CHAPTER III
DRAINAGE

3.1 The Fluvial System

The Sita-Swarna fluvial system is a seventh order stream. It conforms to the category of an exohoreic river system since it originates on the precipitous Western Ghats in the east, transcends the prominent scarp face of the Western Ghats, flows west, and empties into the Arabian Sea. The principal streams that contribute to the Sita-Swarna drainage net are the Sita Nadi and the Swarna Nadi. Both these streams are of the sixth order. The lower order streams that constitute the drainage net of these tributaries, find their origin on the Western Ghats, that is dominated by the younger Greenstone lithoclan. It is these metasediments and metavolcanics that provide the significant morphoelement known as the Western Ghats, that acts as the water divide for the west-flowing and east-flowing rivers of the southwestern part of the Indian peninsula.

In course of these minor streams flowing down the scarp face and adjacent ridges, they assume two prominent drainage axes. The establishment of these axes initiates the entire drainage system with a general orientation of east-west. The culmination of these two sub-systems near the town of Bokapatna, increase the hierarchy to a maximum of the seventh order. The Sita-Swarna river drains an area of 1322 square kilometers, that is made up of granitic gneisses of the Peninsular Gneissic complex, the most dominant lithological unit. The younger Greenstones and laterites are the other less dominant lithological units that provide the initial surface for the genesis of streams.

3.2 The Sita Nadi Drainage Axis

The Sita Nadi is one of the two sixth order streams of the Sita-Swarna fluvial system. It traverses nearly 62.5 kilometers before it merges with the Swarna Nadi in the west.

From its origin at an elevation of 134 meters, the main stream of Sita Nadi orients itself in the SE - NW direction, almost parallel to the trend of the Western Ghats. The stream in this sector is twenty kilometers long. The gradient is about 4.25 meters per kilometer. Near the hamlet of Kanabettu, the Golihole, contributes as a major tributary and at this point
the Sita Nadi realigns its course to the NE-SW direction for five kilometers. The stream, here, experiences a gradient of 1.8 meters per kilometer. At the foot of the Killil Gudda hill, the river reorients its course to the SE-NW flowing for a distance of fifteen kilometers. The stream gradient gradually drops to about 1.3 meters per kilometer. Near the town of Avarshe, the Sita Nadi realigns its course to the NE-SW for a distance of 11 kilometers, prior to which the Honakal Halla a lower order tributary joins the main stream of the Sita Nadi. The stream gradient is less than a meter per kilometer in this stretch. At the town of Mogari, the Sita Nadi flows for a distance of about 11.5 kilometers in almost an east-west direction and reorients its course in the N-S direction for a distance of 4.5 kilometers, prior to its reorientation the Balakattu hole merges with the main stream. At the town of Bokapatna the Sita Nadi unites with the Swarna Nadi, the other principle sixth order tributary.

3.3 The Swarna Nadi Drainage Axis

As in the case of the Sita Nadi, the Swarna Nadi too has its genesis in the form of lower order streams on the Western Ghats. The main stream of the Swarna Nadi originates at an elevation of 52.5 meters. It flows for a distance of 54 kilometers. The initial orientation of the mainstream is in the SE-NW direction for a distance of 16 kilometers, the stream gradient in this reach being 1.22 meters per kilometer. In this stretch, from the point of origin, the Happanadaka Hole, a minor stream joins the Swarna Nadi on its northern bank at a distance of 3 kilometers, while the Durga Hole joins the Swarna Nadi's main stream at the southern bank at a distance of 6.5 kilometers. Further north-west, at a distance of 11 kilometers the Andar hole joins the Swarna Nadi, while at the 16th kilometer, the Kada Hole contributes to the drainage net of the Swarna Nadi. The Swarna Nadi now flows for a distance of 38 kilometers and unites with the Sita Nadi. The average stream gradient is around 0.45 meter per kilometer. The Madisal Hole is the most prominent tributary of the Swarna Nadi, it originates on the Western Ghats, flows NE-SW and joins the Swarna Nadi at a distance of 35 kilometers near the town of Bhadra Giri.

The dominant bed material of these rivers are boulder-cobble-pebble assemblage (Plate Va) in the initial course, the lithological make-up being meta-sediments and meta-volcanics, the basic constituents of the younger Greenstones. While down stream, the lower reaches exhibit pebbles
and coarse-grained sand, grading to finer particle size.

3.4 Dominant Sub-basins

Some of the main streams (Fig. 6) that coalesce to form the Sita Nadi are

a) The Markal Hole
b) The Nemar Hole
c) The Meggade Hole
d) The Kollangar Hole

These streams, apart from being dominated by the younger Greenstones terrain, restrict their basin boundaries to the Western Ghat Scarp. Seventeen prominent peaks contribute to the formation of this watershed and they range from a minimum elevation of 675 to 1150 meters.

As in the case of the Sita Nadi, the Swarna Nadi too has a crown of streams composed of five lower order tributaries, they are

a) The Machette Hole
b) The Durga Hole
c) The Kada Hole
d) The Andar Hole
e) The Happanadaka Hole

The Madisal Hole, a major tributary of the Swarna Nadi, too, originates with a cluster of lower order streams originating at higher elevations. They are

a) The Mathebett Hole
b) The Kelakila Hole
c) The Jaravattu Hole

Some salient features of these streams are presented below.

The Markal Hole

The drainage net of the Markal Hole consists of 52 first, twelve second and four third order streams. Together they possess a channel length
of thirty-five kilometers. The principle drainage axis of the Markal Hole is oriented in the SW-NE direction. The direction of this axis expresses the alignment of the longitudinal consequent streams. The area drained by the Markal Hole is 11.12 square kilometers. The initial relief of the Markal Hole is provided by the Begged Gudda, a prominent peak with an elevation of 1018 meters. Other topographic elevations average 800 meters. The channel consists of boulder-cobble-pebble assemblage with coarse sand, an uncommon entity. The width of the channel varies from four to six meters. The mouth of the Markal hole is located at an elevation of 134 meters.

