Soil Erosion Vulnerability Mapping of Nokrek Biosphere Reserve, Meghalaya Using Geographic Information System

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Abstract

The present study is undertaken to find out the soil erosion vulnerability of Nokrek biosphere reserve of Meghalaya using Geographic Information System. The aspects of slope, drainage density, soil characteristics, geology and land use/ cover are taken into consideration for the study. Landsat ETM Remote Sensing data are used for preparing the land use/ cover map. For slope and drainage density mapping source of data was SOI topographical maps. Geology and soil maps are prepared based on the available literatures. Classification of satellite imagery shows that about 86 percent area of the biosphere reserve is covered by forest. But about 9 percent area is utilized by shifting cultivation irrespective to the vulnerable geological, edaphic and geomorphological factors. The biosphere reserve attains more than 60% area with slope more than 22 degrees. It is again found that only about 11 % of the biosphere reserve area falls under low drainage density and could be considered as stable zones with good vegetation cover. Remaining areas are recognised as vulnerable if they do not have proper vegetative cover. Weighted overlay multicriteria analysis of GIS is applied to find out the spatial distribution of vulnerable areas in terms of soil erosion. By integrating all the thematic layers with proper weightages and influences an area of about 30 sq km from the biosphere reserve is designated as most vulnerable for soil erosion. Moderately high vulnerable area found in the study is about 77.5 sq km. The findings of this study regarding the identification of spatial distribution of areas under risk due to soil erosion could be useful for the management authority to check it from further deterioration.

Key words: *Nokrek biosphere reserve, GIS, weighted overlay, slope, drainage density, shifting cultivation*

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Introduction

Soil erosion and sediment transport are recognised as one of the major environmental hazards globally (Pimentel et al., 1995; Shiferaw and Holden, 1999 & Bewket and Sterk, 2002).The steps involved in soil erosion could be splash erosion, which occurs when soil particles are detached and transported as a result of the impact of falling raindrops; sheet erosion, which removes soil in thin layers and is caused by the combined effects of splash erosion and surface runoff; rill erosion, which is the transport or detachment of soil particles caused by concentrations of flowing water; and gully erosion, which occurs when flow concentration increases and the incision becomes deeper and wider than rills (Mwendera and Saleem 1997; Mwendera et al. 1997; Morgan 2005). The process of soil erosion is governed by the topography, climate (weathering), soil, vegetation cover, and land use and management factors through mechanisms including particle detachment by raindrop impact, hydrology, flow hydraulics and other processes (Kosmas et al.1997; Harvey 2001; Lu et al. 2003;Bodoque et al. 2011). Soil erosion has a range of environmental impacts, including loss of organic matter and nutrients, reduction in productivity and downstream water quality degradation (Newcombe & MacDonald, 1991). Effective control of soilerosion is a critical component of natural resource management (Pimentel et al.,1995).For management and control of soil erosion,cause identification and proper delineation of vulnerable sites is pivotal. Geoinformatics tools and space based information could be utilized for identifying the potential areas of soil erosion considering various physical and anthropological aspects of an area. Geographic Information System (GIS) is well suited for the systematic estimations leading to slope stability evaluation and hazard zonation mapping by handling and analyzing various associated spatial data sets (Boroughs and McDonald, 1998 & Baban and Sant, 2004).

Soil erosion study has become a global issue as a consequence of its applied implications (Valentín et al., 2005). The study related to sheet erosion has been conducted globally depending on its contribution towards the conservation of ecologically fragile areas (Poesen et al. 2003; Smith, 2008; Godfrey et al., 2008 and Reid et al., 2010). The selection of any appropriate hazard modelling technique is dependent upon the management scale, site-specific conditions and data availability (Carrara et al., 1999). The present context could be related with numerous works carried out globally using GIS (Carraraet al., 1991; Van Westen, 1993; Van Westen et al., 2003; Armesto et al., 1978; Prakash and Gupta, 1998; Joshi et al., 2003 & Balaguruet al., 2003).The recent development in spatial data analysis using GIS tools (Issaks and Srivastava, 1989; Rossi et al, 1992; Jackson and

Caldwell, 1993) and its consequent advances allow more extensive examinations of spatial analysis (Palmer and Dixon, 1990; Reed et al., 1993; Wiegand et al., 1997; Pastor et al., 1999; Nicotra et al., 1999; Woods, 2000; Wallace et al., 2000; Palmer et al. 2000; Friedman et al., 2001; Sarma and Barik, 2010).

