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Original Article

Soil Erosion Susceptibility Assessment for Prioritization of Hilly Areas of a Watershed in the Arunachal Himalayas in Northeast India Based on Weighted Sum Analysis Method on Morphometric Parameters

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ABSTRACT

In the present study, soil erosion susceptibility analysis has been carried out in the Dikrong watershed, predominantly located in the Arunachal Himalayas, applying the Weighted Sum Analysis (WSA) technique on some important morphometric parameters. Based on this approach, prioritization of the sub-watersheds has been determined by assigning weightages, derived from the correlation matrix, to the respective parameters and, accordingly, the sub-watersheds have been categorized into three priority levels viz., high, moderate, and low to very low. It has been ascertained that sub-watersheds Niorch, Chimpu, and Pang are high susceptible zones requiring urgent and efficient planning and management for better conservation.

KEYWORDS: *Soil erosion assessment, Morphometric parameters, Weightedsum analysis, Prioritization*

1. INTRODUCTION

Soil erosion results primarily due to reduced infiltration, whereby there is increased run-off as channel flow and overland flow. Besides, deforestation and lack of vegetation cover cause soil erosion. Watersheds located in hilly terrain are prone to severe erosion due to surface runoff, steep slopes and undulating topography. Although, classic hydrologic theory emphasized sheet-flow as the primary process in soil erosion (Horton, 1933), the importance of raindrop splash and the kinetic energy of precipitation were recognized later (Wischmeier and Smith, 1965, 1978). Soil erosion has long-term impacts as it causes loss of fertile top soil. This adversely affects agriculture.The process of soil erosion is regarded as the detachment of productive surface soil, and its transportation and accumulation in a distant place which results in the exposure of subsurface soil (Jain et al. 2001). It is considered to be one of the major environmental issues in both the developing and developed countries of the world. Although the problem persisted on the earth for a longer period, it has become severe inrecent times due to increased man-environment interactions (Rasool et al. 2014). In India, an estimated 175 million hectares (M ha) of land constituting about 66% of total geographical area suffers from deleterious effect of soil erosion and land degradation (Meshram and Sharma, 2015). About 16.4 tonne ha^{-1} $year^{-1}$ of topsoil is eroded annually in India out of which 29.0% is lost to the seas, 10.0% gets deposited in the reservoirs and the remaining 61.0 % gets displaced from one location to another (Dhruvanarayana, 1983). An understanding of nature, intensity and extent of soil erosion is, therefore, essential to protect the land resources from erosion. Soil conservation programme is an expensive and cumbersome process and, therefore, there is a need to assign relative priorities to different regions within a catchment (Jain and Goel, 2002) so that the most vulnerable regions can be taken up for the necessary remedial measures on priority basis. Watershed prioritization is an exercise of assigning ranks to different sub-watersheds of a watershed so that conservation measures can be preferentially applied on those areas found relatively more susceptible to erosion.

For the prioritization of watersheds, Sediment Yield Index (SYI) method was proposed by Bali and Karale (1977). Universal Soil Loss Equation (USLE) method, given by Wischmeier and Smith (1965), has also been extensively used.In some studies, socio-economic aspects, wetland ecosystem management as well as land use and environmental degradation factors were speculated for identifying potential area for sustainable planning and management of sub-watersheds. These empirical and process-oriented models are cumbersome, data hungry and complex for watershed prioritization, which can be reinstated with less data requirement and effective techniques by using morphometric variables of watersheds (Aher et al., 2014). Due to the absence of gauging station for estimation of soil erosion or loss, no field data is available in the study area. Therefore, in such a remotely located area where direct observational setup is non-existent, the application of morphometric parameters have been found to be a good proxy for the purpose of prioritization.

In the catchment area of Dikrong river, light textured unstable soils with the prevalent practice of Jhum cultivation makes the entire catchment area susceptible to erosion. In every monsoon, the river Dikrong carries tremendous amount of silt, gravel, small boulder and causes flood in some parts of the catchment. This indicates serious threat to soil resources (Dabral et al. 2008). Thus, assessment of soil erosion with the objective of prioritization for undertaking conservation measures in a preferential manner has become necessary. In the present study, prioritization of the fifth order watersheds located in the hilly areas of the Dikrong watershed has been carried out based on the "Weighted Sum Analysis (WSA)" technique proposed by Aher et al. (2014) for the stated objective.

