FLUVIAL GEOMORPHOMETRY OF DHAULI–GANGA BASIN

(CENTRAL HIMALAYAS)

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Certified that the dissertation entitled "FLUVIAL GEOMORPHOMETRY OF DHAULI-GANGA BASIN, (Central Himalayas)" submitted by Prahalad Kumar for the degree of Master of Philosophy is a bonafide work to best of my knowledge and may be placed before the examiners for their consideration.

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INTRODUCTION

Geomorphology, the science of the study of the earth skin, has developed rapidly after second world war (1945). In recent years more emphasis has been laid on the intensive quantitative analysis of the drainage basin as a fundamental unit in the study of landforms particularly fluvial terrain. The major conceptual change that has taken place in geomorphology has been in the field of numerical analysis of fluvially eroded landscape. This aspect of morphological study is closely associated with the dynamic nature of the earth's form. The term morphometry is used in different branches of science to analyse the shape, form and structure. In geomorphology this term is applied to the quantitative measurements of the landforms, which is more properly termed as geomorphometry (Gardiner)[1]. This may be concerned with the general landscape study (general geomorphometry) or with a specific type of landform (specific geomorphometry). The studies on drainage basin morphometry have included hundreds of research papers since 1940. Fluvial morphometry has become a fundamental concern of geomorphological studies in U.S.A. and U.K. and is also being rapidly used in other countries of the world

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[1] V. Gardinar, (1981), "Drainage Basin Morphometry: Quantitative Analysis of Drainage Basin Form", Perspective in Geomorphology ed. H.S. Sharma, Concept Publishing Co., New Delhi, p.107.

viz India (Vidyanadhan)[1] Brazil (Christofolethi)[2], Australia and Canada.

REVIEW OF LITERATURE:

The year 1945 is essentially a major historical land mark in the growth and development of geomorphological thoughts (Thoman Kuhn)[3]. Robert E. Horton an eminent hydrologist from United States, provided a new paradigm in geomorphology in a series of contributions.[4] He is the pioneer, who paved the way for quantitative description and dyanamic analysis of drainage basin realizing that the hydrological characteristics of a drainage basin are closely associated with their morphologic characteristics and perhaps he was the first person who analysed the functionality of their inter-relationship in numerical values. Flaired by Horton, Strahler,[5]

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1. R. Vidyanadhan, (1977), "Recent Advances in Geomorphic Studies of Peninsular India: A Review", Indian Journal of Earth Sciences, (S. Ray, Volume) pp. 13-35.

2. A Christofolethi, (1969), "Analyse Morfometrica de bacias hidrograficas" Naticia Geomorfologica, I pp.35-64.

3. T.S. Kuhn, (1962), Structure of Scientific Revolution, Chicago University Press.

4. R.E.Horton, (1926), "Flood Flows Characteristics: Discussion" Trans. Amer. Soc, Civil Engineers, 89, pp.1081-6.

   R.E. Horton, (1932) "Drainage Basin Characteristics", Trans. Amer Geophysical Union, 13, pp. 350-61

   R.E. Horton, (1945), "Erosional Development of Streams and Their Drainage Basins, Hydrophysical Approach to Quantitative Morphology", Bull, Geol. Soc Amer, Vol.56, pp. 2 75-370.

5. A.N. Strahler, (1952), "Hyprometric (area altitude) Analysis of Erosional Topography", Bull Geol. Soc. Amer, 63, pp. 1117-42.

Schumn[1], Melton[2], Kesseli[3], Russell[4], Miller[5], Smith[6], Morisawa[7], Robinson[8], Leopold, Wolmen and Miller[9], Scheidegger[10],

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1. S.A. Schumm, (1956), "The Evolution of Drainage System and Slopes in Badlands at Perth Ambay, New Jersey", Bull. Geol. Soc. Amer, 67, pp. 597

2. M.A. Melton, (1958), "Geometric Properties of Nature Drainage Systems and Their Representation in an EC Phase Space", Journal of Geology, 66,pp. 25-54.

3. J.F. Kesseli, (1946) "A Neglected Field of Geomorphology", Annals of Association of American Geographers, Vol. 86, pp. 93.

4. R.J. Russell, (1949), "Geographical Geomorphology" Annals of Association of American Geographers, Vol.39, pp. 10.

5. V.C. Miller, (1953), "Relation of Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennesse", Technical Report 3, Office of National Research, Department of Geology, Columbia University, New York.

6. K.G.Smith, (1958), "Environal Processes Land Landforms in Ladlands, National Movement, S. Dacota", Bull, Geol. Society Amer.Vol. 69, pp. 975-100.

7. M.E. Morisawa, (1962), "Relation of Quantitative Geomorphology of Streams Flow in Representative Watersheds of Appalachrian Plateau Province", Bull. Geol. Society Amer, Vol. 73, pp. 1025-46.

8. G.C. Robinson, (1963), " A Consideration of the Relation of Geomorphology and Geography", Professional Geographer, Vol. 12, No. 2.0.5-15

9. Leopold, Wolman, Miller (1964), Fluvial Processes in Geomorphology, Eurasia Publishing House Private Limited, New Delhi.

10. A.E. Scheidegger, A.E. (1965), "The Algebra of Stream Order Number", U.S. Geol. Sur. Prof. Paper 525-8, pp.187-189.

Shreve[1] Clarke[2] Chorley[3], Gardiner and Park[4], and a number of others have continuously stressed on the quantitative studies of the drainage net work.

Following Gardiner[5] the study of drainage basin morphometry may consist of five heads i.e net work delimitation, sampling, measurement, variable definition and analysis. Generally, the limitation of drainage net and data related to drainage morphometry are derived either from topographic maps or remote sensing source[illegible] (including aerial photographs) and these sources have certain limitations, such as surveyors conventions for field mapping, process of plotting of streams on the map, scale of the map and a date of the survey because time plays a vital role in development and extention of drainage net (Gregory and Gardiner).[6] Several scholars suggested

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1. R.L. Shreve, (1967), "Infinite Topologically Random Channel Networks" *Journal of Geol*, 75, pp. 178-86.

2. J.I. Clarke, (1966), "Morphometry from Maps, *Essays in Geomorphology*, American Elsevier Publishing Company" New York pp. 235-74.

3. R.J. Chorley, (1966), "The Application of Statistical Methods to Geomorphology", *Essays in Geomorphology*, American Elseview Publishing Company, New York, pp. 275-387.

4. V. Gardiner, and C.C. Park, (1978), "Drainage Basin Morphometry: Review and Assessment", *Progress in Physical Geography*, 2, pp. 1-35.

5. V. Gardiner, (1981), 21, Op.cit. Ref No. 1, pp. 107-142

6. K.G. Gregory and Gardiner V. (1975), "Drainage Density and Climate", *Zeitschrift Fur Geomorphologie*, 19, pp. 287-98.

that functioning identity of drainage net should be based on field survey but it is almost all impossible for a large area. It is also a matter of consideration that different mapping agencies have developed their different methods for definition and depiction of drainage net (Drummond[1], Oveden and Gregory[2]). Several techniques have been developed for the delimitation of drainage net work on the basis of data derived from either source. Morisawa[3] suggested the use of contour crenulations to identify the small streams which exist in the field but not exhibited on the map. This idea has been criticised by Gregory[4] because it may include the fossils of palaeohydrological elements which may have originated under early morphogenetic conditions. Shreve[5]

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1. R.R. Drummond, "Where is a Stream a Stream ? Profession-Geographer, 26, pp. 34-37.

2. J.C. Ovenden and K.J. Gregory (1980), "The Permanence of Stream Networks in Britain", Earth Surface Processes 5, pp. 47-68.

3. M.E. Morisawa (1957), "Accuracy of Determination of Stream Lengths from Topographic Maps", Transactions of the American Geographical Union, 38, pp. 86-8.

4. K.J. Gregory, (1966), "Dry Valleys and the Composition of the Drainage Net", Journal of Hydrology, 4 pp. 327-40.

5. R.L. Shreve, (1974), "Variation of Main Stream Length with Basin Area in River Net Works, "Water Resource Research, 10, pp. 1167-77.

suggested that a value of channel slope declines should determine to define the source of the channel. This technique has been applied by Smart[1] successfully. Except these two methods, hydrological (considering stream lines on the map) and morphological (contour cremulations taking into account), a third method is also employed rarely in U.S.A by the mesh-length extension network. In this method all exterior links, determined either from streamlines on the map or contour cranulations are extended headward to watershed to delimit the basin and drainage net work. In the present work a mixture of former two methods have been used.

Horton was the first person who introduced the idea of stream order which brought a revolution in the field of drainage morphometry. According to Bowden and Wallis[2] the concept of stream ordering is, "the touch stone by which drainage net characteristics could be related to each other and to hydrologic and erosional processes". In Hortonian system of stream ordering each finger-tip stream is considered a first order stream and two second orders combined to give a third order stream and so on. Once this initial ordering had been completed the highest order stream was projected backin to the headwaters along the stream which

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[1] J.S.Smart, (1978), "The Analysis of Drainage Network Composition", Earth Surface Processes, 3 pp. 129-70.

[2] K.L. Bowden and J.R. Wallis, (1964), "Effect of Stream Ordering Technique on Horton's Laws of Drainage Composition" Geol. Soc. Amer Bull, 75, pp. 767-74.

involved least deviation from the mainstream direction. Strahler[1] proposed a modification in the aforesaid scheme, all finger tip streams designated as the first order, two first orders produce a second order segment, two second orders provide a third order and so on. Melton[2] advocated that the advantage of this simple scheme is that it can be derived mathematically from concepts of elementary combinational analysis. However, this method is also criticised on the basis of its limitations; one, the order of trunk stream is not changed by the addition of tributary streams of lower order and another limitation is that the addition of a single first order stream could raise the order of the trunk stream. Shreve[3] proposed a method to overcome these obstacles, which is called as segment ordering, in which each outer link designated magnitude and each subsequent link designated as a magnitude equal to the sum of all first order segments which are tributary to it. Scheidegger[4] also

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[1] A.N. Strahler, (1952), op.cit. Ref No.6, pp. 1117-42.

