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Mmodeling Sediment Dynamics from Catchment to Coasts

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Abstract: Coastal areas in India are diverse in function and form, dynamic and do not lend themselves well to definition by strict spatial boundaries. The methodology for estimating the possible deposition of eroded soil and associated nutrients from the Brahmaputra basin is primarily based on determining the loss of soil and nutrients and their deposition in different sinks by quantifying the sediment and nutrients load in the runoff. Soil loss from erosion was estimated through gauges from different land use systems prevailing in the region as well as from non-agricultural land. We evolved a mathematical model for soil erosion in the catchment and its deposition in different sinks enroute marine waters. The model was evolved taking into consideration; rainfall, slope of the area, temperature, soil clay, soil moisture and vegetation cover. The model was based on multiple regression equation approach. The vegetation is the only independent variable for which the values (1–5) have to be based on visual estimates. For uniformity, the classification used for the vegetation values is: 1, bare soil surface; 2, scrubs or effective covered area below 25%; 3, cropped soil surface or effective covered area of 25 to 50%; 4, open forest vegetation or effective covered area of 50 to 75%; and 5, dense forest or effective area covered >75%. More available data for calculating the values of the coefficients may result in an increase in the predictive power of the model. In principle, the model can be used for predicting soil erosion by flowing water, under a wide range of climatic and physical conditions.

Key words: Modeling · Sediment Dynamics · Catchment · Coasts · Brahmaputra Basin · India

INTRODUCTION

Coastal zones are dynamically evolving systems comprising three components, i.e. the marine, the coastal and the land subsystem. It comprises not only shoreline ecosystem, but also the upland watersheds draining into coastal waters and the near-shore sub-littoral ecosystem influenced by land-based activities. Soil erosion, sediment transport and deposition are considered as the major processes of catchment sediment dynamics. Hydrological events mainly govern sediment dynamics in a river basin which are highly variable in spatial and temporal scales. Human-induced changes in flows of nutrients, sediments and fresh water are major threats to coastal and marine ecosystems worldwide [1, 2]. Coastal and marine waters enriched with nutrients from agricultural fertilizers applied in the catchments, create eutrophic and hypoxic or anoxic conditions that affect the functioning of marine ecosystems and the status of biodiversity and human health [3, 4]. Walling [5] reported that loads of sediments derived from land clearing, urbanization and agriculture have significantly increased in many regions and are a major threat to vulnerable ecosystems such as coral reefs and seagrass beds [6, 7]. Managing such land-based threats is increasingly recognized as a crucial component of maintaining healthy coastal and marine ecosystems globally [7, 8]. Catchment models are powerful tools to explore management options to improve water quality [9] because they link sources of pollutants (sediment, nutrients) to affected areas and ecosystems.

Management actions include implementation of best practices in agriculture and livestock management, water treatment, restoration of riparian vegetation, protection of erosion-prone areas and gully stabilization [10, 11]. For modeling approaches to be relevant for identifying and assessing land-based threats to coastal-marine ecosystems, several considerations are important; such as, spatial and temporal scales, data availability vs. data requirements of models (climate, flow, in situ water-quality sampling), existing technical expertise and constraints on

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time and budget [9, 12]. The activities on the hinterland areas significantly affect the sea area near the coastline as large amount of sediment load is carried from the main land to the sea.

Rainfall increases are expected to reflect disproportionately in heavy precipitation events, with average rainfall intensity increasing, which is also a trend that has been observed in the global climate record [13]. The IPCC's fourth assessment report [14] points to significant changes in river runoff, due to changes in rainfall coupled with an increase in potential evapotranspiration, as higher temperatures increase the atmospheric vapour pressure deficit. These changes, compounded with the increases in rainfall intensity described earlier, can combine to increase significantly the probability of occurrence of large floods [14].

