Remote Sensing (RS), Geographical Information System (GIS), Erosion Susceptibility Zone (ESZ).

1.0 Introduction:

Soil erosion by running water has been recognized as one of the severe hazard as it reduces soil productivity by removing the most fertile topsoil (Shrestha, 1997; Angima *et al.,* 2003). The current rate of land degradation (world-wide) by soil erosion is about 6 million hectares of fertile land a year (Dudal, 1981). Asia has the highest soil erosion rate of 29.95 ton/hectare/year (El-Swaify, 1994) and Asian rivers contribute about 80 % to the total sediments deposited to the world oceans (Stoddart, 1969). In India about 38 % out of the total reported geographical area is subjected to serious soil erosion (Das, 1985). According to information published by the Ministry of Agriculture, Govt. of India in 1980 about 53% of India's total geographical area is subjected to environmental degradation in general and soil erosion in particular (CSE, 1982). In our country >70% population is dependent on agriculture. It has been reported that, nearly 3.7 million hectares land of India suffer from nutrient loss due to soil erosion (Sehgal and Abrol, 1994) with an annual loss of 13.4 million tonnes of cereal, oilseed and pulse production equivalent to about $2.51 billion (Sharda *et al.*, 2010). Therefore soil loss and its sustainability is one of the major issues that is to be addressed more attentively.

Soil erosion entails certain degree of risk related to our environment in general and degradation of land, loss of topsoil and fertility etc. in particular (Blinkov and Kostadinov, 2010). About 30% to 50% of the world's arable land is considerably impacted by soil loss (Pimentel, 1993), affecting rural livelihoods (Kerr, 1997), aquatic resources (Eggermont and Verschuren, 2003), river sediment dynamics (Walling, 2000), global carbon cycling (Lal, 2003), biodiversity and ecosystem (Harvey and Pimentel, 1996; Pimentel and Kounang, 1998) and eventually poverty and food security (Sanchez *et al.,* 1997). To cope up with the risk, the elementary step is to assess susceptibility of an area to erosion. The assessment is one type of land resource evaluation that categorizes land areas into regions of low to high erosion risk zones based on selected hydrologic, geomorphic and soil parameters (Sarkar *et al.,* 2005). Such type of assessment in inadequate data situations, hydro-geomorphological characteristics pertaining to basin-oriented or catchment oriented approach (Chorley, 1969; Jha and Kapat, 2009; Jha and Paudel, 2010) are found to have good predictability. Therefore, systematic and logical amalgamation of geo-morphometric parameters using statistical techniques can be taken as an important tool in this regard. Applications of Geographical Information System (GIS) can make the study more viable as it can handle complex issues and large databases for manipulation and retrieval much efficiently. There are significant literature exists documenting such assessment. Study of Lufafa *et al*. (2002), Baigorria and Romero (2007), Milevski (2008), Amore *et al.* (2004), Lanuzaa and Paningbatan (2010), Prasannakumar *et al.,* (2012), *Sharda et al.,* (2013), Ghosh (2015a), Ghosh *et al.* (2015) deserves worth mention in this connection. In consonance with the global views of soil erosion, addressing the issue is indispensible. In the present swot, a combination of well-known morphometric techniques have used to evaluate the erosion susceptibility of agriculturally dominated Hinglo river basin located at the eastern rim of Chotonagpur Plateau region. Topographic and drainage morphometric characteristics of the river basin have been addressed using spatial information technology. Finally erosion susceptibility zone map have been prepared in GIS environment based on statistical assimilation of 15 morphometric parameters. The aim does not lie in the mere process of quantifying but such results can optimistically be the core of any decision making and supportive in policy formulation for sustaining the environment as a whole coupled with the land productivity.

1.1.0 Geographical Address of the Study Area:

Hinglo River draining through the Rarh regions of Eastern India is a 5th order tributary of the river Ajay (Figure 1). Total length of the main water course is 66.285 km. The entire river catchment (enclosed between 23º42'7.09" N. to 24º0'56.78" N. latitudes and 86º59'32.68" E. to 87º23'31.91" E. longitudes) counting an area of about 444.308sq km, is consisting of eight 4th order, twenty three 3rd order, ninety two 2nd order and three hundred seventy seven 1st order rain fed streams and respective sub-catchment.