The Nemar Hole

The Nemar Hole is a fourth order stream. It drains twenty-five square kilometers of the younger Greenstone-Peninsular Gneissic terrain. The hundred and twenty seven first order streams contribute to the formation of the drainage net. These first order streams express the initiation of lateral consequents that are the actual sustainers to the principal consequent (longitudinal) streams. A total of one hundred and fifty eight streams constitute the Nemar Hole drainage net. The total stream channel length is eighty six kilometers. The principal drainage axis is oriented in the SE-NW direction. There is more than one peak constituting the watershed of the Nemar Hole. The highest peak being the Sujikal Gudda with an elevation of 1078 meters. An average elevation of 932 meters is exhibited by other peaks. The channel material is an association of boulder-cobble assemblage. The valley width varies from two to four meters. The Kuduluthirtha is an important tributary of the Nemar Hole. It is entrenched in an arcuate valley.

The Meggade Hole

The Meggade Hole is a fourth order stream. It drains an area of 11.37 square kilometers. The total stream length of the Meggade Hole is thirty-five kilometers. Sixty one streams contribute to the integration of the drainage net. The principal stream is oriented in the SE-NW direction. The channel width is narrow averaging about 4 meters. The bed material is constituted of pebble-cobble-boulder assemblage. The highest peak of the watershed has an elevation of 1150 meters. The basin mouth is located at an elevation of 134 meters. As in the case of the Nemar and the Markal Hole,
the Meggade Hole is also a consequent stream.

The Kollangar Hole

The Kollangar Hole contributes an area of 18.10 square kilometers to the crown of the Sita Nadi. The principal drainage axis is oriented in the E-W direction. The Kollangar Hole too, is a consequent stream generated by the relief provided by the scarp of the Western Ghats. The stream net comprises of 96 first order streams that have a channel length of forty two kilometers, the second order streams have a total length of eleven kilometers, while the third order contribute a length of 6.25 kilometers. The Kollangar hole is a longitudinal consequent, with the lower order streams occurring as lateral consequents. The bed material is typical in consisting of boulder-cobble-pebble assemblage. The width of the channel is narrow ranging from three to four meters.

The Machitte Hole

The Machitte Hole is a fifth order stream. It contributes 297 streams to the crown of the Swarna Nadi, the total area drained by the Machitte Hole is 116.3 square kilometers. There are 226 first order streams, that are products of initial relief, a result of the younger Greenstone and Peninsular Geneissic disposition. These streams behave as lateral consequents. The principal stream axis is aligned in the SE-NW direction. The initial course of the Machitte Hole is aligned in the NE-SW for a distance of 7.5 kilometers and for the rest of the 22 kilometer length the stream orients itself in the SE-NW directions. The important peaks that contribute to the watershed are the Gadikal Gudda (1192 M), Ichal Gudda (814 M), Kornakal Gudda (1160) and Hullu Gudda (840 M). The channel material is of pebble-cobble association (Plate Vb). The Machitte Hole suggests rejuvenation of the area. It has entrenched itself within its channel, exposing the bluffs of the channel consisting of pebbles.

The Kada Hole

The Kada Hole drains an area of 50 square kilometers. The drainage net is an integration of 208 streams of which 164 streams are lateral consequents of the first order. The total channel length is 124 kilometers.
The prominent peaks contributing to the watershed are the Walkunji Gudda (1039 M), and other peaks which range from 348 meters to 409 meters. The principal stream of the Kada Hole is oriented in the NE-SW direction for about 16 Kilometers. The width of the channel is narrow varying from 3 to 6 meters. The bed material is coarse sand and pebble-cobble associations.

The Andar Hole

The Andar Hole drainage net spreads over 47 square kilometers and 208 streams with a total channel length of 122 kilometers are covered into the terrain constituting the watershed. The prominent peaks have an elevation ranging from 413 to 804 meters. The principal stream axis is oriented along its length in the NE-SW direction. The initial course for the first five kilometers is in the NE-SW direction with a sharp turn in the NW for 3.5 kilometers in the later course. These are the only distinct realignments that the stream assumes. The bed material is predominantly pebble-gravel-coarse sand assemblage.

The Hapanadaka Hole

The Hapanadaka Hole is a fifth order stream. It drains an area of 35.12 square kilometers consisting of younger Greenstones and the Peninsular Gneissic complex. The total number of streams constituting the drainage net are 143 of which 107 streams are subsequent and are dependent on the relief provided by the underlying lithology, these streams are all of the first order. The total stream length draining the area is 97 kilometers. The prominent peak of the area is the Anekal Gudda (932 M). The principal stream is oriented in the NE-SW direction with a length of 11.5 kilometers.

The Durga Hole

This is a fourth order stream flowing in the SE-NW direction for a distance of 43 kilometers. The underlying terrain is granitic gneisses of the Peninsular gneissic complex. The stream drains an area of 74.25 square kilometers. Numerous peaks and ridges dominate the watershed, varying in elevation from 104 meters to 368 meters. 110 first order streams contribute to a system of subsequent channels. The bed material is of
The Mathe Bettu Hole

The Mathe Bettu Hole, a fourth order stream also originates on the scarp of the Western Ghats and flows over the younger Greenstone and Peninsular Gneissic complex. It drains an area of 37.2 square kilometers. One hundred and forty seven streams contribute as the drainage net. The principal stream axis is aligned in the NE-SW direction. The water shed records a maximum elevation of 911 meters. The upper reaches are dominated by boulders while the lower reaches consist of cobble-pebble-gravel as the bed material with pockets of sands.

The Kelakila Hole

Seventy six streams make up the drainage net of the Kelakila Hole. The area drained is 25.75 square kilometers. The principal drainage axis is initially oriented in the SE-NW direction for a length of 3.5 kilometers. Further down stream, it re-orient its course in the NE-SW for a length of two kilometers. The stream re-aligns its course for the last three kilometers in an almost EW direction. The net stream length is 52.5 kilometers with cobble, gravel and coarse sand dominating the lower reaches, and boulders persist in the upper reaches as bed material. The prominent peaks being the Vetti Gudda (350 M) and the Kudamani Gudda (403 M). The lower order streams are categorised as lateral and longitudinal consequents.

The Jaravattu Hole

The Jaravattu Hole drains an area of 3.25 square kilometers. The drainage system is contributed by eighty four streams with a total channel length of 63 kilometers. The principal channel has many bends. Initially the channel course is aligned in the NE-SW direction for two kilometers. It re-orient its course to the NE-SW direction for the next eight kilometers. The streams are of lateral and longitudinal consequents. The bed material is made up of boulders and gravel-pebble associations.

