GEOMORPHOLOGICAL STUDIES
ON
DHANSIRI RIVER BASIN, NORTH-EASTERN INDIA

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CERTIFICATE

The work contained in the thesis entitled, "Geomorphological Studies On Dhansiri River Basin, North-Eastern India" is original and has not been submitted in part or full for any degree or diploma of this or any other university.

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C O N T E N T S

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P R E F A C E

The present work entitled " GEOMORPHOLOGICAL STUDIES ON DHANSIRI RIVER BASIN, NORTH-EASTERN INDIA ", is the result of study, using the remote sensing techniques.

The Dhansiri river originates from Dhansiri reserve forests in the Naga hills. Its catchment area is chosen for investigation of stratigraphic and tectonic set up of the lithounits, landforms and drainage network, evaluation of water resources and statistical analysis of the morphometric parameters.

The work has been presented in six chapters as follows:

CHAPTER I: INTRODUCTION, deals with the general information about the area and aims of the present investigations.

CHAPTER II: MATERIALS AND METHODS, describes the quantitative and qualitative methods used.

CHAPTER III: TECTONOSTRATIGRAPHY, embraces the general lithotectonic setup and structure of the basin as discernible from images.

CHAPTER IV: LANDFORMS AND DRAINAGE, deals with the broad geomorphic features, soil erosion and landslides, drainage system and its evolution, drainage pattern and evaluation of ground water resources.

CHAPTER V: GEOMORPHOSTATISTICAL ANALYSES, includes general statistics, Pearson's correlation matrix and factor analysis of the morphometric parameters.

CHAPTER VI: SUMMARY AND CONCLUSIONS, deals with the summary and results obtained from the present investigations.

Figures are serially numbered as 1,2,3... and tables as I, II, III and so on. They are arranged after their reference in the text. For the sake of convenience larger tables are placed at the end of the thesis as annexures. However, few tables are placed with running matter for convenience. References are alphabetically arranged at the end of the text.

CHAPTER - 1

INTRODUCTION

The proposed study deals with geomorphological investigation of the Dhansiri river basin using the remote sensing techniques.

Dhansiri basin falls approximately within the latitudes 25°-0'N to 26° - 45'N and longitudes 93° - 15'E to 94° - 20'E (Fig. 1). The upper Assam valley is largely formed by the river Dhansiri which flows in a characteristic curve (with convex towards the east) from its source in Dhansiri reserve forest in the Naga hills to join the Brahmaputra opposite the Majuli island in Nowgong district of Assam. From its source upto Dimapur, it forms the boundary between Nagaland and Assam.

Several tributaries discharge into Dhansiri river at a number of places from different directions. The important ones are: the Deopani, the Deori from the Mikir hills and the Kuki, the Diphu and the Manglu from the Naga hills.

PHYSIOGRAPHY

The Dhansiri river receives its water mainly from the Naga hills of Nagaland in the eastern side and the Mikir hills of Assam on the western side.

A) NAGA HILLS:

Ranges of the Assam Himalaya running eastwest take a hairpin bend where they cross the river Lohit in Arunachal Pradesh and thence extend southwards into the Naga hills beyond which they are known

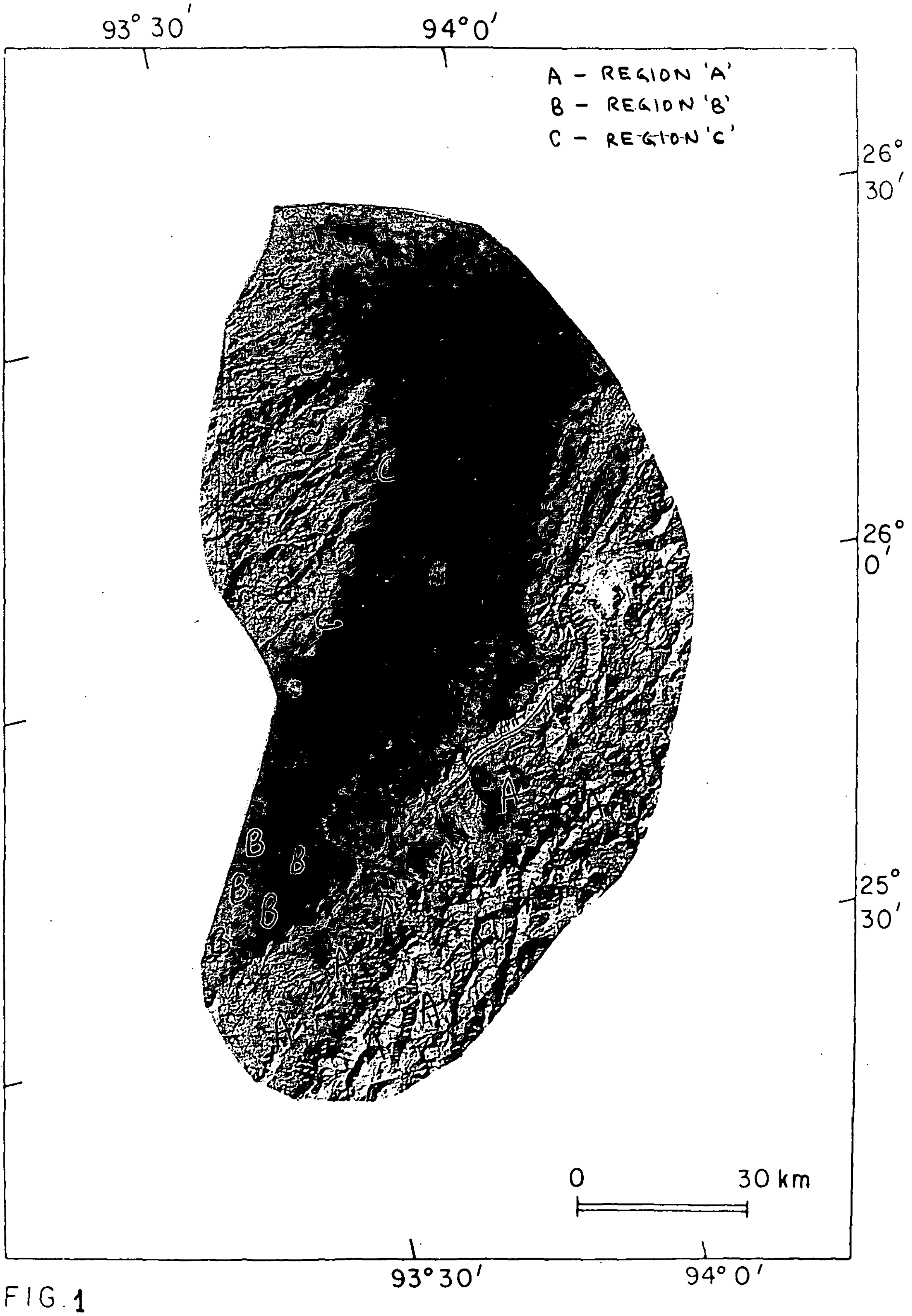
93° 30′
94° 0′
A - REGION 'A'
B - REGION 'B'
C - REGION 'C'
26° 30′
26° 0′
25° 30′
0
30 km
93° 30′
94° 0′

FIG. 1

as the Arakan Yoma. The Naga hills are tightly packed with north-south aligned ranges defined by narrow and parallel valleys. The Barail range piercing from south-west via North Cachar (Assam) runs upto Kohima. Its highest peak Japavo (2970 m) is lying to the south of the town.

The region enjoys a typical monsoon climate varying from tropical to temperate conditions. The rapid changes in topography results in climatic changes locally. The summer temperature range from 7°C to 23°C and the annual rainfall varies between 200 cms and 270 cms. Most of the rains occur during the months of April to October.*

B) MIKIR HILLS:

The Mikir hills are in Assam and have a roughly northerly slope with the outer ranges having an average elevation of about 450 m. However, the Kopili river has formed plain embayments into the interior causing isolation of major part of this section from the main plateau. The average elevation of the ranges is about 1000 m. The drainage system of the area is characterized by a radial pattern as streams emanate from the dome shaped central portion.

The climate in the Mikir hills region is comparatively hot in summers and have low rainfall due to its location in the rain shadow zone, as the moisture bearing monsoon winds are obstructed by the

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* Source: Department of Statistics, Government of Nagaland, Kohima.

Barail ranges before they could reach this part. Total rainfall is about 1200 mm out of which about 1100 mm occur during the premonsoon and monsoon periods. July is the hottest month with an average temperature of 28°C whereas the winter months have a temperature of 14°C on an average, Singh (1971).

SOIL AND VEGETATION

The soils of Naga hills are of two types*:

i) Ferruginous red soil and

ii) Lateritic soil

These soils are derived from Tertiary rocks and are generally rich in organic matter but poor in phosphate and potash content. The pH values fall between 4.8 to 6.5 while the organic carbon content may be as much as 2.943 percent.

A large population in Naga hills practices shifting cultivation (jhumming) which accelerates the soil erosion.

There occur three main types of soils in the Mikir hills region:

i) the red loam or hill soils

ii) the lateritic soils and

iii) the old alluvium.

The lateritic soil is concentrated in southwestern part of the region. These soils are highly leached, poor in plant nutrients and acidic in nature. Red loam is found in pockets in the southwestern Mikir hills. The old alluvium occurs in highland areas bordering the

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* Source: Department of Statistics, Government of Nagaland, Kohima.

plains. It is deficient in phosphate but has an appreciable amount of potash, Singh (1971).

The Mikir hills region has a high density of forest area, as in the Naga hills, with vegetation more similar to that of Central Brahmputra valley. The region is characterized by dense reserves of bamboo and grass with a few scattered trees here and there.

REGIONAL GEOLOGY

Overall, the Mikir hills contain stable Precambrian suit of rocks and, the Naga hills belong to a fairly young mobile belt of the earth. The tightly folded mountain belt of Naga hills is considered to be related to the orogenic development of the Cretaceous-Tertiary complex geosyncline along the eastern margin of Indian plate. Mathur and Evans (1964) gave a comprehensive account of the broad structure and stratigraphy of the Naga hills. They described three major structural features in Nagaland viz:

i) the Belt of Schuppen in the western part consisting of eight or possibly more over-thrust masses.

ii) the Kohima synclinorium in the south extending southwesterly of Kohima town and

iii) the Patkai synclinorium along with middle part of Naga hills and intermediate hill ranges.

The rock sequence in the Naga hills is represented by Disang Group (dark grey slates with thin beds of sandstones), Barail Group (well bedded sandstones with shale intercalations), Surma and Tipam

Groups (shales and sandstones with occasional thin conglomerates and ferruginous sandstones respectively) and Dihing Group (pebble beds, thin clay and sand) in ascending order.

Geological Survey of India has compiled geology of northeastern region in its miscellaneous publication No.30. In the Mikir hills, rock types show a variation from coarse grained porphyritic to foliated biotite granites associated with fine grained banded and foliated gneisses, schists and granulites with intrusive pegmatites, quartz veins and basic sills and dykes. In Koilajan and Miji areas of the central Mikir hills, pyroxene granulites resembling charnockites occur within the Archaeans. Tertiaries are also exposed on south and southeastern flanks of the Mikir hills, Karunakaran (1974).

AIMS OF STUDY

The present state of knowledge of regional geology structures, tectonic set-up and geomorphology of the Dhansiri river basin is so stray and inadequate that the available data cannot evolve a valid model for the geomorphic evolution of the area. Accordingly for clear understanding of the geomorphic evolution the present study is aimed to:

i) investigate the stratigraphic set up in the Dhansiri river basin

ii) study the structure and tectonic history of the basin

iii) study and analyse different types of landforms within the basin

iv) analyse drainage network and its evolution

v) evaluate the water resources in the river valley

vi) work out statistical variation in relation to morphometric parameters of the third order drainage basins with one another and in different litho-tectonic conditions.

C H A P T E R - II

MATERIALS AND METHODS

A variety of methods of observing the earth's surface are now being used by scientists. These methods are collectively known as 'Remote sensing', as the observer is not in contact with the surface being examined. Remote sensing commonly refers to aerial and satellite photography and scanning. Aerial and satellite photography is a passive process in which light is reflected from the earth's surface into a camera held at various heights in aeroplanes, satellites or space stations like skylabs etc. The visible part of the electromagnetic spectrum is most suitable but photographs may also be taken in the infrared portion or less commonly in the ultraviolet portion. Figure 2 shows the electromagnetic spectrum and some imaging sensors. A range of photographic images may be produced in this way in black and white, colour, infrared (black and white or colour), or in false colour (i.e. either extracting a part of the visible spectrum or in a composite of natural and infrared colour). These enable the geologists to recognise signatures of a particular feature for study. Thus, growing vegetation stands out in different hues of red in infrared colour photographs, whilst bare rocks are coloured blue. Photographs taken at increased height no doubt cover larger area, but the image resolution decreases.

MULTISPECTRAL SCANNER

Besides photography, multispectral scanning is being widely used for mapping natural resources. LANDSAT imagery so obtained provides useful data by collecting the radiation that is reflected by various

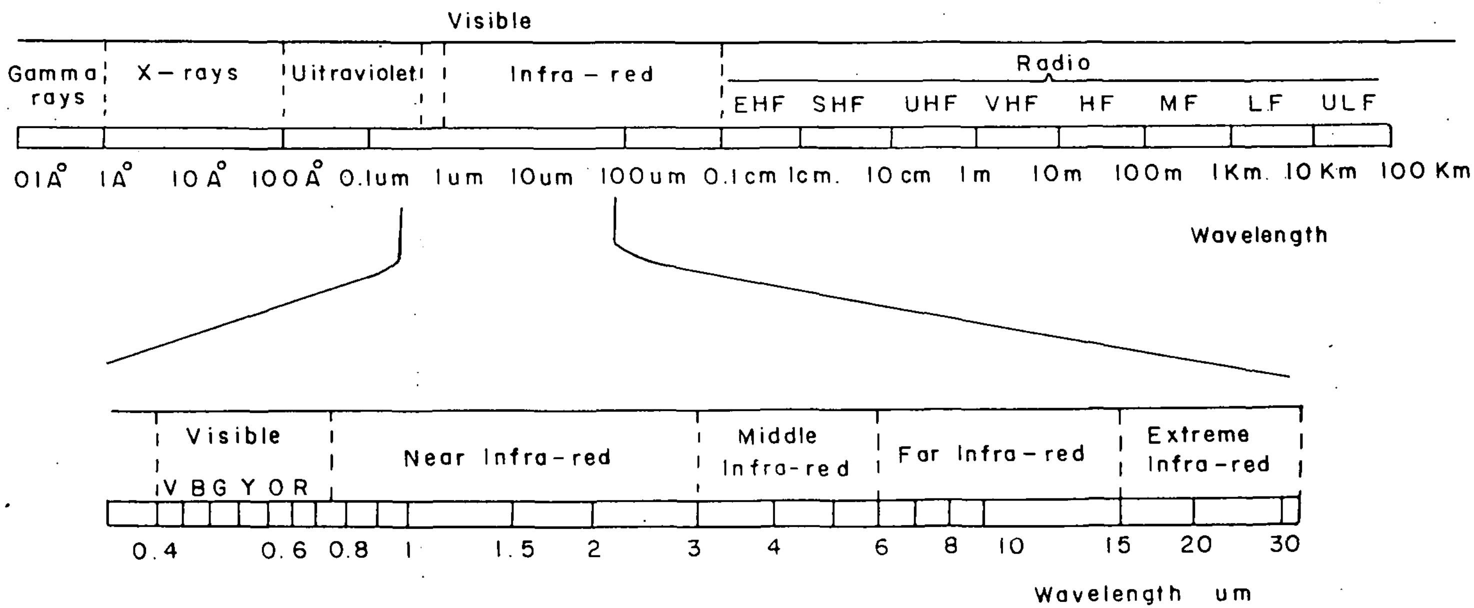


Fig. 2 – THE ELECTROMAGNETIC SPECTRUM

objects on the ground. In order to sense most of these radiations, multispectral scanner (MSS) is used (Figure 3). It is an opto-mechanical scanning device where the scene is imaged in a number of discrete spectral bands. This device is essentially a combination of imaging scanner and spectroradiometer. The incoming radiations are divided into reflected wavelength and emitted wavelength by a dichroic filter. A prism splits the energy (reflected wave-length) into ultraviolet, visible and infrared wavelength. The beam so produced is collected by detectors placed behind the filter and prism into many narrow bands or channels. Normally four spectral bands (MSS 4,5,6 and 7) are used to sense these radiations. These bands correspond to wavelength 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8 and 0.8 to 1.1 micrometers.

QUALITATIVE METHODS

LANDSAT images provide a synoptic view of a large area. For geomorphological analysis of inaccessible and large areas, these images, in multispectral bands offer very useful information. Geomorphic provinces or major structures like thrusts, synclinoria and drainage basins can be observed directly from these pictures. Landform is a function of the agents which produce it, the material of which it is composed, the climate and the time plane through which the process continued. An idea of these can be obtained by viewing the topographic expressions on the LANDSAT imageries.

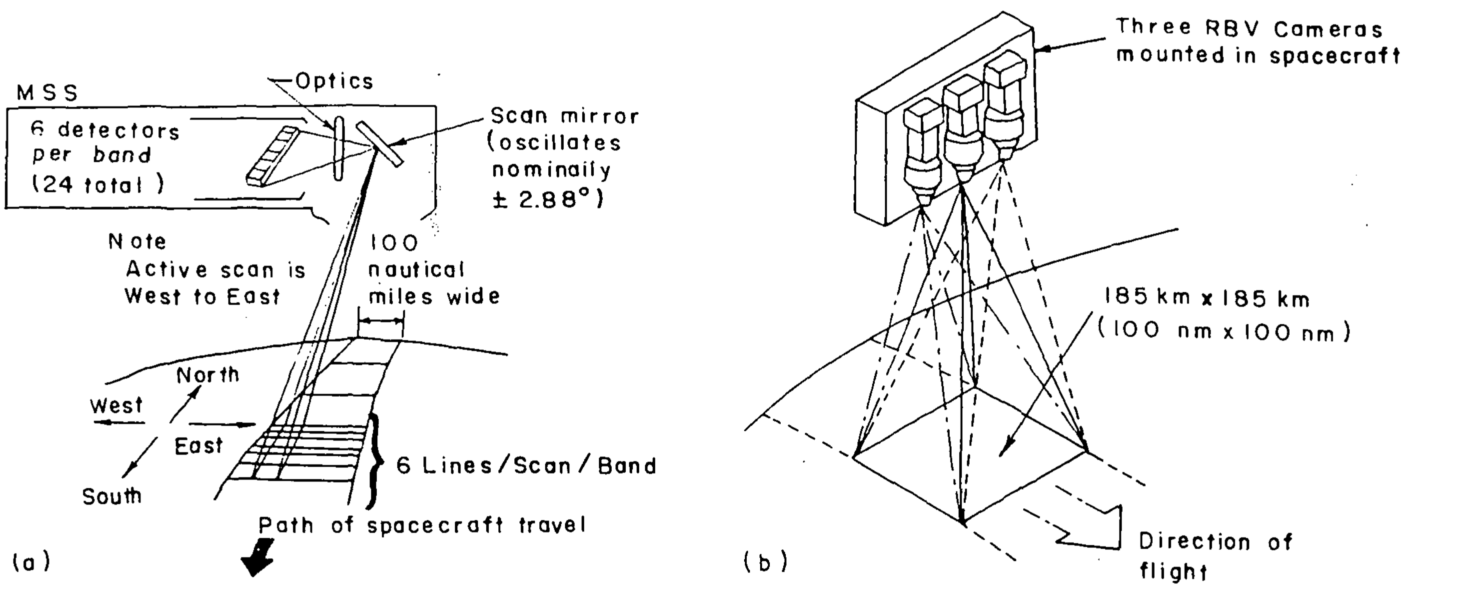


Fig. 3

(a) ERTS-1 multispetral scanning system scan pattern. (b) ERTS-1 return beam vidicon scanning pattern. (Source: NASA)

Ergo, tectonics of the area can also be deciphered because a number of landforms are directly produced by tectonic activities.

Tectonically and geomorphologically active nature of the area of study necessiated the use of remote sensing method in the present work, as indicated by the ongoing discussion. Black and white transparencies (MSS 5 and 7) covering the study area on 1:1 million scale and their enlargement upto 1:250000 scale were interpreted visually to get the idea about the landscape types of the region. Interpretation was based on separating various units depending on their homogeneity based on tone, texture and the drainage pattern. The structural elements like lineaments dislocations, folded ridges and basins were identified directly. A lineament-map was produced and the directions of the lineaments were measured.

A drainage map was produced using false colour composites as certain types of features like moisture zones and water bodies are not entirely well discernible on black and white prints. This map was used to delineate various kinds of drainage patterns. These were in turn, used to understand the geologic structures. Here the term, structure is used in wider connotation as used by Davis, including the litholgy of the area also.

A length versus height plot of a river constitutes its longitudinal profile. Although for detailed work the longitudinal profile of a river valley should be precisely surveyed yet a profile constructed from a large scale map would often provide sufficient evidence to demonstrate a point seen in the field or suggests a possible solution to a particular problem, that can then be checked in the field. Longitudinal profiles of major tributaries of Dhansiri river were constructed in the same way in order to tackle various problems related to tectonic history of the area as well as erosion potential of the drainage.

QUANTITATIVE METHODS

In a classic paper, Horton (1945) emphasized on quantitative geomorphic and hydrologic approaches towards geomorphic evolution of a region. Publication of this paper changed the emphasis of geomorphology and led to what has been referred by Butzer (1973) as the Hortonian revolution in geomorphology. This quantitative revolution in the earth science has now made it possible to measure phenomenon with greater precision and accuracy.

Third order drainage basins were delineated for the quantitative analysis into three sets according to lithology and structure of the area. These were as follows:

Region A	Belt of Schuppen in Naga Hills	Tertiary
Region B	Naga Hills (excluding region 'A')	Tertiary
Region C	Mikir Hills	Precambrian and Tertiary

Basins falling partially in a particular region were not considered. The directional measurements were carried out on all the first, second and third order drainage segments, where the drainage segments take marked swerves average orientation was noted. Rose diagrams were made using directional data of first, second and third order drainages respectively and the dominating directions were noted. Similarly, rose diagrams were made using directions of the lineaments for comparison with those of the drainage.

STATISTICAL METHODS

Statistical methods are helpful in two situations. First, when numerous measurements have been taken and the information they contain cannot be easily assimilated and comprehended. In such a case, the information is organised using various descriptive statistical methods. The second situation is when only a small amount of information has been collected and generalisation is aimed. Application of statistical methods to geomorphological data requires an understanding, of the method of analysis and the nature of geomorphological data as well. It is seldom possible to study all examples of a particular feature or process. However, total population was taken into consideration for present study, as the character of the basins depends upon many factors viz., climate, slope, lithology, structure etc. and there is intraregional variations in these characters. The statistical analysis in present work is carried out on the linear and areal properties of the third order drainage basin of the Dhansiri river.

Statistical methods used here, included computation of mean, variation, standard deviation, coefficient of variation, correlation, and factor analysis. Some of which are as follows. Their details are available in respective chapter.

CORRELATION

If two or more variables are correlatable, i.e. one of them is logically considered as the cause of the other, then identification of the causal relationship between these variables is an important aspect of a scientific study. The factor which is the cause is known as the independent variable and the one which is the effect is known as the dependent variable. A correlation matrix was used to assess the presence, or otherwise, of groups of inter-correlated variables. This was done by resorting the position of the variables around the margin of the table in such a way that the highest positive correlation coefficients fall nearest to the central diagonal line. The correlation coefficient of each variable with rest of the variables for three separate sets (regions) have been shown graphically. Such matrix helped in deciphering the pattern of correlation and their inter-regional variations.

FACTOR ANALYSIS

The aim of factor analysis is to account for the covariances of the observed variates in terms of a much smaller number of hypothetical variates or factors. Through factor analysis many variables may be reduced to a few factors and provide a summary of original data. In the N-dimensional space (where 'N' is the number of variables) it is possible to consider each drainage basin as having a location related to the values of each of its 'N' variables. It is possible to think of factor analysis by imagining a hyper-ellipsoid, with N-dimensions and N-axes enclosing all the location points. The longest of these axes is most closely related to the dominent trend. Some of the variables fall close to this axis (which is known as factor axis I or simply factor I) and these are said to have a high loading on factor I. The axis of this body are labelled, I, II, III, ... in decreasing order of their lengths.

Rotated Matrix:

For a given matrix of correlation, factor method would arbitrarily locate the reference axis in a different position. In order to move the axis from arbitrary location determined by the method of extraction to some position useful for interpretation of the factors and for comparison with other studies, the axes are rotated. The rotational scheme in fact, leads to a position where only a few variables have a high loading on each factor and remaining variables have near zero loading.

C H A P T E R - III

TECTONOSTRATIGRAPHY

INTRODUCTION

The Dhansiri river, a south-bank tributary of Brahmputra, flows, with Mikir hills on west and Naga hills on east, constituting the catchment of the river. The inaccessability of the area has rendered it to be largely unmapped. The geologic, tectonic and stratigraphic investigations carried out for over a century provide information about only few patches in the basin. Recently search for hydrocarbons has given an impetus to the study of the area. The information of each lithological unit has been worked out from previous literature. LANDSAT images have been interpreted visually to fill in the gaps and to delineate various lithotectonic units. Lithounits are differentiated on the basis of tonal contrast. The study of these images has led to the recognition of a large number of small and large lineaments and also to the understanding of prominent structural features. These investigations provide a generalised tectonostratigraphic set up of river basin on a regional scale.

REVIEW OF PREVIOUS LITERATURE

The pioneering work carried out in the area was done by Medlicott 1865, Mallet 1876, Oldham 1883, La Touche 1886 and Smith 1896. Subsequent significant geological contributions were made by Haydon 1910, Brown 1912, Pascoe 1912, Stuart 1923, Evans 1932 and 1964, Mathur and Evans 1964, Karunakaran and Ranga Rao 1976, Nandy 1976, Bharali and Ratnam 1978, Ratnam 1978, Roy and Kacker 1980.