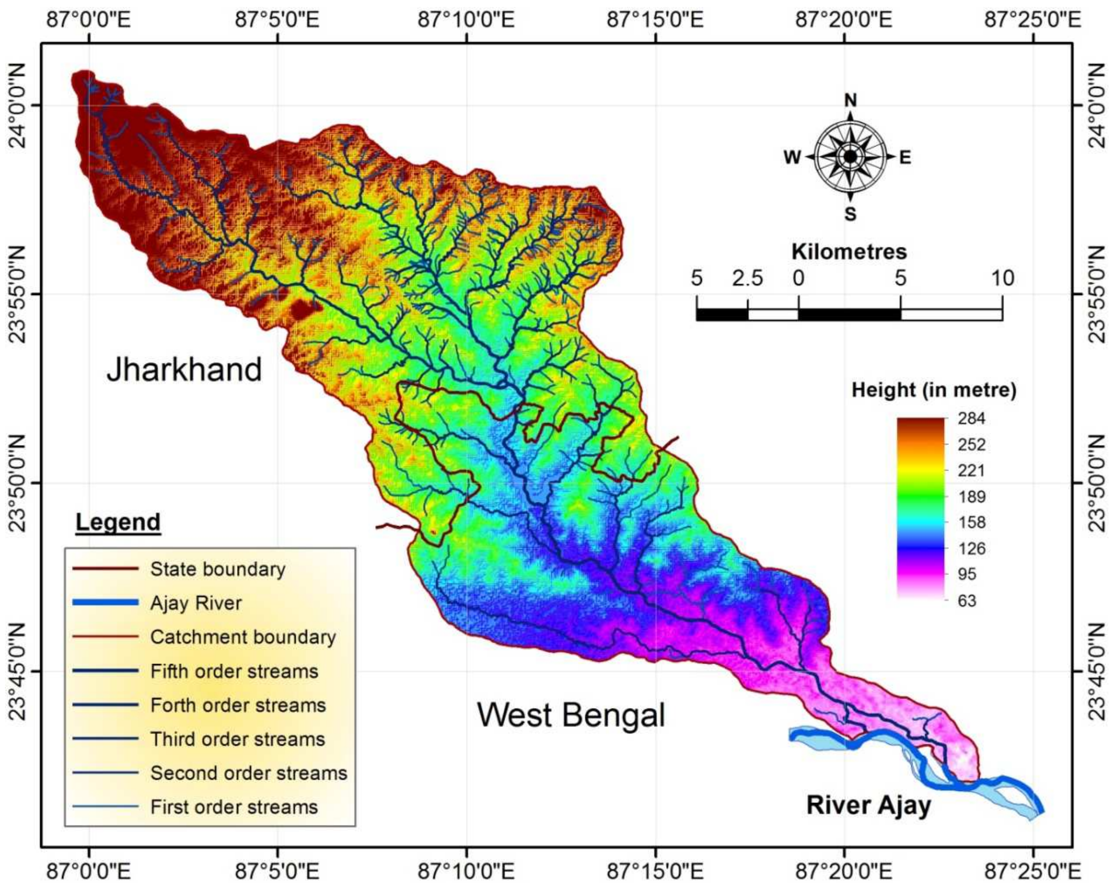

Figure 1: Drainage network over Digital Elevation Model (DEM) of Hinglo river basin.

The catchment area comes under *rarh* bengal (Bagchi and Mukerjee, 1983) with secondary laterite formation (Chakraborty, 1970). It has two major geological segments namely, Granite-Gneiss and Older Alluvium but no significant lineament exists there. Barakar formations and ironstone shale are also found in the lower part (GSI, 1985). About 73% area of the upper catchment is composed with granitic gneissic rock of Pleistocene age overlain by weathered coarse grain lateritic regolith (GSI, 1985). Towards eastern part thickness of the older alluvium increases (from 12 to 20m.) with consequent increase in groundwater yield potentialities of aquifers at a rate about 5-15m^3/hr (Ray and Shekhar, 2009). The water table is moderately deep (5 to 10 mbgl) with high seasonal fluctuation (Mukherjee *et al.,* 2007). The area covered mostly with the reddish, loose and friable soil with ferruginous concretion called laterite. The soil catena consists of plateau fringe with laterite soil; adjacent slopes with sandy and loamy soils and small valley floors with older alluvial soils (NATMO 2001). Moderate physical weathering, mod-max chemical weathering, moderate mass wasting and fluvial processes (rill and gully erosion), laterisation etc. are some pedo-geomorphic processes. Lateritic uplands, deep red weathered zone, duricrust of feroxides and badlands in the North-Western part and rolling alluvial plain in the South-Eastern part characterizes major physiographic features. On consideration of topography, most of the part mainly, the western part is the eastern extension of the Chotonagpur plateau complex. Relief variations (max: 284m.; min: 63m.) are considerable in this tract of lateritic alluvium with average slope ranges from 11° to <1°. Almost throughout the entire catchment, the surface is broken by succession of undulations, the general trend of which is from North-West to South-East. The area experiences sub-humid and subtropical monsoonal type climate with alternate wet and dry season. SW Monsoon (June to September) carries more than 80% rainfall. Forested land is quite less (about 14%) and mostly concentrates in the lower-middle catchment with sick immature *sal* (shorearobusta). Vast area (>90%) of the basin still remain rural. Agriculture is awkward, tedious and challenging in this tract of *rarh* in spite of that >80% of total population is directly or indirectly betrothed in agricultural activities.