[2] M.A. Melton, (1959), "A Derivation of Strahler's Channel Ordering System", Journal Geology, 67, pp. 345-6.

[3] R.L.Shreve, (1966), "Statistical Law of Stream Numbers" Journal of Geology, 74, pp. 17-37.

[4] A.E. Scheidegger, (1965), "The Algebra of Stream Order Numbers", U.S. Geol. Survey Prof. Paper, 525 B, B 187-9.

proposed a method for an algebra of stream segment combinations which is commutative as well as associative. The problems of selection and adoption of an ordering method emerged in recent time rapidly due to the advance computer based techniques of data handling for required analysis. This also requires a regular unit for data collection. Gradiner[1] introduced the use of of grid squares for mapping drainage density. Decey and Krumbein[2] and Gardiner[3] identified the relationship between topological characteristics of drainage net works in selected quadrats.

To obtain an extremely accurate results of an analysis it is more desirable to examine a large area for more accurate data collection. Data collection from a topographic sheet is very tedious and time consuming job, so, it is more desirable to estimate values of morphometric parametres using a comparatively fast method. Richards[4] used this method to identify its applicability to drainage

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1. V. Gardiner, (1977), Estimated Drainage Density and Physical Regions in South-West England, <u>National Georapher</u>, V-12, pp. 115-38.

2. M.F. Dacey and W.C. Krumbein, (1976), Topological Properties of Disjoint Channel Networks Within Enclosed-Regions, <u>Mathematical Geology</u>, Vol. 8, pp. 829-61.

3. V. Gardiner, (1979), Estimation of Drainage Density from Topological Variables, <u>Water Resources Research</u>, Vol. 15, pp. 909-17.

4. K.S. Richards, (1979), "Prediction of Drainage Density from Surrogate Measures" <u>Water Resources Research</u>, Vol. 15, pp. 435-42.

basins. Other methods have also been explored for quick estimation of other indices of particular significance in morphometric analysis. Hypsometric integral (Strahler)[1] geomorphologically is significant but operationally tedious method. It is criticised by Aronivici[2] and Harlin[3] due to its tedious and time consuming nature of operation. Pike and Wilson[4] devised an effective procedure for its quick estimation.

Plethora of variables proposed by various scholars has been conditioned by different purposes, scale and environment of particular studies. It has been suggested (Gardiner[5], Ebisemiju[6]) that various available parameters essentially

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[1] A.N. Strahler, (1952), "Hyprometric (area altitude) Analysis of Erosional Topography", Bull. Geol. Soc Amer, 63, pp. 1117-42.

[2] V.S. Aronovici (1966), "The Area Elevation Ratio Curve As a Parameter in Watershed Analysis", Journal of Soil and Water Conservation, 21, pp. 226-8.

[3] J.M. Harlin, (1978), "Statistical Moments of the Hypsometric Curve and Its Density Function" Methamatical Geology, 10, pp. 59.72.

[4] R.J. Pike, and S.E. Wilson, (1971), "Elevation Relief Ratio, Hypsometric Integral and Geomorphic Area Altitude Analysis", Bull Geol, Soc. Amer, 82, pp. 1079-84.

[5] V. Gardiner, (1978), "Redudancy and Spatial Organization of Drainage Basin Form Indices", Transactions of the Institute of British Geographers, New Series, 3, pp. 416-31.

[6] F.S. Ebisemiju, (1979), " A Reduced Rank Model of Drainage Basin Morphology", Geographisker Annalar, 61 A.P. 103-12.

represent only some fundamental and conceptual elements of basin form. Morphometric data basically comprises of parameters composed by combinations of only a few basic measurements. Therefore, the nature of the relationship between drainage density (L/A, Horton)[1] and basin area (a) has been a matter of great dispute (Gardiner et all[2], 1977, 1978[3] Pethick[4], Ferguson[5]). In uncertain conditions different definitions of a parameter are proposed, for example, at least ten alternative definitions of basin length have

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1. R.E. Horton, Drainage Basin Characteristics Trans. Amer. Graphys, Union , 13. pp. 350-61.

2. V. Gardiner, K.J. Gregory and D.E. Walling (1977, "Further Notes on the Drainage Density Basin Area Relationship" Area, Vol. 9, pp. 117-21.

3. V. Gardiner, K.J. Gregory and D.C. Walling, (1978), "Further Notes on the Drainage Density Basin Area Relationships. Comment Reply" Area, pp. 354-5.

4. J.S. Pathick, (1974) " A Note on the Drainage Density - Basin Area Relationships", Area, V.7, pp. 217-22.

5. R.I. Ferguson, (1978), "Drainage Density Basin Area Relationship Comment", Area Vol. 10, pp. 350-2.

been proposed by Gardiner[1] and Cannon[2].

Shape of the basin is also a strong geomorphic parameter which is a simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh[3], as reviewed by Gardiner[4]) The important aspects of expressing drainage basin shape are as Form Factor (F) proposed by Horton[5], basin circularity ratio (C) introduced by Miller[6], basin Elongation ratio (R) explored by Schumm[7] and Lamniscate (K) developed by Chorley, Malm and Pogorzalski[8]. A more sophisticated method is evaluated by Mc Arthur and Ehrlich[9]

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1. V. Gardiner, (1975), "Drainage Basin Morphometry", <u>British Geomorphological Research Group Technical Bulletin 14</u>, Norwitch; Geo Abstract.

2. P.J. Cannon, (1976), "Generation of Explicit Parameters for a Quantitative Geomorphic Study of the Mill Creek Drainage Basin", <u>Oklahoma Geology Notes</u>, 36, pp. 3-17.

3. S.Singh, (1979), "Shape Analysis of Open and Closed Links of Small Drainage Basins of Ranchi Plateau, India" <u>Geographical Observer</u>, V. 15, pp. 1-6.

4. V. Gardiner, (1975) Ibid Ref. No. 50.

5. R.E. Horton, (1932) op.cit. Ref No. 45.

6. V.C. Miller, (1953), "A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessea", <u>Technical Report</u>, No.3.

7. S.A. Schumm, (1956), Op.cit, Ref No.7, pp. 597-646.

8. R.J. Chorley, Malm, D.E.G. and H.A. Pogorzelski, (1957), "A New Standard For Estimating Basin Shape", <u>Amer. Journal Science</u>, Vol. 255, pp. 138-41.

9. D.S. Mc Arthur and R, Ehrlich, (1977), "An Efficiency Evolution of Four Drainage Basin Shape Ratios", <u>Professional Geographer</u>, 29, pp. 290-5.

in which the basin outline is modelled by a Fourier function, the harmonics of which describe the form (Jarvis).[1] Anderson[2] also proposed a smilar method for three dimensional expression of drainage basin form. Another method based upon the distribution of area within the basin is also proposed by Blair and Biss[3] which may offer considerable potential for process estimation. A number of further indices of drainage basin form have been proposed since Horton's initial examination of a small number of basic basin parameters such as ruggedness number (Strahler)[4] and relief ratio (Schumm)[5]. Other proposed basic parameters are length of overland flow (Horton),[6] constant of channel maintenance (Schumm)[7] stream frequency (Horton),[8] relative stream density

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[1] R.S. Jarvis, (1976) "Classification of Nested Tributory Basins in Analysis of Drainage Basin Shape", Water Resource Research, 12, pp. 1151-64.

[2] M.G. Anderson, (1973) "Measure of Three Dimensional Drainage Basin Form", Water Resources Research, 9 pp. 378-83.

[3] D.J. Blair, and Biss, T.H. (1967), "The Measurement of Shape in Geography, Nottingham", Quantitative Bulletin No. 11, Department of Geography.

[4] A.N. Strahler, (1958), "Dimensional Analysis Applied to Fluvially Eroded Landforms" Bull, Geol. Soc. Amer, Vol. 64, pp. 2 79-300.

[5] S.A. Schumm, (1956), op.cit. Ref No. 7, pp. 567-646.

[6] R.E. Horton, (1945), op.cit. Ref No. 5, pp. 275-370.

[7] S.A. Schumm, (1956), op.cit Ref No. 7, pp. 597-646.

[8] R.E. Horton, (1945), op.cit. Ref. No. 5 pp. 275,-370.

(Melton)[1], drainage intensity (Faniran)[2], network volume (Gregory)[3], texture ratio (Smith)[4], texture (Morgen)[5], microscopic drainage density (Smart)[6] and macroscopic drainage density by Abrahams[7].

Horton explicitly formulated supplimentary'law', all of which followed a geometric form relating the number of streams of each order and their mean lengths and slopes, to the stream order as summarised by Gardiner.[8] Since 1945

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1. M.A. Melton, (1958)", Correlation Structure of Morphometric Properties of Drainage Systems and Their Controlling Agents", Journal of Geology, 66, pp. 442-60.

2. A. Faniran, (1969), "The Index of Drainage Intensity: A Provisional New Drainage Factor", Australian Journal of Science, 31, pp. 328-30.

3. K.J. Gregory, (1977), "Stream Network Volume An Index of Channel Morphometry", Bull. Geol. Soc. Amer, 88, pp. 1075-80.

4. K.G. Smith, (1950), "Standards for Grading Texture of Erosional Topography" " American Journal of Science, 248, pp. 1075-80.

5. R.P.C. Morgon, (1976), "The Role of Climate in the Denudation System: A Case Study From West Malasia in Derbyshire", E, editor, Geomorphology and Climate, London, Wiley, pp. 319-44.

6. J.S. Smart, (1972), "Quantitative Characterisation of Channel Net Structure", Water Resources Research, 8, pp. 1487-95.

7. A.D. Abrahams, (1980), "Channel Link Density and Ground Slope", Annals, Association, Amer Geographer,70, pp. 80-93.

8. V. Gardiner, (1981), op.cit. Reference Number 1, pp. 107-142.

to present time, the first two thirds of the period may be recognized a period of a phase of post Hortonian intensification and development, in which relationships postulated hy Horton were tested by using a huge data. For example Milling and Tuttle[1], used data for 9078 stream segments under different environmental and lithological conditions. Much of this work was carried out in U.S.A. (Strahler)[2] and by U.S. Geological Survey (Langbein)[3]. Except testing the relationships of three basic aforesaid 'Laws' of Horton, further empirical relationships have also been introduced. Schumm[4] explored the laws of drainage basin area and contributing area. Fok[5] introduced one concerning stream relief. The relationship between main stream length and drainage basin area has been a matter of innovation (Hack[6], Smart

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1. M.E. Milling, and S.D. Tuttle, (1964), "Morphometric Study of Two Drainage Basins Near Iowa City, Iowa", Transactions of the Iowa Academy of Science, 71, pp. 304-19.