The minor streams, that go in evolving prominent drainage axes of the Sita Nadi, the Swarna Nadi and its dominant tributary, the Madisal
Hole, range in elevation from less than 100 meters to more than 1000 meters, and these minor subcatchments are the zones where sheet flow of surface run off preceds concentrated flow. The length of overland flow (Horton 1945) is suggested to be governed by vertical elevation and gradient in relation to the available surface area in receipt of effective rainfall. It is hence pertinent to accept that the initiation of the longitudinal and lateral consequents are also the result of vertical elevation and gradient apart from the underlying lithology.

3.5 Network attributes

Hortomian (1945) Laws have been retested, and as such, monotonous bivariable relationships have not been emphasised yet salient morphometric attributes are furnished (Table 5).

**TABLE 5**

**SALIENT MORPHOMETRIC ATTRIBUTES OF THE SITA–SWARNA BASIN**

<table>
<thead>
<tr>
<th>NUMBER OF STREAM SEGMENTS PER ORDER</th>
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<td>2828</td>
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<table>
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<tr>
<th>LENGTH OF STREAM SEGMENTS PER ORDER</th>
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<tbody>
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<td>L1</td>
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<th>BIFURCATION RATIO</th>
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<td>N1/N2</td>
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<tr>
<td>------</td>
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<tr>
<td>4.35</td>
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<table>
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<th>MEAN STREAM LENGTH</th>
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<td>0.47</td>
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3.6 Drainage Patterns

Drainage patterns are the disposition and preferred occurrence of streams on the surface of land. A 'drainage pattern' has been defined as the design formed by the aggregate of drainageways in an area regardless of whether they are occupied by permanent streams (Howard 1967). Numerous factors govern this arrangement, some of which are a) initial slope b) lithology and structure c) meteorological parameters of which precipitation in the form of rainfall, is distinctly assertive in generation of a drainage pattern.

Drainage patterns have been described as 'basic and modified basic' (Zernitz, 1932). Not much of a change in thought occurred till the
work of Howard (1967). Howard retained much of Zernitz's findings, yet he proposed a few pattern varities that are on structural features and type of material. Various types of drainage patterns such as dendritic, radial, trellis, parallel, annular, deranged etc. have been reported to exist in nature, yet a perfect pattern seldom (in perfection to the connotation of nomenclature) exists over time. A change in regime expresses a change in basin characteristics. The most notable characteristic parameter that is susceptible to change is the drainage network (Gregory and Walling 1973). Change in drainage network comprehensively ascribes change in drainage patterns. Such changes are imperceptible in a small scale of time, though they have been demonstrated by Schumm (1956) and Morisawa (1964). These short term episodes that effect a change in the drainage pattern are fundamental in accepting a change in drainage patterns over long periods of time. Transition from one type of pattern to another distorts the perfection of an established (classical) pattern tending to invoke ambiguity in isolating perfect patterns.

The Sita-Swarna basin has varied drainage patterns (Fig.7). The intensity of network of streams varies within the basin. In a broad perspective, the eastern sector of the basin, particularly the Western Ghat scarp is crowded with streams, while the intensity decreases below the ghts. Subparallel, dendritic, radial and deranged patterns have been recognised.

3.6.1 Subparallel

Subparallel has been described by Zernitz (1932) to be a modified basic pattern, deemed to be a parallel pattern basically. The subparallel pattern is confined mostly to the eastern sector of the basin i.e Western Ghat Scarp. In possessing steep to moderate slope, the Western Ghts are seen to initiate the subparallelism of the lower order streams. Majority of the streams descend the slopes of the scarp face, suggesting their initiation to occur on the scarp as consequents or lateral consequents. These streams in majority are of the first order; these, along with the second order streams, align their channels subparallelly and generate third order segments, that continue to be guided by slope. In cases where the drainage depicts lower order streams aligned in a parallel to subparallel fashion on the younger Greenstones, on entering the Peninsular gneissic terrain, they transpose into a partially sub-dendritic to dendritic pattern.
<table>
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<th>Drainage Patterns</th>
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<th>Radial</th>
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<tr>
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</tr>
<tr>
<td>Semi-dendritic</td>
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</table>

**Fig 7**
Such transitory patterns are not less frequent in the pediment zone of the Western Ghat Scarp. Such a stage of transition renders a disparity in distinguishing the two classical patterns from each other.

3.6.2 Dendritic

The dendritic pattern is noticed in the central and western sectors and are uncommon in the eastern sector of the basin. The dendritic pattern being the most wide spread, seems to be etched on the low relief plains dominated by Peninsular gneisses. With the decrease in gradient and slope from the eastern sector, the intensity of dendritic pattern appears to proliferate.

Zernitz (1932) suggested that in an ideal case there are no true consequent streams and that only insequent drainage develop a perfect dendritic pattern. He further suggests that "some of the tributaries are by chance parallel, but such are mere coincidences and have no significance in the classification of the drainage as a whole". Dendritic pattern being dominated by insequent streams alone tends to admit ambiguity, although uniform lithology could prevail. Variation of relief, slope, degree of weathering on a microscale and channel configuration could effect lower order tributaries, a parallel to subparallel course initiating a variation from the dendritic pattern is thus seen to be effected. Such variations are commonly noticed in the eastern half of the basin. There is ample significance in such variations pertaining to the classification of the drainage.

3.6.3 Deranged

The deranged pattern is identified in but a few places in the northwestern sector of the basin. They are restricted to areas of low relief. In the southern sector of the basin the deranged patterns occur at an elevation of 100 meters. This pattern is found restricted to first order streams, and in rare instances they occur in third order streams. The deranged patterns of the southern sector belong to the Swarna Nadi drainage net while those in the northwest belong to the Sita Nadi. Coarse grainsize material of the weathered mantle, and criss-cross joints enhances permeability. Such a condition is unfavourable for the development and integration of the drainage system, as a result the segments that have
developed a deranged pattern, joins larger tributaries prematurely. Deranged patterns have been thought to be basically initial patterns (Small 1970). They are also typical of small streams following irregular course on locally depressed land.

3.6.4 Radial

Radial drainage have been described by Jagger (1901) and by Dake and Brown (1925). It was Zernitz (1932) who was the first to apply the term radial drainage, pattern. Howard (1967) too, identifies 'Radial' drainage pattern as a basic pattern, signifying volcanoes, domes and erosion residuals. Radial patterns substantiate the existence of elevated domal morpho-elements such as peaks atop ridges and residuals of scarp retreat. Although, volcanic cones furnish the most perfect examples of radial drainage (Zernitz 1932), radial drainage in the sub-tropical and tropical terrains characterises a topography that exhibits scarp retreat and its products of bonhardts and other inselbergs; and residuals such as weathered and mantled mounds. Modification of the simple initial pattern on a gradual exposure of less resistant rocks, within the core of a dome, has been suggested by Small (1972) to bring about a radial pattern.

