European Water 36: 15-26, 2011.

Geomorphological Analysis and Distribution of Badland around the Confluence of Narmada and Sher River, India

D.S. Deshmukh[1*], U.C. Chaube[2], S. Tignath[3] and S.M.Pingale[2]
[1] *Department of Water Resources and Environmental Engg., Jimma University ,Jimma, Ethiopia*
[2] *Department of Water Resources Development and Management, IIT Roorkee, Roorkee – 247667, Uttarakhand, India*
[3] *Department of Geology and Geohydrology,Govt. Autonomous Science College, Jabalpur – 486001, M. P., India*
* *email: dsdesh@gmail.com*

Abstract: Badland forms represent an ever increasing erosive network of channels rendering land unfit for agriculture and other uses. The alluvium badland track along Narmada and Sher rivers are located in central part of India. The base map of the area is delineated on the basis of divide of badland and other land using Survey of India (SOI) toposheets. Two distinct major badlands have been identified for their morphological characterization. The different map layers of drainage pattern, contour elevation, and distance map (distance of badland boundary from major river track as origin), isopach (depth of alluvium deposits) and slope are obtained in the GIS environment. Various attributes of map layers have been obtained to compute various morphological parameters. Encroachment of badland area from the main river water course decreases rapidly as it goes farther from main river track reveals distance from main river course is major factor in the expansion of badland. The study concludes that about 75% area of badland area had been developed on alluvium deposits having alluvium depth more than 120 m. Soft alluvium deposit is more susceptible to the gull erosion so it is the root cause for badland expansion onto the alluvium geological area. To identify the severity of erosive condition among badland watersheds, a Morphological Index of Erodibility (MIE) has been developed and applied to the study area and further it is verified from the field observations. Study revealed that MIE is very effective index and can be very helpful for watershed priority treatment. Moreover MIE can be used effectively to restore the watershed at its sustainable state by controlling or reducing number of streams with the help of gully controlling measures.

Keywords: alluvium, badland formation, watershed morphological parameters

1. INTRODUCTION

A ravine is a deep gorge which is formed due to linear fluvial erosion of loose unconsolidated and bare soils by rills and gullies. Once a ravine is formed, it grows by the phenomenon of saturation and slip off from its head and sides. These ravines go on increasing in size and invading the upper table land under the condition of high intensity rains. The expansion of these active gullies and ravines onto the fair land converts fair land into the dissected badland which is moreover unfit for any use. Government of India report (GOI, 1996) classifies ravines as (i) shallow ravine: depth 1 m, side slope 3%, undulating topography, moderately eroded. (ii) Medium ravine: depth 5 m, slope >15%, very severely eroded land, (iii) Deep ravine: depth more than 10m, slope > 15%, very severely eroded land.

Badland are a particular for of land degradation and it is a general term which refers to land becoming unproductive partially or completely due to various reasons such as water erosion, wind erosion, chemical deterioration, inadequate drainage etc. Badlands are densely dissected areas, which have been severely degraded and where soil has disappeared or lost most of its fertility. There are several reasons to form badland and it can be explained as follows.

(i) High intensity rains.
(ii) Considerable height difference between the table land and the stream receiving water from the table land. It causes steep gradient and hence erosive velocity of flow in channels and gullies feeding the stream.
(iii) Soft and deep alluvium soil liable to scouring.

(iv) Uncontrolled biotic interference in the watershed by way of excessive grazing, burning and cutting of vegetation for crop cultivation, fodder and fuel collection. It increases the potential erosion and storm runoff.

The combined effect of climate and continuous use of erosive land for agriculture prevents the soil from forming or recovering its fertility and the erosion continues (Fairbridge, 1968). Formation of badlands gets activated through several processes such as head cutting in gully, scouring, selective erosion transport of sediment (Kirkby and Bull, 2000). Badland formation exhibits particular land topography and stream morphology, which determine the rate of development of badlands (Smith and Bretherton, 1972; Howard and Kerby, 1983).

The subject of gully expansion and badland formation has been widely attempted in various parts of the world. Present study aims to analyze morphological parameters of badland and geological and river network setting so as to develop a better understanding of process of formation of badlands and to develop a morphological index of erodibility for comparing severity of erosion in different watersheds.

1.1 Ravine Affected Land in India

In India ravine land was about 3.975 million ha in the year 1971 (NCA, 1976). As a result of various land reclamation measures it reduced to 2.678 million ha in 1996 (GOI, 1996). On the other hand, degraded forest had increased from 19.494 million ha in the year 1971 to 24.897 million ha in the year 1996. No systematic survey of various categories of land degradation in the country has been carried out by any agency on agreed terms. The figures quoted or reported by various agencies are only based on material available from scattered sources or broad observations. Data generated by Natural Bureau of Soil Survey and Land Use Planning (NBBS&LUP, 2007) are based on 1:1000000 scale map. Soil degradation map prepared by NBBS &LUP is of derivative nature from soil resource map at 1:250000 with soil profile information collected at 10 km grid (GOI, 1996). The estimate of ravine affected area (2.678 M ha) stated in Govt. of India report (GOI, 1996) is based on discussion with various_agencies. The data is not based on ground surveys. It is at best an improvement over other existing estimates.

