CHAPTER VI

D R A I N A G E

VI.1 MORPHOLOGY OF STREAMS

1) General

Lithologically, the area is divisible into two main groups (1) Western side-Tertiary limestone (2) Eastern side Cretaceo-Eocene Deccan Trap lava flows. Out of 18 basins 5 are located on Tertiary limestones and 13 on the traps. All these 18 basin and 6 inter basin areas occupy 3556.71 sq km, about 120 sq km, are occupied by the Okha Rann. Most of the rivers originate from the central part of the Saurashtra on a ridge parallel to Lat. $22^{o}5'$N. The altitude of this ridge progressively reduces from 232 m in the east to 30 m in the west. The length and order of main stream channels show a decrease from 53 km to 14 km and the stream order changing from 6th to 3rd respectively from east to west. This fact is adequately reflected in the gradual variation in the various parameters like Stream Frequency, Drainage Density, Weighted Mean Bifurcation Ratio, Elongation Ratio, Relief Ratio and Gradient.

No major break in profile of any of the river has been observed and they flow on a smooth gently sloping ground. At places, some rapids of 1-2 m are observed in rivers like Nagmati, Sasoi, Phuljar etc; out of these many are due to increased slopes instead of vertical cliffs.

2) <u>River Beds</u>

Most of the rivers being seasonal, have restricted wet channels. The period of water flow, energy of flowing current, gradient and bed rock are the main agents responsible for development of river channels and river beds.

In the upper segments of the rivers as they originate on the mountains and flowing along the hill slope, the gradient is high. The erosion is dominent and hence downward cutting is significant. On account of this, the channel beds are narrow and steeply sloping. Walls of the channels are more or less vertical or highly inclined giving 'V' shaped cross sections. The width of channel bed, measure from a metre to a few metres with depths ranging upto 7-8 m. In the jointed rocks, the shape and size of river beds and side-walls are considerably controlled by joint pattern and intensity of jointing.

Along the river beds, in the localised depressions, rock fragments of varying sizes are seen accumulated, otherwise in the hilly terrain, most of the river beds are barren.

In the middle segments of the river courses, where they flow on the gently sloping plain, their beds show different characteristics. Here, the channels are wide and without any significant gradient. The river courses are not exactly straight, and contain frequent curves. Along these curvatures, because of deposition of point bars on inner side, the river beds slope outwards. Again, the width of beds in the curved zone is mostly more than that the straight zone. All along, the beds are filled with boulders, cobbles and fine clay material. In this segment, the width of channels varies from 10 m to 400 m and depth from 3 to 10 m. Erosion and deposition are counter balanced in this zone and transport is dominant.

The third segments of the river courses i.e. in the coastal plain, are quite wide, curved but not meandering. The river beds are full of sediments of different size ranging from coarse sand to fine clays. Deposition being dominant, river beds do not show any erosional features. The ratio of width to depth is quite high in comparison to the previous two segments. The maximum width of river bed observed in the area is that of Sinhan and Ghi rivers, which is about 600 m and even more in curved zones. The depths of channels vary upto 6 m. At few places, the bed rock is exposed. The sand mixed with clay supports some vegetation while the pure well sorted sands have no vegetation.

3) Down flow direction

All the rivers except, Gomti and Khari, flow north-north-west, though locally, their flow direction may change to west [illegible], east or even some times southward. The rivers Gomti and Khari, flow to west and this direction appears to be due to [illegible] surface topography. For river Khari, the Okha Rann dislocation appears to have controlled its course, while Gomti and other rivers meeting the Arabian sea are geomorphically controlled.

4) Drainage Pattern

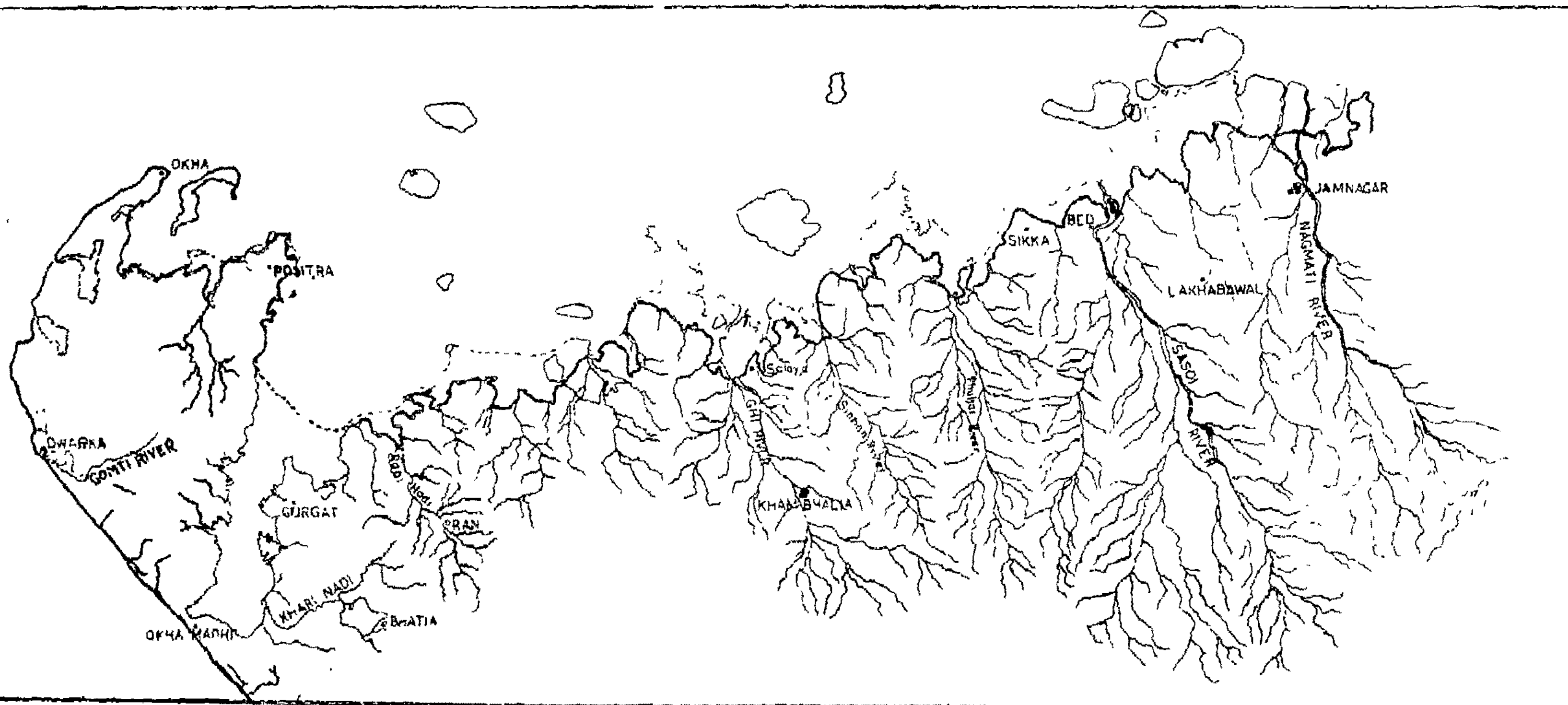
The drainage pattern is uniform all over the area (Fig. VI.1). Being less affected by tectonic activities, the drainage pattern is mainly controlled by erosional activities and lithology. The individual basin's drainage pattern is dendritic, though the main streams of the area are almost parallel to each other. Khari Nadi (river) meeting the Okha Rann is perpendicular to the Rani Nadi. Both of these rivers have originated at the same place and the same altitude of 77 m above M.S.L. Gomti river has originated, it seems, mainly due to a headward erosion of Gomti Creek and hence it is still flowing

DRAINAGE PATTERN OF THE STUDY AREA

FIG VIII

N

0 5 10 KM



towards west. As a whole, the drainage development is on account of the headward erosion of channels. Though the area is cut by a dyke almost parallel to coastline, it has no effect on the stream courses of any of the river or its tributaries.

5) Drainage Divides

To the east of Okha Rann on the mainland part, the main drainage divide extends EW parallel to Lat. 22°5' N. Its height near the source of Nagmati river is 232 m above M.S.L. At this point it extends NS for about 4 km then it takes a sharp turning to the NW, extends for a distance of 3 km again turns to south for a 4 km distance forming 'N' shape ridge. From this point it runs WSW almost in a straight line for about 15 km and comes down to a height of 180 m near the village Ghunda. At Ghunda, it takes a turn of 220° and runs for about 15 km and then to west for 13 km near the village Bhandariya (100 m above M.S.L.). From Bhandariya to Vadatara, a distance of 24 km, its trend is NW-SE and altitude comes down to 40 m. From Vadatara to Sonardi, its trend is EW and from Sonardi to Bhopalka (R.S.), it is SW-NE for distance of about 18 km. From Bhopalka it runs parallel to the railway line to its north, upto Okha Rann near the mouth of the Khari Nadi where it reaches almost the sea level (HWL).

As such this divide is not a well defined sharp ridge running EW, but it comprises a smooth convex surface characterised by numerous small hillocks. Its surface at many places is covered by agricultural soil and at places it is barren with stony waste. Scattered reserve forests are located on the either side of this divide.

The study area to the north of this divide, being a coastal plain, nowhere one finds a sharp hill slope or any sudden fall in gradient. In the 14 basins studied the divides between the two adjacent basins, are always quite smooth running irregularly to meet the Gulf of Kutch. These divides are parallel to each other and have a general trend towards NNW.

Khari River is flowing to west having independant basin and do not have a common drainage divide.

