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COASTAL EROSION AND ACCRETION AT AND AROUND DIGHA IN MEDINIPUR DISTRICT OF WEST BENGAL

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Abstract

The seven and a half kilometre long Digha foreshore, a part of the 65 kilometres long Medinipur coast of West Bengal, which had always been referred to as eroding in nature, at present contains erosional and accretional domains in the east (Old Digha) and in the west (New Digha) respectively. Juxtaposition of a man-made seawall over an eroding foreshore has divided it into four sectors with respect to the physical feature and coastal process operating near shore. Polymodal sediments of the entire Digha foreshore are of fine to very fine size class with well- to moderately well-sorted, nearly symmetrical and platykurtic character. Variation in numerical values of these statistical parameters broadly demarcate erosional and accretional sectors along the foreshore as comparatively coarse, well sorted, positively skewed sediments make up the western accretional domain and comparatively fine, less sorted and negatively skewed sediments dominate the eastern erosional domain. Tendency to achieve an equilibrium condition with respect to sediment character over a wide, low gradient accreting foreshore with uninterrupted swash-backwash movement, has enabled the sediments of the western side of the Digha foreshore to have greater maturity compared to sediments of restricted (through seawall and natural coastal dune), comparatively steep eroding foreshore at the eastern side of Digha.

Introduction

The world's coastline is about 440,000 km long (Pethic, 1984) and 66 percent of the world population lives within a few kilometres of the coast. Consequently this segment of the land surface requires a high percentage of a nation's food production, communications, settlements etc. However, the coastal stretch presents serious problem of land erosion, flooding and pollution, and emerging threat posed by rising sea level. These problems demand constant action in order to preserve man's investment. Such action depends on accurate assessment of the changes and knowledge of the processes by which the natural coastal environment functions.

The Medinipur coastal area of West Bengal is one of the thickly populated zones of our country. It stretches for 65 km from Rasulpur River in the northeast to state border with Orissa in the southwest and makes a part of the northwestern coastline of Bay of Bengal. This coastal area has gained considerable commercial importance as it has shown its potentiality to play an important role in the socio-economic development of the region. Several locations along the Medinipur coast have been developed for recreation, aquaculture and many other purposes and a lot of investment has been made to build up the infrastructure. A small part of this coast at Digha (21° 37'N & 87° 31'E) is at present facing severe marine erosion manifested by retreat of shoreline, destruction of coastal dune, removal of sand cover to expose the underlying clay bed. Active marine erosion has posed great problem in the speedy development of this thickly populated region. An urgent need for systematic and comprehensive study of the present coastal erosional problem for this part of the coast has been voiced by many. In this paper, an attempt has been made to update the shoreline position at and around Digha in Medinipur district, West Bengal. In doing so statistical analysis of the foreshore sediments has also been carried out to identify the effect of the coastal processes over the foreshore material and also to distinguish zones of coastal erosion and accretion with respect to sediment character along the seven and a half kilometre long foreshore of the study area.

Location and geological setup

The township of Digha is situated at the westernmost end of the 65 km long coastal tract of Medinipur district (Fig. 1). The area is covered by Survey of India toposheet and Indian Remote Sensing Satellite (IRS) Geocoded Image No. 73O10. The coastal hinterland is about 30 km wide and contains elongated sub-parallel sand bodies separated from one another by low agriculture lands. The NE-SW trending and slightly concave coast at Digha is nearly seven and a half km long and stretches between the estuary of Digha/ Ramnagar creek in the east and the state border in the west.

Geological and geomorphological studies of Medinipur coastal region have been carried out by Banerjee *et al.* (1997), Chakrabarti (1995) and Niyogi (1970, 1975). Niyogi (1970) mentioned that the area had formed due to the out-building of the Subarnarekha delta through recession of the sea between 6000 years B.P. and present day. The area is constituted of recent alluvium deposits belonging to Balasore-Contai coastal plain. Geomorphological map prepared by him on the basis of air-photo and topographic map analysis showed that Digha and its adjacent area was made up of alternate lines of beach ridges and barrier islands situated on silty or clayey marine terraces. He identified six ancient shoreline positions over the 30 kilometres wide coastal region. Niyogi (1975) recognised geomorphic units of recent deltaic plain as Digha Formation correlating it with Chandbil Formation of Baitarani valley of the east coast of

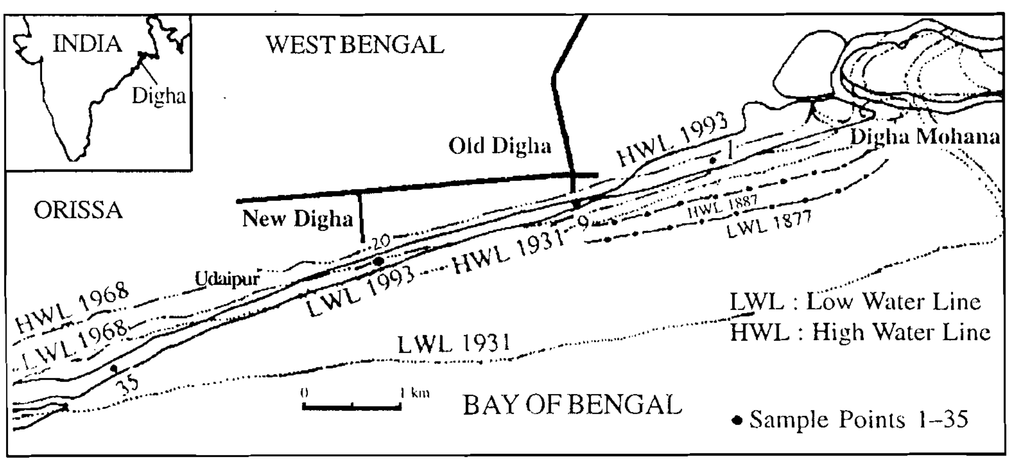

Fig. 1: Progressive shift of the shoreline around Digha between 1877 and 1993

India in Orissa and Nabadwip Formation of Baddhaman area of West Bengal. Chakrabarti (1995) classified various terrain units present in the Digha-Junput coastal plain into geomorphic units of active / abandoned / inactive marine coastal plain and inactive fluvio-tidal flat which were grouped into three geological units *viz.* ancient, older and recent Digha-Junput coastal deposit. He advocated for the presence of only one beach ridge in association with dune rows. Recent work by Banerjee *et al.* (1997), however, shows that the area does not at all contain any beach ridge; the elongated sub-parallel sand bodies are entirely of aeolian origin formed during the last glacial maximum.

Earlier work on coastal erosion and accretion of the area

O'Malley (1911) first reported erosional nature of the coast at Digha operating since the end of the 17th century. But this problem received serious attention in the 1950's when the West Bengal Government started developing the area as a tourist centre for the sea-loving people. Niyogi (1970), who mentioned that since 1949 the shoreline retreat has been parallel to itself and the general rate of retreat is 10 m per year, carried the first quantitative study of the coastal retreat at Digha. Chatterjee (1972) indicated the presence of a strong littoral drift along this part of the coast. Chakrabarti (1977) has shown a cyclic nature in the offshore-onshore movement of beach sediments with the major transfer being towards offshore for most time of the year. Chatterjee and Ghosh (1995) have shown that for all the directions of shore-approaching waves the eastern side of the Digha foreshore receives converging wave orthogonals and western side receives diverging wave orthogonals. According to Bhandari and Das (1997), the elevation of the western side of the beach (at New Digha) has increased whereas the same at the eastern side (Old Digha) has been reduced considerably and the foreshore has gained some gradient. The causative factors of coastal erosion at Digha as identified by these workers are (i) strong littoral drift on a fine grained and flat beach bordered by dune in the landward side, (ii) loss of sandy material inland by wind action, (iii) strong tides during cyclonic storm, (iv) possibility of faulting in the Digha shore-face in the recent past and (v) bathymetry of the inner continental shelf and orientation of the 'Western Brace' with respect to Digha at its shore-face.

Data used and methodology

This study has been done in two phases. First, the zones of erosion/accretion of the present-day foreshore have been identified through time series analysis of available toposheet and satellite data, and second, standard granulometric analysis of the foreshore sediments has been carried out to establish the results obtained from the above-mentioned time series analysis.

The maps and data products used for the first phase of study include (i) Survey of India toposheet of 1931 edition, Scale 1:63,360, No. 73 O/10, (ii) Survey of India toposheet of 1972 edition (surveyed in 1968), Scale 1:50,000, No.73O/10, (iii) IRS-1B L2 B1 Geocoded False Colour Composite (FCC), Date of Pass March 17, 1993, Bands 2, 3 and 4, Scale 1:50,000, No. 73O10. Besides these, the map prepared in 1774 by Rennell and cadastral map of 1877 was consulted but not used as hard data.

The scale of the 1931 toposheet has been changed to 1: 50,000 on Planvariograph for easy comparison with its 1972 version. Positions of High & Low Water Line (HWL & LWL) from these toposheets were marked on the overlay. Next, the line diagram prepared from the FCC was superimposed on the map-overlay through grid matching system and all the three basic data were brought to a single frame. Date of Pass (DOP) and the imaging time of the satellite was so selected that the maximum exposure of the intertidal zone is available. A visual observation of the imagery was made to mark the limits of High Water and Low Water Lines. A time series analysis of these physical lines was made for understanding the nature of shoreline change in the last 60 years (Fig. 1). Using digital planimeter, area of total loss or gain of the coastal land has been calculated. Finally a detail fieldwork was undertaken to fulfil the ground truth verification required with the use of remote sensing data.

For the second phase of study, sampling of the mid-foreshore sediments was done from the same sampling points in the months of November, January and April during 1992-93. In total, more than 100 samples were collected along the shore at intervals of 200 m from the upper 4 cm of the foreshore surface. After carefully preprocessing (Carver, 1971; Muller, 1967) these sediments were dry-sieved for 15 minutes on a Row-Top Sieve Shaker in 1/4 j size intervals. Mean (M_z), Sorting Index (S_o), Skewness (S_k) and Kurtosis (K_g) values of these polymodal sediments were determined following Folk and Ward (1957). Grain size parameters of the foreshore sediments are presented in the Tables: 1, 2 and 3.

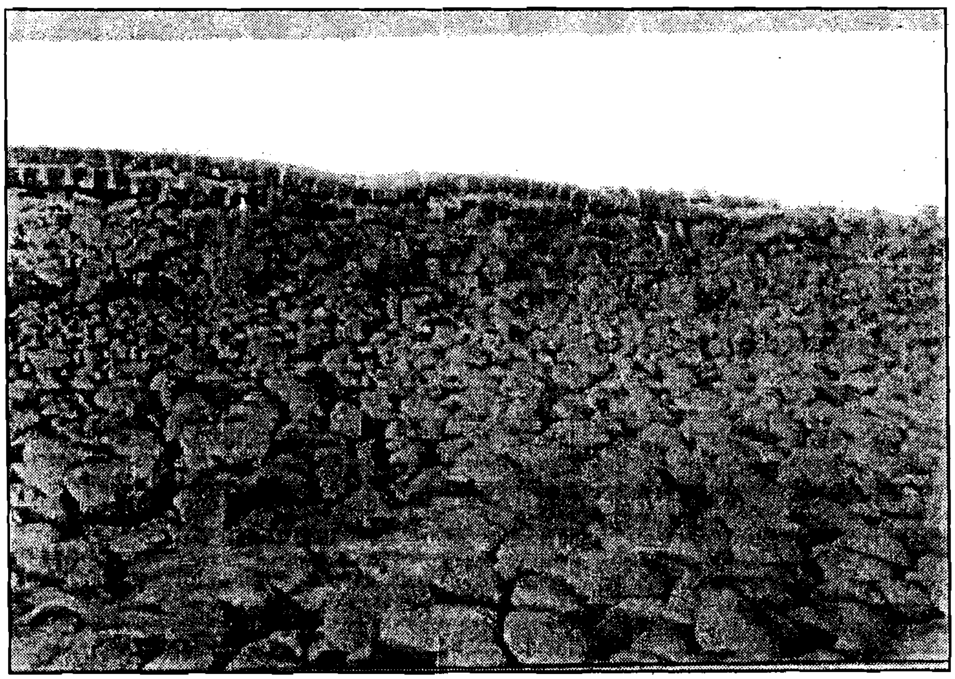

Fig. 2 : Condition of the seawall at Old Digha (Foreshore Sector C). Sea is towards the observer.

Results and discussion

Time series analysis of shoreline changes

The sandy beach at Digha (Beercool) attracted the British in India who also noticed the erosional nature of the sea long back in the 18th century (O'Malley, 1911). Old maps of 1774 and 1877 describe a narrow foreshore along the Medinipur coast. The shoreline (HWL) of 1877 was located far to the south of its 1931 position (Niyogi, 1970, p 23). But the LWL in 1877 was situated north to its 1931 position (Fig. 1). From the beginning of the 19th century, the foreshore at Digha experienced northward migration of the shoreline as well as widening of the foreshore. The toposheet of the year 1931 shows the presence of a wide intertidal zone along the Digha coast. The approximate area of this zone was 26.2 km^2. The foreshore zone was wedge shaped with its narrow end situated in the west (foreshore width nearly 600 m) while the eastern end near Digha Mohana Point was nearly 1.5 km wide. The Digha creek was perpendicular to the shore and used to flow for 1.5 km across the foreshore before meeting the sea. The time series analysis of the toposheets of 1931 and 1972 shows that the shoreline position of early forties changed rapidly in later years. In 1972, the foreshore was 200 to 300 metres wide at Digha. Both High Water Line & Low Water Lines had migrated toward north compared to their positions in 1931. The retreat of LWL was comparatively faster than HWL. During the time 1931 to 1972, an oval shaped submerged sand bar had developed at the mouth of the Digha creek, which had turned westward as a result of the formation of a westward projected spit on its eastern lip. Comparison between the coastal conditions of 1972 and 1993 indicates that the retreat of the HWL still continues in the eastern side of Digha (Old Digha). In this area, the LWL has migrated seaward in the last 20 years. In the west (New Digha), both HWL and LWL have moved towards land.

Fig. 3 : Eroded coastal dune belt at Old Digha (Foreshore Sector D).

Maximum width of the foreshore at New Digha (near the state border) and at Old Digha (near Digha estuary) measures more or less 350 m. Minimum width of the foreshore (less than 50 m) in 1993 is encountered off the Old Digha township area. Thus contrary to the 1972 configuration of the Digha foreshore, it is at present constricted in the middle and widened both east and westward. The configuration of the Digha creek in its estuary has also been changed. Contrary to its 1972 situation, it now opens eastward with the formation of a new meander loop and contains a group of three submerged sand bars near its mouth. Important features of the foreshore found through the field study are the following.

(i) The seven and half km long foreshore at Digha contains a nearly three and a half kilometre long boulder-laden seawall on its landward side facing the sea. The western end (at New Digha) of this guard wall is stable, overlain by thick deposit of sand and contains neo-dunes, whereas its eastern end (at Old Digha) has been severely damaged and experienced undercutting.

(ii) The foreshore beyond the guarded portion in the far west is very flat, contains 10-15 cm high berm above HWL and stable coastal dunes. On the other hand, the foreshore zone beyond the seawall-protected portion in the far east has advanced more than 100 m northward behind the alignment of the seawall. The coastal dune belt belonging to this portion is severely damaged and contains vertical cliff of 3-5 m height on its seaward face (Fig. 2). In some places, width of this natural protection walls measures less than 50 m. This part of the Digha coast is most vulnerable to erosion. Continuous erosion of the coastal dune belt may make way for possible inundation of the low-lying, fertile and densely populated hinterland.

(iii) The eastern and western ends of the foreshore are more or less 350 m wide, low gradient, very hard and remain almost dry during low tide of the full moon. The foreshore at Old Digha Township is less than 50 m wide and remains under a shallow cover of water during low tide. High water surges deteriorate the seawall of this part through toe erosion (Fig. 3), removal of the foreshore material and lowering of the beach. This part of the foreshore contains numerous 3-5 cm wide and 1-2 cm deep shore perpendicular channels, which drain out trapped water from the seawall.

The entire foreshore at Digha is thus divisible in four sectors depending upon the presence and absence of the seawall. These are: (a) seawall-protected erosional foreshore in the east, (b) seawall-protected accretional foreshore in the west, (c) unprotected erosional foreshore in the far east, and (d) unprotected accretional foreshore in the far west.

Grain size analysis

Mean size (M_z): Sediments of New Digha beach have their mean size which vary from 2.93 to 3.47 j in November (post-monsoon) and that in the month of January and April it ranges from 2.68 to 3.38 j and 2.76 to 3.34 j respectively (Table 1). Arithmetic average of these values reveals that the foreshore sediments of New Digha beach fall in the category of fine sand (Table 2). Variation in grain size with respect to time is observed as relatively finer sands are found to occur during winter. A marked difference in average value of mean size of the beach sediments is observed between the beach sectors (c) and (d) of Old Digha (Table 2). In sector (c) i.e., the erosional zone with a seawall at

Table 1 : Grain size parameters of foreshore sediments around Digha

	November, 1992				January 1993				April 1993			
Sl. No.	M_z (φ)	S_o (φ)	S_k	K_g	M_z (φ)	S_o (φ)	S_k	K_g	M_z (φ)	S_o (φ)	S_k	K_g
1	2.91	0.61	-0.08	1.19	2.04	0.56	+0.22	1.15	2.57	0.70	-0.07	0.83
2	2.99	0.69	-0.14	1.06	2.21	0.57	+0.07	0.90	2.98	0.67	-0.14	0.87
3	2.24	0.82	+0.20	0.82	2.38	0.63	-0.18	0.87	2.41	0.67	-0.54	0.76
4	2.99	0.68	-0.21	0.86	2.93	0.85	-0.37	0.97	2.93	0.46	-0.29	2.18
5	2.95	0.71	-0.19	1.26	2.78	0.65	-0.51	1.82	3.05	0.58	-0.21	1.03
6	2.90	0.65	-0.18	1.27	2.54	0.66	-0.13	0.86	2.46	0.54	-0.40	0.76
7	2.88	0.75	-0.18	1.26	2.58	0.66	-0.53	0.79	2.66	0.66	-0.43	0.93
8	3.16	0.62	-0.15	1.27	2.58	0.66	-0.53	0.80	3.20	0.43	+0.07	1.09
9	2.71	0.60	-0.29	1.26	2.71	0.70	-0.53	1.71	2.84	0.43	-0.34	1.86
10	2.90	0.75	-0.24	0.80	2.78	0.59	-0.42	1.67	2.55	0.66	-0.05	0.81
11	2.80	0.76	-0.26	0.96	2.64	0.58	-0.60	2.66	2.88	0.91	-0.32	0.77
12	2.96	0.76	-0.33	1.60	3.29	0.43	+0.10	1.08	3.13	0.56	-0.15	1.13
13	2.90	0.78	-0.24	0.81	3.14	0.53	-0.01	1.26	3.10	0.58	-0.10	1.12
14	3.05	0.61	-0.12	0.96	3.42	0.44	-0.37	1.39	2.88	0.40	-0.66	1.28
15	3.19	0.46	-0.03	1.09	3.07	0.32	0.00	1.41	3.01	0.43	-0.30	2.16
16	3.24	0.40	+0.16	1.04	3.15	0.46	+0.02	1.96	3.19	0.52	-0.06	1.29
17	3.25	0.46	-0.03	0.97	3.12	0.56	-0.13	1.08	2.97	0.26	-0.26	0.89
18	3.22	0.42	+0.11	0.85	2.85	0.40	-0.26	1.29	3.27	0.44	+0.10	1.12
19	3.01	0.24	-0.52	1.88	3.06	0.30	+0.09	1.22	3.28	0.52	-0.03	1.22
20	3.21	0.42	+0.07	0.92	3.11	0.53	-0.08	0.85	2.50	0.52	-0.73	1.63
21	3.22	0.45	+0.09	0.94	2.99	0.28	+0.04	1.47	3.02	0.47	+0.09	1.02
22	3.31	0.42	+0.14	0.99	3.25	0.35	+0.14	0.87	2.77	0.47	-0.28	1.09
23	3.24	0.43	+0.16	0.93	3.38	0.39	-0.12	0.92	3.25	0.40	+0.13	1.04
24	3.13	0.44	+0.04	0.71	3.10	0.62	-0.16	1.18	3.16	0.43	-0.02	2.45
25	3.23	0.44	+0.08	0.96	3.02	0.27	-0.21	1.17	2.76	0.24	+0.25	1.07
26	3.25	0.41	+0.15	0.96	3.14	0.33	+0.17	1.28	3.24	0.35	+0.35	0.85
27	3.47	0.39	-0.26	0.80	3.23	0.44	+0.07	0.99	3.17	0.24	-1.44	1.77
28	3.17	0.41	+0.18	0.78	2.95	0.29	-0.21	1.14	3.07	0.47	+0.02	1.20
29	3.37	0.41	+0.19	0.95	3.16	0.28	+0.27	1.29	3.11	0.52	-0.01	0.88
30	3.25	0.43	-0.02	0.85	3.13	0.37	+0.26	1.77	3.15	0.54	-0.01	1.19
31	3.22	0.48	+0.01	0.94	3.06	0.33	-0.04	1.45	3.18	0.52	0.00	0.97
32	3.21	0.52	-0.11	1.16	2.97	0.40	-0.06	1.18	3.06	0.33	+0.13	2.04
33	3.08	0.42	+0.07	1.22	2.92	0.34	-0.04	1.13	3.15	0.36	+0.03	1.02
34	2.99	0.50	+0.03	1.21	3.10	0.53	-0.08	0.90	2.94	0.36	-0.40	1.69
35	3.93	0.65	-0.36	1.91	2.68	0.39	-0.50	1.88	3.34	0.49	-0.03	1.24

HWL, the average value of grain size falls within the category of very fine sand (range 2.94 to 3.03 j) whereas in beach sector (d) i.e., the erosional zone without seawall, the grain size corresponds to fine sand class. There is a slight variation in grain size in time, the and (d) of Old Digha (Table 2). In sector (c) i.e., the erosional zone with a seawall at HWL, the average value of grain size falls within the category of very fine sand (range 2.94 to 3.03 j) where as in beach sector (d) i.e., the erosional zone without seawall, the grain size corresponds to fine sand class. There is slight variation in grain size in time, the lowest values of both the sectors are observed in the month of January instead of April and January as compared to the accreting sectors. A comparative

Table 2 : Average mean size parameters of foreshore sediments around Digha

	No. of samples	M_Z (j) Range/Avg.	S_o (j) Range/ Avg.	S_k Range/ Avg.	K_g Range/ Avg.	Period
Sector (a)+(b)	15	3.47 3.20 2.93	0.65 0.45 0.39	+0.19 +0.07 -0.36	1.91 1.00 0.71	Nov. '92
	15	3.38 3.07 2.68	0.62 0.37 0.27	+0.27 -0.03 -0.50	1.88 1.24 0.87	Jan. '93
	15	3.34 3.08 2.76	0.54 0.42 0.24	+0.35 -0.07 -1.44	2.45 1.31 0.85	Apr. '93
(c)	16	3.25 3.03 2.71	0.78 0.57 0.24	+0.16 -0.15 -0.52	1.48 1.05 0.81	Nov. '92
	16	3.42 2.93 2.56	0.70 0.53 0.30	+0.10 -0.24 -0.06	2.66 1.37 0.79	Jan. '93
	16	3.28 2.94 2.46	0.91 0.53 0.26	+0.26 -0.24 -0.73	2.16 1.20 0.76	Apr. '93
(d)	4	2.99 2.78 2.24	0.82 0.70 0.61	+0.02 -0.10 -0.21	1.19 0.98 0.82	Nov. '92
	4	2.93 2.39 2.04	0.85 0.65 0.56	+0.22 -0.06 -0.37	1.15 1.97 0.87	Jan. '93
	4	2.98 2.72 2.41	0.70 0.62 0.46	-0.07 -0.26 -0.54	2.18 1.16 0.76	Apr. '93

study of average mean size of the foreshore sediments for all the sampling months and for all the beach sectors shows that this factor is compatible with accreting sectors and sector (c), whereas sector (d) has marked difference from others.