2.0 Materials and Methods:

2.1.0 Experimental Design and Dataset:

This present study involves three basic route-surveillance, recording and interpretation. In the preliminary session topographical maps (Map No: 73M/1, M/5, M/6 and 73P/4; Source: SOI 1974), geological maps (Map No: 73 M; Source: GSI 1985), SRTM DEM (2009) and ASTER GDEM (2011) Data, satellite images (IRS P6 LISS III of NRSC, Hyderabad) and some cognitive books and articles have been consulted. All maps were registered into Universal Transverse Mercator Projection northern zone 45 datum WGS 84. The base map of the study area was prepared from Survey of India (SOI) topographical maps on 1:50,000 scale. The hydro-geomorphic facets have been calculated using standard formulae. Slope of the watershed have been prepared using ASTER GDEM. For spatial mapping the entire basin area has been divided into 465 grids of 1sq km. Then, the relief and drainage morphometric properties have been quantified for each of the individual grid.

In the following session tabulation and mapping have been worked out to represent and assess the ground reality. SPSS 17 and MSO Excel 2007 have used for large calculations and statistical analysis. The cartographic works, ranging from delineation of basin area to thematic mapping have been done in ArcGIS 10 and Surfer 11. Processing of SRTM and ASTER GDEM data, satellite images have been finished in ERDAS 9.1 imagine software.

2.2.0 Methodology for the Assessment of Potential Soil Erosion Risk:

Computation of potential soil erosion risk must deals with a large number of variables concerning relief and drainage. In the contemporary period a number of multi-parameter evaluation methods have been in use for terrain appraisal based on RS-GIS (Jankowski, 1995; Malczewski *et al.,* 2003). Amalgamation of drainage basin morphometric variables is one of the most scientific and logical approach for soil erosion risk assessment. In the present swot 7 relief parameters and 8 drainage parameters (vide Table 1) with ample database have been taken and each attribute have been mapped based on the grid wise data bases.

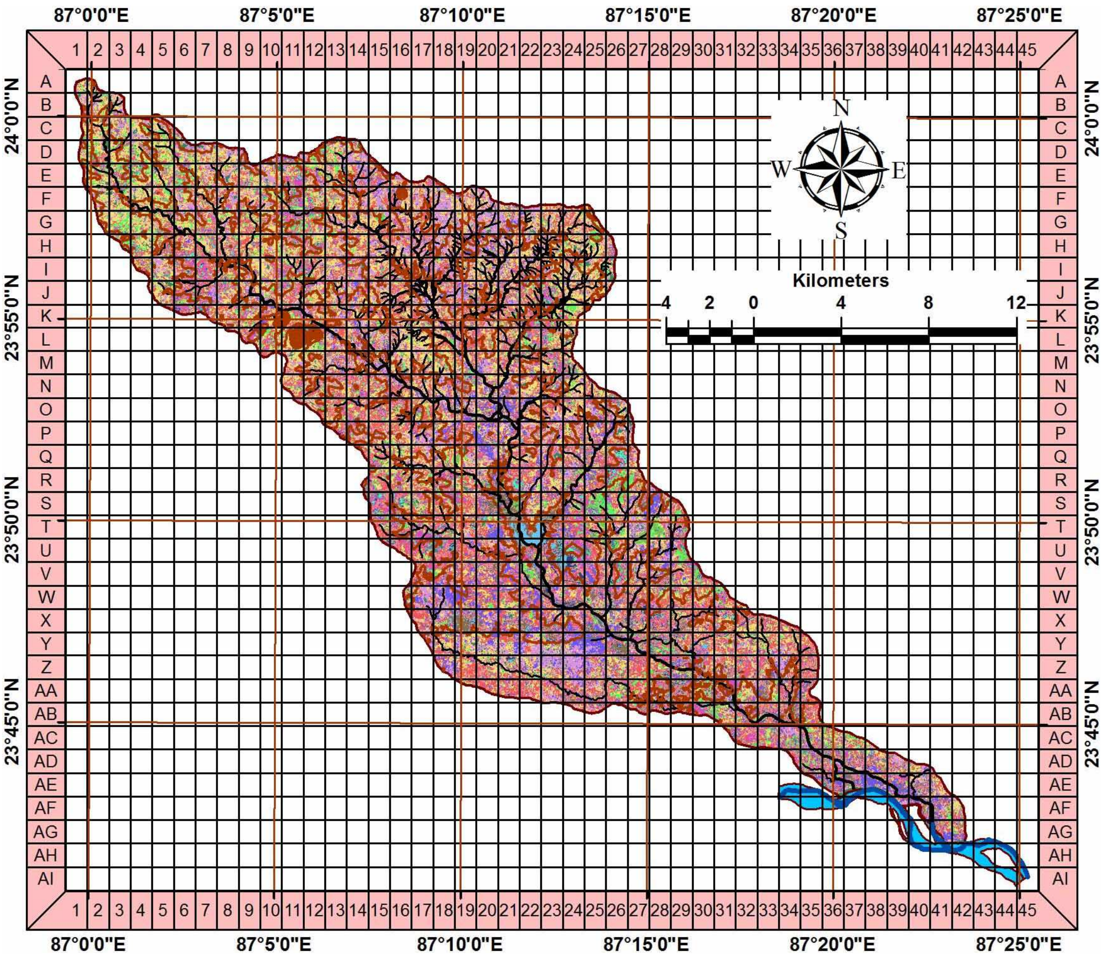

Figure 2: 1 square kilometre grid reference map of Hinglo river basin for morphometric calculation and mapping (Prepared based on IRS LISSIII, SRTM DEM and SOI Toposheets in ArcGIS 10)..