Ravine affected land in the state of Madhya Pradesh where the study area lies was 0.883 million ha in the year 1971. It reduced to 0.623 million ha in the year 1996 (GOI, 1996).

1.2 Study Area location and Climate

The tract of Narmada river at confluence of Sher, Barureva and Umar rivers and along with small tributaries of Narmada shows the developed badland on the alluvium belt (Figure 1). Southern bank of Narmada river which comprises of small tributaries like Dhamani and Saras rivers is completely affected by badland development. While another area around the confluence of Sher, Umar and Barureva with Narmada shows extensive badland formation. The tract along the Sher River is also partially affected with badland development. The alluvium bad land tract along Narmada and Sher river are located between 22.0049’.00” N, 79.0^0.00 E to 23.0^{0}49.0’50.5”N 79.0^0 25.0’ 9.20”E. The badland tracts as indicated are selected to evaluate morphology of the area. History reveals that the area was favorite grazing land and it had the permanent settlements of Nomadic and shepherds (Tignath et al., 2005). The soils of this area are loamy in texture and blended with the clay content. The study area experiences sub-tropical climate with considerable temporal variations in rainfall, temperature and humidity.

Rainfall: The rainy season extends from June to October under the influence of south-west monsoon. The area also receives some rainfall during January and February from north-east monsoon. July and August are the main rainy months. Normally, the rainfall ceases by the end of September. However, some times in recorded years, October also happens to be month of good rainfall. The recorded average annual rainfall of study area is 1187 mm while seasonal average monsoon rainfall is 1053 mm.

Temperature: The temperature in the study area begins to rise rapidly from about March till May which is generally the hottest month. The mean daily maximum temperature in May falls between 39 °C and 45 °C. With the onset of the monsoon in the second week of June, there is an appreciable drop in day temperature. From mid-November on wards, both day and night temperatures decrease rapidly. December and January are the coldest months of the year. Normally, annual temperature varies from the 2 °C to 45 °C. On the whole days are warm and nights are cooler.

Relative Humidity: The relative humidity is highest during morning hours in July, August and September months ranging from 83.9 to 89.6%. March, April and May are the months when relative humidity during morning hours is lowest and ranging from 40.3 to 48.6%. The annual mean relative humidity is 60.5% in the morning and 45.6% in the evening hours.

Wind Speed: The mean annual wind velocity in study area (Narsinghpur station) is 4.35 km/hr in the evening and 2.44 km/hr during the morning hours. The wind velocity is highest during the pre-monsoon period, i.e. during May and June. The highest wind velocity of 7.41 km/hr is observed during the month of June and minimum of the 2.98 km/hr magnitude is observed in the month of January. The mean seasonal wind velocity is 3.05 km/hr during morning and 5.96 km/hr during evening. It is observed that mean wind speeds are higher during the evening hours than in the morning hours.

Potential Evapotranspiration: The potential evapotranspiration (PET) is the quantity of water transpirated in unit time by a short crop completely shading the ground of uniform height which is never short of water. It is observed from the previous studies that PET is highest in May (200 mm) and lowest in December (60 mm).

2. SOCIO-ECONOMIC REASONS FOR THE FORMATION OF BADLAND AREA

Owing to social, economical and political conditions in the pre-independence period, mass migration of population from north and north-central region of India to the central valley of Narmada was prevalent. Besides mass human settlements, livestock also increased proportionally. There were many nomadic and permanent settlements of shepherd (local name gadarias; gadar means sheep) in Narsinghpur district. A number of villages in the region have derived their names meaning shepherd settlements such as Gadarawara, Gadariakhera (village of shepherds), Chhota Gadarawara etc. Thus the area has a long history of over grazing of grasslands (Tignath et al., 2005).

On the other hand, the original tribal inhabitants had several classes such as Raj Gonds (Ruler Gonds), plain inhabitants, forest dwellers (Dhahia means those who burn). Forest produces and shifting cultivation provided means of livelihood to these tribal people. Mass migration of people from outside areas forced local tribal people to shift to upper parts (Satpura forest) causing deforestation.

2.1 Process of badland Formation in the Study Area

Origin of ravine channel systems owes to gullying processes which gradually or rapidly grow in dimensions and network. Brice (1966) defined a gully as a ‘recently extended drainage channel that transmits ephemeral flow, has steep sides, a steeply sloping or vertical head scarp, a width greater than 0.3 m and a depth greater than 0.6 m’. Apparently, Brice fixed the lowest dimension of a gully, while the ravineous limit of gully development has dimensions of many meters, more than 150 m in width at places between upper edges and in depth up to 50 m or even more, for example, Chambal ravines in north Central India. However field observations show that ravines at some places in the study area have average width of the order of 40 - 80 m and depth between 5 m and 10 m. Crosssection geometry varies from U-shaped in nonresistant to V-shaped in resistant subsoils in the channels.