Radial patterns are expressed in the eastern and southeastern parts of the basin. They characterise local zones of pediplanes, with inselbergs, where gneisses dominate. On the ridges parallel to the Western Ghats, are isolated peaks. They tend to initiate radial patterns. These radial patterns are consequent to the underlying morpho-element and its inherent slope.

3.6.5 Scheme of Drainage Pattern Development

Drainage patterns are schemes adopted by streams that develop in open dynamic system. The most dominant factor that needs special emphasis (other than the classical approach in studying drainage patterns as individual varieties) is to assess the state of the terrain, in terms of its morphologically evolved condition, upon which the streams are disposed. The continued trend emphasizing on the highly descriptive attributes of the drainage patterns, fails to appreciate the intrinsic transitions occurring in an entire drainage system of patterns. In a process-response system, the dynamic attributes of a stream have effected the morphology of the
underlying terrain. With time, subsequently, the topography with geological attributes tend to generate drainage pattern systems.

In the Sita-Swarna river basin, the gradient and slope of the Western Ghats cause the genesis of subparallel drainage patterns. These sub-parallel patterns upon encountering lesser gradient and slope, either locally on the scarp face or the pediments, tend to redesign their pattern into a sub-parallel to dendritic, which further on encountering minor ridges, mounds of relatively less relief they assume a subdendritic pattern. The subdendritic pattern is seen to transpose into a dendritic pattern at the low relief, low gradient and low sloping terrains at the central and western sector of the basin.

Though Zernitz (1932) proposed the term 'complex' for an aggregate of dissimilar patterns reflecting different structural controls in adjoining areas; and Parvis (1950) suggested the term "Anomalous" for 'complex' patterns found in areas of differing topography and materials they failed to synthesise the effect of a dynamic system of a river and the terrain with its intrinsic attributes derived in course of the evolution of its morphology. The various drainage patterns when viewed as a system in operation as a whole, reveals a transition, in other words an evolution. The hierarchy of subparallel to dendritic need not hold universality since it is governed more by the morphology of the terrain. Hence a stream originating on a gently tilted plateau, flowing down a scarp, would have a dendritic followed by a parallel to subparallel pattern.

3.7 LONGITUDINAL STREAM PROFILES

Longitudinal stream profiles have been analysed for the Sita-Swarna Nadi, the principal stream of the river basin. Longitudinal profiles have also been constructed for the principal tributaries that are, Sita Nadi, Swarna Nadi and the Madisal Hole. Apart from these important streams, studies of longitudinal stream profiles of selected minor tributaries has been carried out. These minor tributaries are the Markal Hole, Nemar Hole, Meggade Hole and Kollangar Hole. These streams are a part of the head water streams of the Sita Nadi. The Balakattu Hole has also been subjected to a similar analysis, this stream joins the Sita Nadi in its middle reach, while the Achaladi Hole joins the lowermost reach of the Sita Nadi. The Durga Hole, Kada Hole and the Machitte Hole belong to the
upper reaches of the Swarna Nadi, along with these streams, the Madisal Hole too joins the Swarna Nadi, in its lower reaches. The Jaravattu Hole, Kelakila Hole and the Mathebettu Hole are also subjected to similar investigations. These three streams contribute to the upper reaches of the Madisal Hole.

The longitudinal stream profiles have been constructed by taking stream length on the absissa and elevation on the ordinate. The scale is of arithmetic units. Primarily each stream has been divided into three segments. For this, on each individual stream, the mid point of its total length, on the profile was located. Two to four kilometers upstream and down-stream from this midpoint designates the middle reach. The segment upstream to the middle reach contributes as the upper reach, while the segment down stream of the middle reach contributes as the lower reach.

The slope of the curves (stream profiles) serve as an index, termed Gradient Index (GI). The GI has been suggested to equivate with the SL values of the stream profiles though they rarely do (Hack 1981). The GI and SL have been determined following Hack (1981), which runs as follows:

\[ \text{GI} = \frac{H_1 - H_2}{\log L_2 - \log L_1} \]

where \( H_1 \) and \( H_2 \) are the altitudes of each end of a given reach and \( L_1 \) and \( L_2 \) are the distances from each end of the reach to the source of the stream measured along the course of the (longest) tributary.

\[ \text{SL} = S \times L \]

where \( L \) is the distance from the midpoint of the given reach to the source in kilometers and \( S \), is the channel slope of the reach in meters per kilometers.

Hack (1981) cautions, that equation 2 generally will not yield the same value as equation 1. The long profile of the Sita-Swarna river (Fig.8a) depicts the G.I. values of the upper, middle and lower reaches. In the upper reach, the GI value is very high (GI = 541.84), the length of the stream in this stretch is about 27 kilometers. The middle reach demonstrates
a sudden drop to a value of 80.04. A gradual increase is noticed in the last reach, with a GI value of 90.74.

The high GI value in the first stretch (Reach 1) is mainly due to the steep topography of the scarp face of the Western Ghats. In a distance of twentyseven kilometers the elevation ranges from 35 meters to more than 1000 meters. The presence of boulders, cobbles and pebbles as bed material, partially, too, accounts for the Stupendously high GI values. The profile in this sector is notably steep and the waterfalls and rapids are prominent features of the region. The valley of the stream is typically 'V' shaped.

A drastic drop in the GI values in the mid section or the middle reach is effected by the moderate slope of the Peninsular gneissic terrain lack of boulders, presence of coarse sand, and intersecting joints that provide a free access to flow, are reasoned out to be factors that tend to Cohesively curtail the magnitude of the GI Values.

The third reach of the stream is about thirty kilometers. Here a increase in the GI values is noticed. This increase does not tend to be as high as that experienced in reach 1. This last reach has an increase of 10.04 in relation to the middle reach. This gradual increase is attributed to the discharge of bed material from numerous tributaries that originate on the central part of the basin and merge with the Sita Nadi down stream.

The relation of the GI values implies that the middle reach assumes a graded phase. The low GI values are also related to factors other than rock resistance and can be attributed to aggradation characteristics in the form of braids, point bars etc. Hack (1981) suggested that an anomalously high belt of SL value could be due to

1) A belt of resistant rock
2) A zone of uplift along a fault
3) Erosional disequilibrium between two drainage systems.

