CHAPTER-6

DRAINAGE ANALYSIS

Drainage configuration in tectonically active areas is considerably influenced by movements along pre-existing structures. Indepth analysis of drainage is therefore essential to infer the type and relative degree of tectonic activity in the various tectonogeomorphic zones. The studies by Horton (1945) and Strahler (1964) are classic examples of the information that can be generated by incisive analysis of drainage and landscape. As described earlier, the Kim river basin covers three distinct morphostructural domains which show contrasting characteristics in terms of geology, structure and morphology. Keeping this in view, it was found important to carry out a thorough analysis of the major drainage characteristics of the Kim basin. A detailed description of the tectonic controls on the drainage configuration of the Kim river basin is given in the chapter on Tectonic geomorphology. In this chapter, detailed morphometric analysis of selected drainage parameters, considered unique and significant in the Kim river basin are included

The Kim drainage basin is narrow and elongate in shape whose apex lies to the NNE. The basin is markedly asymmetric as the trunk stream occupies the northern edge of the basin. The drainage density is higher in the upland compared to the alluvial tract. The Kim drainage network is better developed in the NE part of the basin (Fig. 6.1). Most of the channel courses appear to be in conformity with the geological and structural set up. Major drainage patterns noticed in the Kim basin are trellis, radial, and rectangular. The trellis drainage pattern is well developed in the Kim and its sub-basins. The meandering drainage pattern, a characteristic feature of drainage in folded and faulted terrains, is exhibited by the tributaries and the trunk stream of Kim river. The central part of the Kim river basin shows radial drainage pattern. All the major tributaries of the Kim river join it on its left bank such as Tokri and Bhaga rivers the only exception being the Gondhwa river which joins it on the right in morphostructural domain-III (Fig.3.1), which joins it at its right bank. The various river channel exhibits curvaceous nature in all reaches. The channel of the Kim river in the alluvial zone is 30 m to 50 m wide and is deeply incised, forming alluvial cliffs as high as 15 m to 20 m.

DRAINAGE PARAMETERS

The composition of the stream system of a drainage basin is expressed quantitatively with stream order, drainage density, bifurcation ratio and stream length ratio (Horton, 1945). In order to study the drainage network orientation, drainage map of the Kim river basin (Fig. 6.1) was traced from topographic maps (scale-1:50,000)