2. A.N. Strahler, (1964), "Quantitative Geomorphology of Drainage Basins and Channel Networks", In V.T.-Chow (ed), Handbook of Applied Hydrology, 4-39-4-76.

3. W.B., Langbein, (1947), "Topographic Characteristics of Drainage Basins", U.S. Geol. Survey Water Supply paper, 968 C, pp. 125-57.

4. S.A. Schumm, (1956), op.cit. Ref No. 7, pp. 597-646.

5. Y.S. Fok, (1971) "Law of Stream Relief in Horton's Stream Morphological System", Water Resources Research, 7., pp. 201-3.

6. J.T. Hack, (1957), " Studies of Longitudinal Stream Profiles in Virginia and Maryland", U.S. Geol. Survey Professional Paper, 294-B, pp. 45-97.

and Surkan[1]; Shreve[2]) and so in between link length ratio and stream order (Ghosh and Scheidegger)[3]. At this juncture it is worth realising that the 'laws' are in reality statistical generalizations which may apply to any branching phenomena. Most appropriate example of this irrelevence may be cited of Milton[4], who applied 'laws' on Plum three and demonstrated the geomorphological irrelevance of the laws. Leopold[5] Woldenberg and Berry[6] have emphasized that the law of stream number atleast is nothing but a statistical propability function, which is restricted by the use of a particular ordering system. So, a danger may be predicted in numerical analysis of drainage basins and it is worth

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1. J.S. Smart and A.J. Surkan, (1967), "The Relation Between Main-stream Length and Area in Drainage Basins", Water Resources Research 3, pp. 963-74.

2. R.L. Shreve, (1974), "Variation of Main Stream Length With Basin Area in River Networks", Water Resources Research, 10, pp. 1167-77.

3. A.K. Ghosh, and A.D. Scheidegger, (1970), "Dependence of Stream Link Lengths and Drainage Areas on Stream Orders, "Water Resources Research 6, pp. 336-40.

4. L.E. Milton, (1966), "The Geomorphic Irrelevance of Some Drainage Net Laws", Australian Geographical Studies, pp. 89-95.

5. L.B. Leopold, (1971), "Trees and Streams, The Efficiency of Branching Patterns", Journal of Theoretical Biology 31, pp. 339-54.

6. M.J. Woldenberg, and B.J.L. Berry, (1967),"River and Central Places: Analogous Systems", Journal of Regional Science, 7, pp. 129-39.

advisable that quantitative techniques should not be the goal of the study but it should apply as a tool to an understanding of the genesis of land form. Carson[1] also emphasized for a greater understanding of the meaning of correlation between different morphometeric parameters. King[2] explained that perhaps it is inevitable in the initial stages of a major change of technique, until the value of various quantitative techniques can be properly assessed.

Drainage basin morphometric characteristics are analysed by non-statistical techniques and the analysis of spatial variation of morphometric variables is of a considerable importance (Gregory)[3]. Mather and Doornkamp[4] analysed the spatial pattern of drainage basin characteristics in Uganda. Gardiner[5] in his studies in Devon mapped various morphometric parameters and related them to environmental characteristics to develop a land classification method based on them.

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1. M. Carson, (1966), "Some Problems with the Use of Correlation Techniques in Morphometric Studies in Slaymarker", H.O. Editor, <u>British Geomorphological Research Group Occassional Paper. 4.</u>

2. C.A.M. King, (1976), "Land Forms and Geomorphology", <u>Annals of Association Amer Geographers</u>, pp. 86-93.

3. K.J. Gregory (1978), "Fluvial Processes in British Basins, in Embelton, C., Brunsden, D and Jones", D.K.C Editors, <u>Geomorphology, Present Problems and Future Prospects</u>, Oxford.

4. P. Mather and J.C., Doornkamp, (1970), "Multivariate Analysis in Geomography with Particular Ref to Drainage Basir Morphometry", <u>Trans Inst, British, Geog</u>, 51, pp.163-87.

5. V. Gardiner,(1974),"Land Form & Land Classification in North-West Denon" <u>Transactions of the Devonshire Asso.</u> 106, pp. 141-53.

In the last phase of post Hortonian period several attempts have been made to determine and examine the basin morphometry in different climatic and lithological environments. Different types of work by the varying approaches of different disciplines regarding the basin morphometry has been published in various parts of the world. Ghose et al[1], Ghose and Pandey[2], Singh and Ghose[3] produced work on the basin morphometric characteristics of arid zones. Some studies have been produced on the theme of comparison of drainage morphometry between different rock types, for example, Gardiner[4], Brunsden[5], Tandon,[6] Padmaja[7] Sharma

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1. B. Ghose, S. Pandey and G. Lal, (1967), "Quantitative Geomorphology of the Drainage Basins in the Central Luni Basin in Western Rajasthan", *Zeitschrift fur Geomorphologie* I, pp. 146-60

2. B. Ghose and S. Pandey (1963), "Quantitative Geomorphology of Drainage Basins", *Journal of the Indian Society of Soil Science,* 11, pp. 259-74

3. S. Singh and B.Ghose, (1973), "Interrelationships Between Quantitative Geomorphic Characteristics of the Drainage Basins in Sub-humid to Humid Environment of Rajasthan", *Annals of Arid Zone,* 12, pp.82-9.

4. V. Gardiner, (1971), "A Drainage Density Map of Dartmoor" *Reports Transactions of the Devonshre Associations for the Advancement of Science 103*, pp. 167-80

5. D. Brunsden, (1969), "Dartmoor, *Geographical Association*".

6. S.K. Tandon, (1974), "Litho-control of Some Geomorphic Properties: An Illustration from the Kumaon Himalayas, India", *Zeitschrift fur Geomorphologie 18*, pp.460-71.

7. G. Padmaja, (1975), "Some Aspects of Quantitative Drainage Characteristics of the Dhund Basin", *Geographical Review of India*, 37, pp. 158-64.

Padmaja[1], Mithal et al[2] and studies on a single lithologic background include pumice (Selby)[3] and on deeply weathered rock (Cunha et al[4]). Climatic conditions of basins in determination of morphometry have been considered by Gregory[5], Gregory and Gardiner[6]. Dry valley systems have also been examined by these techniques (Gregory[7], Morgan)[8] Karst drainage basins too, by some modified methods (Bassette

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1. H.S. Sharma and G. Padmaja, (1977), "Quantitative Geomorphic Characteristics of Streams of the Morel Basin Rajasthan," Geographical Review of India, Vol.39, pp. 353-366.
2. R.S. Mithal, B Prakash and I.P.Bajpai, (1974), "Drainage Basin Morphometric Study of a Part of the Garhwal Himalayas," Himalayan Geology, Vol. 4, pp. 195-215.
3. M.Z. Selby, (1968), "Morphometry of Drainage Basins in Areas of Pumice Lithology", Proceedings of the Fifth New Zealand Geographical Conference, New Zealand Geographical Society, pp. 169-74.
4. S.B. Cunha, M.B. Machado and Meis de Moushine M.R. (1975), "Drainage Basin Morphometry on Deeply Weathered Bedrocks", Zeiths Chrift fur Geomorphologie, 19, pp.125-39.
5. K.Z. Gregory, (1976 I), "Drainage Networks and Climate in Derbyshire", E., editor, Geomorphology and Climate, London, Wiley,
6. K.Z. Gregory and V. Gardiner, (1975), "Drainage Density and Climate", Zeitschrift fur Geomorphologie, 19, pp. 287-98.
7. K.Z. Gregory, (1976 II), "Drainage Density Changes in South-west England, in Gregory, K.Z. and Ravenhill," W.E.D. editors, Exetu Essays in Geography, Exter.
8. R.P.C. Morgan, (1971), "A Morphometric Study of Some Valleys Systems on the English Chalklands", Transactions on the Institute of British Geographers. 54 pp. 33-44.

and Ruhe[1], Williams[2]). Techniques of Hortonian analysis have also been applied to non-fluvial land forms as sand dunes (Goudie[3]) and glacial troughs (Maynes[4]) as summarised by Gardiner[5]. Attempts have also been made to relate runoff to purely topological properties of the network, in both empirical (e.g Surkan[6], Dellaur and Lee[7]) and theoretical Kirkby[8]) studies.

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[1] J.L. Bassett, and R.V. Ruhe, (1973), "Fluvial Geomorphology, in Karst Terrain", Morisawa, M.E. (Ed), *Fluvial Geomorphology*,Binghampton, New York University New York Press.

[2] P.W. Williams, (1972), "The Analysis of Spatial Characteristics of Karst Terrains in Chorlay" R.J. (ed) *Spatial Analysis in Geomorphology*, London, Methuen.

[3] A. Goudie, (1969), "Statistical Laws and Dune Ridges in Southern Africa", *Geographical Journal 135*, pp. 404-6.

[4] V.M. Haynes, (1972), "The Relationship Between the Drainage Areas and Sizes of the Outlet Troughs of the Sukkertoppon Ice Cap, West Green Land", *Gegraphisker Annaler*, 54A, pp. 66-75

[5] V. Gardiner, (1981), op.cit. Reference No. 1, pp.107-142.

[6] A.J. Surkan, (1974), "Simulation of Storm Velocity Effects on Flow From Distributed Channels Networks" *Water Resources Research*, 10, pp. 1149-60.

[7] J.W. Delleur and M.T. Lee, (1973), "A Rainfall Runoff Model Based on the Watershed Stream Network", *Proceedings of the Symposium on the Design of Water Resources Projects with Inadequate Data*, Vol. I, Madrid, pp.75-87.

[8] M.J. Kirkby, (1976), "Tests of the Random Network Model and Its Application to Basin Hydrology", *Earth Surface Processes*, Vol. I, pp. 197-212.

