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MORPHOMETRIC ANALYSES OF THE RIVER BASINS IN GOA

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ABSTRACT : Morphometric analyses of seven river basins in Goa have been carried out. The linear and areal aspects of these basins are reported here. The plots of stream order versus stream numbers and stream orders versus mean stream lengths are found to satisfy Horton's Laws. The bifurcation ratios show the maturity of the dissected basins. Except for the basins of Mandovi and Zuvari rivers which are more elongated and less circular, the other five basins are more circular and less elongated. The high permeability of the laterite cover has resulted in low drainage density values. It is observed that the drainage has adjusted very well to the structures of the country rocks. Cymatogenic movements have resulted in limited formation of river terraces. Local emergence of the land has occurred as indicated by the Sal river. The presence of drowned topography at the mouth of the rivers is indicative of submergence.

Introduction

The study area lies between 14°48' N to 15°48' N parallels and 74°20' E and 75°40' E meridians and is bounded on the north by the Terekhol river, on the south by the Galjibag river, on the east by the Western Ghat escarpment and on the west by the Arabian Sea. Physiographically the region has been broadly divided by De Souza (1965) into: (1) the coastal tract consisting of recent broad alluvial plains, vast estuaries, beaches and dunes; (2) the tract between the coast and the Ghats ("sub-ghats" region), and (3) the Western Ghats. Except for the work of De Souza (1965, 1968), Wagle and Misra (1975), Dessai and Peshwa (1981) and Wagle (1982) who dealt with the geomorphic features in detail and the drainage in general no work exists as regards the morphometric parameters of the river basins in Goa. This paper discusses the drainage networks and their characteristics, carried out with the aid of topographical sheets, aerial photographs and field work.

Geology

A major part of Goa is covered by the pre-Cambrian and Cuddapah rocks. The rock types representing the Dharwars are quartzites, phyllites, chlorite-schists, gneisses, granites, metabasalts, metagabbros, metagraywackes and banded hematite quartzite. These unfossiliferous metasediments of Cuddapah age are profusely intruded by basic dykes (Oertel 1958). The regional trend of the pre-Cambrian rocks is NNW-SSE on the north and it veers to east-west on the south (Wagle and Misra 1975). The Deccan Traps cover the ancient crystalline formations in the northeast. Laterites of variable thickness are found to occur capping the rocks from the high plateaus of the Sahyadri down to the sea level.

Physiography

The following five physiographic zones can be recognized in Goa.

<i>Altitude</i>	<i>Distribution and coverage of total area</i>
Sea level to 60 metres	Coastal plains, the pediplains and inland pediments (45 per cent).
60 to 160 metres	Remnants of planar surfaces and lateritized, undulating landscape (30 per cent).
160 to 300 metres	Undulating landscape (10 per cent).
300 to 600 metres	Highly dissected hills (9 per cent).
Above 600 metres	Steep and rugged hills (1 per cent). The rest (5 per cent) is covered by estuaries and rivers.

Geomorphologically Goa can be divided into five units such as: the dissected high hills over 300 metres in altitude; the dissected low hills with laterite up to 300 metres; the dissected low hills without laterite up to 300 metres; the buried pediments/pediplains up to 60 metres, and the coastal plains. Rao *et al.* (1981) classified Goa into four geomorphic units: the coastal plains on the west dominated by marine landforms; the denudational landforms on the east; the Western Ghats; and the limited fluvial forms.

An examination of the contours on the topographical sheets shows that the ridges south of the river Terekhol are elongated in a north-western direction and an "amphitheatre" has formed at the upper course of the river Galjibag with the contours broadening towards the west. In general, the contours of the study area are open with the hill slopes having a gentle gradient.

Climate

Goa enjoys a tropical maritime and monsoon type of climate in which the mountains play an important role. The climate is equable and moist throughout the year. A regular and sufficient rainfall is brought about by the south-west monsoon winds during the months of June to September. The annual rainfall is of the order of 300 to 350 centimetres. The mean daily temperature is around 30°C during May and 25°C in January.