The main factors influencing soil erosion are rainfall, land use and management, topography and soil and their properties [15]. Several models that are commonly used include the Wind Erosion Equation [16] and the Universal Soil Loss Equation (USLE) [17]. All of these models have climate components and are capable of being manipulated to predict erosion risk under different climate change scenarios [18]. Despite scientific advances, the problem of accelerated soil erosion is more serious now than ever before. In addition to more regionally reliable GCMs, accurate and reliable databases of parameters such as rainfall, slope, vegetation cover, soil properties and temperature are needed. These parameters were used to construct the mathematical model and is reported in this paper.

Study Site and Methodology

Study Site: The Brahmaputra river basin in India extends to four north-eastern states; namely, Arunachal Pradesh, Assam, Meghalaya and Nagaland, with an area of 1.94 x 10^5 km^2 (Fig. 1). The river has more than 100 tributaries, of which 15 in the north and 10 in the south, are fairly large. The average annual runoff in the Brahmaputra river is 537.2 km^3, varying from 3200 m^3 see^{-1} to 19,200 $m^3 see^{-1}$ during lean period and monsoon season, respectively. The river and its tributaries produce enormous sediment load when they flow through geologically young and unstable terrain and banks being extremely unstable, are subjected to huge soil and nutrient erosion as well as subsidence. The basin is endowed with rich resources of water, soil and vegetation but their indiscriminate use has rendered them in a fragile state [19]. About 438.7 million tonnes (Mt) of soil is lost every year through erosion and this huge quantity of soil, along with runoff, takes away

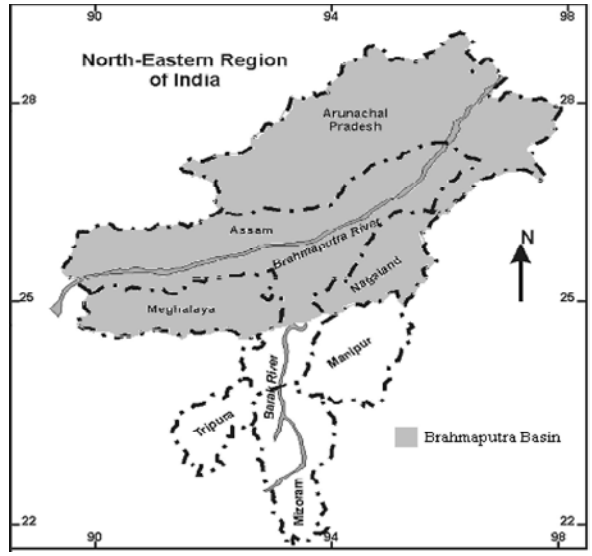

Fig. 1: Brahmaputra basin in India

large amounts of absorbed and dissolved crop nutrients to different sinks [20]. The basin has a steep gradient in the north and eastern sides but extremely gentle in the south.

Methodology: The methodology for estimating the possible deposition of eroded soil and associated nutrients from the Brahmaputra basin is primarily based on determining the loss of soil and the deposition at different places by quantifying the sediment and nutrients load in the runoff. Soil loss from erosion was estimated through gauges from different land use systems prevailing in the region as well as from non-agricultural land [21]. It may be difficult to justify the exact sediment load displaced from such a large area. However, total soil and nutrient load was estimated as a product of soil loss from the gauged areas of watersheds studied, extrapolated to the total areas of the basin, taking into consideration slope, rainfall, vegetation and clay content of the soil. Deposition of the eroded soil in the sediment sinks was estimated by analyzing the water samples for the dissolved and un-dissolved elements. Total amount of sediment deposited was determined by multiplying with the quantity of water collected in different sinks. The sediment load transported to the sea was estimated by subtracting the sediment load in different sinks (except sea) from the total sediment lost from the basin. Nutrient content was estimated by standard procedures [22].

The model: In the present case; the soil erosion prediction model involves a partial regression equation of the form:

Table 1: Calculation of partial and multiple correlation coefficients*.