Although, the quantitative studies of drainage net work are much in advance in U.S.A. and European countries, the emergence of this branch of geomorphology in India is of recent origin and the progress in this field has been comparatively slower. The names which are worth mentioning for the development of quantitative analysis of landforms are Chatterji[1], Varma[2], Singh[3], Bose[4], West[5], Sen[6], Choubey[7],

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[1] S.P. Chatterji and K. Bagchi, (1957), "Geomorphic Regions of East Rajasthan Pathar", Geographical Review of India, Vol. 19, No.4, pp. 42-47.

[2] P. Varma, (1957), "Panchi Plateau: Its Geomorphological and Human Settlements", Unpublished Ph.D. thesis University of Allahabad, Allahabad, U.P.

[3] R.P. Singh, (1960), "Geomorphological Evolution of the High Lands of Rajmahal", National Geographical Journal of India, Vol. VI, March, Part 1, pp. 1-13.

[4] S.C. Bose and A.K. Sen, (1961), "Some Preliminary Observations on the Geomorphology of the Lower Lunic Basin," Geographical Review of India, Vol 23, No.4, pp. 47-54.

[5] W.D. West, (1962), "The Line of Narmada Son Valley", Current Science, Vol. 31, pp. 143-44.

[6] A.K. Sen, (1965), "Mapping of Micro-Geomorphic Units of Simana Area Western Rajasthan", Annal of Arid Zone, Vol. 4, No.1, pp. 56-63.

[7] V.D. Choubey, (1966), "The Geological Structure and Geomorphology of the Country Around Katangri, Jabalpur District" Unpublished Ph.D. Thesis, of Saugar, Sagar, M.P.

Ahmad[1], Sharma[2], Rai[3], Kharkwal[4], Bhandhopadhyay[5] and Mukerji[6]. But very few references may be cited for the development of pure statistical techniques in the field of quantitative geomorphology viz. Ghosh Pandey and Singh[7],

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1. E. Ahmad, (1968), " Distribution and Causes of Gully Erosion in India" Selected Papers, 21st International Geographical Congress, Vol. 1 pp. 1-3.

2. H.S. Sharma, (1969), "Physiography of the Lower Chambal Valley and Its Agricultural Development", Concept Publishing Company, New Delhi.

3. R.K. Rai, (1970), "Geomorphology of the Sonar Berma Basin, M.P.", Unpublished Ph.D. thesis, University of Saugar, Sagar, M.P.

4. S.C. Kharkwal, (1970), "Morphometric Study of A Himalayan Basin - A Sample Study", National Geographical Journal of India, Vol. 16, Part 1, pp. 47-60.

5. M.K. Bandhopadhyay, (1972), "Geomorphic Characteristics of Southern Part of Khori Hills" Geographical Review of India, Vol. 34, Part 2, pp. 184-189.

6. A.B. Mukerji, (1975), "Geomorphological Study of Choe Terraces of Chandigarh, Siwalik Hills India", Himalayan Geology, Vol. 5, pp. 302-26.

7. B. Ghosh, Panday and Singh (1967), "Quantitative Geomorphology of the Drainage Basins in Central Luni Basin the Western Rajasthan" Annals of Geomorphology, New Folge Band 11, Hoft 2, Scitan, pp.146-60

Sharma,[1] Dutta[2], Pal[3], Sharma[4], and Padmaja[5] are a few who have publicized and tested Horton's and Strahler's models in different climatic and lithological conditions in different parts of the country.

Since the development of quantitative analysis of landforms in our country, several studies have been done by many scholars on different aspects of geomorphometry. Singh[6], produced chronological accounts of the Raj Mahal Highlands, earlier history of the landscape has been treated by tracing

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1. V. Sharma, (1968), "Quantitative Terrain Types Chaur Rajgarh Tract of the Lesser Plimalayas", Geographical Review of India, Vol. 6, Part 1, pp. 31-43.

2. G.K.Dutta, (1970), "Geomorphology Techniques and Applications", Geographical Review of India, Vol.32, No. 2, pp. 113-24.

3. S.K. Pal, (1972), "Classification of Morphometric Methods of Analysis", Geographical Review of India, Vol.34, Part I, pp. 61-85.

4. H.S. Sharma, and G. Padmaja, (1976), "Quantitative Geomorphic Characteristics of Morel River Basin, Rajasthan", Annals of Geomorphology, Germany.

5. G. Padmaja, (1976), "Geomorphology of the Mej Basin (Rajasthan)" Unpublished Ph.D. theisis, University of Rajasthan, Jaipur.

6. R.P. Singh, (1960), op.cit, Reference No. 23, pp. 1-13.

the denudational choronology of the region. Asthana[1], in his study of morphometric evaluation of land form in Almora and its environs, considered three aspects of the terrain i.e geology, configuration and drainage and tried to establish relationships among these three components and some selected basin characteristics. Singh[2] and Kumar in their studies after Horton and Strahler, on the topa and Silphi basins of Ranchi, Unravel various characteristics of drainage net in such a manner that an inter-relationship between length and drainage area and number of each stream under becomes distinct. The length of basin of any order increases rapidly than their width and the area of a small stream order is greater than the area of master stream in a region of high precipitation. Singh[3], in his study of Hoshiarpur, (Kangra tract) by correlating different basin parameters with the basin circularity ratio concluded that the basin circularity ratio as a terrain type element is controlled by slope, relief, basin area, underlying stratigraphy and ruggedness of the area. Kharkwal[4], produced an account of morphological character of certain

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1. V.K. Asthana, (1967), "Morphometric Evaluation of Land Form in Almora and Its Environs", N.G.J.I, Vol. XIII, March, Part 1, pp. 37-54.

2. R.P. Singh and A.Kumar, (1969), "Geomorphological Evolution of Stream Orders of Topa and Silphi Basins, Ranchi", National Geographical Journal of India, Vol XV March, Part 1, pp. 38-44.

3. Labh Singh, (1970), "Basin Circularity Ratio As a Terrain Type Element: A Case Study of Hoshiarpur Kangra Tract", The Deccan Geographer, Vol. VIII, No. 1 June December, pp. 119-128.

4. S.C. Kharkwal, (1970), "Morphometric Study of a Himalayan Basin - A Sample Study", The National Geographical Journal of India, Vol. 16, Part 1, pp. 47-60.

drainage basins as proposed by Horton, Strahler and Schumm in quantitative terms. The results of the study indicate that basin height, ground slope of the basin, channel gradient and drainage density have a good but negetive correlation with the hypsometric integral in accordance with strahler. It also presents a relative picture of the valley slopes and channel gradient. Dikshit[1], in his study deduced four important erosion surfaces over the polycylic landscape of western Maharashtra on the basis of existing relief features and proved that rejunevations and interruptions of the cycles are associated with the climatic change and not with eustatic changes of tectonic movements. Kharkwal[2] presents an account of different geomorphic parameters in development and distribution of slope features in a Himalayan terrain i.e Nainital and environs. Tandon [3], in his study in a part of the Kumaon Himalaya explains the frequency distributions of selected parameters of third order basins in relation to the various stratigraphic units and proved that basin relief and basin

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1. K.R. Dikshit, (1970), "Polycyclic Landscape and the Surfaces of Erosion in the Decan Trap Country with Special Reference to Upland Maharashtra", National Geographical Journal of India, Vol. XVI, Parts II-IV, (September-December), pp. 236-252.
2. S.C. Kharkwal, (1971), "Slope Studies in a Himalayan Terrain", National Geographical Journal of India, Vol. XVII, Part 1, PP. 1-15.
3. S.K. Tandon, (1971), "A Study in the Stratigraphic Frequency Distribution of Various Third Order Basin Parameters in a Part of the Kumaon Himalayas" The National Geographical Journal of India, Vol. XVII, (June-September) Parts 2 & 3, pp. 127-133.

slope are influenced considerably **by** stratigraphy. The influence of lithology and structure is not so pronounced on the frequency of first order streams, basin shape and drainage density, these seem to be more dependent upon the local climatic conditions. Kayerker and Wadhawan[1], relate the knowledge of terrain nature and its basic characteristics to plan improvement in landuse and exploitation of land resources in virgin areas and areas of extensive and intensive landuse. Singh, Ghose and Kaith[2], in their study discussed the present landform features of Chattare taluk of Mysore and it has been divided into, the erosional land surfaces, the depositional land surfaces and a combination of erosional depositional land surfaces. All these geomorphic units have been subjected to soil erosion of different intensities. Satpathy[3] analysed the land forms of Kalhan highlands (Deo river basin) of Singhbhum on the basis of morphological informations and thus throws some light on the nature, evolution and denudation of the present landscape of the region. Pal[4], in his paper

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1. M.V. Kayarker, S.K. Wadhawan, (1972), "A Geomorphic Classification of Terrain", The Deccan, Geographer, Vol. X January-June, No.1, pp. 48-58.

2. S.Singh, B.Ghose, (1973) "Some Geomorphological Aspects of Challakere Taluk" The Deccan Geographer, Vol. XI, January-December, No.1, and 2, pp. 85-92.

3. Debidutta, P.P.P. Satpathy, (1972-73), "Quantitative Analysis of Landforms - A Case Study in the Deo River Basin, Singhbhum~~,~~ Bihar," Geographical Outlook, Vol. IX, pp. 57-66.

4. S.K. Pal, (1973), "Quantitative Geomorphology of Drainage Basins in the Himalaya", Geographical Review of India, Vol. 35, pp. 81-101.

quantitative geomorphology of drainage basins in the Himalaya tries to demarcate the statistical significance of the variations in drainage behaviour for eight river basins selected in the eastern as well as in the western Himalaya. The results of the study explain more ruggedness and more elongation for the river basins in the former as compared to the latter. More run off due to heavy rainfall in the eastern Himalaya is suggested as the cause of the differences. Pofali, Hirakerur and Bhattacharjee[1] in their papers produced a comprehensive study of two distinct geomorphic tracts in the vicinity of Nagpur. The western and southern tract occupied by basltic plateau show the characteristics of youthful landscape while eastern tract is a plain land showing complex geolithologic structure. Mukhopadhyay[2], provides an account of upliftment in Subarnrekha river basin where bed rock type terrace provides clues for the investigation of tectonic movement. The Stratigraphic and terrace evidences of the of the Subarnrekha valley seem to recognize mainly the tectonic control of base level consistent with rejuvenations of the drainage by repeated earth movements in recent times. Chakraborty and Ghosh[3], made an attempt to identify the methdology

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[1] R.M. Pofali, L.R. Hirekerur and J.C. Bhattacharjee,(1973), "Geomorphological Studies in the Vicinity of Nagpur", *Geographical Review of India*, Vol. 35, Sep 35, S pp. 2 8 9 - 298.