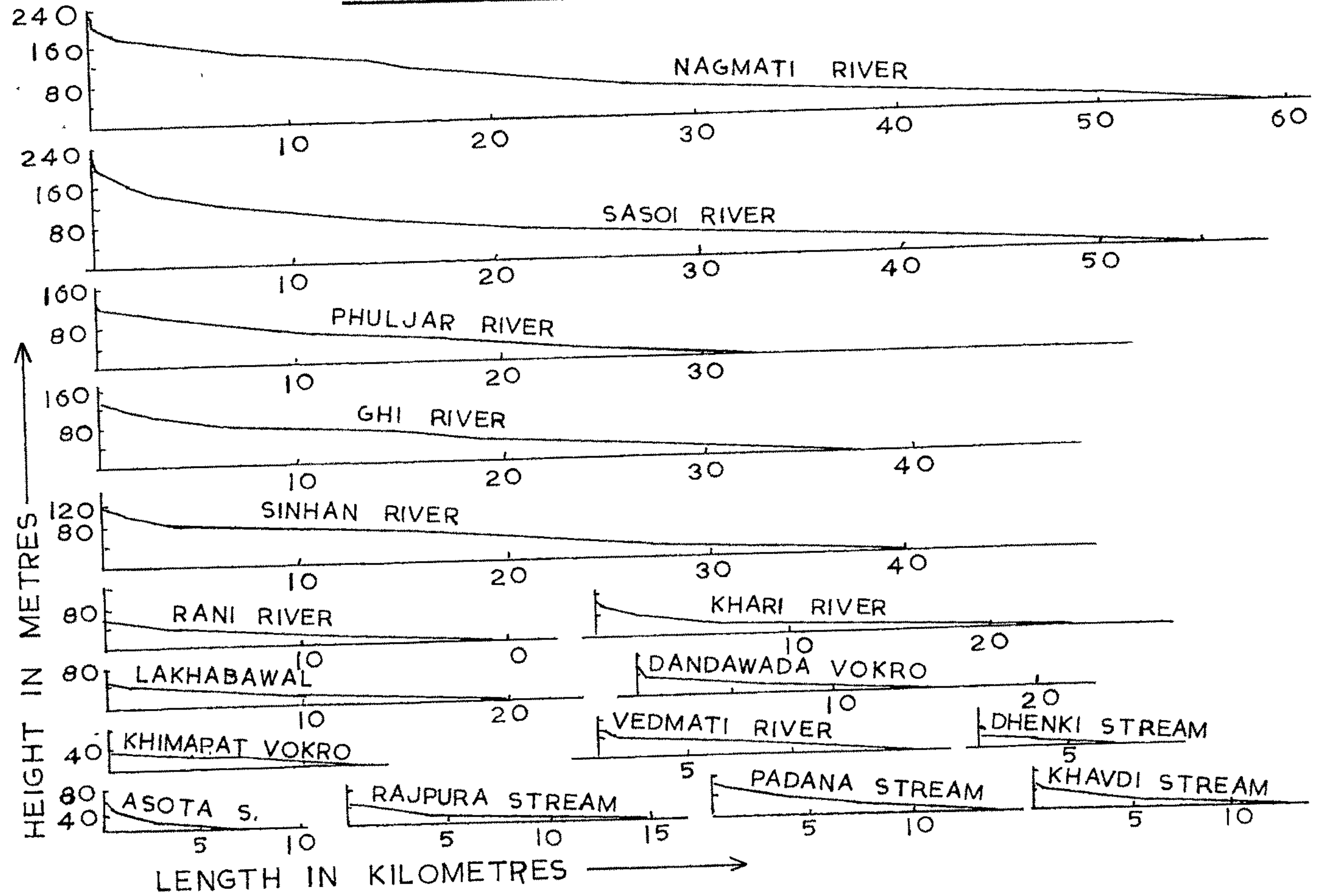
In the Okha Mandal region, the 3 basins viz. those of River Gomti, Rajpura stream and Dhinki Charakla stream are independant, and they do not have a common drainage divides as such. The rivers originate from a high land in semi arid area, hence the drainage is poorly developed.

6) Longitudinal Profiles

Longitudinal profile is a configuration of the channel bottom in longitudinal view (Fig. VI.2) and is represented by a graph of elevation versus distance above mean sea level of a stream channel. Most of the longitudinal profiles are concave upward, except for the rivers Nagmati, Ghi and Rajpura. These rivers show breaks in profiles at 12.5 km, 14.5 km and 1 km from their source respectively. The Rajpura stream is ephemeral flowing in the arid zone and having more seepage and evaporation which may be the cause for having a convex profile or the break in the profile. The breaks described above are in the upper one third segment of the streams. In this segment, downward cutting is dominant. Small waterfalls and rapids are present in this segment. The bigger streams originate on the hilltops and flow down the hill slopes. When these rivers enter the gently sloping region, they show a sudden break in profile forming the first upward concavity. Majority of the small streams (4th order) originate on the plain and don't show breaks or concavities.

FIG. VI 2

LONGITUDINAL PROFILES



The concave profiles of stream are generally water gaining profiles and indicate that decrease in gradient downstream depends more on the increase in discharge. The lower segments of river Nagmati, Sasoi, Ghi, Phuljar etc. come under this category, and here deep channels intersect the water tables giving springs and seepages.

The lower reaches of the rivers are the areas of curvatures and wide courses with sediments on the river bed. Here, the river profiles show gradients lower than the middle and upper segments. Nowhere in the study area, the rivers show typical characteristics of old age stage like levees, flood plains, meanders etc. The reason may lie in the submergence of the coastal part where traces of highly curved channels have been recognised. Similarly, because of submergence, the base level of erosion has also gone down, giving rise to some rejuvenation.

The middle segments comprise the transition zone between those of erosion and deposition. Here, the gradients are higher than those of the lower segments.

Channel courses show open smooth curves. Except the deposition of coarse sand to fine clay, other features of erosion or deposition are seen developed.

Shaping the stream channel is a function of a number of interdependant factors such as discharge, load, size of debris, flow resistance, velocity, width, depth and slope along with climate, rainfall, lithology and gradient (Leopold, 1969).

The physical properties, rock type and lithology of the rocks also play an important role in the modification of gradient and longitudinal profile. Brush (1961) found in his studies of some streams in the folded Appalachians of Pennsylvania that gradient decreases as hardness of rock decreases. The studies of Morisawa (1962) in the Appalachian Plateau Province have shown that when a stream flows along a resistant layer the gradient is gentle but when it flows through or across such a rock, the gradient is steep.

In the present study, the author found that the gradients of the streams of same order flowing on hard rock were more than that of those flowing on soft rock :

	River	Gradient
On Deccan Trap	1. Lakhabawal	0.0031
	2. Padana	0.0043
	3. Khavdi	0.0051
	4. Dandawada Vokro	0.0033
	5. Khimapat Vokro	0.0031
	6. Vedmati	0.0033
On Limestones	1. Rani Nadi	0.0032
	2. Rajpura Stream	0.0029
	3. Khari Nadi	0.0030
	4. Gomti Nadi	0.0021

In the Deccan Trap region, nicks in the river profiles are observed. Most commonly are at the junction of two lava flows where red soil is inter-bedded. At these nick points, waterfalls and rapids have developed. The heights of these rapids vary from a metre to more than 5 m. At places, it is observed that these nicks are not vertical but are sloping at varying angles. Such type of waterfalls and rapids are not developed in the limestone area though the stream valleys are deep and narrow and uniform graded profiles are developed.

VI.2 DRAINAGE ANALYSIS

1) General features

The basin study has shown that all the parametric units used for morpho-analysis change considerably in trap and limestones.

In traps, however, from east to west the change is gradual and connected. That is, the values for basin gradient, basin length, stream length, stream frequency, drainage density etc. decrease progressively and gradually (Table VI.1). No abrupt change is observed. Two factors appear to be responsible for this variation. Firstly, the distance between the water divide and the coast, and secondly the progressive decrease in rainfall from east to west, the western side being almost semi arid.

Out of the 18 basins recognised 5 are located on limestones of Tertiary age and 13 are on the Deccan Trap. The latter are elongated in SSE-NNW direction parallel to one another and they meet the Gulf of Kutch, while the former 5 basins do not show any mutual relationship and are randomly oriented; 1) Rani river flowing North, 2) Khari river flowing West, 3) Gomti river flowing WSW, 4) Rajpura stream flowing North and 5) Dhinki-Charkla flowing ESE.

For each basin the author has investigated the drainage characteristics from the most recent

Table VI .1 : Morphometric parameters of different river basins.

Stream Order	No. of streams	Total length in Km.	Average length Km.	Bifurcation ratio	Total length of all order streams	Basin area Sq. Km.	Drainage density L/A	Basin relief mts.	Stream frequency N/A	Stream length ratio	Length of basin Km.	Length of main stream Km.	Elongation ratio
1	2	3	4	5	6	7	8	9	10	11	12	13	14
						1. BAGMATI RIVER BASIN							
1.	409	337.78	0.826							1.67[illegible]			
2.	105	144.89	1.380	.895	649.93	502.62	1.293	232.00	1.132	1.[illegible]17	43.00	52.00	0.588
3.	49	68.75	1.403	2.143						[illegible].946			
4.	5	62.76	12.552	9.8						2.34[illegible]			
	1	35.75	5.0										
						2. LATI[illegible] NAL STREAM BASIN							
1.	60	54.75	0.9125							1.[illegible]			
2.	18	29.65	1.647	3.333	106.5	56.00	1.109	50.00	[illegible].65	1.366	12.0	16.00	0.921
3.	4	9.00	2.25	4.50						5.[illegible]22			
4.	1	13.10	13.10	4.00									
						3. SAS[illegible]I RIVER BASIN							
1.	1312	857.5	0.654							[illegible]			
2.	320	549.72	1.[illegible]93	4.1						[illegible]			
3.	[illegible]	186.79	2.524	[illegible].354	1585.73	750.00	1.910	220.[illegible]	[illegible]	[illegible]	4[illegible]	[illegible].5	0.699
4.	[illegible]	104.88	5.827	4.111						2.[illegible]72			
5.	4	48.29	12.072	4.50						3.163			
6.	1	38.25	38.25	4.00									
						4. [illegible] STREAM BASIN							
1.	37	28.10	0.759							1.[illegible]37			
2.	11	12.00	1.[illegible]1	3.364	51.40	33.00	1.557	65.00	1.545	1.[illegible]54	11.00	15.00	0.589
3.	2	2.30	1.15	5.50						[illegible]			
4.	1	9.00	9.00	2.00									
						5. PHULJAR RIVER BASIN							
1.	467	312.88	0.670							1.559	30.00	33.5	0.563
2.	110	122.35	1.112	4.245	557.89	223.77	2.493	140.00	2.739	2.297			
3.	27	69.00	2.555	4.074						1.264			
4.	8	25.84	3.23	3.375						3.613			
5.	1	27.82	27.82	8.00									

Contd...