The initial reach of the Sita-Swarna river is dominated by the metasediments and metavolcanics of the younger Greenstone clan, in relation to the middle reach which is dominated by the granitic gneisses of the Peninsular Gneissic complex. Since the initial reach flows on relatively less resistant rock, in the terrain being studied, the first suggestion of
Hack seems to be negated in relation to the GI analysis. Instead of a belt of resistant rock', it is seen here that it is the stupendous gradient of the Western Ghat scarp that effects an abnormally high GI value. The two other suggestions, subtly seen to be complimentary in effecting the high GI values. The 'Western Ghat Scarp' providing the intrinsic criteria, deemed to be possessed by a zone of uplift along a fault'. The two major tributaries in the Sita Nadi and Swarna Nadi equate with 'Erosional disequilibrium between two drainage systems'.

In analysing the stream profiles individually, for the principal tributaries, the following observations are notable.

The GI value of first reach of the Sita Nadi (Fig.8b) is 63.57. Except for the first few kilometers, the stream flows on the Peninsular Gneissic complex. The general trend of the younger Greenstones is in conformity with the general orientation of the flow axis of the stream in the initial course. The increase in the GI value of the second or middle reach is accountable by the fact that the structural trend is followed only for a few kilometers and the river cuts across the gneissic trend (NNE-SSW). The minor tributaries that discharge their load in this middle reach, provides the gneissic and quartzitic pebbles and cobbles, boulders being less frequent. Coarse sand too is a component of the bed material. These inhomogenous assemblage of bed material along with that derived from upper reach of the main stream along with the gneissic basement are reasoned out to be factors that collectively enhance the higher GI. The low GI (7.80) in the last sector segment suggests the 'sink zone' (Schumm 1977). Here the bed material is coarse to fine sand. The terrain exhibits low relief and slope of the terrain is at a minimum.

In case of the Swarna Nadi, (Fig.8c) a steady increase in the GI values from the initial reach through the middle reach to the downstream reach is observed. The initial GI is low 15.56, increases to 50.33 in the middle reach and culminates in the final reach with a GI value of 54.81.

The low GI value in the initial reach is because the stream flows on a low relief terrain, with the bed material being an assemblage of coarse sand and cobble pebble assemblage. The stupendous relief of the prominent scarp face of the Western Ghats is lacking, and the stream has succeeded
in flowing across the gneissic structure. The increase in the GI value to a moderate value of 50.33 in the second reach implies the role of the basement rock, with lesser structurally weak attributes and the coarser bed material deposited by minor tributaries. A further increase in the GI value (54.81) in the last reach, (down stream) is attributed to the merging of the Madisal Hole in this sector, where the addition of sediment discharge affects the channel conditions.

The main stream Madisal Hole (Fig.9a) originates and flows almost entirely on the Peninsular Gneissic terrain. It cuts across the gneissic trend for the initial six kilometers where relative to the middle reach, the GI value is high (GI=8.10). In the second reach the Madisal Hole follows the gneissic trend intermittently and it is in this stretch that the GI value decreases (1.73). This clearly defines the zone II of Schumm (1977). In the final reach of the Madisal Hole, the GI value increase to a higher value (10.65), which is indeed low in comparison to the values generated in the Sita Nadi and the Swarna Nadi tributaries. This indicates that the entire Madisal Hole behaves as a transient system.

The longitudinal profiles of selected tributaries that originate on the scarp of the Western Ghats express a very high GI, this is the outcome of the terrain upon which these tributaries are generated. The scarp of the Western Ghats possesses very high relief, commencing from 100 meters MSL to 1210 Meters MSL.

The headwater tributaries of the Sita Nadi (Fig.10. a,b,d,e) include streams such as the Markal Hole, Nemar Hole, Meggade Hole and the Kollangar Hole. The GI values in the initial reach of the Markal Hole is 553.44, this is a resultant of the steep scarp and peaks like the Begged Gudda (1018 M.MSL). The middle reach is relatively more gentle with a GI value of 419.18, while the final reach there is an appreciable decrease in the GI (294.5) value. The stream profile of the Markal Hole tends to be convex from the commencement of the middle reach. If the rate of increase of particle size down stream is large enough, the profile tends to be convex (Leopold, Wolman and Miller 1964). It may be noted here that the initial reach of the profile is restricted to the flanks of the Begged Gudda and adjacent peaks, whereby debris flow accumulates in the channels of the second and third order streams and gradual input into the main stream of the Markal Hole accounts for the convexity noticed. Schists and
ALTITUDE IN METERS
DISTANCE IN KILOMETERS
Fig 9

(a) MADISAL HOLE
SL 12 5

(b) MACHITTE HOLE
SL 410 4

(c) DURGA HOLE
SL 113 96

(d) KADA HOLE
SL 408 93

ALTITUDE IN METERS
Fig 9
quartzites contribute as bed material in the size range of boulder, cobble and pebbles.

In the case of the Nemar Hole, the profile is not smooth, indicative of a highly unstable equilibrium prevailing at intermittent distances along the stream. This could be attributed to localised variations in channel form. The reach of the initial segment has a moderately high GI (207.44) value which progresses to a high value (963), while in the last segment the value immensely increases (GI=1188). Such stupendous increases in the GI (SL= GI) describes a zone of high stream energy (Hack 1981).

The Meggade Hole has an increase in GI more in the initial segment (207.85) and decreases in the middle reach (106.2) while the third reach shows a sudden increase in the GI (518.96). The profile has a pronounced convexity in the middle reach, indicative of a decrease in the bed material and this reach acts as a zone of transport. The increase in the final reach is brought about by localised deposition of quartzite and schistose bed material in the form of cobble-pebble assemblage with boulder being uncommon.

The Kollangar Hole has a relatively low GI value (246.95) in the initial stage and exhibits a sharp increase (730.22) in the middle reach and a lesser value in the final reach (429.97). The high value in the middle reach is contributed by a prominent tributary that increases the bed material essentially with cobble-boulder-pebbles of the younger Greenstone heterogeneity.