[2] S.C. Mukhopadhyay, (1973), "River Terraces of the Subarnrekha Basin," *Geographical Review of India*, Vol.35, June, pp. 152-170.

[3] S.C. Chakraborty, and A.R. Ghosh, (1974), "Longitudianal Profiles in Fluvial Process: An Analytical Study", *Geographical Review of India*, Vol. 36 (March), pp. 31-37.

for analysis of river basins by a standard technique for establishing the history of major epeirogenic movements and the resultant landforms evident in the long profiles of the rivers. Four periods have been classified to commensurate with the number of profiles identified and finally, concluded that the technique could apply for construction of the history of physiographic evolution of the region. Taher[1], in his paper made an attempt to identify the different micro-geomorphological units in the area with their distinguished characteristics and explains why the river changes its course frequently through innumerable meanders creating ox-bow lakes and marshes. Kumar[2], has tried to distinguish the relationship between variables of a drainage basin by applying pair-wise correlation techniques for selected third order basins of upper Burha basin. Singh, Gupta, and Kaith[3], presented a multiple relationship among morphometric attributes and concluded that bifurcation ratio seems to be the dominant factor which influences the discharge and distribution of

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[1] Mohammed Taher, (1974), "Fluvial Processes and Geomorphology of the Brahmaputra Plain", Geographical Review of India, Vol. 36, (March), pp.38-44.

[2] Anil Kumar, (1973-75), "Pair-wise Relationship of Basin Area and Stream Length - A Case Study of the Upper Burha Basin," Geographical Outlook, Vol. X, Pp.49-58.

[3] S. Singh, B.S. Gupta and D.S. Kaith, (1976),"Multiple Relation-ships Between Bifurcation Ratio and Some Morphometric Variables of Drainage Basins in Banas Catchment", The Deccan Geographer,Vol. XIV, No. 2 (July-December), pp. 151-156.

surface run-off. But this factor itself is a dependent on other factors. Chadha[1], studied the geomorphological features around Udhampur as area is divided into the physiographic regions. Dikshit[2], in his paper tries to identify the intensity of erosion in different erosion surfaces and different stages of valley slope development on the Konkan region resulted from a process of rejuvenation initiating a fresh cycle on a planation surface - the coastal lateritic plateau, in which the rivers are entrenched. Padmaja[3], produced her work on Mej river basin and tested Horton's and Strahler's models and variations in morphological attributes in different geological formations. Singh and Srivastava[4] in their study over Belan river basin produced an account of slope development and distribution and dimarcated different slope zones. Sharma, and Padmaja[5], made an attempt to correlate various geomorphic

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[1] S.K. Chadha, (1976), "The Geomorphological Features in An Area Around Udhampur,""The Deccan Geographer.,, Vol. XIV, No. 2, July-December, pp. 145-150.

[2] K.R. Dikshit, (1976), "Drainage Basins of Konkan: Forms and Characteristics", National Geographical Journal of India, Vol. XXII, Part 3 and 4, pp- 79-105.

[3] G. Padmaja, (1976), op.cit. Reference No. 39.

[4] S. Singh and R. Srivastava, (1977), "A Statistical Analysis of the Average Slopes of the Belan Basin", The Deccan Geographer, Vol. XV (July, Dec), pp. 307-316.

[5] H.S. Sharma, G. Padmaja, (1977), "Quantitative Geomorphic Characteristics of Streams of the Moreal Basin, Rajasthan" Geographical Review of India, Vol. 39, December, No.4, pp. 353-366.

variables in varying lithology of Morel river basin and concluded that bifurcation ratio differs from basin to basin according to underlying lithological conditions. Singh[1] produced his study on Palamau upland to verify the validity of 'sinuosity index' as a key to the geomorphological character of the region. This study follows the lines of Mueller. Peshwa and Sukhtankar[2] made an attempt to reveal the lineaments with the help of toposheets as well as aerial photographs, following the definition of O' Leory et al and concluded that either toposheets or aerial photographs do not represent the complete structural set up of the area. A better picture may be carried out of linear features with the help of both toposheets and aerial photographs. Verma and Bhattacharya[3] established relationships in some graphic theoretic measurements by analysing 101 third order basins. They concluded that some distinct relationships are found to exist between inner and outer nodes and between nodes

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1. O.P. Singh, (1978), "Sinuosity Index of Rivers: A Case Study of Palamau Upland", Geographical Review of India, Vol. 40, No.2, pp. 195-97.

2. V.V. Peshwa, and R.K. Sukhatankar, (1978), "Study of Limeaments with the Help of Toposheets and Aerial Photographs from Lonavala Area" Geographical Review of India, Vol. 40, No.4, pp. 309-11.

3. V.K. Verma and G. Bhattacharya, (1978), "Graph Theoretic Concept and Drainage Nets" National Geographical Journal of India, Vol. 24, Parts 3 and 4, September-December, pp. 62-65.

and between nodes and edges. These relationships are apparently valid even with varying lithologics. Kumar and Singh[1] produced a paper on quantitative classification of landform regions of unique physiographic units of Chotanagpur highlands, based on the identification and inherent characteristics of the terrain and through the combinations of some important morphometric attributes. Singh[2] produced a study of drainage density of 23 small basins selected from 5 physiographic regions of Ranchi plateau. The results of the study reveal that geological structure, rainfall intensity and slope appears to be dominant controlling factors of drainage density. Singh and Singh[3] published a paper on morphmetric evaluation of terrains and morpho-genetic mapping in different terrain type areas of India. For this study four localities from two different terrain type areas i.e the Himalaya and the Peninsular uplands have been selected and findings of morphometric attributes have been combined with the geological informations, aerial photographs and other

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[1] A. Kumar and N.P. Singh, (1978), "Quantitative Classification of Landform Region of the Western Higher Plateau, Bihar", Geographical Review of India, Vol. 40, No.4, pp. 378-85.

[2] Savindra Singh, (1979), "A Geomorphological Study of of Drainage Density of Small Drainage Basins of the Ranchi Plateau, India", National Geographical Journal of India, Vol, 35, Parts - 3-4, (September-December) pp. 213-230.

[3] R.L. Singh and S. Singh Bahadur, (1979), "Morphometric Evaluation of Terrain and Morpho Genetic Mapping in Different Terrain Type Areas of India", The National Geographical Journal of India, Vol. 25, Parts 3 and 4, (September - December) pp. 200-212.

micro details of terrain features from topographical sheets and empirical knowledge to bring out technique for morphogenetic mapping. **Mukherjee**[1] made this efforts to conclude the fact that lithology, is the most important factor which influences slope forms. Singh[2] selected fourteen drainage basins in Simla hill region of Himachal Pradesh and analysed all attributes of drainage basins and the results are compared to Horton's analysis. The drainage frequency, bifurcation ratio and the length of the streams calculated on the basis of different orders, do not show geometerical progression as suggested by Horton. The study also helps in dividing the whole terrain into graded stage and degradational stage or in other words late mature, to early mature stage of its geomorphic development. Prasad[3] made an attempt to analyse the drainage basin growth of Barakar basin on the basis of source heads and confluence points. The distribution of source heads and confluence points expresses the phases of drainage evolution and clearly depicts the nature of land and influence of structure.

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1. Sudershan Mukherjee, (1979), "Slope Analysis of Brahamputra Basin in Nagaland" Geographical Review of India Vol. 41, No.3, (September), pp. 284-290.

2. S. Bahadur Singh, (1979), "Quantitative Analysis of Selected Drainage Basins of Simla Hill Region" The National Geographical Journal of India, Vol. XXV, Part 1, March, pp. 50-64.

3. Nageshwar Prasad, (1979), "Hydrographic Network and Drainage Basin Analysis: A Case Study of the Barkar Basin" Geographical Review of India, Vol.41, No.4, pp. 2979-303.

Rawat[1], calculated three sinuosity indices in the Sona basin as proposed by Mueller[2]. These computations made possible to classify the drainage system in its differential roles in ladscape evolution. Prasad[3] produced a similar study on some aspects of meandering streams of the Barkar basin. The results of this study reveal that the streams of the Barakar basin are in the maturity or in the middle stage between youth and old stage of the cycle of erosion. The entrenched character of the meandering streams leads to the conclusion that the region has experienced rejunevnvation. Pof~~o~~ali[4], produced an account of linear, areal and relief characteristics of the drainage network of Vidarbha region. Singh and Upadhyaya[5],

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1. J.S. Rawat, (1980), "River Sinuosity in Sona Basin: Its Significance in Landscape Analysis", Geographical Review of India, Vol. 42, No.2, Geographical Note: 2, pp. 181-82.

2. J.E. Mueller, (1968), "An Introduction to Hydraulic and Topographic Sinuosity Index", Annals of Assoc. Amer Geographers, Vol. 58, No. 2, pp. 371-85.

3. Nageshwar Prasad, (1980), "Some Aspects of Meandering Streams of the Barkar Basin and Their Sinuosity Indexes" Geographical Review of India, Vol. 42, (Sep) No.3, pp. 296-299.

4. R.M. Pofali, (1979), "Linear Characteristics of The Drainage Network of Vidarbha Region", The Deccan Geographer, Vol. XVII, No. 2, pp. 631-43.