The Nokrekbiosphere reserve (NBR) of Meghalaya in north-east India is one of the 18 biosphere reserves notified on 1st September 1988 and has many distinct and unique bio-physical features that need to be conserved. It is a unique area with a number of rare and endangered species of plants and animals. NBR is severely affected by sheet erosion mainly because of the age old tradition of shifting cultivation in the fragile hills slopes aided by other anthropogenic activities. Shifting cultivation is regarded as one of the main drivers for this degradation (Sarma and Barik 2010; Yadav et al., 2012) (Figure 1). The heavy rainfall during summer accelerates the erosion rate in the areas which are free from vegetation cover. This indiscriminate activity within the biosphere reserve has been detrimental to the fragile ecosystem and has resulted in large-scale degradation of the landscape, soil, water and forest causing serious threat for its existence (Sarma and Barik, 2012). Vegetation is one of the major factors controlling soil erosion, while most soil erosion occurrences are due to removal of vegetation and topsoil (Bochet and Fayos, 2004).

This paper aims to identify and map the spatial distributions of different categories of risk zones of soil erosion for the management authorities to check it from further degradation. The main objectives of the study include collection and collation of data related to soil erosion vulnerability, preparation of spatial database for Nokrek biosphere reserve pertaining to soil erosion, preparation of risk map indicating various zones, and proposing remedial measures based on the outputs of the study.

Figure 1: Photograph shows the base for sheet erosion in different slopes after removing the vegetation for shifting cultivation in the buffer of Nokrek biosphere reserve

Study area

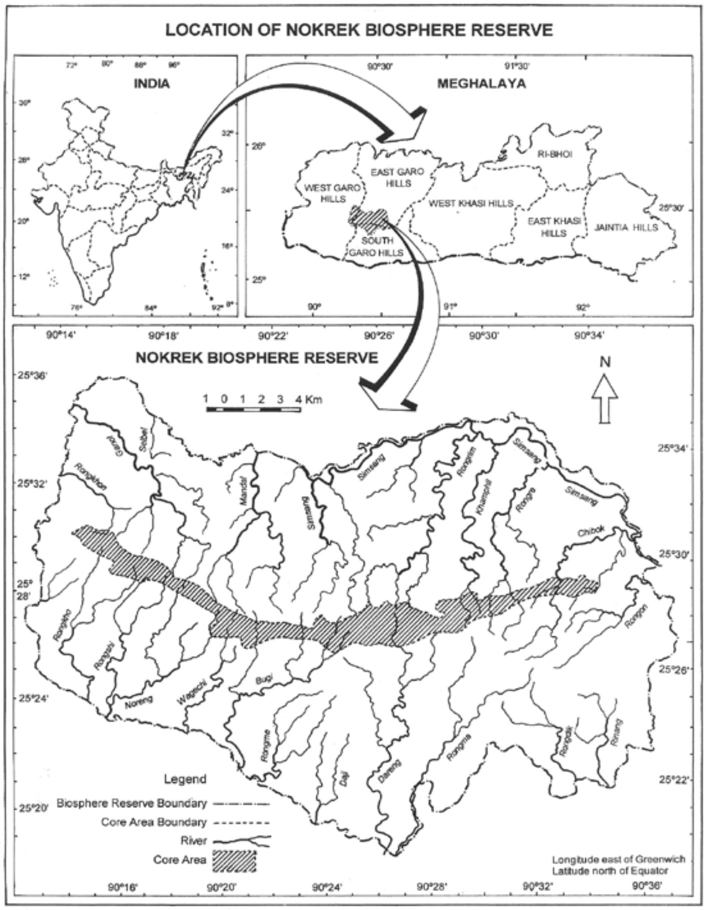

Figure 2: Location of Nokrek biosphere reserve of Meghalaya

The present study was carried out in the western part of Meghalaya, having an area of 820 sq km covering all the three districts of Garo Hills viz., East Garo Hills, West Garo Hills and South Garo Hills that has been designated as Nokrek biosphere reserve. The biosphere reserve lies between 25° 18’ 39” N and 25° 36’ 07” N latitudes and 90° 13’ 30” E and 91°37’17” E longitudes (Figure 2). NBR is located in the Tura range, which is a part of Meghalaya plateau, having an average altitude of 600 m. The highest point in this region is the Nokrek peak (1,412m) lying within the biosphere reserve. The core area of the biosphere has been designated as Nokrek national park, which is spread over an area of 47.48 sq km.