The Balakattu Hole (Fig.10 f) and the Achaladi Hole (Fig.10.c) are generated on the lowlying Peninsular Gneissic complex. They show in contrast, low GI values in all the three reaches. This essentially implies the lowlying plains, unlike the Western Ghats Scarp face, provides a moderate to low relief upon which these minor tributaries are generated. The bed material consists of pebble-gravel coarse sand and rarely boulder-cobble assemblage. Finer sand particles dominate the lower reaches of these streams, asserting the low GI values.

The Jaravattu, Kelakila and the Mathebettu hole (Fig. 11.a,b,c) are headwater streams of the Madisal Hole, and owe their genesis to the
Western Ghats. The initial reach of the Jaravattu Hole has a high GI value of 225.73, where the stream cuts across the general gneissic trend, indicative of the high stream energy. The middle reach indicates a decrease in the GI value (218.0) and this stretch is confined to a broad valley with steep bluff with bed material being gneissic and schistose pebbles with sandy pockets. The GI value drops in the third segment (24.83) and the stream follows the general gneissic trend (NNE-SSW).

The Kelakila Hole, as in the case of the Jaravattu Hole has initially high GI value (185.98). In the middle reach the GI decreases (60.24), while the least GI value is recorded in the final stretch (21.22). Like the Jaravattu Hole, this stream too, cuts across the general gneissic trend in the initial segment and finally conforms to the gneissic trend.

The Mathebettu Hole, unlike the Jaravattu Hole or the Kelakila Hole possesses a high GI (396.97) value in the initial reach followed by a relatively low GI in the middle reach (165.98). A rise in the GI value is seen in the third segment. The initial part of the first reach of the stream flows discordant to the gneissic trend, whereas in the second stretch of the first reach concordance is established with the gneissic trend. The channel is filled with boulder-cobble bed material in the first reach. The second reach has a low GI value whereas relatively the GI value increases (204.54) in the final reach. The bed material is dominated by coarse sand and an assemblage of cobble-pebble-boulder.

The Machitte Hole, Kada Hole and the Durga Hole (Fig.9.b,c,d) are head water streams of the Swarna Nadi. The initial segments of the Machitte Hole and the Kada Hole are in conformity with the younger Greenstone trend. The bed material is chiefly constituted of boulders and cobbles. The initial reaches indicate high GI values of 511.41 and 419.21 respectively. The bed material and high relief along with the moderately high relief is reasoned out to be the factors for the high GI values. The middle reach of the Machitte Hole has a higher GI value than the final segment and this is caused by the quartzite and schist pebbles (Plate Vb) along with the moderate relief.

The Durga Hole, unlike the other tributaries, indicates a gradual increase in the GI (84.10) from the primary reach to 85.60 in the middle reach. The GI increases further to 139.4 in the final reach. This stream
flows on the gneissic terrain and is discordant to the structure. The gradual increase in the final segments is attributed to the localised accumulation of pebble-cobble and gravel in the channel.

3.8 Transverse Profiles

Transverse profiles for the major tributaries, the Sita Nadi, Swarna Nadi and the Madisal Hole (Fig.12 a,b,c) were constructed to understand the lateral morphology and relevant implications. The configuration of the valley is clearly depicted in transverse profiles. The transition from 'V' shaped valleys to broad channels are inferred.

On each tributary at an interval of ten kilometers, transverse profiles were constructed and the lateral extension across the stream was restricted to one kilometer.

The Sita Nadi, Swarna Nadi and the Madisal Hole depict 'V' shaped valleys (Fig.12 aI, bI and cI) at the commencement of their streams. These 'V' shaped valleys suggest the youthful condition of the streams. In the case of the Sitanadi, these 'V' shaped valleys dominate the channel configuration up to the thirtieth kilometer from the origin (Fig.12 aII, aIII, aIV). At the fortieth kilometer the channel tends to widen (Fig.12 aV). The widening of the valley suggests the initiation of the early mature stage of the Sita Nadi. Such a configuration increases in lateral dimensions downstream where broad valleys are noticed, suggesting the transition of a rugged to a senile topography (Fig.12, aVI, aVII), where flood plains and valley-fills of coarse to fine grained sand dominate.

The Swarna Nadi too in its initial thirty kilometers (Fig.12, bI, bII, bIII, bIV) of flow exhibits the transition from 'V' shaped valleys to broader lateral dimensions. The Swarna Nadi, around the fortieth kilometer from the headwaters, flows between two lateritic hillocks called the Swarna Nadi Gudda and the Kalinga Gudda (Fig.12, bV). After the fortieth kilometer, the stream has expansive flood plains and the valley broadens with the channel bluffs less than two meters in height.

The transverse profiles of the Madisal Hole are typical in exhibiting 'V' shaped valleys in the initial course. The pronouncement of the rugged topography being observable up to the tenth kilometer (Fig.12,
TRANSVERSE STREAM PROFILES

Fig 12
From the twentieth kilometer the valley commences to broaden with the reduction in height of the valley walls (Fig. 12. cIII). From the thirtieth kilometer the river loses its youthful profile and depicts broad valleys, a stage of maturity being expressed.

The transverse profiles thus are suggestive of the dynamic condition of the stream in the initial course and a transition of the fluvial system to a less dynamic condition as is expressed from the middle reaches to the final reaches of the stream.

3.9 Meandering and Sinuosity

Meandering is a property that expresses the inherent or intrinsic tendency of a stream to cease its flow pattern from a relatively straight course, tending to assume a curved course. The change defines certain geometrical criteria of a wave. The progradation of a meander initiates braiding in streams. Meanders are deemed to be a result of various attributes of the stream channel and the material that flows in it. Helicoidal currents that exist in river bends cause the erosion of the outer bank (concave) and affect deposition at the inner bank. The process of meandering, once initiated by the consequence of high velocity water scoring the outer bank, this mechanism intensifies and progresses downstream.