5. S. Singh, D.P. Upadhyaya, (1981), "Topological and Geometric Study of Drainage Network, S.E. Chota Nagpur Region (India)" Perspectives in Geomorphology ed H.S. Sharma, Vol. 2, Concept Publishing Company, New Delhi, pp. 191-233.

proved in their study that it is hazardous to relate the morphometric properties of drainage network to the stages of basin development in Davisian fashion. Study also reveals that Horton's and Strahler's model related to drainage net work may not be applied in totality but linear relationship is very much validated. Padmaja and Soundarvalli[1] discussed the behavioral pattern of bifurcation ratios in the Godavari and Krishna basins. Noted the variations of bifurcation ratio in these two basins and attributed their variation varying lithological formations and climatic conditions. Besides these there are many other studies which have also been produced so far. This discussed review of literature particularly published in India so far, gives an impression to be somewhat monotonous in nature. A chunk of the published literature has been produced on the establishment of quantitative relationships of various parameters of geomorphometry. Different 'laws' and 'models' of basin morphometry are being tested in different climatic conditions of various parts of the country.

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1. G. Padmaja and Soundarvalli, (1981), "The Behavioural Pattern of Bifurcation Ratios in Godavari and Krishna Basins (A.P.)", Perspectives in Geomorphology, ed. H.S. Sharma, Vol. 2, Concept Publishing Company, New Delhi, pp. 235-45.

A few authors have studied the theoretical aspects, which draw some conceptual inferences from the application of statistical and mathematical techniques in data interpretation. While all other sciences have laid emphasis on the practical applicability of the research, it is worth realizing that mere methematical and statistical jargon is of no use, if it does not prove its field utility.

SIGNIFICANCE OF THE STUDY

Keeping, all these facts in mind in the present study an attempt has been made towards the more comprehensive and intensive analysis of certain parameters of drainage morphometry. From the existing inter-relationship of various parameters, it has been tried to draw some inferences for the proper understanding of quantitative approach in description of drainage morphometry. The proper understanding of morphometric attributes will be helpful in recognising the nature of land configuration, which is quite essential before the preparation of frame work for the regional planning. On the basis of inter-relationship of certain morphometric variables, the development of a model to project the intensity of erosion and to demarcate the zones of erosion has been tried. This will be the most significant applied aspect of the present study, which will give a clear understanding of the stability of land configuration. It may be indispensible tool of regional planning. Further, this aspect of the study may be applied for the better site selection for dam construction. A site which receives minimum sediment and maximum water volume may be considered rather suitable. Such site may be explored by tracing out the stability of land and small embankments may be constructed across the tributaries which help in deposing the sediment within their own bottom beds and have only the water to enter the trunk stream (which brings in more sediment, to deposite sediment in their bottoms and only the water gets flow into trunk stream). Thus the reservoir may be prevented from the heavy sedimentation.

Except this, the present study throws some light on the factors which show their influence over the development of basin area. Similarly the development of slope of the terrain and drainage density, have also been discussed in relation to the factors which govern them. This is an another significant aspect of the present study, which contributes to the academic aspect of the subject.

SELECTION OF THE STUDY AREA:

Dhauli-ganga basin situated in the lap of central Himalaya has been selected as a basic unit of study on the recommendations of Chorley[1] and Lee[2] because of

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[1] R.J. Chorley (1969), "Water, Earth and Man" Methuen, London.

[2] R.Lee (1964), "Potential Insolation as a Topoclimatic Characteristic of Drainage Basins", Bull International Association Schietific Hydrology, Year I, pp. 27-41.

being a limited, convenient and usually clearly defined and unambiguous topographic unit, available in a nested hierarchy of sizes on the basis of stream ordering, secondly, it is an open physical system in terms of inputs of precipitation and solar radiation and outputs of discharge, evaporation and re-radiation.

The rationale of the selection of this particular basin is its location in higher Himalaya. Himalaya the highest mountain of the world is of recent origin of Tertiary period and possesses the diversity of landforms, which is quite significant for the geomorphological studies. The other significant reason is the two different and well distinguished processes working in the basin i.e fluvial process and glacial process. A comparative study of the features developed by different processes is possible. On the other hand, this virgin land where this type of work has not been carried out so far, has two distinct lithological formations i.e metamorphics and sedimentary. The comparative study of landforms developed by two different processes over the different lithological conditions will be of great interest, even academically.

GEO-IDENTITY OF THE STUDY AREA:

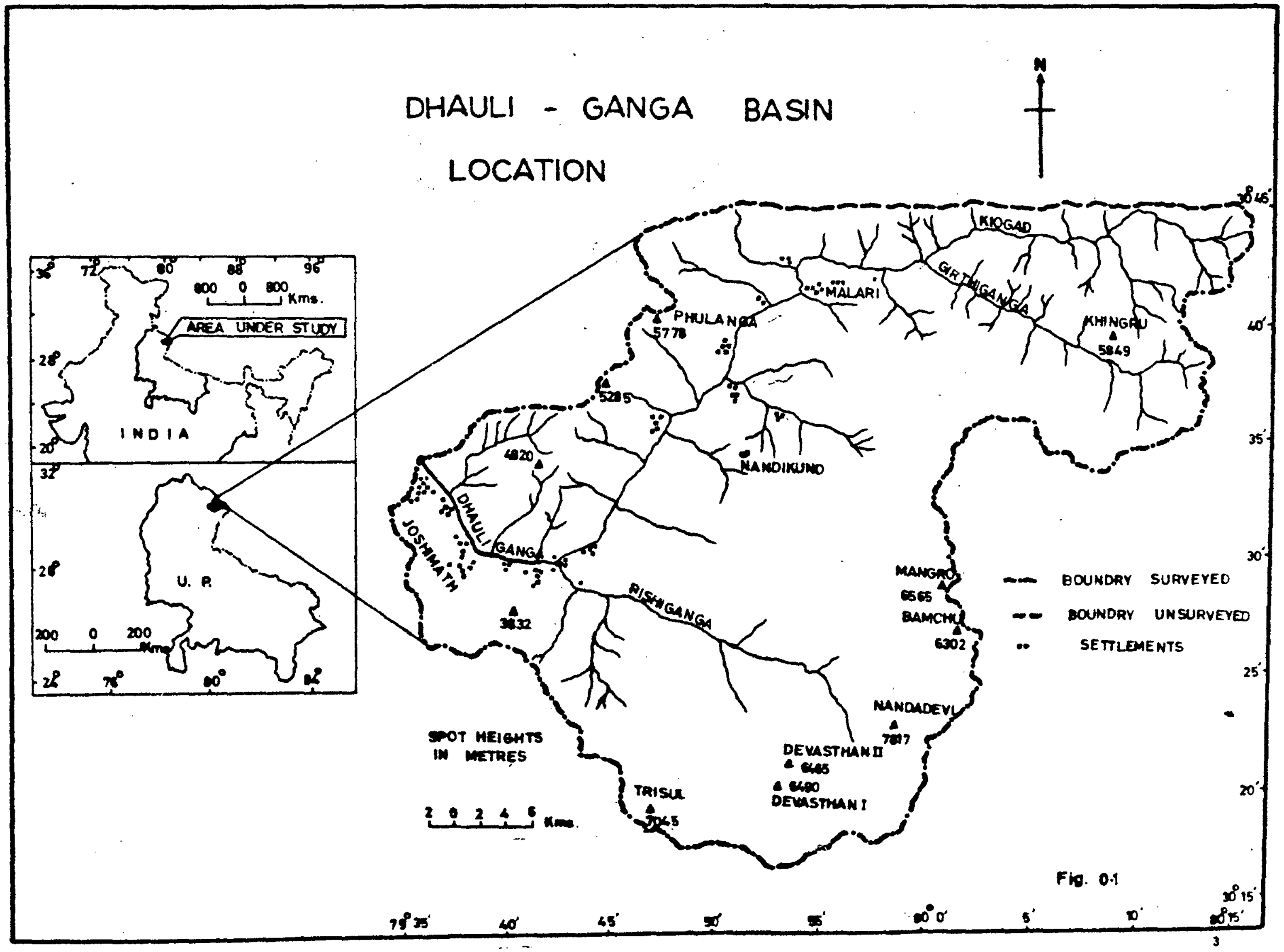
Dhauli-ganga is an important east bank tributary of Alaknanda river in Garhwal Himalaya. It drains over an area of 1992 Km^2 and forms a bit 5 shaped basin. This basin is situated near the China border on the transitional area of Garhwal and Kumaon regions of central Himalaya. Geographically the Dhauli-ganga basin extends from 79° 30' E to 80° 15' E logitude and 30° 15' N to 30° 45' N latitude. Politically, the basin covers an area of Chamoli district of Garhwal region and Pithoragarh district of Kumaon region, in extreme north region of Uttar Pradesh. (Fig. 0.1).

PLAN OF THE WORK

The present study consists of detailed analysis of secondary source of data and available literature. The whole work has been divided into 4 chapters excluding introductory chapter, dealing with various aspects of geomorphometry, for the sake of convinience. An introduction has been provided in the initial stage covering various aspects such as the subject, review of literature, objectives of the present study, selection bases of the study area and Geoidenty of the area under study.

Chapter I deals with the general characteristics of the study area viz, climate, general land use, general geology, and in the latter half hypotheses, data base and methodology etc. have been provided.

The Chapter II deals with the relief and drainage analysis of the study area. The development and distribution of slope and drainage density have been discussed



DHAULI - GANGA BASIN

LOCATION

Fig. 0·1

in context to the factors which govern them. In the same chapter different geomorphic regions in the basin have been projected with the help of different geomorphic variables viz drainage density, stream frequency, ruggedness number, dissection index, relative relief and average slope by superimposition techniques.

Recent quantitative techniques have been applied to all 40 third order basins from the entire basin, to analyse the topological and geometric characteristics of the drainage network in Chapter III. The stage of basin development, shape and size, nature of configuration and inter-relationship of parameters have been discussed by taking 25 variables of drainage morphometry into account.

The last Chapter has been divided into two halves, in first half, it analyses a vivid account of inter-relationship between drainage basin area and other variables of drainage morphometry, which provides a best set of explanatory variables of basin area or gives a notion of factors, which control the basin extension. In the later half, zones of different erosion intensity have been demarcated on the basis of relationship between dissection index, as a determinant of erosion intensity and erosion enhancing agencies.