2. STUDY AREA

The Dikrongriver originates in the Lesser Himalayan ranges of Arunachal Pradesh. It is an important tributary of the Subansiri river, the latter being a major north-bank tributary of the Brahmaputra. The Dikrong watershed, having an areal extent of 1550 km^2, is bounded by latitudes $26^0$55'N and $27^0$20'N and longitudes $95^0$15'E and $94^0$0'E (Fig. 1). Of the total area, 1300 km^2lies in the lower Subansiri district of Arunachal Pradesh and 250 km^2 lies in the Lakhimpur district of Assam. The watershed is constituted of 2 sixth order, 10 fifth order, 42 fourth order, 193 third order, 911 second order, and 4063 first order sub-watersheds. There are five litho-units within the basin area. The Sub-Himalayan zone comprises Siwalik rocks, while the Lesser Himalayan zone contains two litho-units namely, Gondwana Group and the Precambrian gneissic unit of the Bomdila Group. The Quaternary alluvial part of the area comprises piedmont and floodplain deposits. The Main Boundary Thrust (MBT) separates the Gondwana from the Siwalik rocks, while the Himalayan Frontal Fault (HFF) separates the Siwaliks from the Quaternaries. Geomorphologically, the study area is divided into four units viz., highly dissected hills (predominantly in the BomdilaGroup), structural hills (between the dissected hills and the piedmont), piedmont zone, and the alluvial plain.

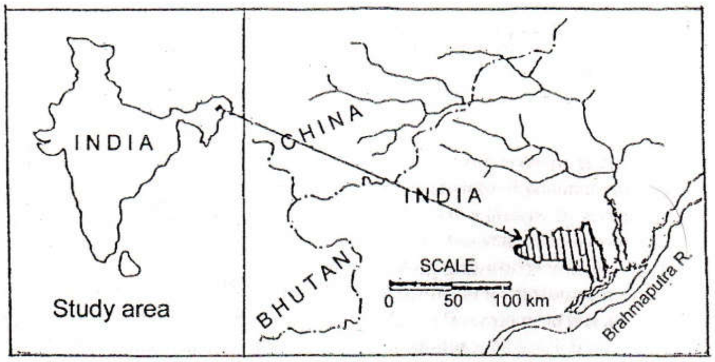

Figure 1: Location of Dikrong watershed

3. METHODOLOGY

In the present study, the morphometric parameters, i.e., mean bifurcation ratio (R_b), drainage density (D_d), compactness coefficient (C_c), stream frequency (F_s), drainage texture (T), watershed shape (B_s), form factor (R_f), circularity ratio (R_c) and elongation ratio (R_e) have been considered for prioritizing sub-watersheds because these parameters are the erosion risk assessment parameters. The formula and definition of the parameters relevant to the present study has been given in Table 1.

Table 1: Methodology adopted for computations of morphometric parameters.

Aspect	Morphometric parameters	Formula & definition	Reference
Linear aspects	Stream order (N_u)	Hierarchical order	Strahler (1964)
	Length of main channel (L_m)	Length along longest water course from the outflow point of to the upper limit of catchment boundary	Schumm (1963)
	Total stream number (N_u)	ΣN_u; N_u is thenumber ofstreams of any order 'u'	Strahler (1964)
	Total stream length (L_u)	ΣL_u; L_u is the length of streams of any order 'u'	Horton (1945)
	Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$;R_b is the ratio of number of streams of order 'u' (N_u) to that of the next higher order (N_{u+1})	Horton (1945)
	Stream length ratio (R_L)	$R_L = L_u / L_{u-1}$; R_L is the ratio of mean stream length of streams of order 'u' (L_u) to that of the next lower order (L_{u-1})	Horton (1945)
	Basin length (L_b)	Distance between outlet and farthest point on the basin boundary	Ratnam et al. (2005)
Areal aspects	Basin area (A)	Area enclosed within the boundary of watershed divide	
	Stream frequency	$F_s = \Sigma N_u / A$; F_s is the ratio of total stream number(ΣN_u) of all orders in a basin to the basin area (A).	Horton (1932)
	Drainage density (D_d)	$D_d = \Sigma L_u / A$; D_d is the ratio of total stream length of all orders (ΣL_u) in a basin to the basin area (A).	Horton (1932)
	Basin shape (B_S)	$B_S = Lb^2/A$	Gregory and Walling (1973)