Sorting index (S_o): The sorting index values of accreting sectors of Digha foreshore vary between 0.37 to 0.45 j and for the sectors (c) and (d) these values range from 0.53 to 0.57 j and 0.62 to 0.70 j respectively. In general, a well-sorted class represents an accretional domain, although the erosional domain of Digha contains moderately well sorted sediments. For erosional sectors, the maximum value is found in November and minimum value in April, whereas for accretional sectors, maximum and minimum values of sorting index are observed in the month of November and January respectively. The numerical values of sorting index gradually increase from accretional domain at the far west to erosional domain in far east.

Skewness (S_k): Positively skewed sands are abundant in the accretional domain which ranges from 40 to 76 per cent in January and November. The same parameter remains within 10 to 30 per cent in erosional domain in April and January (Table-III). This indicates that positively skewed *i.e.*, comparatively finer fractions of the sediment population dominates the accreting foreshore while eroding foreshore is made up of negatively skewed *i.e.*, comparatively coarser fraction of the sediment population.

Table 3 : Changes in average mean size and skewness values

	No. of samples	M_z	S_k	Range	% of + / -	Period
Sectors	15	3.20 ø	13(+), 04(-)	+0.19 to -0.36	80%(+), 20%(-)	Nov. '92
(a) + (b)	15	3.07 ø	06(+), 09(-)	+0.27 to -0.50	40%(+), 60%(-)	Jan. '93
	15	3.09 ø	07(+), 07(-)	+0.35 to -1.44	50%(+), 50%(-)	Apr. '93
	20	2.78 ø	04(+), 16(-)	+0.16 to -0.52	20%(+), 80%(-)	Nov. '92
(c) + (d)	20	2.39 ø	06(+), 14(-)	+0.22 to -0.60	30%(+), 70%(-)	Jan. '93
	20	2.72 ø	02(+), 18(-)	+0.10 to -0.73	10%(+), 90%(-)	Apr. '93

Kurtosis (K_g) : This parameter does not show any marked difference in erosional and accretional sectors of Digha. Though these values vary from platykurtic to leptokurtic classes but most of them fall in a meso- to leptokurtic range.

Grain size parameters for the seven and half km long foreshore at Digha reveals that during all post monsoon months the grain size decreases from west to east which may be indicative of the fact that the source of sediment is situated further west of the study area. If the Subarnarekha river is considered to be the source (Niyogi, 1970), the easterly directed longshore current may have transported these sediments towards east. Sorting index of sediments also gradually decreases from west to east of the Digha foreshore. Relatively poorest sorting of the beach sediments is observed in the eroding beach sector (d), which is situated in the eastern side of the study area and contains eroded coastal dune belt at HWL. The high tide breakers specially those of New and Full Moon days run up to the base of the dune belt and make it collapse through toe-erosion. The littoral current acting from west to east direction causes mixing of two sub-environments along the beach sector (d) in the eastern side of foreshore. Mixing of littoral drift and/or offshore sediments with that of the dune sediments yields poor sorting in the beach sector (d) than other sectors of the Digha foreshore. Uninterrupted swash-backwash movement over an wide, almost flat beach with sediment supply from a single source has enabled the foreshore sediments of New Digha to establish an equilibrium condition with respect to their sorting character. Dominance of comparatively finer and coarser fractions of sediments in the western and eastern side respectively, as revealed from the skewness values, strongly speaks in favour of presence of accretional and erosional domains in the western and eastern side respectively of the Digha foreshore (USACE, 1961).

Conclusions

The Digha beach has always been described as eroding in nature. But the present study of old maps and toposheets and time series analysis of these hard data and satellite imagery reveals that process of coastal erosion and accretion along the Digha foreshore is cyclic in nature. At present, both erosional and accretional domains exist side by side along the seven and half km long foreshore. Ground truth verification of the foreshore zone at Digha helped in demarcating four foreshore sectors which are divisible with respect to coastal process and physical character of the study area in question. Grain size analysis of the foreshore sediments also speaks in favour of these divisions. Whether the variation in numerical parameters of granulometric analysis responds to time or space is yet not established. Any conclusive statement interlinking grain size parameters and foreshore zones of erosion and accretion for a coast with low gradient, wide and smooth continental shelf like that of the present study area, will not be appropriate at this moment. This requires more field data from sedimentology as well as physical oceanography and meteorology, which are absolutely lacking for this part of the Indian coast.

Acknowledgement

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GENESIS AND MORPHOLOGY OF COASTAL POTHOLES : A CASE STUDY FROM NORTH KONKAN IN MAHARASHTRA

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Abstract

Potholes are the results of concentrated gyratory erosion by water. Though they are formed in fluvial as well as in coastal environments, the processes of their formation are different. This paper is a discussion of the formation and morphology of coastal potholes around Kelshi area in North Konkan in Maharashtra State. Quantification with reference to diameter, depth and overhang shape has been attempted for a large number of potholes observed in this area. Variations in these different attributes, including lithology and structure, indicate that their genesis is controlled by different processes independently or in combination with others. Hence these have been classified into different groups, each representing a distinct set of processes or lithological characteristics. Morphological diversity among the potholes on relict and active platforms was also found. Analyses of the morphometric variables also suggest that there may exist an equilibrium condition for pothole depth and diameter. This concept of equilibrium can be used to identify various stages of pothole development, from origin to maturity. Their contribution in overall down wearing of platforms is also significant, because processes operative in pothole development are faster than normal wave abrasion.

Introduction

Potholes are common microforms in fluvial as well as in coastal environments. These are circular, oval or irregular shaped shallow depressions in the parent rock, which seldom exhibit a singular occurrence. A group of potholes, closely spaced as well as fused into one another, is rather a familiar sight. The process of pothole development is generally attributed to concentrated circular erosion by water (Alexander, 1932). This appears to be the logical outcome of the observation of the deep circular shapes of the potholes. However, a detailed study of various morphological characteristics of potholes may reveal various operative processes and stages in their formation. In this paper coastal potholes near Kelshi along the North Konkan Coast of Maharashtra (Fig. 1) have been dealt with, and an inquiry has been attempted into their types, stages of evolution and processes operating for their development.

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Location and methodology

The coastal potholes on the shore platforms between Velas and Kelshi were investigated upon. They were classified into two types according to their positions. The potholes of the first category were from a lower level platform and from the zone of tidal inundation. Another category was of seemingly defunct ones and occupied a higher level shore platform 8 to 10 m above the high-tide mark well above the tidal wash zone. Along with visual interpretation, measurements were made and the field data of morphometric

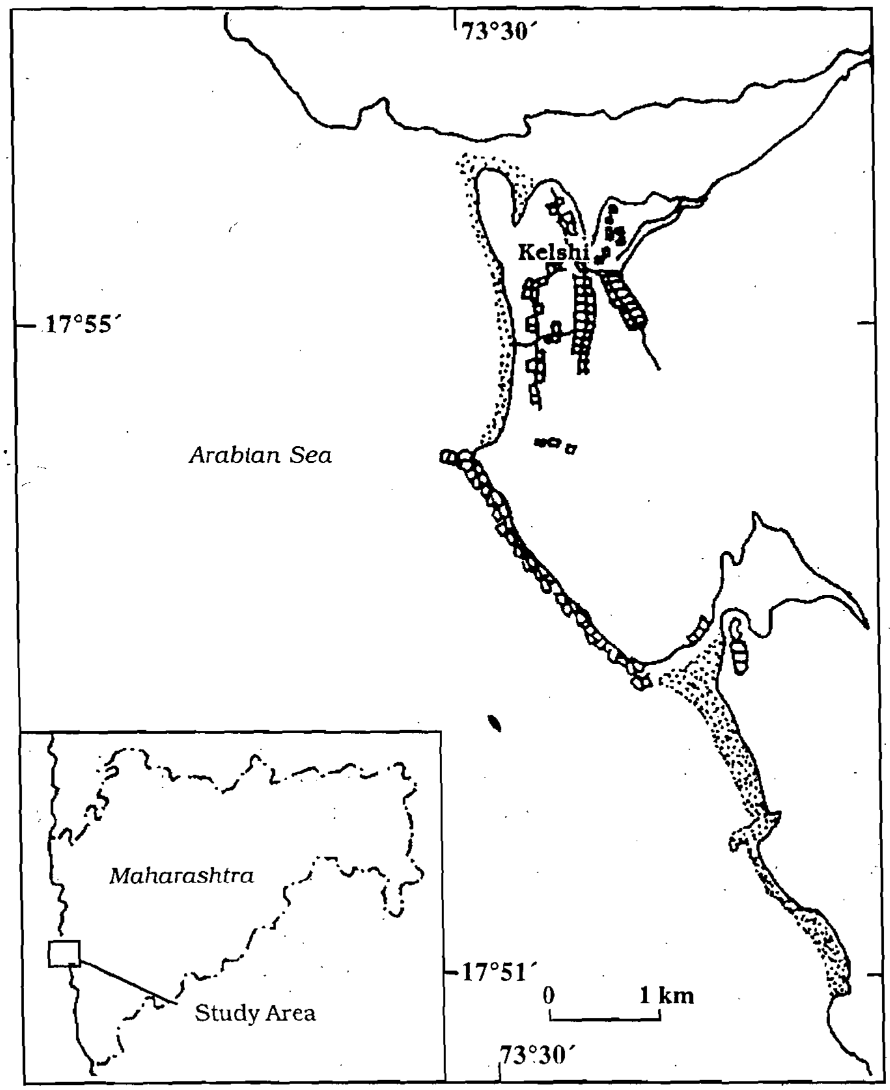


Fig. 1 : Location of the study area

variables, such as diameter of the potholes (longer axis in case of oval and irregular ones), depth, depth-diameter ratio, depth of overhangs (where present) orientation and shape were collected (Table 1).

Table 1 : Morphometric characteristics of the potholes surveyed in the field

Sl. No.	Diameter in cm (long axis)	Depth in cm	Depth/ Diameter Ratio	Overhang in cm. (where present)	Orientation (where noticable)	Shape
Potholes at lower level						
1	130	35	0.27	11	Slightly landward	Roughly circular
2	100	30	0.30	25	do	do
3	210	50	0.24	–	–	Round
4	175	45	0.26	–	–	Circular
5	255	30	0.12	–	Parallel to platform edge	Oval
Potholes at upper level						
6	120	25	0.21	–	–	Circular
7	120	30	0.25	–	–	do
8	260	45	0.17	–	Parallel to platform edge	Oval
9	180	15	0.08	–	do	Oval
10	230	25	0.11	–	do	Circular
11	230	67	0.29	–	–	do
12	645	160	0.25	–	–	do
13	440	85	0.19	–	–	do
14	580	35	0.06	–	Parallel to platform edge	Oval

Findings

Analysis of the variables presented in the above table leads to the following findings.

- Most of the potholes, which are smaller than 25 cm in depth, show an oval or irregular shape, whereas potholes having greater depths are circular in shape.
- Diameter and depth of potholes (in case of circular potholes) are directly proportional to each other. Larger the diameter, deeper the pothole.
- Potholes on the lower level platforms are roughly circular but show an inclination of axis towards the land.
- Presence of grinding stones is common in the case of upper level potholes, whereas the potholes on the lower platforms are generally devoid of grinding stones.
- In general, larger potholes existing on the upper level have grinding stones.
- Lower level potholes have smooth overhangs and polished surfaces. Upper level potholes, on the other hand, do not have overhangs and have comparatively rough walls.
- Irregular-shaped potholes are generally found on the lower platforms within the splash zone.

Considering all the above-mentioned observations together, some assumptions regarding the process of formation of the potholes have been drawn. These are as follows.

1. All the potholes are not the result of simple erosion. Though it is commonly taken as a result of circular movement of water, irregular shaped depressions cannot be accounted for by this explanation. In the warm tropical areas where chemical weathering is intensive, depressions may be created by block disintegration along lines of weakness or by granular weathering (Birkeland, 1974; Smith, 1978). In the study area, such potholes are found near the swash zone, where alternating wetting and drying take place and weathering has a major role to play.

2. Potholes developed by weathering are shallow. An irregular depression, once formed, collects water during high tides. This collected water does not completely drain away during low tides and continues to be in the same location for a longer period even in the low tide period. Shallow pools of water are thus created (Fig. 2 a). The fastest rate of rock disintegration occurs where alternate wetting and drying takes place. The bottom of the pool is always kept wet by collected water. As a result, downward penetration of weathering becomes slow, whereas lateral widening takes place easily as the edges of depression become wet and dry frequently. Increase in surface area of depression helps to collect more water in it and the widening process repeats itself. This phenomenon continues till a comparatively resistant material in the rock is encountered at the edges, which checks its lateral expansion. Due to shallow depth and more surface area the depth-width ratio remains very low, which is exhibited in all irregular shaped potholes. Their presence is be restricted to the swash zone where periodic wetting and drying takes place.

3. Potholes with circular shape are the results of circulatory motion of water and resultant erosion. They seem to have developed near seaward edge of the shore platform, where waves break releasing tremendous shock pressure on the rock. A block removal may provide the initial notch where gyratory action of water gets concentrated. The diameter of the pothole and its depth increases. Since the main action is concentrated at the bottom, the depth increases faster producing a high depth-width ratio, as seen in Table 1.

At times, the block dislodged by the wave attack may be too large to be carried by waves. Such loosened large blocks are trapped within their casings and are rotated by incoming and outgoing flow of water. Their rotation makes the casing roughly circular in shape and at the same time the block themselves assume a spherical shape. However, continuous abrasion of the irregular edges of the block gives the pothole only a rough circular shape. The pothole edges remain unpolished and irregular (Fig. 2b).

The dimensions of the dislodged boulder directly control depth of such large potholes with grinding stones. Presence of the grinding stone in the pothole prevents further deepening by restricting the gyratory movement of water underneath. The waves, however, rotate the grinding stone resulting in the enlargement of the diameter of the pothole.

4. It has been observed that the size of potholes and presence of grinding stones are

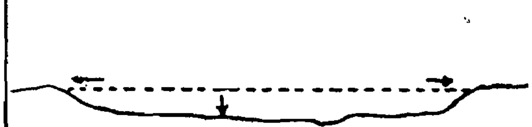


Fig. 2a Development of a shallow pool of water

Fig. 2b Irregular and unpolished edge of a pothole

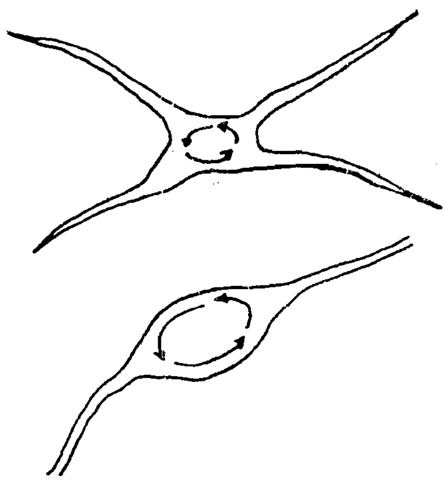


Fig. 3 Development of potholes through widening of the junction of joints

Fig. 4a Characteristic forms of potholes

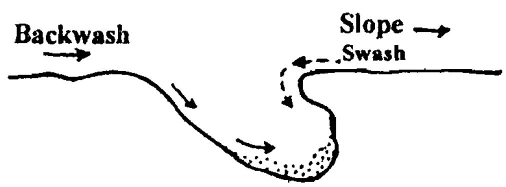


Fig. 4b Axis inclination of a pothole is usually towards the sea

Fig. 5a Fusion of weathering depressions and remnant stack

Fig. 5b Grinding stones in a pothole

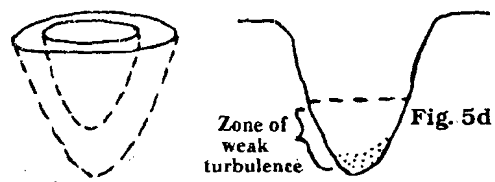
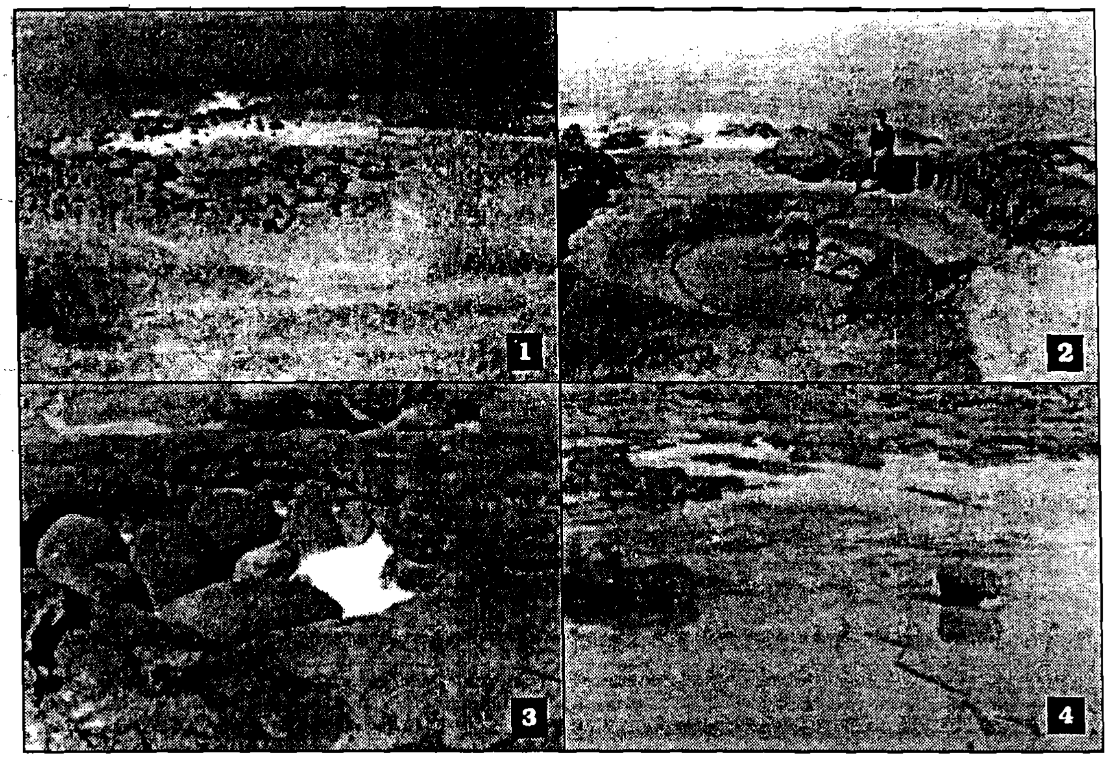


Fig. 5c Diameter too large to sustain circular movement

directly related *i.e.*, large potholes have grinding stones in them. Such relationship is logical since the small dislodged blocks can be carried out from their casings by waves. The resultant potholes are supposed to be shaped by the action of water alone. On the other hand, it is only due to the size and weight that large grinding stones are not removed. Hence, only large potholes have grinding stones. Such large potholes, formed by turning of large grinding stones by water, obviously would require a high-energy wave environment that can be found only within the swash zone. In the study area, such potholes are observed at about eight metres above sea level where only a weak spray action is observed. Presence of circular potholes and spherical grinding stones at this height indicate a higher relative sea level in the past.