The soil of most part of the biosphere reserve is red loam and is poor in silica but rich in clay forming materials. The soil is generally loamy but often found clay to sandy loam. The surface horizon which is about 30 cm thick has colours ranging from reddish brown to dark reddish brown. The soils are rich in organic matter and nitrogen but deficient in phosphorous and potassium and they areacidic in reaction (Sarma and Barik, 2012). The climate of the area no word as monsoomic is found in english dictionary directly influenced by the south-west monsoon. The vegetation of Nokrek biosphere reserve can be broadly classified into tropical and subtropical types depending on the altitude. The tropical vegetation is found up to an elevation of about 1000m (Sarma et al., 2005).

Materials and Methods

Landsat ETM satellite data of 06.02.2010 and 30.01.2010 with path and row 138 & 42 and 137 & 42 are used for the present study. The satellite image with bands (7) were stacked to prepare an FCC of bands 3(Red), 2(Green) and 1(Blue). The relevant topographic maps and image were geometrically rectified in 1:50,000 scale using geographic projection system UTM; speroid and datum used were WGS 84 with UTM zone 45N. The thematic features of drainage and contours were delineated from the topographical maps. Soil and geology maps are prepared based on available maps (Sarma, 2002; Sing and Singh, 2000). Sufficient field survey was carried out for validation after image interpretation. The GIS and image processing software used are ArcGIS 2010, Erdas IMAGINE 2011 and Quantum GIS.

Land use/cover mapping

The image features on the satellite data were interpreted to prepare land use/ cover map using the various image elements like tone, texture, pattern, shape, size, shadow, location and association (Garg et al., 1988 & Lillesand and Kiefer, 1987).

Slope analysis

The slope analysis was estimated following Zakrzewska (1967), the modified version of Wentworth (1930).

Slope in degree = $\tan \theta = V * N / 0.6366\,K$

Where, V = Vertical contour interval in meter or in feet

N = Number of contour crossing per square kilometer or per square mile

K = Constant, 1000 for metric units and 5280 for British units

Thus, to find out the nature of average slope and its characteristics, the area had been divided into one by one kilometer grids and the number of contours crossing per square kilometer were counted and average slope per grid was computed. Based on the results, a slope map had been prepared and classified into five categories of slope i.e., high (above 29°), moderately high (23° to 29°), moderate (16° to 22°), moderately low (9° to 15°) and low (2° to 8°).

Drainage density analysis

Drainage density was analysed by following a simple device developed by Horton

(1945) as expressed in the formula below:

Du = (EL) u / Au

Where, Du= Drainage density in km per square kilometer

(EL) = Sum of the total length of streams of all orders in km

Au = Total area of drainage basin in square kilometer

To know the variation, drainage density has been computed per square kilometer for the entire biosphere reserve. The area had been divided into one by one kilometer grids and drainage density per grid was computed. Four categories of drainage density were delineated i.e., high (above 9 km/sq km), moderately high (7 to 9 km/sq km), moderately low (5 to 7 km/sq km) and low (below 5 km/sq.km).

Weighted Overlay Analysis

Integration of thematic layers was performed using weighted overlay analysis. Based on the contribution and understanding the behaviour of different thematic layers a weightage which is a qualitative assessment, has been given range on a scale of 1 to 9 depending on their hazard potential level for soil erosion. The influence percentage of each thematic layer has also been assigned according to the contribution (Table 1). All the thematic layers which include land use/cover, slope, drainage density, geology and soil types were converted into grid with related item weight and integrated with one another through GIS (ArcInfo spatial analyst environment). The cell size assigned is 30m x 30m. As per this analysis, the total weightage of the final integrated grids were derived as sum of the weightage assigned to the different layers based on suitability. In the present study, soil erosion hazard mapping of NBR has been generated by integration of all above grid layers. The delineation has made by grouping the grids of final integrated layer into four vulnerable zones.