The river basin falls in the Naga hills and the Mi[illegible] hills. Mikir hills are separated from the Naga hills by alluvium [illegible] he Dhansiri river. The stratigraphic framework of the area was discussed by Evans (1932) and Mathur and Evans (1964) and tectonic framework was discussed by Evans (1964) (Fig. 4). Geological survey of India workers reported that in the Mikir hills, Archeans are exposed consisting of a variation from coarse grained, porphyritic to foliated biotic chlorite granites associated with fine grained banded and foliated gneisses, schists and gramulites. The Archeans are overlain by Precambrian rocks in the northern part of the North Cachar hills and over a small area on the western flank of the Mikir hills across the Kopili valley. Here the rocks mainly consist of quartzite and phyllites. These occurences of crystalline rocks and associated ancient sediments have long been recognised as an outlying portion of Peninsular India, Evans (1932). According to him this basement complex extends northeast beneath the alluvium of Brahmputra. The area where crystalline basement rocks occur at the surface or are known to occur beneath the Alluvium is referred to as the "Foreland Spur" by him. In the Mikir hills, Tertiar deposition commenced with a typical transgressive sequence of sandstone shale with coal beds unconformably overlying the metamorphic basement, Ran Rao (1983). According to him the base of Tura Formation of Jaintia Group, is marked by a sandstone with quartz pebbles. The maximum thickness of the formation measured in Mikir hills does not exceed 30 m, Ranga Rao (op.cit). The Sylhet outcrops occur as discontinuous patches clos to the metamorphic basement overlapping the Tura as in the Deopani river. The formation mainly consists of cream and grey coloured sandy foraminiferal limestone bands. Shales are grey or yellowish to chocolate

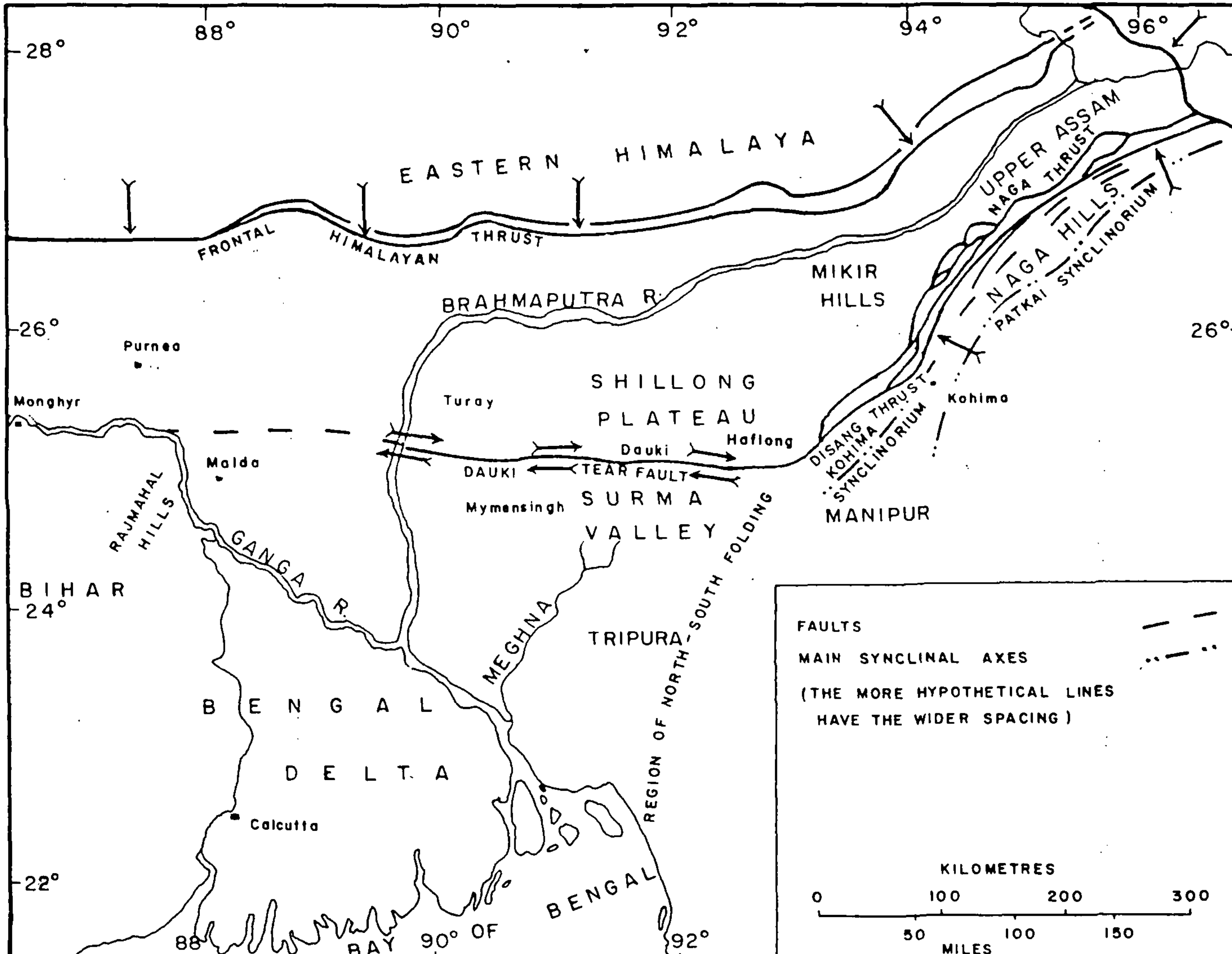


Fig. 4 - TECTONIC MAP OF NORTH-EASTERN INDIA

coloured and are fossiliferrous. Coaly streaks and thin coal bands are common. The formation becomes more arenaceous towards east. The Kopili Formation is exposed as wide belt in the western part of the Mikir hills and is overlapped eastward by the Surma. The formation consists predominantly of sandstone in the lower part grading upwards into sand-shale alternations.

In southern part of the basin is Disang, mainly made up of grey, dark-grey and black shales, fissile and splintery with minor sandstones. Finely communited carbonaceous matter is distributed throughout this formation. On the eastern side along Dimapur-Kohima road, it was found possible to subdivide the Disang into three units (Mitra et.al. 1975). The lower unit comprises of dark grey splintery needle weathering shale and cliff forming non-calcareous siltstone and silty sandstone; the middle unit consists of dark grey splintery shale, white concretionary shales, sandy silt and sandstones comprise the top unit. The total thickness of Disang is estimated here to be + 3000 m.

The Barails are subdivided into three formations viz. Laisong, Jenam and Renji. All these are exposed in the upthrust blocks along Dimapur-Kohima road. The Laisong Formation dominantly consists of thin to thick bedded grey well sorted sandstone. Jenam is a predominantly argillaceous sequence of dark grey siltstone, shale and mudstone with thin sand wedges overlying the Laisong Formation along Dimapur-Kohima road. Renji Formation along Dimapur-Kohima road comprises of thick sandstone beds alternating with thin bedded grey sandstone siltstone and shale. The sandstone consists of alternating cross-bedded and horizontal laminated units, and is bioturbated, Ranga Rao (1983).

It is generally held that an important widespread unconformity occurs at the top of Barail Evans (1932), Mathur and Evans (1964), Dasgupta (1977). The Surma has been subdivided into two stages viz. Bhuban and Bokabil. In the Mikir hills only Bokabil is exposed. The base of Bokabil is marked by a distinct unconformity. Here the basal conglomerate is succeeded by a sequence of thin alternations of sandstone, siltstone and shale. The thickness of these varies from a few millimeters to several centimeters, Roy et. al (1975). The Barail range has been considered as the type area for the Surma rocks. The lower Bhuban developed at Barail range consists of alternations of sandstone, shale, siltstone with frequent bands of conglomerate. Middle Bhuban is primarily an argillaceons sequence composed of grey shale with siltstone and subordinate sandstone. The upper Bhuban on the other hand is predominantly an arenaceous sequence. The Surma rocks as a whole show a general reduction in thickness from southwest to northeast in the " Belt of Schuppen ". Overlying the basal conglomerate marking the unconformity between the Barail and Bhuban, a sequence of sandy shale with lenticular bedding; mudstone and siltstone is included in the Middle Bhuban Formation. The Upper Bhuban Formation adjacent to the Naga thrust is characterized by flaggy alternations of thin to medium bedded, grey fine grained sandstone and ripple laminated grey silts/shales with grey mudstones. Overlying the alternations of the Upper Bhuban is a sequence of grey laminated shale with a typical flaky weathering character. These belong to the Bokabil Formation.

The Tipam Formation is exposed in most of the structural units of " Belt of Schuppen ". The formation comprises massive to thick bedded grey sand stone. The sandstones are generally multistoreyed with layers of intraformational conglomerate. In the Mikir hills these overlie the Bokabil Formation as a thick arenaceous sequence of grey thick bedded sandstone interbedded with greenish grey claystone towards the top. The sandstone shows medium to large scale cross stratification, Ranga Rao (1983).

The Girujan Formation in " Belt of Schuppen " is widely exposed in most of its structural units. The formation comprises of red, brown, orange, mauve, mottled claystones with subordinate sandstone beds varying in thickness from 2m to 10m. The Dihing Group comprise pebble beds, gravels, thin clays and sands (unconsolidated at places).

PRESENT INVESTIGATION

Previous work gives a preliminary idea of geology and lacks regional analysis of structure and lithologic continuations. Therefore, the present investigations were carried out on regional scale using LANDSAT images. This remotely sensed data has revealed some additional information which were not reported earlier. However, the detailed interpretation leading to appraisal of stratigraphy and structure of the region became possible mainly due to available information from the previous literature. Various lithounits were recognised on the basis of the following criteria:

i) variation in greytone

ii) surface configuration, shape, size and orientation of the terrain segments

iii) vegetation patterns

iv) drainage patterns

v) surface and soil cover

Table - I shows interpretation keys used in the present study to recognise various lithological units.

The stratigraphic sequence of the area is given in Table-II. A lithotectonic map (Fig. 5) has also been prepared to show lithounits in the area.

PRECAMBRIAN

Rocks belonging to Precambrian age occur on Mikir hills only. These hills are believed to be fragmented outlier of the Archean Shillong plateau. The rock type consists of biotite granite, foliated gneisses, schists and granulites.

JAINTIA GROUP

These rocks occur in the Mikir hills region. Rocks belonging to the Tura, the Sylhet and the Kopili Formations in ascending order and flank the southern and southeastern region of the Mikir hills. These predominantly consist of sandstone, limestone and sandstone and shale respectively.

DISANG GROUP

The Disang Group of rocks covers a large part of the study area in the Naga hills region. These rocks occur in eastern and southeastern part of the basin. Rocks include monotonous sequence of shale, black to dark grey in colour and are highly splintery. These are associated with thick beds of sandstone, siltstone and sandy shale. Disang is

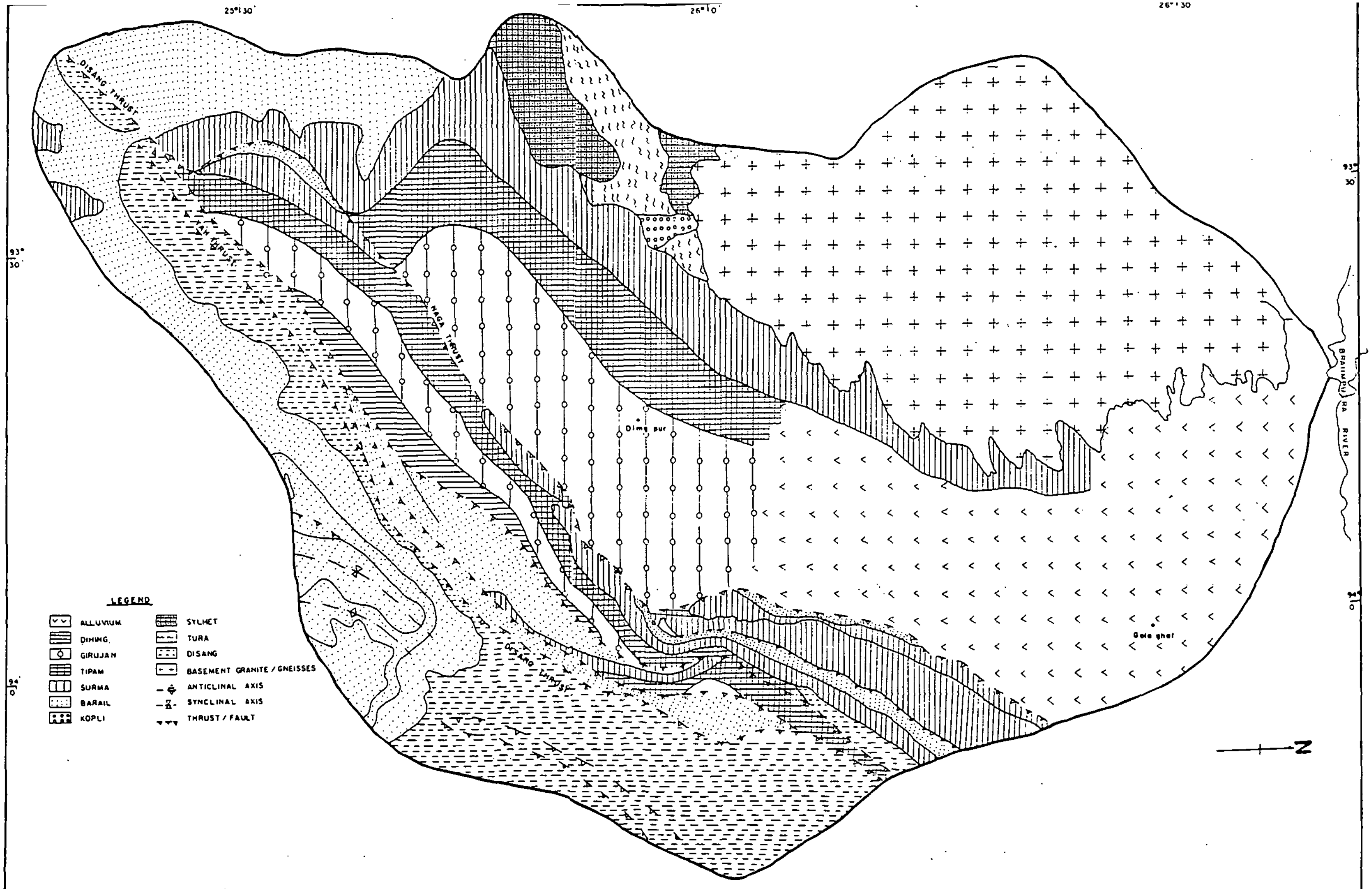


Fig. 5 – LITHOTECTONIC MAP OF THE DHANSIRI RIVER BASIN

invariably truncated at the base of Disang and Yah thrusts and only the upper part of the group is preserved. From the southern part of the basin it continues towards northeast and is truncated against Yah thrust. It remains sandwiched between Barail on both sides and widens out at the end of the Barail range in northeast (Fig. 5).

BARAIL GROUP

In the Barail range, the rocks of Disang Group are conformably overlain by Barail Group, which usually occupies high ground and form prominent ridges. The splintery shale and siltstone of Disang are succeeded in turn by cleaner and hard sandstone with little sandy shale which pass into the overlying arenaceous facies of the Barail. In the " Belt of Schuppen ", Barail Group of rocks truncate against Yah and Disang thrusts from south to northeast of the basin respectively. In the northwest side these rocks abut against Sanis Chongliyemsen and Piphima thrusts respectively (Fig. 5).

SURMA GROUP

The Surma sediments comprise alternation of felspathic sandstone, shale and clay. In the Naga hills region, the Surma are exclusively confined to the " Belt of Schuppen ". On the other hand, these rocks run parallel to the Mikir hills truncating against and sometimes penetrating into them. Rocks belonging to the Surma truncate against the Naga thrust in two patches (Fig. 5).

TABLE: I INTERPRETATION KEYS FOR IDENTIFICATION OF LITHOUNITS ON LANDSAT IMAGES

LITHOLOGY	MSS - 7
1. River Alluvium	Light greytone
2. Boulder Conglomerate Beds	Pitted dark and light greytone
3. Sandstone, Shale, Mudstone	Light greytone, well developed drainage network and gully erosion
4. Basic Volcanics	Dark greytone
5. Dolomite and Dolomitic Limestone	Dark grey and mottled tone
6. Carbonaceous Shale	Dark greytone and dendritic drainage pattern
7. Limestone	Very dark greytone and gully erosion
8. Quartizite	Pitted light to dark greytone
9. Schist, Phylllite Slate	Light graytone, dark grey to blacktone sub parallel, dendritic pattern

TABLE: II STRATIGRAPHIC SUCCESSION OF THE DHANSIRI RIVER BASIN

Age	Group	Naga Hills	Mikir Hills
	Formations and Local Names		
Plio Pliestocene	Alluvium	Dihing Formation	-
	Unconformity		
	Tipam	Girujan Formation	
		Tipam Sandstone	-
Mio-Pliocene			
	Surma	Bokabil	Bokabil
		Bhuban	Bhuban
	Unconformity		
Upper Eocene to Oligocene	Barail	Renji	-
		Jenam	
		Laisong	
Upper Eocene			Kopili
	Jaintia/Disang	Disang	Sylhet
			Tura
Precambrian			Archeans

TIPAM GROUP

The rocks belonging to this group have wide occurrence in the basin. However, these are also restricted to the "Belt of Schuppen". The Tipam Group of rocks are mainly arenaceous particularly in lower region. These are massive to thick bedded felspathic and ferruginous sandstone. In the Naga hills region these rocks remain parallel to Naga thrust from south and then remain truncated against it except for the places where the Surma is exposed. Later towards northeast these rocks alternate with Barail and Surma. These are also exposed on the western side of the Dhansiri river and run parallel to it till the alluvium overlaps them.

GIRUJAN CLAY

Clay being susceptible to weathering, outcrops of Girujan are scanty. Mottled grey and variegated clay is the dominant rock type of this argillaceous formation with subordinate siltstone and sandstone. In south of the basin, rocks of this formation truncate against Disang Thrust. These run parallel to the Naga thrust according to the general trend of the "Belt of Schuppen", and then get truncated against Sanis Chongliyemsen thrust in northeast. North of the Naga thrust, it is overlain by low level Alluvium.

DIHING FORMATION

Girujan is unconformably overlain by Dihing. Thick beds of gravel with subordinate clay represent this lithounit. On the eastern side these are truncated against Sanis Chongliyemsen thrust.

LINEAMENTS AND TECTONICS OF THE AREA

The area exhibits many small and large scale lineaments. The nature and origin of lineaments can only be conjectured since they were identified on a regional scale. The following criteria have been used to identify these features:

i) straight course of streams
ii) fault scarps or triangular facets
iii) straight and curvilinear features
iv) anticlinal spur lines
v) synclinal valleys
vi) structurally controlled drainage pattern and
vii) relief impact on faulted, down thrusted blocks

A lineament map (Fig. 6) based upon visual interpretation of LANDSAT images was prepared. The azimuth of each lineament was recorded and rose diagrams for each region were prepared separately. It is apparent from the rose diagrams that most of the lineaments in the area of study are trending NE-SW. In the Region 'A' majority of lineaments are concentrated between $60^{o} - 90^{o}$. In the case of Region 'B' they are between $30^{o} - 60^{o}$ and in Region 'C' viz. the Mikir hills, the concentration of lineaments is more between 30^{o} and 90^{o}. This is probably because the Indian plate subducted under the Burmase plate in a direction approximately perpendicular to it.

Some of the identified mega linear features which are previously discussed as regional thrusts are as follows:

i) Naga thrust
ii) Sanis Chongliyemsen thrust

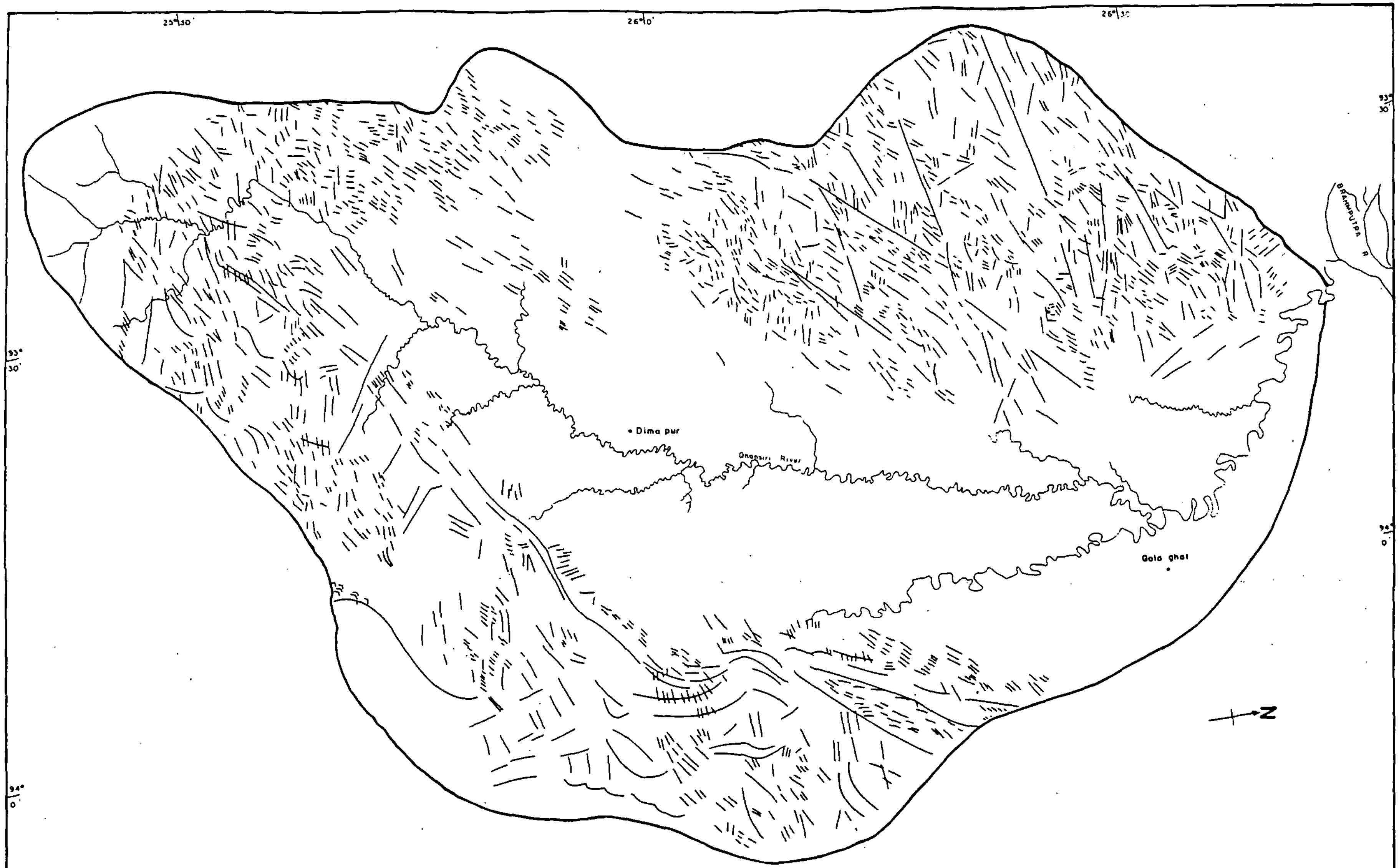


Fig.6 — LINEAMENT MAP OF DHANSIRI RIVER BASIN

iii) Piphima thrust

iv) Yah thrust

v) Disang thrust

Naga Thrust

It marks the culmination of Naga ranges and separates the Naga hills from the Dhansiri Alluvium. It is the thrust which controls the movement of the Dhansiri river at its origin. Tipam and Surma sediments are juxtaposed for a long distance along this thrust. It meets Barail sediments at around lat. 25° 58'N. It is now believed that subduction of Indian plate under the Burmese plate has now started at this thrust (an ongoing neotectonic activity) Roy and Kacker (1980). It marks the outer margin of the 'Belt of Schuppen'. The trend of this frontal thrust is NE-SW, which is in accordance with the regional trend.

Disang Thrust

The belt of Schuppen is about 20 km broad with its northwestern edge as the Naga thrust, following closely the boundary of Assam valley Alluvium, and the northeast edge as Disang thrust. The Disang thrust runs parallel to the Naga thrust trending NE-SW. Near Jaluki, Disang thrust bifurcates into many thrusts. Before the bifurcation it has Barail sediments on the hanging wall side. After joining Yah thrust it makes the boundary between Disang and Barail.

Sanis-Chongliyemsen Thrust

The Disang thrust bifurcates at lat. 25° - 37°N and from here on Sanis Chongliyemsen thrust separates Barails from Dihing till lat. 25° - 52'N and 25° - 59'N where it has Girujan and Tipam on the footwall side respectively. The trend of this thrust is also NE-SW.

Yah Thrust

The Yah thrust also runs parallel to the Naga thrust. It separates Barail from Disang. The Barail rocks which are sandwiched between Disang and Yah thrusts, show intricate fold patterns because of their wedging between two closely spaced thrusts. The trend of Yah thrust is also NE-SW. It meets Disang thrust at lat. 25° - 37'N.

Piphima Thrust

It gets separated from the Sanis Chongliyemsen thrust and runs through the Barail till lat. 25° - 43'N where it separates the Surma from the Barail. It gets in contact of Tipam at lat. 25° - 52'N. It also separates the Girujan from the Barail at lat. 25° - 57'N and ultimately meets the Disang thrust. It derives its name from Piphima Village on National highway No. 39 just before Kohima where it can be observed very closely. It also trends NE-SW.

The 'Belt of Schuppen' is 20 km wide. In the belt, eight separate thrust sheets have been demarcated with overthrust forming a complex pattern, higher ones in places, overriding the lower ones. Out of these, five main thrusts have been described. The frontal thrust though known as Naga thrust is seen to comprise, in a longitudinal distance of 100 km, some six different thrusts. The easternmost thrust of the belt is known as the Disang thrust. As regards the stratigraphical throw of the individual thrust, it varies greatly but 3000 to 8000 m is usual for the larger thrusts, Evans (1964). The horizontal displacements are not known; they are almost certainly many times the stratigraphical throw Evans (op.cit.) suggested that the movement of individual masses might be from 20 to 40 km giving a total crustal shortening for the eight thrusts of anything between 150 km and 300 km. The 'Belt of Schuppen' is later cut by numerous lineaments which indicate that the thrusts are still active. It is further evidenced by the geomorphic features like reoccurence of landslides and structurally controlled streams. Other important evidence is that the area is seismically active experiencing many earthquake.

SEISMICITY

The northeastern belt of India, comprising of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura is highly susceptible to seismic activity. The area has witnessed some of the severest earthquakes recorded in history. The location of the epicentres i.e. points on the earth's surface immediately above the centre of origin indicate their concentration near major dislocation zones. It is, therefore, reasonable to assume that earthquakes normally originate from deep zones where accumulated stresses give rise to movements along the fault planes. The Mikir hills constitute the remnants of the continuous massif which during pre-Himalayan eon formed the structural backbone of northeast India, Development of mountain building stresses in the region during the passage from Cretaceous to Eocene period initiated the growth of pressure lines within and around this pivotal mass. Under the influence of this stress field the fold resistant massif slowly degenerated into a present state of distorted, partially disjointed and isolated block separated by regions of more recent geological formations. A considerable diminutinn of seismic activity upto some distance to the east of Mikir hills is indicative of the maturity of such hidden features. The major causes for earthquakes in the area of study can be attributed to the presence of following major tectonic lineaments:

i) the basement faults consisting of the EW Dauki fault along the southern margin of the Shillong plateau extending upto Haflong.

ii) the 'Belt of Schuppen' - a NE-SW belt of intricate thrusts in the Naga hills.

These lineaments remained active throughout different stages of tectonic cycles from Upper Cretaceous to Pleistocene times and are probably still active. The occurrence of earthquakes in the area is because of the above mentioned tectonic lineaments. It is now believed that Haflong-Disang-Naga thrusts form the surface expression of a probable subduction zone where the Indian plate moving southeastward has later started subducting below the Burmese plate in the Arakan-Yoma folded belt, Roy and Kacker (1980).

The tectonostratigraphic set up and earthquakes recorded in the study area, which forms a part of seismic northeastern belt of India, clearly show that the area is tectonically active and falls in the active earthquake prone belt.

CHAPTER - IV

LANDFORMS AND DRAINAGE

The area characterises a very fascinating geomorphic set up. Visual interpretation of LANDSAT images and their superposition on topographic maps helps in identification of various types of landforms in the area.

Synoptic view of the Dhansiri river basin on LANDSAT pictures provide three fold classification as follows :-

i) Higher hilly tract (Mikir hills and Naga hills)

ii) Lower hilly tract (Piedmont zone)

iii) Alluvial plains.

Table III shows the interpretation key for the delineation of landforms and surface cover areas.

HIGHER HILLY TRACT :

In the Mikir hills, higher hilly terrain is exclusively composed of hard rocks. On the other hand, these are composed of soft sedimentary rocks in the Naga hills. These geomorphic units have risen to their present elevation through a combination of several endogenic and exogenic processes operating over a long geological past. Having this supreme position of existence as well as outline, these have commanded the development of other younger geomorphic units of the area. Its expression on the LANDSAT images is very distinct having two well defined sets (Fig. 7).