In the study area, the gully-channel network extends from the main channel of entrenched nature, distinguished as the streams flowing in steep walled trench cut in alluvium, from the valley slope gullies which are small, steep walled and steeply incised (Figures 5 to10). Normally, for the initiation of gully, a continuum of erosion is visualized ranging from sheet erosion to micro channel or rill erosion, and then gully erosion when water concentrates in definite channels, often succeeding the two previous stages (Gregory and Walling, 1971). This description however (a) does not incorporate other factors governing gully initiation and (b) does not distinguish stream entrenchment from gullying in the off-shoot network. It is of common experience that the gully erosion is attributed to scouring on the sides and erosion over well defined headscarp.

Brice (1966) and Tuckfield (1964) among many others estimated the rate of gully development, which may not be uniform or continuous. According to Brice (1966), one gully extended 228 m in fifteen years, and 107 m of this length developed in only one year as a result of very high run-off. About 15 km south of the present study area in Kareli Block in Narsinghpur district, the channel entrenchment along some of the 2nd and 3rd order tributaries of Sakkar river near Imalia-Khari village is seen to be of the order of 1000 m which occurred in the span of about fifty years (Tignath et al., 2005). In valley-floor gullies, the scarp normally advances up-valley, facilitated by sloughing of material around the margins of plunge pool, and this process leads to increase in height of the head scarp (Blong, 1966). Tuckfield (1964) showed the development of gullies to start from evenly spaced pits on valley floor.

3. MATERIAL AND METHODS

The base map of the area has been delineated on the basis of divide of badland and other land with the help of topographic survey map (Survey of India topomaps of the year, 1972).

3.1 Morphological Analysis of the Badland using GIS

The two badlands; one along the Narmada river and the other on the Sher river have been selected for their morphological characterization. Different map layers have been created using GIS software (ILWIS 3.0, 2001). These GIS map layers are drainage pattern map (Figure 1), isopach map (The line joining equal magnitude of alluvium deposits depth) (Figure 2), encroachment distance map (distance of badland encroachment from major river track as origin) (Figure 3), and digital elevation map (DEM) (Figure 4). Slope values of these badlands are estimated from the DEM of the study area. The extracted attributes of map layers further used in computation of various morphological parameters are given and defined in the following sub-section.

3.2 Morphological Index of Erodibility (MIE)

A badland area (ravine affected area) consists of large number of micro watersheds which need to be analyzed separately for the assessment of severity of degradation and for identification of specific measures required for reclamation. Researchers have been using remote sensing, GIS technique and sediment yield index model in prioritization of micro watersheds (Chakraborti, 1991; Biswas et al., 1999; Nookaratnam, 2005). Nookaratnam (2005) used morphological analysis of watershed for prioritization of micro watersheds belongs to large basin. Previous research conclude that linear parameters (D_d, D_f, T and R_h) favor erodibility of watersheds whereas shape parameters (R_c, R_e, and R_f) have inverse relationship with erodibility. Biswas et al. (1999) and Nookaratnam et al. (2005) used ranking system to compare degradation of watersheds. Ranking system is thus useful for prioritization of watershed within a specified area. However it can not be used as a measure of morphological influence on erodibility. Comparison of watersheds in terms of large number of parameters is usually complicated and confusing. In the present study a morphological index of erodibility (MIE) as defined below has been proposed for assessing combined influence of several morphological parameters on erodibility.

$$\text{MIE}= (D_d \times D_f \times T \times R_h)/ (R_c \times R_e \times R_f)$$

In the above equation: MIE = Morphological Index of Erodibility

Drainage density (D_d): It is the ratio of total length of the streams of all the orders of a basin to the area of the basin. It is expressed in 'km/km^2'

$$D_d = \sum_{u=1}^{n} L_u / A$$

Drainage frequency (D_f): Horton (1932) proposed the drainage frequency factor as the ratio of the total number of streams in a basin to the basin area. It is expressed in no./km^2.

$$D_f = \sum_{u=1}^{n} N_u / A$$

Texture ratio (T): Texture ratio is defined as the number of streams of first order to the perimeter of the basin. It is express in 'number of first order streams/km'

$$T = N_1 / P$$

Relief ratio (R_h)*:* Relief ratio is the total relief of the basin (H) divided by the maximum length (L_b) of the watershed. It is an indicator of the potential energy of the system to drain off. It can be expresses in 'm/km'

$$R_h = H/L_b$$

3.3 Basin shape parameters

Shape parameters (R_c, R_e and R_f) describes watershed shape through its range of values (0 to 1). A value close to one assures weather it is close to circular or elongated. In general, elongated watershed shows delayed surface runoff and consequently yield less erosion and it is vice versa in case of circular watershed.