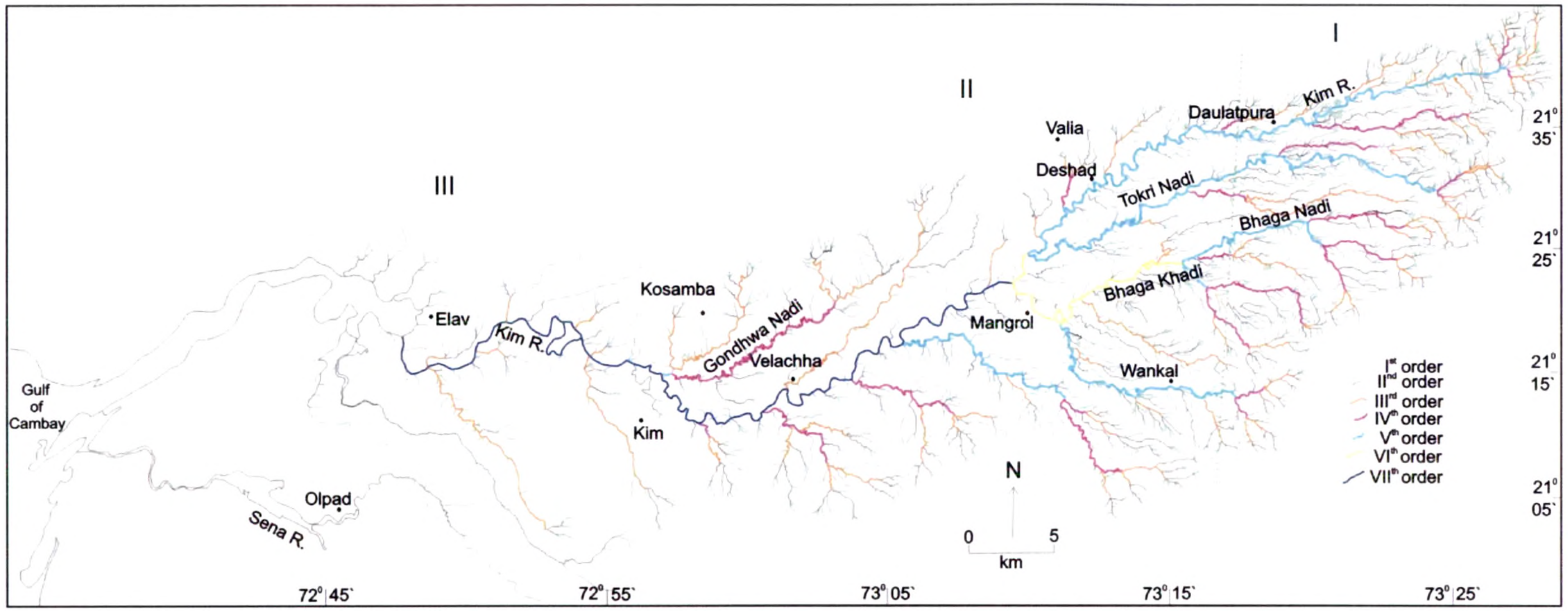

Fig. 6.1 Drainage map of Kim river basin showing the stream orders.

prepared by Survey of India. The analysis was carried out for all the three morphostructural domains since it is likely that streams of different orders are controlled by tectonics in different domains and the whole basin network. The data was obtained, compiled and interpreted for each domain separately before synthesizing the same for comparison purposes. The hydrographic network of each basin was recorded according to the Strahler's (1957) method. The field studies indicate that the stream course follow structural trend which also affect the sinuosity of the channel. In view of this, the stream orientations and sinuosity characteristics of the Kim river basin were taken up for analysis. The bifurcation ratios were calculated as a natural consequence of the stream ordering done for the study and are useful for estimating the degree of dissection of an area. The Kim river has been identified as a seventh order channel (Fig. 6.1).

BIFURCATION RATIO

Bifurcation ratio is the foremost parameter to link the hydrological regime of a watershed to lithological and climatic conditions. The term bifurcation ratio is used to express the ratio of the number of streams of any given order to the number of streams in the next higher order. The bifurcation ratio (Rb) varies from a minimum of 2 in "flat or rolling drainage basins" to 3 or 4 in mountainous or highly dissected drainage basin (Horton, 1945). The bifurcation ratio for Kim river basin as a whole varies from 2.0 to 4.8 In the morphostructural domain-I, the average bifurcation ratio is 3.91 and the maximum bifurcation ratios between 1st and 2nd orders of the Kim basin (Table 6.2). While in the morphostructural domain-II, the average bifurcation ratio is 3.04 and the maximum bifurcation ratio between 2nd and 3rd orders of the basin (Table 6.2). In the morphostructural domain-III, the maximum bifurcation ratio is 5.50 and the maximum ratio between 3rd and 4th order of the Kim basin (Table 6.2). (Table 6.1).

Table 6.1 Bifurcation Ratios of Kim river basin.

Stream Order	No. of Streams	Bifurcation Ratio (Rb)
1	1637	4.80
2	341	4.10
3	83	3.60
4	23	3.28
5	7	3.50
6	2	2.00
7	1	-

The high bifurcation ratio, in all the three morphostructural domains (Table 6.2) is suggestive of a highly dissected and rejuvenated terrain.