Figure 7 showing landforms and drainage in the Dhansiri river basin. Also note the Ox-bow lakes in the viscinity of the Dhansiri river

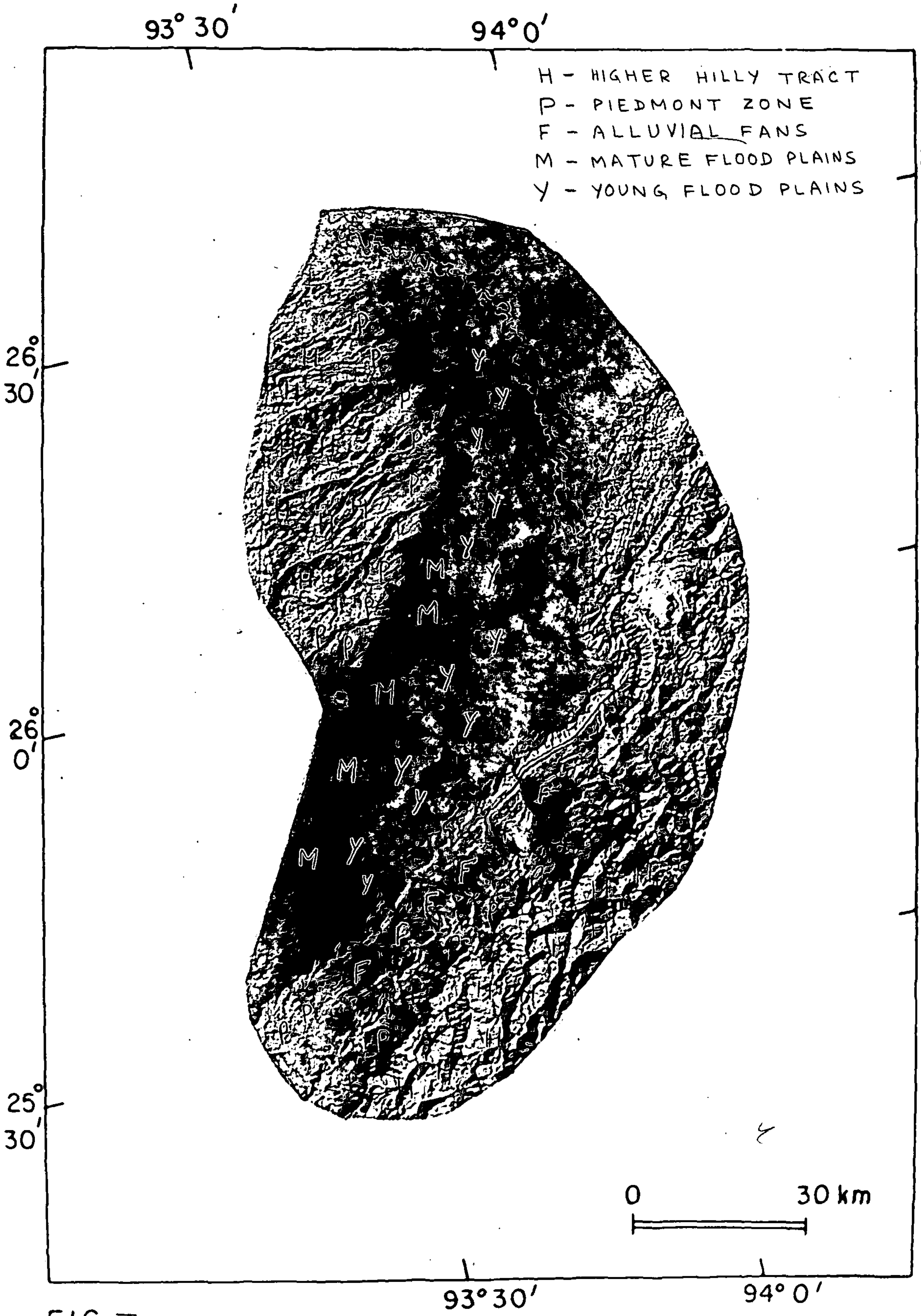

93° 30′
94° 0′
H - HIGHER HILLY TRACT
P - PIEDMONT ZONE
F - ALLUVIAL FANS
M - MATURE FLOOD PLAINS
Y - YOUNG FLOOD PLAINS
26° 30′
26° 0′
25° 30′
0
30 km
93° 30′
94° 0′

FIG.7

The Mikir hills region is at a little distance from the warped Tertiary ranges of the Naga hills. This is supposed to be a fragmented outlier of the Shillong plateau further west. It is believed that these have a sub-terranean extension via the Dhansiri valley towards northeast across the Brahmputra at triple junction in Lohit. The domal shape of these hills gave rise to radial drainage patterns at many places. The Mikir hills attain a height upto 1400 m.

Highland area in the Naga hills region consists of sharp hilly country, running as convex arch facing the Dhansiri valley. The Barail range enters from southwest of the Naga hills and runs in a northeast direction upto Kohima. The Naga hills attain a height of about 2000 - 2500 m. Most of the landforms are younger than the Tertiary age. The topography is controlled by geological structure and the physical characters of the rock types. The topography is youthful as represented by

i) high rising ridges

ii) steep gradient of streams and water courses actively eroding the rocks giving rise to deep gorges.

iii) 'V' shaped valleys.

iv) absence of flood plains.

LOWER HILLY TRACT :

The tributaries from both sides of the Dhansiri river, progressively enter the lower altitudes. Due to considerable change in gradient they form the depositional landforms and are identified on the LANDSAT images as follows :-

i) Piedmont zone and

ii) Large alluvial plains.

PIEDMONT ZONE

A piedmont zone, located at the foot hills of mountainous terrain, shows medium to dark greytone on LANDSAT images. In the Mikir hills as well as in the Naga hills, piedmont zone, by and large, consists of tertiary sediments. The fault generated scarps are common in the Naga hill's piedmont zone as it consists of 'Belt of Schuppen'. The streams are thrust controlled. The gorge like valleys are also commonly straight upto large distances.

ALLUVIAL FANS :

It is a general notion that alluvial fans are aggregations of stream debris. These generally develop where the stream leaves the mountainous area. Due to this sharp gradient loss, the material deposits in a radiating fashion from the emerging point. An alluvial fan is reproduced on LANDSAT images in the form of a triangle with its apex directed towards the hills and the spread out base touching the surrounding foothill plain. The alluvial fans of varying dimensions are common morphological features in the river basin (Fig. 7). The regionally distributed alluvial fans are identified on the LANDSAT imaged at the Naga foothills. The material of these alluvial fans has mainly been derived from the Tertiary sediments.

ALLUVIAL PLAIN :

The third geomorphic unit i.e. the large Alluvial plains (Fig. 7) recognised on LANDSAT images, is divided on the basis of tonal and textual contrasts into :

i) Meanders

ii) Ox-bow lakes

iii) Mature flood plains and

iv) Young flood plains

Mature flood plains are identified by light graytone whereas young flood plains by relatively darker tone. This tonal contrast is due to variation in soil moisture and vegetation pattern. The streams show intense meandering immediately after entering the plains. A large number of ox-bow lakes has been observed. A plausible explanation for genesis of these features has been attempted latter under the heading "Drainage System, Pattern and Evolution".

SOIL EROSION AND LANDSLIDES

When the soil is being formed the processes of erosion are also in action - physical and chemical forces causing the break down and downslope movements of rock debris and soil. Erosion is a dynamic process. In some areas soil erosion can be so fast and continues for such a period that the majority of the soil is lost. In an agricultural terrain such as the study area the loss of soil and its fertility must be given due emphasis.

The area is also severely effected by landslides, particularly in the Naga hills. A combination of adverse factors - high relief topography, complexly folded and faulted rock formations, and high rainfall make it vulnerable to soil erosion and landslides. A forest cover is important in proper management of soil and water resources. Of the four major factors that affect soil erosion viz. rainfall, soil, slope and land-use, it is not feasible to change the first three. However, land use pattern may be suitably adopted.

The major problem in the area is that of shifting cultivation on steep slopes resulting in soil erosion and landslides. This may be reduced by contour cultivation and buffer tree strips.

In the process of "jhuming", forest is cleared and debris are burnt. A subsistance crop is grown for about two years using handtools with least labour. The removal of forest cover by burning, results in the exposure of bare soil to rains and sun, leading to enormous soil losses. The surface layer of the soil is often washed away completely.

There are three main groups of erosion in this area viz., surfacial, mass movement and fluvial.

Sheet erosion is the removal of a thin surface layer of topsoil by the flow of a thin layer of water over the land. It is more often in the Naga hills region of the basin as it experiences one of the heaviest rainfalls in the world. The impact of raindrops on the exposed soil breaks up the surface layer and loosens particles movable by the water flow. Sheet erosion is not usually a problem in forested areas. However, the soil at many places in the Naga hills has been exposed because of jhuming.

Mass movement, as the name suggests, is the downhill movement of entire block of soil and rock. This includes soil slip, earth slip, debris avalanche, earthflow and slump. As already stated, the area is tectonically unstable. The 'Belt of Schuppen' includes faulted, fractured, and jointed softer rocks, facilitating the mass movement.

Soil slip and earth slip erosions are extensive and economically most important. Slips have serious consequences. This was demonstrated by the heavy rainfall in the Naga hill region in October, 1986, when, because of rapid sliding or flowing of soil and subsoil, the roads were blocked for many days at "Pagla Pahar" region on national highway No. 39 (personal experience). Slips are frequent in this region, as the slip surfaces are further eroded by sheet and rill erosion which inhibit revegetation. Earthflows usually occur in conjunction with this type of erosion. In this kind of movement, surface cover is generally not destroyed, as the entire soil mass and rock material flows downhill. Associated with these erosion types are the slumps. One of the most severe slump took place in October 1986, when approximately 3 km. of the National highway No. 39 near Kohima subsided. These occur most commonly in Tertiary sediments of the Naga hills "Belt of Schuppen". The heavy rains saturate the pores, fractures and joints of these rocks. As the soil becomes saturated, the water forces the particles apart. This weakens the entire unit, at a critical point, gravity moves it downhill.

Another destructive erosion type active in this region is gullying. It is usually associated with weak, jointed and fractured rock types. Gullies, in this region, develop when the protective vegetation cover is broken by sheet and soil slip erosion or by direct anthropogenic activities like shifting cultivation.

DRAINAGE SYSTEM, AND ITS EVOLUTION

Rivers are the most wide spread, and thus the most effective, denudational agents on the earth. Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, Playfair (1802). As the streams flow downslope they are joined by other streams or tributaries, and river run off progressively increases and the drainage system of the area established.

As referred earlier, the Dhansiri river originates from the Dhansiri reserve forest and flows towards northwest along the Naga thrust. It enters the upper Assam plains and then takes a right turn to flow towards northeast parallel to the Naga thrust. It again takes a turn towards northwest at Golaghat and then falls into the Brahmputra river. Over time, the course of the Dhansiri river and its tributaries have become adjusted to the structure as the water finds it easier to erode along faults, joints and other lineations in the rocks over which they flow.

The tributaries coming from the Mikir hills show more or less graded profiles in contrast to the ones coming from the Naga hills, which in turn possess more energy and power for more erosion and transportation. This is because of:

a) the gravitational pull, which is one of the causes of water movement through a channel, is greater in the case of the Naga hills tributaries.

b) their greater height above base level of erosion, imparting 'potential energy'.

c) the greater steepness of their stream channels which is one of the main causes that controls the velocity of water flow (greater the velocity, greater will be the amount of 'free' or 'kinetic energy') responsible in the movement of water and its load.

It can be clearly observed on the LANDSAT images that the tributaries coming from the Naga hills start meandering intensely as soon as they enter the plains. The meandering pattern represents a least work tendency and equalization of power expenditure, Langbein and Leopold (1966). Meandering by these streams, immediately after reaching the plains may be due to the fact that these streams did not have the time to dissipate the energy before reaching the plains and extra energy had to be balanced by taking a sinuous route. A large number of ox-bow lakes indicates the erosive powers due to greater unbalanced energy.

The drainage basin sandwiched between the Naga hills and the Mikir hills, is elongated parallel to the former. The river flows from southwest to northeast. (Fig. 8)

A striking feature that constitutes two unequal sections of the Dhansiri river basin is its asymmetry. It is observed on the drainage map of the basin (Fig. 8) that the western part of the basin is relatively much larger than the eastern part. The western section is comprised of

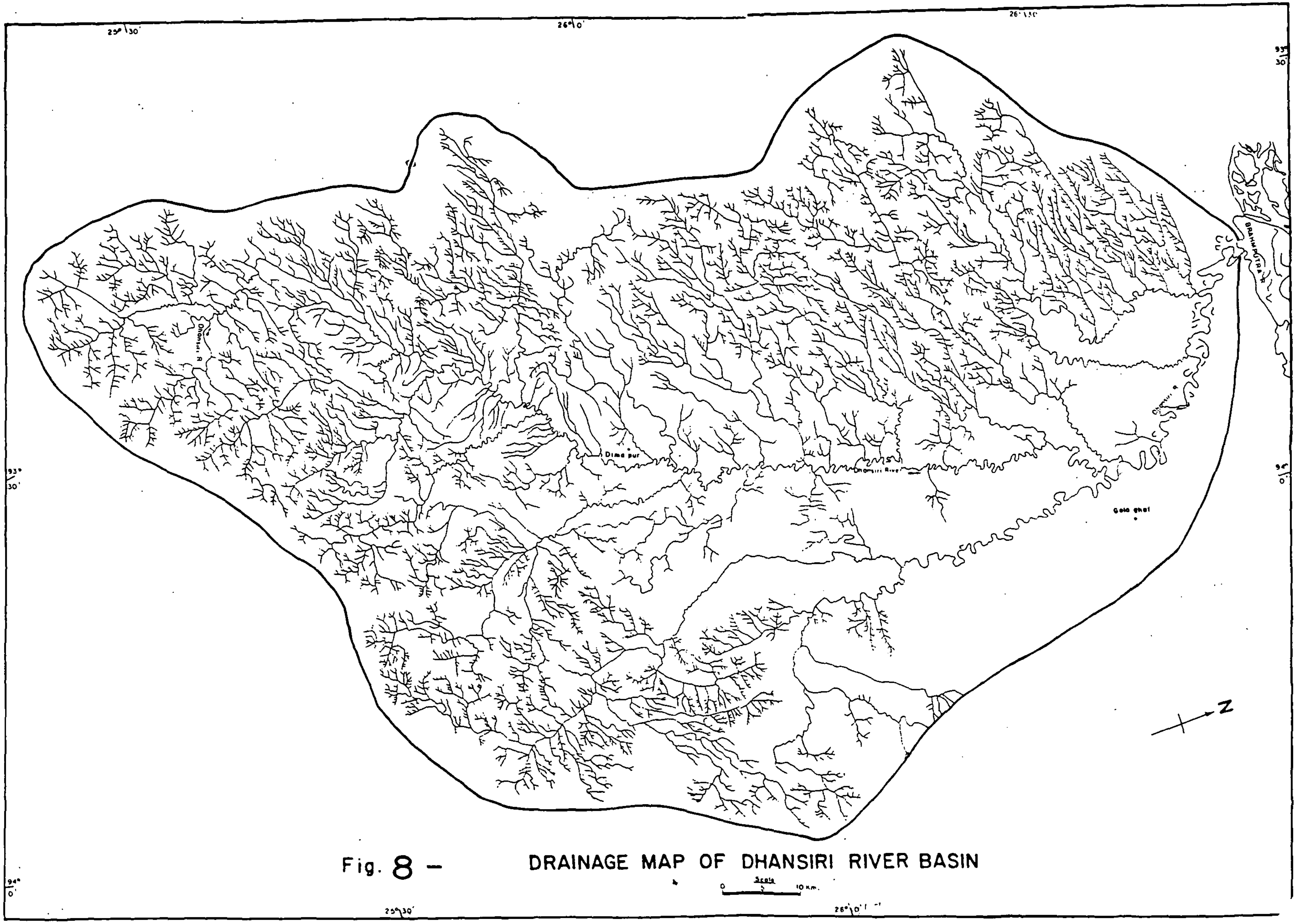


Fig. 8 — DRAINAGE MAP OF DHANSIRI RIVER BASIN

drainage on the eastern slopes of the Mikir hills and the eastern section includes the network on the western slopes of the Naga hills. The left bank tributaries (western section) of the drainage system flow on gentler slopes and also are longer than the right bank tributaries (eastern section) (Fig. 9). In short all major tributaries of the Dhansiri river viz. the Daigurung, the Kaliani and the Deopani are left bank tributaries. Basin asymmetry is relatable to the geomorphic history of the two sections. The eastern drainage is younger than the western drainage because the longitudinal profiles of the latter are more nearly graded than the former. Thus the left bank tributaries have had more time to grade their profiles. This is because the Naga hills are young mobile belt and the Mikir hills are much older.

River Capture: An interesting feature of the course of the Dhansiri river is the rectangular bend just after the river enters the upper Assam plains. Left bank tributaries at this bend are rather small. It seems, that the Lumding river, which almost touches this bend, had its origin in the Naga hills. Trend of the Naga thrust and the subsurface structure of Assam valley facilitated and set the stage for stream capture. Because of this, conditions developed whereby a headward eroding Dhansiri river could capture the upstream portion of the Lumding river. The two streams near the bend are aligned in such a way that the upstream portion of the present day Dhansiri river can easily be extended into the Lumding river. A wind gap is identified at this point (Figure 10).

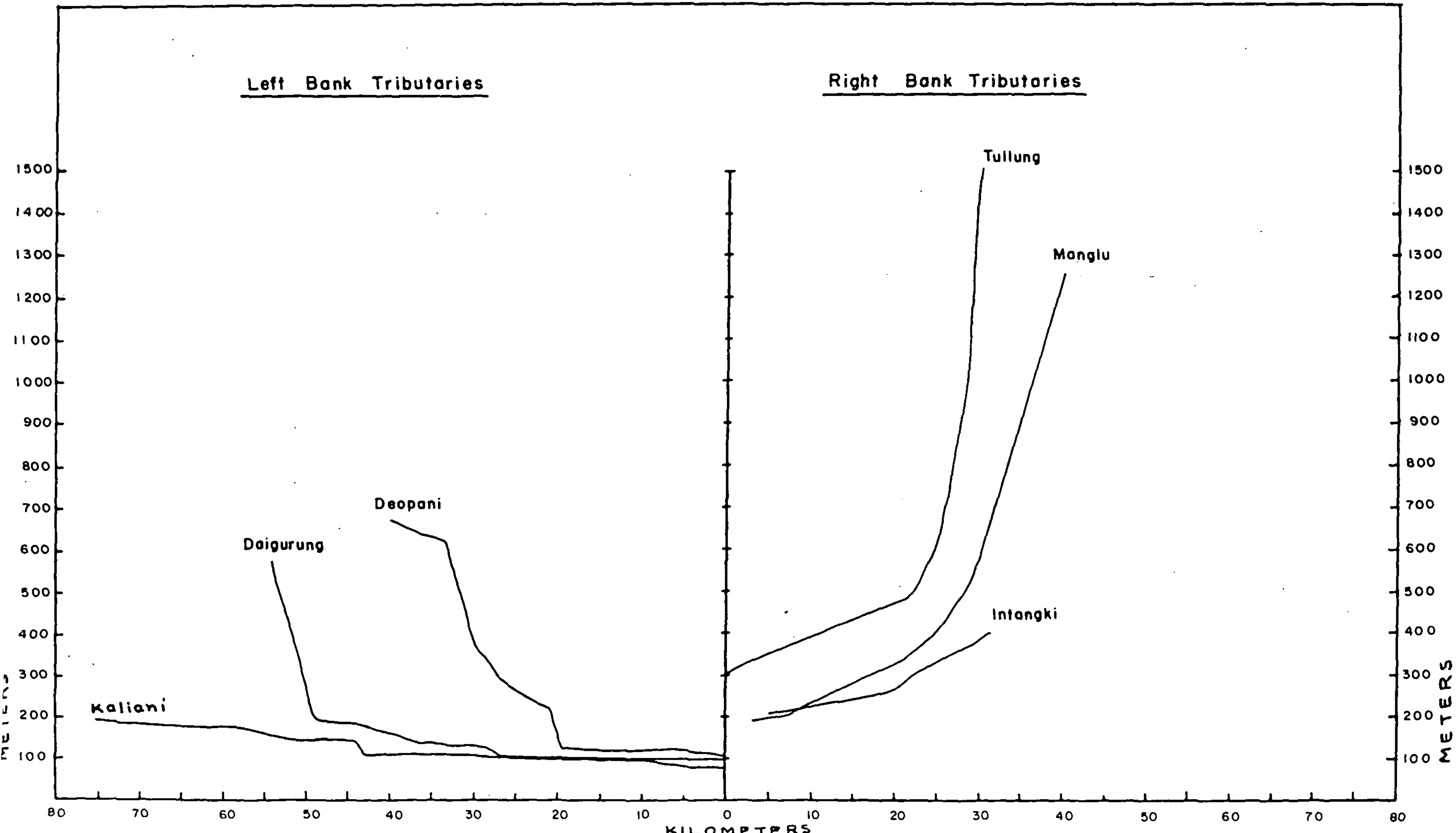


Fig. 9 – Longitudinal profiles of the Western (shown to left) and Eastern (shown to right) tributaries of the Dhansiri River

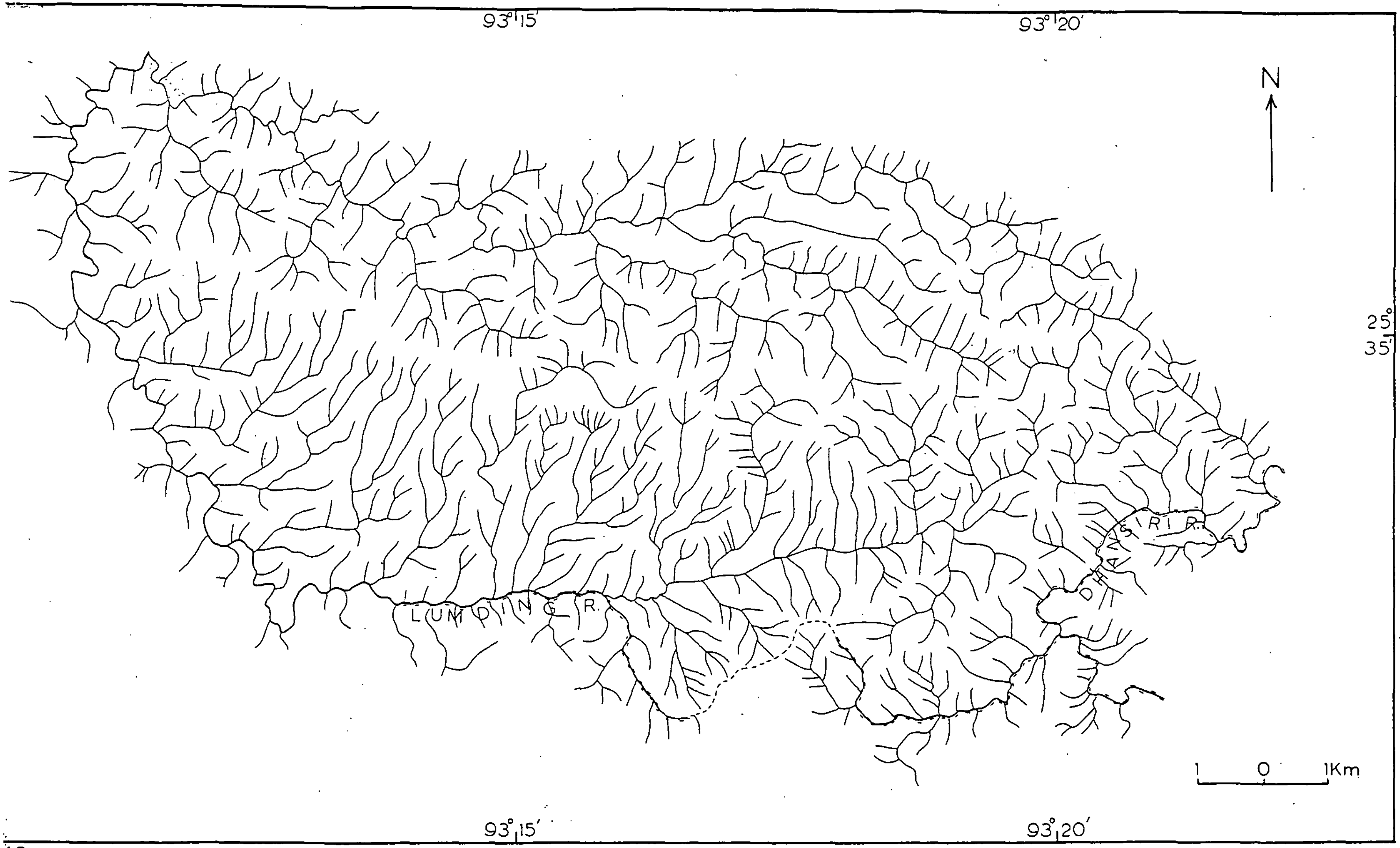


FIG.10-SHOWING PROBABLE RIVER CAPTURE

DRAINAGE PATTERN

The Dhansiri river and its tributaries traverse through three main physiographic regions, the Naga hills (Tertiary), the Mikir hills (Precambrian) and alluvial deposits (Recent). All these regions have their own distinct lithological and structural setup which mainly influence the drainage network in the area. The Dhansiri river and its tributaries form a characteristic drainage pattern, which includes the spatial arrangements of stream and its tributaries in the catchment as they are viewed from the air or on map. The arrangement of drainage segments is a function of :

i) geologic structure
ii) lithology
iii) slope
iv) time factor in drainage evolution
v) climatic conditions of the area.

It is evident that drainage pattern may reflect original slope, structure and lithology or the successive episodes by which the surface may have modified from time to time. As the streams cut into the underlying rock lithology, structure and the resistance to erosion varies and give rise to characteristic drainage pattern. A single drainage pattern may be result of single or multiple factors. Therefore, their analysis has a significance in the identification and interpretation of geologic structure, lithology, physiographic and climatic condition of the area. They form one of the most immediate approaches to an understanding of geologic structure.

Following different types of drainage patterns are identified in the study area :

i) Dendritic

ii) Parallel to sub-parallel

iii) Barbed

iv) Radial

v) Pinnate

vi) Rectangular

vii) Trellis.

DENDRITIC PATTERN

It is characterised by tree like irregular branching of streams in several directions without any systematic arrangement. True and perfect dendritic patterns are developed by random headward erosion of the insequent streams on horizontally bedded rocks which have uniform resistance. They show lack of structural control. Tributaries join the mainstream at an acute angle ($7\ 90^{\circ}$) from any direction (Fig. 11). It is the most common type of drainage pattern, which can be seen at several areas in the study basin.

PARALLEL TO SUB PARALLEL PATTERN

As the name indicates the main channels are parallel or sub-parallel to each other (Fig. 12). Tributaries join main stream at low angle. Parallel drainage pattern implies pronounced regional slope or closely spaced faults/joints or monoclinal or isoclinal folds. In the Dhansiri basin such pattern is controlled by closely spaced parallel lineament and steep slope.