Table VI .1 : Contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
						6. [illegible] BASIN							
1.	60	42.4	0.707							1.549			
2.	16	18.65	1.[illegible]6	3.75	71.20	37.00	1.924	54.[illegible]	2.216	[illegible].575	9.00	10.5	0.762
3.	5	3.35	0.67	3.20						[illegible].149			
4.	1	6.80	5.[illegible]	5.00									
						7. GHI RIVER BASIN							
1.	606	443.5	0.732										
2.	153	230.9	1.50[illegible]	3.960						2.951			
3.	35	86.2	2.465	4.371	824.85	347.8	2.372	13[illegible].00	2.52[illegible]	1.881	31.0[illegible]	50.00	0.679
4.	9	41.7	4.635	3.838						0.459			
5.	3	6.38	2.126	3.00						7.0[illegible]			
6.	1	16.17	16.17	3.00									
						8. [illegible] BASIN							
1.	369	343.80	0.932										
2.	98	97.00	0.9[illegible]	3.765						1.0[illegible]2			
3.	22	58.37	2.65[illegible]	4.454	532.08	197.87	2.6[illegible]	1[illegible]	2.4[illegible]	2.6[illegible]	24.00	27.5	0.561
4.	4	16.56	4.14	5.50						1.[illegible]60			
5.	1	16.35	16.35	4.[illegible]						[illegible].49			
						9. DANDAVAD [illegible]							
1.	115	83.15	0.723							1.586	12.00	13.5	0.689
2.	22	25.25	1.148	5.227	[illegible]6.[illegible]	53.72	2.360	44.00	2.[illegible]	1.157			
3.	7	9.3	1.32[illegible]	3.143						6.852			
4.	1	9.1	9.10	7.00									
						10. [illegible]							
1.	32	23.45	0.733										
2.	6	3.9	0.65	5.333	35.75	18.00	1.9[illegible]	39.[illegible]	2.[illegible]	0.887	9.5	12.5	0.504
3.	2	2.8	1.40	3.00						2.154			
4.	1	5.6	5.60	2.00						4.00			
						11. VEIMATI NADI BASIN							
1.	89	79.45	0.895										
2.	23	26.40	1.148	3.869	129.2	76.00	1.70	53.00	1.539	1.285			
3.	4	19.15	4.787	5.75						4.1[illegible]98	14.00	16.00	0.703
4.	1	4.20	4.20	4.00						0.877			

Contd...

Table VI.1 : Contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					12.	RANI NADI BASIN							
1.	76	102.85	1.353										
2.	21	38.45	1.331	3.619	168.8	124.00	1.361	77.00	0.831	1.353	10.[illegible]	24.00	0.661
3.	5	14.00	2.[illegible]0	4.20						1.529			
4.	1	13.50	1[illegible].50	5.00						4.82[illegible]			
					13.	[illegible]OTA ASCT[illegible] S[illegible] BASIN							
1.	19	10.65	0.[illegible]										
2.	6	5.75	0.5[illegible]	3.156	20.65	7.50	2.75[illegible]	[illegible]	3.[illegible]	1.710	5.00	8.00	0.618
3.	2	3.75	1.75	3.[illegible]0						1.[illegible]57			
4.	1	0.50	[illegible]	2.00						.266			
					14.	[illegible] NADI BASIN							
1.	56	25.50	[illegible]										
2.	10	9.60	[illegible]	3.60	42.25	21.[illegible]	2.012	5[illegible]	[illegible]	1.5[illegible]6	[illegible]	[illegible]	0.75[illegible]
3.	2	4.00	[illegible]	[illegible]						[illegible]			
4.	1	3.15	[illegible].15	2.00						1.[illegible]			
					15.	[illegible] BASIN							
1.	73	60.05	[illegible]										
2.	18	23.70	[illegible]	4.[illegible]55	12[illegible].7	90.[illegible]	1.[illegible]52	7[illegible]	[illegible]	1.[illegible]	16.[illegible]	2[illegible].00	0.598
3.	4	23.95	[illegible]	[illegible]						1.[illegible]			
4.	1	15.00	1[illegible]	1.[illegible]						2.[illegible]			
					16.	[illegible] SUB BASIN							
1.	69	67.85	[illegible]										
2.	20	34.75	1.7[illegible]	3.45	131.75	120.00	1.[illegible]	4[illegible]	.[illegible]	1.[illegible]7	14.[illegible]	1[illegible].00	0.583
3.	7	14.90	2.1[illegible]	.[illegible]57						1.[illegible]			
4.	2	6.60	[illegible]	3.50						[illegible]			
5.	1	5.65	5.[illegible]	2.[illegible]0						1.514			
					17.	[illegible]							
1.	15	18.7	1.[illegible]47										
2.	3	7.5	2.5[illegible]	5.[illegible]0	32.[illegible]0	74.00	0.458	3[illegible]	0.[illegible]57	2.005	12.50	14.00	0.776
3.	1	7.7	7.7	3.00						3.[illegible]8			
					18.	DHIRTI – GHARAT[illegible] SUB BASIN							
1.	23	12.3	[illegible].535										
2.	6	6.25	1.04	3.83	24.35	52.00	0.761	32.00	1.[illegible]12	1.944	[illegible].00	6.35	0.798
3.	3	2.1	.7	2.30						.373			
4.	1	3.7	3.7	3.00						5.236			

Contd...

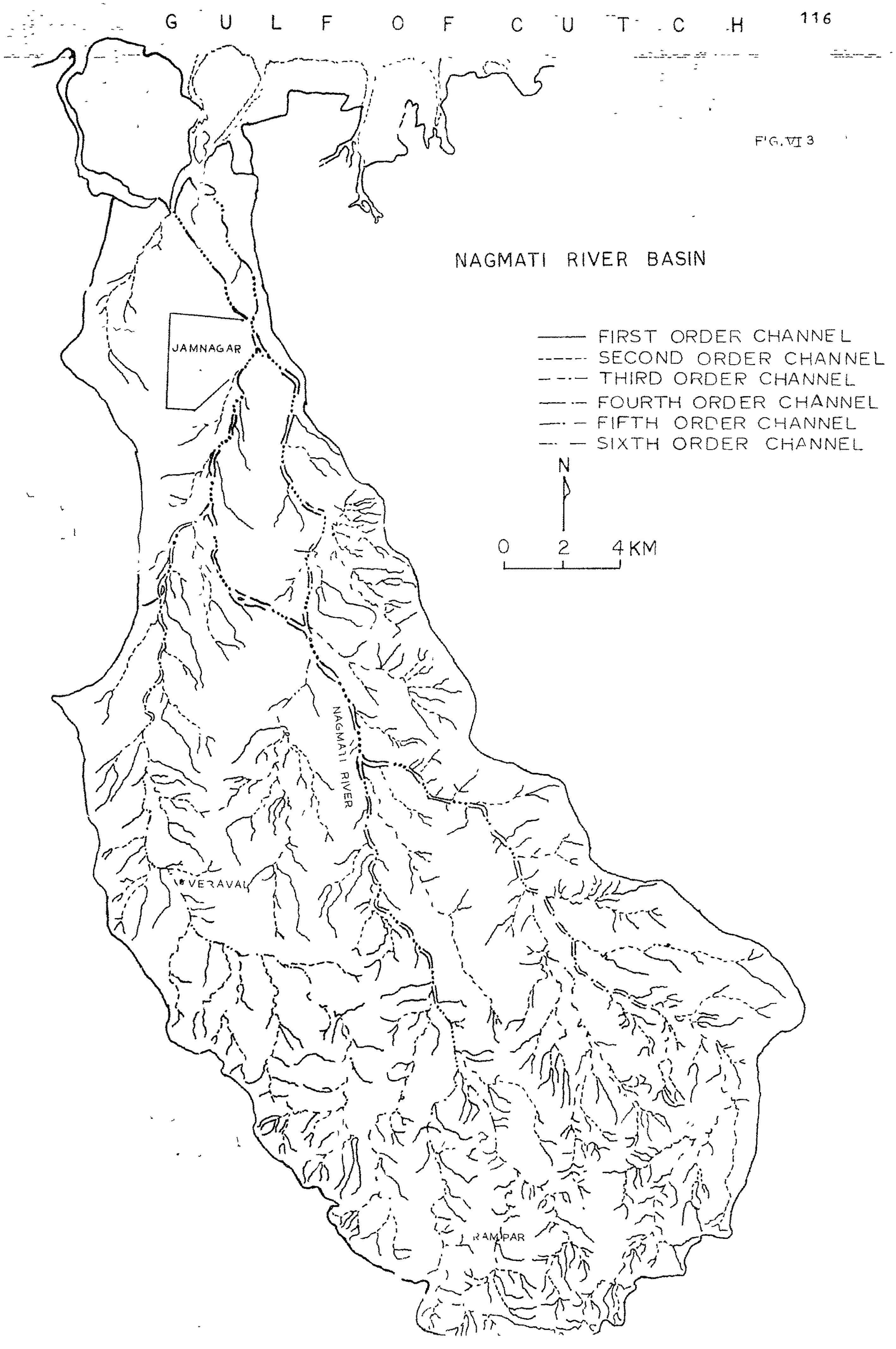
Table VI .1 : Contd.