1	a_{11}	a_{21}	a_{31}	a_{41}	a_{51}	a_{61}	1	0	0	0	0	0
2		a_{22}	a_{32}	a_{42}	a_{52}	a_{62}	0	1	0	0	0	0
3			a_{33}	a_{43}	a_{53}	a_{63}	0	0	1	0	0	0
4				a_{44}	a_{54}	a_{64}	0	0	0	1	0	0
5				a_{45}	a_{55}	a_{65}	0	0	0	0	1	0
6						a_{66}	0	0	0	0	0	1
7	a_{11}	a_{21}	a_{31}	a_{41}	a_{51}	a_{61}	d_{11}	0				
8	1	b_{21}	b_{31}	b_{41}	b_{51}	b_{61}	e_{11}	0				
9		$a_{22.1}$	$a_{32.1}$	$a_{42.1}$	$a_{52.1}$	$a_{62.1}$	$d_{11.1}$	$d_{12.1}$	0			
10		1	$b_{32.1}$	$b_{42.1}$	$b_{52.1}$	$b_{62.1}$	$e_{11.1}$	$e_{12.1}$	0			
11			$a_{33.2}$	$a_{43.2}$	$a_{53.2}$	$a_{63.2}$	$d_{11.2}$	$d_{12.2}$	$d_{13.2}$	0		
12			1	$b_{43.2}$	$b_{53.2}$	$b_{63.2}$	$e_{11.2}$	$e_{12.2}$	$e_{13.2}$	0		
13				$a_{44.3}$	$a_{54.3}$	$a_{64.3}$	$d_{11.3}$	$d_{12.3}$	$d_{13.3}$	$d_{14.3}$	0	
14				1	$b_{54.3}$	$b_{64.3}$	$e_{11.3}$	$e_{12.3}$	$e_{13.3}$	$e_{14.3}$	0	
15					$a_{55.4}$	$a_{65.4}$	$d_{11.4}$	$d_{12.4}$	$d_{13.4}$	$d_{14.4}$	$d_{15.4}$	0
16					1	$b_{66.5}$	$e_{11.4}$	$e_{12.4}$	$e_{13.4}$	$e_{14.4}$	$e_{15.4}$	0
17						$a_{66.5}$	$d_{11.5}$	$d_{12.5}$	$d_{13.5}$	$d_{14.5}$	$d_{15.5}$	$d_{16.5}$
18						$b_{66.5}$	$e_{11.5}$	$e_{12.5}$	$e_{13.5}$	$e_{14.5}$	$e_{15.5}$	$e_{16.5}$
19	b'_{61}	b'_{62}	b'_{63}	b'_{64}	b'_{65}		c'_{11}	c'_{12}	c'_{13}	c'_{14}	c'_{15}	c'_{16}
20	b'_{51}	b'_{52}	b'_{53}	b'_{54}		b'_{56}		c'_{22}	c'_{23}	c'_{24}	c'_{25}	c'_{26}
21	b'_{41}	b'_{42}	b'_{43}		b'_{45}	b'_{46}			c'_{33}	c'_{34}	c'_{35}	c'_{36}
22	b'_{31}	b'_{32}		b'_{34}	b'_{35}	b'_{36}				c'_{44}	c'_{45}	c'_{46}
23	b'_{21}		b'_{23}	b'_{24}	b'_{25}	b'_{26}					c'_{55}	c'_{56}
24		b'_{12}	b'_{13}	b'_{14}	b'_{15}	b'_{16}						c'_{66}
25							r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}
26**								r_{22}	r_{23}	r_{24}	r_{25}	r_{26}
27									r_{33}	r_{34}	r_{35}	r_{36}
28										r_{44}	r_{45}	r_{46}
29											r_{55}	r_{56}
30												r_{66}

*The subscripts have been abbreviated, thus $b_{65.4} = b_{65.1234}$.