Table 1: List of selected morphometric parameters and their respective methodology

Sl No	Parameters		Formulas/methods	References
1	Relief Parameter	Maximum relief (Rmax)	The maximum elevations of a unit area say a river basin.	Smith (1935)
2		Mininum relief (Rmin)	The lowest elevation of a unit area say, a river basin on its catchment out let.	Smith (1935)
3		Average relief (Ra)	$\text{Ra} = \frac{\text{R max} + \text{R min}}{2}$	--
4		Relative relief (Rr)	Rr = (Rmax–Rmin) Where, Rmax = Relief maximum; Rmin = Relief minimum	Smith (1935)
5		Dissection index (Di)	$Di = \frac{Rr}{R\max}$	Nir (1957)
6		Ruggedness number (Rn)	$Rn = \frac{Rr \times Dd}{K}$ K = a conversion constant 1000 when Rr is expressed in meter and Dd in km,/sq. km.	Patton and Baker (1976)
7		Average slope (ɵ)	$\tan\phi = \frac{N \times I}{636.6}$ N = number of contour cuttings per miles or km., I = contour interval, 636.6 = constant	Wentworth (1930)

8	Drainage Parameter	Drainage frequency (Df)	$Df = \frac{\sum Nu}{A}$	Horton (1945)
9		Drainage density (Dd)	$Dd = \frac{\sum Lu}{A}$	Horton (1932)
10		Drainage texture (Dt)	$Dt = \frac{\sum Nu}{Pb}$	Horton (1945)
11		Length of over land flow (Lof)	$Lof = \frac{1}{2Dd}$	Horton (1945)
12		Constant of channel maintenance (CCM)	$CCM = \frac{1}{Dd}$	Schumm, 1956
13		Drainage intensity (Din)	$Din = Df / Dd$	Faniran (1968)
14		Infiltration number (In)	$In = Df \text{ X } Dd$	Faniran (1968)
15		Frequency of stream junctions (Fsj)	FSJ = $\frac{\sum J}{A}$ Where, J = No. Stream Node	---

To combine all the variables Weighted Composite Score (WCS) method (Andrew and Brendon, 2013) have used. First, weights of relative importance (Table 2) have assigned to each attribute from component score coefficient matrix (Rummel, 1967) of Principal Component Analysis (PCA). For PCA the 1 sq. km grid data matrix values of all the above listed fifteen variables have incorporated and calculation have done with the aid of SPSS 17. In the present case Regression-weight where, each item is weighted according to its factor loading (Wang and Stanley, 1970; DiStefano *et al.*, 2009) instead of unit weight (Einhorn and Hogarth, I975; Kao and Hung, 2005) approach has used as it is technically more valid (Fralicx and Raju, 1982). The raw scores for individual parameters for each grid have then converted to normalized scores by multiplying the weight assigned to those parameters. A total score (WCS) is then obtained for each grid by summing the products (normalized scores) of all attributes. To reduce the extent of weighted composite value, Average Weighted Composite Score (AWCS) has been calculated subdividing Weighted Composite Score (WCS) by the number of parameters. The function can be presented using the following formula.

Table 2: Relation of the selected parameters to soil erosion and their respective weight

Sl No	Parameters	Relation	Weight Assigned
1	Absolute relief, Rmax	Direct (+ve)	.089
2	Minimum relief, Rmin	Direct (+ve)	.078
3	Average relief, Ra	Direct (+ve)	.088
4	Relative relief, Rr	Direct (+ve)	.060
5	Dissection index, Di	Direct (+ve)	.032
6	Ruggedness number, Rn	Direct (+ve)	.094
7	Average slope, ϴ	Direct(+ve)	.076
8	Drainage frequency, Df	Direct (+ve)	.140
9	Drainage density, Dd	Direct (+ve)	.130
10	Drainage texture, Dt	Direct (+ve)	.134
11	Length of overland flow, Lof	Indirect (-ve)	-.099
12	Constant of channel maintenance, CCM	Indirect (-ve)	-.097
13	Drainage intensity, Din	Direct (+ve)	.072
14	Infiltration number, In	Direct (+ve)	.130
15	Frequency of stream junctions, FSj	Direct (+ve)	.140

$$\text{Average Weighted Composite Score } (\text{AWCS}) = \frac{\sum_{i=1}^{n} Pij \times \text{Wi}}{N} \quad (1)$$

Where, Pij means i[th] parameter value at j[th] grid/location, Wi means weight of i[th] parameter and N is the number of parameters. The AWCS is based on the concept of a weighted average (Eastman, 1997 and 2006).