Results and Discussions

Land use/cover analysis

The land use/ cover of Nokrek biosphere reserve has been broadly classified into dense forest, open forest,

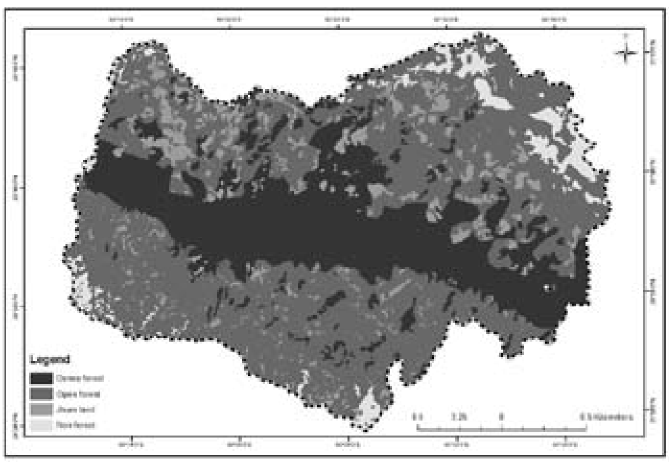

Figure 3: Land use/cover of Nokrek biosphere reserve

shifting cultivation and non-forest area (Figure 3). A considerable portion of the biosphere reserve is under forest cover (86%) either dense or open. Out of the non-forest about 8.8 percent falls under current or abundant shifting cultivation area.

Slope characteristics

More than 60 percent of the total area of NBR attains more than 22 degree slope. Area with slope degree less than 8 occupies about 7.5 percent. The slope map reveals that the most of the central and the central northern part of the biosphere reserve have the higher average slope (more than 16°). The high slope zone is confined along the Tura range in the western part and three small pockets in the northern fringe. The area under moderately high slope falls mainly along the central ridge and northwestern

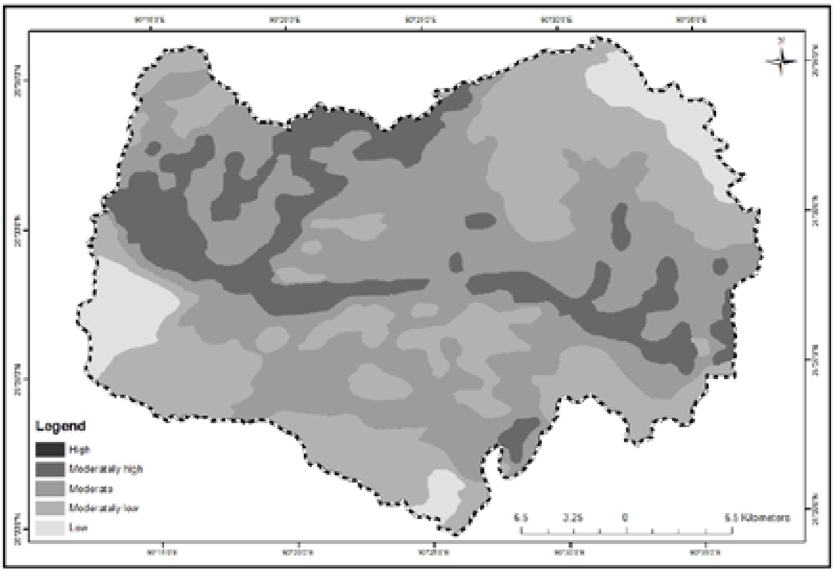

Figure 4: Slope categories of Nokrek biosphere reserve (Sarma and Bari, 2010)

part. The moderate slope occupies the central part of the biosphere reserve. The moderately low slope is confined to the northeastern, southern and southwestern corner. The area under low slope falls in the southwestern and northeastern corner and a small area in the southern part (Figure 4).