Circularity ratio (R_c): Circularity ratio is computed as:

$$R_c = 12.57 A / P^2$$

Form factor (R_f): Form factor is the ratio of the basin area (A) to the square of the maximum length of the basin (L_b).

$$R_f = A / L_b^2$$

Elongation ratio (R_e): Elongation ratio is defined as the ratio between the diameters of a circle with the same area as that of the basin to the maximum length of basin.

$$R_e = 1.128 A^{0.5} / L_b$$

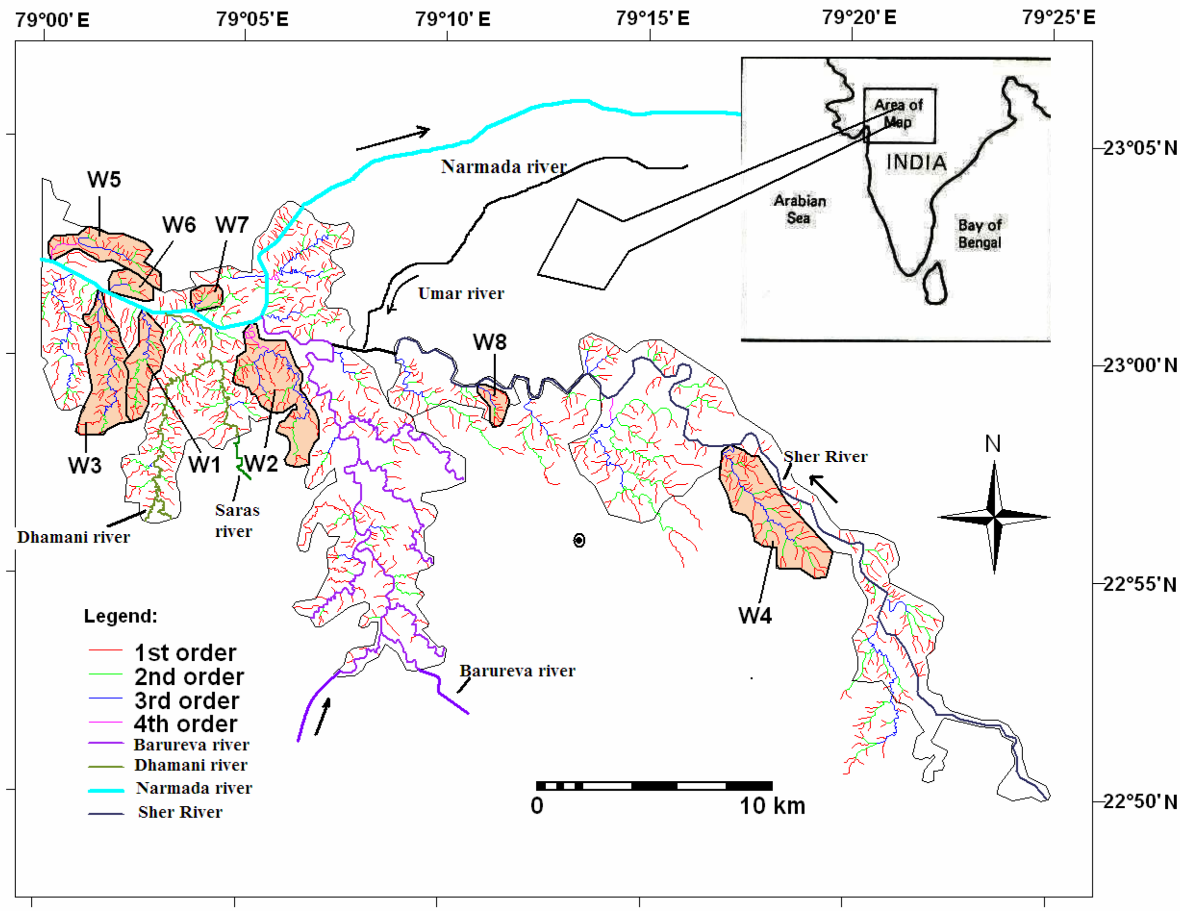

Figure 1: Drainage pattern in bad land area and location of selected watersheds.