5. The smaller depressions may be the result of removal of small boulders or widening at the junction of joints (Fig. 3). Grooving action of water then shapes such small depressions. A concentrated drilling action at the bottom increases their depth. They do not have any grinding stones; hence movement of water controls increment in diameter. Such potholes are smaller in diameter and depth than the ones having grinding stone. Nevertheless, their main characteristics are their smooth edges, larger linear diameter and smooth sharp overhangs (Fig. 4a). Abrasion and polishing by sand, and lateritic pebbles are the reasons of the development of their existing characteristics (Swinnerton, 1927; Wentworth, 1944). Sand particles being heavier, tend to settle at the bottom. At the time of high tide when the water rushes in and develops gyratory flow, these particles are lifted up in suspension and are rotated with water. Maximum cutting and polishing is thus done at a little height from the bottom (Fig. 4b). Finer the abrasive material, smoother is the pothole edges and overhangs. A maximum of 25 cm overhang was observed in potholes with diameter of 100 cm. Potholes with larger linear diameters and overhangs were not found on the higher platform away from tidal wash zone. It



Plates : 1. The two levels of shore platforms. The larger potholes are seen in the upper level; 2. A view of the largest upper-level pothole with grinding stones; 3. A view of another upper level pothole with overhangs and large grinding stones; 4. General lowering of the lower level platform by fusion and extension of the weathering pits.

seems that as the wave attack ceases or the potholes become defunct, the overhangs are eroded and crumble, making the potholes rough and irregular.

The axis and orientation of the potholes also vary according to their process of formation. Weathering-induced depressions usually develop upon joints and other planes of weaknesses, hence they do not show any particular orientation with respect to wave attack. Large potholes, formed due to grinding by dislodged boulders, are roughly circular but with a perpendicular axis. Their axis inclination is usually towards the sea (Fig. 4b). This appears to be due to either of the following two reasons: (a) The platforms slope towards the sea hence abrasion against the slope by incoming waves is weak; particles in response to gravity tend to roll towards slope and carve a seaward inclined axis. (b) The flow of water is not unilateral as in the case of fluvial erosion; the backwash is equally strong which counters the swash and deflects the axis of erosion.

Evolution of potholes

After being matured as landform, potholes are constantly acted upon by waves or by sub-aerial processes. However, they remain microforms, and one does not observe an infinite increment in their dimensions. This suggests that potholes may have an equilibrium stage after which they cease to change its size as well as shape. If there occurs any change in the processes, the equilibrium would get disturbed. The alterations in the shape and size of the pothole would take place until a new equilibrium is reached. Such stages of equilibrium may be identified in all the above mentioned categories of potholes.

In the case of weathering pits, the bottom of the pothole is constantly kept wet and hence less weathering becomes involved. Hence the depth remains shallow and the lateral extension takes place on a larger extent. Such wide shallow pools, extending from both sides, often fuse together leaving behind resistant parts as small pinnacles or stacks (Fig. 5a). A pothole at this stage becomes a part of newly exhumed surface of a platform. Pothole development may then start afresh on this surface.

Potholes, which have large grinding stones in them, do not increase much in depth since process of grinding does not allow any effective circular flow of water. Their width initially increases due to sidewall abrasion. However, after sidewalls are widened a little more than the size of grinding stone, the stone rotates within the casing but may not strike the sidewalls very frequently. By this time the grinding stones get reduced in size due to abrasion. Hence with a constant reduction in size, there occur lesser chances of the grinding tool striking the sidewalls. There cannot be any further increase in width or depth after this stage (Fig. 5a). As the grinding stones are reduced in size, they can be picked up and carried away outside the pothole by waves. The remnant depression may come under wave action as a potential site for a new pothole.

Potholes in the swash zone, which are shaped only by circulation of water and abrasion by fine tools, show an interdependence of width (diameter) and depth. Initially, with the rotation of water in the pothole its diameter increases (Fig. 5c). As a result, wider potholes become deeper. However, after attaining a certain size, the surface diameter appears to be too large to maintain a single circular flow of water. Moreover, the velocity of the flow also falls, and only a sluggish movement of water takes place. At this stage widening and consequent deepening of the pothole also stop. This condition of pothole may be considered as the equilibrium condition.

In another condition an increase in depth may also bring about equilibrium. Under lithological control a pothole may become unusually deep as compared to its diameter. A narrow, pipe-like depression with small diameter and large depth is thus developed (Fig. 5d). Here the water column from the bottom of the pothole to its surface is too high to be rotated freely by waves. Hence, turbulence at the surface hardly makes any impact on the pothole bottom, where the water remains almost stagnant. Depth ceases to increase at this point. However in course of time, the platform level generally wears down and the deep potholes may become shallow again. At this stage the waves can make impact on the pothole bottom and deepening may start afresh.

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CAUSES AND CONSEQUENCES OF LANDSLIDES IN DARJILING TOWN

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Abstract

Landslide hazards around the Derjiling township area, usually occurring upon highly foliated gneissic rocks and markedly thin soil-cover, have been assessed. Main reasons of the growing events of landslides, particularly since independence, have been attributed mainly to the rapid urbanisation and mass deforestation. On the basis of the scale of intensity five types of landslide-prone areas have been identified. The existing water management system being maintained for Darjiling town has also been evaluated.

Introduction

Landslide is perhaps the most rampant environmental hazard threatening the Darjiling town itself. During or after every monsoon, landslips create havoc in and around the Darjiling township area. Numerous slips have occurred in the past; however, the intensity, cause and severity of the slides are being recorded only since 1899 (Fig.1). From the records of the recent landslide events, it is clearly revealed that the frequency of landslips is increasing year after year. In order to have an insight into the probable causes of such increased vulnerability of the Darjiling town it is necessary to trace the course of events from the very inception of the town.

Geomorphological background of the study area

Darjiling is situated at the northern extremity of a ridge, which extends southwards through Ghum and is bifurcated by numerous spurs extending at all angles. The main ridge and the spurs are narrow and steep and are separated by water channels of steep gradient locally known as *Kholas* and *Jhoras*.

Within the confines of Darjiling town the foliation dips of the gneissic rocks are generally towards the east, ranging from 20° to 40°. There are two prominent sets of joints, one running roughly northwest to southeast and the other north-northwest to south-southeast. Both the joints have steep westerly dips varying from 40° to 70° (Fig. 2). The direction of the hill spurs agreeing with the joint directions indicates that blocks of rocks loosen easily along these joints.

In Darjiling town, there is a top soil of about 3 to 5 m near the crest of the ridges, but the thickness decreases downwards and lower slopes are generally covered with boulders rolled down from the top. The soil everywhere is residual as it is derived from

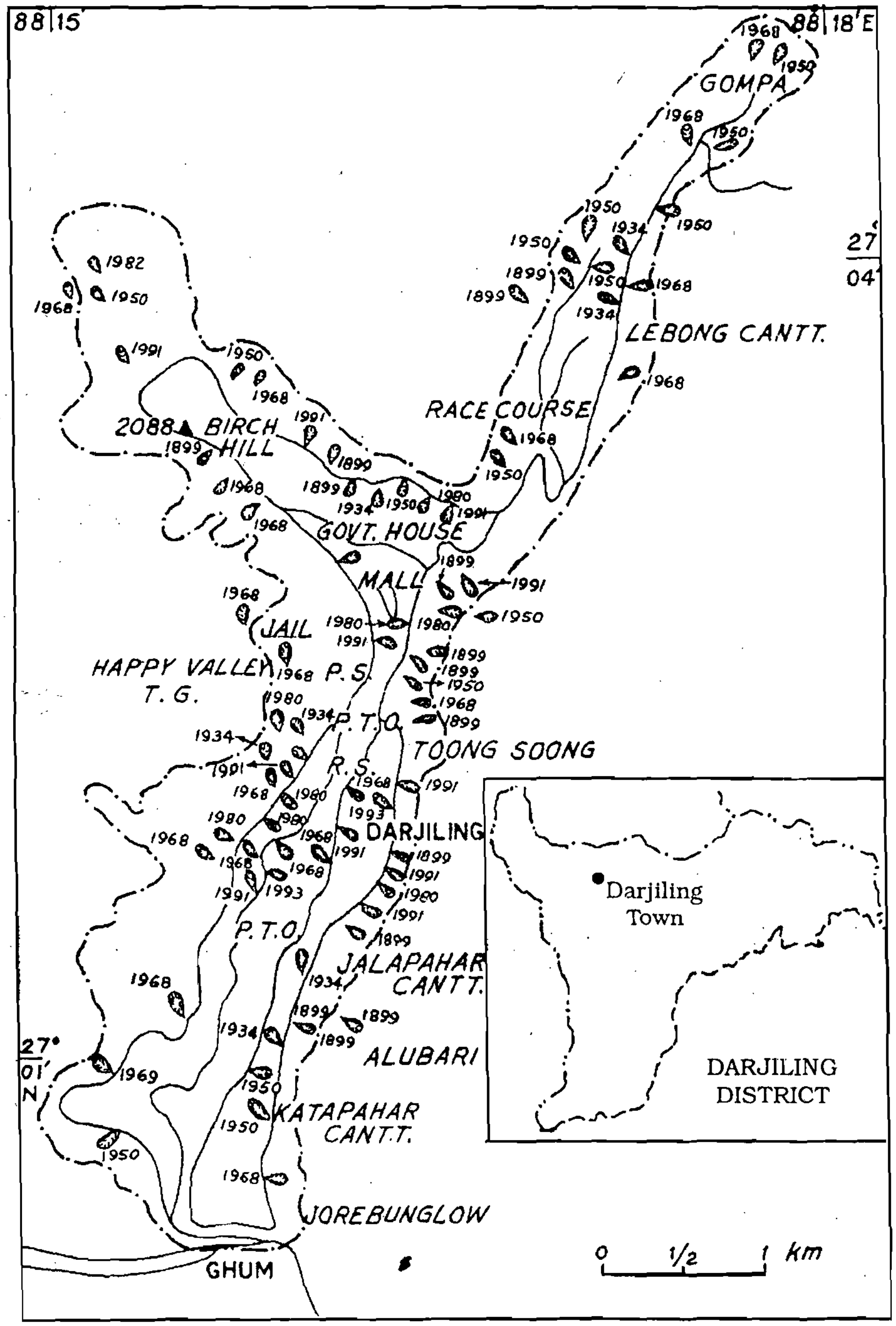

Fig. 1 : Chronology of landslips around Darjiling town (1899 – 1993)

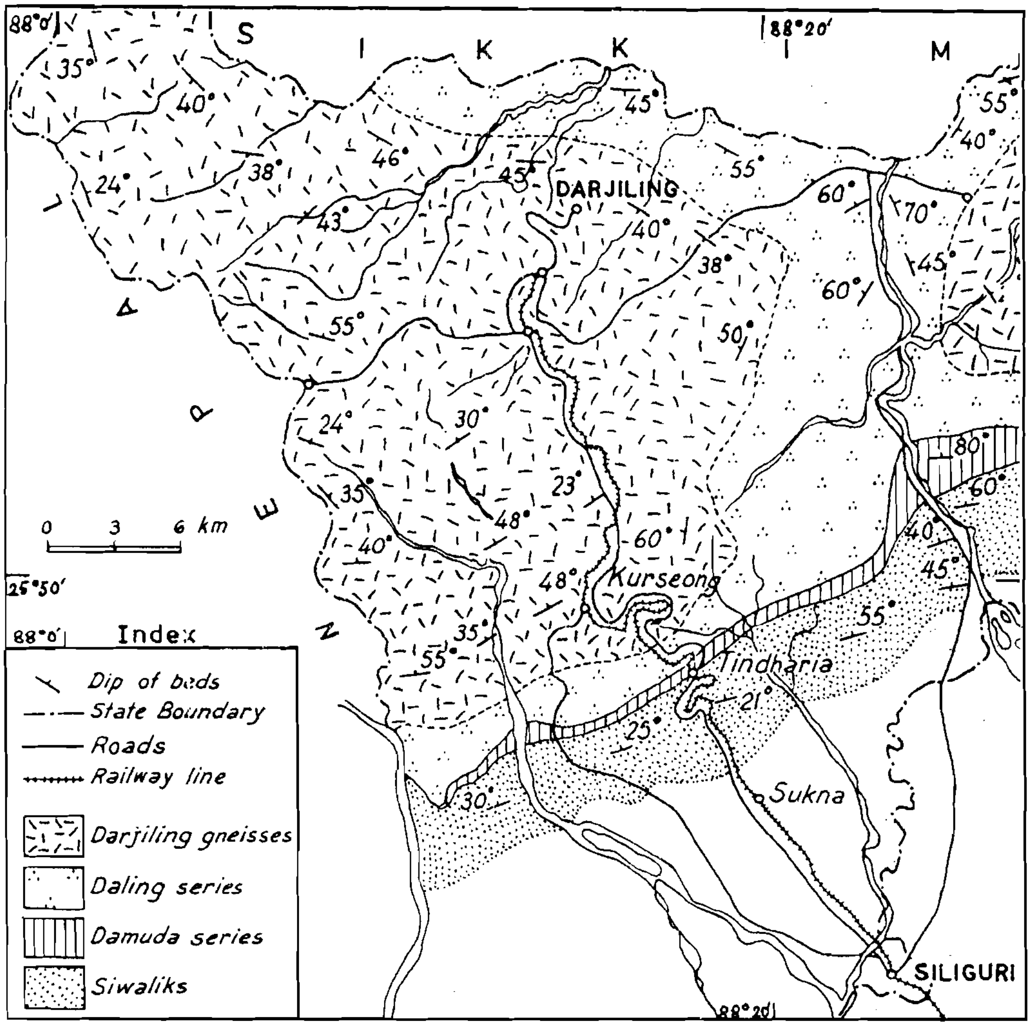

Fig. 2 : Geological formations around Darjiling

the weathering of gneissic rocks. Weathering is selective in these rocks and proceeds along some susceptible bands— mica rich bands in preference to quartzose bands and also along joints and shear planes. Consequently, blocks of fresh rocks are generally found encircled on all sides by highly weathered rocks of the nature of clay. The clay is found mixed up with grains of quartz, feldspar and flakes of mica. This has an important bearing on the slips, as the air, filling up the voids in clayey soil, gives it an apparent cohesion, which is lost as soon as the pores get filled with water during rains.

The reason for formation of the soil-covered (1.5 to 3 m) western slope contrasting with the boulder-covered eastern slope is probably to be attributed to the characteristic structural features of the underlying rocks (joints, foliation, dip etc.) in the respective area. On the eastern slope, foliation plane and joints are favourable for loosening of blocks to form talus while on the western slope, the foliation dip being inward, the looseness of blocks is retarded and the rocks get time to weather into soil.

Development of Darjiling Town

On the 1st of February 1835 by a deed of grant by the King of Sikkim, Darjiling was ceded to the East India Company. At the onset, the population consisted only of a few hundreds of people. With the establishment of a sanatorium for ailing British soldiers, purchase of land by Europeans for residential purposes, opening up of barracks for soldiers and a bazaar, population grew up to 10,000 in the following 50 years. When the tea gardens were being open out (1873) and the communication with the plains became easier with the construction of the Hill Cart Road and Darjiling Himalayan Railway, labourers poured in and a phenomenal growth of population (16,924 persons) resulted in 1901. Success of tea plantation, partition of Bengal, introduction of tourism and the resultant massive construction works (expansion of roads, construction of new urban structures etc.) ushered in more and more immigrants from the neighbouring countries and thereby almost doubling the population of Darjiling (33,605 persons) in 1951 and by 1991 the town recorded a population of about 71,471 persons. The density figure changed from 1603 persons/km^2 in 1901 to 6,769 persons/km^2 in 1991 (Table 1) with a consequent change in percentage of increase by 322.

Table 1 : Decrease in forest and increase in built-up area & population in Darjiling

Year	Forest Area (%)	Built-up Area (%)	Population
1800	95.0	Nil	100
1850	87.0	3.0	10,000
1901	65.0	7.5	16,924
1951	40.0	39.0	33,605
1991	15.0	52.0	71,479
2001	10.0	65.0	85,000 (Projected)

Source: Census Reports forest Census and other documents on Darjiling.

Up to the first half of the present century, there were certain regulations for the commercialisation of the hill slopes, but since independence, in a desperate attempt to acquire as much arable land as possible, extensive area under forest cover was gradually encroached upon. The ever-increasing number of people haphazardly settled in every bit of land available. During the British period, it was made a rule that forest on the upper part of the hills should not be brought under ordinary commercial forest management. They had the notion of the ecological disaster that it would bring if these forests were denuded. But after independence, the demand for timber increased at an unprecedented rate, and even the upper layer of the forest was not spared (Dasgupta,

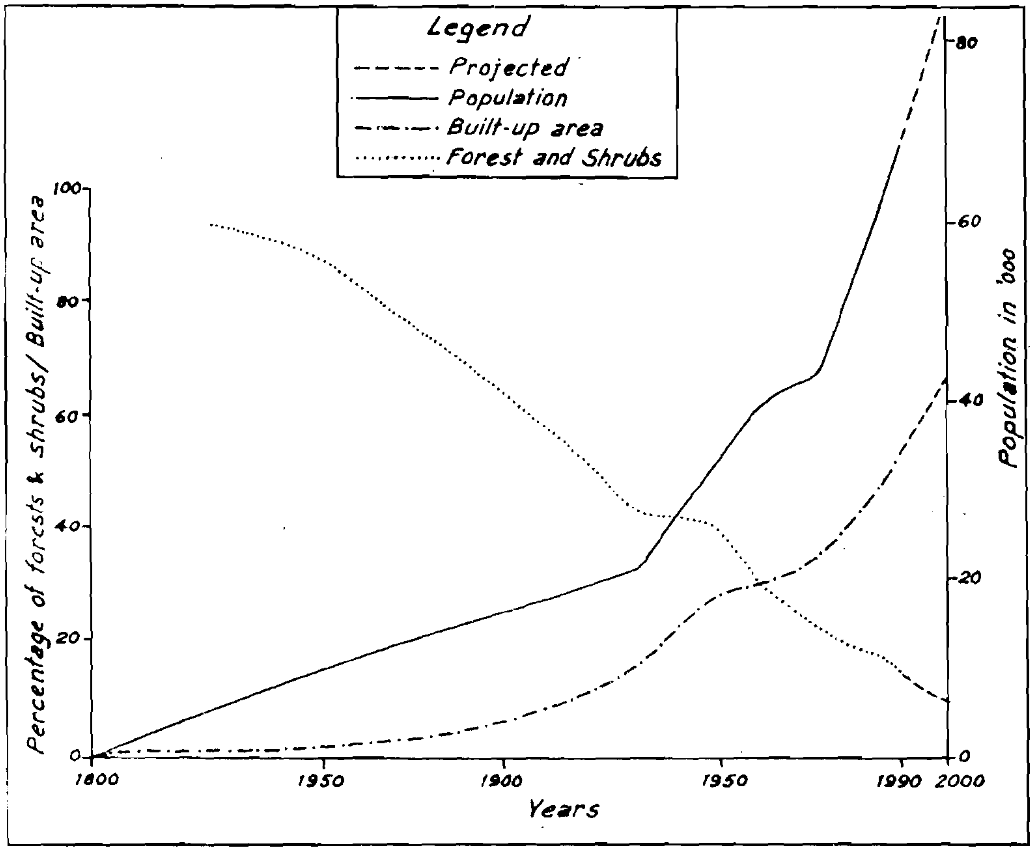

Fig. 3 : Decline of forest area vs. rise of population and urban areas in Darjiling Municipality area

1986). Even after mass afforestation programmes have been implemented, a big gap remains between felling and replanting. It has been estimated that 70 per cent of the cooking energy needs of the people is still being met by firewood. Needless and reckless obliteration of forests along with unscientific use of slopes (especially in construction works), coupled with geological, rainfall and slope characteristics have changed the local scenario completely (Fig.3). As a result Darjiling, one of the most densely populated tourist-centres in a comparable environment, exists on the verge of an environmental catastrophe as with just one concentrated shower of 50 mm/h would initiate numerous landslides endangering the lives and properties of the local inhabitants.

Landslide events

From the available records, it is found that the first disastrous landslip occurred on the 24th September 1899, in Darjiling town (Table 3). Unprecedented rainfall (Table 2) of 1065.5 mm during 23rd to 25th September (4 days) triggered about fifteen landslides in different parts of Darjiling town killing 72 persons and causing enormous loss to land and property (Griesbach, 1899-1900). Most of these slips were confined to the soil-cap overlying the gneissic rocks. The immediate cause of the slips was attributed to excessive rainfall. The instability of the hillside gradually increased due to increased saturation caused by absorption of moisture and the cutting of hillslopes both for natural and artificial needs increased this instability further. Defective drainage was also considered an important factor in the absorption of moisture.

Table 2: Daily and cumulative totals of rainfall during major landslips in Darjiling town.

Days	Rainfall in mm	Cumulative Total in mm
22.9.1899	76.0	76.0
22.9.1899	291.5	367.5
24.9.1899	485.0	852.5
25.9.1899	213.0	1065.5
Total 4 days	*1065.5*	*1065.5*
10.6.1950	14.1	14.1
11.6.1950	104.0	118.1
12.6.1950	462.0	580.1
13.6.1950	254.0	834.1
Total 4 days	*834.1*	*834.1*
2.10.1968	95.25	95.25
3.10.1968	439.42	534.67
4.10.1968	481.33	1016.00
5.10.1968	105.40	1121.40
Total 4 days	*1121.40*	*1121.40*
2.9.1980	45.0	45.0
3.9.1980	72.0	117.0
4.9.1980	222.0	339.0
5.9.1980	5.0	344.0
Total 4 days	*344.0*	*344.0*
10.7.1993	47.0	47.0
11.7.1993	87.5	134.5
12.7.1993	102.0	236.5
13.7.1993	15.0	251.5
Total 4 days	*251.5*	*251.5*

Source: Darjiling Planters' Club, Darjiling.