Table 6.2 Bifurcation Ratios for different morphostructural domains

	Morphostructural domain-I		Morphostructural domain-II		Morphostructural domain-III	
Stream Order	No. of Streams	Bifurcation Ratio (Rb)	No. of Streams	Bifurcation Ratio (Rb)	No. of Streams	Bifurcation Ratio (Rb)
1	857	5.29	582	4.27	201	4.56
2	162	3.68	136	4.38	44	4.00
3	44	2.93	31	2.81	11	5.50
4	15	3.75	11	1.83	2	-
5	4	-	6	3.00	-	-
6	-	-	2	2.00	-	-
7	-	-	1	-	1	-

STREAM ORIENTATION ANALYSIS

Inferences on the tectonic trends responsible for shaping the drainage basin may be drawn from the analysis of stream channel orientations. Preferred stream orientations usually indicate the dominant structural trend. However, it is common that various orders of streams may show variable preferred orientations. The stream orientation study for Kim basin was carried out for each separate order for each of the morphostructural domains. The direction of each of the stream or reach of a stream was measured and rosettes were drawn from the measured azimuthal data.

Morphostructural Domain- I

In the morphostructural domain-I, the azimuthal distribution of the 1st order streams of Kim river basin shows roughly E-W direction as the most dominant direction (Fig. 6.2). N-S is the other direction of importance next to E-W direction. In the 2nd order streams the dominant directions are E-W, N-S and NE-SW while the 3rd order streams show a dominant direction of NW-SE. The 4th, 5th and 6th order streams show a clear dominance of E-W directions. This indicates that the lower order streams in morphostructural domain-I show the influence of both the E-W and N-S tectonic trends. The higher order streams, however, point to the influence of E-W tectonic trend only. This is in conformity with the field observations which indicate the overall dominance of the E-W tectonic trend on the landscape of the upland zone.

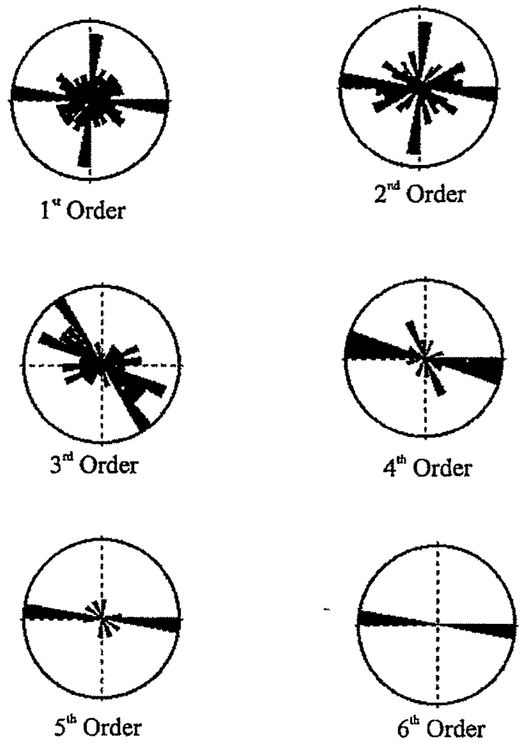

Fig. 6.2 Rosettes showing Stream Order Orientations of domain-I.

Morphostructural Domain-II

The rose diagram of the 1st order stream channels of this domain shows N-S as a prominent direction (Fig. 6.3). The 2nd order streams show dominance of NW-SE direction while N-S and E-W directions are also of some significance. The 3rd order streams are oriented in N-S direction and the 4th order stream in N-S and E-W direction. The 5th and 6th orders streams are very few which show E-W and ENE-WSW directions. In totality the streams of Kim basin show dominance of N-S followed by E-W channel orientation directions in this morphostructural domain-II. The morphostructural domain-II is a zone of extreme tectonic deformation which has strongly controlled the topography. The anticlinal highs and the associated faults in the Tertiary rocks show ENE-WSW as the main and only structural trends. The lower order streams in this domain which show a preferred orientation along N-S and NW-SE direction therefore are in contrast with the dominant tectonic trend. It is inferred that the lower order streams are slope controlled in morphostructural domain-II, which arise from the morphostructural highs and flow down the structural slopes to meet the trunk streams. The 5th and 6th order