Drainage density analysis

The zones with dissected hilly terrain of high altitude, high negative relief and high

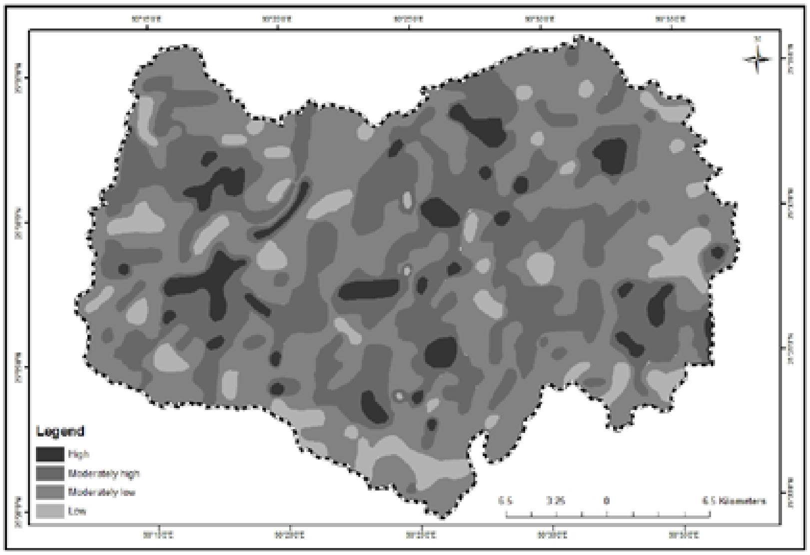

Figure 5: Area under different drainage density categories of Nokrek biosphere reserve (Sarma and Barik, 2010)

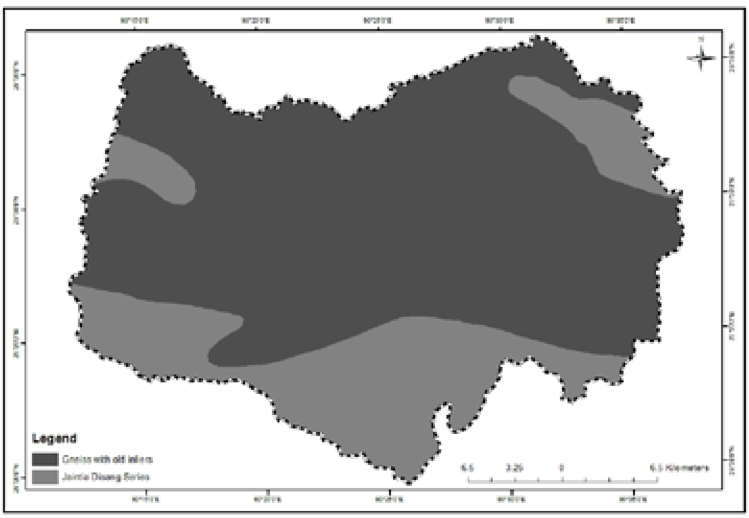

Figure 6: Geology of Nokrek biosphere reserve (Singh and Singh, 2000)

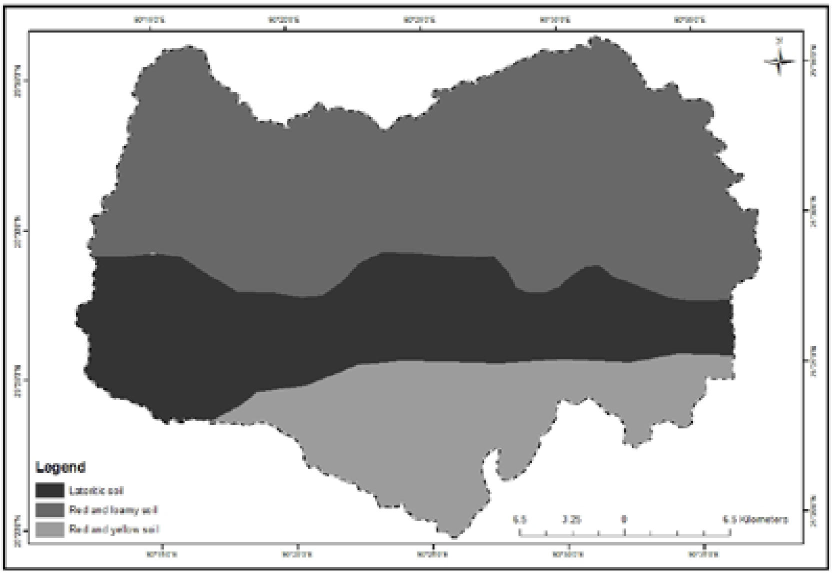

Figure 7: Spatial distribution of soils of Nokrek biosphere reserve (Sarma, 2002)

average slope usually show high drainage density (Sarma 2002). As Nokrek biosphere reserve itself is a dissected hilly terrain with high average slope, the drainage density shown in the area is quite high (Figure 5). Only 87 sq km

(10.6%) of the total areas fall under low drainage density zone which could be considered as stable zones with good forest cover.