Table 3 : Major events of landslips in Darjiling town and their effects

Dates of major events of Landslips	Localities/Sectors affected	Remarks
22nd to 25th September, 1899	*Settlement Sector:* Tongsoong *busti*, Pradhan *busti*, Singamari, Hermitage, Eastern slope of the Observatory hill, Jalapahar, Alubari and below the Railway Station. *Road Sector:* Jalapahar Road, Tenzing N. Road, Birch Hill Road, Rangit Road, Hill Cart Road and Lebong Cart Road	72 lives lost within the town (62 Indians and 10 Europeans). The value of property destroyed amounted to lakhs of rupees. The precipitous eastern slope from Toongsoong *busti* to Observatory Hill experienced a series of devastating landslips and most of the houses were destroyed.
10th to 13th June, 1950	*Settlement Sector:* Jalapahar cantonment; Pradhan , Moharlal, Lebong, Hermitage, Toonsoong, Bhutia *bustis* and eastern slopes of Katapahar. *Road Sector :* Gandhi Road, Jalapahar Road, Convent Road, East Mall Road, Birch Hill Road, Lebong Cart Road and Lebong Circular Road. *Railway Sector:* Large portions of Darjiling-Siliguri Railway in the vicinity of the town were washed away and not re-laid until late 1951.	Several hundreds of people were rendered homeless, as the whole hill sides with buildings, farms and trees collapsed. The loss of life reported was 100. The slips breached the main arterial roads and the town was cut-off for 5 days from the outside world. Water and electricity supply stopped completely. Happy Valley tea Garden sustained ravages.
2nd to 5th October, 1968	*Settlement Sector:* Lebong near Gompa, below Race course, Bhutia *busti*, Limbu *busti*, Toongsoong, around the jail, Vineeta House (Jalapahar), Kotwali, Rajbari, Kagjhora, Butcher *busti*, Mayapuri and Manpari *busti*. *Road Sector:* Hill Cart Road, Gandhi Road, Lebong Circular Road, Victoria Road, Tenzing N. Road, Tonga Road and Acharya Jagdish Ch. Bose Road.	The Hill Cart Road was blocked at 18 different points. Heavy loss of life and property occurred especially in the neighbouring tea gardens.
2nd and 5th September, 1980	*Settlement Sector:* Opposite Glenery's near Planters hospital, Toongsoong, Bhutia *busti*,	Heavy loss of life, damage to dwelling houses and disruption

Dates of major events of Landslips	Localities/Sectors affected	Remarks
	Manpari *busti*, near Mt. Hermon school. Butcher *busti* and below the Railway station. *Road Sector:* Hill Cart Road, Lebong Circular Road, Parts of T.N. Road, Tonga Road, Victoria Road and Acharya Jagadish Ch. Bose Road.	of communication, drinking water and electricity supply. Helicopters had to be sent to evacuate the affected people. According to the District Report (1980) the total damage to the property amounted to Rs.647.90 lakhs.
14th to 16th September, 1991	*Settlement Sector:* Almost all old sites of Landslides, near Missionary of Charity, below Birch hill near North Point College, Toongsoong and Singamari. *Railway Sector:* Certain parts of Darjiling-Siliguri railway line.	Two people died. Drinking watersupply stopped in certain parts of the town. The Darjiling-Himalayan Railway had to be closed for some months.
10th to 13th July, 1993	*Settlement Sector:* St. Paul's School behind the Padry's grave yard. *Road Sector:* Certain parts of Hill Cart Road, Jalapahar Road, near Youth Hostel, and near Catharine Villa.	Disruption of water-pipes, as a result, certain parts of the town could not get water for more than 15 days.

(Compiled from official records and field observations)

The second major event of landslips in the town took place on the 15th January 1934 due to Bihar-Nepal earthquake, which was responsible for widespread destruction though not of equal magnitude as was experienced in 1899.

On the 11th and 12th June, 1950, the hill slopes in and around Darjiling town was affected by another disastrous event of landslips causing several deaths and heavy damage to roads, houses and public works, due to heavy shower (834.1 mm) from 10th to 13th June, 1950.

Darjiling town and its environs were again eclipsed with large scale landslips owing mainly to very heavy and concentrated rainfall that continued from 2nd to 5th October, 1968 with a total of 1121.40 mm. Such landslides caused widespread damage to human lives, properties, roads, railways and cut off the town from the rest of world for about a week.

The period between 1969 and 1979 was relatively undisturbed. But heavy and continuous rain on the 27th August and again during 3rd to 4th September 1980 triggered off widespread landslips in and around Darjiling.

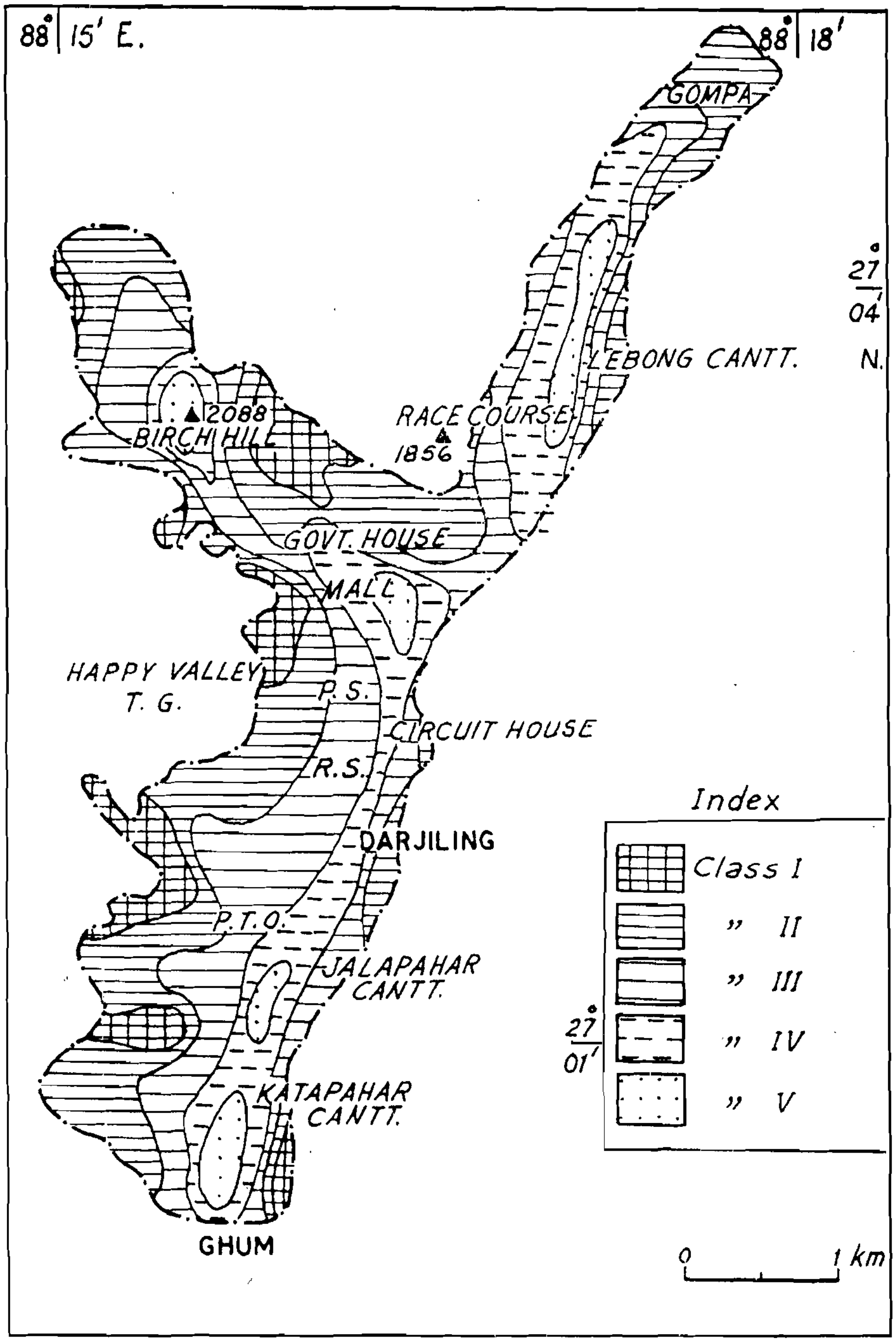

Fig. 4 Landslip-prone areas in and around Darjiling town (see text for explanation of classes)

Since 1980, it has been observed that almost in every monsoon some parts of the town have been suffering from major or minor landslips causing loss of life and properties. The years 1991, 1993, 1995 and 1998 are the latest cases of landslips in Darjiling town.

Landslide-prone areas

For a better understanding of the geographical distribution of landslip-prone areas in Darjiling town, a map (Fig. 4) has been produced with the help of a 'check list', topographical sheets (78 A/4 & 78 A/8) and direct field observations at 35 sample sites. The following five categories of susceptibility zone have been put forwarded for further discussions. In this context, it is interesting to note that the map of soil erosion (Fig. 5) also shows a more-or-less similar trend.

Class-I: Extremely high slip-prone zone: Almost after every torrential rain, these tracts experience slips. They are mostly found on the eastern slopes of Jalapahar-Katapahar ridge mainly covering the areas like Alubari, Manpari *busti*, Toongsoong, Pandam tea garden, Bhutia *busti* and Hermitage, eastern slope of Lebong spur around Ging and Bannockburn tea gardens and in small pockets on western slope of the Lebong spur i.e. Pattabong and Rangit tea gardens. It is also noticed along the western part of the town below Batasia.

Class-II: Very high slip-prone zone: These are the areas where slips occur for more than five times in ten years. They are found along both the eastern and western slopes of the ridge i.e. upper Alubari, upper Toongsoong, along the Tenzing Norge Road, C.R. Das Road, eastern slopes of the Mall, below Raj Bhavan. It is also to be found on both sides of the Lebong spur mainly in the tea gardens of Bannockburn, Rangit and Pattabong. On the western slopes of the ridge it covers Rajbari *busti*, Kagjhora, Victoria falls, Dr. Zakir Hussain *busti*, Dhobitala, around the jail, below the railway station, Lochanger, Haridas *hatta* and Singamari.

Class-III: High slip-prone zone: It covers the western spur of the town along the Hill-Cart Road, Gandhi Road, Nimkidara, Police line, Mary Villa, Mayapuri, upper Kagjhora, below the convent cemetery, Dr. Zakir Hussain Road, along the Birch Hill spur and the Lebong spur. Here landslips occur 2-5 times in ten years.

Class-IV: Moderate to low slip-prone zone: In this zone, landslips occur once or twice in last ten years. It is found mostly along the ridges of Jalapahar-Katapahar up to the Mall, including the bazaar area and also along the Lebong spur including the Lebong Cart Road.

Class-V: None to negligible: It is found in pockets on the ridge tops of the Jalapahar-Katapahar ridge, the Lebong ridge (Military Cantonments) and the Observatory hill and on the top of Birch Hill ridge where slips occur rarely.

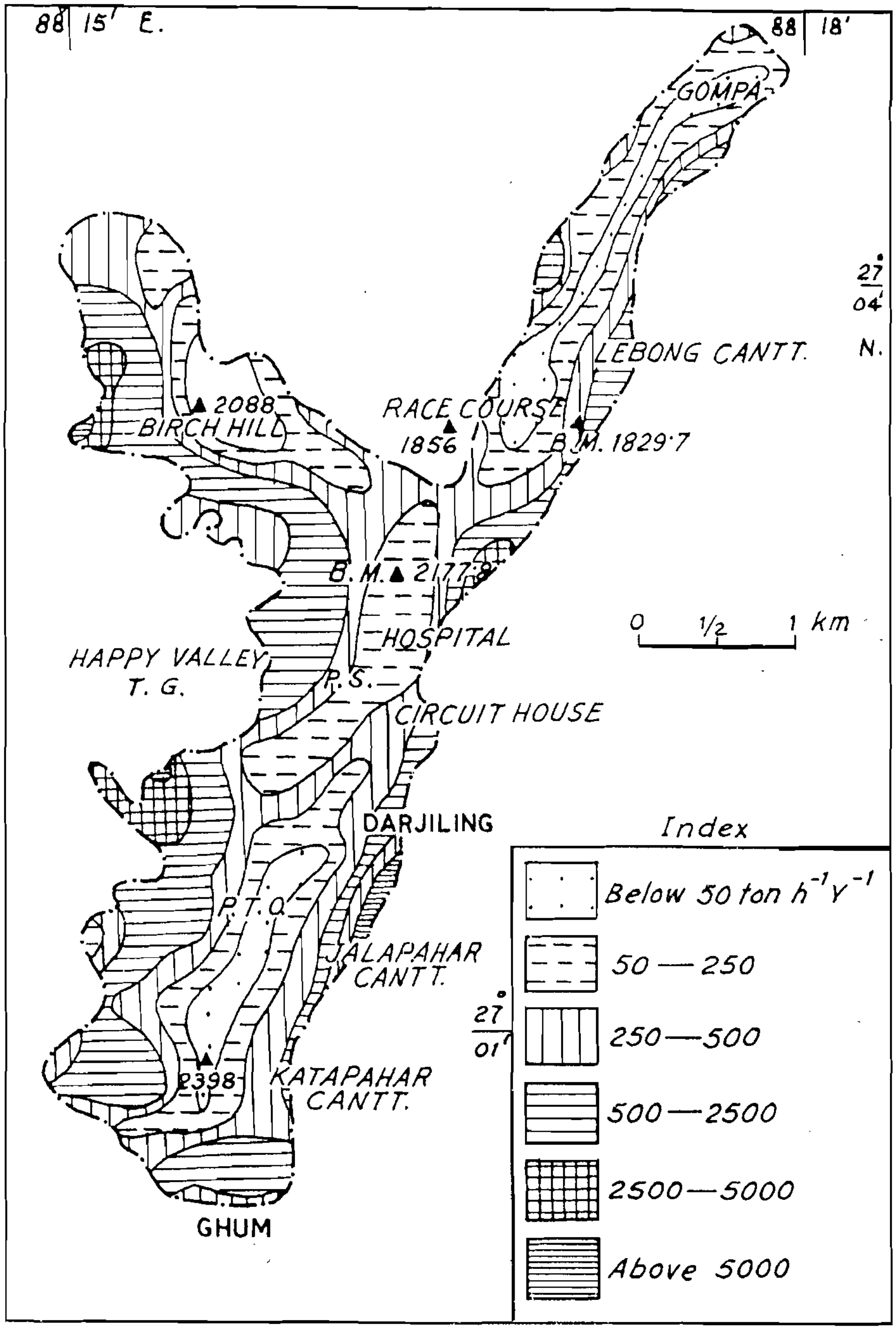

Fig. 5 Predicted soil loss in and around Darjiling

Recommendations

Identification of landslide prone areas and the study of individual slips within the town have helped in producing a map on soil conservation (Fig.6) and this indicates that there is no portion, excepting only the very top of the ridges which is stable against slips. However, the western slopes of the ridges and spurs are comparatively more stable than the eastern slopes. In the western slopes, the debris-cover is fairly thick below the present town limit, *i.e.*, below the Cart Road and Victoria Road where the gradient is also steeper. So, construction of buildings on the debris-covered slopes should be restricted. In soil slopes, building may be constructed but they should be provided with proper revetment walls with adequate weep-holes.

Narrow drains extending only a few metres down the hillside are found to have helped in the seepage into the hill-slope below causing slips. *Pucca* (cemented or plastered) drains wide enough to drain out the storm discharges should be constructed from the top to below, the lower level of the town.

In the *busti* areas (slums), especially Bhutia, Toongsoong, Alubari, Manpari, Butcher, Kagjhora etc., the greater incidence of slips is mainly due to bad drainage, from the densely packed houses. Here, in the absence of proper outlets, water gets absorbed in the soil. Unscientific and badly managed terrace cultivation adjoining the houses aggravates soil erosion. Low, badly designed and poorly constructed revetment walls also assist the slip instead of providing protection against them. Hence, measures should be taken to ensure wider spacing of the houses with proper drainage and suitable revetment walls. Here in the *busti* areas the bearing capacity of the soils and the debris rich in sand particles ranges between 4.5 to 6.6 kg/cm^2, corresponding to the strength suitable for the construction of three-storeyed buildings only (Bandyopadhyay, 1980). So any construction beyond this limit must be prohibited. Moreover, along the *nullah* (unlined drain) courses in the *busti*, spaces should be left on either side at an angle of 45° with the *nullah* bank, which are unstable zones for construction as there are chances of slope failure within that zone.

Water management in Darjiling Town

Slope instability has a direct relation to water supply in Darjiling town. At present, the town almost wholly depends on the supply of 182,000 m^3 of drinking water from the following three lakes on Senchal ridge.

South Lake	-	49,000 m^3	- opened in 1910
North Lake	-	76,000 m^3	- opened in 1932
Sindhap Lake	-	57,000 m^3	- opened in 1978
Total	-	*182,000 m^3*	

Taking the UN human water requirement standard of 0.076 m^3/individual/day, the total demand for Darjiling town has been estimated by the Municipal authority as 110 million gallons (Darjiling Municipality, 1991). Considering the present population of

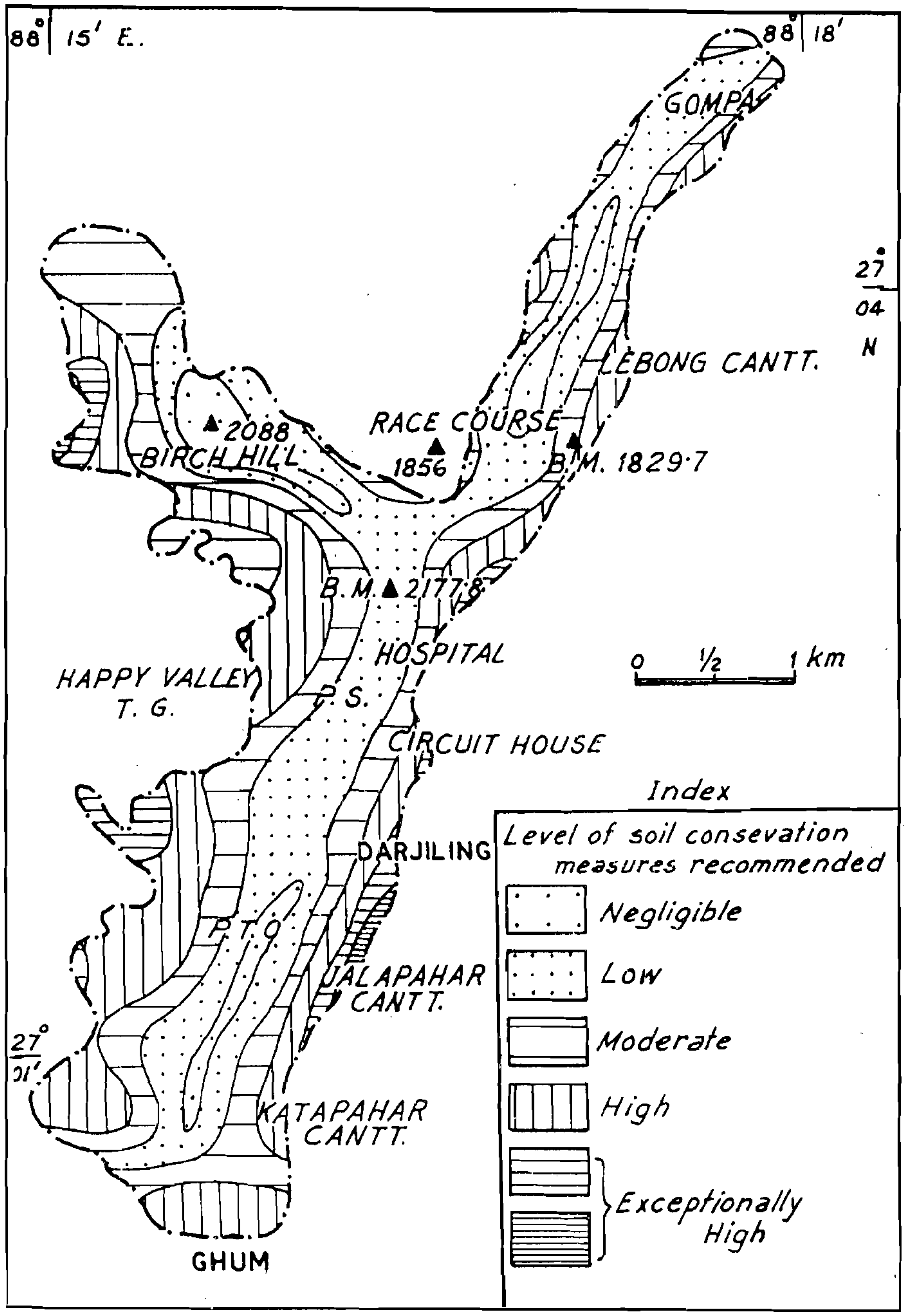

Fig. 6 Proposed soil conservation scheme for Darjeeling towns and its environs

71,479 (1991) this demand will be much more in the future, pointing to a perpetual crisis in water in Darjiling town. There would not be any water crisis if the storage capacity could be enhanced by the construction of at least five more reservoirs of the capacity of 38 thousand m^3 each. But the Senchal ridge is hardly stable enough to stand such construction of reservoirs. At the most, one more reservoir can be constructed. So, at present only eight out of 26 *Jhoras* feeding the Senchal lakes are kept alive during the monsoons and the rest are cut off because there is no capacity to store (Rumba, 1986). The Rockville reservoir at the centre of the town above the railway station was affected by landslip in 1950 and it was feared that the reservoir also might be damaged and its bursting might cause further damage. The area that slipped, involved only the superficial layer of sandy clay and boulders originally resting at an angle of 40°, which is greater than the angle of repose for such materials. Lubrication further lowered the angle of repose and caused the slip (Nautiyal, 1966). Nearly 1,000-m length of the top-most water pipe line located on the eastern slope of Darjiling-Jalapahar ridge was damaged during 1950 monsoon. Slips had damaged and twisted the pipes at various places, causing temporary stoppage to water supply. The damages to pipes can be prevented by burying them underground. This, however, would be costly and frequent inspection would not be possible. However, some protective measures should be provided to the pipelines in order to protect them against the impact of falling materials (Dutta, 1966). In 1988 and 1993 landslides damaged water pipelines in different parts of Darjiling also.