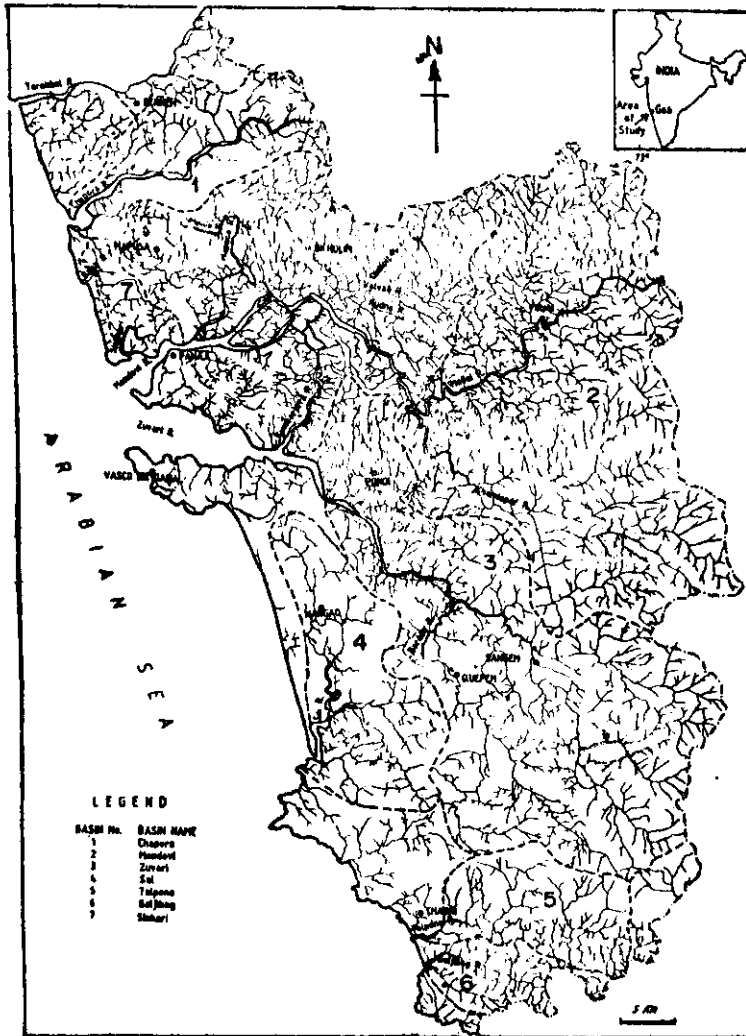


Figure 1. River basins in Goa

Lineaments

The study (Wagle 1982) revealed that the majority of lineaments along the Goa coast trend towards NW-SE, NE-SW and a few towards ENE-WSW. Of these the NW-SE trend is predominant. The lineaments are manifested as incised fractures, vegetation lineaments, vegetation change lineaments, lineaments expressed in stream courses and

lineaments due to abrupt linear topographical changes. Though the area has been subjected to three distinct episodes of folding, namely, NW-SE, E-W and ESE-WNW (Wagle and Misra 1975), most of the lineaments appear to have been formed during the intense NW-SE folding episode. The other two trends are normal to the major one and may be the result of cross folding of the Dharwar orogeny. The major lineaments occur along the westerly flowing rivers like the Terekhol, Chapora, Mandovi and Zuvári. The minor ones are difficult to discern due to the presence of laterites.

Drainage

The important rivers draining the area, from north to south, are the Terekhol, Chapora, Mandovi, Zuvári, Sal, Talpona and Galjibag (Figure 1). The Baga river joins the Sinkeri which in turn flows to meet the Mandovi river, just at the latter's mouth. All these rivers are under tidal influence for most of their length near the coast. The rivers run mostly straight with sharp bends and meandering is a rare phenomenon. The rivers are estuarine in character. Owing to heavy rainfalls the rivers have tremendous capacity to erode headward, resulting in river piracy at places.