	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$; A is the basin area and L_b is the basin length. It is expressed as the diameter of a circle of the same area as the basin to the basin length.	Schumm (1956)
	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	Miller (1953)
	Form factor (R_f)	$R_f = A/Lb^2$	Horton (1932)
	Compactness constant (C_c)	$C_c = 0.2821P/A^{0.5}$	Horton (1945)
	Drainage texture (T)	$T= N_u/P$	Horton (1945)
Relief aspect	Basin relief (R)	R = H-h; it is the difference in elevation between the highest (H) and the lowest (h) point of the basin	Hadley &Schumm (1961)
	Relief ratio (R_r)	$R_r = R/L$; it is the ratio of basin relief to basin length.	Schumm (1963)

Of these, bifurcation ratio, stream frequency, drainage density, and drainage texture are directly related to erosion and, therefore, their higher values suggest more chances of erosion. As such, in priority ranking with regards to erosion susceptibility, the highest value of these parameters is ranked 1, the next lower value is ranked 2 and so on. The lowest value of these parameters is rated last in rank. Conversely, the shape parameters – form factor, elongation ratio, circularity ratio, compactness co-efficient, and watershed shape, are inversely related to erodibility. Therefore, in case of the shape parameters, the lowest value has been assigned the highest rank 1, the next higher value is ranked 2 and so on. The highest value is rated the last rank. Relief parameters have been ignored to avoid attributing excessive weightage, since they are involved in the evolution of some linear and areal parameters of the watersheds, thereby justifying their exclusion in rank determination.

Studies on erosion susceptibility and prioritization of watershed based on morphometric parameters, carried out by many workers in the past, considered the values of compound parameters for assigning rank to watersheds for prioritization. The compound parameters were obtained by averaging the total rank values of individual morphometric parameters. Equal importance was, therefore, given to all the morphometric variables and the importance of weightages of the parameters was ignored which is erroneous considering the variability of characteristics of different watersheds. In the present study, therefore, a method proposed by Aher et al. (2014), called "Weighted Sum Analysis" (WSA), has been considered to overcome such limitations.

The WSA technique requires ranking of the different morphometric parameters i.e., linear and shape parameters followed by framing of correlation matrix of correlation coefficients based on the ranking. The correlation coefficients of individual parameters are added to obtain the sum of correlation coefficients (ΣCOR). A grand total (GT) is obtained by adding the ΣCOR of all parameters. The final weightages for each parameter were calculated by dividing ΣCOR by GT (ΣCOR/GT).

4. RESULTS AND DISCUSSION

The morphometric linear and shape parameters of the ten fifth order sub-watersheds have been shown in Table 2. The highest value of the linear and areal parameters (R_b, F_s, D_d, and T) have been rated rank 1, the next higher value is assigned rank 2, and so on (Table 3), whereas in case of the shape parameters, as has been already stated, the lowest value is assigned rank 1, the next lower value is rated rank 2, and so on.

Table 2: Table showing morphometric parameters of the sub-watersheds

Sub-watershed	**R_b**	**F_s**	**D_d**	**T**	**R_f**	**R_e**	**R_c**	**B_s**	**C_c**
Senkhi	4.22	4.90	3.08	8.42	0.36	0.68	0.46	2.76	1.48
Niorch	3.78	3.70	2.65	5.53	0.35	0.67	0.53	2.85	1.37
Chimpu	3.58	3.63	2.81	5.26	0.75	0.98	0.48	1.33	1.43
Shu	4.22	4.24	2.90	6.99	0.31	0.63	0.46	3.23	1.47
Langbah	3.82	5.23	3.28	8.22	0.33	0.64	0.60	3.04	1.29
Pang	3.77	3.68	2.94	6.37	0.40	0.71	0.56	2.48	1.33
RachiPabung	3.97	4.37	2.90	7.40	0.36	0.68	0.55	2.77	1.35
Pare	4.68	4.12	2.96	10.48	0.51	0.81	0.63	1.94	1.25
BartasoPabung	3.72	5.34	3.32	6.51	0.38	0.70	0.48	2.61	1.43
Nimte	3.74	4.44	3.23	6.19	0.46	0.77	0.73	2.17	1.17