Geology and soil mapping

The geology of NBR is mostly composed of two types i.e., Gneiss with old inliers (72.3%) and Jaintia Disang Series (27.7%) (Figure 6). In case of soil major portion of the biosphere reserve comprises of red and loamy soil (52%) followed by lateritic and red and yellow soils (Figure 7).

Weighted Overlay Analysis

By utilising the weighted overlay analysis model (Table 1) a map showing different soil erosion vulnerable potential zones of most vulnerable, moderately high vulnerable,

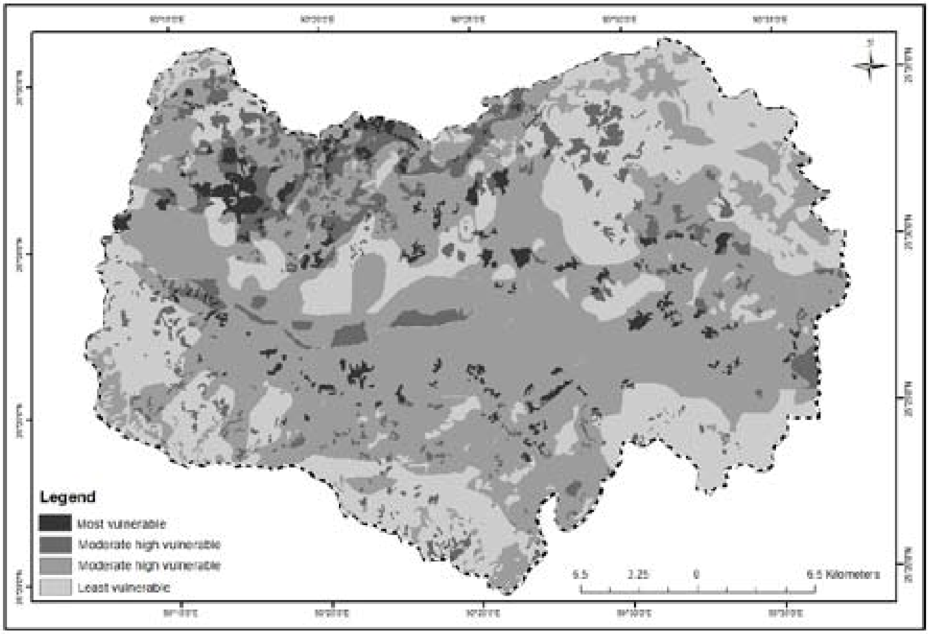

Figure 8: Soil erosion potential zones of Nokrek biosphere reserve

moderately low vulnerable and least vulnerable has been prepared (Figure 8). The findings of the study reveals that a considerable portion of the biosphere reserve (about 4 percent) is found to be most vulnerable probably due to maximum anthropogenic influences in terms of shifting cultivation which are free from vegetation cover with steeper slopes comprising of loose soil conditions. These all criteria attribute for delineating the areas under risk due to soil erosion in NBR.

Soil erosion is the result of interrelationships among vegetation, topography, drainage, bedrock and soil (Lucía et al., 2010). The present study shows that primary forests of NBR have been destroyed to a great extent by age old tradition of shifting agriculture which is extensively practiced in the studied area as well as in hilly regions of the north-east India (Ramakrishnan, 1992 & Yadav et al., 2012). This activity has led to the development of a variety of successional plant communities ranging from open forest to recently abandoned shifting cultivation fields (Prabhu 2004). Sarma and Barik (2010) concluded that steep slopes of Nokrek biosphere reserve are also exploited for the purpose of shifting cultivation. The buffer zones of the biosphere reserve represent a mosaic of degraded landscape owing to the gentle slope of the area. This finding is similar to that of Susana and Mario (2000) who reported that deforestation may be widespread in areas where slopes are relatively gentle. Steep slopes of Nokrek biosphere reserve have remarkable influence on the forest cover. Similar results have been observed by Balaguru et al. (2003) from Shervaryan hills, Eastern Ghats of India. Strahler (1960) postulated that a region underlined by massive, hard sandstone beds under heavy forest