The drainage is predominantly in two directions, NW or NNW and the east-west, which follow the regional trend and coincide with the major faults, fractures and shear zones. This is a good example of a structurally controlled drainage pattern. Dessai and Peshwa (1978) reported drainage anomalies due to lithological and structural controls.

Terekhol river: This river has its source in the Karnataka part of the Sahyadri (Western Ghats). It flows along the border with only the left bank being in Goa. Its total length is hardly 13 kilometres in Goa. The Kadasi is a major tributary of the Terekhol. It is sinuous and has knick points at places. There are two sharp meanders wherein meander bars are noted. The drainage pattern is radial and dendritic. The Terekhol basin has not been included for the present study.

Chapora river: It originates from Ram Ghat hills of the Belgaum district in Karnataka. It has a total length of about 31 kilometres in Goa. It has a major tributary in the form of the Kalina river in the north and other minor ones. At its upper course it is termed as the Tilkari river which has a right angled bend and tends in its lower reaches to meander very distinctly with deposition of meander bars. At the mouth of the river mud banks and mangrove swamps are common.

Mandovi river: It takes its source from the "sub-ghat" region at an elevation of 888 metres. It has a length of about 77 kilometres and has the largest drainage basin. Numerous islands are present along its course. Typical features of drowned topography are evident. Various tributaries contribute directly or indirectly to its discharge. The tributaries are the Dicholi (which joins the Kudne and Valvat) Mapuka Kudne, Khandarpar and Moide rivers. The Moide has nearly a east-west trend but near about its middle reaches it has possibly been captured by the Mapuca

Table 1
Basin length parameters of rivers in Goa

Stream order	Stream length (kilometre)	Length ratio	Mean length (kilometre)
Chapora river			
1	45	—	0.34
2	34	0.778	0.89
3	20	0.425	2.86
4	5	—	5.00
Mandovi river			
1	410	0.724	0.29
2	265	1.276	0.64
3	124	0.521	1.44
4	74	—	3.70
5	23	2.794	5.75
6	20	—	20.00
Zuvari river			
1	166	0.900	0.25
2	100	1.261	0.51
3	57	0.882	1.43
4	41	—	5.85
5	26	1.334	13.00
6	22	—	22.00
Sal river			
1	36	—	0.23
2	26	1.705	0.56
3	20	0.650	2.00
4	10	—	10.00
Talpona river			
1	45	0.859	0.37
2	24	1.587	0.64
3	11	—	1.57
4	8	0.859	2.66
5	5	—	5.00
Galgibag river			
1	29	—	0.40
2	13	1.373	0.56
3	8	1.016	1.60
4	5	—	5.00
Sinkeri river			
1	5	—	0.17
2	5	0.400	0.83
3	2	—	2.00

(near the village Sirsai). Due to cultivations and habitations along the Moide river, no apparent drainage anomaly or the presence of wind gap is noticed. The minor streams join the major tributaries nearly at right angles, which indicates the control of lineaments on the drainage. The tract of land between the Chapora and the Moide rivers is quite peneplaned with shrubs and cashew trees.

The Mapuca joins the Mandovi at Penha de Franc : the latter ultimately discharges into the sea at Aguada Bay with the formation of mud banks and swamps. The drainage channels of the Mapuca river are braided and not distinctly defined. Two islands, Vanshi and Diwadi, exist in the lower course of the Mandovi.

Zuvari river : It originates from the "sub-ghat" region and is 34 kilometres long. The Kumarjuwa river is the major tributary which flows in a southwesterly direction in a parallel course and joins just above the Zuvari mouth. This appears to be a feature of river capture by the Zuvari of a part of the Mandovi along a major lineament trending NNW. But no distinct drainage lines are seen to conform this at its upper course. Towards the lower course of the Zuvari on the east, the drainage is dendritic, and on the west the land is cultivated. The Zuvari joins the sea at Marmagao Bay.

Sal river : It has a course parallel to the coast (NNW) with drainage lines nearly at right angles, indicative of structural control. The Sal joins the sea at Betul. Meander deposits are present.