** $r^2_{1\text{-}.23456} = a_{12}b'_{12} + a_{13}b'_{13} = a_{14}b'_{14} + a_{15}b'_{15} + a_{16}b'_{16}$

$$y_e = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 \quad (1)$$

where; y_e is the soil erosion (t ha^{-1}) and b_1, b_2, b_3, b_4, b_5 and b_6 are the partial regression coefficient for rainfall (x_1) in cm, temperature (x_2) in °C, slope (x_3) in %, vegetation cover (x_4), soil clay content (x_5) in % and Soil moisture (x_6) in %, respectively. The equation was developed using the Dolittle method [23], which gave a reasonably high degree of accuracy in prediction or estimation of soil erosion loss. The vegetation is the only independent variable for which the values (1–5) have to be based on visual estimates. For uniformity, the classification used for the vegetation values is: 1, bare soil surface with soil stirred or ploughed; 2, scrubs or effective covered area below 25%; 3, cropped soil surface or effective covered area of 25 to 50%; 4, open forest vegetation or effective covered area of 50 to 75%; and 5, dense forest or effective area covered >75%. More available data for calculating the values of the coefficients may result in an increase in the predictive power of the equation. In principle, the model can be used for predicting soil erosion by flowing water, under a wide range of climatic and physical conditions. The developed model can be used for predicting soil erosion reliably, may be with certain limitations. There is need to improve and refine the model by including observed data from recent studies as well as by additional systematic studies of the factors that control soil erosion. There is one dependent variable, soil erosion (y) and six independent variables such as rainfall (x_1), temperature (x_2), slope (x_3), vegetation(x_4), soil clay content (x_5) and soil moisture (x_6).

The greater the prediction power of this equation, the closer the agreement between the actual and predicted values of y. Hence the prediction power of this equation can be measured by the simple correlation r_{yy2}. This actually is the multiple correlation coefficient, $r_{y.12}$ and obviously its minimum value is zero and maximum value is +1. It does not have a range of -1 to +1 as in the case of simple correlation between two variables. In the analysis of the sums of squares of Y, we have:

$$\Sigma y^2 = \Sigma(Y-Y_e)^2 + \Sigma(Ye-\square)^2 \quad (2)$$

$$\text{or } \Sigma y^2 = \Sigma y_d^2 + \Sigma y_e^2 \quad (3)$$

as in the case of simple correlation, but the corresponding degree of freedom in this case will be:

n - 1 = (n – p - 1) + p

where p is the number of independent variables. The multiple correlation coefficients were calculated as per the methodology given in Table 1 [23]. A test of significance of the multiple regression equation or of the multiple correlation coefficient is given by calculating [23].

$$F = \frac{\sum y_e^2}{p} \times \frac{n-p-1}{\sum y_d^2} \quad (23)$$

The table of F is entered under n – p – 1 degrees of freedom. When the correlation only are known, F can be calculated from:

$$F = \frac{r^2{}_{1.23\cdots p}}{1 - r^2{}_{1.23\cdots p}} \left(\frac{n-p-1}{p}\right) \quad (24)$$

This arises from the fact that

$$r^2{}_{1.23\cdots p} = \frac{\sum y_e^2}{\sum y^2} \quad (25)$$

and

$$1 - r^2{}_{1.23\cdots p} = \frac{\sum y_d^2}{\sum y^2} \quad (26)$$

Putting (26) into the form

$$r^2{}_{1.23\cdots p} = 1 - \frac{\sum y_d^2}{\sum y^2} \quad (27)$$

is also of value in an interpretation of the multiple correlation coefficient. As the deviation from regression approach zero, the coefficient approaches +1.