1	2	3	4	5	6	7	8	9	10	11
						BHARANA - SINGAG. [illegible]				
1.	130	91.[illegible]	0.705							
2.	25	21.9	0.376	[illegible].2	110.35	47.00	2.518		3.447	1.242
3.	7	4.85	0.093	5.571						.791
						TOTVAD - [illegible]				
1.	81	[illegible]	[illegible]							
2.	21	2 .3	[illegible]	3.057	86.00	42.00	2.060	65.[illegible]	2.548	1.4[illegible]0
3.	4	8.45	[illegible]	5.25						[illegible]
4.	1	5.65	4.[illegible]							[illegible]74
						[illegible]A ASHTA AREA				
1.	35	21.05	[illegible]							
2.	7	5.0	[illegible]	5.[illegible]	27.75	10.[illegible]	2.775		4.[illegible]	1.3[illegible]
3.	1	1.1	[illegible]	7.[illegible]						1.375
						BHI - ATIANAND[illegible] - [illegible]				
1.	235	135.50	[illegible]							
2.	58	49.45	[illegible]	4.052	204.[illegible]	71.70	2.257		4.254	1.470
3.	11	17.60	1.[illegible]	5.275						1.[illegible]79
4.	1	2.30	[illegible]	11.[illegible]						1.437
						SOINDS - GAO[illegible] - [illegible] AREA				
1.	54	60.15	1.114							
2.	10	25.[illegible]	1.[illegible]17	5	[illegible]4.[illegible]	151.00	0.724		0.5[illegible]	1.[illegible]72
3.	4	9.20	2.5[illegible]	4.[illegible]						1.523
						[illegible] AREA				
1.	122	91.5	0.75	4.21						1.[illegible]
2.	29	26.55	[illegible].15	4.23	1[illegible]7.00	362.73	055		0.473	1.631
3.	6	8.05	1.492							

1 : 50,000 Survey of India Toposheets. The data obtained were utilized to have comparative studies of the different basins. The drainage characteristics of the various basins were compared following the Horton's laws of Morphometry (1945) modified by Strahler (1956). The verious basins, falling within the two different lithological and climatological environments show quite different characteristics.

2) Morphometric Parameters

The morphometric parameters investigated for each basin include the various linear, areal and relief aspects. Among the linear aspects, the relationship of various stream orders with the number of channels and stream lengths have been investigated. The smallest finger-tip tributaries are designated as first order. Where the two first order channels join, the channel segment of second order is formed and so forth. The channels of higher order also receive the drainage of the smallest orders (Fig. VI.3 to VI.7).


G U L F O F C U T C H
FIG. VI 3
NAGMATI RIVER BASIN
FIRST ORDER CHANNEL
SECOND ORDER CHANNEL
THIRD ORDER CHANNEL
FOURTH ORDER CHANNEL
FIFTH ORDER CHANNEL
SIXTH ORDER CHANNEL
N
0 2 4 KM
JAMNAGAR
NAGMATI RIVER
VERAVAL
RAMPAR


GULF OF KUTC
SALAYA
GHI RIVER
SINHAN RIVER
KHAMBHALIYA
N
0 2 4 KM
FIRST ORDER CHANNEL
SECOND ORDER CHANNEL

DRAINAGE OF SASOI AND PHULJAR RIVERS

FIG. VI.5

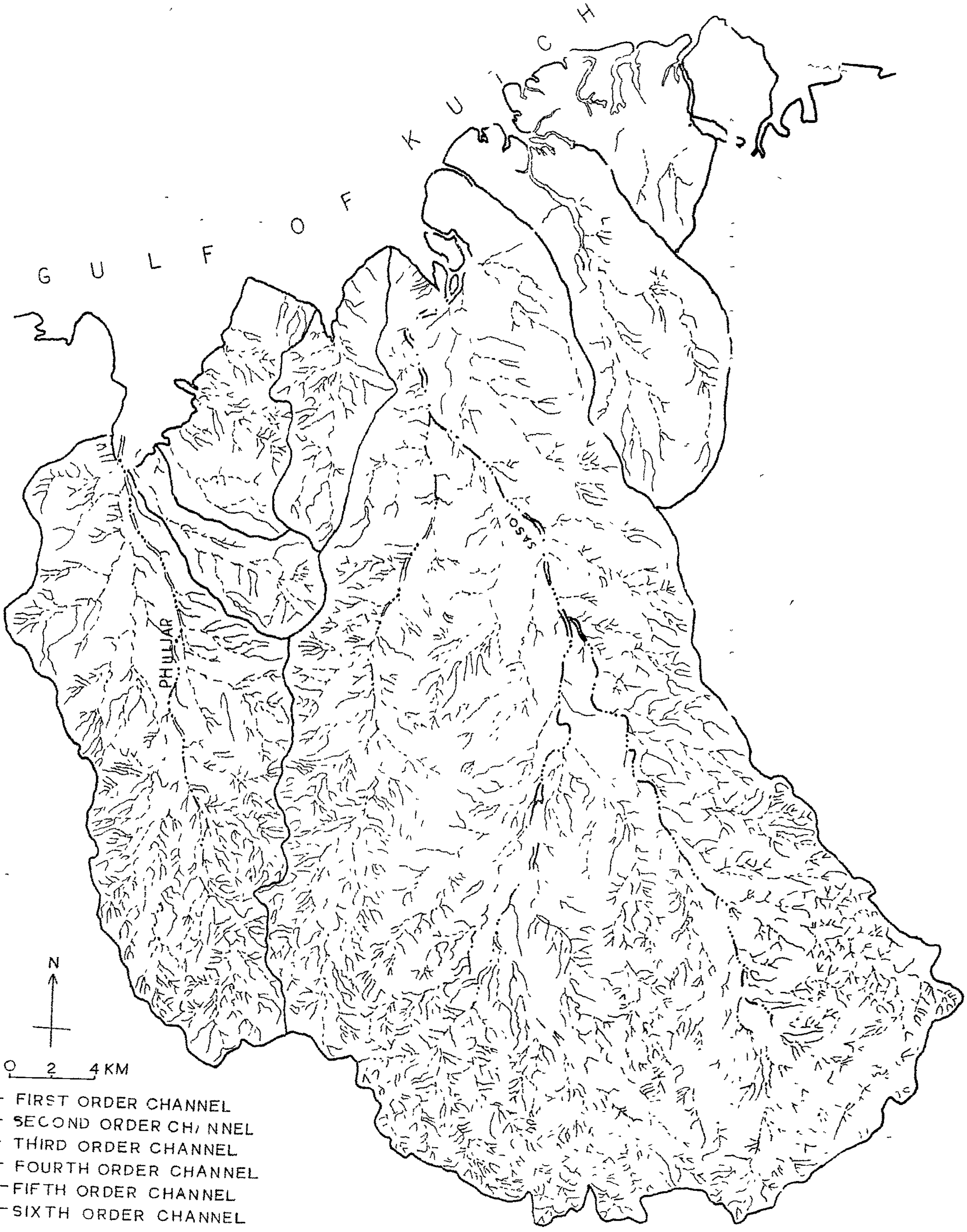
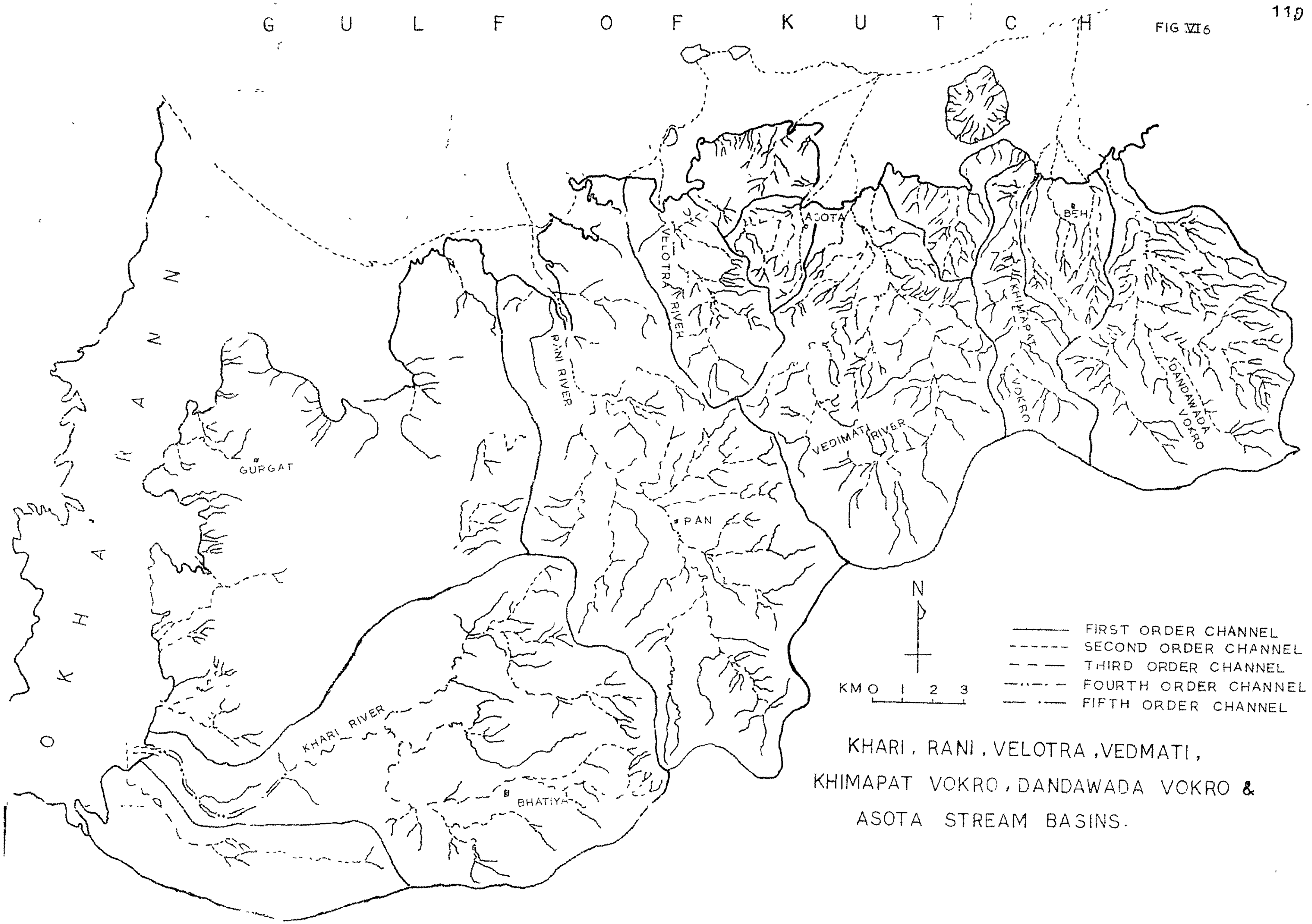
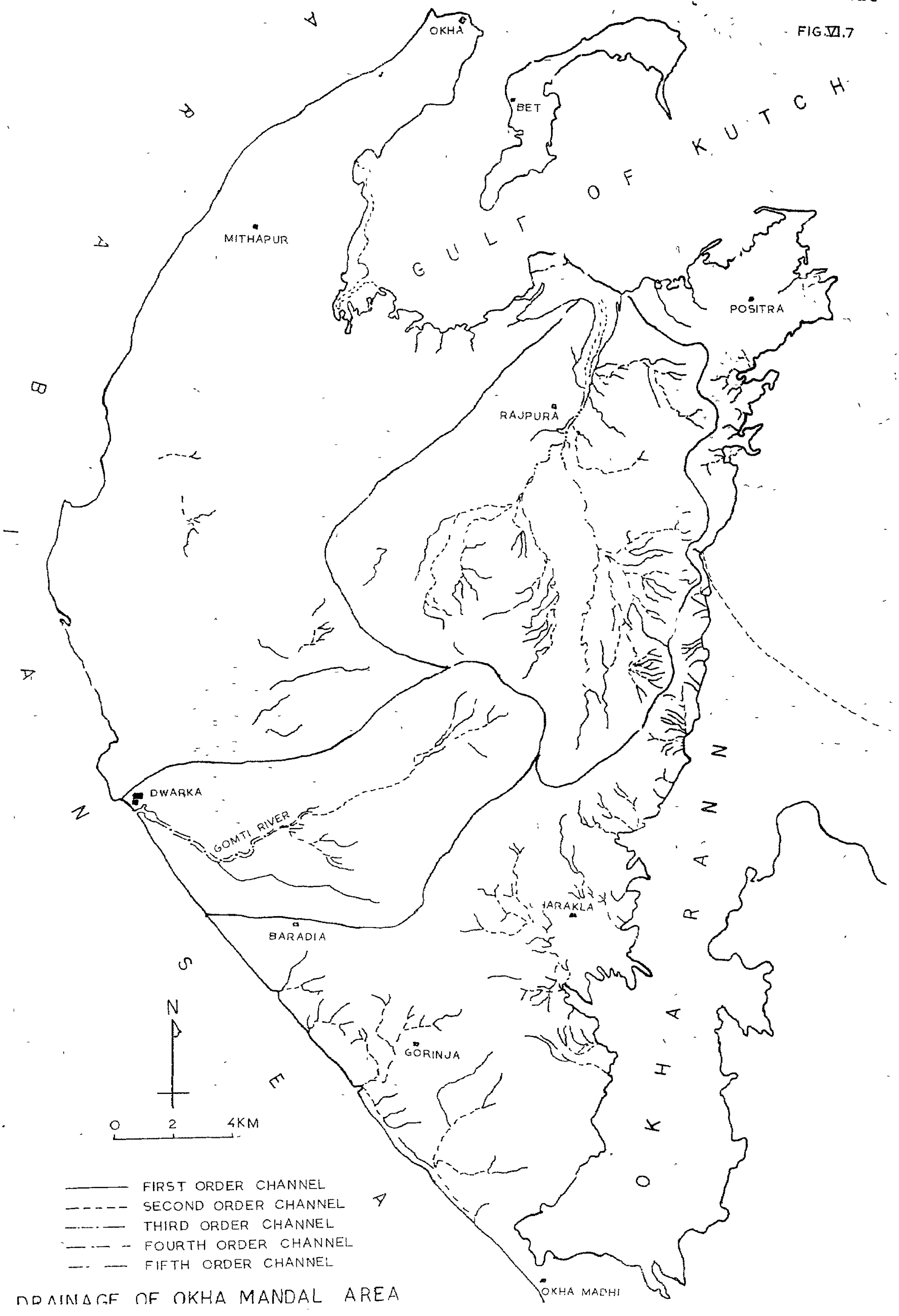