Table 3: Ranking based on morphometric parameters of the sub-watersheds

Sub-watershed	**R_b**	**F_s**	**D_d**	**T**	**R_f**	**R_e**	**R_c**	**B_s**	**C_c**
Senkhi	3	3	4	2	5	5	1	6	10
Niorch	6	8	10	9	3	3	5	8	6
Chimpu	10	10	9	10	10	10	4	1	7
Shu	2	6	7	5	1	1	2	10	9
Langbah	5	2	2	3	2	2	8	9	3
Pang	7	9	6	7	7	7	7	4	4
RachiPabung	4	5	8	4	4	4	6	7	5
Pare	1	7	5	1	9	9	9	2	2
BartasoPabung	9	1	1	6	6	6	3	5	8
Nimte	8	4	3	8	8	8	10	3	1

Based on ranking, the correlation coefficients are determined. From the correlation matrix, the sum of correlation matrix (ΣCOR) of the parameters determined are 2.757 (F_s), 2.164 (D_d), 2.951 (T), 2.261 (R_b), 1.993 (R_f), 1.993 (R_e), 0.272 (R_c), -1.994 (B_s), and -0.271 (C_c). The grand total (GT) obtained is 12.126. The final weightages, calculated for each parameter by dividing ΣCOR by GT, are shown in Table 4.The weightages of the respective parameters are linked to the parameters to obtain the formula for prioritization as stated below:

Prioritization = (0.186 x R_b) + (0.227 x F_s) + (0.178 x D_d) + (0.243 x T) + (0.164 x R_f) + (0.164 x R_e) + (0.022 x R_c) – (0.164 x B_s) – (0.022 x C_c)

Table 4: Correlation matrix of morphometric parameters

Correlation Parameter	**R_b**	**F_s**	**D_d**	**T**	**R_f**	**R_e**	**R_c**	**B_s**	**C_c**
F_s	0.091	1.000	0.818	0.479	0.369	0.369	0.091	-0.370	-0.090
D_d	-0.054	0.818	1.000	0.430	-0.030	-0.030	-0.176	0.030	0.176
T	0.806	0.479	0.430	1.000	0.236	0.236	-0.018	-0.236	0.018
R_b	1.000	0.091	-0.054	0.806	0.418	0.418	0.042	-0.418	-0.042
R_f	0.418	0.369	-0.030	0.236	1.000	1.000	0.333	-1.000	-0.333
R_e	0.418	0.369	-0.030	0.236	1.000	1.000	0.333	-1.000	-0.333
R_c	0.042	0.091	-0.176	-0.018	0.333	0.333	1.000	-0.333	-1.000
B_s	-0.418	-0.370	0.030	-0.236	-1.000	-1.000	-0.333	1.000	0.333
C_c	-0.042	-0.090	0.176	0.018	-0.333	-0.333	-1.000	0.333	1.000
Sum of									

correlations (ΣCOR)	2.261	2.757	2.164	2.951	1.993	1.993	0.272	-1.994	-0.271
Grand total (GT)	12.126	12.126	12.126	12.126	12.126	12.126	12.126	12.126	12.126
ΣCOR/GT	0.186	0.227	0.178	0.243	0.164	0.164	0.022	-0.164	-0.022

Description of the parameters applied in the prioritization formula

Of the parameters considered in the prioritization formula, bifurcation ratio is a linear parameter, whereas the rest are all areal parameters.

Bifurcation ratio (R_b): Thisis a linear parameter since areal aspects of a watershed are not involved in its determination. It is defined as the number of streams of any given order to that of the next higher order. The R_b value of a sub-watershed given in Table 2 is the mean value obtained by averaging the R_b values of successive orders of the sub-watershed. The lowest value obtained is for Chimpu (3.58) and the highest value is given by Pare (4.68) (Table 2). Values of R_b between 3 and 5 are characteristic of homogeneous geologic condition. It can thus be said that the drainage development in the present study area is not significantly influenced by geologic structures.

Stream frequency (F_s): Stream frequency is defined as the ratio of the total number of stream segments of all orders in the basin to the total area of the river basin (Horton 1932). It represents different stages of landscape evolution where the occurrence of stream segments is related to soil nature, vegetation covers, rainfall pattern, physiography, etc. (Jahan et al. 2018). As indicated in Table 2, F_s ranges from 3.63 (Chimpu) to 5.34 (BartasoPabung). Higher F_s implies more run-off along channels.