During tourist season, when the population almost doubles itself, the problem of water scarcity reaches its maximum. In these months (April to June and Late September to November) the hotels bribe the municipal authorities to divert the maximum water to their establishments by illegally tapping the pipelines. In such situations, the local people the most badly affected lot. It is true that landslides affect the water supply in the Darjiling town, but for aggravating the problem, it is man himself who is to be blamed.

Depletion of forests and the increase in average runoff (about 2180.86 mm at present) has helped in drying up of many local springs which used to supply water to local people. The situation has deteriorated further in recent years. Villagers have to walk a few kilometres in search of water during non-monsoon months and even the tourists living in moderate hotels have to pay five to ten for a bucket of water during peak tourist season in the month of May.

Conclusions

In view of the ever-increasing problems of landslides in Darjiling town, man must be made aware of the possible dangers that he is inviting due to his careless dealing with nature. It is true that one has to make room for the growing population and in this pursuit, he has to utilise every piece of land available. But the precautions that have to be adopted should not be neglected. In the town, the revetments are not maintained properly, the weep-holes are choked and the drains are dumped with garbage restricting free drainage of water. Moreover, the present land-use system should be properly evaluated. The construction of high rise buildings should be stopped immediately. The

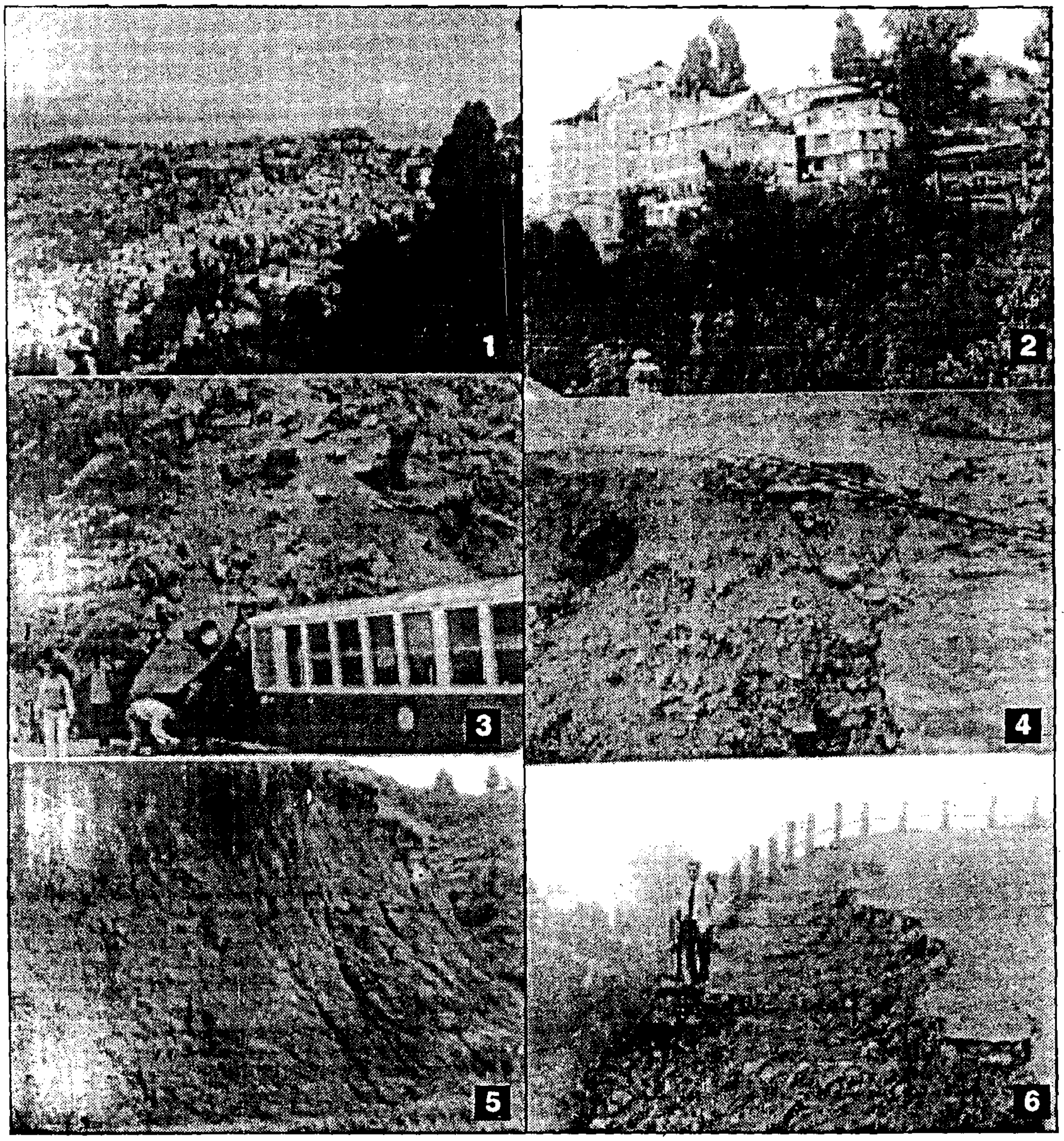

Fig. 7 The landscape and features of landslide around Darjiling
(1) A panoromic view of Darjeeling town, (2) High-rise buildings in around the heart of Darjiling town, (3) A landslide on the toy train, (4) Landslips dislodging the Darjeeling Railway line on the hill, (5) Landslide on Tonga Road, 6) Landslide on the road at the Viewpoint in the town.

people should be provided with some alternate sources of energy through construction of mini hydel power projects utilising the springs, which can be an option to prevent them from cutting down more trees. But above all, it should be of utmost priority to develop mass-awareness among both the local people and the tourists, so that they become aware of the possible dangers they are inviting by interfering with natural laws.

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R-MODE FACTOR ANALYSIS OF THE 2nd ORDER TDCN BASIN PROPERTIES : A CASE STUDY OF THE LODHAM KHOLA BASIN, EASTERN HIMALAYA

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Abstract

Factor analysis (FA) is a sophisticated statistical tool for any multivariate analysis in advance geomorphological research. It determines a set of descriptive ideas that summarise the relationships among the components of a system of interacting variables and thereby, helps to identify the common characteristics within the variables, which result in their inter-correlation and explains the differences in characteristics among them. Thus eigen values and eigen vectors are extracted and the structure of the variance-covariance matrix is properly interpreted. It is very useful particularly in the identification of the most diagnostic and significant variable that can best be used to characterise the multivariate system in general and to differentiate it from others. Many scientists conducted similar experiments on drainage basin morphometry in different parts of the world. With a data matrix of twelve morphometric variables of the eighteen 2nd order TDCN basins of the Lodham Khola in Darjeeling Himalaya this paper attempts a thorough discussion on the various issues and aspects of Factor Analysis.

Introduction

Structural configurations of a channel networks (CN) is topologically expressed either by the system of binary strings (Shreve, 1966; Liao and Scheidegger, 1968; Smart, 1969, 1978) or by the system of network codes (Sarkar, 1984, 1994). CNs may be topologically identical (TICN) or topologically distinct (TDCN) depending on whether the associated binary strings are identical or singular in occurrence. A higher order basin is essentially composed of a set of a lower order TICNs and TDCNs, each of which is attributed by its own characteristic set of morphometric properties (as controlled by the initial relief, river regimes and geological constraints) that collectively make up the final topographic texture of the area concerned.

Objectives

Lodham Khola is a 6th order right bank tributary of Rangbang river that joins the parent Tista river on its right bank (Fig. 1). Draining the eastern flank of the Singalila Range, the basin is bounded by two ridges : the Rimbik on the north and the Deorali on the south. It is more or less rectangular in shape tapering slightly toward northeast with the long axis oriented in the NE-SW direction. It contains eighteen 2nd order TDCN basins with, at least, twelve morphometric attributes of highly varying nature. The prime objective of this article is to : (i) study quantitatively the differences and similarities between and among the morphometric properties of the TDCNs and

(ii) identify the combination of the variables that best explains the variation within the morphometric properties of these basins.

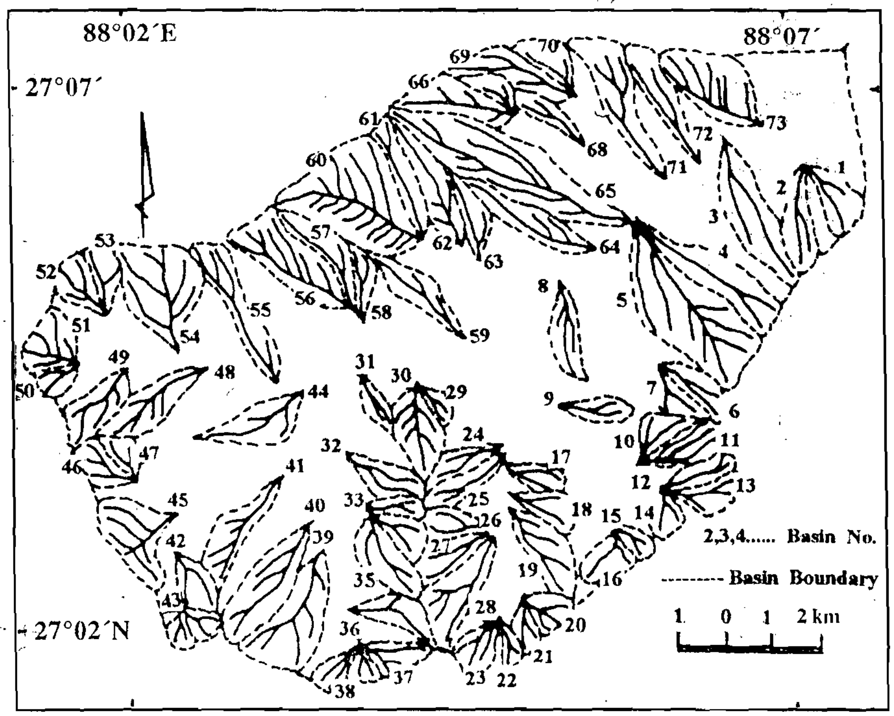

Fig. 1 : 2nd order TDCN basins of Lodham Khola network

Database

The network appears to be purely non-Hortonian and structurally irregular with a widely varying bifurcation ratio and dominance of adventitious channels (Table 1). Only eighteen of the seventy-four 2nd order basins have been identified as Topologically Distinct Channel Network or TDCN (Table 2).

Geologically, the area is a part of the Darjeeling Himalayas with the inner belt mainly consisting of the Dalings and Darjeeling gneiss with classical features of inverted metamorphism (Gansser, 1964). The underlying low grade metamorphosed Daling series consists of slates, phyllite and low grade schists with subordinate quartzites. The overlying Darjeeling gneiss dominantly consists of schists and gneiss of higher grade with subordinate quartzites and lenticular or isolated bodies of calcsillicate rocks. The schists and gneiss ultimately give way to a garnetiferous sillimanite gneiss / schist in the upper structural levels (Acharyya, 1970). The twelve basin properties of these 18 TDCNs derived from the Toposheet No. 78A / 4 (SOI, 1931, 1:63,360) apparently show a spectacular heterogeneity and form the data base for the present analysis (Table 3).

Table 1 : Network composition of the Lodham Khola Basin.

Order	No. of Links	Bifurcation Ratio(R_b)	Mean R_b
1	385		
2	74	5.18	
3	18	4.12	3.48
4	5	3.60	
5	2	2.50	
6	1	2.00	

Table 2 : Binary strings of the 2nd order TDCNs, Lodham Khola Basin.

Serial No	No. of Exterior link	Binary String	Serial No	No of Exterior Link	Binary String
1	2	011	10	5	010101011
2	3	00111	11	6	00100011111
3	3	01011	12	6	01000101111
4	4	0101011	13	6	001011111
5	4	0001111	14	7	0000010111111
6	4	0100111	15	7	0000001111111
7	5	01010111	16	8	010100010101111
8	5	001001111	17	8	000010100111111
9	5	000011111	18	15	01010101010100100100111111

Factor analysis

In factor analysis **(FA)**, the relationship within a set of **p** variables reflects the correlation of each of the variables with **k** mutually uncorrelated underlying factors: the usual assumption is that **k < p**. Variance in the **p** variables is therefore derived from variance in the **k** factors, but in addition a contribution is made by unique sources which independently affect the **p** original variables. The **k** underlying factors are common factors while the independent contributions are unique factor. The **FA** model is given by :

Table 3: Data Matrix of Morphometric Composition of the TDCN basins

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
2	1728	0.99	0.14	1.57	0.69	7.07	0.74	14.05	576	1.01	23.83
3	2110	1.54	0.19	2.10	0.98	8.11	0.68	18.35	900	0.41	23.33
3	1783	1.24	0.16	1.75	0.68	7.75	0.84	15.42	758	0.27	31.13
4	2275	2.05	0.24	2.40	0.98	8.54	0.79	18.82	1025	0.60	22.25
4	3350	2.66	0.38	2.90	1.37	7.00	0.75	22.93	2425	1.11	22.43
4	2817	2.09	0.28	2.87	1.22	7.46	0.67	17.74	1450	0.65	23.20
5	3850	1.97	0.26	2.50	1.09	7.58	0.73	18.88	1500	0.82	19.12
5	2650	2.49	0.47	3.00	1.13	5.29	0.84	15.03	1450	0.81	18.73
5	2425	2.25	0.29	2.40	1.15	7.76	0.66	15.60	1825	1.06	18.07
5	950	1.68	0.22	1.60	0.53	7.64	0.96	9.14	550	0.31	18.57
6	1350	2.35	0.28	2.40	0.50	8.39	1.52	16.16	200	0.38	5.70
6	2300	2.24	0.28	2.00	0.87	8.00	0.73	11.22	1000	0.42	24.27
6	2750	3.49	0.51	3.00	1.15	6.84	0.83	13.86	1950	0.84	23.73
7	3200	3.77	0.39	3.00	1.31	9.67	0.72	18.12	2200	0.94	23.90
7	2200	3.17	0.40	2.60	1.06	7.93	0.78	13.27	1200	0.68	18.48
8	5108	6.57	0.86	5.00	2.36	7.64	0.67	22.83	4200	1.92	22.50
8	4000	5.12	0.83	4.20	1.87	6.17	0.71	16.69	2700	1.38	20.33
15	2900	6.44	0.88	4.10	1.43	7.32	0.91	15.00	2000	1.04	20.02

$$\mathbf{X} = \mathbf{F}\Lambda + \mathbf{E} \quad \text{..................[Eqn. 1]}$$

where, **X** represents a **(n x p)** matrix, Λ is the "*factor loading matrix*" which, in geometrical terms, gives the co-ordinates of the points representing variables relative to the axes of a **k**-dimensional space, *i.e.*, a **(p x k)** matrix **F** is a "*factor score matrix*", which gives the co-ordinates of the observations in the **k**-dimensional space defined by Λ. The influence of the factors on the individual cases is expressed by the elements of **F**. **E** represents the "*residual matrix*" that expresses the effects of the specific factors affecting the variables together with measurement error.

The individual observations $\mathbf{X_{ij}}$ are thus seen to be the product of two matrices, Λ and **F**, plus the associated disturbance or residual terms:

$$\mathbf{X_{ij}} = \Sigma\lambda_{\mathbf{ir}} \cdot \mathbf{f_{ir}} + \mathbf{e_{ij}} \quad \text{......................[Eqn. 2]}$$

where, $\mathbf{r} = 1$ **to** $\mathbf{k}$, $\mathbf{f_{ir}}$ is the $\mathbf{r}^{th}$ common factor, $\mathbf{k}$ is the number of specified factors,λ_{ir} is the loading of the $\mathbf{i}^{th}$ variate on $\mathbf{r}^{th}$ factor, i.e., the loading on the principal components and $\mathbf{e_{ij}}$ is the random variation unique to the original variable $\mathbf{X_{ij}}$. The basic *assumptions* in the factor model are as follows.

i] $\mathbf{E (f_i) = E (e_i) = 0}$, ii] the $\mathbf{f_i}$ and $\mathbf{e_i}$ are independent, iii] the elements $\mathbf{e_{ij}}$ are independent of one another, iv] the variance - covariance matrix, ψ of the **e's** is diagonal and non-singular, v] Σ, the variance – co-variance matrix of the **X's** , has rank $\mathbf{k}$, vi] $\mathbf{k < p}$, and vii] each $\mathbf{X_i}$ is correlated with at least one other of the **X's**.

Although factor analysis may *reduce the dimensionality* of a problem to manageable size, the meaning of the factors may be difficult to derive as the positions of **p** orthogonal factor axes in **k** space are constrained by **m-p** unnecessary axes that must also be placed orthogonally through the sample space. These *extraneous orthogonal axes* can be *eliminated* through a variety of *rotational schemes*, of which Kaiser's *varimax* scheme is most popular. In this each factor axis is moved to positions so that projections from each variable onto the factor axes are either near the extremities or near the origin; the method operates by adjusting the factor loading so they are either near ± 1 or near zero. For each factor , there will be a few significantly high loading and many insignificant loading. Interpretation, in terms of original variables, is thus made easier. The fundamental postulate of **FA** can be given (*cf.* Anderson & Rubin,1956; Joreskog,1963) by:

$$\Sigma = \Lambda F \Lambda' + \psi^2 \quad \text{......................[Eqn. 3]}$$

where , Σ is the *variance-covariance matrix* derived from **X**. The off-diagonal elements of Σ can be reproduced from a knowledge of the factor loading Λ and the correlation between the factors, ϕ, since ψ^2 is a *diagonal matrix*. The elements of the diagonal of the Σ are the sum of two variances, i.e., one derived from or attributable to the common factors [or, $(\Lambda F \Lambda')_{ij}$] and the other of the residuals [or, $(\psi^2)_{ij}$]. The first part of the variance of a variable is the " *communality* " of the particular variable and the second is its *uniqueness*. Hence, *Eqn. 3* becomes :

$$\mathbf{R} = \Lambda F \Lambda' + Y^2 \quad \text{......................[Eqn. 4]}$$

and $\mathbf{R^* = R} - \psi^2$ is known as the matrix of " *reproduced correlation* ". If **k** is chosen correctly and if the factor model [*i.e., Eqn. 1*] holds, the " *residual correlation* " *given by the off-diagonal elements of* $\mathbf{R^+ = R - R^*}$ *should be randomly distributed about a mean of zero . Hence,* $\mathbf{R^*}$ *(or* Σ^**) is of rank* k , *that is, it has exactly* k *non-zero eigenvalues.*

Analysis of the results

Descriptive measures: Lodham Khola basin contains eighteen 2nd order TDCN basins with apparently highly varying morphometric characteristics. To measure the morphological and morphometric characteristics of these , twelve variables have been chosen for the present analysis; of these, four are *morphologic*, i.e., X_1 (*number of* *exterior link*), X_3 (*drainage length*), X_7 (*drainage density*) and X_{11} (*link length*) and the remaining eight, i.e., X_2 (*basin relief*), X_4 (*basin area*), X_5 (*basin perimeter*), X_6 (*maximum basin length*), X_8 (*elongation ratio*), X_9 (*lemniscate ratio*), X_{10} (*link relief*) and X_{12} (*link slope*) are *morphometric* in nature.

The statistical description of the distribution of these for the eighteen TDCN basins (Table 4) shows that: i) the SE. of mean is lowest for X_8 and highest for X_2; ii) the magnitude of standard deviation is in all cases smaller than that of the mean; iii) in general, variability is lowest for X_7 and highest for X_{10}; iv) normally the standard deviation increases with an increasing value of the mean; the existing linear relation has been evaluated as :

$$\sigma = 10.31867 + 0.43476\,x \quad [r = +0.96,\ n = 12]$$

Table 4 : Descriptive statistics of the 18 TDCN basins

Variable	Name	Mean	SE. Mean	Std Dev	Variance	Coeff Variation (%)
X_1	No of Exterior Link	5.72	0.68	2.87	8.21	50.17
X_2	Basin Relief(ft)	2652.56	236.99	1005.47	1010979.91	37.91
X_3	Drainage Length(miles)	2.91	0.39	1.64	2.68	56.55
X_4	Basin Area (sq. miles)	0.39	0.06	0.24	0.06	61.54
X_5	Basin Perimeter(miles)	2.74	0.22	0.92	0.84	33.57
X_6	Max. Basin Length(miles)	1.13	0.11	0.46	0.21	40.71
X_7	Drainage Density (miles/sq mile)	7.56	0.22	0.94	0.89	12.43
X_8	Elongation Ratio	0.81	0.05	0.21	0.04	24.69
X_9	Lemniscate Ratio	16.28	0.83	3.52	12.42	21.62
X_{10}	Link Relief(ft)	1550.51	225.17	955.34	912665.32	61.61
X_{11}	Link Length(miles)	0.81	0.11	0.42	0.17	51.85
X_{12}	Link Slope(degrees)	21.09	1.17	4.96	24.61	23.52

The correlation matrix : The *degree* of correlation varies considerably between one pair of variables to another (Table 5). As expected the *elongation ratio* (X_8) is found to be negatively related with the remaining variables and with the set of {X_2, X_6, X_{10}, X_{12}}, it emerged significant. Significantly positive relation has been found between *maximum basin length* (X_6) and {X_1, X_2, X_3, X_4, X_5, X_9, X_{10}, X_{11}, X_{12}}, *link relief* (X_{10}) and {X_1, X_2, X_3, X_4, X_5, X_6, X_9, X_{11}}, *basin relief* (X_2) and {X_3, X_4, X_5, X_6, X_9, X_{10}, X_{11}}, *basin perimeter* (X_5) and {X_1, X_2, X_3, X_4, X_6, X_9, X_{10}, X_{11}}, *drainage length* (X3) and { X_1, X_2, X_4, X_5, X_6, X_{10} , X_{11}}. *basin area*(X_4) and {X_1, X_2, X_3, X_5, X_6, X_{10} , X_{11}}, *link length*(X_{11}) and { X_2, X_3, X_4, X_5, X_6, X_9, X_{10}} , *no. of exterior link* (X_1) and {X_3, X_4, X_5, X_6, X_9, X_{10}} and between *lemniscate ratio* (X_9) and {X_2, X_5, X_6, X_{10} , X_{11}}. *Drainage density* (X_7) and *link slope* (X_{12}) transpired to be the least significant variables determining the morphological and morphometric characteristics of the TDCN basins.