Talpona river : It originates from a height of 510 metres on the east. Towards the upper course the drainage lines are linear. The middle and lower courses have bar deposits and swamp formations respectively.

Galjibag river : It originates from the hills which lie on the east. The important feature is the nearly linear disposition of the river (NW-SE) with streams joining at right angles to form a trellis pattern.

Morphometric analyses

Seven basins belonging to the rivers Chapora, Mandovi, Zuvari, Sal, Talpona, Galjibag and Sinkeri were quantitatively studied for their linear and areal aspects. The linear aspects include the stream order, stream number and stream length. The areal aspects are the basin area, drainage density, constant of channel maintenance, length of overland flow, stream frequency and basin configuration.

The modified version by Strahler (1957) of Horton's (1945) was adopted for ordering streams. The data together with the arithmetic and weighted mean of the bifurcation ratios were calculated. The plot of stream number against stream order shows that the plots are linear conforming to Horton's first law of stream numbers. The various stream segments were measured orderwise by means of a curvimeter (Table 1) along with the length ratios. The plots of mean length against stream order satisfy Horton's second law of stream lengths.

Table 2
Drainage basin parameters of rivers in Goa

Basin	Area (square kilometres)	Drainage density per square kilometre (kilometre)	Constant of channel maintenance (square kilometre per kilometre)	Length of overland flow (square kilometre per kilometre)	Stream frequency (Number per square kilometre)
Chapora	191.58	0.54	1.85	0.92	0.93
Mandovi	1317.76	0.70	1.42	0.71	1.44
Zuvari	930.18	0.44	2.27	1.13	0.96
Sal	255.18	0.36	2.77	1.38	0.82
Talpona	174.49	0.53	1.88	0.94	0.96
Galjibag	69.42	0.79	1.27	0.63	1.45
Sinkeri	24.46	0.49	2.04	1.02	1.44

Schumm (1956) defined the constant of channel maintenance as the unit area required to maintain an unit length of channel (Table 2). In other words it is the reciprocal of the drainage density. It is a useful parameter to ascertain the hydrological conditions.

The length of overland flow refers to the length of the runoff of the rain water on the ground surface before it gets localized into definite channels. Since this length of overland flow, on an average is about half the distance between the stream channel. Horton (1945) for simplicity considered it to be half the constant of channel maintenance. It affects the hydrologic and physiographic developments of a drainage basin. Table 2 shows the values obtained in the present case.

Conclusion

All the rivers of Goa generally satisfy Horton's (1945) First Law of Stream Numbers. Out of the 25 ratios, most of the values lie between 3 and 5. This indicates the maturity of the dissected drainage basin. The high value of 10 of the Sal river is somewhat anomalous and is probably due to the channelizing of the lower order streams along fracture zones. These streams in turn, form less number of highest order streams. Moreover, only two of the third order streams join to form the fourth order, whereas the rest drain directly into the fourth order streams without joining among themselves. The parallel course of the Sal river with tributaries joining at right angles might well be regarded as a small coastal plain due to local emergence (De Souza 1965). The semilogarithmic plots of the mean lengths against the stream orders are straight lines thus satisfying Horton's (1945) Second Law of Stream Lengths. Five of the basins are more circular and less elongated except for the basins of Mandovi and Zuvari rivers which are more elongated and less circular.

Due to the highly permeable nature of laterite cover which is predominant over the major part of the area, the drainage density values are quite low.

In conclusion it can be said that the drainage pattern has adjusted well to the structure of the country rock. There is no evidence of the rivers having reached the old age. This suggests that the area has not reached a stage of mature topography. River terraces are limited in their occurrence and their disruption, at times, may be because of cymatogenic movements. Rao *et al.* (1981) reported the recession of the Western Ghats further inland as being due to the headward erosion of the Mandovi and Zuvari rivers. This according to them had occurred along the ENS-WSW and north-south trending lineations. The submergence and emergence of the land mass are indicated by the presence of drowned topography, at the mouth of the rivers, and by the Sal river, which flows nearly straight and parallel to the coast, respectively.

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