FIG VII 6



KHARI, RANI, VELOTRA, VEDMATI, KHIMAPAT VOKRO, DANDAWADA VOKRO & ASOTA STREAM BASINS.

FIG.VI.7



DRAINAGE OF OKHA MANDAL AREA

3) Parameters Studied

In all 18 basins and 6 interbasinal areas have been evaluated, and along with the characters of each basin, the author has calculated following parameter values for the whole area.

1) Channel order
2) Length
3) Area
4) Maximum Altitude of Basin
5) Basin Relief
6) Stream Frequency
7) Drainage Density
8) Bifurcation Ratio
9) Elongation Ratio
10) Weighted Mean Bifurcation Ratio
11) Relief Ratio

The first four parameters could be directly measured while the remaining ones have been calculated. Basin Relief is the difference between the highest and lowest points (i.e. M.S.L.). Stream Frequency is the number of stream segments per unit area. Drainage Density is the ratio of total channel segment lengths calculated for all orders within a basin to the basin area as projected on horizontal plane. Bifurcation Ratio is the ratio between the number of segments of a given order to the number of segments of the next higher order. Elongation Ratio (Schumm, 1956) is the ratio of diameter of a circle of the same area as the area of the basin to the maximum length of the basin. Weighted Mean Bifurcation Ratio is obtained by multiplying the bifurcation ratio for each successive pair of order by the total number of streams involved in the ratio and taking the mean of the sum of these values. Relief Ratio, a dimensionless number is the ratio between maximum basin relief and the horizontal distance parallel to the main drainage line (Schumm, 1956). It is a measure of overall steepness of the drainage basin.

4) Drainage Characteristics of Mainland Basins

As a whole, the mainland area to the east being triangular in shape, morphometric parameters do not hold good for comparison. The stream lengths do not provide adequate comparison of various morphometric parameters. The 4th order tributaries of some of the bigger rivers in the east being far away from the coast and at higher altitude differ from those (4th order) of the coastal streams in the west and north in all aspects. Hence a comparison could be made only of those 4th order streams that are close to the spots where they meet the sea.

The following basins were taken into account for comparison :

1) Lakhabawal stream (west of Jamnagar)
2) Padana stream
3) Khavdi stream
4) Dandawada vokro stream
5) Khimapat vokro stream
6) Vedmati river
7) Rani Nadi
8) Mota Asota stream
9) Velotra Nadi
10) Khari Nadi

Morphometric studies of the drainage network components of the study area included measurements of stream channel lengths and drainage basin areas for all stream orders, so that each component could be studied independently. Such analysis permits comparison of the drainage network developed in the area with patterns originating under natural conditions.

The law of stream numbers is (Horton, 1945) as under, "The number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the Bifurcation Ratio". In case of geometric series a straight line of points results if the number of streams of each order are plotted on a logarithmic scale on the ordinate against order numbers on an arithmetic scale on the abscissa (Fig. VI.8).

From the graphs it is seen that the plots for the rivers 1) Lakhabawal stream, 2) Khavdi stream, 3) Dandawada Vokro, 4) Vedmati river, 5) Rani river and 6) Khari Nadi almost observe a geometric progression indicating near-normal development while the plotted points for rivers 1) Padana stream, 2) Khimapat Vokro, 3) Mota Asota stream, and 4) Velotra river show upconcavity, indicate under development of the individual basins, pointing to a rejuvenation of the area.