Table 1: Influences and weightages of different thematic layers for contributing potential soil erosion hazard along with the areas under each category of Nokrek biosphere reserve

Raster data	% Influence	Field	Scale value	Area (sq.km)	% Area
Drainage Density	15	Moderately low	3	368	44.88
		Moderately high	5	274	33.41
		Low	2	87	10.61
		High	6	91	11.1
			1 to 9	**820**	**100**
Geology	5	Gneiss with old inliers	5	593	72.26
		Jaintia Disang Series	3	227	27.74
			1 to 9	**820**	**100**
Land use/cover	30	Non forest	6	41	4.97
		Shifting cultivation	8	72	8.78
		Open forest	3	453	55.27
		Dense forest	1	254	30.99
			1 to 9	**820**	**100**
Slope	35	High	8	13	1.58
		Low	2	61	7.44
		Moderate	5	367	44.76
		Moderately high	7	116	14.15
		Moderately low	3	263	32.07
			1 to 9	**820**	**100**
Soil	15	Red and yellow soil	3	157	19.17
		Lateritic soil	5	237	28.91
		Red and loamy soil	3	426	51.92
	100		**1 to 9**	**820**	**100**

Table 2: Areas under different soil erosion vulnerable classes of Nokrek biosphere reserve		
Vulnerable class	**Area**	**%**
Most vulnerable	30	3.7
Moderately high vulnerable	77.5	9.5
Moderately low vulnerable	451.8	55.1
Least vulnerable	260.7	31.8
Total	**820**	**100.0**

cover shows the drainage density averaging 1.8 to 2.5 km/sq.km. The region with medium drainage density averaging 7.5 to 10 km/sq.km is underlined by thin bedded sandstones and thick shales, relatively easily eroded and is characterized by the development of thick deciduous forest. The finding of thisresearch absolutely supports this observation. The present area under investigation is again similar to the findings of Kirkby (1980, 1993) who predicted that under a humid climate, drainage density should decrease with increasing slope.

Baban and Sant (2005) while studying the susceptibility mapping for the Caribbean island of Tobago using GIS, multi-criteria evaluation techniques with a varied weighted approach found that about 6.4% of the total area is under severe risk of soil erosion. This finding is in support of the present research. Anbalagan et al. (2008) analysed the relationships of slope morphometry with different aspects like lithology, structure, land use/ cover, and relief. They assigned the maximum influences where higher slope is free from vegetation cover and with the influence of other anthropogenic activities. Their approach is an agreement to the present study.The findings of this research show that soil erosion rates are influenced by slope, drainage, geology, soil and human induced activities. Besides other factors vulnerability is maximum in the areas where human interferences are more. This study is a point to the findings of Neil and Fogarty,1991; Prove et al., 1995 & Edwards and Zierholz, 2001. In another study Neil and Galloway (1989) compared the soil erosion rates in the cultivable lands with native forests in the plateau of New South Wales. Their results show that there is significant increase of erosion rate in the cultivable land though the nature of slope is same. Similar observations are found by Erskine et al., (2003) and Mahmoudzadeh et al.(2002). The probable vulnerable areas of soil erosion as depicted after the present research is an agreement to these observations.

Conclusion

Nokrek biosphere reserve supports a dense forest cover that is mainly concentrated in the core zone and should therefore be conserved for biodiversity. However, this zone is also slowly encroached by the local people for shifting cultivation and other anthropogenic activities which are threatening the biodiversity of the biosphere reserve. Slush and burnt practice even in the steep slopes creates havoc towards the sustainability of the ecosystem. The drainage showed high density in open forest and non-forest areas indicating vulnerability in terms of soil erosion. The shifting cultivation cycle should be at least 15-20 years against existing 3-5 years as short cycle not only effects soil fertility but also exposes the top soil for erosion. Further, the conversion of forest areas of buffer zones into other land use should be properly planned. The most important step that needs to be undertaken to prevent the area from further deterioration is to educate the people and make them aware of the consequences of deforestation and shifting cultivation. The spatial distributions of different categories of risk found in this study could be useful for the management authority to check it from further degradation.

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