The spatial pattern of soil erosion risk has been approximated from the isoline plotting of AWCS of all the grids throughout the basin. Note, greater the score greater the potentiality of erosion risk and vice versa.

3.0 Results and Discussion:

3.1.0 Evaluation of the Morphometric Parameters:

A major emphasis on geomorphology over the past few decades has been on the use of morphometry to explain the hydro-geomorphological process and responses on a catchment scale. Many scholars have found that it has immense utility in soil erosion risk studies in corroboration with RS-GIS techniques (Sanware *et al.*, 1988; Prasad *et al.*, 1992; Sharda *et al.*, 1993; Shrimali *et al.,* 2001; Dabral and Pandey, 2007; Sharma *et al.*, 2008; Jha and Kapat, 2009; Ghosh, 2015a, Ghosh *et al.,* 2015**)**. In the present erosion risk assessment scheme statistical assemblage of drainage (2 dimensional) and relief (3 dimensional) morphometric parameter have been done. Their respective spatial maps, prepared with the help of Computer Aided Cartography (CAC) have been shown in Figure 3 and Figure 4. Before assimilating all the 15 map-data layers into final integrated map layer (vide figure 5), spatial status of individual parameter can be assessed because each map-data layers may help to understand the nature of control of each parameter on soil erosion.

3.1.1 Evaluation of the Relief Morphometric Parameters:

It has been found that, nearly all the relief parameters namely, *relative relief*, *dissection index*, *ruggedness number* and *slope* (Figure 3a to g) are virtually high in the upper middle and upper catchment of the Hinglo river basin and low in the lower middle and lower catchment. Higher relief supports prompt runoff and hence directly related to soil erosion propensity (Phillips, 1990). More specifically speaking, about one third (33%) of the study area lies under the high Rr, Di and Rn categories where average slope is found to be more than 4.5 degree especially in the upper middle and upper catchment above the contour height 120 m. This indicates the structural complexity of the terrain in association with the high relief and more drainage (Bhunia *et al.*, 2012) and implies that the area is more susceptible to soil erosion (Kumar *et al.,* 2014).

3.1.2 Evaluation of the Drainage Morphometric Parameters:

Drainage frequency, drainage density and *drainage texture* is directly related to lithological characteristics (Abrahams 1984, Hajam *et al.,* 2013). Significantly high of Df, Dd and Dt as noticed in north-middle and uppermost Hinglo river catchment (Figure 4a, 4b and 4c) indicates high mountainous relief, weak and impermeable subsurface material, low infiltration capacity and high runoff conditions which in turn intensify the erosion mechanisms in this counterpart. Notably, stream population decreases from upper catchment (West) to lower catchment (East). The change is abrupt in the catchment transition between upper and upper-middle. As the reciprocal of drainage density *length of overland flow* and *constant of channel maintenance* signifies how much drainage area is required to maintain a unit length of channel or channel consistency (Ritter, 1995). Low Lof and CCM value in the north-middle and uppermost Hinglo river basin (Figure 4d and 4e) signifies that drainage flow paths are shorter, permeability is low and surface runoff is high due to steep slope and structural disturbance is also quite high. *Drainage intensity* and *frequency of stream nodes* are important dimensionless areal morphometric indices to detect the stream concentration per unit area. According to Faniran (1968), low value of Din implies that Dd and Df have little effect on the extent to which the surface has been eroded by the agents of soil erosion and vice versa. The spatial pattern of Din and Fsj (Figure 4f and 4h) again signifies erosional vulnerability of the north-middle and uppermost Hinglo river basin. *Infiltration number* is inversely proportional to the infiltration capacity of the basin (Horton, 1940). Higher infiltration number (vide Figure 4g) reveals impermeable lithology and higher relief and greater soil erosion prospective.