The high order rivers like Nagmati, (5th order) Sasoi (6th order), Phuljar (5th order), Ghi (6th order) and Sinhan (5th order) show that they have attained normal stage of development and nowhere,

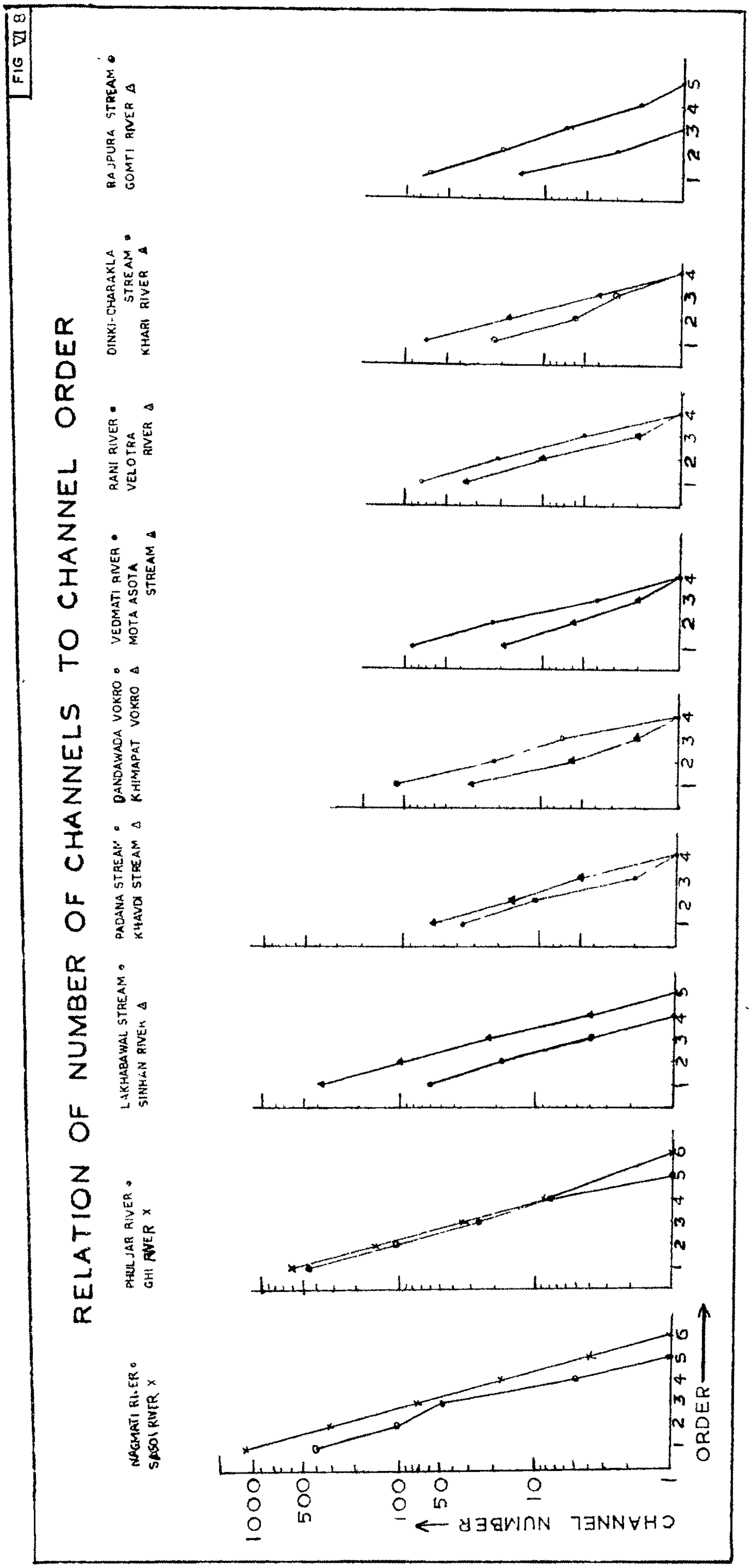


FIG VI 8
RELATION OF NUMBER OF CHANNELS TO CHANNEL ORDER
NAGMATI RIVER o
SASOI RIVER x
PHULJAR RIVER o
GHI RIVER x
LAKHABAWAL STREAM o
SINHAN RIVER Δ
PADANA STREAM o
KHAVDI STREAM Δ
DANDAWADA VOKRO o
KHIMAPAT VOKRO Δ
VEDMATI RIVER •
MOTA ASOTA STREAM Δ
RANI RIVER •
VELOTRA RIVER Δ
DINKI-CHARAKLA STREAM •
KHARI RIVER Δ
RAJPURA STREAM o
GOMTI RIVER Δ
1000
500
100
50
10
1
CHANNEL NUMBER
ORDER
1 2 3 4 5 6

over development of basins is observed. Thus, these rivers also point to the phenomenon of rejuvenation of the area by increasing gradient and scope for the development of basins.

The Drainage Density and Stream Frequency values are also low than required for the well drained basins.

Mean Bifurcation Ratio is the ratio of total number of streams of one order to that of the next higher order (Horton, 1945). Because of chance irregularities, bifurcation ratio between successive pairs of orders may differ within the same basin even if a general observation of a geometric series exists. For more representative bifurcation number, Strahler (1953) therefore used a Weighted Mean Bifurcation Ratio obtained by multiplying the bifurcation ratios for each successive pairs of order by the total number of streams involved in the ratio and taking the mean of the sum of these values. An example from the Khavdi stream is given below :

1. Stream order	2. Number of streams	3. Bifurcation ratio	4. Number of streams involved in ratio	5. Products of Columns 3 & 4
1.	60	3.75	76	284.00
2.	16	3.20		
3.	5		21	67.20
4.	1	5	6	30.00

Total No. of streams used in Column 4 = 103

Sum of products of column 5 = 381.20

Weighted mean bifurcation ratio $= \frac{381.20}{103}$

$= 3.7$

Accordingly, the 'Weighted Mean Bifurcation Ratio for the various rivers has been calculated (Table VI.2)

Table VI.2

Basins on mainland	Weighted mean bifurcation ratio
Nagmati	3.97
Lakhabawal	3.61
Sasoi	4.41
Padana	3.73

Contd...

Table VI.2(Contd.)

Basins on Mainland Area	Weighted mean bifurcation ratio
Phuljar	4.22
Khavdi	3.71
Ghi	4.02
Sinhan	2.84
Dandawada Vokro	4.96
Khimapat Vokro	4.75
Vedmati	4.23
Rani	3.80
Asota	3.03
Velotra	3.80
Basins on Okha Mandal block	
Dhinki Charakla	3.36
Khari	4.13
Rajpura	3.54

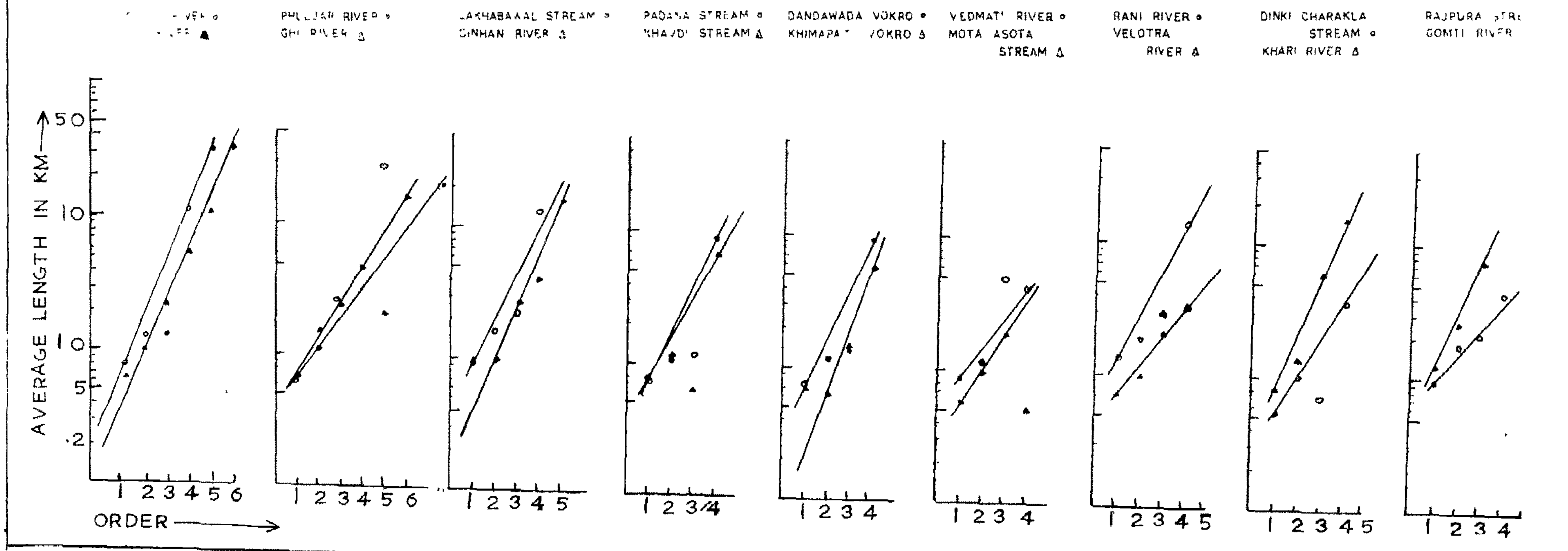
The Second Law of Horton (1945) concerns stream length, "The average lengths of streams of each of the different orders in a drainage basin tend closely to approximate a direct geometric series in which the first term is the average length of streams of the first order".

The average length of streams of each order was obtained by measuring all the drainage channels within a basin of a given order and dividing the sum by the number of channels. This average length was plotted against order number on single log paper (Fig. VI.9). The Nagmati, Ghi, Khari and Gomti rivers tend closely to approximate a direct geometric series. While the rivers Phuljar, Sinhan, Lakhabawal stream, Padana stream, Khavdi stream, Dandawada vokro, Khimapat vokro and Rani Nadi basin systems adhere to Horton's Law of Stream Lengths though the values of higher order channels are high. This might be because of a continued and over development of channels. On the other hand the Mota Asota Stream and Rajpura stream have low values of their 4th order segment. The shortness of 4th order segment of Mota Asota stream basin may be due to the close vicinity of the Gulf.

Small area for the development for Rajpura stream, short length of 4th order channel may be explained due to truncation of the drainage pattern at the front along the Gulf by a recent uplift of the Okha Mandal block.

FIG VI 9

RELATION OF AVERAGE LENGTH TO CHANNEL ORDER



Horton (1945, p. 294) has inferred that Mean Drainage basin Areas of each order should form a geometric series. Plots of the Mean Areas for all fourth order stream basins are shown in (Fig.VI.10) and it is seen that the Vedmati river, Khimapat vokro, Padana stream, Velotra Nadi, Mota Asota stream and Khari Nadi form the geometric series. Characteristically all the basins, except Rani Nadi and Khari Nadi, show a sudden fall in the area occupied by 4th order segment. This feature point to the submergence of the Gulf coast, such that the lower portions of the basins might be under the Gulf water.