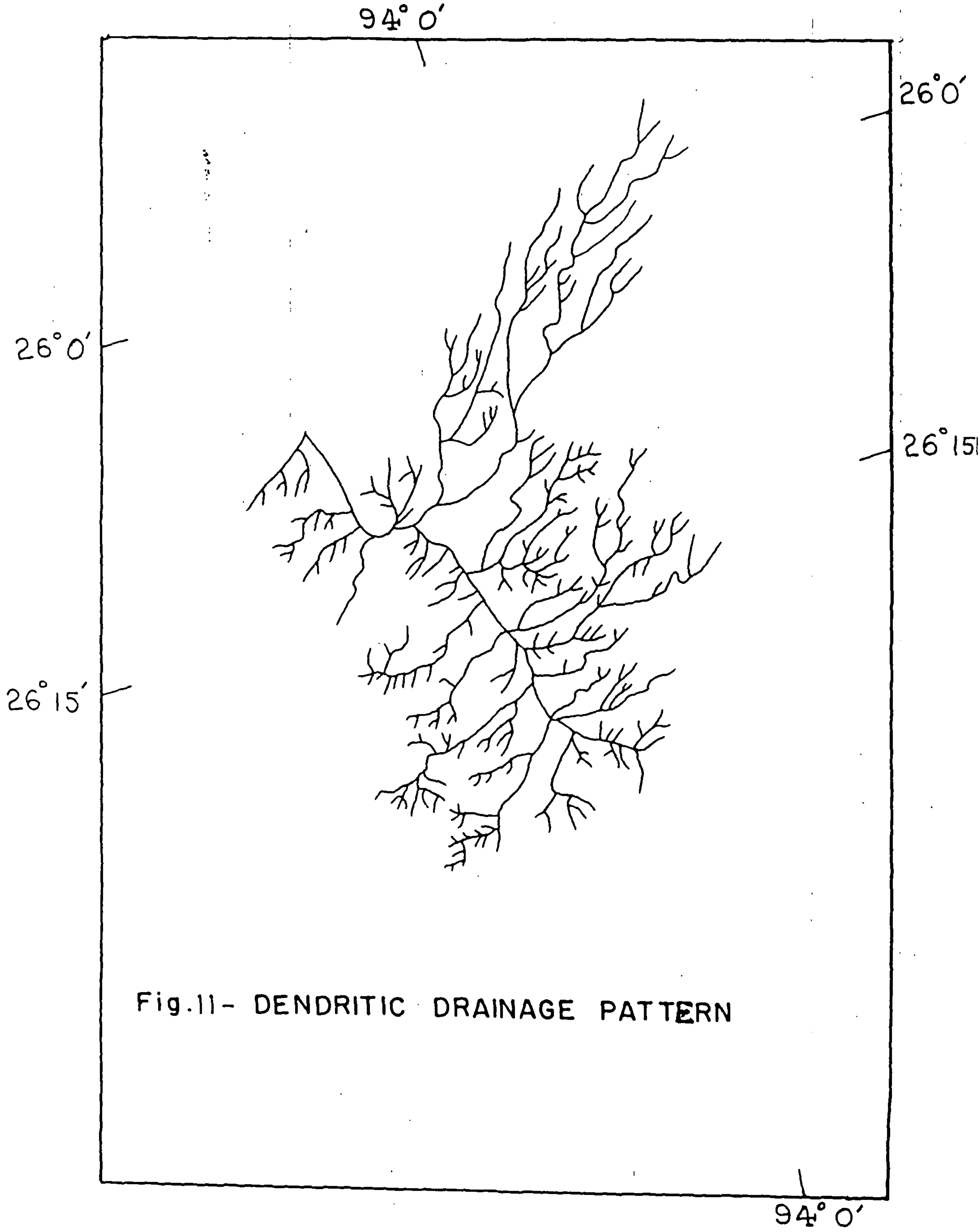


Fig.11- DENDRITIC DRAINAGE PATTERN

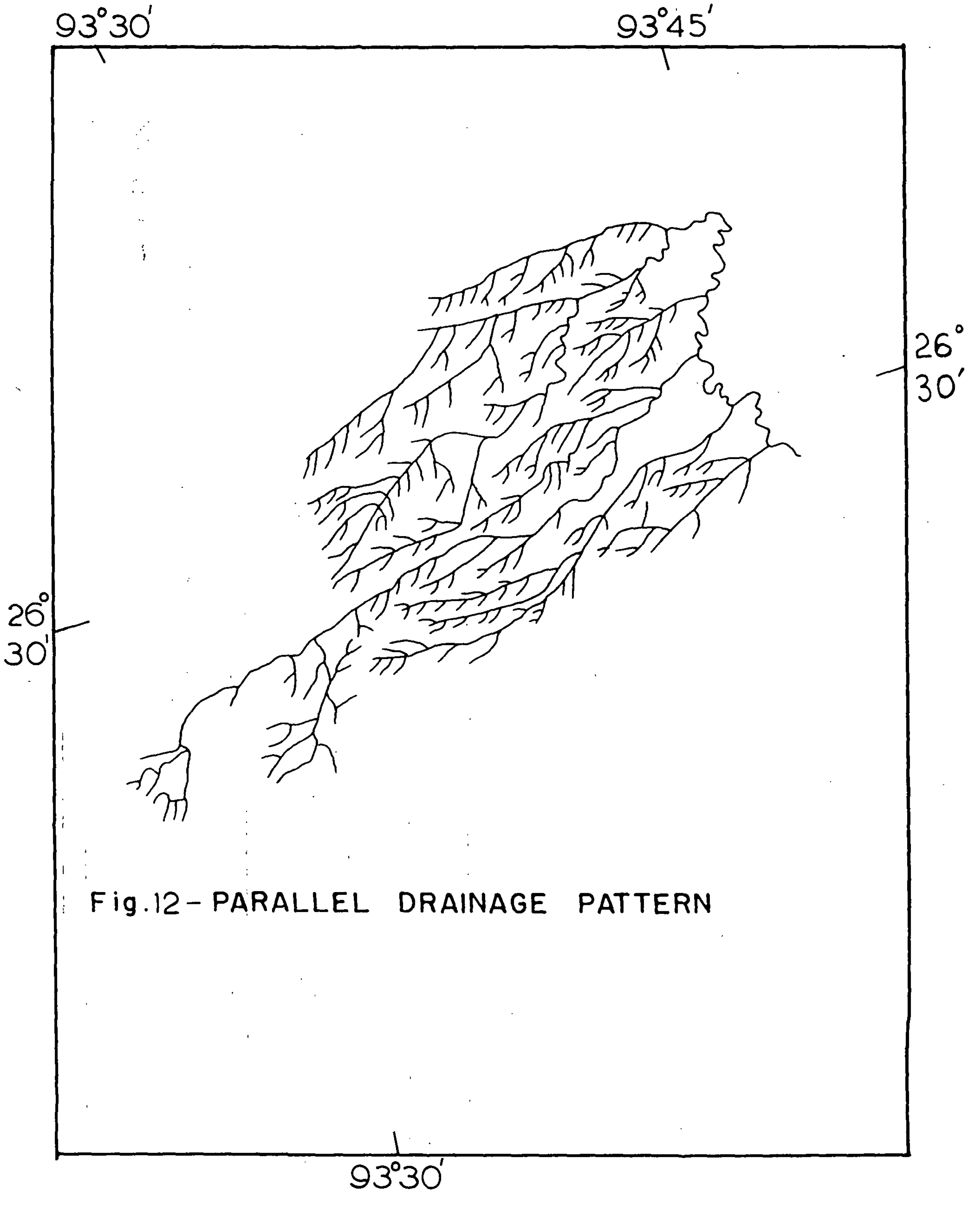


Fig.12 - PARALLEL DRAINAGE PATTERN

BARBED PATTERN

These are rather uncommon patterns and found at or near the head of the drainage system. In barbed pattern, tributary streams flow in a direction opposite to the main streams. It joins the main stream in a hook-shaped bend (Fig. 13). Actual control of such pattern is not well understood. This probably may be attributable to the river capture or some tectonic causes. It is seen in the "Belt of Schuppen" in the study area.

RADIAL PATTERN

In radial pattern streams flow outward from a central locale (Fig. 14). Volcanic cones provide the most suitable geological sites for the development of such pattern but they can as well be formed on any uplifted domal structure. This pattern is frequently seen in the Mikir hills region and also at few places in the Naga hills. It is not necessary that all the stream necessarily flow away from each other in normal radial pattern. Individual streams may, owing to irregularities in the initial slope of dome or due to other causes flow for parts of their courses obliquely toward each other and may even join with each other.

PINNATE PATTERN

Pinnate pattern is considered as a subtype of dendritic drainage. It is characterised by feather like extension of many closely spaced short tributaries (Fig. 15). This pattern is indicative of an area underlain by easily erodible sediments. Such patterns are observed in the Naga hills and at foot hill region of the Mikir hills.

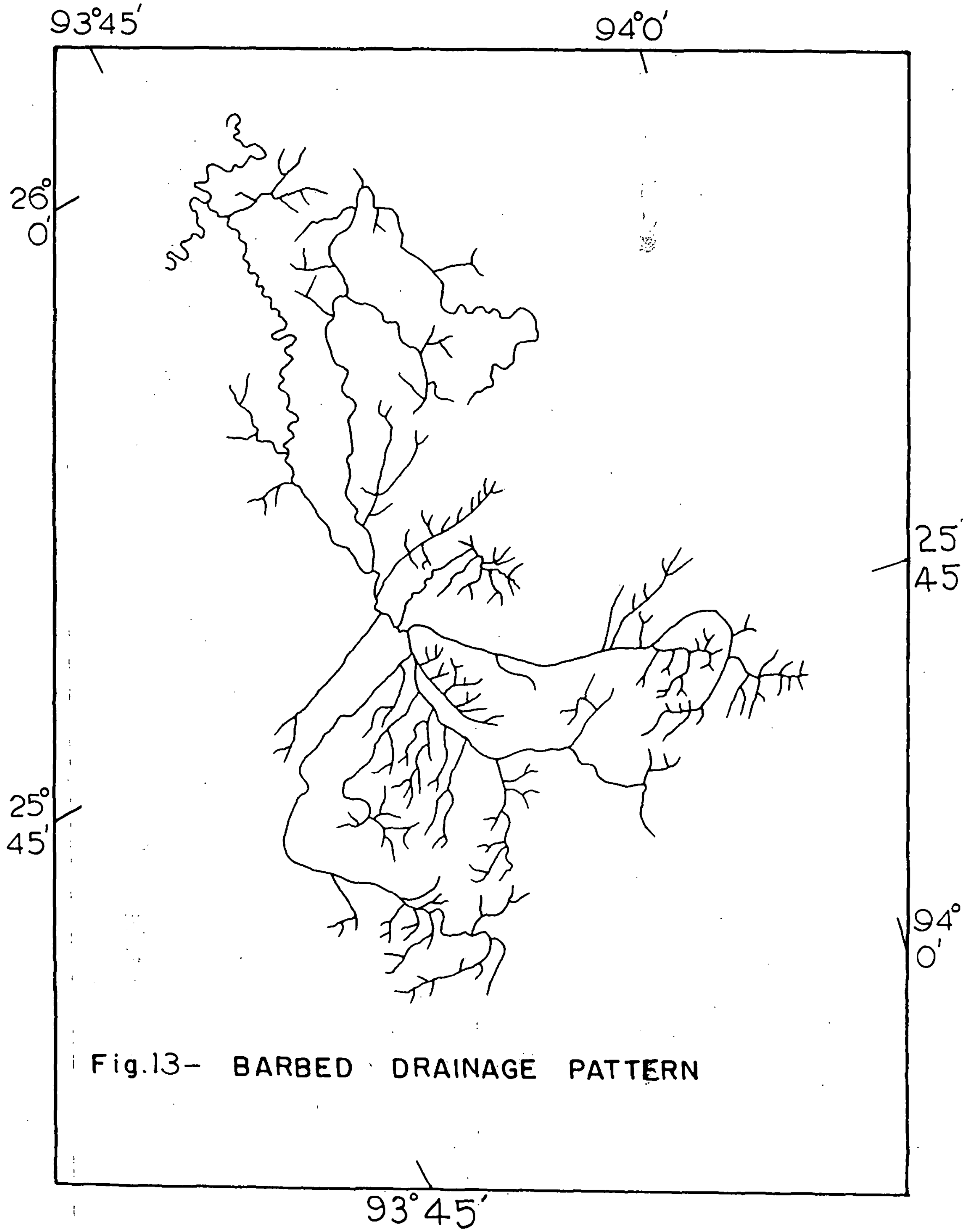


Fig.13- BARBED DRAINAGE PATTERN

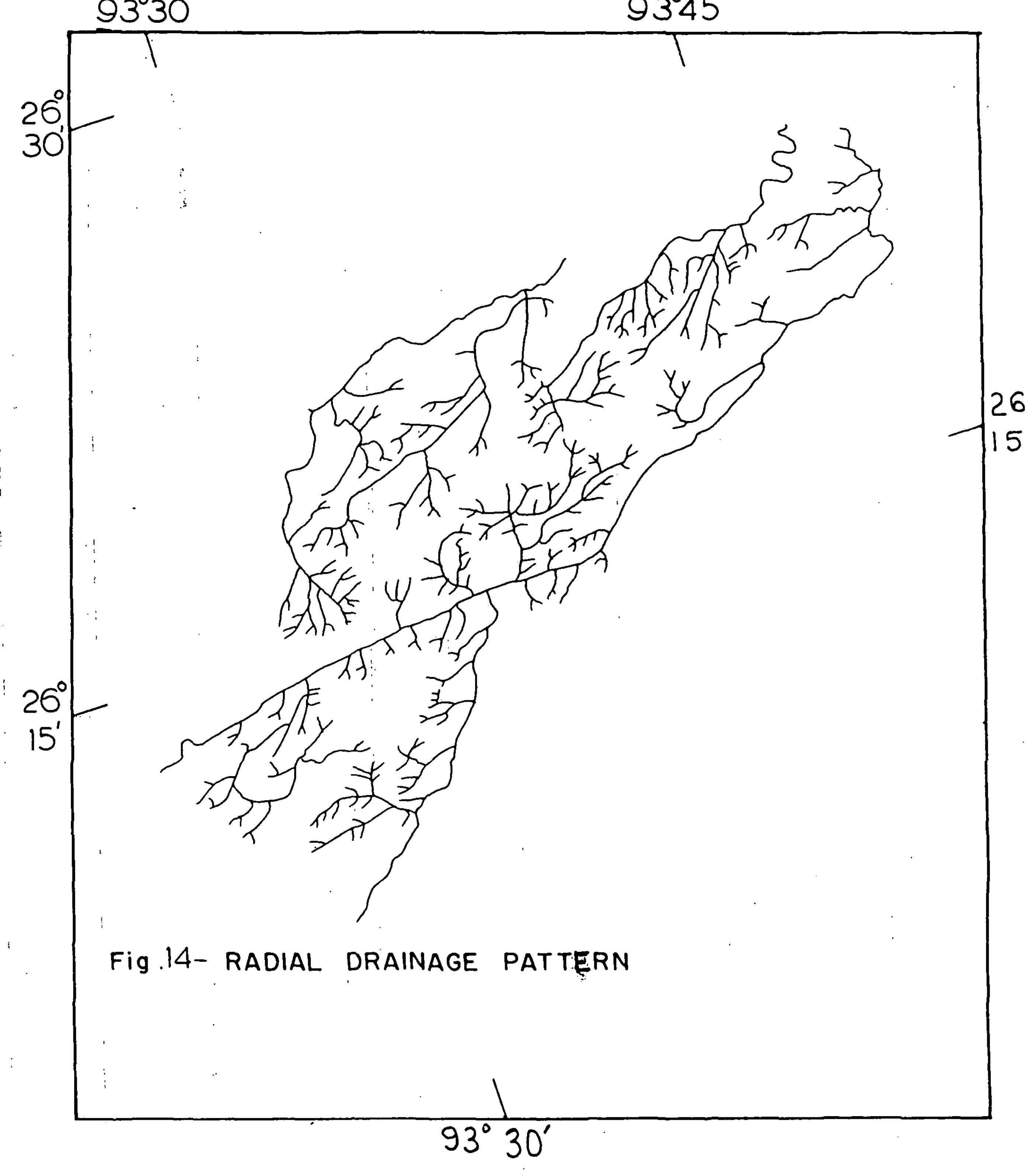


Fig .14- RADIAL DRAINAGE PATTERN

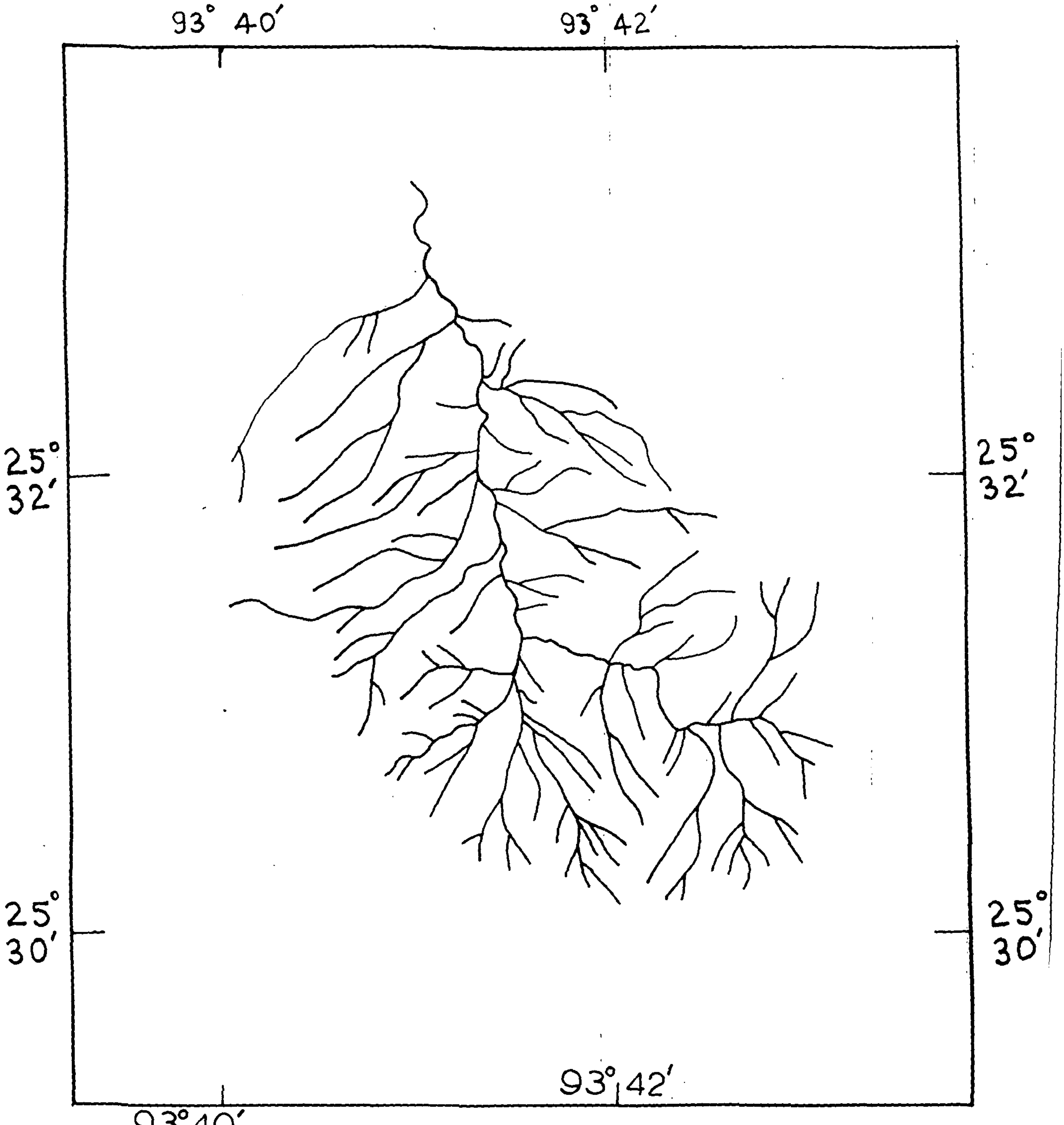


Fig.15 — PINNATE DRAINAGE PATTERN

RECTANGULAR PATTERN

It is structurally controlled pattern, characterised by right angle bends in the main stream (Fig. 16). It can be seen in the upper reaches of the Dhansiri river. Right angle bends at several places indicate that in this part of the region the stream is controlled by some major lineaments or hidden faults.

TRELLIS PATTERN

This kind of pattern is generally controlled by tilted or folded alternatively hard/soft sediments or metasediments and the lineaments. In this case a dominant drainage direction develops with a secondary direction perpendicular to it. Primary tributaries join the main stream at right angles and the secondary tributaries parallel the main stream. In the basin it is found in "Belt of Schuppen" of Naga hills (Fig. 17).

GROUND WATER POTENTIAL

In some areas the water and land resources are not evenly matched and the one which is short becomes a constraint on the maximum use of the other. There are some other areas where water is surplus. From such areas excess water can be transferred to other basin or can be utilised for artificial recharge.

The water resources in this region need to be evaluted scientifically and planned for optimal development for various uses viz. power generation, irrigation, industries and domestic purposes.

The knowledge of topographic features, structures and lithology is necessary in order to tap water from these sources with maximum efficiency.

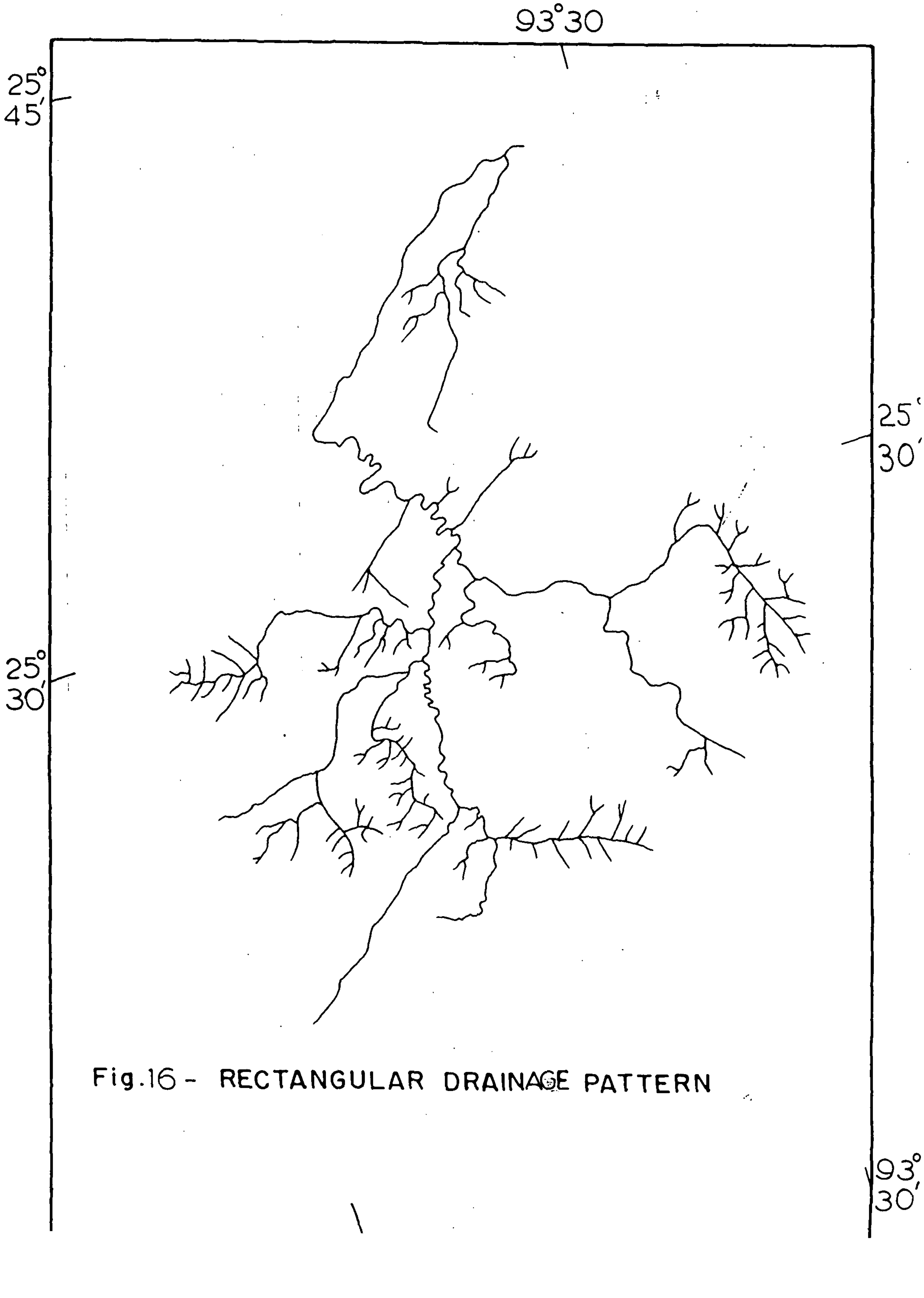


Fig.16 - RECTANGULAR DRAINAGE PATTERN

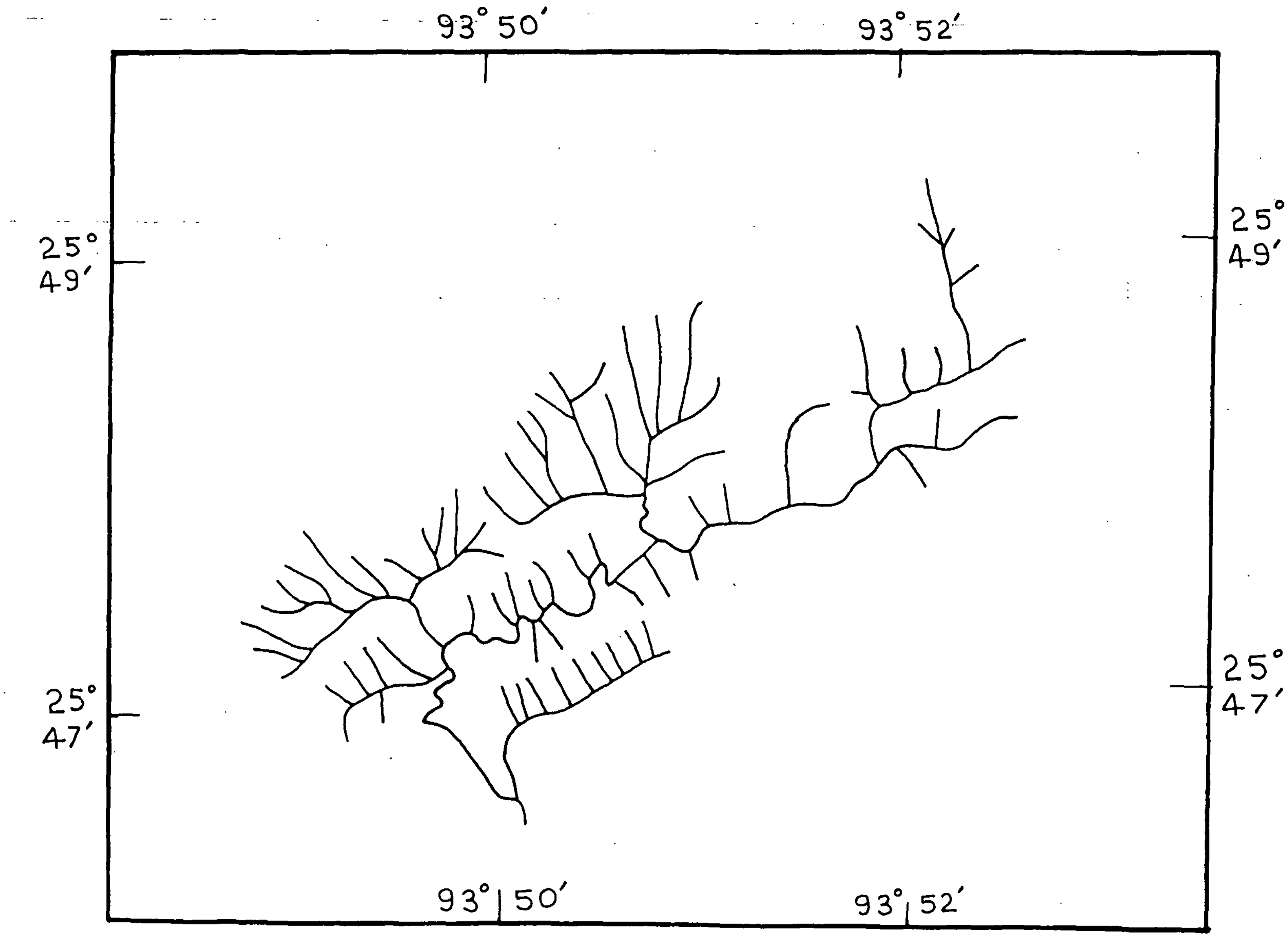


Fig 17 - TRELLIS PATTERN

Even though, the Dhansiri river basin receives heavy rainfall, there is scarcity of potable water in the region. It may be due to lack of knowledge regarding ground water potential and its management.