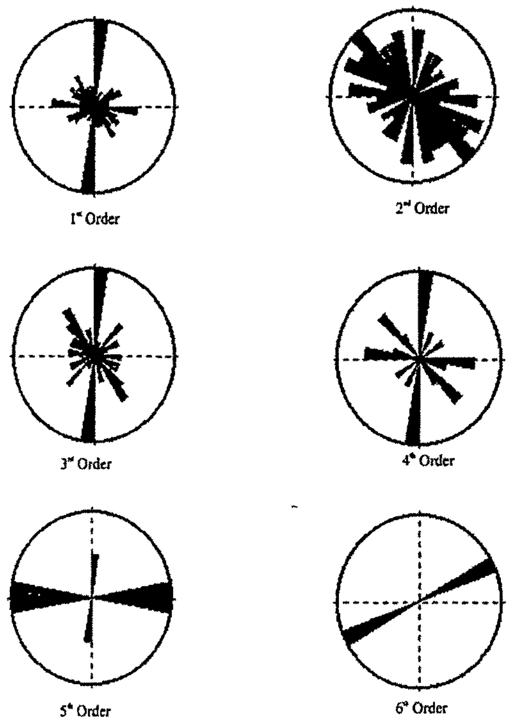

Fig. 6.3 Rosettes of Stream Order Orientations of domain-II.

streams show ENE-WSW and E-W as the dominant direction which is also the general trend of the Kim river suggesting that the dominant E-W tectonic trend controls the major drainage basin in morphostructural domain-II.

Morphostructural domain-III

In this morphostructural domain 1st and 2nd order streams show N-S and E-W as the dominant directions (Fig. 6.4). The 3rd order streams show NW-SE and N-S directions while the 4th order streams are oriented in NE-SW directions. The 6th order streams show roughly E-W direction.

As seen in morphostructural domain-II, the lower order streams in this domain also are slope controlled channels which flow down from the geomorphic highs. The 6th order streams are tectonically controlled and hence show E-W as the dominant stream direction. The stream orientations of the various morphostructural domains were combined and replotted to examine the overall stream directions. The total drainage network of Kim basin shows three main azimuthal directions in N-S, NW-SE and E-W directions.

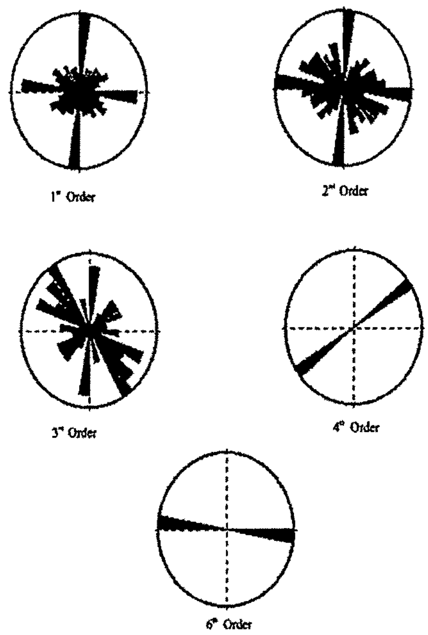

Fig.6.4 Rosettes of Stream Order Orientation of domain-III.

The 1st order streams are oriented in E-W, N-S and NW-SE in their order of importance (Fig. 6.5). The streams of second order also show orientation in E-W, N-S and NE-SW directions. The 3rd order streams show NW-SE and N-S as dominant directions. The 4th order streams show control of E-W, N-S and NE-SW directions. The 5th and 6th order streams show roughly E-W as a dominant direction. The rose diagram of Kim river streams in totality shows, E-W, N-S and NE-SW as main controlling directions. . The E-W trend is reflected by higher order stream channels.