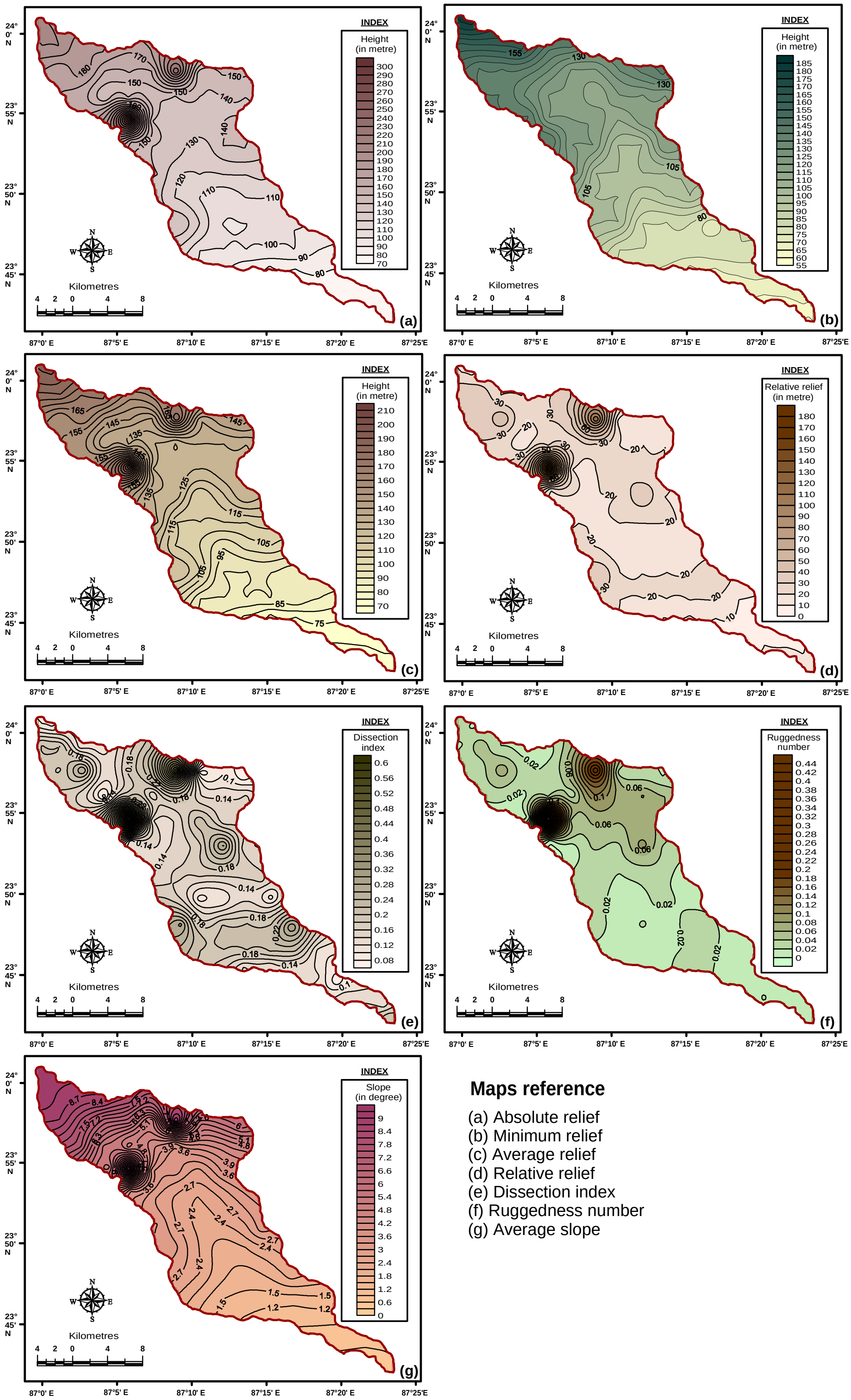

Figure 3: Relief morphometric maps of the Hinglo river basin

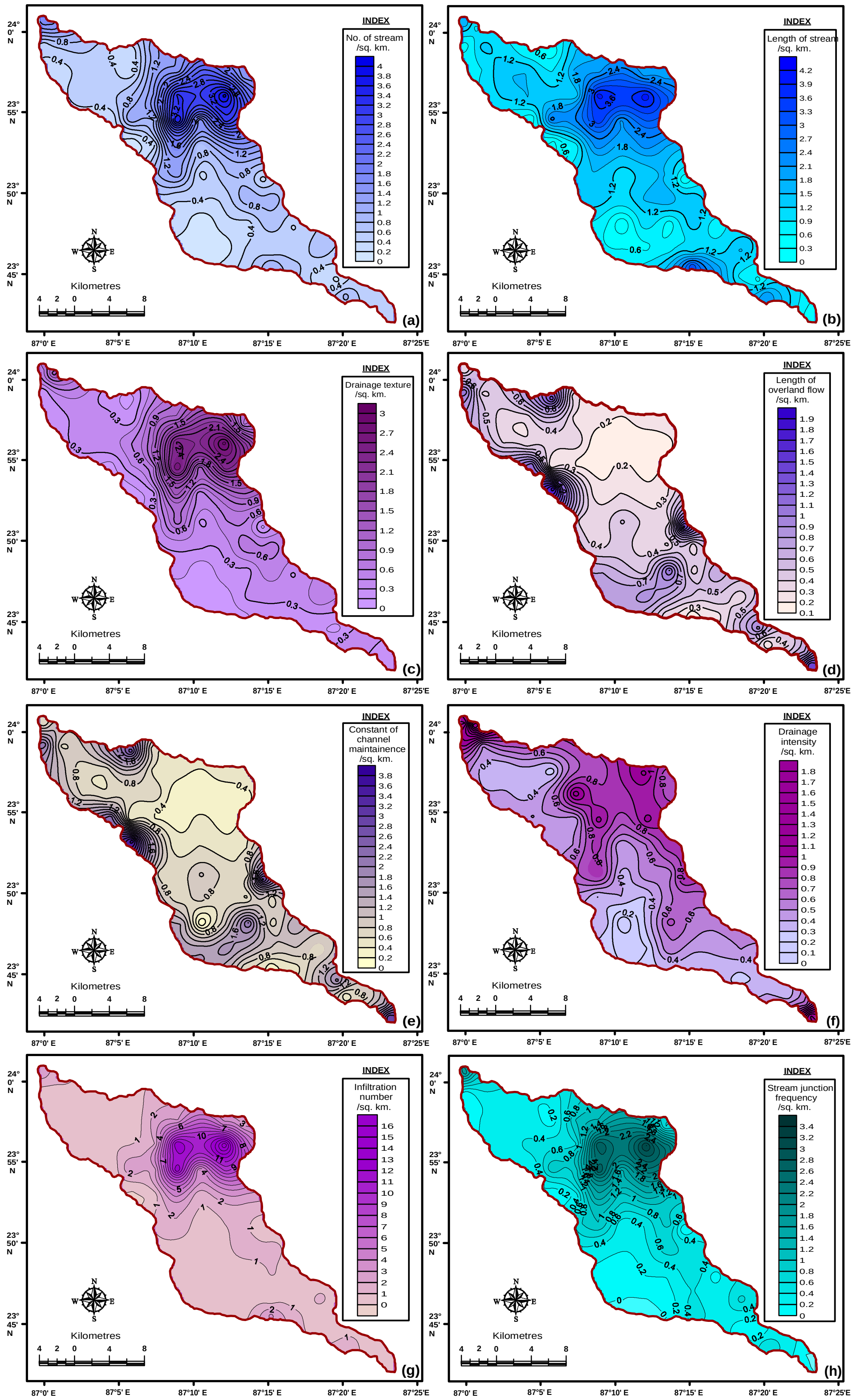

Figure 4: Drainage morphometric maps of the Hinglo river basin (a) Drainage frequency, (b) Drainage density, (c) Drainage texture, (d) Length of overland flow, (e) Constant of channel maintenance, (f) Drainage intensity, (g) Infiltration number, (h) Frequency of stream junctions

3.2.0 Spatial Erosion Susceptibility Assessment: From the previous subsection it is obvious that potential areas for soil erosion under individual parameters have not exactly resembled because of their spatial multi-directionality. Amalgamation of all the parameters is therefore necessary for concluding erosion susceptibility of the study area. The soil erosion susceptibility map of the Hinglo river basin (Figure 5) shows the relative potential erosion vulnerability sites, generated from average weighted composite scores, calculated from the terrain and drainage conditions. Higher scores indicate greater susceptibility of soil loss and vice versa. The red colour zones are representing high receptiveness of soil erosion. However, there is significant spatial variation of erosion propensity in this counterpart. Therefore the entire catchment area needs to be segmented according to the overall suitability scores and each segment should be assessed individually.