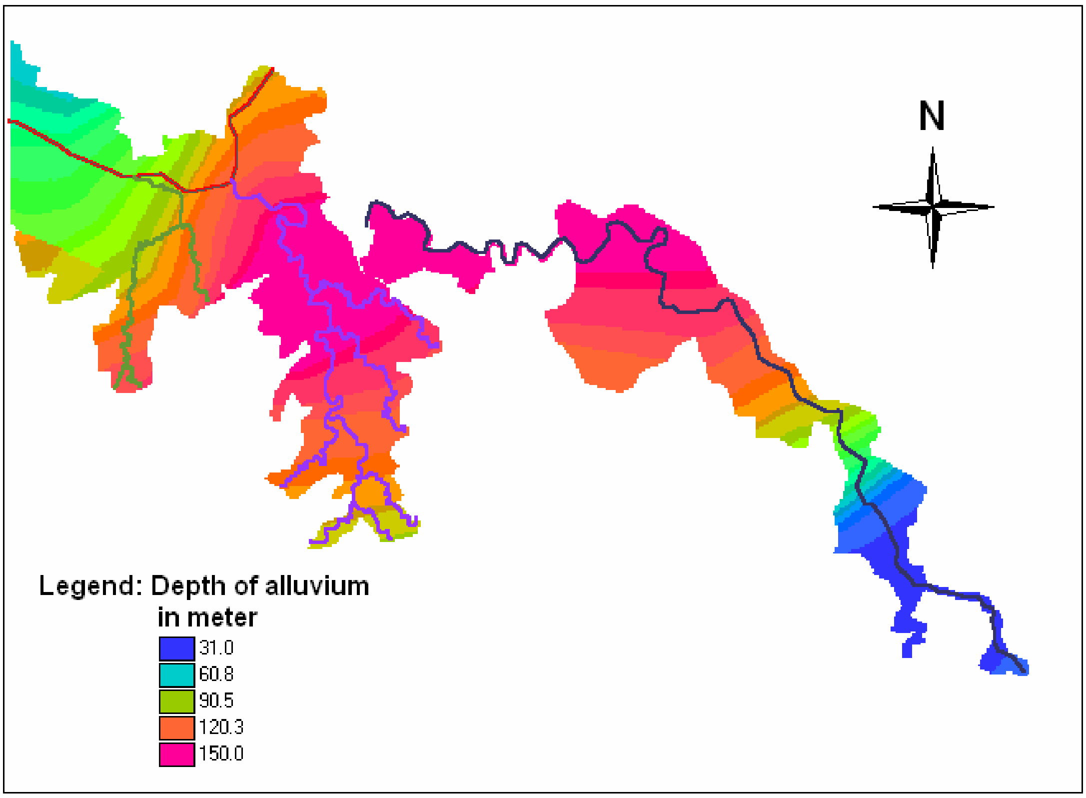

Figure 2: Isopach (depth of alluvium deposit) of badland area

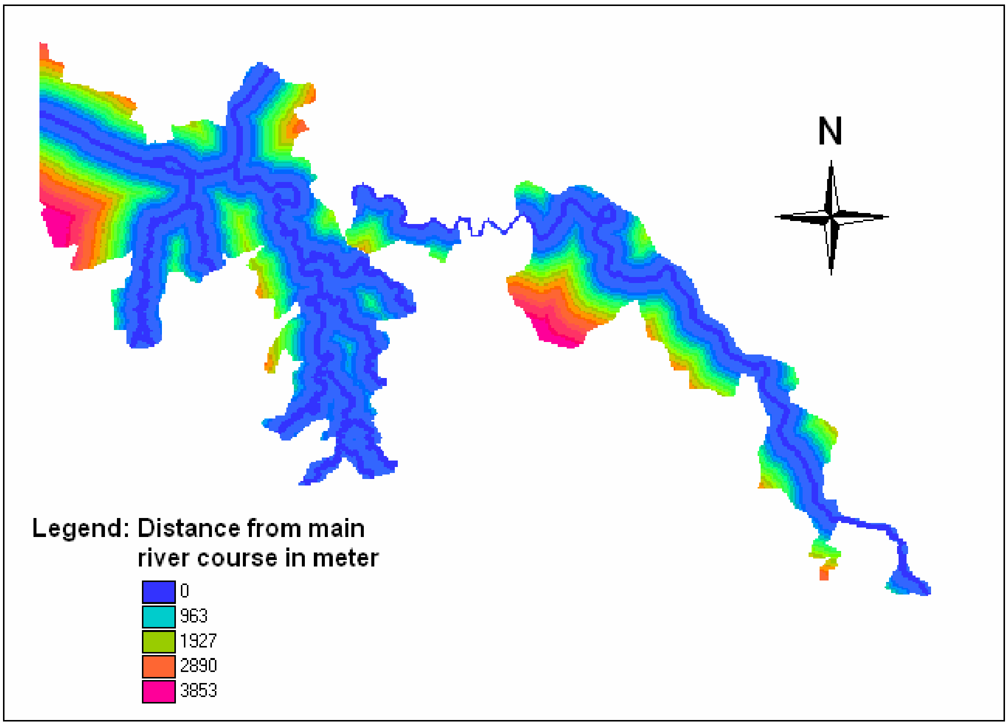

Figure 3: Encroachment distance of badland area from the main river course.