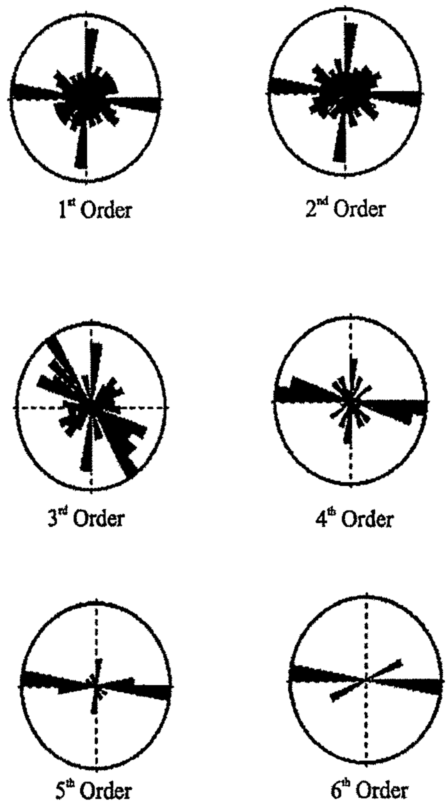

Fig. 6.5 Rosettes of stream order orientation after combining the data from all the three morphostructural domains in Kim river basin.

SINUOSITY PARAMETERS

The channel of Kim river and its tributaries follow highly sinuous courses. The channels are characterized by deeply incised meanders and are structurally controlled. The analysis of the sinuosity characteristics of the various streams was carried to bring out the subtle differences and variations which could then be interpreted in relation to the structural framework and tectonic activity. Various methods for calculation of sinuosity parameters are in vogue. However, the primary requirement of the analysis is the division of the channel into several segments. In general, high values of sinuosity are attributed to tectonic and structural influences. Following Friend and Sinha (1988) the river channels were divided into segments (Fig. 6.2) and the sinuosity parameter for each segment was determined (Table 6.3, 6.4, 6.5, 6.6) using the formula (Fig. 6.6).

$$P = L_{cmax} / L_r ,$$

Where; P is the sinuosity parameter, L_r is the channel segment length and L_{cmax} is the mid-channel length.

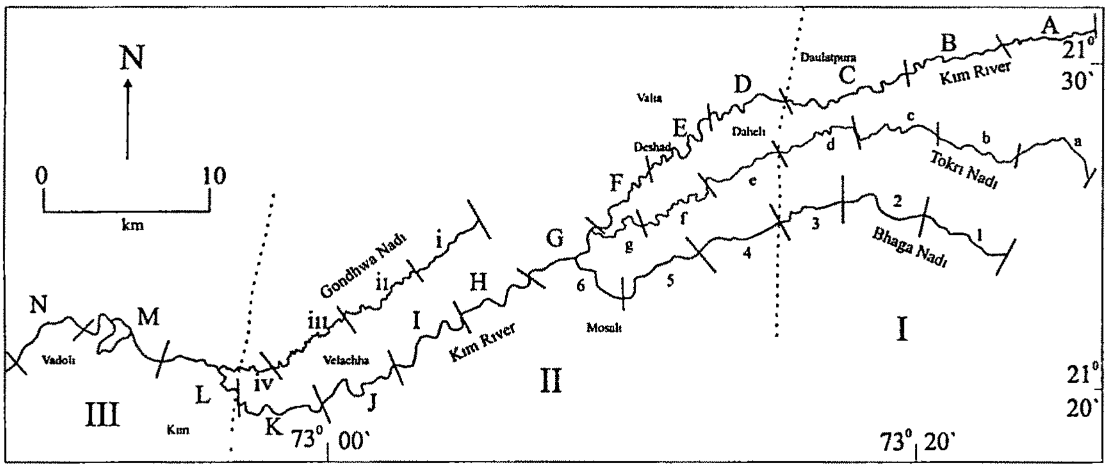

Fig. 6.6 Kim and its tributaries showing various segments taken up for sinuosity studies and sinuosity fractal dimension (SFD) analysis.