Table 5 : Correlation coefficient matrix

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.00											
X_2	0.36	1.00										
X_3	0.86	0.69	1.00									
X_4	0.82	0.69	0.97	1.00								
X_5	0.69	0.83	0.94	0.95	1.00							
X_6	0.48	0.93	0.82	0.83	0.93	1.00						
X_7	-0.02	-0.18	-0.11	-0.34	-0.24	-0.22	1.00					
X_8	0.14	-0.49	-0.07	-0.09	-0.16	-0.48	0.11	1.00				
X_9	-0.05	0.69	0.29	0.24	0.50	0.60	0.09	-0.24	1.00			
X_{10}	0.44	0.92	0.79	0.78	0.88	0.97	-0.17	-0.46	0.59	1.00		
X_{11}	0.39	0.84	0.73	0.74	0.81	0.89	-0.27	-0.39	0.55	0.91	1.00	
X_{12}	-0.22	0.18	-0.07	-0.08	-0.07	0.16	-0.01	-0.72	0.08	0.19	0.04	1.00

The factors: The *factor values* are related to the degree of intercorrelation of the variables. In cases of smaller correlation coefficients, *factors* are smaller and the values more equal on each successive factor; it implies that the *axes* are shorter and the *hyper-ellipsoid* tends more towards a *hyper-spherical* form. In the present analysis high correlation are many; hence only a few fundamental variables can be used to characterise the whole basin. Basically the greater the homogeneity of the TDCN basins in terms of relief and drainage, the less the factors can hope to expose by way of variation. The initial and final statistics (Table: 6) show that: i) four factors have been extracted by the PCA, that together accounted for the 93.9% of the total variation; these are: *Factor 1* (58.0%), *Factor 2* (18.4%), *Factor 3* (9.6%) and *Factor 4* (7.9%) respectively, and ii) the *eigen values* of the first *three* factors are larger than 1.00

Table 6 : Initial and final statistics: Principal component analysis

Variable	Initial Communality	Factor	Eigenvalue	% Varn.	Cum %	Final Communality
X_1	1.00	1.00	6.95958	58.00	58.00	.94497
X_2	1.00	2.00	2.20544	18.40	76.40	.92167
X_3	1.00	3.00	1.15294	9.60	86.00	.99198
X_4	1.00	4.00	0.95228	7.90	93.90	.98671
X_5	1.00	5.00	0.31727	2.60	96.60	.97281
X_6	1.00	6.00	0.17618	1.50	98.00	.98050
X_7	1.00	7.00	0.10793	0.90	98.90	.97976
X_8	1.00	8.00	0.07908	0.70	99.60	.89258
X_9	1.00	9.00	0.03696	0.30	99.90	.90671
X_{10}	1.00	10.00	0.00837	0.10	100.00	.95187
X_{11}	1.00	11.00	0.00247	0.00	100.00	.85748
X_{12}	1.00	12.00	0.00150	0.00	100.00	.88318

Factor loadings : The individual factors are related to the character of the variables (Table 7). The loading on the different variable give and insight about the role the variables play in accounting for the variation within the area. Significantly *high and positive* loading on $\{F_1\}$ of $\{X_6, X_5, X_{10}, X_2, X_4, X_3, X_{11}, X_1, X_9\}$, on $\{F_2\}$ of $\{X_8, X_1\}$, on $\{F_3\}$ of $\{X_7, X_9\}$ and on $\{F_4\}$ of $\{X_7\}$ respectively have been found. The loading on $\{F_2\}$ of $\{X_{12}\}$ have only been found to be significantly *high and negative*. VARIMAX converged in 8 iterations. After VARIMAX rotation - Kaiser normalisation, loading on $\{F_1\}$ of $\{X_1, X_3, X_4, X_5, X_6, X_{10}, X_{11}\}$, on $\{F_2\}$ of $\{X_9, X_2, X_{10}, X_{11}, X_6, X_5\}$, on $\{F_3\}$ of $\{X_{12}\}$ and on $\{F_4\}$ of $\{X_7\}$ emerged significantly large and positive; only loading of $\{F_3\}$ on $\{X_8\}$ emerged as significantly large and negative.

Classification : The individual factor weighting of the 18 *2nd order TDCN basins* are of utmost importance as they characterise the TDCN basins in terms of the first and second factors. It may be taken as an important index for identifying the degree of *homogeneity/heterogeneity* of the TDCN basins in terms of drainage and relief characteristics (Table 8 and Table 9).

Table 7 : Factor Loading Matrix - Unrotated and Rotated

	F_1	F_2	F_3	F_4	Rotated F_1	Rotated F_2	Rotated F_3	Rotated F_4
X_1	0.61	0.62	-0.13	0.41	0.95	-0.06	-0.15	0.07
X_2	0.91	-0.25	0.13	-0.09	0.47	0.79	0.26	-0.12
X_3	0.91	0.36	-0.03	0.22	0.93	0.34	-0.01	-0.02
X_4	0.91	0.35	-0.21	0.06	0.91	0.32	-0.02	-0.25
X_5	0.96	0.19	0.02	-0.03	0.78	0.58	-0.02	-0.15
X_6	0.98	-0.15	0.03	-0.02	0.62	0.71	0.26	-0.14
X_7	-0.24	-0.01	0.72	0.63	-0.08	-0.02	-0.03	0.99
X_8	-0.36	0.81	0.26	-0.21	0.00	-0.31	-0.89	0.11
X_9	0.55	-0.37	0.62	-0.29	-0.04	0.94	0.01	0.15
X_{10}	0.96	-0.18	0.06	0.00	0.59	0.72	0.28	-0.11
X_{11}	0.91	-0.11	0.02	-0.18	0.52	0.71	0.15	-0.25
X_{12}	0.08	-0.77	-0.31	0.41	-0.08	0.00	0.93	0.04

Thus, although the TDCN basins are all of identical Strahler order, their network configuration along with the morphologic and morphometric attributes varies significantly, which can be explained successfully by the loading on *factor-1* by the variables - max. basin length, basin perimeter, link relief, basin relief, basin area, drainage length and link length in case of *unrotated* analysis while by the set of variables - no. of exterior link, drainage length, basin area and basin perimeter in case of *rotated* analysis. The actor score *plots of* F_1 *and* F_2 also conform the fact that the concept of morphologic and morphometric distinctiveness of the TDCN basins of a given channel order can not have a sound geomorphic footing; in other words, TDCN basins vary in drainage and relief characteristics (Fig. 2). However, on the basis of first factor, at least seven to eight different classes of TDCN basins (each with a significant degree of homogeneity) have been identified with the highest statistical precision.

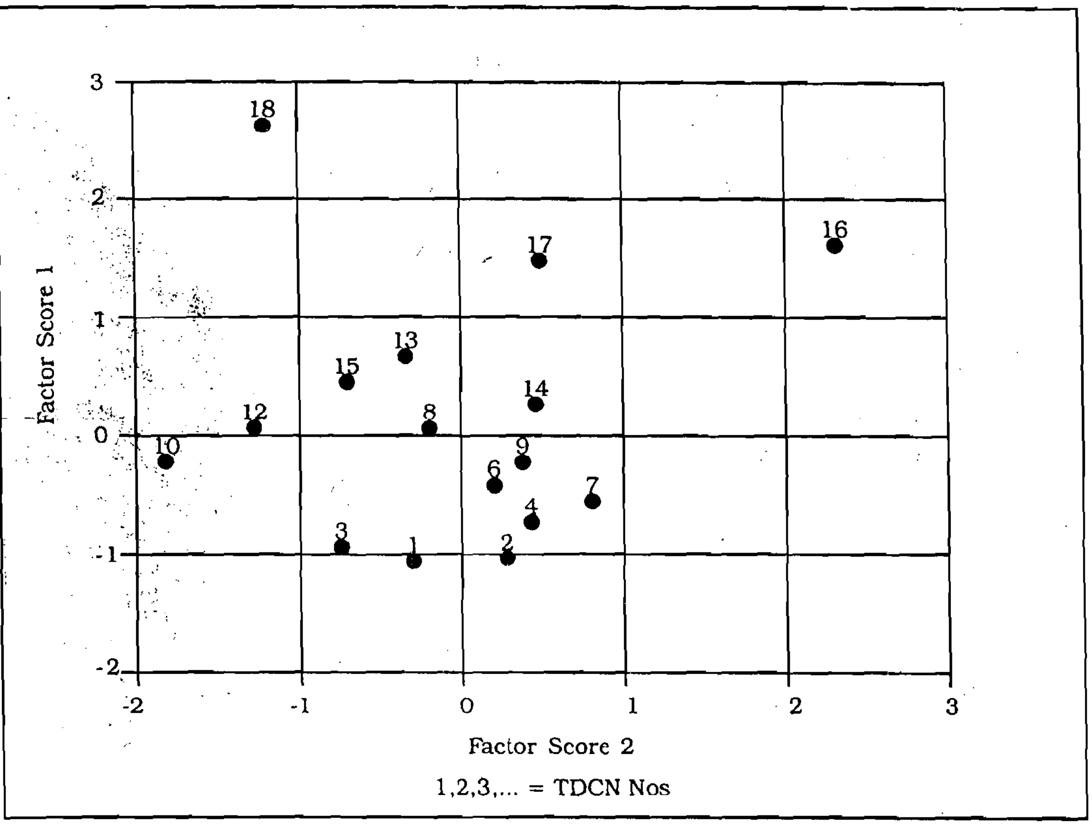

Fig. 2 Plots of rotated factor scores

Table 8 : Morphologic - morphometric Groups of TDCNs of the Lodham Khola

Range of Factor Scores	TDCNs based on F1	TDCNs based on F2	TDCNs based on Rotated F1	TDCNs based on Rotated F2
1.00 and above	16,17,18	11,18	18,16,17	16,5
0.60 to 1.00	5.00	10.00	-	7.00
0.30 to 0.60	14.00	15,17	14,13,15	17,14,6,4
0 to 0.30	13,8,7	8,13	12.00	9,2
-0.30 to 0	9,6,15	12,9	10,8	11,8
-0.60 to -0.30	4.00	16,14,4,7	9,11,7,6	1,13
-1.00 to -0.60	12,2,1	6,1,2,5,3	4,5,3	15,3,18
less than -1.00	3,11,10	-	2,1	12,10

Table 9: Factor Scores Matrix - Unrotated and Rotated

TDCN No	F_1	F_2	F_3	F_4	Rotated F_1	Rotated F_2	Rotated F_3	Rotated F_4
1	-0.93	-0.82	-0.73	-0.66	-1.19	0.42	0.47	-0.82
2	-0.67	-0.91	0.55	0.16	-1.01	0.12	0.46	0.62
3	-1.04	-0.99	-0.43	0.74	-0.85	-0.85	1.11	0.36
4	-0.46	-0.49	1.05	0.32	-0.68	0.31	0.04	1.05
5	0.52	-0.92	0.73	-1.31	-0.79	1.59	-0.06	-0.44
6	-0.09	-0.79	0.06	-0.21	-0.56	0.34	0.48	-0.08
7	0.01	-0.53	0.69	-0.69	-0.71	0.84	-0.16	0.03
8	0.05	0.28	-1.56	-1.81	-0.24	0.12	-0.45	-2.41
9	-0.08	-0.29	0.14	-0.21	-0.33	0.21	0.07	-0.03
10	-1.31	0.82	-0.87	0.42	-0.17	-1.77	-0.33	-0.13
11	-1.11	2.69	1.98	-1.25	-0.41	-0.11	-3.64	0.75
12	-0.65	-0.14	-0.77	1.27	0.15	-1.31	0.88	0.41
13	0.21	0.12	-1.04	0.03	0.46	-0.47	0.37	-0.75
14	0.39	-0.39	1.49	1.84	0.52	0.43	0.62	2.25
15	-0.21	0.53	-0.24	0.66	0.44	-0.73	-0.05	0.31
16	2.56	-0.37	0.91	-0.13	1.42	2.33	0.31	0.14
17	1.54	0.31	-1.07	-0.67	1.24	0.58	0.13	-1.47
18	1.25	1.92	-0.86	1.55	2.71	-0.98	-0.26	0.22

Conclusions

The analysis, *ut supra*, systematically emphasised on the various aspects of factor analysis. The means and standard deviations provide the most useful preliminary description of the TDCN basins in terms of the variables used. The correlation matrix provides the data on which the values of the factors and factor loading are based. The factors indicate the degree to which any TDCN basin can be expressed in terms of the inter-relations between the variables. Where these inter-correlate strongly the factors are greater and the variation is explained to a greater degree on the first factor. The factor loading provides a valuable indication of the part each variable plays in accounting for the total variability. The individual factor weighting, provide the means to establish the nature of the difference between the TDCN basins in quantitative terms. In the case of greater homogeneity of the TDCN basins the individual factor weighting for each basin separately have less value.

Hence, it transpires from the foregoing analysis that the 18 2nd order TDCN basins of the Lodham Khola are very different in their characteristics. Max. basin length, basin perimeter, link relief, basin relief, basin area, drainage length and link length emerged as the most significant variables that together explains and accounts for the apparent variations in basin morphology and morphometry. However after varimax rotation (varimax converged in 8 iterations) and Kaiser normalisation, no. of exterior links, drainage length, basin area and basin perimeter emerged as the most important variables which, as a whole, show highest inter-correlations in the Lodham Khola basin.

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STRUCTURAL CONTROLS ON THE REGIONAL GEOMORPHOLOGY OF ORISSA

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Abstract

The regional geomorphology of Orissa is characterised by a NNE–SSW trending central highland representing a horst flanked on either side by graben-like feature; e.g. the low-lying coastal graben on the east and the West Orissa graben to its west. These are subsequently cut across by the Mahanadi graben separating the northern highland from the southern highland. The intersection of the Mahanadi graben with the coastal graben has given rise to the development of Mahanadi-Brahmani compound delta. The formation of grabens and horsts are results of crustal movements along major faults.

Introduction

The development of various types of topographic features on the earth's surface is strongly controlled by the lithologic composition of the ground (e.g. hard rock, soft rock, unconsolidated sediments), tectonic features developed in the rocks (e.g. folding, faulting, igneous intrusion etc.) and activity of geological agents (e.g. river, wind, sea, glacier etc.) acting over a period of geological time. Resistant rocks show positive features while weak formations wear out easily and form negative features. Tectonic elements in rocks give shape to topographic features. Here the regional topographic features of Orissa, Eastern India, are discussed, showing their lithologic and structural controls. Detailed accounts of geomorphology, structure and lithology of Orissa are given elsewhere by Mahalik (1984, 1996, *in press* a & b) and Mahalik *et al.*, (1996).

Satellite image in the study of geomorphology

Satellite images present synoptic overview of large areas on the earth surface and are useful in delineating regional earth surface features such as geomorphology, drainage, water bodies, forest cover etc. These are very useful for morphological studies. A mosaic of images of a particular region gives a clear impression of the geomorphology of the area.

A mosaic of the false colour composite (FCC) images of Orissa, published by the US National Academy of Sciences (1977) was interpreted for the geomorphology. It was clearly observed that a NNE–SSW trending central highland, mostly forest covered, is flanked by intermediate uplands and peneplains on both sides and a low-lying coastal plain on the east (Fig. 1). Two major rivers, Mahanadi on the south and Brahmani on the north were seen cutting across these topographic features and making a compound delta at the coastal plain. They divide the central highland into three sectors: the northern highland, the central river basin and the southern highland. The central river basin is

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known as the Mahanadi graben or Mahanadi rift in which coal bearing Gondwana rocks were deposited. It is now believed that the Mahanadi graben of Orissa was continuous with the Lambert rift of East Antarctica, which later separated due to continental drifting (Hofmann, 1996).

The central axial highland varies in height from 600 m upwards to 1,300 m above mean sea level and has many plateau surfaces, such as the Similipal, Keonjhar, Phulbani and Koraput plateaus (Fig. 2). The altitude of the western uplands varies from 300 m to 600 m and consists of the peneplains of Ib, Mahanadi, Tel and Indravati rivers in the districts of Sambalpur, Bargarh, Bolangir, Kalahandi and Koraput. The eastern upland varies in height from 20 m to 150 m and consists of undulating uplands and flat lateritised peneplains. The coastal plains rise maximum up to 20 m above sea level.

Geology and structure of orissa

Lithologically, the central highland consists of rocks of Iron Ore Group in the north

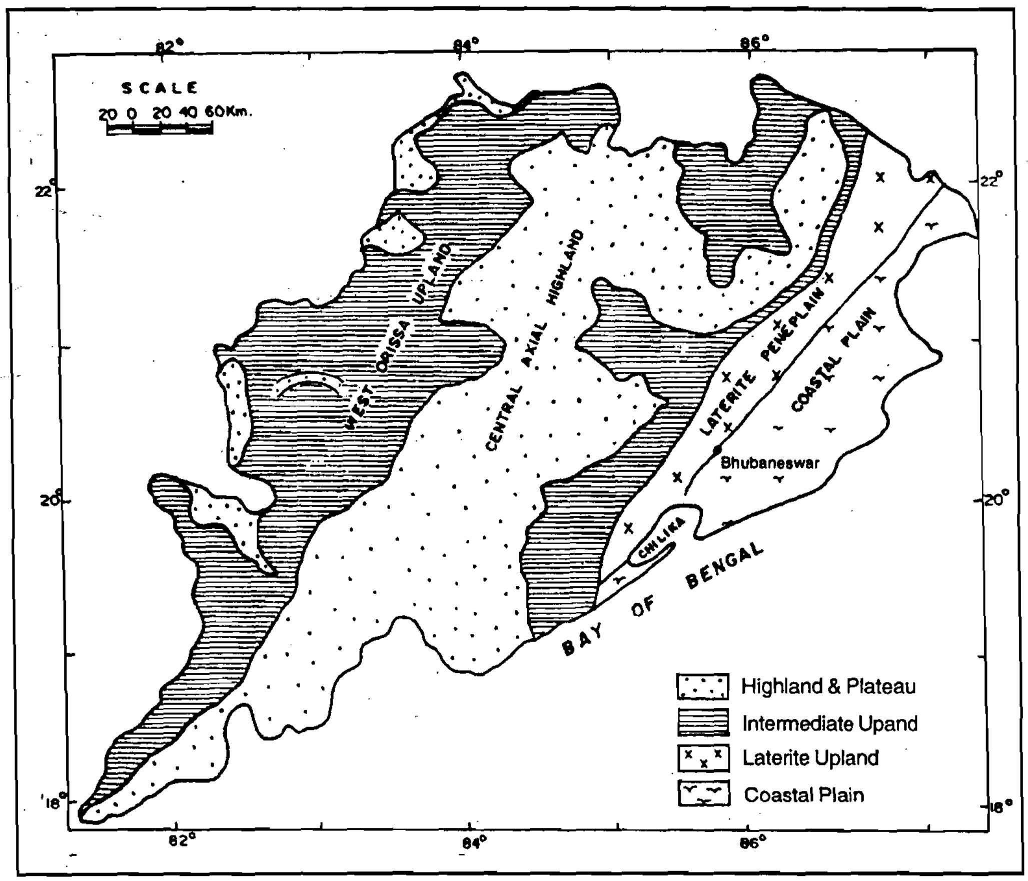

Fig. 1 : Major geomorphic divisions of Orissa

(banded hematites, quartzites, basic volcanics etc.), Gondwana group of sedimentary rocks in the Mahanadi-Brahmani river valleys in the centre and Eastern Ghat Group of rocks in the south (khondalites, charnockites etc.). To the west of the highland lie the granite peneplains in the river basins of Ib, Mahanadi, Tel and Indravati. Immediately to the east of the highland is the low-level lateritised upland made up of diverse rocks from north to south. Extensive laterite peneplains occur around Bhubaneswar, Khurda, Sukinda and Dhenkanal. These lateritised peneplains are bordered by flat coastal alluvium to the east (Fig. 1).