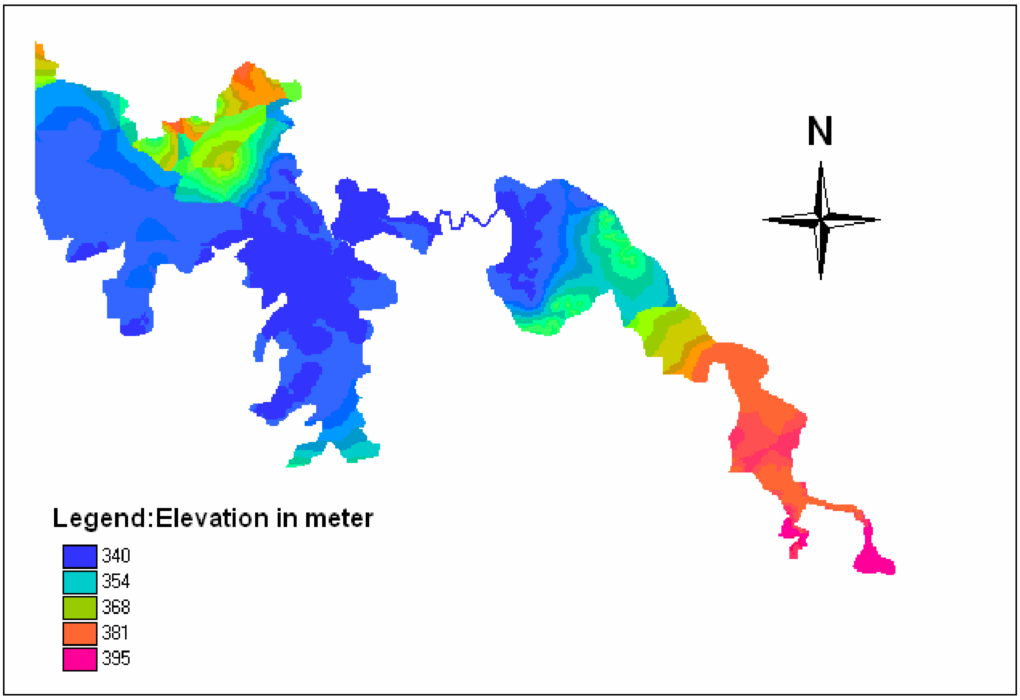

Figure 4: DEM of the badland area.

3.4 Other morphological parameters related to drainage network

A number of parameters have been developed to represent drainage pattern. Stream order by Strahler (1964) method is used to analyze the drainage pattern of the area. The basic rules of stream ordering are suggested as follows:

1. Streams that originate at a source are defined to be first order streams.
2. When two streams of order *u* join, a stream of order *u+1* is created.

3. When two streams of different order join, the channel immediately downstream has the higher of order of the two joining streams.
4. The order of a basin is the order of the highest stream.

Stream number (N_u): Steam number is the number of stream segments of various orders.

Total stream length (L_u): Total stream length is the sum of all lengths of all the stream order. Total stream length divided by the number of stream segments of that order gives the mean steam length for that order.

Bifurcation ratio (R_b): Bifurcation ratio is the ratio of the number of streams of given order *u* to the number of streams of next higher order *u+1*. It reflects the complexity and degree of dissection of a drainage basin.

$$R_b = N_u / N_{u+1}$$

Length ratio (R_t): The length of a stream is a measure of the hydrological characteristics of the underlying rock surfaces and the degree of drainage. Horton (1945) proposed the factor length ratio which is the ratio of the average stream length (L_u) of order *u*, to average stream length (L_{u-1}) of the next lower order *u-1*.

$$R_t = L_u / L_{u-1}$$

4. RESULTS AND DISCUSSION

The GIS based analysis of the selected badland areas provides extensive information regarding the pattern, location and areal extent of badland formation in the study area. It is observed that Sher (49.67 km), Barureva (66.26 km), Dhamani (23.21 km) rivers course length are partially affected by badland formation while entire Saras river approaching toward the confluence of Narmada exhibit extensive badland development. The stream ordering of badland area exhibits third and forth order stream network (Figure 1).

Area of badland formation is very intense along the Narmada tract i.e. Barureva, Dhamani and Saras rivers (A=161.53 km^2) as compared to badland network of Sher river (A=91.41 km^2). Comparison of morphological parameters (Table 1) revealed that the selected badlands have nearly similar magnitude of drainage density and drainage frequency which are major factors responsible for badland formation. However, texture ratio of Narmada tract is twice as that of the Sher badland which makes it extensively degraded badland. From the Table 2, it is apparent that first order streams have the major share in the badland formation and it is highest for Narmada badlands with 78.46% compared to the badland of Sher river (64.66 %). This analysis suggests that emergence or presence of high number of first order streams along the main river water course creates the badland situation.

Table 1: Morphological parameters of the badland area.

Sl. No.	Morphological parameters	Badland along Narmada river	Badland along Sher river
1.	Area (A), km^2	161.53	91.41
2.	Perimeter (P), km	114.01	111.11
3.	Circularity ratio (R_c)	0.39	0.31
4.	Drainage density (D_d), km/km^2	2.45	2.22
5.	Drainage frequency (D_n), no./km^2	4.74	4.74
6.	Texture ratio (T)	5.27	2.52
7.	Relief (H), m	44	70
8.	Average slope (S), %	5.86	3.30
9.	Constant channel maintenance (Cm), km^2/km	0.41	0.45

Table 2: Drainage analysis of the badland area.