The value of sinuosity parameter for Kim river varies form 1.25 to 2.25, for the Tokri river 1.28 to 2.20, for the Bhaga river 1.10 to 1.69 and for the Gondhwa river it varies from 1.68 to 2.80. In morphostructural domain-I, the sinuosity parameter for Kim river and its tributaries varies from 1.25 to 1.80. In the morphostructural domain-II, the sinuosity parameter for Kim river and its tributaries are varies from 1.10 to 2.80 which is

Table 6.3 Sinuosity Parameters of the Kim River basin

Morpho-Structural Domain	Segment No.	Left bank Distance (Kms)	Right bank Distance (Kms)	Average Distance (Kms) Lcmax	Straight Distance (Kms) Lr	Sinuosity P
I	A	7.25	7 25	7.25	5	1.45
	B	6.40	6 15	6.25	5	1.25
	C	8.00	8 60	8.30	6	1.38
II	D	8.10	8 00	8.05	5	1.61
	E	8.10	8.00	8.05	5	1.61
	F	11.2	11.3	11.25	5	2.25
	G	8.50	8.70	8.60	5	1.72
	H	7.20	7.00	7.10	5	1.42
	I	7.60	7.50	7.55	5	1.51
	J	7.20	7.00	7.10	5	1.42
	K	7.80	8.10	7.95	5	1.59
III	L	9.10	8.70	8.90	5	1.78
	M	6.30	6.50	6.40	5	1.28
	N	11.50	7.50	9.50	5	1.90
	O	6.20	6.50	6.35	5	1.27

Table 6.4 Sinuosity Parameters of the Tokri River

Morpho-Structural Domain	Segment No.	Left bank Distance (Kms)	Right bank Distance (Kms)	Average Distance (Kms) Lcmax	Straight Distance (Kms) Lr	Sinuosity P
I	A	6.50	6 50	6.50	5	1.30
	b	6.50	6.70	6.60	5	1.32
	c	8.20	8.50	8.35	5	1.67
	d	5.30	5.50	5.40	3	1.80
II	e	6.50	6.35	6.40	5	1.28
	f	11.00	11.00	11.00	5	2.20
	g	7.50	7.00	7.25	3.5	2.07

Table 6.5 Sinuosity Parameters of the Bhaga River

Morpho-Structural Domain	Segment No.	Left bank Distance (Kms)	Right bank Distance (Kms)	Average Distance (Kms) Lcmax	Straight Distance (Kms) Lr	Sinuosity P
I	1	7.10	7.10	7.10	5	1.42
	2	7.7	7.70	7.70	5	1.54
	3	4.00	4.20	4.10	3.25	1.26
II	4	5.00	5.10	5.05	5	1.10
	5	7.20	6.70	6.95	5	1.39
	6	7.50	8.10	7.80	4.60	1.69

Table 6.6 Sinousity Parameters of the Gondhwa River

Morpho-Structural Domain	Segment No.	Left bank Distance (Kms)	Right bank Distance (Kms)	Average Distance (Kms) Lcmax	Straight Distance (Kms) Lr	Sinousity P
II	i	8 40	8.40	8.40	5	1 68
	ii	12.30	12.30	12.30	5	2.46
	iii	14.00	14.00	14 00	5	2.80
III	iv	6.50	6.50	6.50	3	2 16

quite high. In morphostructural domain-III, the sinuosity parameter for Kim river and its tributaries varies from 1.27 to 2.16.

The values indicate that all the stream channels in the Kim basin show intermediate to high sinuosity. The high values of sinuosity parameter of the Kim basin in the morphostructural domain-II is attributed to the high degree of structural complexity. This is also reflected as a distinct change in meander pattern of the river as it enters morphostructural domain-II.

The sinuosity of a meandering stream is the result of both topographic and hydraulic factors which can be characterised by a ratio called the index of sinuosity (Muller, 1968). The indexes of sinuosity are determined as under:

$$\text{HSI (Hydraulic Sinuosity Index)} = \frac{CI - VI}{CI - 1} \times 100$$

$$\text{TSI (Topographic Sinuosity Index)} = \frac{VI - 1}{CI - 1} \times 100$$

$$\text{SSI (Standard Sinuosity Index)} = \frac{VL}{CL}$$

$$\text{CI (Channel Index)} = \frac{\text{CL (Channel Length)}}{\text{AL (Air Length or Straight Length)}}$$

$$\text{VI (Valley Index)} = \frac{CL}{VL}$$

The sinuosity indexes calculated are shown in Table 6.7. High values of Hydraulic Sinuosity Index (HSI) and correspondingly higher values of Topographic Sinuosity Index (TSI) in the upland zone suggest that the area has been rejuvenated there by indicating the role of tectonic uplift.