Drainage density (D_d): Horton (1932) defined drainage density as the total length of the channels of all orders to the area of the watershed. Therefore, D_d indicates the closeness of channels. Like stream frequency, drainage density also depends on the permeability of sub-surface material, vegetation and relief or physiography. Generally, high $D_d$is observed in regions having low permeability sub-surface material, sparse vegetation and high relief (Suresh, 2004). The D_d values, ranging from 2.65 (Niorch) to 3.32 (BartasoPabung), have a positive power function relation with F_s in the study area which can be understood from the following regression equation (Chakravartty, 2007):

$$\text{Log } F_s = 1.4311 \text{ Log } D_d - 0.0450$$

Drainage texture (T): According to Horton (1945), drainage texture is the ratio of the total number of stream of all orders to the perimeter of the basin. It is the relative channel spacing in a fluvial dissected terrain and depends upon a number of natural factors such as climate, rainfall, vegetation, rock/soil type, rate of infiltration, relief and evolutionary stage of the basin (Kale and Gupta, 2001). Smith (1950) classified D_d into five drainage texture (T) viz. less than 2 (very coarse); 2-4 (coarse); 4-6 (moderate); 6-8 (fine); and greater than 8 (very fine). In the present area, drainage texture ranges from 5.26 (Chimpu) indicating moderate T to 10.48 (Pare) indicating very fine T. The variation in T value depends on natural factors like climate, rainfall, vegetation, soil type and their infiltration capacity and relief of the basin.

Form factor (R_f): The form factor has been defined by Horton (1932) as the ratio of the basin area to the square of maximum basin length. It quantitatively expresses basin shape and ranges in value from 0 to 1. Smaller R_f value indicates elongated watershed, while a larger value corresponds to a more circular watershed. The R_f ranges from 0.31 (Shu) to 0.78 (Chimpu). The basins having high value (near circular) is characterized by high peak flow for shorter duration, whereas those with low R_f (elongated) have low peak flow but for longer duration.

Elongation ratio (R_e): Elongation ratio (R_e) has been defined by Schumm (1956) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin.

The value of R_e varies from 0 (in highly elongated shape) to unity i.e. 1.0 (in circular shape). The higher the R_e value the more circular is a basin, whereas elongated shape is characterized by lower value. Typical values are close to 1 for areas of very low relief and are between 0.6 and 0.9 for regions of strong relief and steep ground slope (Strahler, 1964). The Chimpu sub-watershed exhibits the highest value (0.98) and the lowest value is given by the Shu sub-watershed (0.63). Elongation ratio is directly related to form factor and in this study area the relation can be understood from the regression equation (Chakravartty, 2007):

$$\text{Log } R_e = 0.467 \text{ Log } D_d - 0.3715$$

Circularity ratio (R_c): The Circularity ratio is defined as the ratio of basin area (A) to the area of a circle with the same perimeter as that of the basin (Miller, 1953). As basin shape approaches a circle,the circulatory ratio approaches unity. The $R_c$ranges from 0.46 (Senkhi) to 0.73 (Nimte). Circularity ratio, does not correlate well with the other shape parameters viz. R_e and R_f.

Basin shape (B_S): According to Gregory and Walling (1973), basin shape is the ratio of the square of maximum basin length to the area of the basin making it a dimensionless parameter. Elongate basins have shape values ranging from 4 to 8. In the present study area, the basin shape ranges from 1.33 (Chimpu) to 3.23 (Shu). Like the other shape parameters (R_f and R_e), B_S also indicates that Shu is relatively the most elongated and Chimpu the most circular of the different sub-basins.

Compactness constant (C_C): Compactness constant is defined as the ratio of basin perimeter to the perimeter of a circle having the same area as the basin (Horton, 1945). The C_C ranges from 1.17 (Nimte) to 1.48 (Senkhi).

Final ranking of the sub-basins based on WSA technique

The compound parameter constants for the sub-watersheds have been derived based on the prioritization formula and final ranking has been assigned to the different sub-basins based on the compound parameter constants (Table 5).

Table 5: Final ranking based on compound parameter constant

Sub-watershed	**Compound parameter constant**	**Priority Ranking**
Senkhi	4.187	Ninth
Niorch	3.039	First
Chimpu	3.313	Second
Shu	3.564	Fourth
Langbah	4.124	Eight
Pang	3.366	Third
RachiPabung	3.743	Sixth
Pare	4.764	Tenth
BartasoPabung	3.805	Seventh
Nimte	3.619	Fifth

Finally, the sub-watersheds are delineated into three priority levels and the sub-basins are placed in these levels based on their compound parameter values (Table 6, Figure 2).