On the basis of the AWCS four distinct *Erosion Susceptibility Zone* (SEZ) can be delineated namely *severe erosion susceptibility zone* (AWCS = ≥3), *high erosion susceptibility zone* (AWCS = 2.5-3.0), *moderate erosion susceptibility zone* (AWCS = 1.8-2.5) and *less erosion susceptibility or nearly stable zone* (AWCS = <1.8). *Severe erosion susceptibility zone* covers almost 11.92% (52.95 sq km) and mainly concentrated in upper and upper-middle catchments of the basin. Steep to very steep slopes, high dissection and ruggedness index and excessive stream association explain more erosion propensity in this area. This zone located within granitic gneissic belt of the Chotonagpur plateau rim with fragile lateritic soil, which is prone to frequent rill and gully erosion (Bandopadhyay, 1987; Jha and Kapat, 2009). Moreover, sparse vegetation and lessening of floral cover due to population presser on land as well as high seasonal variability of rainfall (c.v.= 97.13%) with increasing number of short durated heavy rainfall events over the decade (Ghosh 2015b) have magnified the erosion rate. This zone is associated with very shallow to moderately shallow soils and well to excessive drainage conditions and need immediate attention to take up mechanical soil conservation measures, gully control structures and grass waterways to protect the topsoil loss.