Table 6.7 Various parameters for sinuosity indexes.

Segment No.	Air Length AL	Channel Length CL	Valley Length VL	SSI= CL/VL	HSI= CI-VI X100 / CI -1	TSI= VI- 1X 100 / CI-1	CI=CL/AL	VI= VL/AL
A	5	7.25	7.10	1.02	6.66	93.33	1.45	1.42
B	5	6.25	6.20	1.00	4.00	96.00	1.25	1.24
C	6	8.30	8 00	1.03	13.15	86.84	1.38	1 33
D	5	8.05	8.00	1.00	1.63	98.36	1.61	1.60
E	5	8.05	7.95	1 01	3.27	96.72	1.61	1.59
F	5	11.25	11.10	1.01	2.40	97.60	2.25	2.22
G	5	8.60	8.45	1.01	4.16	95.83	1.72	1.69
H	5	7.10	7.00	1.01	4.76	95.23	1.42	1.40
I	5	7.55	7.40	1.02	5.88	94.11	1.51	1.48
J	5	7.10	7.00	1.01	4.76	95.23	1.42	1.40
K	5	7.95	7.80	1.01	5.08	94.91	1.59	1.56
L	5	8.90	8 70	1.02	5.12	94.87	1.78	1.74
·M	5	6.40	6.15	1.04	1.78	82.14	1.28	1.23
N	5	9.50	9.30	1.02	4.44	95.55	1 90	1.86
O	5	6 35	6 15	1.03	14.81	85.18	1.27	1.23

This is observed in the basinal part in the lower reaches where there is a relative decrease in Hydraulic Sinuosity Index (HSI) though it remains substantially lower than the Topographic Sinuosity Index (TSI) (Table). In all the morphostructural domains, the Topographic Sinuosity Index (TSI) is greater than the Hydraulic Sinuosity Index (HSI) indicating a dominant control of topography which shows a obvious control of the structural and tectonic framework in Kim river basin.

Sinuosity fractal dimension

To characterise the amount of sinuosity of a river channel Sinuosity fractal dimension (SFD) has been used (Rhea 1993, and Snow, 1989). According to Richardson (1961) a log-log plot of total length against unit length approximates a straight line with finite slope. Subtracting the slope from one gives the value of Sinuosity fractal dimension (SFD). Snow (1989) indicated that the lower values of SFD points to a less sinuous course of the river and high values to a more sinuous course. Rhea (1993) used this to indicate the role of tectonism.

The wiggles studied for sinuosity fractal dimension of the Kim river and its various tributaries are shown in (Fig. 6.3). The representative graphs obtained by plotting log unit length versus log ruler length for calculating the sinuosity fractal dimensions (Table 6.8) of Kim river are shown in Fig. 6.7.

The sinuosity fractal dimension (SFD) values of the Kim river basin show interesting patterns. The sinuosity fractal dimension (SFD) values are lowest in the upland areas whereas they tend to increase towards the lower reaches suggesting that the increase in sinuosity in the morphostructural domains II and III could be due to rejuvenation of the area in the recent geologic past. The rivers on the right flank of Kim in the uplands i.e. Gondhwa river shows variable sinuosity fractal dimension (SFD) values. This may be due to the fact that it flows in the transitional zone between morphostructural domains II and III.