More important than the lithologic setup is the structural fabric of Orissa, which has controlled the regional geomorphology. Fig. 3 shows the structural and tectonic features including the major faults. On the west lie the Eastern Ghat Boundary Fault (EGBF) and the Ib-Mahanadi shear, which form the western boundary of the central highland. These two faults run south to north from the southern tip of Orissa to the northern boundary. On the east are the coastal lineament and Kamakhyanagar-Nilgiri faults. They form the eastern margin of the central axial highland. Another group of

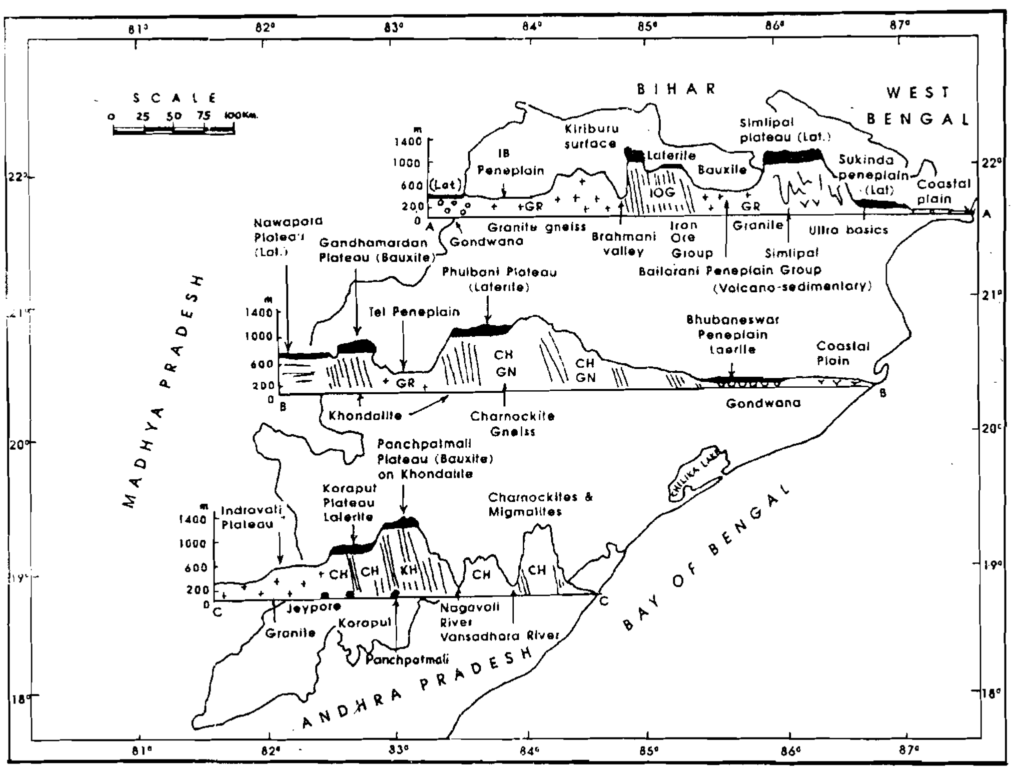

Fig. 2 : Selected topographic profiles of Orissa

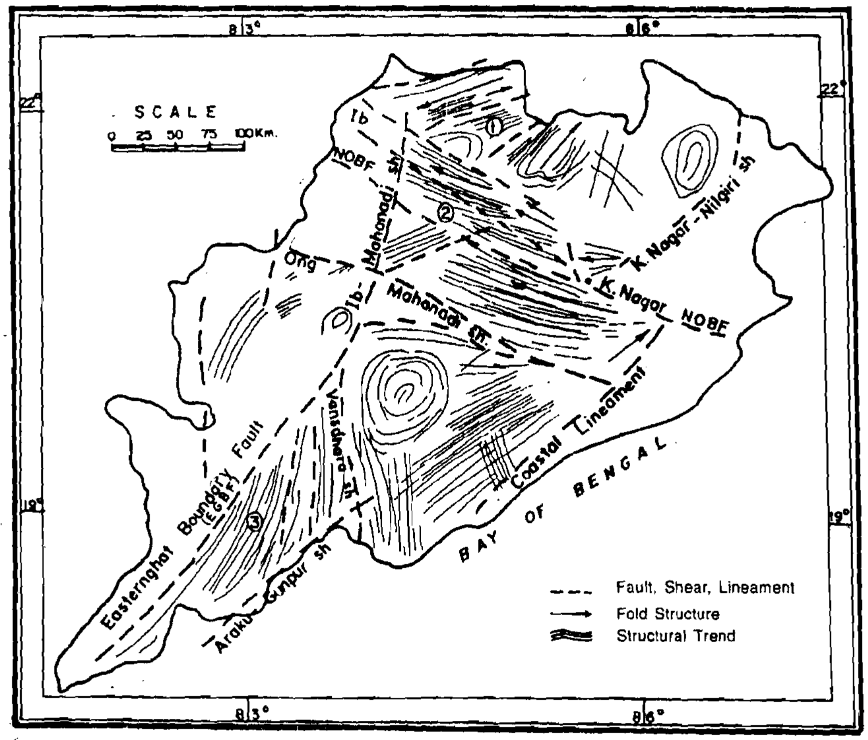

Fig. 3 : Structural features of Orissa. 1 : North Orissa (NE-SW features), 2 : Central Orissa (ESE-WNW features), 3 : South Orissa (NE-SW and NW-SE features)

ESE–WNW trending faults designated as Mahanadi-Ong shear, North Orissa Boundary Fault (NOBF) and Ib-Kamakhyanagar shear, cuts across these faults and shears. The Brahmani and Mahanadi rivers flow along these faults and shear zones. Disparity in lithology across the faults is responsible for topographic variation on either side of them. Vertical movements along the faults also have caused rise and fall of ground on either side.

Formation of horsts and grabens

The NNE–SSW oriented highlands, upland peneplains and coastal plains are now believed to be the result of vertical reactivation movements along major faults and shears such as the EGBF, Ib-Mahandi shear, coastal lineament and Kamakhyanagar-Nilgiri shear. These movements have given rise to the Eastern Ghat horst in the centre flanked by the western Orissa and coastal grabens (Fig. 4). Similarly, vertical movements along the Mahanadi-Ong shear and NOBF have given rise to Mahanadi graben cutting across the horsts and grabens formed earlier. Significantly, the intersection of Mahanadi graben with coastal graben has been the site of extensive delta development. The Mahanadi-Brahmani compound delta has formed along this intersection.

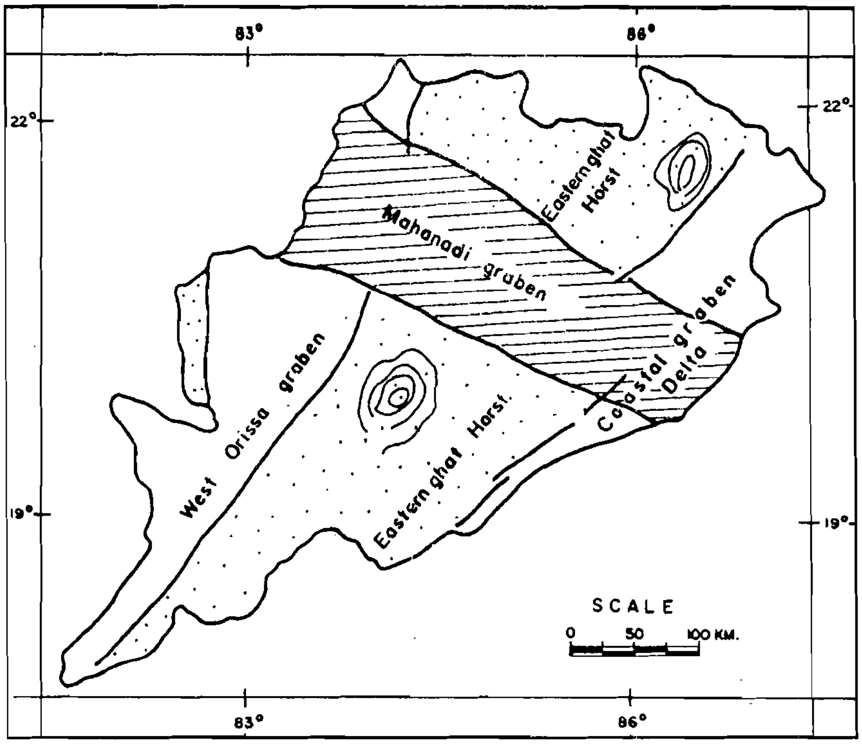

Fig. 4 : Horst and graben structures of Orissa

Conclusions

It is observed that the broad regional topographic features of Orissa are structure-controlled. The horsts and grabens are formed by vertical movements along some major faults. The major features identified are a central highland of the nature of a horst flanked on either side by west Orissa graben and coastal graben. These are cut across by Mahanadi graben that has given rise to a northern and a southern highland with a major river basin in between. Mahanadi-Brahmani compound delta is formed at the intersection of the Mahanadi and coastal grabens.

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CADASTRAL MAP OVERLAYING UPON IRS-1C HYBRID IMAGE : A CRITICAL ANALYSIS

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Abstract

Cadastral maps, showing plots of land for each village, town or city, with position, boundaries, survey numbers and ownership, are utilised as base for tax evaluation, legal rights determination and landuse mapping at micro-level. Today both ground survey methods and the aerial photogrammetric methods are utilised for cadastral level surveys. Development of satellite based imaging technique has opened new possibilities for large-scale map making. It has been noticed in several instances that cadastral maps have been overlaid upon medium spatial resolution satellite images. Such overlay can be utilised for developmental planning at micro-level, such as at village level. A methodology has been developed here to obtain such overlay upon relatively high spatial resolution images. The geometric accuracy of such overlay was found to be satisfactory. The utility of it has been critically analysed.

Introduction

Cadastral maps are very important tools for environmental studies at micro level. These maps demonstrate the plots of land for each village, town or city with their position, boundaries and survey numbers, and are utilised for a number of purposes including tax evaluation, legal rights, landuse, quality of soil, availability of irrigation and others. In India these survey works are conducted by the State Governments within revenue villages, towns or cities. The accuracy aimed at in cadastral surveys is that the areas of plots determined from the map should not be more than one per cent in error. Keeping this in mind and taking cognizance of economic value of the land, size and shape of individual plots, nature of crops and economic use of land, different scales adopted for cadastral mapping in the country are 1:4,000 to 1:10,000 for villages with plots and holdings consisting of cultivated lands and 1:500 to 1:1,000 for towns and cities. In order to meet the desired accuracy on 1:5,000 the minimum mappable size of a plot should be 1.25 m × 1.25 m. This is because the minimum possible error in measurement on 1:5,000 – 0.25 mm – translates into an error of (1.25 × 1.25) m^2 in actual area.

Cadastral mapping through ground survey and remote sensing

Conventional methods, used in cadastral mapping, are ground survey methods using sophisticated instruments, like Transit Theodolites, Electromagnetic Distance Measurement (EDM) instruments and, more recently, the Global Positioning System

(GPS). The advancement of modern technology has now introduced the aerial photographs as the official base for the land registration system. In this system the basic criteria is that, the property lines or points should appear in the photographs and should be recognisable with the naked eye. To achieve this, the spatial resolution of the photograph should be at least 20~50 cm for rural areas and 2.5~5.0 cm for the urban areas. This is easily achieved by modern generation aerial photography. The advent of satellite imaging technique with improved spatial resolution has made inroads into the map-making domain. The SPOT satellite data with 10 m resolution and the Indian Remote Sensing Satellite IRS-1C/1D data with 5.8 m resolution in panchromatic band have opened a new era in topographic mapping on 1:50,000 or 1:25,000 scales. Future satellites, scheduled to be launched from a number of countries including India, are planned to provide data with much finer spatial resolution of even less than one metre. Therefore, there is a high expectation of the cartographic community to utilise these data for large-scale mapping. However, it is not clear whether the community can expect to avail the data for cadastral mapping— which needs at least 25 cm of spatial resolution—in near future. Considering the pace of improvement in spatial resolution of remote sensing satellites, the community is optimistic for the availability of such data by the beginning of the 21st century.

A national level project entitled Integrated Mission for Sustainable Development (IMSD) has been initiated by the Ministry of Rural Development, Government of India, since 1987 and is being carried out by the Department of Space (DOS). This project aims at optimum utilisation of natural resources by using satellite-based information, such as the IRS LISS II data. In this programme, the final goal is to prepare an action plan for optimum landuse on the basis of integration of a number of thematic maps and satellite images at block level using Geographic Information System (GIS) techniques (Das *et al.*, 1997). Also, a few derivative maps, e.g. water utilisation plans, are proposed to be prepared. If the cadastral maps are overlaid on the maps produced by the IMSD projects, they help in identifying the plots and their owners where implementation of the action plan is proposed (Rao *et al*, 1996). Though it appears unrealistic to overlay the micro-level details of a 1:4,000 cadastral map an 1:50,000 map (some of which are generated from coarse 36 m resolution data), with some minor errors it has been successfully achieved by some users on image data as on well as action plan maps. It has been of great help in implementing the action plan in small watersheds covering about 4~5 villages. Here the plots and their owners can easily be identified where some action, like construction of gully control structures, is proposed. With experience from this, the user community, particularly the block development officials, is now demanding such overlays over the satellite images. The increased spatial resolution of IRS-PAN data can help to improve the quality of such overlay. Further, the panchromatic data of 5.8 m can be fused with the simultaneously acquired IRS-LISS III data of 23 m spatial resolution in multispectral mode, to obtain a hybrid image in a False Colour Composite mode. This integration further enhances the image quality. Under this background the present study is designed to find a methodology for overlaying cadastral maps on IRS-1C hybrid fused images and to critically analyse its utility.

Plate 1 : Kharagpur IIT Campus, as viewed by IRS-IC (LISS III + PAN)

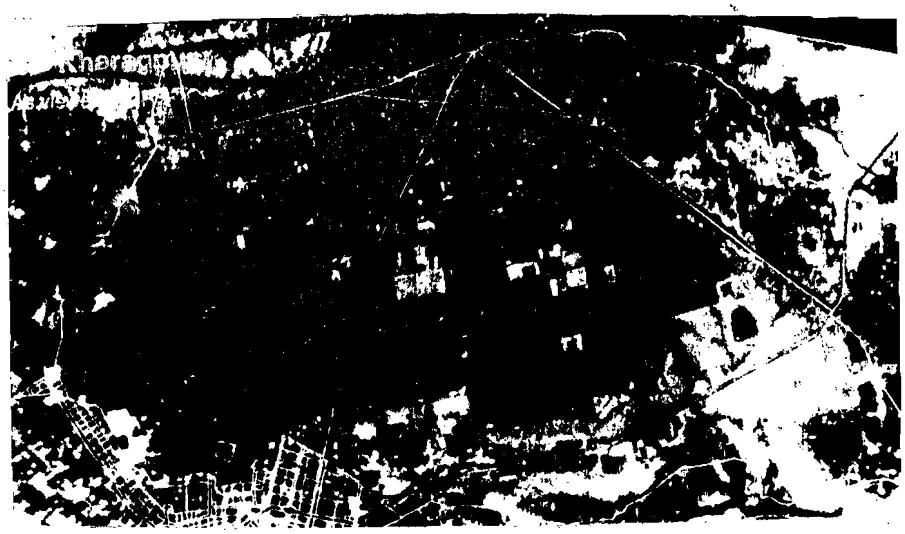

Plate 2 : Cadastral Map overlaid on IRS-IC (LISS III + PAN) merged data

Materials and methods

Materials used : The Indian Institute of Technology (IIT) Campus, Kharagpur, was selected as the study area. This is a semi-urban area portraying a large number of ground features. Three classes of data and materials were used These include: (i) A 1937 cadastral map on 1:4,000 scale of Kharagpur IIT Campus. This was the latest version available. (ii) IRS-1C LISS III data of Path-Row 107-56. The Date of Pass was February, 1996. LISS III has a spatial resolution of 23 m. (3) IRS-1C PAN data of same Path-Row and same Date. PAN has a spatial resolution of 5.8 m.

Creation of Digital Cadastral Maps : The cadastral map was scanned using a Contex FSS 8000 scanner at 50 dots per inch (~20 dots per cm). The resulting digital cadastral map therefore possessed a 2-m spatial resolution. This was compressed to provide a workable digital cadastral map with 4 m of spatial resolution in order to provide an optimum base for study of 5.8-m resolution PAN data.

Geometric Registration of IRS-1C PAN Data : Conventionally, the raw satellite images are rectified with respect to Survey of India topographic maps on 1:50,000 scale. Subsequently the Digital Cadastral Maps (DCMs) are geometrically registered with respect to the already rectified satellite images. In this study a different approach was followed. The IRS-1C PAN digital data was geometrically registered with respect to DCM of 4 m resolution. This was done using some well identifiable ground objects appearing on the image data as well as on the digital map. About eight such points, called Ground Control Points (GCPs), were used for the purpose with a second-degree polynomial transformation model. The residual error in this is less than one pixel level (Table 1). It may be mentioned here that, in the present study only a few GCPs could be used since the cadastral map was quite dated.

Generation of Hybrid Image : The LISS III multispectral data of 23 m resolution was geometrically registered with respect to the already rectified panchromatic data with 4 m resolution. The three multispectral bands with Red, Green and Blue (RGB)

Table 1: Residual errors at various Pixel levels

Serial No.	Pixel No.	Line No.	Rectified Pixel No.	Rectified Line No.	Residual Error
1	788	223	553	212	0.59
2	812	416	546	331	0.43
3	375	49	321	57	0.39
4	372	502	269	334	0.47
5	457	239	350	185	0.24
6	42	72	114	35	0.28
7	81	444	97	267	0.33
8	806	100	577	137	0.23

RMSE Error = 0.39 pixels ~ 1.56 m; Maximum Error = 0.29 pixels ~ 2.4 m components were converted to Intensity, Hue and Saturation (HIS) components. The Intensity component from this was replaced by the Intensity component of the panchromatic data. The new HIS component was again converted back to the RGB component from which a False Colour Composite (FCC) was generated. This output contains the sharpness of the panchromatic data with enhanced colours. This product is considered as a hybrid, merged or fused product (Das, 1997).

Overlay of Digital Cadastral Map : The details of the cadastral map were digitised to obtain a vector output. This was overlaid on the panchromatic data as well as merged (fused) image.

Results and conclusions

The LISS-III + PAN merged product, resulting from the study, is shown in Plate 1. The cadastral overlay on the fused data is presented in Plate 2.

From the study it has been observed that overlaying of cadastral map is very helpful for environmental planning. But unfortunately most of the significant cadastral details, such as land parcels, cannot be recognised satisfactorily on a PAN data. At a few places contrast between two adjacent fields influences the image formation and two fields appear separately on the image data. However, this cannot be ensured in all terrain conditions. Further, considering the spatial resolution of data, the delineation of boundaries from this is not likely to meet the stringent accuracy requirements of cadastral mapping. Therefore updating of cadastral maps on the basis of the overlay is undesirable. The few prominent features, such as railway tracks, roads, tanks, ponds etc., identifiable on the image data as well as on the cadastral map, can be utilised as reference points in establishing an overlay. At some places it may be difficult to find such details making the process of overlaying difficult. However, once overlaying becomes possible, the overlay of ground plots on the image data or deduced maps are reliable to a large extent. The merged FCC of LISS-III + PAN exhibits superior quality for interpretation and can be employed for landuse mapping at micro-level such as cadastral level.

The geometric accuracy from such registration is a pointer towards the high geometric quality of PAN data. Usually, the control points for such registration are taken from topographic maps on 1:50,000 scale having an accuracy of 15~25 m which is compatible with the spatial resolution of LISS III (23 m). Therefore, a mosaic digital cadastral map of the villages constituting a micro-watershed where implementation of an action plan is proposed, can be utilised for geometric rectification of IRS-1C PAN data or merged data of PAN with LISS III. Large scale FCCs on 1:12,500 can then be generated with cadastral overlays for such micro watersheds.

Acknowledgments

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Short Communications

AGROBIODIVERSITY AND DROUGHT RESISTANT AGRICULTURAL PRACTICES AMONG THE TRIBAL PEOPLE OF JASHIPUR IN MAYURBHANJ DISTRICT OF ORISSA

Introduction : An attempt has been made here to explore the main features of agrobiodiversity and drought-resistant agricultural practices among the tribal people of Jashipur in Mayurbhanj district of Orissa. The major objectives were (i) to recognise and record the names of all possible varieties of rice cultivated by the villagers and (ii) to find out micro-ecological reasons behind the practice of cultivation of different types of rice.

The Study area : The fieldwork for the study was conducted by the first author during the months of August-November, 1997 in the Jashipur block of the Mayurbhanj district of Orissa, which lies about one hundred kilometers to the west of Baripada, the headquarter of the Mayurbhanj district. Being situated amidst the Simlipal Reserve Forest in the hill forest environment the block has a total area of 46,629.14 ha, of which less than fifty percent (22,373.00 ha) remains under cultivation. The average annual rainfall in this block is below 2,000 mm. According to 1981 census the total population of the block was 65,379, of which the scheduled tribes comprised 43,300 persons while the Scheduled Castes 4.538 persons. The topography of this area is characteristically an undulating terrain and on field investigation two types of soil, *viz.*, red lateritic and clay with sand were found in this area.

A prolonged and open ended interviewing of the tribal and non-tribal people of eighteen mouza villages under the Podagarh Gram Panchyat of the Jashipur block was done to find out the names of the indigenous varieties of rice cultivated by the villagers in this region.

The findings : The undulating topography of this area has micro-level variations in elevation. The local people recognise and classify these lands in three categories according to their water-retaining capacity and soil composition; namely *Gurajami*, *Dhipajami*, and *Berhajami*. The *Gurajami* is situated at the highest level having red lateritic soil mixed with very little amount of clay, and it has the least water retaining capacity. In our study this land has been considered as the 'high-level land'. The *Dhipajami* is situated just below the level of *Gurajami*, having relatively greater amount of clay content, and its water retaining capacity is higher than the 'high-level land'. We have considered it as 'medium-level land'. The *Berhajami* is situated at the lowest level and has the highest possible proportion of clay and fine-sand in it, and also it has the maximum water retaining capacity. This land type was found to be most fertile in terms of crop yield and we have used the term 'low-level land' to identify it.

Through our intensive field investigation it was possible to find out as many as seventy one distinct varieties of rice which were being cultivated by the villagers on the three types of land as identified above. A list of the different types of rice on the three land categories have been presented in Table 1.