Order of stream	Number of streams (N_u)	Percent to total stream number %	Stream length (L_u) km	Percent to total stream length %	Av. stream length $(L_u)_{av}$ km	Bifurcation ratio(R_b)	Length ratio (L_u)
Badland along the selected Narmada river track							
First order	601	78.46	271.03	68.44	0.45	4.32	-
Second order	139	18.14	72.21	18.24	0.52	6.04	1.15
Third order	23	3.00	46.95	11.86	2.04	7.66	3.93
Fourth order	3	0.39	5.82	1.46	1.94	-	0.95
Total/average	766	100	396.01	100.00		$(R_b)_{av}$ =6.01	$(L_u)_{av}$=2.54
Badland along the selected Sher river track							
First order	280	64.66	130.81	64.51	0.46	1.97	-
Second order	142	32.80	45.00	22.19	0.32	14.20	0.68
Third order	10	2.31	25.98	12.81	2.60	10.0	8.20
Fourth order	1	0.23	0.97	0.48	0.96	-	0.37
Total/average	433	100	202.77	100		$(R_b)_{av}$ =8.72	$(L_u)_{av}$ 4.43

Stream lengths of the remaining orders show similar distribution pattern in both badlands significantly confirms the role of first order streams in the badland formation. The observed values of bifurcation ratio R_b for both badlands are higher than 5.0 suggests the presence of structural control (of badland process) on the drainage network over the geomorphic control (Strahler, 1957). High bifurcation ratios of both badlands indicate the presence of soft geological foundation and it is consistent with the available information i.e. the isopach map (Figure 2) showing alluvium deposits underneath, in the range of 30 m to more than 150 m in depth. Wide variation in length ratios of the Sher badland indicates less homogeneity in the structure of underneath rock. It means that alluvium formation under Sher badland shows extensive varying depth of alluvium deposits.

Moreover it is observed that formation of badland is extensive (66.57% area) within 1 km distance of major river course as seen in Figures 5 to 10. Therefore it can be concluded that badland formation area goes on decreasing with its distance from the major river course. The maximum distance of badland encroachment from the main river course is 4.6 km (Figure 3). In addition to this, from the Figure 2, it is seen that the encroachment of badland is found to be more intense (about 75% badland area) in an alluvium geological formation which has alluvium depth 120 m or more.

Eight watersheds (W1 to W8) adjacent to Narmada and Sher rivers (Figure 1) have been selected for analysis of erodibility. Morphological parameters of these eight watersheds and an agricultural watershed are given and compared in Table 3. The proposed MIE has been computed using equation (1) and given in the same table for each selected watershed. The range of MIE varies from 450 to 7888 for the badland watersheds depicting the rank of severity. The watershed W5 is highly degraded and it is ranked as first whereas watershed W6 is the least degraded in comparison. The one of the agricultural sub watershed (not affected by badland) from very nearby area has been selected as reference watershed to compare the extent of severity of badland watersheds (W1 to W8). The chosen reference agriculture watershed (85 U) is free from gully erosion and it is most stable in Umar river basin situated in the vicinity of badland area (Deshmukh et. al, 2009). This reference watershed 85 U yields MIE at 201 so this value acting as decisive value which demarcates badland watersheds from non erosive and stable watersheds. Therefore any watershed having MIE equal or below 201 can be considered as non erosive and stable watershed. The least observed MIE is 450 for W6 watershed belongs to badland area and it is nearly 225% of the MIE value of reference watershed. Therefore a watershed in this region may be characterized as badland if its MIE index is more than or equal to 225 % of MIE of reference watershed. These badland once existed as stable grazing land in the vicinity of main river course. Noteworthy, badland areas are same like agriculture areas in contexts of slope, soil and geological formation except presence of active gullies makes them more dissected and unfit for agriculture use.

Figure 5:Gully development process along Narmada river in sub watershed W5.

Figure 6: Gully cutting and its advancement stage along Narmada river in sub watershed W5.

Figure 7: Vertical cutting along main water course of Sher river.

Figure 8: Series of vertical cutting of gullies along main water course of Sher river.

Figure 9: Badland area along the main water course of Sher river.

Figure 10: Badland area along Barureva river in W2 sub watershed.

5. CONCLUSIONS

Deep layers of alluvium deposits formed over several years at the confluences of Narmada with their tributaries due to high influx of sediment loads is the principle cause for the formation of badland. The formation of first order streams along the main river water course is also another reason for the expansion of badland formation. Therefore a value of MIE is significantly depends upon number of first order streams formed due to uncontrolled gully erosion. A morphological index of erodibility (MIE) for comparing severity of erosion in micro watersheds has been applied and verified by field observations. A watershed in the study area may be characterized as badland if its MIE value is more than two and half times MIE of a reference agricultural watershed. It is possible to reclaim the badlands and can be converted into the productive land by applying innovative watershed measures such as gully plugging, stone bunding, and vegetation stripping along the side slope of active gullies. By fixing MIE as that of agriculture stable watershed (MIE=201), we can decide how many number of streams need to be reduced for badland watershed through gully control measures (converting gully into flat lands). Henceforth it is possible to convert badland into the level land by plugging or flattening the gullies through gully control measures.

Table 3: Morphological parameters and MIE for selected sub watersheds.