Remote sensor data provide the information for ground water assessment. Infilteration of precipitated water represents the main source for the ground water recharge. The rate of infilteration depends on both the nature of intensity of precipitation as also on permeability of soil and rocks. Such factors as geology, relief, surface water and tectonic peculiarities, determine the hydrogeologic conditions.

LANDSAT images offer the hydrogeologists significant information on regional drainage systems, lithological units, landforms, and structural features which are indispensible for groundwater investigations. Two aspects of utilising the remotely sensed data for this area are :

i) simple qualitative observations

ii) determination of geometric forms, dimensions and geographic locations of trend lines, lineaments, fractures and faults.

Remotely sensed data are more concerned with the boundary conditions rather than ground water system. The background knowledge from the orientation of drainage, topographic expressions and lineaments, as discussed earlier, are important factors for estimation of the subsurface water resources. Accordingly a ground water potential map has been prepared using LANDSAT images (Fig. 18). Table - IV shows the key for identification of hydrological features. Hydromorphologically the basin has been divided into following units :-

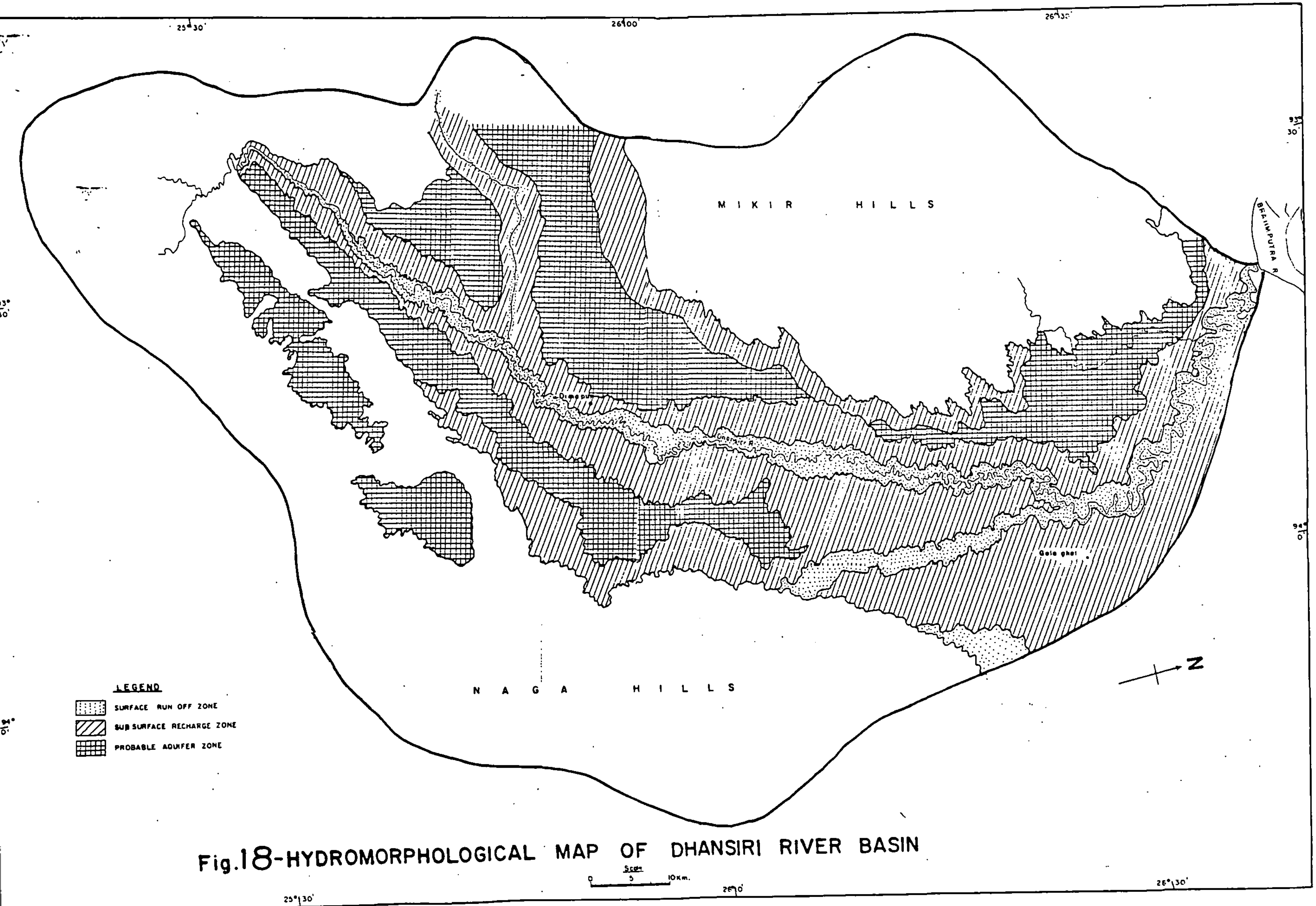


Fig.18-HYDROMORPHOLOGICAL MAP OF DHANSIRI RIVER BASIN

TABLE IV

KEY FOR IDENTIFICATION OF HYDROLOGICAL FEATURES

FEATURES	MSS - 5	MSS - 7
Piedmont	clear	not clear
Lineaments	clear	very clear
Water bodies	clear	very clear
Springs	very clear	poorly defined
Stream courses	clear	very clear
Valley fill	very prominent	Poorly defined
Palaeo -channel	very clear	poorly clear
Channel bar	clear	very clear
Braiding	clear	very prominent
Alluvium Boundary	clear	poorly defined
Soil moisture	poorly clear	clear

1. Mountain regions
2. Piedmont zone and Alluvial fans
3. Mature and young flood plains
4. Meander loops

. Mountain Regions

In mountain regions, ground water occurs in waste mantles, as well as in cracks and tectonic openings. The map (Fig. 6) shows plethora of lineaments some of which are of tectonic origin viz. Disang thrust, Naga thrust etc. The Mikir hills region is also influenced by lineaments of tectonic and/or Geomorphic origin. The precipitated water easily through them and recharges the aquifer system down slope. Large ground water flows are frequently observed in alluvial deposits of mountain rivers. The tributaries of the Dhansiri river either come from the Naga hills or from the Mikir hills. However, this generalization may not be true for the Naga hill region as the rocks in this region are highly permeable because of primary porosity as well as secondary porosity due to the area being tectonically disturbed. The precipitated water infilterates in these openings and flows down slopes towards the plains.

Piedmont zone and Alluvial fans

A large part of hill region in the area of study consists of piedmont zone. Thick clastic sediments accumulate in these zones, their material being supplied by rivers, small gullies and slope wash. It is a recharge-zone because the channel gradient is relatively lower than the hilly terrain. The braiding nature of the channel also supports this recharge zone.

As mentioned earlier, the rivers that cut mountain ranges transport large masses of clastic material varying in its grain size and degree of sorting. When such a river enters a plain, its flow velocity decreases and so does its energy levels, depositing the material in the form of alluvial fans. These fans contain, the ground water, recharged partly by the rain water infilteration and partly by the trapping of river water. Within the alluvial fan, the ground water level is deep close to the mountains and shallow towards the margins of the fan. Alluvial fan is reproduced on the LANDSAT images in the form of a triangle with its apex directed towards the hills and the spread out base touching the surrounding inclined foot hill plain. In the Dhansiri river basin, coalescing alluvial fan surfaces are shown in (Fig. 7).

Mature and Young Flood Plains

The flood plains are spread over a large area (Fig. 7). The mature flood plains are exploited for urban and agricultural lands. The young flood plains indicate the presence of channel bars. These possess good aquifer system.

Meander Loops

The meander loops are identified in the area as the dark graytone and fine texture. The ox-bow lakes constitute an integral part of meandering system of the Dhansiri river (Fig. 7).

DRAINAGE AZIMUTH

Apart from various types of landforms and drainage system in the area asimuths of the first, second and third order streams have been recorded for all the regions. These azimuthal data are graphically represented in the form of rose diagrams (Fig. 19-30), which reveal that in regions B and C majority of the streams flow in NE-SW direction suggesting their structurally controlled behaviour. Whilst in region A they flow at right angles to the lineaments in NW-SE direction. The later (Region 'A') streams, following the regional slope, are kinetically emergised to cut across the structural trend of the area.

Figure 19 Rose diagram showing drainage azimuth of first order streams in region 'A'

Figure 20 Rose diagram showing drainage azimuth of second order stream in region 'A'

REGION — A

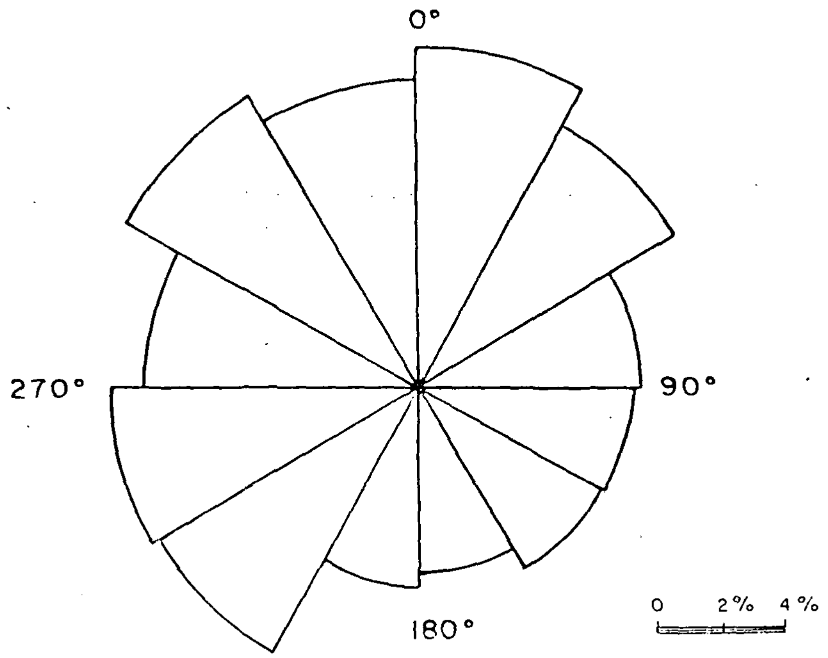


Fig.19

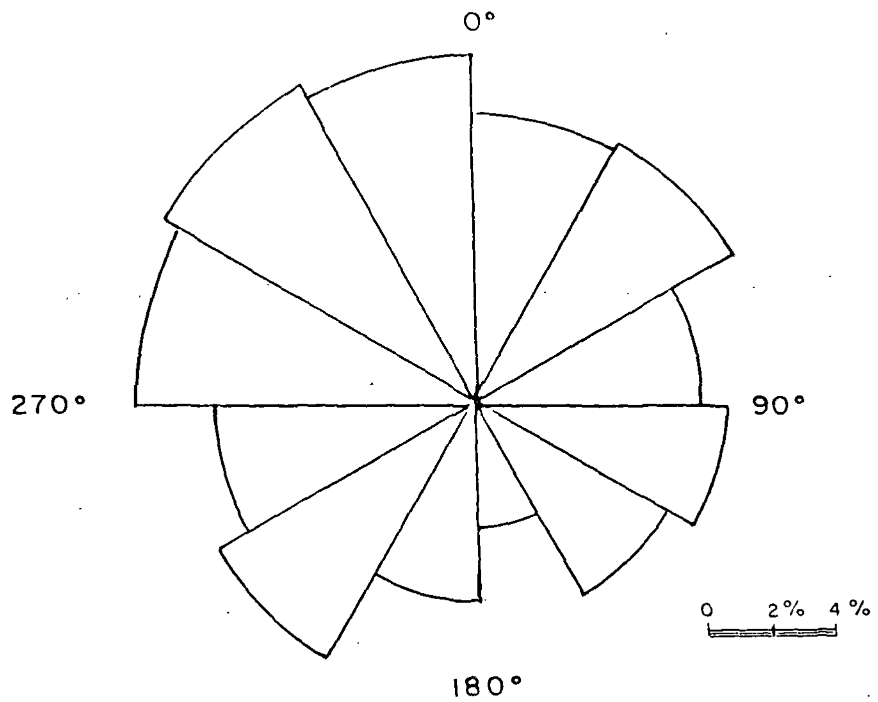


Fig.20

Figure 21 Rose diagram showing drainage azimuth of third order streams in region'A'

Figure 22 Rose diagram showing direction of lineaments in region 'A'

REGION - A

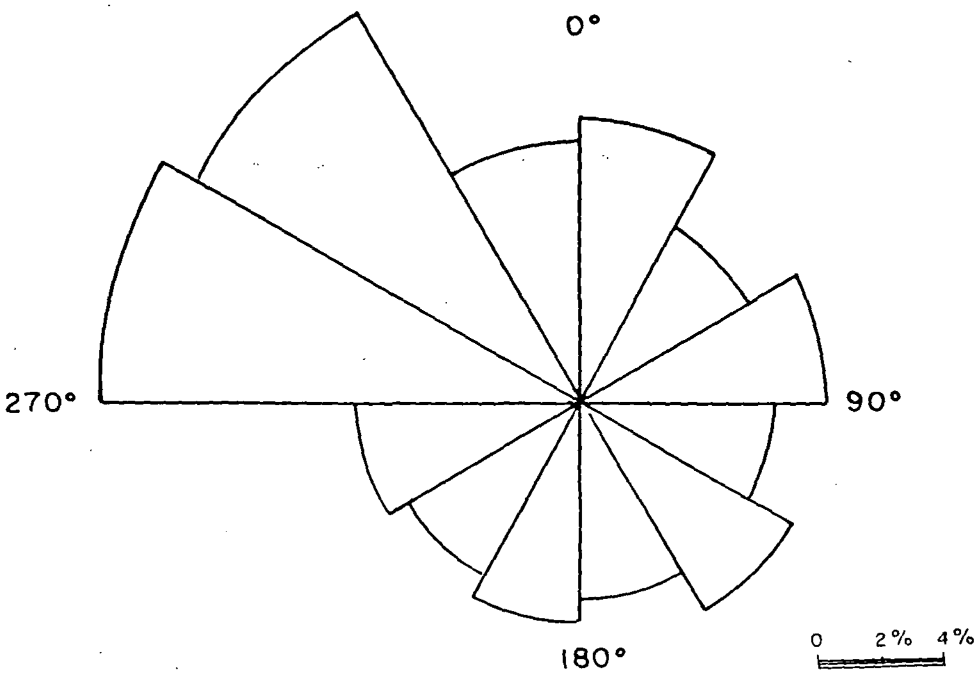


Fig.21

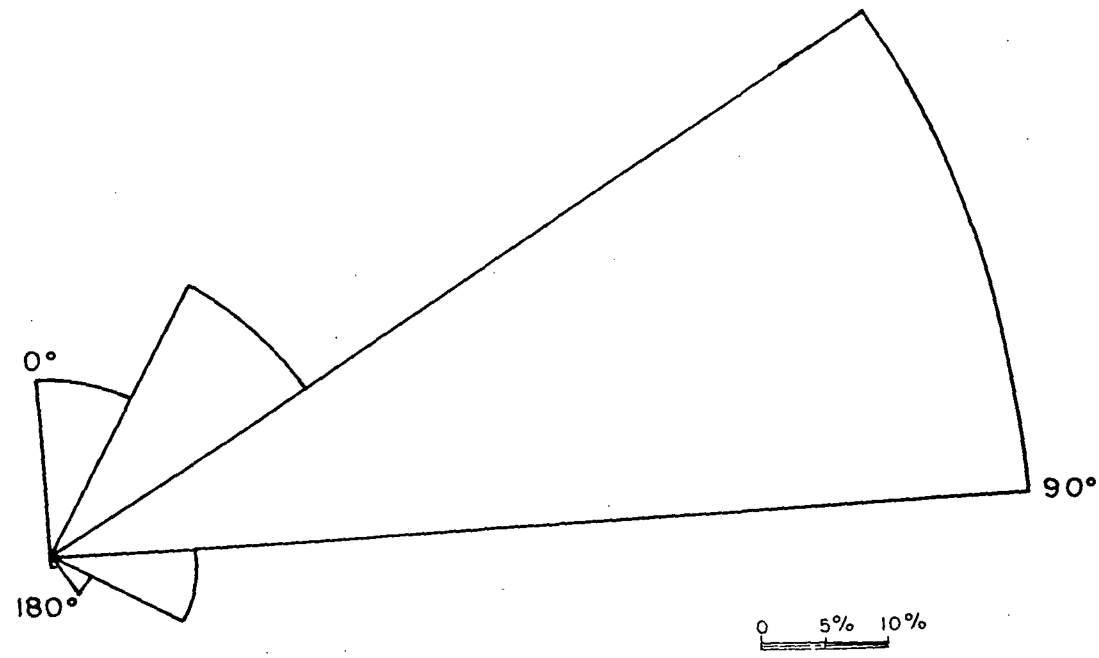


Fig.22

Figure 23 Rose diagram showing drainage azimuth of first order streams in region 'B'

Figure 24 Rose diagram showing drainage azimuth of second order streams in region 'B'

REGION - B

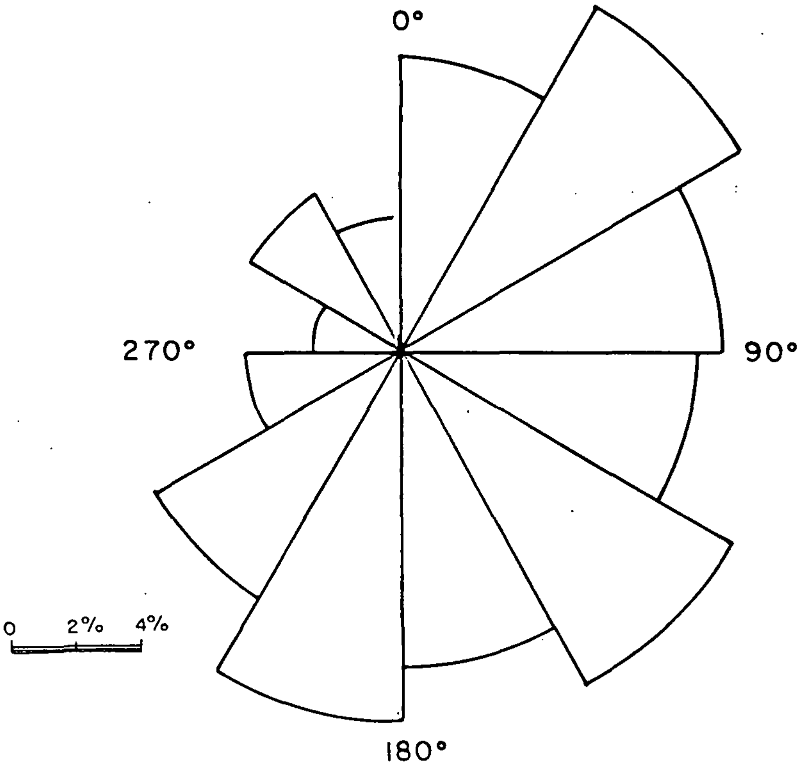


Fig. 23

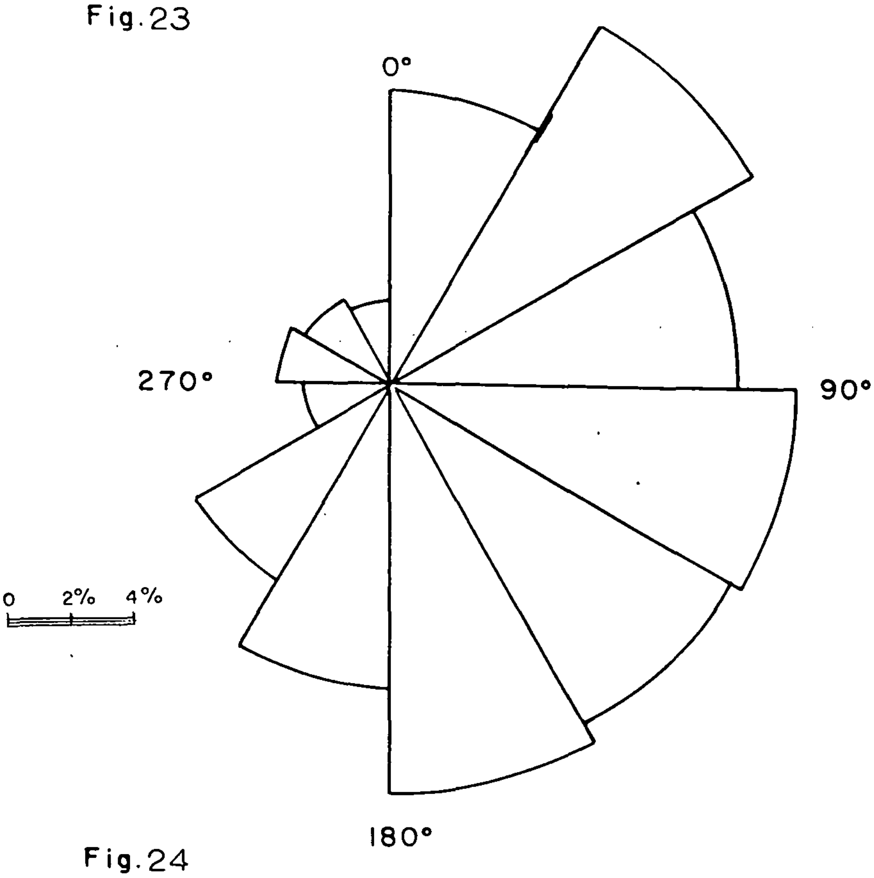


Fig. 24

Figure 25 Rose diagram showing drainage azimuth of third order streams in region 'B'

Figure 26 Rose diagram showing direction of lineaments in region 'B'

REGION - B

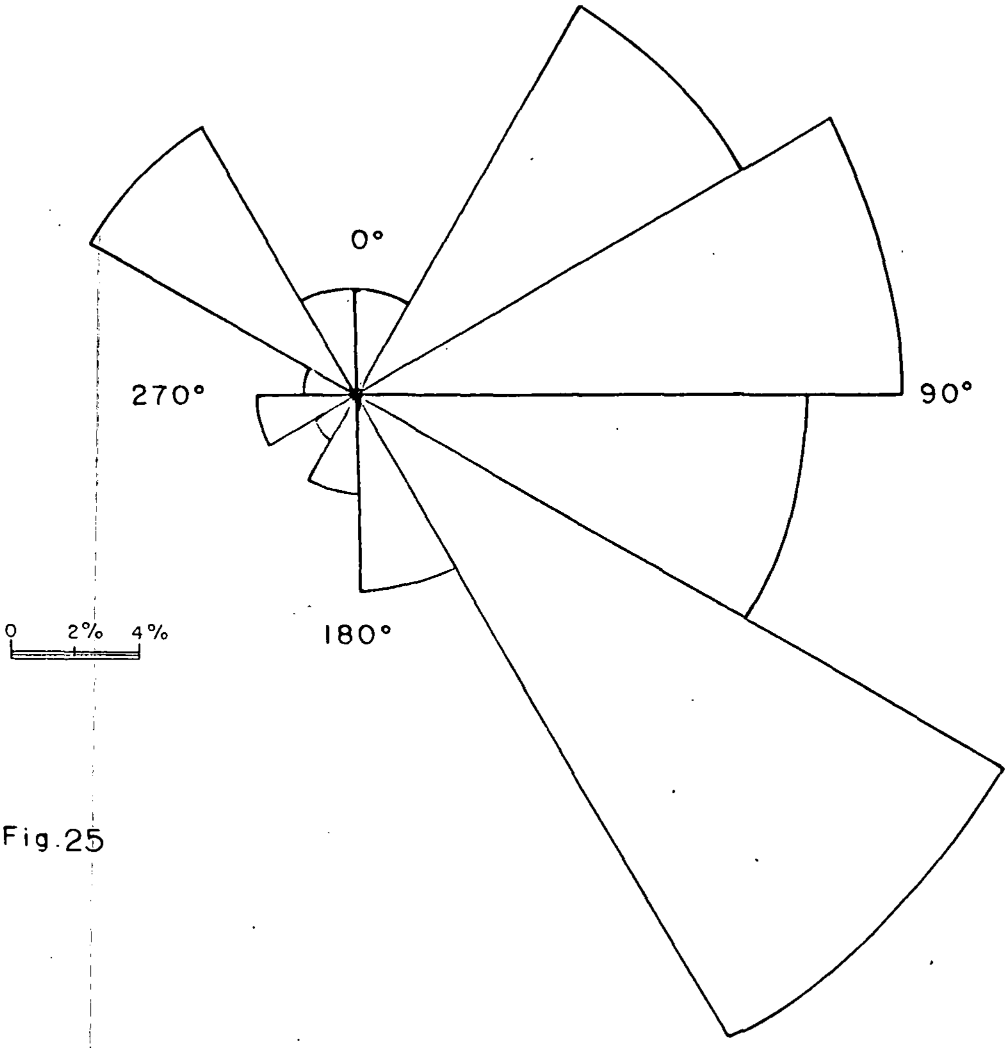


Fig. 25

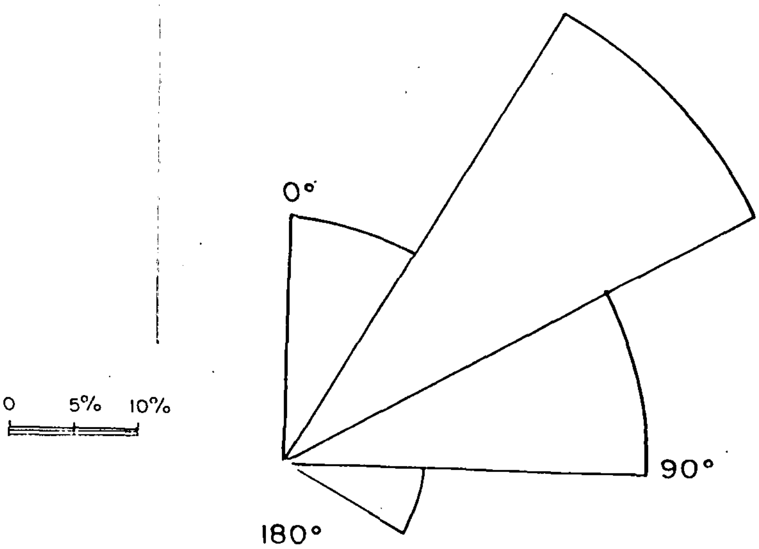


Fig. 26

Figure 27 Rose diagram showing drainage azimuth of first order streams in region 'C'

Figure 28 Rose diagram showing drainage azimuth of second order streams in region 'C'