Table 1 : Different types of rice cultivated in the three types of land in Jashipur

Gurajami (High-level land)	Dhipajami (Medium-level land)	Behrajami (Low-level land)
1. Sarjam	1. Arababa	1. Bera Martha
2. Anand Rakha	2. Rangi	2. Sitasal
3. Bhaluk Chamar	3. Merum Kata	3. Agniswar
4. Merum Kata	4. Sunga Bata	4. Parbat Kaya
5. Chingri	5. Maranam Machhi	5. Rakta Mali
6. Gura Baba	6. Asu Bhojna	6. Bibisal
7. Bhatuka	7. Kala Jhinga	7. Latasal
8. Kashiphula	8. Rajamoni	8. Malati
9. Dhani	9. Asu	9. Bera Bhojna
10. Jangeli	10. Rudri Khandi	10. Narda
11. Resh	11. Kathisole	11. Somtai
12. Bhojna	12. Suanar	12. Namal Kathi
13. Hade Gurababa	13. Musdi	13. Agnisal
14. Kala Garia	14. Nimai Ata	14. Mugi Bera
15. Marthi Kabir	15. Kantha Rangi	15. Sakra
16. Lali	16. Dashahara Chuti	16. Karanjai
17. Kacheidhana	17. Kusuma	17. Jamaidhuti
18. Gurdhana	18. Jhinga	18. Mararhan Majh
19. Alsangha	19. Laudagi	19. Mandum
20. Jhingerhe	20. Sarishaphula	20. Kanta Mugdi
21. Kachai Bhojna	21. Gangaram	
22. Kakri	22. Saljhuti	
23. Zira	23. Babui Lachha	
24. Gayabali	24. Panidupki	
25. Kabri		
26. Tabru Jhinga		
27. Nimai Kanta		

Each variety of rice, as identified above, was found to have some unique quality in terms of its taste as well as other adaptive characteristics in the context of micro-ecological variations. All the varieties of rice, which grow on the high-level land, are short duration crops and can survive under very little amount of water and fertiliser. In seasons of less rainfall these highland varieties become very much useful for the villagers. These varieties of rice are so adapted to this specific type of land that they cannot be grown in medium-level and low-level lands where water-storing capacity of the soil is much higher, and waterlogging condition continues for longer period of time. On the other hand, the rice varieties of low-level land are best grown in seasons of higher rainfall. They are also of longer duration and higher yield.

Besides elevation and water requirement, there are other interesting qualities of these different varieties of rice which are cultivated by the local people using their traditional skill and knowledge. For example, there are two varieties of rice, *viz.*, (i) Bhaluk Chamar (grown in the high-level land) and (ii) Parbat Kaya (grown in the low-level land), which have thin pointed string-like structures in their husk to prevent the wild birds from eating up the shooting crop in the growing season.

It was also found through our field investigation that out of about twenty two types of high yielding varieties of rice, introduced so far by the Department of Agriculture, Govt. of Orissa, only six types can be grown in the high-level land and their per acre yield would be markedly lower than the traditional varieties of rice grown in this type of land. Also none of the high yielding variety crops, which have been recommended for the high-level land sectors as above, can survive drought situations. Table 2shows the details of the different traditional and modern varieties of rice in a comparative perspective.

Table 2 : Particulars of the traditional and HYV rice in a comparative perspective

Type of Land	Type of Rice	Sowing season	Harvesting Season	Number of Varieties	Yield per Acre
High-level Land	Traditional	June - July	Aug. – Sept.	20	3 – 4 Qtls
	HYV	June - July	Oct. – Nov.	6	3 – 5 Qtls
Medium-Level Land	Traditional	May - June	Oct. – Nov.	27	6 – 8 Qtls
	HYV	May - June	Oct. – Nov.	11	8 – 10 Qtls
Low-level Land	Traditional	April - May	Nov. – Dec.	24	10 – 12 Qtls
	HYV	April - May	Nov. – Dec.	5	12 – 15 Qtls

Concluding remarks : The above findings reveal that most of the illiterate and so called backward class tribal people, living in the very remote forest-covered villages in Jashipur in Orissa, possess a rich storehouse of traditional knowledge and skill of cultivation of rice for generations. This rich reservoir of knowledge as regards the cultivation of rice crops, the staple food of the people of this region, is a reflection of the adaptation of the farmers to the local geographical and climatic conditions.

This communication is presented in this journal with the expectation that it would open necessary scientific discussion and receive suggestions about how to protect the community rights over the agrobiodiversity of the Jashipur region in the context of Trade Related Intellectual Property Rights (TRIPS) agreement of GATT in this era of globalisation.

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STORM WATER DRAINAGE PROBLEMS OF THE RAPIDLY URBANISING GUWAHATI CITY : AN ASSESSMENT

Introduction : Rapid urbanisation and the subsequent increase in the built-up area have reduced ground water infiltration and increased discharge as a whole in the city of Guwahati in recent years. These have created tremendous pressure on the city sewerage system, which generally do not keep pace with the increase in built-up area. Under such circumstances, a slight increase in rainfall intensity leads to widespread waterlogging of the city bringing life almost to a standstill. An attempt has been made here to analyse the main controlling factors and locate the problem areas for planning alleviation measures.

Method of study : Five hundred and seventy spots of the city were selected on a random basis for sampling on drainage conditions. Among these, 64 per cent of the total spots reported storm water congestion as a major problem. The growth trend of population, built-up area and discharge characteristics of the spots with drainage problem have been analysed and possible remedies have been suggested.

Pattern of urbanisation in the Guwahati city : The unusual growth of population and the remarkable expansion of the built-up area in Guwahati can be assessed from Tables 1 and 2.

Table 1 : The pattern of growth in population and motor vehicles, Guwahati

Year	Population	Growth in %	Year	Motor vehicles	Growth in %
1961	100,707	—	1957	19,897	—
1971	146,026	145.0	1960	24,079	121.0
1991	577,591	395.5	1987	79,160	328.7

Table 2 : Expansion of built-up area in Guwahati from 1911 to 1991

Year	Built-up Area	Expanded Area
1911	7.00 km^2	Uzan Bazar, Chenikuthi, Fancy Bazar, Sukleswar, Cachari (Panbazar)
1961	83.80 km^2	Chandmari, Panbazar, Pachali, Bharalu, Athgaon, Santipur
1991	**132.19 km^2**	Dispur, Basistha, Kahilipara, Beltola, Fatashil, (Ambari), Kamakhya, Gate, Durgasarubar, Sixmile

As is evident from Table 1, the growth in population and number of motor vehicles has been phenomenal in Guwahati. According to Table 2, the built-up area also increased comparably, from 7 km^2 in 1911 to 83.80 km^2 in 1961, representing a growth rate of

1197.14 per cent. It further increased to 132.19 km^2 from 1961 to 1991, registering a growth of 157.51 per cent. The growth of vertical built-up area far exceeds that of the horizontal built-up area due to a marked increase in the construction of multi-storeyed buildings during this time. Increase in the built-up area and the number of motor vehicles is in response to the high growth rate of population. The apparent population influx seems to have been associated with (i) shift of the state capital from Shillong to Guwahati in the early sixties leading to the establishment of a large number of offices and companies; (ii) refugee influx after the Bangladesh War in 1971 and (iii) improvement in transport network through introduction of night buses and suburban trains.

Problems of urbanisation in the Guwahati city : Rapid urbanisation and the associated increase in impervious area have reduced the rate of groundwater recharge on the one hand and increased population density, garbage and wastewater on the other. In fact, the volume of sewerage has increased by almost fifteen times of the previous record. The latter is however not matched by adequate extension of drainage and sewerage system, thereby reducing the carrying capacity of the drainage and sewerage network of the city. This leads to frequent waterlogging in spite of a low intensity of rainfall. This not only disrupts transport and communication network but also leads to frequent outbreak of epidemics of water-borne diseases like cholera, jaundice, gastroenteritis etc., and other diseases like malaria etc. Besides, cases of respiratory diseases triggered by air pollution like bronchitis, tuberculosis etc. are also registering an alarming increase.

Possible remedies : Following the physical setting and natural slope (from west to east) of the Guwahati city, a two-phased storm water discharge can be suggested. The first phase should involve release of storm water into the Solarbeel and Diparbeel lakes via the Bharalu river. The second phase should involve facilitating discharge from the Bharalu river into the Brahmaputra. The rationale behind this two-phase discharge system is to avoid undue cost due to planning and laying out of the sewerage network. The Bharalu river, Diparbeel and Sonarbeel are conveniently located for storm water discharge points. Two essential prerequisites for the execution of this plan are (i) convergence of all storm water drains near their outlet into Bharalu river and (ii) establishment of a sewerage treatment plant near the outlet of storm water drains to prevent pollution of the lakes and other drainage lines.

Conclusions : Rapid urbanisation and the associated increase in the built-up area reduced infiltration, increased runoff and discharge and put tremendous pressure on the already inadequate sewerage network of Guwahati. Waterlogging naturally follows even after a low intensity and amount of rainfall, bringing in its wake disruption of life and spread of diseases. The study recommends laying down of greater number of storm water drains following the natural slope of the land and the discharge of the storm water into Brahmaputra via the Bharalu river, Sonarbeel and Diparbeel in two phases after proper treatment to prevent pollution of the water bodies.

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MORPHOLOGICAL CHANGES OF GHORAMARA ISLAND, WEST BENGAL : A DOCUMENTATION

Introduction : The coastal region, being a fragile and dynamic environmental system, is very sensitive to changes caused by natural processes and anthropogenic activities. This communication deals with the geomorphic changes of the Ghoramara Island using Survey of India topographical maps and multispectral data derived from the Indian Remote Sensing Satellite. The island is a part of the Hugli estuary, West Bengal (c. 21°55′N, 88°10′E). The major villages of the island include Khasimara, Baishnabpara, Baghpara, Raipara, Mandirtala and Chunpuri (Fig.1).

Methodology : A 1:50,000 Survey of India topo-sheet (map number 79C/1), surveyed in 1967-68, was used to trace the configuration of the Ghoramara Island and to identify Ground Control Points for geometric rectification of IRS-1B LISS II data of 5th January

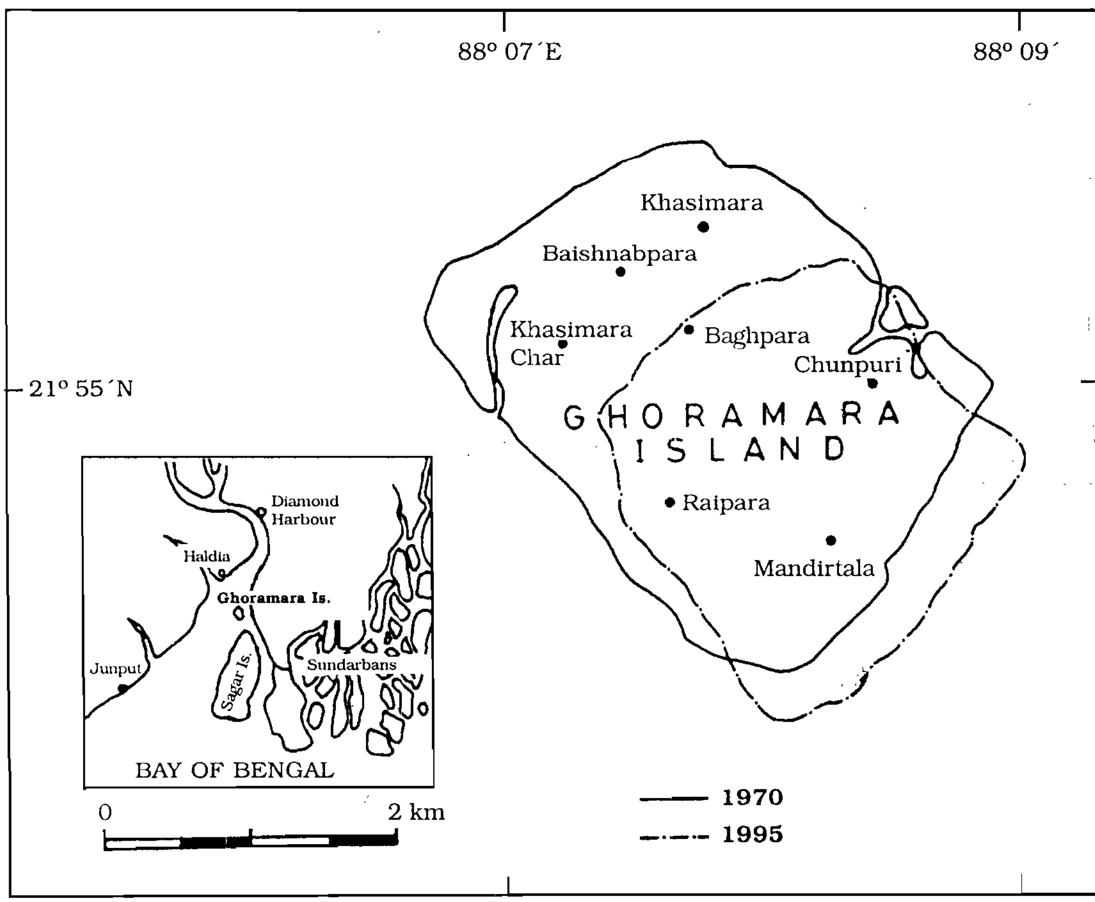

Fig. 1 : The changing configuration of the Ghoramara Island

1995 (scene number 18-53). An image of Ghoramara was then generated from the data on 1:50,000 and was superimposed on the 1967-68 configuration of the island to identify patterns of geomorphological changes (Fig. 1).

Finally, area of the island in 1967-68 and 1995 were measured. It may be noted that water level at the time of acquisition of the satellite data was about 0.32 m above mean sea level under ebb-tide conditions.

Results : Some of the important changes observed between 1967-68 and 1995 include shifting of the Ghoramara Island and decrease in its area.

The island has laterally shifted eastward almost retaining its original shape. The lateral shift has been caused by extensive erosion of its western side and considerable deposition in the eastern part. Within the 28-year interval between 1967-68 and 1995, erosion in tune of 8.18 km caused a net loss of 3.19 km of island area. The western part of the island faced maximum erosional hazard, which completely eroded the villages of Khasimara, Baishnabpara, Raipara and Baghpara.

Discussion : The Hugli is a fully mixed estuary experiencing strong tidal currents and low freshwater influx. The geomorphological changes observed in the Ghoramara Island are largely the results of changes in the estuarine hydrodynamics influenced both by natural processes and anthropogenic activities. The islands of the Hugli estuary including Ghoramara experienced a stable existence when the freshwater influx of River Ganga was high. After the eastward shifting of the course of Ganga due to the tectonic uplift (Blasco, 1977), the freshwater inflow into the estuary was drastically reduced and the estuary experienced an imbalance in its natural setting. The freshwater inflow increased again after the construction of Farakka barrage in 1976 but it eliminated the effect of seasonal changes to a large extent. The geomorphic changes occurred in Ghoramara Island is possibly influenced by these processes. Detailed field and bathymetric investigations are in progress to bring out specific conclusions.

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Book Review

Dimensions of Human Geography: Essays in Honour of Prof. Bireswar Banerjee, *edited by Jayati Hazra. An anthology containing thirty individual contributions on different facets of geography. Published by Rawat Publications from Jaipur and New Delhi in 1997. 474 pages in one-eighth double demy. Price: Rs. 650.*

The eminence of Professor Bireswar Banerjee, as a human geographer, has been so well-established that no anthology is probably capable of reflecting the true image of this evergreen protagonist of Indian approach to geography, particularly that of the Calcutta school. I feel proud that I was a student of this illustrious guru who helped me to identify the 'wrong steps' taken by budding geographers. Those who feel indebted to Prof. Banerjee for his intellectual guidance and those who appreciate the feelings of his students and admirers, have done a commendable job in bringing out his collection of essays on human geography of the particular kind which does not separate itself by a rigid boundary from its peripheral sub-disciplines including physical geography. In fact, human geography is itself the interface of the material and the mental spheres of any subject concerned with space—the particular specific space which shapes community behaviour, social modes of production, social attitudes of life, collective interpretations of hazards and problems and, ultimately, the ideograms of a planned society and planned landscape.

If the above characterisation of human geography is in proximity to truth, then this anthology, at least in terms of the nature and variety of its contents, has served a very useful purpose for all human geographers, geographers in general or, for that matter, all social scientists and even physical scientists capable of detecting the false dichotomy between the physical and human. I cannot resist the temptation of quoting my friend Avijit Gupta (now in Leeds), himself a physical geographer who, after lamenting upon the failure of geographers to become acknowledged environmental managers, does not fail to observe "above all, we need to avoid the false dichotomy prevalent in our subject and self aggrandisement that arises out of it" (page 58). Full many a paper in this volume finds it convenient and meaningful to treat the 'physical' and the 'human' as indivisible. To name a few, Md. Shafi's *Biodiversity in North-eastern Hills*, A.P. Desai's *Micro-level Planning for Backward Regions of Gujarat*, J. Diddee and R. Naik's *Agriculture in the Mahabaleswar Region*, S. Das's *Resource Management and Conservation of Ecology in South 24 Parganas*, A.K. Ghosal's *Ecological Impact of Coal Mining in West Bengal*, A.K. Paul's *Human Use of Coastal Lands in West Bengal* etc., quite successfully demonstrate the synthesis that human geography is capable of doing, and is expected to do.

Others, who prefer to specialise in specific areas, have done justice to their chosen fields in the sense that even antipodal disciplines are bound to find their work as smooth and valuable. The articles of P.K. Sen on *Canal Irrigation in the Lower Damodar*, S.K. Munsi on *Indian Population Growth, Food Supply and Sustainable Agriculture*, S. Banerjee Guha on *Multinational Corporations*, R. Pal and C.R. Pathak on *Decentralised Planning*, A. Sarkar on *Spatial Pattern of Urban Growth in West Bengal*, K. Sita and D. Mukherji on *The City Core of Calcutta*, A. Nandi on *Cultural Ecology on*

Jhumias of Tripura, D.E. Christensen on *New World Order in Geography*, R.W. Steel on his personal reflections on *Links between Indian and British Geographers*, contributions of A.T.A. Learmonth on *Arthur Geddes and India*, F. Stang and R. Brusseler on *Rourkela*, K. Roy on the *Metropolitan Authority of Calcutta* and J. Hazra on *Disease Ecology*—are all conceptually, technically or information-wise sound scientific discourses which demand the attention of students, scholars and teachers of human and physical geography alike. Capable readers would not fail to appreciate the height of the plane from which Prof. Munsi, Pathak, Steel, Learmonth, Mishra and a few others address their chosen themes.

The book is divided into five parts: *Part I, Geography and Geographers; Part II, The Evolutionary Process; Part III, Sustainable Development Strategies; Part VI, Planning and Management Issues* and *Part V, Ecological Issues*—with a total number of thirty contributions from India and abroad. The partitioning could possibly be avoided or directed in a different line, because the question of sustainable development is essentially ecological and that of planning and management cannot be divorced from sustainability and ecological issues.

There are obvious weak links in the thread that binds the beads together, but this is probably unavoidable in any milieu that tries to fuse experience with youthful enthusiasm, wisdom with discrete observation, theory with empiricism and the maestro with the novice. The stylistics could have been improved, methodologies could have been better spelt out, and indices should have been more accurate and effective. For example, the indices of 'surplus workers' and 'dependency ratio' used in pages 211 and 212 are far from satisfactory. All said and done, most of the articles are relevant, logical, well supported by positive information, well illustrated, well written and worth reading. The volume should be considered as a possession in the libraries of individuals and institutions.

Lastly, at least one of the reasons for which the book should be considered as a prized possession of the libraries of individuals, is the foreword written by Prof. Mohit Bhattacharya, the erstwhile Vice-chancellor of the University of Burdwan, my erstwhile academic guardian and present friend and philosopher. Prof. Bhattacharya's foreword is a singular example of a non-geographer's appreciation of geography and an appropriate one. Thanks to the editor Dr. Jayati Hazra that she has the ability to locate the right person for the right job. My tribute to Prof. Bireswar Banerjee for being so fortunate to have a band of efficient and dedicated followers of the example set forth by him.

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Landuse Planning for Wastelands *by Gyanendra Kumar Dutt. Published by School of Fundamental Research from Calcutta in1997. 160 pages. Price: Rs. 300.*

This book is an outcome of indepth study of fifty villages in Puruliya District of West Bengal sponsored by the Department of Science and Technology, Government of India. Landuse planning at grassroot level is very much constrained by the scarcity of authentic data on various aspects of land utilisation particularly that of wastelands. This study has tried to bridge the gap to a great extent in information base towards micro-level planning. The study presents the status of landuse in fifty villages upstream of Kangsavati river. The figures are projected for the years 1997, 2000, 2003 and 2005 A.D. A comprehensive socio-economic and landuse survey has been conducted on a pre-tested structured proforma in each of the fifty mouzas. The data have been tabulated and mapped on a cadastral scale (16 inches to 1 mile) demarcating each landuse type. Two sets of soil maps of each mouza on a scale of 1 cm to 100 m, have been prepared. The information gathered covered topography, vegetation, water supply, soil characteristics, agricultural landuse, land holdings, livestock, population structure, occupational breakup, food, fuel and fodder requirements and available social services for each mouza. Survey was carried out by a team of trained field staff in 1995, with a common framework and questionnaire. The questionnaire may serve as model survey schedule that could be used elsewhere with suitable modification if necessary.

The study is not limited to mere data collection. A detail analysis of each sector has been undertaken to ascertain the present-day status and also projected for future requirements for planning and development. Special studies have been made on the nature, extent and scope of wasteland development for each village. Puruliya is a drought prone district where the wastelands account for 22.88 per cent of its area. The wastelands are either uplands or rocky normally not available for cultivation. There has been widespread plantations of exotic variety of vegetation which hardly reduce wasteland development. These plantations could hardly increase the biodiversity or restore ecological balance.

This type of landuse and socio-economic study is the urgent need for down-to-earth planning for development. The outcome of this study would help the local government at Panchayat level in decision making for landuse planning.

Dr. Dutt has done a commendable job in meeting the data gap for microlevel planning. Village-wise cadastral mapping is unique in this book. It will provide the required information for each village and very exhaustive in coverage.

A summary version of the study could be published in local language to help the farmers in planning for land utilisation. I am sure the readers and actual users of the study will be very much benefited.

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