Watershed parameter	Unit	Sub watersheds								
		W1	W2	W3	W4	W5	W6	W7	W8	Reference Agriculture Watershed
A	km^2	4.57	10.22	8.38	11.75	5.17	1.78	1.22	1.33	45.33
P	km	10.22	18.56	15.38	16.45	13.06	5.33	4.2	5.04	38.61
L_b	km	6.02	6.46	4.71	6.86	4.9	1.8	1.46	1.8	15.79
R_c	-	0.55	0.37	0.45	0.55	0.38	0.79	0.87	0.66	0.38
R_e	-	0.4	0.56	0.69	0.56	0.52	0.84	0.85	0.72	0.48
R_f	-	0.13	0.24	0.38	0.25	0.22	0.55	0.57	0.41	0.18
Total streams	No.	28	46	52	51	43	10	14	13	72
D_d	km/km^2	4.21	3.72	3.87	3.57	4.01	2.33	5.23	5.04	1.44
D_f	$no./km^2$	6.13	4.50	6.21	4.34	8.32	5.62	11.48	9.77	1.81
T	-	2.35	2.05	2.67	2.43	2.53	1.13	2.38	1.98	1.76
C_m	km^2/km	0.24	0.27	0.26	0.28	0.25	0.43	0.19	0.21	0.69
H	m	16	15	16	17	20	20	15	15	23
R_h	m/km	2.66	2.32	3.40	2.48	4.08	11.11	10.27	8.33	1.44
MIE		5634	1587	1864	1223	7888	450	3484	4191	201
Rank of degradation		2	6	5	7	1	8	4	3	-

REFERENCES

Biswas, S., Sudhakar, S., Desai, V. R., 1999. Prioritization of subwatersheds based on morphometric analysis of drainage basin, A Remote Sensing and GIS approach. *J. of Indian Soc. Remote Sensing*.: 27(3):155-166.

Blong, R. J., 1970. The development of discontinuous gullies in a pumice catchment, *Amer. J. Sci,*: 268:369-83.

Brice, J. C., 1966. Erosion and deposition in the loess-mantled Great Plains, Medicines Creek drainage basin, Nebraska. U.S. Geol. Survey Prof. Paper 352-H: 255-339.

Charkraborti, A. K., 1991. Sediment yield prediction and prioritization of watershed using remote sensing data. Proc. 12th Asian Conference on Remote Sensing, Singapore: pp.Q-3 to Q-3-6.

Daniels, R. B., 1966. Physiographic history and the soils, entrenched stream systems and gullies, Harrison Co., Iowa. U.S. Dept. Ag. Tech. Bull.: 1348: 51-83.

Deshmukh, D. S., Chaube, U. C., Tignath, S., 2009. Development of Geomorphological Permeability Index (GPI) for assessment of ground water availability and watershed measures. Water Resource Management,Vol 23 (4), DOI 10.1007/s11269-011-9882-2

Fairbridge, R. W., 1968. Encyclopedia of Geomorphology. Reinhold Book, New York.

GOI.1996. Report of working group on soil and water conservation for formation of ninth five year plan, Department of Agriculture and Co-operation, Ministry of Agril., Govt. of India: 35-43.

Gregory, K. J., Walling, D.E., 1971. Field measurements in the drainage basin, Geography 56: 277-292,

Howard, A. D., Kerby, G., 1983. Channel changes in badlands, Geo.Soc.Am.Bull., 94:739-752.

ILWIS 3.0., 2001. Integrated Land and Water Information System. ILWIS User Guide, ITC, Enschede, The Netherlands,: pp. 520.

Kirkby, M. J., Bull, L. J., 2000. Some factors controlling gully growth in fine-grained sediments: a model applied to South-East Spain. Catena, 40:127–146.

NBSS&LUP, 2007. Soils of Madhya Pradesh, Their kinds, distribution, characterization and interpretations for optimizing land use, NBSS Publ.59, soils of India series 6, NBSS&LUP, Nagpur, India.

NCA, 1976. Report of National Commission of Agriculture of Government of India.

Nookaratnam, K., 2005. Check dam positioning by prioritization of micro-watershed using SYI model and morphometric analysis-Remote sensing and GIS perspective. J. of the Indian Soc. of Remote Sensing, 30(1):39-61.

Pakhmode, V., Kulkarni, H., Deolankar, S. B., 2003.Hydrological-drainage analysis in watershed- programme planning: a case from the Deccan basalt, India. Hydrogeology Journal, 11: 595-604.

Singh, G., Venkatraman, C., Sastry, G., Joshi, B. P., 1994. Manual of Soil and Water Conservation Practices, Third Edition, Oxford and IBP Pub. Co. Pvt. Ltd., New Delhi.

Smith, T. R., Bretherton, F. P., 1972. Stability and the conservation of mass in drainage basin evolution. Water Resources Research: 1507-1529.

Strahler A N.1957. Statistical analysis in geomorphic research. J Geol., 62:1–25.

Tignath, S., Chaube, U. C., Mishra, S. K., Awasthi, A. K., 2005. System approach to socio-economic and ecological management of a small badland in Narmada Valley (India), Proc. of International Conf. on Hydrological Perspectives for Sustainable Development-(HYPSED-2005):485-496.

Tuckfield, C.G., 1964. Gully Erosion in the New Forest, Hampshire. Am. J. Sci. 262:795-807.