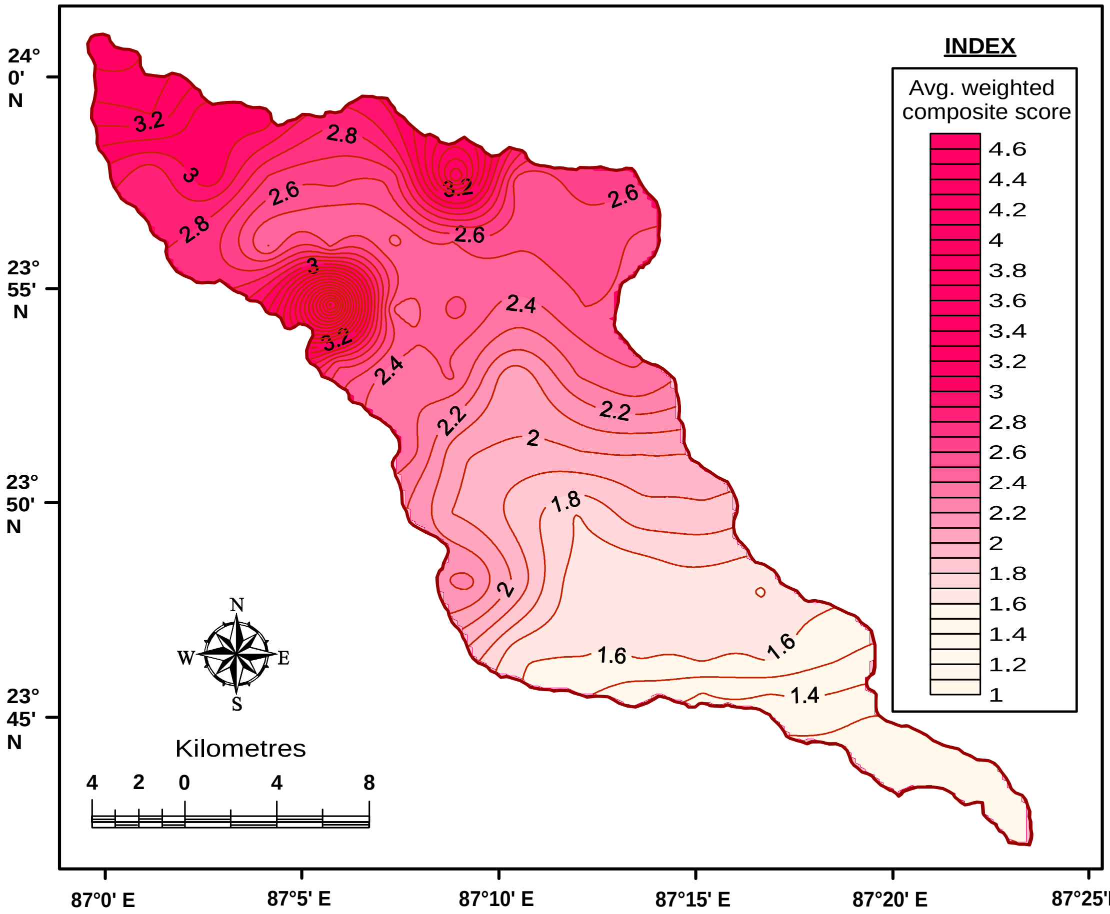

Figure 5: Erosion Susceptibility Zone (ESZ) map of Hinglo river basin prepared based on the weighted composite scores of Rmax, Rmin, Ra, Rr, Di, Rn, ϴ, Df, Dd, Dt, Lof, CCM, Din, In and FSj.

High erosion susceptibility zone covers about 22.93% (101.89 sq km) of the basin area. This zone consist of gentle to steep slope, moderate to high dissection and ruggedness index, very high drainage density, stream frequency, moderate drainage intensity, infiltration number. Flimsy lateritic alluvium with least biomass content in this counterpart is easily weathered and leached due to seasonal drying and wetting (Jha, 1996 and 2009). Pedimental regolith contributes such friable soil with deep lateritic content and encourages strong erosion in the region. The majority area of these zones coincides with shallow to deep soils. These moderately severe erosion susceptibility zones require combination of mechanical and agronomical measures to arrest the soil loss. *Moderate erosion susceptibility zone* is having AWCS between 1.8 and 2.5 and covers about 37.25% (165.49 sq km) of the basin area. This zone consist of moderate to gentle slopes, moderate drainage density, stream frequency, low stream junction frequency. The majority of the area is in association with shallow to deep soils. *Loss erosion susceptibility or stable zone* covers almost 27.9% (123.98 sq km) of the basin area and is associated with lower slopes, low drainage density, stream frequency, lowest number of stream junctions, slight dissection and ruggedness index is also low. This very slight erosion susceptibility zone is found in the area of deep soils near the confluence. This moderate and slight erosion susceptibility zone needs agronomical measures to protect the sheet and rill erosion.

4.0 Conclusion:

The present piece of writing delineates potential erosion vulnerable areas of the plateau fringe Hinglo river basin of western Birbhum district, West Bengal using geo-statistical method taking into consideration 15 soil erosion driving relief and drainage parameters. This present approach will certainly help planners and decision makers in judicious treatment of small hydrologic units and may help to take effective decision concerning where soil protection plan should be execute in priority basis. The study revealed that, almost one third (34.85%) of the study area is potentially erosive. Adoption of suitable measures in these erosion hotspot areas is indispensable to defend nutrient rich topsoil loss in such agriculturally dominated landscape. However, this identified impending erosion susceptible zone needs further appraisal and proposition regarding soil conservation measures considering the geographical conditions and local perception. Empirical pegging operation based measurement and scientific model based hypothetical estimation of soil loss rates in the erosion vulnerable areas may be more appropriate for further decision making. In the subsequent work we will try in this regard to gather the empirical data for better assessment of the same.

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