Table 6: Delineation of sub-watersheds into priority levels

Priority level	**Priority type**	**Sub-watershed**
< 3.500	High	Niorch, Chimpu, Pang
3.501 to 3.650	Moderate	Shu, Nimte
3.651 to 4.764	Low to very low	Rachi Pabung, Bartaso Pabung, Langbah, Senkhi, Pare

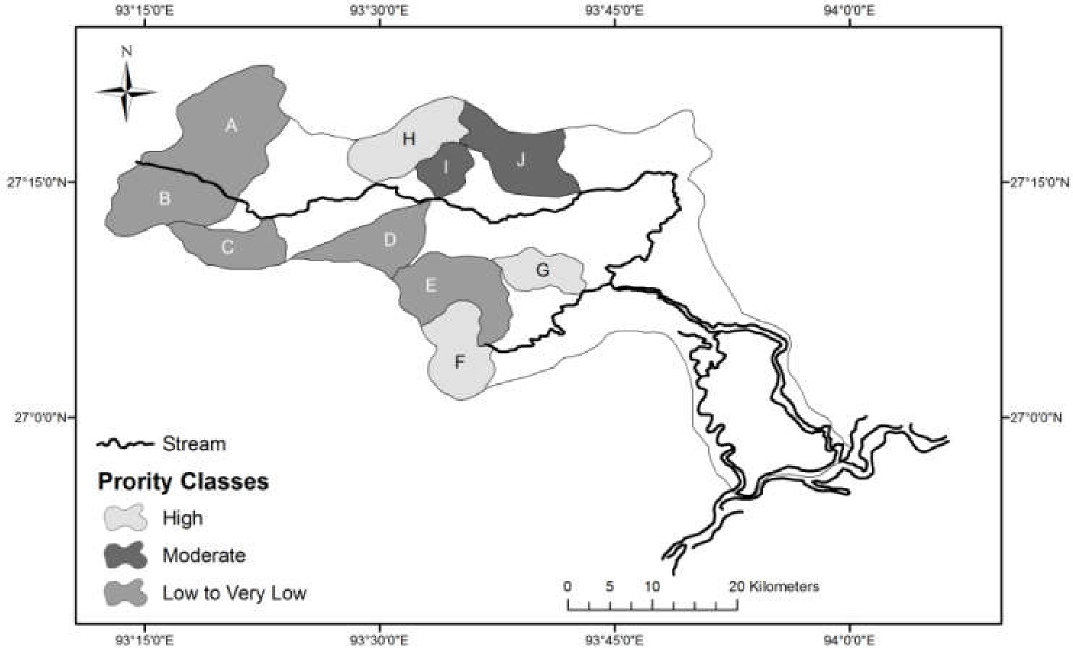

Figure 2: Priority-wise classification of sub-watersheds of the Dikrong watershed
A – Pare; B – RachiPabung; C – BartasoPabung; D – Langbah;
E – Senkhi; F – Chimpu; G –Niorch; H – Pang; I – Nimte; J – Shu

The categorization of the sub-watersheds into different priority types based on their respective priority levels has revealed that the sub-basins Niorch, Chimpu, and Pang are ofthe highest priority type. The sub-watersheds Rachi Pabung, Bartaso Pabung, Langbah, Senkhi, and Pare are of low to very low priority type, whereas the sub-watersheds Shu and Nimte are of moderate priority type as shown in Table 6.

5. CONCLUSIONS

In the present study, the consideration of statistical weightages to the respective morphometric parameters used for erosion assessment has made this procedure for prioritization more scientifically logical. This technique can be particularly useful in hilly and not easily accessible areas where the relevant field data is not available. Further, this technique is much more simplified and easy for consideration of effectivemanagement strategies and conservation measures.

In the catchment area of Dikrong river, light textured unstable soils with the prevalent practice of Jhum cultivation makes the entire catchment area susceptible to erosion. In every monsoon, the river Dikrong carries tremendous amount of silt, gravel, small boulder and causes flood in some parts of the catchment. This indicates serious threat to soil resources. Priority determination, thus carried out, has revealed that sub-watersheds Niorch, Chimpu, and Pang, being of the highest priority type, require immediate remedial and conservation measures to arrest further topsoil erosion. The sub-watersheds Shu and Nimte also require urgent attention. However, Rachi Pabung, Bartaso Pabung, Langbah, Senkhi, and Pare are not presently of much concern and should, therefore, come last in preferential treatment.

CONFLICT OF INTEREST

I declare that there is no conflict of interest of any kind.

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