REGION - C

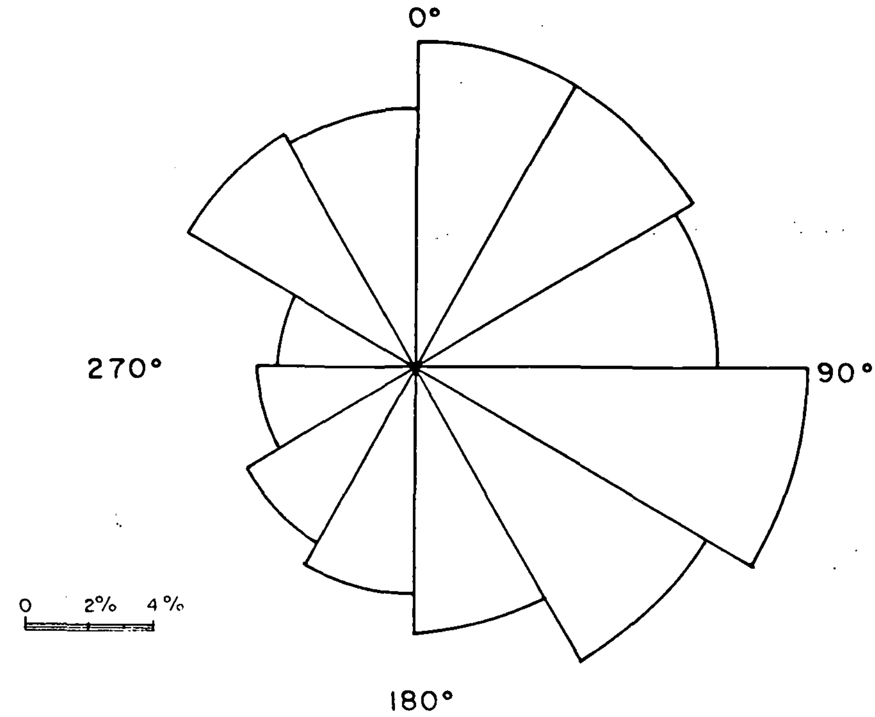


Fig.27

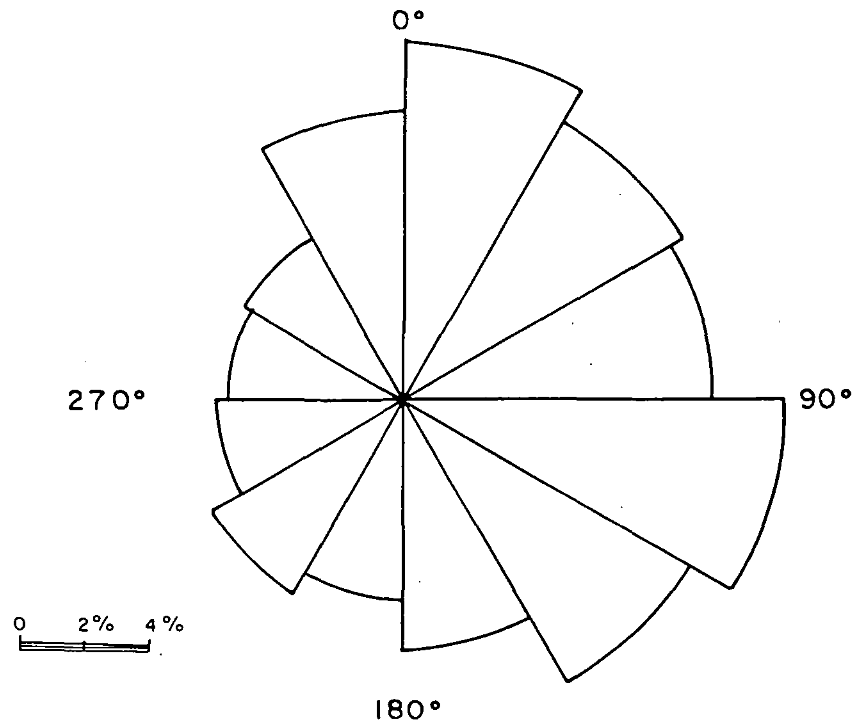


Fig.28

Figure 29 Rose diagram showing drainage azimuth of third order streams in region 'C'

Figure 30 Rose diagram showing direction of lineaments in region 'C'

REGION - C

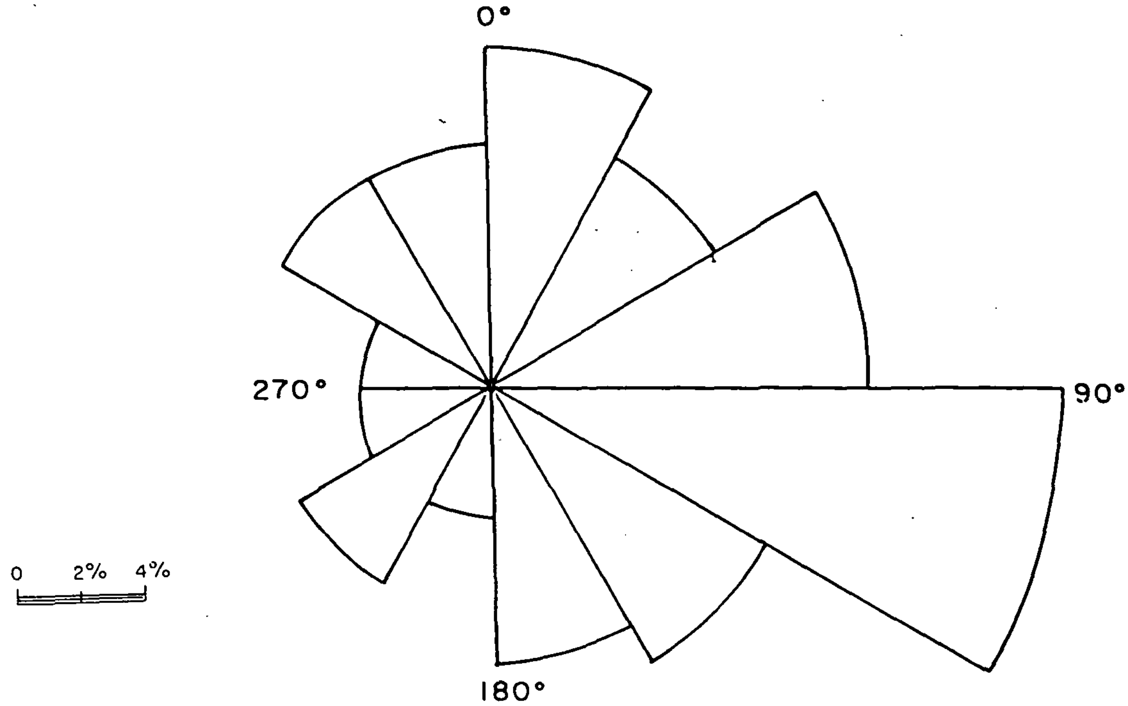


Fig. 29

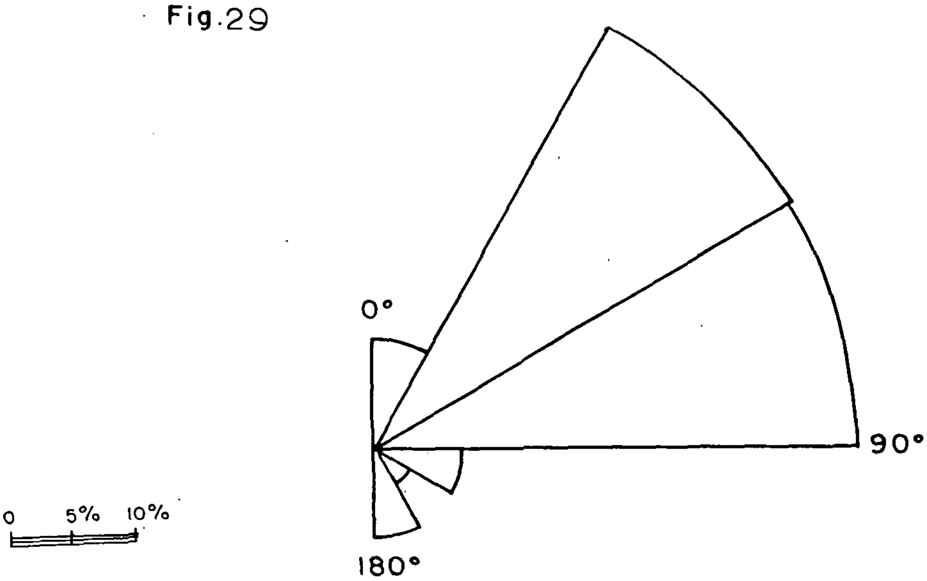


Fig. 30

C H A P T E R - V

GEOMORPHOSTATISTICAL ANALYSIS OF THE BASIN

A drainage basin is comprised of a network of streams, delineated by a drainage divide, which is the boundary of the system. It may be modified by wind, glaciers, sub-surface and running waters. Thus, it is both a fundamental and complex unit of landscapes, Chorley (1969). Running water is most important geomorphic agent responsible for the modification of drainage basin components.

Field studies of drainage basins are restricted to relatively small areas in which the geology, climate and vegetation are uniform and erosion intensity is moderate. The slowness with which the drainage system changes through time and because of numerous variables that control the drainage basin morphology, researchers are handicapped and forced to study small and simple drainage basin. Geomorphostatistical analysis of a drainage network helps in establishing the relationship between various morphometric parameters and between same parameters under different geological conditions. A new development in the study of drainage network has been that of quantitative measurement and to express in numerical terms the characteristics of a drainage system. Statistical approach to drainage basin began with the ideas of James Hutton, whose 'Law of Accordant Tributary Junctions' was expressed by Playfair in 1802. More recently drainage basin morphology has been treated as a part of broader discussion of landforms by Leopold et.al.(1964), Morisawa (1968), Hagget and Chorley (1969), Scheidegger (1970), Doornkamp and King (1971), Gregory and Walling (1973) and Mather (1976).

Gravelius (1914) pioneered the quantitative approach to drainage basin studies. Horton (1932) realised the importance of quantitative analysis in hydrological studies. Horton (1945) Langbein (1947) and Strahler (1957) laid the basis for the development of quantitative geomorphalogy. Horton's statement of laws of drainage composition and his introduction of concepts such as length of overland flow, stream frequency and drainage density led directly to subsequent regorous quantitative efforts to understand drainage basin morphology and evolution. Strahler's quantitative analysis further improved the quality and reliability of geomorphic investigations and laid the basis for the application of geomorphology to hydrology, land management and erosion control.

Landform and drainage patterns are now being studied by more and more elaborate methods. The increasingly accurate methods of measuring landforms and geomorphological process provide a vast amount of quantitative data. These data have to be statistically analysed to determine the orderly behaviour amongst the mass of accumulated data. The simplest statistical tests can bring out significant points related to the landscape. But usually landforms are very complex having many measurable properties and this demands the geomorphologist an appreciation of the value of multivariate statistical analysis. There are varying degree of complexity associated with geomorphological data. In its simplest from interest may be centred upon a single characteristic of certain landform. This variable can be measured and its proportion can be analysed through univariate statistics. In many cases, geomorphologist needs to know the relation between two or more variables. This requires the use of bivariate or multivariate statistical analysis respectively.

Fluvially eroded landscapes are composed of drainage basins, providing convenient units, into which an area can be subdivided. The development of a landscape is equal to the sum total of the development of each individual drainage basin of which it is composed. The analysis of drainage basins as a single unit or as a group of basin taken together,comprising a distinct morphological region, has a particular relevance to geomorphology. Therefore it is logical to know what is a drainage basin. The problem of defining a drainage basin does not lie in a definition of the term but in locating the boundary of the basin on ground or on a map. Concept of stream ordering is the fundamental to any numerical analysis of drainage basin characteristics. Stream ordering system was suggested by Gravelius (1914) but Horton (1932, 1945)'s work marked the beginning of the widespread use of stream ordering system in geomorphology. Strahler (1952) modified the stream ordering system suggested by Horton (op.cit.). The usual method of stream ordering practiced today is that suggested by Strahler (1952). In this system all streams which do not have any tributary are known as first order streams. When two such first order streams join together they form a second order stream, two second order streams join to form a third order stream and so on. An increase in stream order only occurs when two streams of same order join each other. There is no change in the order of stream if a lower order stream joins the higher order stream. In this system the head of second order stream occurs at the junction of two first order streams. In the system used prior to Strahler (1952) head of the second order stream extends back to the head of the longest of its first order tributaries, and so on for higher orders. Alternative systems of stream ordering have been suggested by Scheidegger (1965), Woldenberg (1966) and Shrieve (1967). However, for the present investigation of stream ordering system suggested by Strahler (1952) has been applied in view of its implicity and easy subjectivity to statistical treatment.

The present chapter deals with the statistical analysis of the morphometric parameters of the third order basin. The base map used for the investigation is on 1: 50,000 scale Survey of India Toposheets and black and white panchromatic LANDSAT images of 5 and 7 MSS bands. As indicated earlier, on the basis of lithology, structure, physiography and climatic variation the area under investigation has been divided into three regions:

Region-A	'Belt of Schuppen' in Naga hills	Tertiary	145 3rd order basins
Region-B	Naga hills	Tertiary	257 3rd order basins
Region-C	Mikir hills	Precambriam and Tertiary	248 3rd order basins

Once the streams are ordered, drainage basins are delineated and the area was divided into regions, measurements were made on Channels, geometry, attitude and dissection etc. The morphometric variables used in the present study are listed in (Table - V).

TABLE - V MORPHOMETRIC VARIABLES USED IN PRESENT STUDY

Variables	Symbols
Frequency of first order stream	F_1
Frequency of second order stream	F_2
Length of first order stream	L_1
Length of second order stream	L_2
Length of third order stream	L_3
Length of Basin	BL
Perimeter of Basin	BP
Area of Basin	BA
Bifurcation ratio	F_1/F_2
Length ratio of first and second order streams	L_1/L_2
Length ratio of second and third order streams	L_2/L_3
Drainage density	DD
Stream frequency	SF
Drainage Texture	DT

The linear aspects are studied using the methods of Horton (1945). Areal aspects are based on the methods suggested by Horton (1932), Miller (1953), Schumm (1956), Strahler (1956) and Chorley (1957) and the relief aspects employing the techniques of Horton (1945), Strahler (1952), Broscoe (1959) and Melton (1961). The frequency distribution analysis of the drainage basin follows the conventional statistical procedures.

The respective values of all morphometric parameters, have been statistically analysed by using IBM computer at DRDO Computer Centre, Metcalfe House, Delhi. The result obtained from the statistical analysis are shown in annexure 'A'.

GENERAL STATISTICS

Minimum number of first order stream is four and is consistent in all regions and maximum fifty three in region A. The value of standard deviation varies from 7.23 in region A to 8.10 in region C and indicates that in all regions their deviation from mean is very high. High value of standard deviation reflects widely scattered values about the mean and tendency for central clustering is rather weak.

Frequency of Second Order Stream (F2)

Average frequency of second order streams is more or less same in all the regions. Its minimum and maximum value is 2 and 11, 2 and 7, 2 and 11 in region A, B and C respectively. Standard deviation varing from 1.37 to 1.65 is comparatively low and indicates that, these valuers in contrast to those for F_1 above have tendency for central clustering.

Length of First Order Streams (L1)

Average length of first order streams is almost constant in all the regions. Minimum lengthis 1 Km in all the regions and maximum 29 Km in region C. Standard deviation varies from 3.28 to 4.32 indicates moderate scattering of these values from the mean. They are in order of decreasing length in the regions C, A and B.

Length of Second Order Streams (L2)

Values of all statistical parameters except kurtosis viz. minimum, maximum, mean, standard deviation, variance and Skewness are basically same in all regions. Average length of second order streams varies between 1.89 Km (region A) to 2.29 Km (region C). Kurtosis value is minimum (1.95) in region C and maximum (5.03) in region A.

Length of Third Order Streams (L3)

Like length of second order streams values of all calculated statistical parameters (except kurtosis) for the length of third order streams are same. Average length varies between 1.49 Km to 1.54 Km. Values of standard deviation indicates that they have tendency of Central clustering.

Basin Length (BL)

Minimum basin length is observed in region A (0.51 Km) and maximum (900 Km) in region C. The values indicates that basins are more elongated in region C and least in region A. Rest of the calculated statistical parameters are almost constant in all regions.

Basin Perimeter (BP)

Minimum value of basin perimeter (1.5 Km) is in region C and maximum (23 Km) in region B. Average basin perimeter varies between 7.01 Km to 7.47 Km. Standard deviation (2.69 to 3.43) indicates moderate deviation from the mean value.

Basin Area (BA)

The size of the basin area range between 0.5 sq.km (region C) and 29 sq.km (region C). There is a marginal difference of average basin area in all regions. It is in order of increasing area in the region A, C and B respectively.

Since discharge of a stream increases with increasing basin area, therefore it is inferred that discharge is minimum in regian A and maximum in region B.

BIFURCATION RATIO (F1/F2)

It is the ratio between streams of any order (n) to the number of streams of next higher order (n + 1) of the basin, Horton (1932). In a region of uniform climate, rock type and stage development it shows stabilities of values, Strahler (1964). Average value of bifurcation ratio in all the regions are almost same, varying from 3.99 (region C) to 4.13 (region B). Standard deviation ranges from 1.33 to 1.55 and shows less deviation from the mean, and therefore have tendency of central clustering, which shows uniformity in climate, lithology and stage of drainage development in respective regions.

LENGTH RATIO (L1/L2)

Length ratio is defined as a ratio of total length of 'n' order of stream in a drainage basin to the total length of next higher order (n + 1).

Average length ratio between first and second order streams is minimum (3.03) in region 'B' and maximum (3.64) in region 'A'. Standard deviation is practically same in all the regions. It shows minimum value in region B followed by regions C and A respectively.

Average length ratio between second and third order streams is minimum in region A (1.83) and maximum in region C (2.67). Low value of L2/3 and high value of L1/L2 in region 'A' indicates that in this region formation of second order stream is delayed and third order streams form soon rendering the second order streams of small sized.

DRAINAGE DENSITY (DD)

Horton (1945) suggested the concept of drainage density as a measure of dissection and is defined as the length of stream per unit area. It can be expressed as:

$$D = \Sigma L/A$$

Schumm (1956) proposed use of the reciprocal of drainage density.

$$C = \frac{A}{\Sigma L} = \frac{1}{D}$$

Where C is the constant of channel maintenance expressed in square feet per foot. Since the constant of channel maintenance represents the drainage area required to maintain one unit of channel length, it is a measure of watershed erodibility. Regions of resistant rock type or with a surface of high permeability or with a thick forest cover should have a high constant of channel maintenance and a low drainage density. On the other hand a low constant of channel maintenance or high drainage density is characteristic of watersheds with weaker rocks, little vegetation and low soil infilteration and permeability.

Mean values of drainage densities ranges between 1.68 to 2.11. It is minimum in region B Naga Hill, (moderately deformed tertiaries) and maximum in region (Mikir hills) (less deformed Tertiaries and Precambrains) while intermidiate 1.92 in the region A (Naga Hills - "Belt of Schuppen ") (highly deformed tertiaries).

STREAM FREQUENCY (SF)

Stream frequency is a measure of number of streams in a unit area (one sq. km) Horton (1945). In Dhansiri basin average stream frequency ranges between 3.21 (Region 'B') to 3.85 (Region 'A'). Standard deviation values for all these regions indicate very little deviation from its mean and have tendency of central clustering. Lower value of stream frequency in the " Belt of Schuppen " may be because of the fact that water is not retained on the surface as it gets seeped into the fractures and recharges the ground water zones.

DRAINAGE TEXTURE (DT)

Drainage texture is defined as the relative spacing of drainage lines and is the product of stream frequency and drainage density. It is referred to as coarse, medium, fine and ultra fine. Strahler (1964) explained that regions of low drainage density have coarse texture, medium drainage density have medium texture, high drainage density have ultra fine texture. This does not always appear to be true, because two regions may have same length and drainage area but the number of streams may be different.

CORRELATION COEFFICIENT

For geomorphostatistical analysis fourteen different morphometric variates have been measured for third order drainage basins. It becomes necessary to look beyond the simple analysis of pairwise relationships among such variables, and to seek the numerical relationships which may exist between several variables taken together. This may be done:

1. by finding sets of intercorrelated variables within a correlation matrix.
2. through multiple correlation.
3. through multiple regression techniques.

In the present investigation Pearsons correlation matrix is used to look into the interrelationship between various morphometric parameters. It is also known as 'Zero-order' product moment correlation coefficient and is used to define the degree to which changes in values of one parameter (X) are repeated in relation to another parameter (Y). More precisely, this correlation coefficient is the ratio of co-variation to the square root of the product of variations in X and Y.

It is defined by the equation $r = \frac{\sum_{i=1}^{N} (x_i-\bar{x})\ (Y_i-\bar{Y})}{\left\{\left[\sum_{i=1}^{N} (x_i-\bar{x})^2\right]\left[\sum_{i=1}^{N} (Y_i-\bar{Y})^2\right]\right\}}$

Where x_i = the ith observation of parameter X

Y_i = the ith observation of parameter Y

N = number of observations

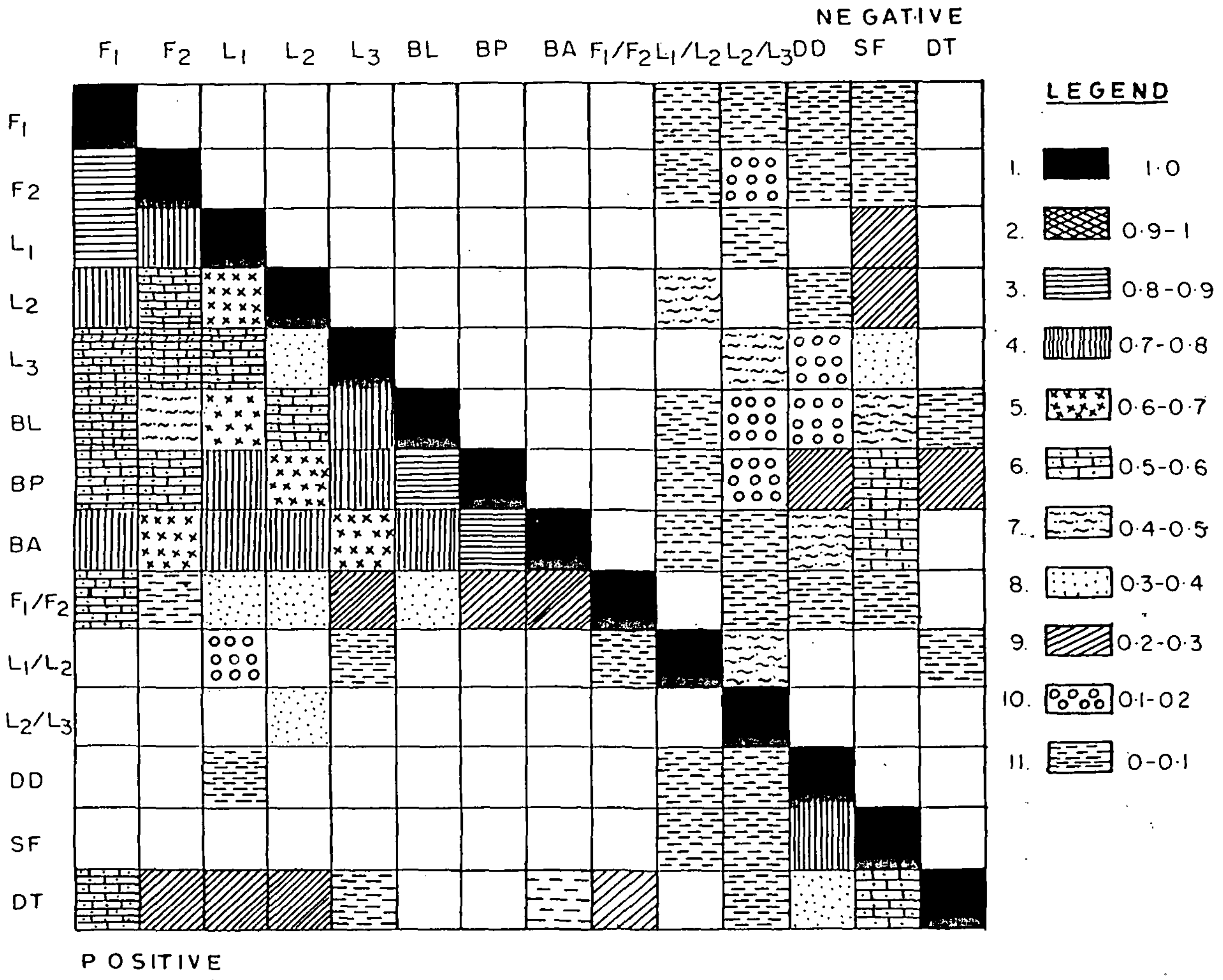
$\bar{x} = \sum_{i=1}^{N} \frac{x_i}{N}$ and is mean of parameter X

$\bar{Y} = \sum_{i=1}^{N} \frac{Y_i}{N}$ and is mean of parameter Y

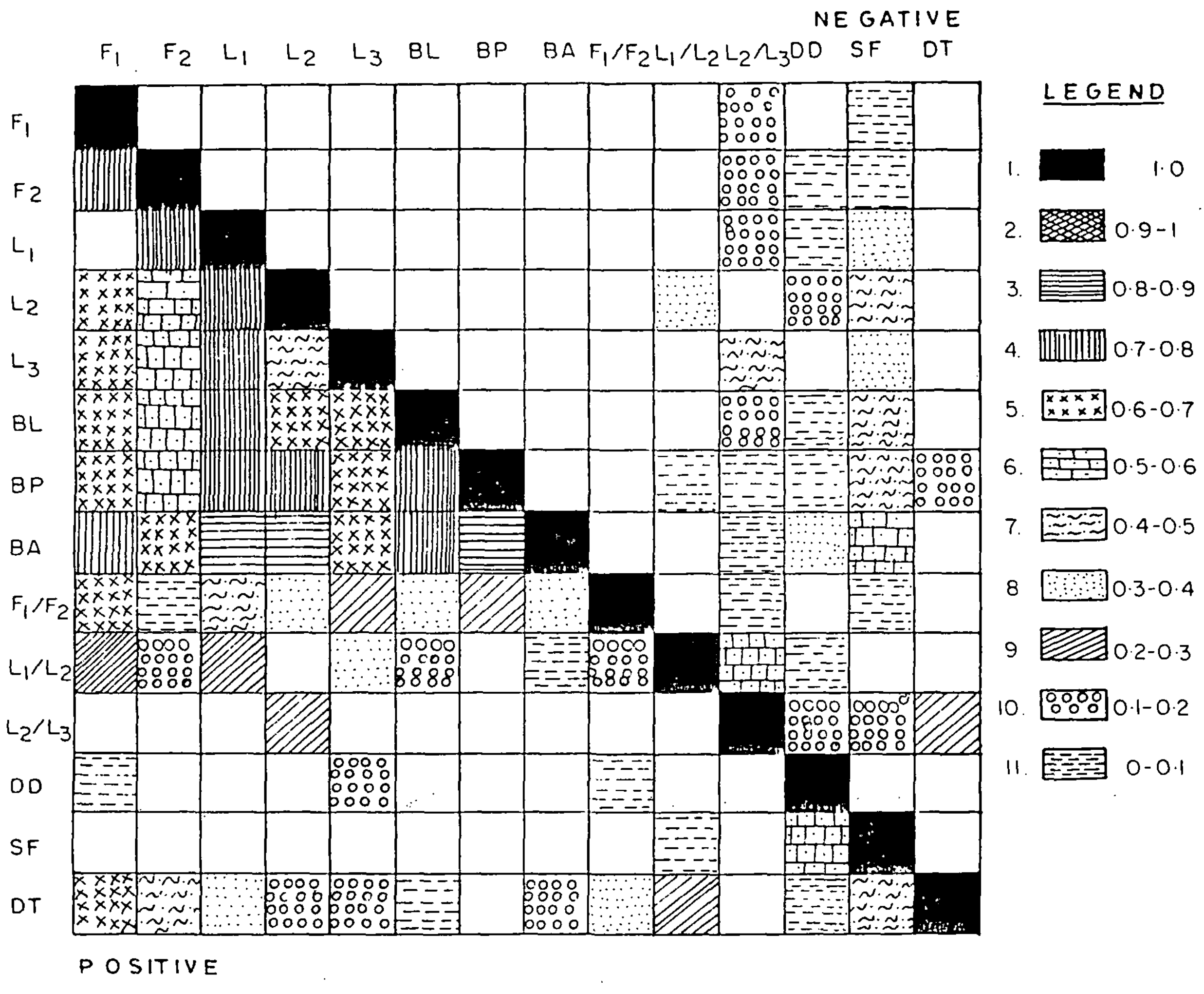
The equation used in statistical analytical system (SAS) file, is slight modification of the above equation, for computing Pearsons correlation matrix. It is

$$Y = \frac{\sum_{i=1}^{N} x_i Y_i - (\sum_{i=1}^{N} x_i)(\sum_{i=1}^{N} Y_i)/N}{\left\{\left[\sum_{i=1}^{N} x_i^2-(\sum_{i=1}^{N} x_i)^2/N\right]\left[\sum_{j=1}^{N} Y_j^2-(\sum_{j=1}^{N} Y_i)^2/N\right]\right\}^{1/2}}$$