The author has also compared the Relief Ratio and Drainage Density for fourth order, fifth order and sixth order channels (Fig. VI.11, Table VI.3) and found a definite positive trend in the mature basins. Most of the points lie above the normal trend and show youthful stages of higher order streams like Phuljar, Ghi, Sinhan and Sasoi river. In these rivers, it is evident that the basins of 5th and 6th order show youthful stage of development.

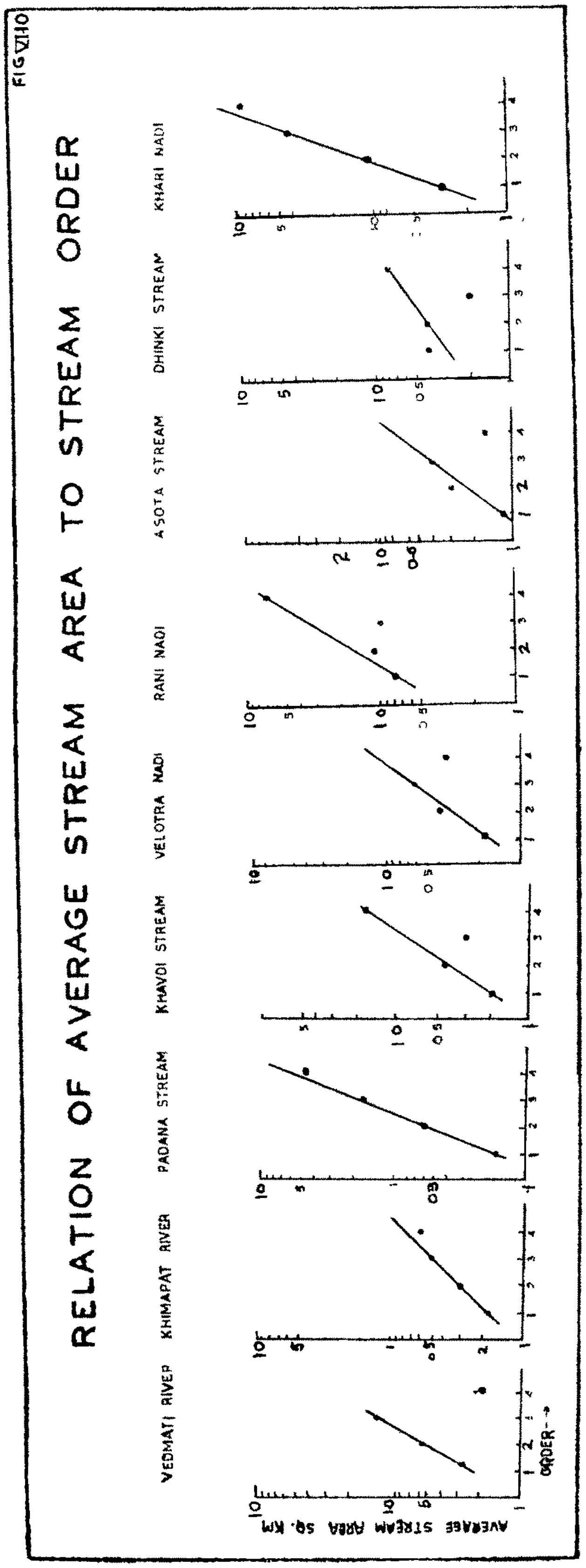
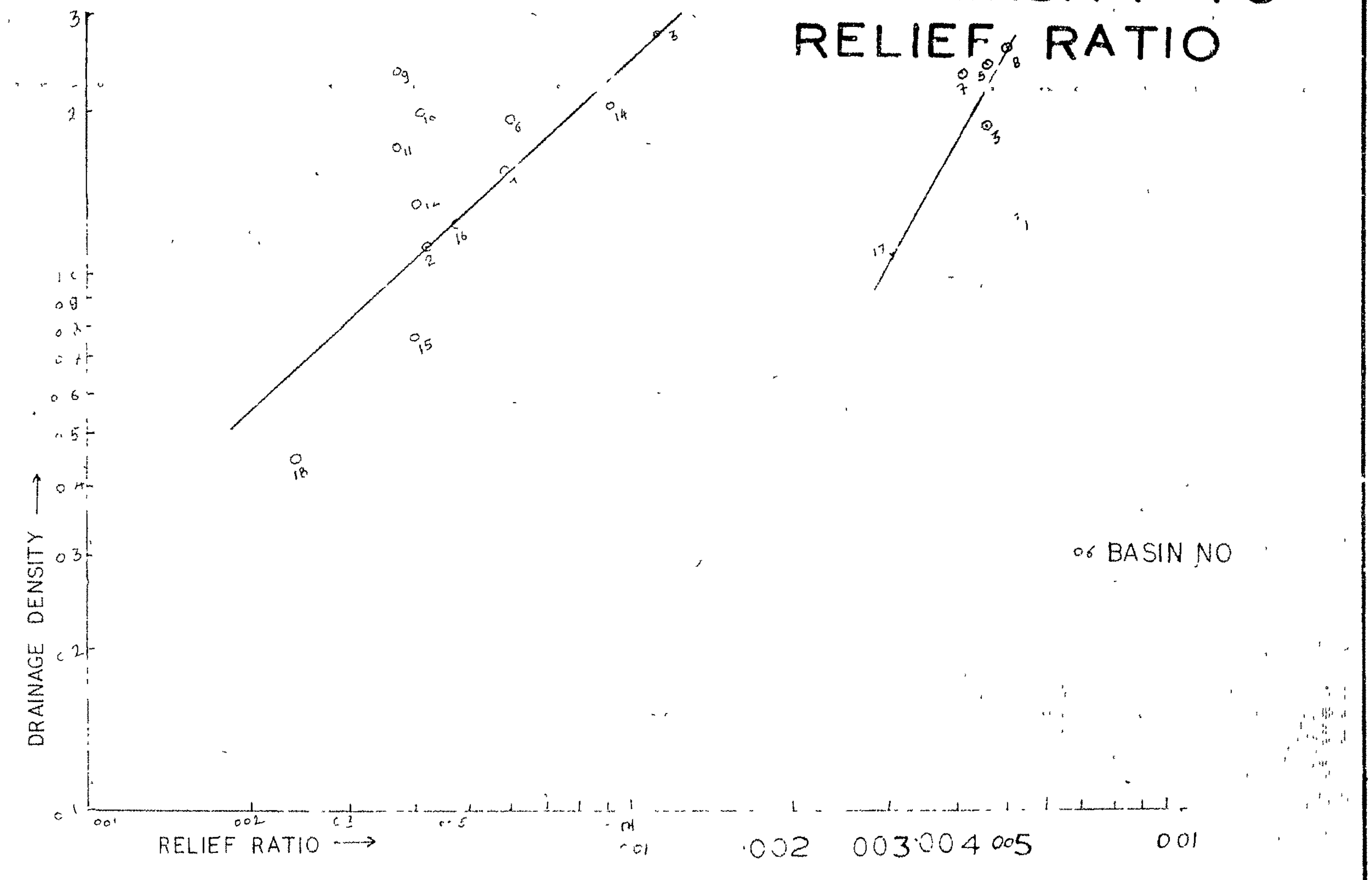


FIG VI.10
RELATION OF AVERAGE STREAM AREA TO STREAM ORDER
VEDMATI RIVER
KHIMAPAT RIVER
PADANA STREAM
KHAVDI STREAM
VELOTRA NADI
RANI NADI
ASOTA STREAM
DHINKI STREAM
KHARI NADI
AVERAGE STREAM AREA SQ. KM
ORDER→

FIG: VI 11

RELATION OF DRAINAGE DENSITY TO RELIEF RATIO



On the other hand, 4th order basins of Dandawada vokro, Khimapat vokro and Vedmati nadi (having low relief) indicate maturity of basins. Their Weighted Mean Bifurcation Ratio is higher in comparison to the remaining basins which have comparatively Low Weighted Mean Bifurcation Ratio (and high relief) and youthful basins.

Table VI.3

Basin Number	Mainland area	Drainage density	Relief ratio
1	Nagmati	1.293	0.0054
2	Lakhabawal	1.109	0.0042
3.	Sasoi	1.910	0.0047
4	Padana	1.557	0.0059
5	Phuljar	2.493	0.0047
6	Khavdi	1.924	0.0060
7	Ghi	2.372	0.0042
8	Sinhan	2.689	0.0051
9	Dandawada vokro	2.360	0.0037
10	Khimapat vokro	1.986	0.0041
11	Vedmati	1.70	0.0037
12	Rani	1.361	0.0040
13	Asota	2.753	0.0114
14	Velotra	2.012	0.0092
15	Khari	1.252	0.0048
	Okha Mandal Area		
16	Dhinki Charakla	0.761	0.0040
17	Rajpura	1.098	0.0031
18	Gomti River	0.458	0.0024