Various workers have suggested the mode and mechanism for the generation of meanders. Scheidegger (1969) states that no exact mathematical theory based upon a proper analysis of the effect of helicoidal currents can be given which would correlate the size of meanders with other dynamical variables characterising the rivers. In discussing intrinsic thresholds, Schumm (1973) relates the progressive increase in channel sinuosity and meander amplitude to a special type of intrinsic threshold called the 'Geomorphic Threshold'. This seems to validate the combined effect of process with form that results in meandering. Keller and Melhorn (1981) consider meandering channels as a special type of sinuous channel characterised by rise of relatively symmetrical curves with a sinuosity greater than 1.5. The implication of symmetry, being debatable, they advocated the term 'Meandering' be applied to any sinuous channel with a sinuosity greater than 1.5, as also suggested by Leopold et al (1964).
It is pertinent to comprehend sinuosity and meandering. Brice (1962) has aptly related meandering and sinuosity - "Meandering is applied to sinuous channels that exhibit a certain degree and regularity of sinuosity". Sinuosity thus is an index which is derived by dividing the length of a reach as measured along a channel, by the length of a reach as measured along the valley. Based on the values of Stream Sinuosity Index (SSI), a stream having an SSI of 1.0 is termed straight, just over unity to 1.3 as sinuous and more than 1.3 as meandering (Nageshwar Prasad 1982). Muller (1968) suggested a sinuosity index, giving due importance to channel and surface configurations. He introduced the terms Hydraulic Sinuosity Index (HSI) and Topographic Sinuosity Index (TSI) which are supplementary to each other (on combining they approach 100.\%). The HSI suggests the departure (percentage) of a stream from a straight line because of the hydraulic factors within the valley. TSI expresses the influence of topographic features in effecting the deviation of a stream from a straight path.

HSI and TSI are derived in the following way:

\[
\text{HSI} = \frac{CI - VI}{CI - 1}
\]

\[
\text{TSI} = \frac{VI - 1}{CL - 1}
\]

Where \( CI = \) Channel Index = \( \frac{\text{Air}}{CL} \)

\( VL = \) Valley Length

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

\( CL = \) Channel Length

\( VL = \) Valley Length

\( Air \ L = \) Shortest Straight Length
SSI has been determined for the entire Sita-Swarna fluvial system. The Main tributaries like the Sita Nadi and the Swarna Nadi, both being the only sixth order streams along with the Madisal Hole, a fifth order tributary to the Swarna Nadi have also been subjected to SSI analysis. The SSI values obtained (TABLE 6) categories the Sita-Swarna drainage system as a Meandering fluvial system (SSI = 1.33). Likewise the Sita Nadi and the Madisal Hole conform to a meandering system. The Swarna Nadi by virtue of possessing an SSI of 1.24 falls with the category of a sinuous stream. In all the three major tributaries the T.S.I. is low ranging from 3.20 to 17.90 on the contrary the HSI is extremely high. It is at a maximum of 96.80./. in case of the Swarna Nadi, 90.50./. for the Madisal Hole and 80.10./. for the Sita Nadi. These high values of H.S.I. are in conformity with the entire 7th order system. The Sita Swarna system possesses a HSI of 72.73./. and a low TSI of 27.27./.. The high values of HSI in all the three major tributaries is further evidenced by the presence of well developed flood plains in their lower reaches.

The extremely high HSI value of the Swarna Nadi indicates the effect of the head water tributaries on the principal stream channel configuration. It may be noted that the uppermost reaches of the Swarna Nadi flow across pebble-cobble-gravel assemblages. Where the headwaters are incised, the bluffs of the channel consist of pebbles that are well compacted and in some instances have slumped into the channels.

The topographic control on the channel deviation is extremely low as is indicative of the TSI. The high HSI suggests a greater regularity of the initial surface that is dominated by the peninsular Gneissic complex. The Peninsular Gneissic complex in comparison with the Western Ghats is a plain of low relief and is relatively more resistant than the younger Greenstone terrain of the Western Ghats. The prominent morpho-element, the Western Ghat Scarp is devoid in the Gneissic complex and such a contrasting combination is probably the criteria that determines the high HSI and low TSI.

The head water tributaries of the Sita Nadi are dominated by the Western Ghats. The terrain consists of ridges and hilly ranges with peaks of prominent elevation. The lithology being dominated by the younger Greenstones. None of these streams are meandering systems since their SSI values are less than 1.3. The Markal Hole has the highest SSI of 1.23,
Nemar has a value of 1.12, Megadde Hole with a value of 1.18 and the Kollangar Hole has a value of 1.15. The streams are short in length ranging from 6.5 to 9 kms.

The Markal and Megadde Hole have high HSI of 75.95./. and 82.60./. respectively, in contrast the Nemar and Kollangar Hole, having values of 20./. and 45./. respectively. The TSI of Nemar (80%) and Kollangar Hole (54%) streams are high to moderately high, while, the Markal Hole has a low TSI of 24.05./. and it is lesser in the case of the Megadde Hole where the TSI is 17.40./. This clearly indicates that the Nemar Hole and the Kollangar Hole owe their channel deviation from a straight path to a sinuous flow to topographic controls. The sinuosity in the case of Markal Hole and the Megadde Hole is governed by the attributes of hydraulic factors.

The tributaries of the Swarna Nadi headwaters are dominated by the Peninsular Gneissic and younger Greenstone terrain. The Durga Hole and the Kada Hole are categorised as meandering systems. They possess an SSI of 1.35 and 1.99 respectively. These streams are narrow, incised to the extent of 4 to 6 meters. The Machitte Hole is in contrast a sinuous stream with an SSI of 1.10. The T.S.I. of the Machitte Hole is 76.39./. The Kada and the Durga Hole have extremely low (2.09 and 29.32./. respectively) TSI, complimentary to which they possess extremely high H.S.I. of 97.91./. and 70.68./. respectively. This expresses the dominant channel configuration and material.

Of the tributaries of the Madisal Hole, the Mathebettu Hole is governed by the topographic attributes as is indicated by the TSI (84.90./.) and a relatively low HSI (15.10./.). The Kelakila Hole with a sandy and pebble-cobble bed material, has moderately high HSI (62.50./.) and a TSI of 37.50./. The Jaravattu Hole is a more balanced system operating. This is suggestive of the TSI and HSI values (56.81./. and 43.91./. respectively). The younger Greenstones and Peninsular gneisses provide the initial surface for these streams.

The Goli Hole, Dujli Hole and the Honakal Hole are sinuous streams, being neither straight nor meandering. This is indicated by the SSI value of 1.15, 1.22 and 1.16 respectively. The Dujli Hole is dominated by HSI (75./.) than TSI (25./.), while in the Goli Hole TSI is moderately
high (54.77./.) and HSI is 45.23./. The Honakal Hole characteristically exhibits a symmetrical distribution of HSI and TSI of 50./. each. This could be reasoned out to be because of the rugged and steep terrain on which its upper reaches are located, while the lower reaches enter relatively flat plains.