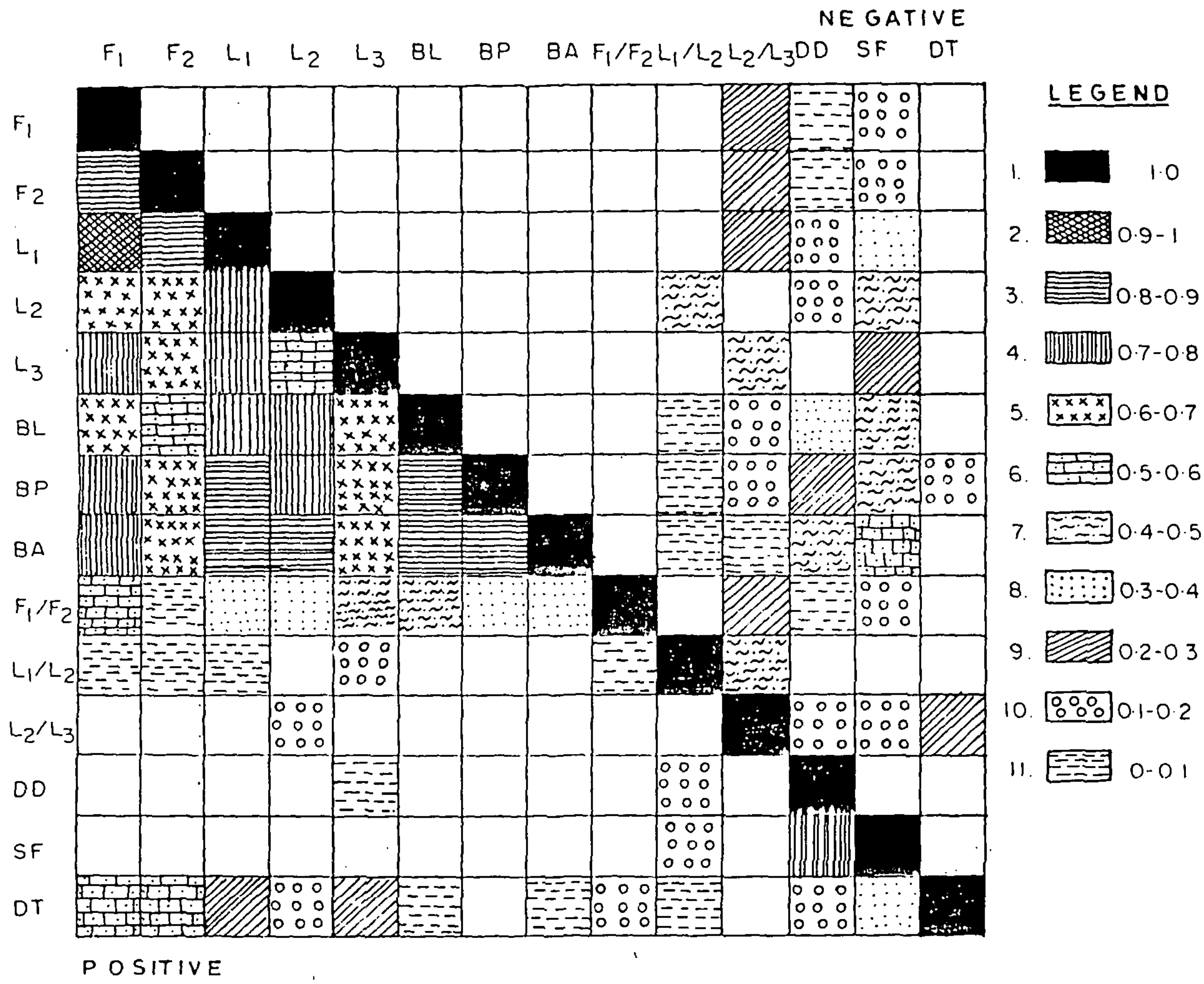
Matrices are prepared for all the three litho-stratigraphic regions and overall data for the purpose of relative comparison with each other as shown in annexure 'B'. In this position all variables are arranged in such a way that the highest correlation coefficients fall nearest to the central diagonal line. A greater visual impact is made by representing the level of correlation by a density. Thus the numerical informations are replaced in figures 31 - 34 by a density shading. The black rectangle indicates hundred percent correlations between the two parameters. The values of positive and negative correlations are plotted above and below the diagonal formed by joining black rectangles respectively.



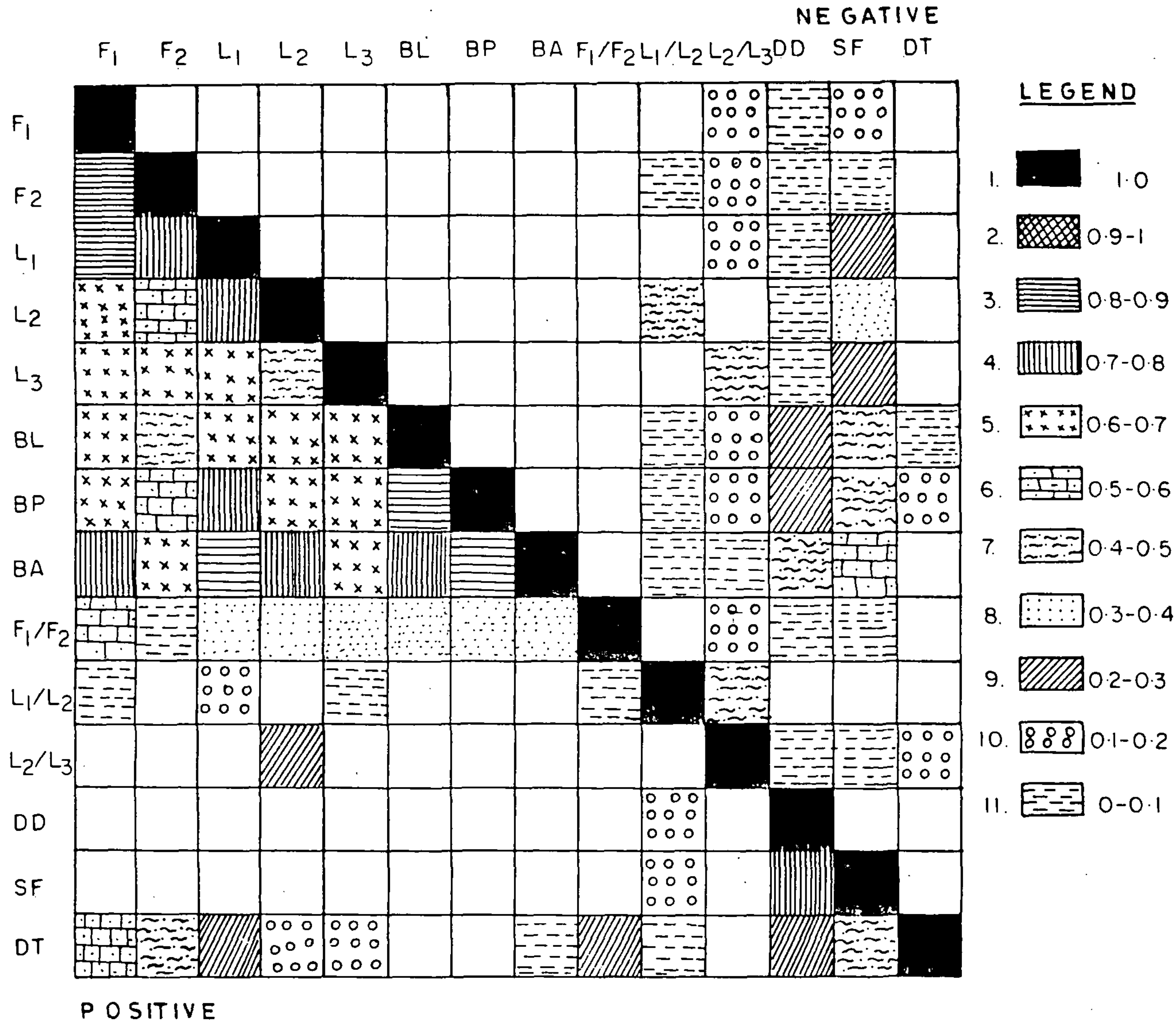
FIG·31–INTERCORRELATION OF MORPHOMETRIC PARAMETERS
REGION: A



FIG·32-INTERCORRELATION OF MORPHOMETRIC PARAMETERS
REGION: B



FIG·33-INTERCORRELATION OF MORPHOMETRIC PARAMETERS
REGION: C



FIG·34-INTERCORRELATION OF MORPHOMETRIC PARAMETERS

The values of correlation coefficient varies between + 1 (positive correlation) and - 1 (negative correlation). If one parameter increases in exact ratio to the increase in other parameter then r = 1 and if one parameter increases in exact ratio to the decrease in other parameter then r = -1. r = 0. When two variables are absolutely independent of each other. The degree of correlation extracted from the matrices is summarised in (Tables VI - XIX). The criteria adopted in this scrutiny is as follows:

i)	0. 4	-	weak correlation
ii)	0. 4 - 0.7	-	moderate correlation
iii)	0. 7	-	strong correlatian

On the basis of Pearsons correlation matrices following observations have been made among various morphometric parameters in the Dhansiri river basin.

TABLE VI - FREQUENCY OF FIRST ORDER STREAM

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A		L_3, BL, BP F_1F_2, DT	F_2, L_1, L_2,BA	L_1/L_2,L_2/L_3 DD, SF		
B	L_1/L_2,DD	L_2,L_3, BL, BP, F_1/F_2, DT	F_2,L_1, BA	L_2/L_3, SF		
C	L_1/L_2	L_2,BL,F_1/F_2 DT	F_2,L_1,L_3 BP, BA	L_2/L_3,DD,SF		
All Regions combined	L_1/L_2	L_2,L_3,BL,BP F_1/F_2, DT	F_2,L_1,BA	L_2/L_3,DD,SF		

TABLE VII - FREQUENCY OF SECOND ORDER STREAM

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_1/F_2	L_2, L_3, BL, BP, BA, DT	F_1, L_1	L_1/L_2, L_2/L_3, DD, SF		
B	L_1/L_2, F_1/F_2	L_2, L_3, BL, BP, BA, DT	F_1, L_1	L_2/L_3, DD, SF		
C	F_1/F_2, L_1/L_2	L_2, L_3, BL, BP, BA, DT	F_1, L_1	L_2/L_2, DD, SF		
All Regions Combined	F_1/F_2	L_2, L_3, BL, BP, BA, DT	F_1, L_1	L_1/L_2, L_2/L_3, DD, SF		

TABLE VIII - LENGTH OF FIRST ORDER STREAM

Regions	Positive			Negative		
	Weak Correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_1/F_2, L_1/L_2; DD, DT	L_2, L_3, BL	F_1, F_2, BP, BA	L_2/L_3, SF		
B	L_1/L_2, DT	F_1/F_2	F_1, F_2, L_2, L_3, BL, BP, BA	L_2/L_3, DD, SF		
C	F_1/F_2, L_1/L_2, DT		F_1, F_2, L_2, L_3, BL, BP, BA	L_2/L_3, DD, SF		
All Regions Combined	F_1/F_2, L_1/L_2, DT	L_3, BL	F_1, F_2, L_2, BP, BA	L_2/L_3, DD, SF		

TABLE IX - <u>LENGTH OF SECOND ORDER STREAM</u>

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_3, F_1/F_2, L_2/L_3, DT	F_2, L_1, BL, BP	F_1, BA	DD, SF	L_1/L_2	
B	F_1/F_2, L_2/L_3, DT	F_1, F_2, L_3. BL	L_1, BP, BA	L_1/L_2, DD	SF	
C	F_1/F_2, L_2/L_3, DT	F_1, F_2, L_3	L_1, BL, BP, BA	DD	L_1/L_2, SF	
All Regions combined	F_1/F_2, L_2/L_3, DT	F_1, F_2, L_3, BL, BP	L_1, BA	DD, SF	L_1/L_2	

TABLE X - LENGTH OF THIRD ORDER STREAM

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_2, F_1/F_2, L_1/L_2, DT	F_1, F_2, L_1, BA	BL, BP	DD, SF	L_2/L_3	
B	F_1/F_2, L_1/L_2, DD, DT	F_1, F_2, L_2, BL, BP, BA	L_1	SF	L_2/L_3	
C	L_1/L_2, DD, DT	F_2, L_2, BL, BP, BA, F_1/F_2	F_1, L_1	SF	L_2/L_3	
All Regions Combined	F_1/F_2, L_1/L_2, DT	F_1, F_2, L_1, L_2, BL, BP, BA		DD, SF	L_2/L_3	

TABLE XI - LENGTH OF BASIN

Regions	Positive			Negative		
	Weak Correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_1/F_2	F_1,F_2,L_1,L_2	L_3,BP, BA	$L_1/L_2,L_2/L_3$, DT, DD	SF	
B	F_1/F_2, L_1/L_2,DT	F_1,F_2,L_2,L_3	L_1,BP, BA	L_2/L_3, DD	SF	
C	DT	F_1,F_2,L_3, F_1/F_2	L_1,L_2,BP,BA	$L_1/L_2,L_2/L_3$ DD	SF	
All Regions Combined	F_1/F_2	F_1,F_2,L_1, L_2,L_3	BP, BA	$L_1/L_2,L_2/L_3$, DD, DT	SF	

TABLE XII - BASIN PERIMETER

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_1/F_2	F_1, F_2, L_2	L_1, L_3, BL, BA	L_1/L_2, L_2/L_3, DD, DT	SF	
B	F_1/F_2	F_1, F_2, L_3	L_1, L_2, BL, BA	L_1/L_2, L_2/L_3, DD, DT	SF	
C	F_1/F_2	F_2, L_3	F_1, L_1, L_2, BL, BA	L_1/L_2, L_2/L_3, DD, DT	SF	
All Regions Combined	F_1/F_2	F_1, F_2, L_2, L_3	L_1, BL, BA	L_1/L_2, L_2/L_3, DD, DT	SF	

TABLE XIII - <u>AREA OF THE BASIN</u>

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_1/F_2, DT	F_2, L_3	F_1,L_1,L_2, BL, BP	L_1/L_2, L_2/L_3	DD, SF	
B	F_1/F_2, L_1/L_2, DT	F_2, L_3	F_1,L_1,L_2, BL, BP	L_2/L_3, DD	SF	
C	F_1/F_2,DT	F_2, L_3	F_1,L_1,L_2, BL, BP	L_1/L_2, L_2/L_3,	DD, SF	
All Regions Combined	F_1/F_2,DT	F_2,L_3	F_1,$L_1$$L_2$, BL,BP	L_1/L_2, L_2/L_3	DD, SF	

TABLE XIV - BIFURCATION RATIO (F_1/F_2)

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	F_2, L_1, L_2, L_3 BL, DP, BA, L_1/L_2, DT	F_1		DD, SF, $L_2/$, L_3		
B	L_2, L_3, BL, BP BA, L_1/L_2, DD DT, F_2	F_1, L_1		L_2/L_3, SF		
C	F_2, L_1, L_2, BP BA, L_1/L_2, DT	F_1, L_3, BL		L_2/L_3, DD, SF		
All Regions Combined	F_2, L_1, L_2, L_3 BL, BP, BA, L_1/L_2, DT	F_1		L_2/L_3, DD, SF		

TABLE XV - LENGTH RATIO (L_1/L_2)

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_1/L_3, F_1/F_2, DD, SF			F_1,F_2, BL, BP, BA, DT	L_2,L_2/L_3	
B	F_1,F_2, L_1,L_3, BL, BA, F_1/F_2, SF,DT			L_2,BP,DD	L_2/L_3	
C	F_1,F_2, L_1,L_3, F_1/F_2, DD,SF,DT			BL,BP,BA	L_2,L_2/L_3	
All Regions Combined	L_1,L_3,F_1, F_1/F_2, DD,SF,DT			F_2,BL,BP,BA	L_2L_2/L_3	

TABLE XVI - LENGTH RATIO (L_2/L_3)

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_2, DD, SF, DT			F_1, F_2, L_1, BL, BP, BA, F_1/F_2	L_3, L_1/L_2	
B	L_2			F_1, F_2, L_1, BL, BP, BA, F_1/F_2, DD, SF, DT	L_3, L_1/L_2	
C	L_2			F_1, F_2, L_1, BL, BP, BA, F_1/F_2, DD, SF, DT	L_3, L_1/L_2	
All Regions Combined	L_2, DD, DT, SF			F_1, F_2, L_1, BL, BP, BA, F_1/F_2	L_3, L_1/L_2	

TABLE XVII - DRAINAGE DENSITY (DD)

Regions	Positive: Weak correlation	Positive: Moderate correlation	Positive: Strong correlation	Negative: Weak correlation	Negative: Moderate correlation	Negative: Strong correlation
A	L_1, L_1/L_2, L_2/L_3, DT		SF	F_1, F_2, L_2, L_3 BA, BP, F_1/F_2	BA	
B	F_1, L_3, F_1/F_2, DT	SF		F_2, L_1, L_2, BL, BP, BA, L_1/L_2, L_2/L_3		
C	L_3, L_1/L_2, DT		SF	F_1, F_2, L_1, L_2, BL, BP, F_1/F_2, L_2/L_3	BA	
All Regions Combined	L_1/L_2, DT		SF	F_1, F_2, L_1, L_2, L_3, BL, BP, F_1/F_2, L_2/L_3	BA	

TABLE XVIII - STREAM FREQUENCY (SF)

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_1/L_2, L_2/L_3	DT	DD	F_1, F_2, L_1, L_2, L_3, F_1/F_2	BL, BP, BA	
B	L_1/L_2	DD, DT		F_1, F_2, L_1, L_3, F_1, F_2, L_2, L_3	L_2, BL, BP, BA	
C	L_1/L_2, DT		DD	F_1, F_2, L_1, L_3, F_1/F_2, L_2/L_3	L_2, BL, BP, BA	
All Regions Combined	L_1/L_2	DT	DD	F_1, F_2, L_1, L_2, L_3, F_1/F_2, L_2/L_3	BL, BP, BA	

TABLE XIX - DRAINAGE TEXTURE (DT)

Regions	Positive			Negative		
	Weak correlation	Moderate correlation	Strong correlation	Weak correlation	Moderate correlation	Strong correlation
A	L_1, L_2, L_3, BA, F_1/F_2, L_2/L_3, DD	F_1, F_2, SF		BL, BP, L_1/L_2		
B	L_1, L_2, L_3, BL, BA, F_1/F_2, L_1/L_2, DD	F_1, F_2		BP, L_2/L_3		
C	L_1, L_2, L_3, BA, F_1/F_2, L_1/L_2, DD, SF, BL	F_1/F_2		BP, L_2/L_3		
All Regions Combined	L_1, L_2, L_3, BA, F_1/F_2, L_1/L_2, SF, DD	F_1/F_2		BL, BP, L_2/L_3		

a) Frequency of first order stream shows strong (or high degree of positive correlation) with frequency of second order stream; length of first order stream and basin area in all the lithotectonic regions. It shows high degree of correlation with length of second order stream in region A, length of third order stream and basin perimeter in region 'C'.

It shows moderate positive correlation with length of third order stream, basin length, perimeter, bifurcation ratio (F_1/F_2) and drainage texture in all the regions. Length of second order stream shows moderate positive correlation with frequency of first order streams in region B and C.

Length ratio (L_1/L_2) shows weak positive correlation with frequency of first order streams in region B and C and negative in region A. This shows that in Region 'A' there are many places where more than two first order streams meet to make a second order stream. Length ratio (L_2/L_3), drainage density and stream frequency show weak negative correlation with frequency of first order streams in all the regions except B. The degree of correlation of first order streams with rest of the morphometric parameters in the Dhansiri river basin is mainly controlled by change of lithology, structure and variation in rainfall.

The rate of increase of frequency of second order stream with every 100 units increase in frequency of first order stream is:

81% in region A
76% in region B
88% in region C
84% when regions A,B and C are combined.

The rate of increase or decrease of one parameter with the other parameter can be calculated by multiplying the value of correlation coefficient with 100.

b) Frequency of second order stream is negatively (weak) correlated with drainage density, stream frequency and length ratio (L_2/L_3) in all the regions and with length ratio (L_1/L_2) of region A and that of the whole basin. Frequency and length of first order streams show high degree of correlation in all the regions. Length of second and third order streams, basin length, perimeter, area and drainage texture shows positive moderate correlation in all the regions. Bifurcations ratio (F_1/F_2) is weakly correlated in all the regions while weak correlation of length ratio (L_1/L_2) is restricted to regions A and C.

High degree of correlation of frequency of second order streams with frequency and length of first order streams suggests that most of the first order streams are joined together to form second order streams instead of joining with the higher order streams in all the regions.

c) Length of first order streams are directly proportional to frequency of first and second order streams, basin length, perimeter and area. Bifurcation ratio (F_1/F_2) length ratio (L_1/L_2) and drainage texture show weak correlation in all their region. Length ratio (L_2/L_3) and stream frequency and drainage density are negatively correlated in all the regions except in region A where drainage density is positively correlated.

d) Basin perimeter and area shows high degree of positive correlation with basin length in all the regions and is negatively correlated with stream frequency.

e) Area of the basin is directly proportional to frequency and length of first order stream, length of second order stream, basin length and perimeter of the basin, frequency of second order streams and length of third order streams and moderately correlated with length ratio (L_1/L_2), (L_2/L_3) drainage density and stream frequency shows negative correlation.

f) Bifurcation ratio (F_1/F_2), length ratio $(L_1/L_2$, $L_2/L_3)$ and drainage density show a very weak positive or weak negative correlation with all morphometric parameters in all the regions.

g) Drainage density and stream frequency shows good correlatinn with each other in all lithotectonic regions. With rest of the morphomatric parameters it shows either weak positive or weak negative correlation.

FACTOR ANALYSIS

Factor analysis was carried out for the data of three regions separately. Regionwise results (annexure 'C') thus obtained are discussed hereunder.

REGION 'A'

A total of 4 factors were extracted accounting for 42.89, 17.70, 12.29 and 7.42 percent of variance respectively. Most of the variables show very high values of communalities excepting DD and L_1/L_2; the communality of DD being the lowest . These two variables have a higher amount of unique variance. Very high communalities (7 0.90) are shown by F_1, F_2, BA and F_1/F_2. These variables have very low unique variance and are practically wholly explainable through other variables.

Variance of A Variable Accounted For By All The Factors

Factor 1 and factor 4 account for 84.20 percent of variance in frequency of first order streams. Factors 1,2 and 4 account for 91.06 percent of variance in frequency of second order streams. In the length of first order streams 80.1 percent of variance is accounted for by factors 1 and 4. 83.92 percent and 71.08 percent of variance is accounted for by factors 1 and 3 in the length of second order and the length of third order streams respectively.

In the basin length 72.43 percent of variance is accounted for by the factors 1,2 and 4. 90.9 percent and 87.25 percent of variance is accounted for by the first two factors in basin perimeter and basin area respectively. In the bifurcation ratio (F_1/F_2), 92.48 percent of variance is accounted for by the first and fourth factors. In the length ratio (L_1/L_2) all the factors except the third factor (62.41 percent) show very low variance. 70.56 percent of variance in length ratio (L_1/L_2) is accounted for by Factor 3 only. Factor 2 above accounts for 51.84 percent of variance in the drainage density. Factors 1 and 2 account for 86.44 percent of variance in the stream frequency and 77.89 percent in the drainage texture.

Factor 1

The factor loadings of Factor 1 show that it has a positive correlation with F1, F2, L1, L2, L3, BL, BP and BA accounting a variance of 77.44, 75.69, 75.69, 54.76, 60.84, 56.25, 62.41 and 75.69 percent respectively.

Factor 2

Factor 2 has high loading on the drainage density, stream frequency and the drainage texture accounting a variance of 51.84, 77.44 and 68.89 percent respectively. It has a positive correlation with all these variables.

Factor 3

The loading of Factor 3 shows that it has a negative correlation with the length ratio (L_1/L_2) accounting a variance of 62.41 percent only.

Factor 4

It has a very high positive correlation with the bifurcation ratio (F_1/F_2) accounting 86.64 percent of variance.

REGION 'B'

A total of five factors were extracted accounting 45.37, 11.45, 11.16, 8.32 and 7.23 percent of variance respectively. Most of the parameters show communality values above 80 pcercent excepting the basin length and length ratio (L_1/L_2) and communality value of basin length being the lowest.

Variance of the Variables Accounted for by all the Factors

Factors 1,2 and 5 account for 95.5 percent of variance in frequency of first order streams, and the same factors account for 96.16 percent of variance in the frequency of second order streams. Factor 1 and 2 together account for 90.61 percent of variance in the length of first order stream and Factors 1 and 3 accounting for 89.14 percent of variance in the length of second order streams.

The same factors are responsible for 82.33 percent of variance in the length of third order streams. Factor 1 only accounts for 68.89 percent of variance in the basin length. The same factor accounts for 84.64 percent of variance in the basin perimeter. In the case of the basin area, Factors 1 and 4 account for 93.05 percent of variance. Factor 6 alone accounts for 86.49 percent of variance in the bifurcation ratio (F_1/F_2). The variance in the length ratio (L_1/L_2) is due to Factor 3 and is 75.69 percent. Similarly the same factor accounts for 70.56 percent of variance in the length ratio (L_1/L_2). The variance in the drainage density is accounted for by Factor 4 and is 94.09 percent. Factors 1,2 and 4 together account for 86.73 percent variance in the stream frequency. 86.49 percent of the variance is accounted for by Factor 2 in the case of drainage texture.

<u>Factor 1</u>

Loading of Factor 1 shows that it has high positive correlation with F1, F2, L1, L2, L3, BL, BP, and BA. This factor accounts for more than 50 percent of variance in above mentioned variables.

<u>Factor 2</u>

Drainage texture is found to have high positive correlation with this factor. It accounts for 86.49 percent of variance in this variable.

<u>Factor 3</u>

The length ratio has high loading on this factor. L_1/L_2 has negative and L_2/L_3 has positive correlation with the variance as 75.69 percent and 70.56 percent respectively.

Factor 4

This factor in general has low correlation with all the variables excepting drainage density, with which it has negative correlation explaining 94.09 percent variance in it.

Factor 5

Except for bifurcation ratio, this factor has low correlation with all variables. It has high positive correlation with the bifurcation ratio explaining 86.49 percent of variance in it.

REGION 'C'

Three independent factors have been extracted with variance of 47.31, 18.02 and 9.95 percent respectively. Ten variables show communality value above 70 percent. Bifurcation ratio (F_1/F_2), length ratio (L_2/L_3), drainage density and drainage texture show communality value of 34.0, 69,0, 62.0 and 62.0 percent respectively.

Variance of a Variable Accounted by all the Factors

In the number of streams of first order 86.49 percent of variance is explained by the Factor 1. 73.96 percent of variance in number of streams of second order is accounted by Factor 2. The same factor explains 86.49 percent variance in the lengths of first order streams. Factors 1 and 3 explain 84.5 and 75.56 percent variance in the length of second and third order streams respectively. Factors 1 and 2 account for 77.86, 83.81 and 88.65 percent of variance in the basin length, basin perimeter and basin area respectively. Bifurcation ratio has low variance and 31.45 percent is accounted by Factors 1 and 3 together. The variance in length ratios L_1/L_2 and L_2/L_3 is explained by Factor 3 and is 67.24 and 60.84 percent respectively. 56.25 percent variance in the drainage density is explained by Factor 2 above. Factors 1 and 2 account for 80.17 and 62.66 percent variance in the stream frequency and drainage texture.