RESULTS AND DISCUSSION

Climate Change and the Coastal Zone: Two physical hazards that pose risks for the coastal zone are coastal inundation and coastal erosion. Erosion and inundation events are affected by oceanic extreme events such as storm surges and waves which in turn are related to atmospheric storm events. Climate change will affect the frequency and severity of these hazards in the future through rising sea levels, changes to the distribution and intensity of climate and weather systems that influence wave climates and extreme wave and storm surge events. Soil erosion, sediment transport and deposition are considered as the major processes of catchment sediment dynamics. Hydrological events mainly govern sediment dynamics in a river basin which are highly variable in spatial and temporal scales. An accelerated rate of soil erosion and sedimentation would affect the sustainability of nature adversely to a great extent, since soils are a major component of enormous environmental processes [24] and on the other form, sediment controls lake and river pollution extensively [25]. In fact, sediment dynamics in a river basin are natural processes and had been going through almost in a balanced way till the beginning of modern civilization. But, nowadays sediment dynamics in a river basin are accelerated in an alarming way due to climate change conditions such as increasing rainfall intensity and frequency, changing land use pattern, etc. As a result of anthropogenic activities like pollution of the atmosphere with greenhouse gases, aerosols and human modifications of the land surface, significant climate change is also expected in the next century. The impact of global climate change processes at local scale will be entirely uneven. Many hydrological components are also expected to be changed adversely both spatially and temporally at local scale due to climate change which would trigger a high soil erosion and sedimentation [26].

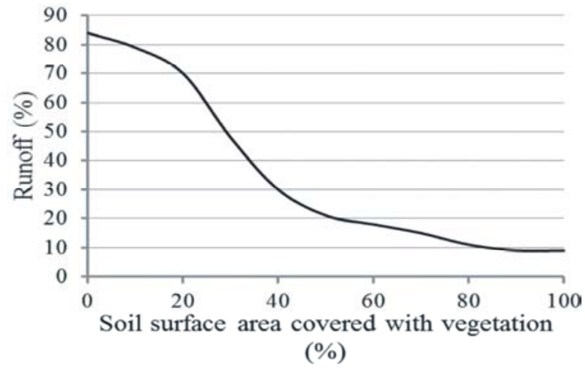

Fig. 2: Effect of vegetation cover on the runoff (%).

Sediment Yield from Brahmaputra Basin: Besides climatic parameters, anthropogenic factors also play an important role in the basin. Extent of land surface covered with vegetation showed a significant effect on runoff generation and subsequently the sediment yield from the basin (Fig. 2). Rapid population growth, urbanization, uncontrolled developmental works, encroachments and land use have significantly contributed to flood events and risk enhancement.

The sediment yield is reduced considerably even if about 40% of land surface is covered by vegetation. The combined effect of prolonged and intense rainfall,

Table 2: Sediment yield from Brahmaputra basin in India

State	Sediment yield	N	P	Nutrient K	loss Mn	('000 t) Zn	Ca	Mg
Arunachal Pradesh	177.7	217	36.6	153	8.2	4.9	19.1	15.2
Assam	178.4	201	34.4	155	7.6	5.0	20.6	15.1
Meghalaya	57.7	62	7.4	48	1.6	1.1	4.0	3.1
Nagaland	24.9	26	3.2	20	0.8	0.4	2.1	1.5
Total	438.7	506	81.2	376	18.2	11.4	45.8	34.9

Table 3: Sinks for sediment yield from Brahmaputra basin

	Soil		Nutrient (10^3 t)			
Sink	(10^6 t)	N	P	K	Mn	Zn
River	62.7	57.2	9.5	41.9	2.0	1.4
Flood area	32.7	35.8	6.1	26.8	1.3	0.8
Streams	48.1	53.1	8.4	39.1	1.9	1.5
Valleys	42.4	42.5	7.2	31.6	1.5	1.1
Temporary water storages	21.7	20.2	4.0	14,7	0.7	0.6
Lakes and reservoirs	4.3	5,6	1.0	4.0	0.1	0.2
Sea	226.8	291.6	45.0	217.9	10.7	5.8
Total	438.7	506.0	81.2	376.0	18.2	11.4

steep slope, well-developed drainage network and the fragile geology of the mountain make the land inundation an annual event. Problems related to high stream flows are complex and are affected by natural as climatic, hydro-geologic, morphology etc. and anthropogenic such as urbanization, irrigation, water works, socio-economic factors and human interference through deforestation and land use. Extreme floods in the basin are a product of meteorological input, precipitation being the major player; as well as spatially and temporally variable basin properties. Annual soil displacement from the basin is 438.7 million tonnes. It was estimated that annual loss of N, P, K, Mn, Zn, Ca and Mg is 506, 81.2, 376, 18.2, 11.4, 45.8 and 34.9 thousand tonnes, respectively (Table 2).