The Balakattu Hole is characterised as a meandering stream as it possesses an SSI of 1.33. It originates on the peninsular gneissic terrain that is well jointed in an intersecting fashion. Most part of the Balakattu Hole is dominated by sandy bed material and the terrain on which it flows is dominated by low relief and sandy plains. This type of a stream advocates the dominance of HSI (70.90./.) and low TSI (29.10./.) so is the Nadur Hole with an HSI of 64./. and a TSI of 36./. and an SSI of 1.44. These streams do not contribute as head water streams and form lower reach tributaries.

Most of the studies pertaining to river meandering concerns morphological, sedimentological and hydraulic variables that focus on either genesis or on progressive changes in time. Theoretical work has been well exemplified by Scheidegger (1970), Spight (1965), Sooky (1964), Chang and Toebes (1970) and Ingle (1964), while, geometrical studies of meander loops have been carried out by Schumm (1967), Bades (1939), Leopold and Wolman (1957) and others. Experimental and simulation studies have been brought about by Kahn (1971), Friedkin (1945), Shepherd and Schumm (1974), Schumm and Khan (1972), and Ackers and Charlton (1971). Flow separation and related hydraulic components have been discussed by Leliavsky (1955), Bagnold (1960) Leder and Bridges (1975) Wenner (1951), Lagom in and Leopold (1966), Scheidegger (1970). Hooke and Harvey (1983) and Brice (1981) deal with changes in meander loops. Most of these workers have laid stress on variables as individual entities in their studies.

In retrospect of this background of work, it is attempted here in assessing the inter-relationship of individual variables. Topographic sheets (1,50,000) have been used for basic measurements followed by selective field investigations. These quantifications conform to the earlier reported work using Air-photographs and topographic sheets (Raghavan and Sreedharamurthy 1987).
Quantification of meander loop (Fig.13) parameters such as meander length and amplitude have been determined by conventional techniques as has been illustrated by Leopold and Wolman (1960), and Scheidegger (1970), Sinuosity index (SI) for these individual meander loops have been determined following Leopold and Langbein (1966). The ratio of meander radius to width (bend tightness), has been estimated following Leader and Bridges (1975). Meander Ratio and Tortuosity have been estimated following the method adopted by Raghavan and Sreedharamurthy (1987).

Correlation coefficients between the six variables have been determined followed by regression analysis (Fig.14a). Cluster analysis following Davis (1973), in the form of a dendrogram, has been derived from the initial correlation matrix (Fig.14b). This method of analysis is presented to elucidate the interrelation of the variables.

The interrelation between Meander Ratio (Z1), Tortuosity (Z2), Sinuosity (Z3), Radius of Curvature to width (Z4), Meander length (Z5) and Amplitude (Z6) has enabled Z5 to exhibit a very high correlation coefficient ($r=0.96$) with Z6; and Z4 with Z5 ($r=0.69$). The other less distinctive correlations are exhibited between Z4 and Z6 ($r=0.64$). This analysis suggests the intrinsic behaviour of Z5. The cluster analysis in the form of a dendrogram (Fig.14c) expresses the presence of two distinct major clusters. In the first cluster Z5, Z6 and Z4 are seen to associate whereas in the second group Z1, Z3 and Z2 are observed to group into a distinct cluster. These groups together, reveal just one significant protocluster with a similarity coefficient value exceeding 0.9. This protocluster has Z5 and Z6 as the two critical variables.

In synthesizing the correlation analysis and the cluster analysis, it may be inferred that of the six variables, Z5 and Z6 play a critical role in a meandering system. The behaviour of meander length is seen to define its position distinctly with amplitude and 'bend-tightness' and exhibits poor correlation with Sinuosity and Tortuosity and almost nil with Meander Ratio. The intrinsic association of Meander Length at varying degrees had also been earlier inferred to be isolated as a critical variable in the meandering system (Raghavan and Sreedharamurthy 1987).
TABLE 5: SSI, HSI AND TSI OF SITA SWARNA BASIN

<table>
<thead>
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<th>River/Basin</th>
<th>SSI</th>
<th>HSI</th>
<th>TSI</th>
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<tr>
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<td>73</td>
<td>27</td>
</tr>
<tr>
<td>Sita Nadi</td>
<td>41</td>
<td>92</td>
<td>17</td>
</tr>
<tr>
<td>Madisal Hole</td>
<td>1.32</td>
<td>90</td>
<td>09</td>
</tr>
<tr>
<td>Svarna Nadi</td>
<td>26</td>
<td>96</td>
<td>03</td>
</tr>
</tbody>
</table>

CORRELATION MATRIX

<table>
<thead>
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<th>Z2</th>
<th>Z3</th>
<th>Z4</th>
<th>Z5</th>
<th>Z6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.39</td>
<td>0.43</td>
<td>0.01</td>
<td>0.006</td>
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<tr>
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<td>0.11</td>
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</tr>
<tr>
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<td>0.20</td>
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<td></td>
</tr>
<tr>
<td>Z4</td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Z6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SIMILARITY COEFFICIENT

Fig 14
Salient attributes of the fluvial system

The Sita-Swarna drainage system exhibits the following significant attributes:

(1) Majority of the lower order streams that integrate in generating the fluvial system owe their genesis to the Western Ghats scarps. These streams are in majority, consequent streams. The initial-surface is dominated by the high relief provided by the Western Ghats.

(ii) The major tributaries i.e. Sita Nadi, Swarna Nadi and the Madisal Hole possess numerous lower order tributaries that constitute a crown of streams, analogous to zone I of Schumm's (1977) simple model.

(iii) Sub parallel, dendritic, deranged and radial drainage patterns prevail in the basin. Transition of patterns are envisaged, and are deemed to be governed by the intrinsic attributes derived in the course of evolution (morphologic) of the terrain.

(iv) Longitudinal stream profiles project a high stream Gradient Index value for the initial reaches of the streams, suggestive of the scarps of the Western Ghats. The low gradient values denote the pediments and pediplains.

(v) Transverse profiles depict 'V' shaped valley configurations in the upper reaches of the streams and broad valleys downstream, suggestive of the dynamic conditions prevalent at various stretches of the fluvial system.

(vi) The major tributaries envisage a low Topographic Sinuosity Index, conversely the Hydraulic factors dominate the system.

(vii) Meandering and non-meandering fluvial systems characterize the minor tributaries.
The interrelations between Meander Ratio, Tortuosity, Sinuosity, radius of curvature to width, meander length, and amplitude have enabled Meander length and Amplitude to be discerned as critical independent variables of meander loops.