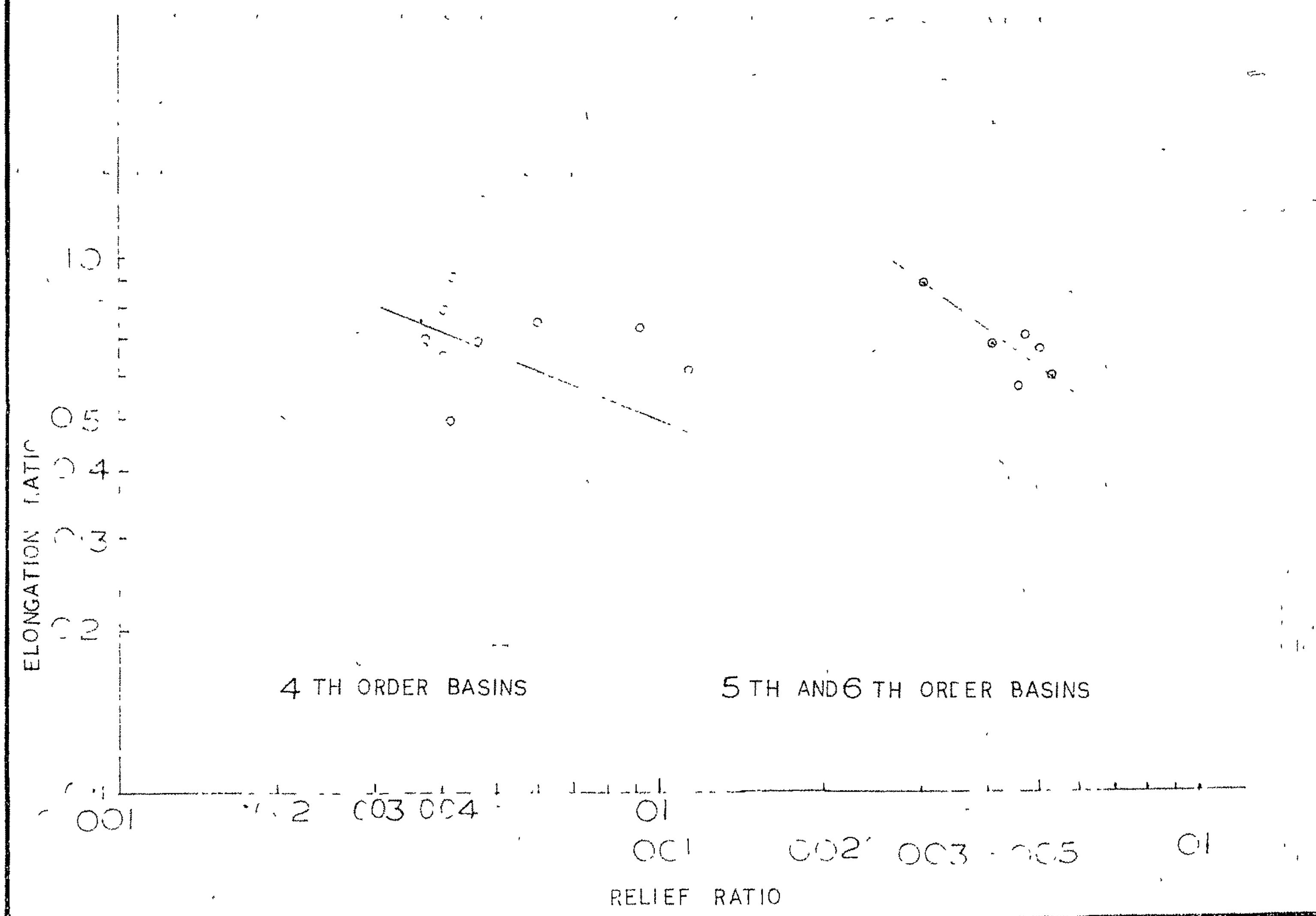
In the Fig. VI.12 shape of the drainage basin is plotted against relief. The trend is negative. Here the comparison is made among 4th order basins. The higher order basins (5th and 6th order) also follow the same negative trend. This indicates that as the relief ratio increases the drainage basin becomes more elongate (Table VI.4).

Table VI.4

Basin Number	Mainland Area	Relief ratio	Elongetion ratio
1	Nagmati	0.0054	0.588
2	Lakhabawal	0.0042	0.921
3	Sasoi	0.0047	0.699
4	Padana	0.0057	0.589
5	Phuljar	0.0047	0.563
6	Khavdi	0.0060	0.762
7	Ghi	0.0042	0.679
8	Sinhan	0.0051	0.661
9	Dandawada Vokro	0.0037	0.689
10	Khimapat Vokro	0.0041	0.504
11	Vedmati	0.0037	0.703
12	Rani	0.0040	0.661
13	Asota	0.0114	0.618
14	Velotra	0.0092	0.739
15	Khari	0.0048	0.698
	Okha Mandal Area		
16	Dhinki charkla	0.0040	0.798
17	Rajpura	0.0031	0.883
18	Gomti River	0.0024	0.776

FIG. VI. 12

RELATION OF ELONGATION RATIO TO RELIEF RATIO



This negative trend is not followed by all basins. For example the plots for basins of Sasoi, Ghi, Lakhabawal, Khavdi, Vedmati, Velotra, Dandavada Vokro, Dhinki-Charakla, Rajpura and Gomti rivers lie well above the negative trend line. This is indicative of increase in Elongation Ratio which is obviously because of the partial submergence of the lower part of the basins of Sasoi, Ghi, Lakhabawal, Vedmati, Velotra and Dandavada Vokro rivers in the Gulf, and truncation of basins of Dhinki-Charakla, Rajpura and Gomti rivers by recent uplift along the faults in Okha Rann and Gulf of Kutch of the Okha Mandal block.

VI.3 COMPARISON OF MORPHOMETRIC PARAMETRES

The comparison of various morphometric parameters for the 4th order basins, that meet the Gulf of Kutch has been made for 1) Drainage Density, 2) Stream Frequency, 3) Bifurcation Ratio, 4) Elongation Ratio and 4) Relief Ratio.

Out of the eleven basins, last three are on the Tertiary limestones, while former eight are on Deccan Trap lava flows. The hardness of the rocks of these two areas differ greatly. The trap rocks have hardness two times more than limestones, hence the rate of mechanical and chemical weathering also differs. In the limestone area rate of headward erosion is more than Trap rocks. Therefore the rate of erosional development to attain maturity or next stage of erosional development is higher in limestone area. The rainfall of the two areas is not equal (Dwarka 200-300 mm and Jamnagar 400-500 mm).

It is important to note that the lengths of basins of limestone region are more than that on trap region. Moreover, the infiltration is more in limestone area with the resultant low values for Drainage Density and Stream Frequency. Basins on the limestone areas show Low Gradient and Higher Elongation Ratio while those of Traps show relatively High Gradient and Low Elongation Ratio. This means that the basins on trap rock are relatively close to youthful stage while those on limestone are attaining maturity.

According to Horton (1945) the basins having drainage density (Dd) more than 2.74 are well drained basins. In the study area Asota stream basin, having 2.75 drainage density and 0.0114 relief ratio, provides an example of a well drained basin.

The other basins having Drainage Density as Khimapat Vokro (Dd 1.986), Dandawada Vokro (Dd 2.36), Khavdi (Dd 1.924), show that they are tending to become well drained basins with high relief on the Trap rocks. On the other hand Rani Nadi, Khari Nadi and Dhinki-Charakla stream basins have low Drainage Densities i.e. Rani (Dd 1.36), Khari nadi (Dd 1.25) and Dhinki Charakla (Dd 0.761) and low Relief Ratio, hence are poorly drained basins on the limestones.

The Stream Frequencies are also indicative of lithologic differentiation (Table VI.5). The stream basins on Trap rock have stream frequencies ranging between 1.5 to 3.7 while on limestone region they are comparatively low between 0.83 to 1.03. This variation in values is mainly because of difference in lithology.

Table VI.5 : Stream frequencies on lithologically differing areas

Sr. No.	Name of Basin	Stream frequency
	Basins on Deccan Trap region	
1.	Lakhabawal stream	0.865
2.	Padana stream	1.545
3.	Khavdi stream	2.216
4.	Dandawada vokro	2.699

Contd...

Table VI.5 (Contd.)

Sr. No.	Name of Basin	Stream frequency
5.	Khimpat vokro	2.277
6.	Mota Asota stream	3.733
7.	Vedmati nadi	1.539
8.	Velotra nadi	2.33
	Basins on limestone region	
9.	Rani nadi	0.831
10.	Khari nadi	0.979
11.	Dhinki Charakla stream	1.031
12.	Rajpura stream	0.825
13.	Gomti nadi	0.257

VI.4 CONCLUSIONS

The drainage study has adequately thrown light on the nature and evolutionary history of the river basins of the study area. Within a small area of about 3557 sq km, characterised by topographic variations, lithological differences, tectonic factors and climatic differences, the drainage characteristics show an interesting diversity, which is the sum total of the effects of the above mentioned phenomenon during the Quaternary period.

Lithology has controlled the Drainage Density and stream Frequency. The trap areas to the east of Okha Rann, have given rise to numerous streams with high Drainage Density and high Stream Frequency. While the limestone areas of Okha Mandal block, characterised by high rate of percolation and low rate of surface run off and low water table, contain streams with low Drainage Density and Stream Frequencies.

Variation in rainfall has also added to the diversity. Slightly higher rainfall in the eastern part has given rise to large surface run off resulting into development of large number of streamlets (1st order stream segments), and obviously providing more erosion. On the other hand, the streams in the Okha Mandal, where the rainfall is less, the 1st order segments are always much smaller in numbers.

The most striking and interesting control on the drainage is that of tectonics. The E-W fault that extends along the southern limits of the Gulf of Kutch and the NNE-SSW fault running along the western flank of the Okha Ram, have considerably influenced the drainage behaviour and basin characters. The Gulf fault progressively shows increasing throw westward, while the Okha Rann fault has resulted in the uplift of the Okha Mandal block in comparison to the mainland to the east. The net result is reflected in the progressively increasing negative trend of the Elongation Ratio of individual 4th order basins from east to west resulting in increase in the values of Elongation Ratios. This is due to increasing submergence of the lower part of the basins of the eastern mainland.

On the other hand, the streams of the Okha Mandal block typically shows effects of uplift, pointing to abrupt truncation of lower parts of the basins.