Sinks for Sediment from Catchment to Sea: Fluvial erosion, sediment transport and sediment deposition make up the complex of channel processes. Human induced erosion and accumulation processes on agricultural hill-slopes have a number of principal differences from natural erosion. Human accelerated soil erosion has important implications on nutrients erosion as well. It is now well established that, in addition to its physical effects, suspended sediment plays an important role in the transport and biogeochemical cycling of nutrients and other contaminants in the aquatic system. The land use has many effects on environmental systems as well as influencing the efficiency of slope-channel transfer. High sediment loads in surface water in the region have reduced water quality and a negative effect on ecology. The enormous load of sediments to the sea, causing clogging of sea shores and damaging ports and harbors. The sediment load in flood water contains 1500-30000, 6.4-25.8, 2.3-8.5, 15.4-33.8, 0.3-1.6, 0.8-2.4, 0.1-0.3 and 6.3-18.4 mg L^{-1} of soil, NO_3-N, P-PO_4, K_2O, Zn, Mn, Cu and Fe, respectively (Sharma and Sharma, 2006). Sediment dynamics is accelerated in an alarming way due to the climate change conditions such as increasing rainfall intensity and frequency, changing land use pattern, etc. Out of the total annual sediment load of 438.7 million tons of soil and 506.0, 81.2, 376.0, 18.2 11.4, 45.8 and 34.9 thousand tons of nitrogen, phosphorus, potassium, manganese, zinc, calcium and magnesium from four states of northeastern hills region of the Brahmaputra basin due to runoff; 226.8 million tons of soil and, 291.6, 45.0, 217.9, 10.7, 5.8, 26.8 and 20.6 thousand tons of above nutrients, respectively, is transported to sea, resulting in shrinkage of the ports. The rest sediments settle in different sinks on the way (Table 3). It shows that about 51.7% of eroded soil and 57.6% of nutrients are transported to the sea (Fig. 3). This may be due to the reason that a part of nutrients remain in dissolved form and carried away by the flowing water except, that part which remain attached with the soil particles settling more in different sinks due to suspension [20, 21].

Factors Affecting Erosion Rates: The major factors affecting soil erosion are; precipitation, slope, vegetation, soil clay content, vegetation, soil moisture and temperature. The amount and intensity of precipitation is the main climatic factor governing soil erosion by water. The relationship is particularly strong if heavy rainfall occurs at times when, or in locations where, the soil's surface is not well protected by vegetation. The rainfall intensity is the primary determinant of erosivity, with higher intensity rainfall generally resulting in more soil erosion by water. Larger and higher-velocity rain drops have greater kinetic energy and thus their impact will displace soil particles by larger distances than smaller, slower-moving rain drops [27]. Other climatic factors such as average temperature and temperature range may also

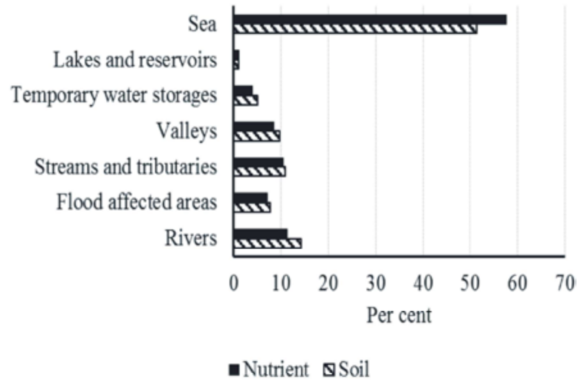

Fig. 3: Per cent of eroded soil and nutrients deposited in different sinks.