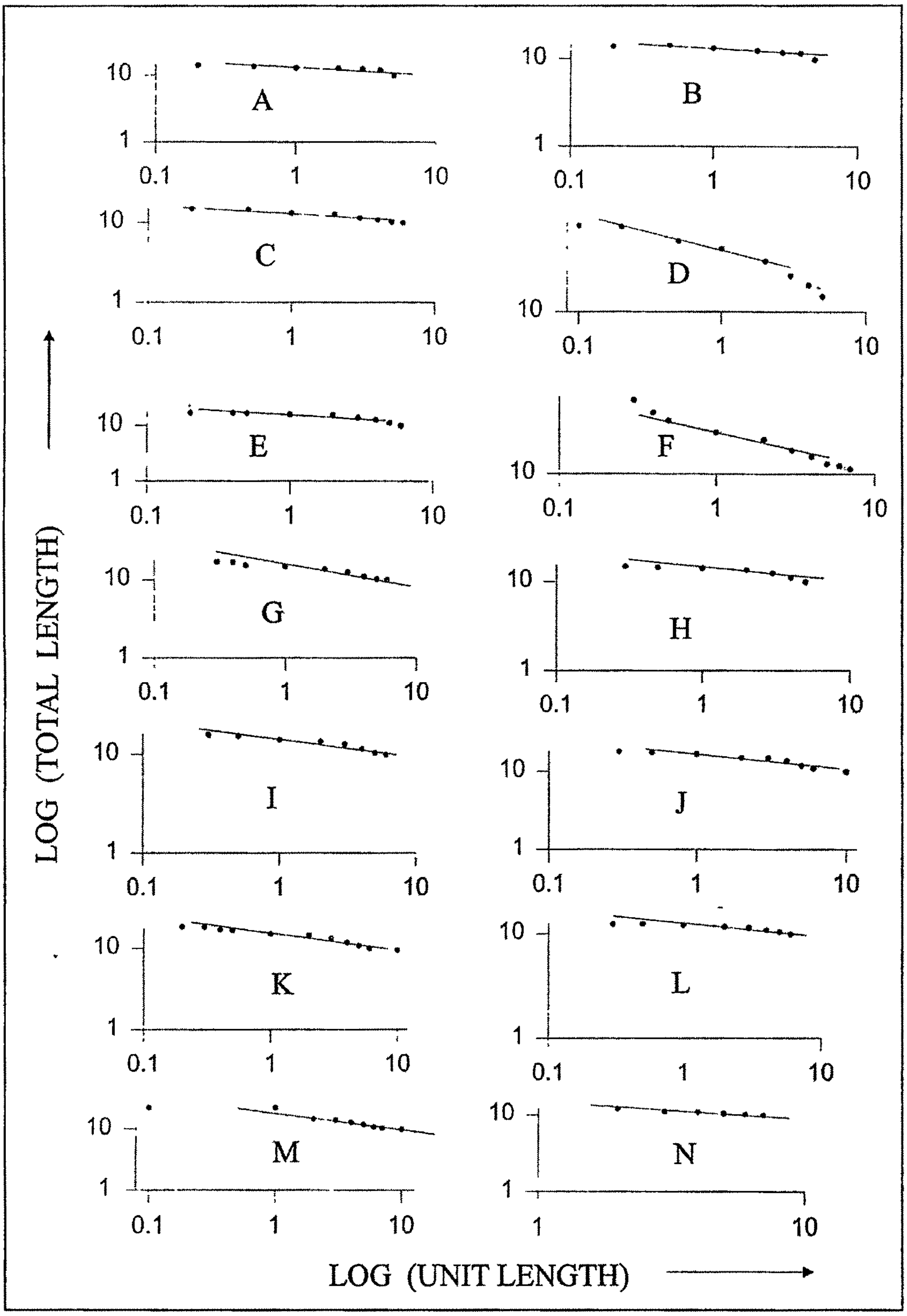

Fig. 6.7 Richardson plots for various wiggles studied for Kim River.

Table 6.8 Calculated values of sinuosity fractal dimension (SFD)

Segment No.	SFD Value
A	1.693
B	1.746
C	1.925
D	1.920
E	1 775
F	1.984
G	1.942
H	1.806
I	1.898
J	1.873
K	1.949
L	1.832
M	1.822
N	1.984

A remarkable correlatability is thus observed in the pattern of sinuosity fractal dimension values and the sinuosity parameters and indexes. Higher values of sinuosity fractal dimension are corroborated by higher sinuosity indexes (SSI and TSI).