Factor 1

The factor shows high positive correlation with F1, F2, L1, L2, L3, BL, BP and BA. It is found to account for 86.49, 73.96, 86.49, 72.25, 64.0, 65.61, 72.25 and 75.69 percent of variance in above mentioned variables respectively.

Factor 2

Only drainage density and stream frequency show high positive correlation with Factor 2 having 56.25 and 70.56 percent of explainable variance respectively.

Factor 3

The length ratios (L_1/L_2) and (L_2/L_3) show high correlation with this factor where L_1/L_2 show positive and L_2/L_3 negative correlation. Factor 3 explains 67.24 and 60.84 percent of variance in these variables respectively.

FACTOR RESULTS

The communality data has helped in identifying variables drainage density (DD) and the length ratio (L_1/L_2) in region 'A', basin length and length ratio (L_2/L_3) in region 'B' and bifurcation ratio (F_1/F_2), length ratio (L_2/L_3), drainage density (DD) and drainage texture (DT) in region 'C' which show higher unique variance than the rest. From factor analysis the following groups of variables have emerged:

FACTORS

REGION 'A'

1. F1, F2, L1, L2, L3, BL, BP, BA
2. DD, SF, DT
3. L_1/L_2
4. F_1/F_2

REGION 'B'

1. F1, F2, L1, L2, L3, BL, BP, BA
2. DT
3. L_1/L_2, L_2/L_3
4. DD
5. F_1/F_2

REGION 'C'

1. F1, F2, L1, L2, L3, BL, BP, BA
2. DD, SF
3. L_1/L_2, L_2/L_3

From the groupings of variables in three different regions it is seen that the drainage basin parameters such as F1, F2, L1, L2, L3, BL, BP, BA and DD are the most important ones as far as the variances (in drainage basins) are concerned since these parameters collectively explain a major part of total variance in the basin. The remaining parameters are, however, found to cluster differently in the three regions; they also contribute although less significantly to the total variance in the drainage basin.

CHAPTER - VI

SUMMARY AND CONCLUSIONS

The Dhansiri River, a south bank tributary of the Brahmuputra, flows from southwest to northeast with a catchment constituting the Mikir hills on the west and the Naga hills on the east. Its basin falls approximately within the lat. 25°-0'N to 26°-45'N and long 93°-15'E to 94°-20'E.

The Naga hills region temperature ranges between 1°C to 23°C and the annual rainfall varies between 200 cms and 270 cms. The soils of this region are of two types; ferruginous red soils and lateritic soils. The Mikir hills fall in rain shadow zone. The total annual rainfall is about 120 cm. The temperature ranges from 14°C to 28°C. There are three main types of soils in this region: the red loam or hill soils, the lateritic soils and old alluvium. The catchment represents stratigraphic succession from Precambrian to Recent. The Mikir hills contain stable Precambrian suit of rocks and the Naga hills belong to a fairly young mobile belt of the earth containing Tertiary rocks. The birth of latter is considered to be related to the orogenic development of the Cretaceous-Tertiary complex geosyncline along the eastern margin of Indian plate. The Mikir hills region is supposed to be a fragmented outlier of the Shillong plateau further west.

The present investigations reveal the geomorpholgical set up of the Dhansiri River basin. This study is mainly based on the interpretation of LANDSAT imageries and Survey of India topographic maps. Black and white LANDSAT imageries of 1:1000,000 scale and their enlargements upto four times are visually interpreted to delineate various lithounits, lineaments, landforms and surface cover. Apart from these qualitative analysis, various morphometric partmeters of the drainage basin have also been measured. These parameters are statistically analysed to work out the hydrological conditions and lithotectonic controls in the basin. Statistical analysis includes general statistics, correlation and factor analysis.

The rocks belonging to Precambrian age occur in the Mikir hills only. These consist of biotite granite, foliated gneisses, schists and granulites. The Jaintia Group of rocks are also restricted to the Mikir hills. These rocks flank the southern and southeastern region of the hills with the formations namely the Tura, the Sylhet, and the Kopili consisting of sandstones, limestones and sandstones and shales respectively. The Disang Group of rocks include black to dark grey shales associated with thick beds of sandstones. These are invariably truncated at the base of Disang and Yah thrusts and only upper part of the group is preserved. In the Barail range, the rocks of Disang Group are overlain by arenaceous Barail Group which usually occupies high ground and form prominent ridges. In the Naga hills, the Surma are exclusively confined to the "Belt of Schuppen". However, these rocks run parallel to the Mikir hills truncating against and sometimes penetrating into them. The Tipam Group of rocks are also restricted to "Belt of Schuppen" in the Naga hills, truncating against the Naga thrust except for the places where the Surma replaces them.

These are also exposed on western side of the Dhansiri River running parallel to it till the alluvium overlaps them. Girujan clays also parallel the Naga thrust. These are overlain unconformably by Dihing. Thick beds of gravel and subordinate clay represent this lithounit. On the eastern side these are truncated against Sanis Chongliyemsen thrust.

The area exhibits many small and large scale lineaments. In the 'Belt of Schuppen' majority of lineaments are concentrated between 60°-90°. In the case of region 'B' they are between 30°-60° and in region 'C' the concentration of lineaments is more between 30°-90°. This is probably because the Indian plate subducted under the Burmese plate in a direction approximately perpendicular to these. Some of the mega linear features, which are identified as regional thrust are as follows :

i) Naga thrust

ii) Sanis Chongliyemsen thrust

iii) Piphima thrust

iv) Yah thrust

v) Disang thrust.

The northeastern belt of India is highly susceptible to seismic activity, major causes of which can be attributed to the following tectonic lineaments.

i) the basement faults consisting of the E-W Dauki fault along the southern margin of the Shillong plataeu upto Haflong.

ii) the 'Belt of Schuppen' :- a NE-SW belt of intricate thrusts in the Naga hills.

Three major types of landforms are observed in the river basin :

i) Hilly tracts

ii) Piedmont zone

iii) Alluvial plains

The hilly tracts of the Mikir hills are dome shaped giving rise to radial drainage pattern. The topography of highland areas in the Naga hills is youthful as represented by

i) high rising ridges

ii) steep gradient of streams and water courses actively eroding the rocks giving rise to deep gorges.

iii) 'V'-shaped valleys

iv) absence of flood plains.

The tributaries from both sides of the river, progressively enter the lower altitudes giving rise to depositional landforms :

i) Piedmont zone

ii) large alluvial plains.

Regionally distributed alluvial fans are identified at the Naga foot hills in the piedment zone. The alluvial plains consist of meanders, ox-bow lakes, mature flood plains and young flood plains.

A combination of adverse factros of high relief topography, complexly folded and faulted rock formations and high rainfall makes the area vulnerable to soil erosion and landslides. These also occur due to shifting cultivation, which is very common in the Naga hills. Three main groups of erosion, which are common in the area are :- surficial, mass movement and fluvial erosion.

Rivers are most wide spread and thus the most effective denudational agents. The tributaries coming from the Mikir hills show more or less graded profiles in contrast to the ones coming from the Naga hills, which in turn possess more energy and power for erosion and transportation.

The Dhansiri River divides its drainage basin into two areally unequal and geomorphically distinct sections. The section lying west of the river is older and thus is drained by streams which are longer, have well developed longitudinal profiles and are flowing on gentler gradient. The section lying east of the river, show the reverse of the above and hence it is regarded geomorphologically younger. Phenomenon of river capture is also observed in the area. Various types of drainage patterns includes dendritic, sub-parallel, barbed, radial, pinnate, rectangular and trellis.

In mountain regions, ground water occurs in waste mantles, as well as in cracks and tectonic openings. Other places in the basin where there is a possibility of finding aquifer system are alluvial fans, mature and young flood plains and meander loops.

The drainage azimuth data show that most of the stream in regions 'B' and 'C' follow the lineaments. However, in region 'A' streams following the regional slope are kinetically energised to cut across the structural trend of the area.

For geomorphostatistical analysis on the basis of lithology and tectonics entire basin is divided into three regions :-

Region A	'Belt of Schuppen' in Naga hills	Tertiary
Region B	Naga hills (excluding Region 'A')	Tertiary
Region C	Mikir hills	Precambrian and Tertiary

Geomorphostatistical analysis include the interrelation of results obtained by general statistics, Pearsons correlation matrix and factor analysis.

Statistical analysis suggests that first order streams frequently join each other instead of joining directly the higher order streams to form second order streams. The third order basins are more elongated in region 'C' then in region 'A' and 'B'. This is indicated by the basin length. The drainage density is highest in region 'C' and lowest in the region 'B'.

The analysis based on 'Pearsons correlation matrix suggests that most of the drainage basin parameters of each region are related to one another and that the difference among them are controlled by litho-tectonic variation. Almost all of the measured variables show moderate to high degree of correlation with one another. However, the derived variables commonly show average to weak correlation. Frequency of second order streams show a high degree of correlation with the frequency and length of first order streams.

Factor analysis indicates that most of the independent parameters i.e., frequencies of first and second order streams, lengths of first, second and third order streams, basin length basin perimeter and basin area are associated with factor 1. The following groups of variables have emerged :-

Region 'A'

1. F1, F2, L1, L2, L3, BL, BP, BA.
2. DD, SF, Dt.
3. L1/L2.
4. F1/F".

Region 'B'

1. F1, F2, L1, L2, L3, BL, BP, BA.
2. DT
3. L1/L2, L2/L3
4. DD
5. F1/F2

Region 'C'

1. F1, F2, L1, L2, L3, B1, BP, BA.
2. DD, SF
3. L1/L2, L2/L3

In brief, the following conclusions have been arrived at :-

1. The area is tectonically active and the ongoing neotectonics is the primary cause of seismicity.
2. Three major types of landforms are identified viz. hilly tracts, piedmont zone, and alluvial plains. The topography in the Naga

hills region is youthful and on the contrary, the Mikir hills posess relatively mature topography.

3. Soil erosion and landslides are common in the Naga hills region. One of their causes is shifting cultivation.

4. The section of the drainage basin lying west of the river is geomorphologically older than the one lying on the east.

5. In region 'A', streams follow the regional slope and are more dynamic cutting across the structural trend of the area.

6. The third order basins are more elongated in Region 'C' than in Regions 'A' and 'B'.

7. The measured morphometric parameters show good correlation but the derived ones show average to weak correlation. The variables constitutes Factor 1 and the computed measures of dissection viz. Drainage density, stream frequency and Drainage texture constitute the Factor 2. Other factors are relatively less significant.

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Annexure 'A'

GENERAL STATISTICS

FREQUENCY OF FIRST ORDER STREAM - F1

	Minimum	Maximum	Mean	Standard Deviation	Variance	Skewness	Kurtosia
Region A	4	53	12.82	7.23	52.33	1.96	6.56
Region B	4	43	12.25	6.99	48.86	1.24	0.81
Region C	4	47	12.54	8.10	65.60	1.76	3.36
Total	4	53	12.63	7.52	36.55	1.8	4.56
FREQUENCY OF SECOND ORDER STREAM - F2							
Region A	2	11	3.18	1.40	1.95	1.43	2.47
Region B	2	7	2.97	1.37	1.87	2.08	5.24
Region C	2	10	3.11	1.65	2.73	1.97	4.10
Total	2	11	3.13	1.49	2.22	1.77	3.73
LENGTH OF FIRST ORDER STREAM - L1							
Region A	1	20	5.62	3.28	10.77	1.51	3.07
Region B	1	16	5.57	3.39	11.48	1.30	1.13
Region C	1	29	6.35	4.32	18.67	2.01	5.44
Total	1	29	5.88	3.72	13.86	1.87	5.25

BASIN PERIMETER - BP

Region	A	3	22	7.01	2.69	7.26	1.70	5.87
Region	B	3	23	7.56	3.15	9.95	2.16	7.52
Region	C	1.5	21	7.47	3.43	11.78	1.56	3.18
Total		1.0	23	7.26	3.05	9.32	1.76	5.08

BASIN AREA - BA

Region	A	0.73	22.85	5.22	3.44	11.87	1.84	4.51
Region	B	1.86	20.64	5.68	3.68	13.58	1.86	4.14
Region	C	0.5	29	5.56	4.51	20.33	2.14	6.18
Total		0.5	29.96	5.41	3.90	15.20	2.08	6.17

FREQUENCY RATIO - F_1/F_2

Region	A	0.75	9.5	4.02	1.33	1.78	0.98	1.16
Region	B	2	9.5	4.13	1.55	2.44	1.08	1.21
Region	C	2	10.50	3.99	1.33	1.78	1.44	3.64
Total		2	10.50	4.02	2.36	1.86	2.77	2.07

LENGTH OF SECOND ORDER STREAM - L2

Region	A	0.25	7	1.85	1.26	1.60	1.79	5.03
Region	B	0.5	7	2.04	1.33	1.77	1.61	2.75
Region	C	0.25	7	2.29	1.53	2.33	1.30	1.95
Total		0.25	8.5	2.06	1.38	1.92	1.57	3.27

LENGTH OF THIRD ORDER STREAM - L3

Region	A	0.25	7	1.54	1.23	1.50	1.90	5.04
Region	B	0.25	5	1.49	1.19	1.41	1.30	1.13
Region	C	0.25	7	1.54	1.48	2.18	1.75	3.40
Total		0.25	7	1.53	1.32	1.73	1.80	4.07

BASIN LENGTH - BL

Region	A	0.5	8.5	2.67	1.21	1.46	1.29	3.23
Region	B	1	6	2.88	1.30	1.68	1.32	2.63
Region	C	0.5	9	2.70	1.40	2.02	1.37	2.84
Total		0.5	9	2.71	1.30	1.69	1.34	3.08

LENGTH RATIO - L_1/L_2

Region A	0.5	17.0	3.64	2.25	5.04	2.42	8.36
Region B	0.67	6.5	3.03	1.24	1.54	0.76	0.55
Region C	0.83	16.0	3.31	2.03	4.11	2.46	9.65
Total	0.50	17.0	3.43	2.06	4.25	2.50	9.69

LENGTH RATIO - L_2/L_3

Region A	0.2	12.0	1.83	1.71	2.92	2.58	9.42
Region B	0.30	12.00	2.33	2.55	6.52	2.45	5.84
Region C	0.25	16.0	2.67	2.61	6.80	2.43	7.48
Total	0.17	16.0	2.21	2.23	4.98	2.69	9.21

DRAINAGE DENSITY - DD

Region A	0.55	6.16	1.92	0.69	0.48	1.94	7.83
Region B	0.58	2.86	1.68	0.35	0.12	0.34	2.80
Region C	0.33	7.25	2.11	0.80	0.64	2.31	10.59
Total	0.55	7.25	1.96	0.71	0.51	2.26	10.68

STREAM FREQUENCY - SF

Region	A	0.69	15.07	3.85	1.60	2.58	2.05	11.07
Region	B	1.21	5.74	3.21	0.96	0.93	0.15	0.07
Region	C	0.47	14.01	3.82	1.93	3.71	2.47	10.18
Total		0.47	15.07	3.75	1.68	2.81	2.36	11.81

DRAINAGE TEXTURE - DT

Region	A	0.53	11.0	2.51	1.03	1.05	2.98	22.58
Region	B	0.73	4.17	2.18	0.71	0.50	0.59	0.21
Region	C	0.67	5.14	2.28	0.81	0.65	1.12	1.73
Total		0.53	12.18	0.38	0.92	0.84	2.48	17.40

Annexure 'B'

Correlation Matrix : Region - A

	F1	F2	L1	L2	L3	BL	BP	BA	F1/F2	L1/L2	L2/L3	DD	SF	DT
F1	1													
F2	0.81	1												
L1	0.80	0.70	1											
L2	0.70	0.58	0.69	1										
L3	0.57	0.56	0.56	0.39	1									
BL	0.55	0.44	0.61	0.55	0.73	1								
BP	0.58	0.50	0.71	0.60	0.73	0.81	1							
BA	0.71	0.62	0.79	0.70	0.66	0.74	0.84	1						
F1/F2	0.55	0.01	0.37	0.33	0.24	0.35	0.27	0.29	1					
L1/L2	-0.07	-0.08	0.11	-0.44	0.02	-0.08	-0.04	-0.08	0.04	1				
L2/L3	-0.07	-0.12	-0.08	0.30	-0.44	-0.07	-0.15	-0.09	0.00	-0.40	1			
DD	-0.08	-0.08	0.03	-0.03	-0.11	-0.19	-0.26	-0.42	-0.01	0.07	0.06	1		
SF	-0.08	-0.08	-0.29	-0.24	-0.32	-0.44	-0.53	-0.56	-0.02	0.02	0.08	0.71	1	
DT	0.52	0.45	0.24	0.23	0.05	-0.05	-0.22	0.05	0.27	-0.06	0.06	0.32	0.58	1

Correlation Matrix : Region - B

	F1	F2	L1	L2	L3	BL	BP	BA	F1/F2	L1/L2	L2/L3	DD	SF	DT
F1	1													
F2	0.76	1												
L1	0.92	0.77	1											
L2	0.66	0.54	0.75	1										
L3	0.66	0.58	0.72	0.41	1									
BL	0.61	0.51	0.76	0.62	0.62	1								
BP	0.62	0.56	0.77	0.77	0.63	0.70	1							
BA	0.75	0.65	0.89	0.83	0.65	0.73	0.86	1						
F1/F2	0.61	0.00	0.49	0.36	0.26	0.33	0.29	0.36	1					
L1/L2	0.21	0.13	0.24	-0.37	0.34	0.12	-0.01	0.06	0.16	1				
L2/L3	-0.16	-0.13	-0.11	0.25	-0.48	-0.13	-0.03	-0.05	-0.07	-0.52	1			
DD	0.02	-0.03	-0.03	-0.10	-0.19	-0.01	-0.09	-0.33	0.06	-0.01	-0.15	1		
SF	-0.08	-0.08	-0.33	-0.41	-0.30	-0.47	-0.48	-0.57	-0.02	0.02	-0.15	0.52	1	
DT	0.63	0.49	0.39	0.11	0.19	0.09	-0.13	0.16	0.38	0.24	-0.20	0.05	0.43	1

Correlation Matrix : Region – C

	F1	F2	L1	L2	L3	BL	BP	BA	F1/F2	L1/L2	L2/L3	DD	SF	DT
F1	1													
F2	0.88	1												
L1	0.90	0.84	1											
L2	0.66	0.63	0.75	1										
L3	0.75	0.64	0.71	0.59	1									
BL	0.65	0.53	0.70	0.70	0.68	1								
BP	0.72	0.63	0.82	0.74	0.68	0.84	1							
BA	0.71	0.65	0.81	0.80	0.65	0.84	0.86	1						
F1/F2	0.50	0.07	0.39	0.30	0.41	0.42	0.39	0.34	1					
L1/L2	0.05	0.01	0.08	–0.41	0.10	–0.09	–0.05	–0.07	0.07	1				
L2/L3	–0.29	–0.23	–0.22	0.10	–0.48	–0.13	–0.15	–0.08	–0.21	–0.43	1			
DD	–0.07	–0.07	–0.10	–0.18	0.02	–0.31	–0.24	–0.44	–0.08	0.18	–0.15	1		
SF	–0.15	–0.11	–0.30	–0.42	–0.20	–0.44	–0.43	–0.53	–0.19	0.19	–0.12	0.79	1	
DT	0.50	0.50	0.27	0.11	0.28	0.00	–0.14	0.07	0.16	0.09	–0.23	0.18	0.37	1

Correlation Matrix : All Regions

	F1	F2	L1	L2	L3	BL	BP	BA	F1/F2	L1/L2	L2/L3	DD	SF	DT
F1	1													
F2	0.84	1												
L1	0.85	0.77	1											
L2	0.67	0.59	0.73	1										
L3	0.66	0.60	0.65	0.48	1									
BL	0.60	0.48	0.67	0.62	0.69	1								
BP	0.64	0.56	0.77	0.69	0.69	0.81	1							
BA	0.71	0.63	0.81	0.76	0.66	0.78	0.85	1						
F1/F2	0.53	0.03	0.39	0.32	0.31	0.37	0.32	0.32	1					
L1/L2	0.00	−0.02	0.10	−0.42	0.08	−0.07	−0.05	−0.07	0.06	1				
L2/L3	−0.19	−0.18	−0.14	0.21	−0.45	−0.14	−0.11	−0.07	−0.10	−0.41	1			
DD	−0.07	−0.07	−0.02	−0.08	−0.03	−0.23	−0.22	−0.40	−0.04	0.11	−0.04	1		
SF	−0.11	−0.08	−0.28	−0.33	−0.26	−0.44	−0.47	−0.54	−0.09	0.10	−0.05	0.74	1	
DT	0.51	0.47	0.25	0.15	0.14	−0.02	−0.18	0.06	0.24	0.02	−0.11	0.24	0.48	1

Annexure 'C'

The Share of Variance of each Factor

Region - A

	Eigen Values	% of variance	cum % of variance
1.	6.00	42.89	42.89
2.	2.48	17.70	60.59
3.	1.72	12.29	72.88
4.	1.04	7.42	80.30
5.	0.89	6.34	86.64
6.	0.74	5.26	91.90
7.	0.33	2.33	94.23
8.	0.23	1.61	95.84
9.	0.19	1.38	97.22
10.	0.16	1.17	98.39
11.	0.12	0.86	99.25
12.	0.05	0.38	99.63
13.	0.03	0.21	99.84
14.	0.02	0.16	100.00

Unrotated Factor Matrix

Region - A

Variables	Factors 1	2	3	4	h^2
1.	0.85	0.41	-0.04	0.05	0.90
2.	0.74	0.33	-0.07	-0.49	0.90
3.	0.87	0.19	-0.11	0.03	0.80
4.	0.77	0.25	0.47	0.00	0.87
5.	0.77	-0.11	-0.34	-0.13	0.75
6.	0.82	-0.19	-0.05	0.10	0.73
7.	0.87	-0.29	-0.01	0.03	0.84
8.	0.93	-0.16	0.08	-0.03	0-90
9.	0.41	0.25	-0.05	0.83	0.93
10.	-0.10	-0.12	-0.77	0.20	0.67
11.	-0.13	0.22	0.82	0.15	0.76
12.	-0.25	0.66	-0.20	0.03	0.54
13.	-0.45	0.79	-0.18	-0.05	0.87
14.	0.15	0.87	-0.10	-0.07	0.79

Rotated Factor Matrix

Region – A

Variables	Factors 1	2	3	4
1.	0.88	0.24	0.08	0.26
2.	0.87	0.24	0.05	-0.31
3.	0.87	0.05	-0.03	0.21
4.	0.74	0.00	0.54	0.17
5.	0.78	-0.16	-0.32	0-00
6.	0.75	-0.33	-0.06	0.23
7.	0.79	-0.43	-0.04	0.15
8.	0.89	-0.34	0.08	0.12
9.	0.28	0.10	0.00	0.92
10.	-0.09	0.05	-0.79	0.17
11.	-0.19	0.05	0.84	0.15
12.	-0.14	0.72	-0.06	0.06
13.	-0.30	0.88	-0.02	-0.02
14.	0.30	0.83	0.11	0.07

The share of variance of each factor

Region - B

	Eigen Values	% of variance	cum % of variance
1.	6.35	45.37	45.37
2.	2.44	17.45	62.82
3.	1.56	11.16	73.98
4.	1.16	8.32	82.30
5.	1.01	7.23	89.53
6.	0.49	3.52	93.05
7.	0.36	2.58	95.63
8.	0.29	2.06	97.69
9.	0.13	0.94	98.63
10.	0.10	0.70	99.33
11.	0.04	0.27	99.60
12.	0.03	0.20	99.80
13.	0.02	0.15	99.95
14.	0.01	0.05	100.00

Unrotated Factor Matrix

Region - B

Variables	Factors 1	2	3	4	5	h^2
1.	0.90	0.30	0.25	0.11	0.02	0.97
2.	0.75	0.19	0-11	-0.02	-0.59	0.96
3.	0.97	0.09	0.05	0.02	0.00	0.96
4.	0.80	-0.39	0.37	-0.22	0.02	0.93
5.	0.77	0.25	-0.35	-0.28	-0.02	0.86
6.	0.81	-0.11	-0.15	-0.16	0.11	0.73
7.	0.84	-0.30	-0.10	-0.23	0.03	0.87
8.	0.94	-0.24	0.06	0.12	-0.04	0.96
9.	0.47	0.24	0.27	0.22	0.76	0.98
10.	0.16	0.59	-0.59	0.29	0.09	0.81
11.	-0.15	-0.62	0.58	0.10	0.00	0.75
12.	-0.10	0.47	0.21	-0.80	0.17	0.94
13.	-0.42	0.68	0.45	-0.17	-0.11	0.88
14.	0.32	0.68	0.44	0.39	-0.16	0.94

Rotated Factor Matrix

Region – B

Variables	Factors 1	2	3	4	5
1.	0.75	0.55	–0.11	–0.02	0.30
2.	0.72	0.56	–0.08	0.02	–0.36
3.	0.90	0.31	–0.12	0.06	0.19
4.	0.83	0.09	0.45	0.06	0.16
5.	0.77	0.03	–0.48	–0.18	0.00
6.	0.83	–0.07	–0.12	0.01	0.15
7.	0.92	–0.16	0.04	0.04	0.05
8.	0.91	0.09	0.00	0.32	0.11
9.	0.28	0.19	–0.06	–0.04	0.93
10.	0.00	0.14	–0.87	0.14	0.13
11.	–0.08	–0.05	0.84	0.19	0.05
12.	–0.01	–0.01	–0.06	–0.97	0.04
13.	–0.50	0.53	–0.02	–0.58	–0.01
14.	0.07	0.93	–0.015	–0.03	0.20

The share of variance of each factor

Region – C

	Eigen Values	% of variance	cum % of variance
1.	6.62	47.31	47.31
2.	2.52	18.02	65.33
3.	1.39	9.95	75.28
4.	0.93	6.68	81.96
5.	0.88	6.31	88.27
6.	0.60	4.29	92.56
7.	0.32	2.29	94.85
8.	0.27	1.93	96.78
9.	0.19	1.37	98.15
10.	0.12	0.85	99.00
11.	0.06	0.45	99.45
12.	0.04	0.27	99.72
13.	0.03	0.20	99.92
14.	0.01	0.08	100.00

Unrotated Factor Matrix

Region – C

Variables	Factors 1	2	3	h^2
1.	0.90	0.32	–0.11	0.92
2.	0.30	0.30	–0.30	0.82
3.	0.93	0.15	–0.05	0.88
4.	0.83	–0.22	–0.36	0.87
5.	0.81	0.29	0.14	0.76
6.	0.86	–0.19	0.10	0.78
7.	0.89	–0.16	0.11	0.84
8.	0.92	–0.23	0.03	0.89
9.	0.47	0.10	0.32	0.34
10.	–0.05	0.51	0.66	0.70
11.	–0.24	–0.58	–0.55	0.69
12.	–0.27	0.70	–0–24	0.62
13.	–0.44	0.74	–0.29	0.82
14.	0.23	0.66	–0.37	0.62

Rotated Factor Matrix

Region - C

Variables	Factors 1	2	3
1.	0.93	0.18	0.15
2.	0.86	0.27	-0.03
3.	0.93	0.01	0.11
4.	0.85	-0.04	-0.35
5.	0.80	0.04	0.34
6.	0.81	-0.35	0.07
7.	0.85	-0.34	0.09
8.	0.87	-0.36	-0.01
9.	0.43	-0.16	0.36
10.	-0-10	0.11	0.82
11.	-0.20	-0.18	-0.78
12.	-0.16	0.75	0.14
13.	-0.31	0.84	0.10
14.	0.35	0.71	0.05