affect erosion, due to their effects on vegetation, evapotranspiration and soil properties. The composition, moisture and compaction of soil are all major factors in determining the erosivity of rainfall. Sediments containing more clay tend to be more resistant to erosion than those with sand or silt, because the clay helps bind soil particles together [28]. The soil moisture also affects soil erosion, because it controls the amount of water that can be absorbed by the soil and hence prevented from flowing on the surface as runoff. Wet, saturated soils will not be able to absorb as much rain water, leading to higher levels of surface runoff and thus higher erosivity for a given volume of rainfall. Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. The topography of the land determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff. Longer, steeper slopes are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes. The warmer atmospheric temperatures are expected to lead to a more vigorous hydrological cycle, including more extreme rainfall events [29]. The formation of rills and gullies in the catchment enhances soil erosion as more soil surface is exposed to erosion processes, thus contributing more sediment delivery to the coasts.

Soil Erosion Model: Monitoring and modeling of erosion processes can help in better understanding the causes, make predictions and plan how to implement preventative and restorative strategies. Erosion models are also non-linear, which makes them difficult to work with numerically and makes it difficult or impossible to scale up to making predictions about large areas from data collected by sampling smaller plots [30]. Model-based impact assessment studies can evaluate the potential and magnitude of these impacts. In the context of climate change vulnerability assessment frameworks, such as the one proposed by [31], modelling studies can be useful to assess the sensitivity of soil erosion processes to climate shifts. Modelling exercises have differed in terms of objectives, model used, spatial and temporal extent of the study and climate change scenario strategy. The model developed was:

Soil erosion from catchment (t ha^{-1}) = 21.38 + 0.0138 x rainfall (mm) + 0.381 x slope (%) – 0.387 x clay in soil (%) – 6.105 x vegetation (1 to 5 scale) - 0.084 x temperature (°C) + 0.162 x soil moisture (%).

Thus, the soil erosion from a catchment; having 2000 mm of rainfall, 30% slope, 15% average soil clay content, vegetation scale 3, 25°C average temperature and 15% average soil moisture content will be 36.62 t ha^{-1} and from a catchment having; 400 mm of rainfall, 5% slope, 15% average soil clay content, vegetation scale 3, 25 °C average temperature and 8% average soil moisture content will be 3.88 t ha^{-1}. In the second situation, the sediment yield will be almost zero, if the rainfall is only 120 mm.

The yield of sediments will vary according to the amount and intensity of rainfall. Recent advances in Geographic Information Systems (GIS) technology, especially support for modeling with multivariate functions [32], along with the exponential growth in computational power, stimulate the shift from empirical, lumped models to physically based, distributed ones [33]. Advances in the use of GIS and Digital Elevation Models (DEMs) have promoted the development and application of spatially distributed models of soil erosion and sediment delivery at the catchment scale [33-37]. An important limitation of these developments has, however, been the lack of data for model validation and, more particularly, for validating the spatial pattern of sediment redistribution *within* a catchment predicted by the model.

CONCLUSIONS

The coastal regions are generally highly fragile and vulnerable to natural and anthropogenic factors. Three factors responsible for debris flow are; climate change, terrestrial and socio-economic systems, whose relative order of importance is site specific. Soil erosion: modelling and its impact on the environment role of soil erosion models is to estimate soil loss as a function of precipitation patterns, topography and physical transport processes such that management strategies can be developed or evaluated for maintaining soil losses at more sustainable levels. Reliable predictions require any model to capture key aspects of experimentally obtained data. The important issue is to promote the conservation and sustainable use of natural resources which allow long term economic growth and enhancement of productive capacity, along with being equitable and environmentally acceptable. This would also help in reducing runoff and soil loss and, climate change impacts could be mitigated. Consequently, even in areas with increased precipitation, higher ET rates may lead to reduced runoff, implying a possible reduction in soil erosion. A model based on real time data will help in predicting the soil loss through fluvial system, which can be used for making genuine prediction in ungauged areas. More the data, the more will be the prediction capacity of the model. The evolved mathematical model can be used under wider climatic and topographical situations for making reliable estimates of soil erosion and its possible deposition in different sinks enroute, before final deposition in coasts and sea.

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