CHAPTER I

GENERAL CHARACTERISTICS OF THE STUDY AREA AND METHODOLOGY

Dhauli-ganga basin is a 6th order basin in Strahler's stream ordering fashion developed on the east bank of Alaknanda river. It forms an unique shaped basin over an area of 1992 square kilometres. A general glance at the basin clearly gives a notion of different physiographic characteristics viz., the water divide of the basin is encircled by the high mountains with higher peaks including Nandadevi (7817 m), south and south-eastern portions of the basin are covered by glaciers, valley of Dhauli-ganga is a bit flat near the mouth in south of the river, where maximum settlements of the entire basin are situated and some cultivable land is also available. Some patches of dense forest can also be observed in the central part of the basin from Joshimath to Malari along Dhauli-ganga and Rishi-ganga. Bare rock landscape may be observed in eastern portion of high altitudes with huge boulders under the phenomenon of rocks falling.

GEOLOGY

The geological background of the Dhauli-ganga basin is directly associated with the geological episodes of the upliftment of the Himalaya. The present topographical features of the area are a result of endogenetic and exogenetic forces working in the region. Unless those stage of upliftment are not clarified, the present landform features can hardly be explained. So, far a clear understanding of present landscape it is must to look back into the main episodes of its upliftment history. The upliftment history of the Himalaya is summarised below.

UPLIFTMENT OF THE HIMALAYA:

It has now been well established that the Himalaya did not attain its present height in one single phase. Geological data show that Himalaya has developed during five or more phases of upliftments with intervening periods of quiescene. The first movement took place during the middle to upper ~~c~~Cretaceous when the Tethys was furrowed into a series of ridges and basins running longtitudinally. Into the basins we had the deposition of Palaeocene - Eocene rocks (Subathus in lesser Himalaya). Then followed a period of comparative rest after which the another upheaveal took place during the upper ~~e~~Eocene after which the sea nearly vanished and brackish water deposits of Dagshai-Kasauli or ~~m~~Murees were formed. The third movement which was probably most powerful of the all, took place during the middle Miocene times. During this period the Himalaya acquired its major features and the Tethys completely vanished being replaced by mountain ranges with shallow marshes and large river valleys. At this time a long narrow trough or fore-deep in front of the rising

Himalaya was formed in which fresh water Siwalik sediments were deposited by the rivers flowing from the Himalaya and the Peninsular India.

At the end of the Siwalik sedimentation i.e towards the close of the Pliocene, a fourth upheavel took place. This was followed by an ice age during Pleistocene. The final phase of Himalayan upliftment took place in early Pleistocene when Pir Panjal was raised to its present height. This happened in other parts of the Himalaya as well. This is evidenced by the occurrence of Pleistocene deposits on the flanks of the Pir Panjal several thousand feet above the level of lakes in which they were originally deposited. Before this movement, man had already appeared on the globe and must have witnessed the final phases of the rise of the Himalaya. Minor adjustments have been taking place since then, as some of the faults are still active.

The Himalaya are still rising is evident from the presence of river deposits hundreds of feet above the present river level. The present rate of uplift is estimated to be 0.5 - 0.8 cm per year. The geological formations in the basin can be categorised under 2 heads-schists and gneisses of older formation associated with sedimentaries of newer formation. A detailed account has been provided below on the basis of Heim and Gansser's[1] work.

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[1] A. Heim and A. Gansser, (1939), "<u>Central Himalaya Geolo-gical Observations of the Swiss Expedition</u>" 1936, Denkschhr Schweiz Naturf, Ges, p. 73.

THE BADRINATH GROUP (THE UPPER ALAKNANDA) TECTONICS AND GEOLOGY:

Descending to the gorge at Vishnuprayag, the gneiss is exposed below the slided block field. It is biotite gneiss with minute fluidal folding of the Darjeeling type. Above it, also regionally dipping 45° to N 10 E, follows a repretition of highly metamorphic mica schists and paragneiss with injections of the following approximate thickness:

a) 1200 metres of chiefly mica schists with garnet;

b) 400 metres of chiefly gneiss;

c) 700 metres of chiefly mica schists with garnet;

d) 9400 metres of quartzite with subordinate mica schists.

With slight changes of the strike, the dip of this enormous mass of well-bedded quartzite varies from 40-70°. No indications of tectonical repetitions having been found, we are forced to consider (Heim and Gansser)[1] it as a normal succession. Only above the waterfall of Kaliankoti, between the two iron bridges, the rock changes into a highly metamorphic sedimentary series with injected augen gneiss, characterized by lime-silicates. The dip is 55-65° to N 15 W.

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[1] A. Heim and A. Gansser, (1939), op.cit. p.73

The next sub division sets in with a series of quartizites and lime silicates, injected and inter bedded with amphibiotic layers. The latter can also be traced on the walls on the west side of the valley by their rusty weathering. This series shows minute zig zag folding.

The two last sub divisions have a thickness of about 1.5 kilometers. The trail following the east side of Alaknanda now enters moraines. As seen from the distance, on the high walls of the western side, the injected series with lime-silicate layers continues and gradually steepnes to a vertical and even over vertical position in the shape of a synclinal fan. Its vertical axis, striking W20°s, passes the river below the Bamani, 1.5 to 2 km. south of the temple of Badrinath. There, the succession towards the north is as follows:

a) Biotite gneiss and mica schists, about 80 metres dip 80° to s 30 E;

b) Banded lime - silicates, about 100 metres;

c) Gneiss and gneiss - quartzite, dip 60° to S 25 E;

d) Highly metamorphic sediments with injected gneiss and calc silicates forming a flat anticline, of 10 - 20° pitch to W 15S, thickness about 1 kilometre.

Summarizing the Alaknanada section from the thrusted basal mica-schists and gneisses at Urgam valley up to Badrinath, we (Heim and Gansser)[1] find the three following sub

---

[1] A. Heim and A. Gansser, (1939), op.cit.

divisions, of which the first two are apparently in a normal succession:

1) 7.8 kilometres mica-schists with gneiss;
2) 9.4 kilometres quartzite ("granulite").
3) About 4 kilometres of injected paraschists characterized by lime-silicate layers.

This latter series, above Mana and thence to the west becomes to a great extent replaced by granite with aplitic dykes and sills.

<u>DHAULI-GANGA AND RISHI-GANGA:</u>

On the north side of Kauri pass the Dhauli-ganga has formed a deep valley in the shape of an arch with its convex side turned to the south, first making a transverse section and then cutting a longitudinal valley down its confluence with the Alaknanada at Joshimatha - Vishnuprayag. The rocks are mica schists with quartzite layers, alternating with real biotite gneiss which becomes predominant towards Joshimath. The dip is 20° to N and NNE at the Kauri Pass and gradually steepens up to 45° towards N. (Fig 1.1).

About 2 km below the mouth of Rishi-ganga, the trail passes over a spur of gneiss with muscovite, biotite and Kyanite together with layers of marble and lime silicates dipping 38° to E 25 N.

In the Rishi Gorge the mica schists, full of garnet, are seen still dipping 30° strike to S 30 E.

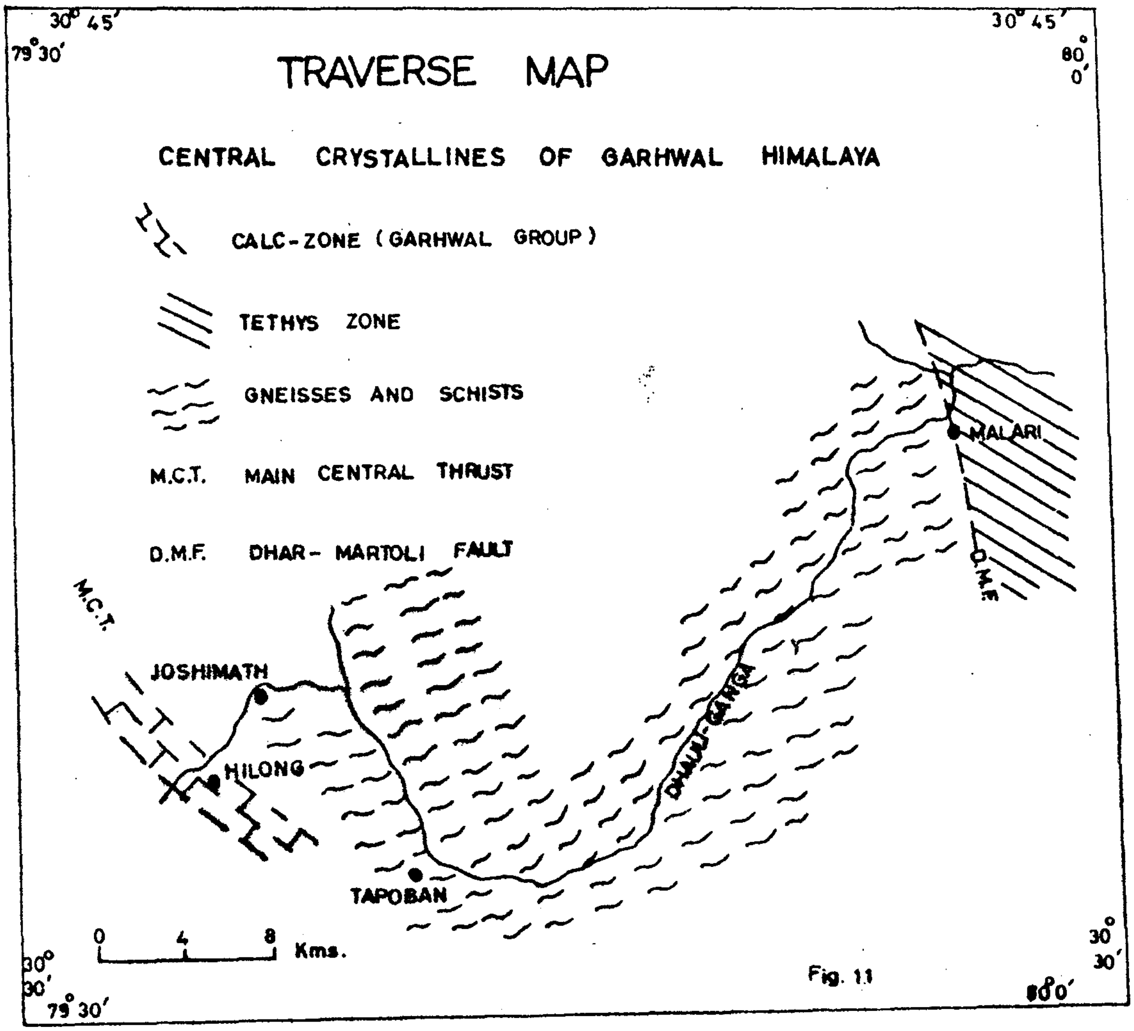


Fig. 11

SOURCE: HIMALAYAN GEOLOGY, VOL. V, 1975, P 456

GENERAL LAND-USE OF THE AREA:

The general landuse of the study area may be classified broadly into five categories viz., the area under cultivation which is available in the vicinity of Joshimath along the south bank of Dhauli-ganga, area under settlements which may be observed along the rivers in valleys, forested land which is also observed in river valleys along main rivers of the basin, glaciated landscape is well developed on high mountains which is spread in south and south-east area of the basin and other hilly bared land scape. The distribution of land under different above mentioned catagories is exhibited in the map (Fig 1.2) and area of each category is demonstrated in the numerical terms in the Table (1.1) below (Approximate);-

TABLE - 1.1

GENERAL LAND USE OF THE AREA

S.No.	Land Use Categories	Area Km^2	Percentage
1.	Cultivated land	23	1.15
2.	Land under settlements	42	2.11
3.	Forested land	248	12.44
4.	Glaciated Area	592	29.75
5.	Other hilly tract	1087	54.54
	Total	1992	100.00

DHAULI-GANGA BASIN

GENERAL LANDUSE

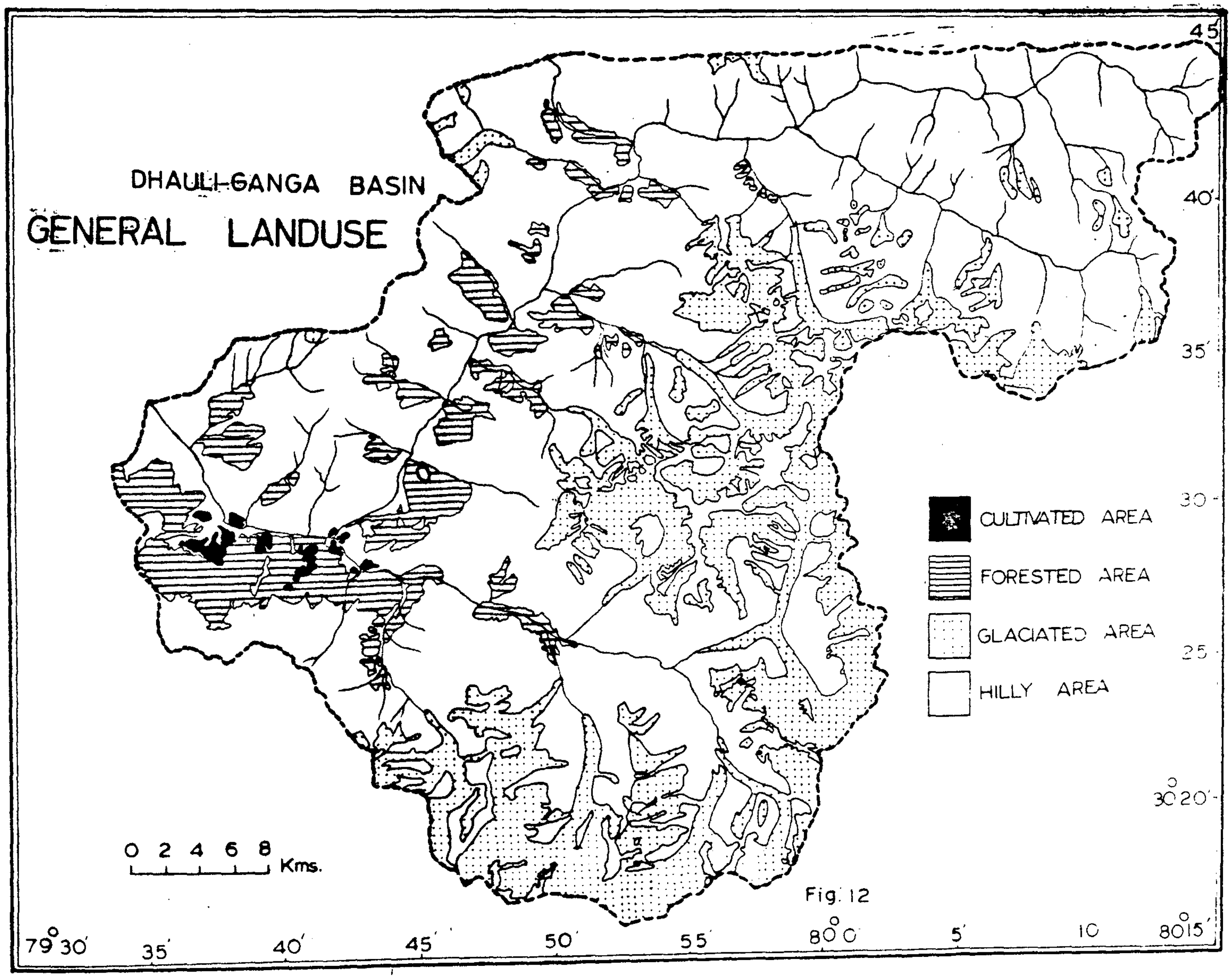


Fig. 12

The Table (1.1) and map (Fig 1.2) clearly portray that maximum area of the basin lies under the hilly and glaciated landscape, which is 84.29% of the entire basin. Very few patches may be observed under cultivated land, which are generally in the south of Dhauli-ganga from Rini Village, situated on the fork of Dhauli-ganga and Rishi-ganga to Joshimath urban area. This is the area which lies below a height of 3000m and is rather flat, comparatively. Maximum settlements of the basin are also observed in this area and some are scattered along Dhauli-ganga upto Malari which is an important settlement in the basin situated on the confluence point of Dhauli-ganga and Girthi-ganga. Other important settlements of the area are Passani, Khanla, Balgaon, Biolgarh, Reagaon, Tapoban, Ringi, Karchhigoon, Soldhan, Subhain, Rini, Lata, Paing, Markura, Juma, Jelam, Garpak, Kosa, Kurkuti and Bampa etc. The glaciers in the basin which contribute water to Dhauli-ganga and its contributries are, Kamet and Dhaulagiri in north, Gankhwi, glacier, Dangri bank, Siraunch gaul, Kalla bank, Lampak gaul situated in south-eastern corner of the basin. The big glaciers of the basin are, Uttar Rishi glacier, Dakshini Rishi glacier, Uttar Nanda Devi glacier, Dakshin Nanda Devi glacier, Trishul glacier, Hanuman glacier, Battartali glacier, Raunthi glacier, Nanda Ghungti glacier and Changabang glacier etc all are situated in south part of the basin (Fig. 1.2).

CLIMATE:

Climate is an important factor in shaping and modifying the landscape of a region. The intensity of different exogenetic forces over a landscape is a phenomenon governed by climatic conditions of the region. The present study area falls under the humid zone of the country. The main sculpturing processes of topography are weathering and running water sub-ordinated by the action of glacier movement. The entire basin enjoys the extreames of temperature, rainfall and snowfall. The elevation of the area controls the different aspects of climate, therefore, it largely depends on altitude and varies according to the the aspects of elevation. The elevation of the area ranges from 2000 m above mean sea level in the valleys in west and 7000 m in the snow bound Himalayas in the South and South east. Although, a bit tropical heat may be experienced in the valleys during the summer, the winter is severe. As most of the area of the basin is situated on the southern slopes of the Himalayas, monsoon currents penetrate through the deep valleys and results maximum rainfall in the monsoon season (June to September) particularly in the valleys. The southern area of the basin also gets a considerable rainfall and snowfall during the winter season which lasts frommid November to March.

RAINFALL:

Records of rainfall in the basin are not available as no meteorological observatory has been established in the basin. However, the draft on rainfall of the area has been prepared on the basis of records available in neighbourhood of the basin. The distribution of rainfall generally increases in river valleys owing to the nature of the terrain which is highly variable from place to place. July and August are the rainiest months which obtain 76% to 85% of the annual precipitation. In the monsoon season, there are a few occasions when there are spouts of heavy rain in the hills causing floods in the rivers. The amount of precipitation decreases rapidly after the month of September and it is lowest in November. During winter the precipitation occurs in the form of snow and ice.

TEMPERATURE:

The temperature of an area is an important factor which controls the climatic conditions and ultimately governs the sculpture of earth surface. It has already been mentioned that there is no meteorological observatory in the basin. Therefore, the account of temperature is based mainly on the records of the observatries in neighbouring areas, where similar meteorological conditions prevail. Variation in the temperature is significant from place to place which depends on altitude. The temperature in high altitudes in summer is considerably higher in the open valleys, than the areas lying under shadow. January is considered to be the coldest month of the year with a mean maximum temperature 10° c at a height of 2000 m. above the mean sea level, the mean minimum temperature being at the freezing point. (0° C). The cold waves in the wake of western disturbances often make winter conditions rigorous. The temperature is much lower at higher altitudes towards the area of glaciers and precipitation at higher altitudes occurs mostly in the form of snow which accumulates considerably in the valleys. After January, both day and night temperature begin to rise, rapidly. March and June are the warmest months with a maximum temperature of 25° c at 2000 m above sea level, 15° c to 18° c at 3000 m elevation and still lower at higher altitudes. With incessmion of the monsoon currents, temperature falls slightly by about 3° to 5° c.

HUMIDITY:

The humidity in the area is highest during the monsoon period and also for a short spell when the region is affected by western disturbances. Generally sky remains clear or lighly clouded during the rest of the year.

NATURAL VEGETATION:

The natural vegetation of the area may be classified into four categories according to the height and type of vegetation viz sal forest, Chir forest, coniferous forests and short bushes, flower plants and lichane. Few patches of dense forest occur in the area (Fig 1.1) mainly in the river valleys. Salforests occur in the area of low altitudes upto the 2200 m. height on a south aspect, Chir trees are dominating because of their power of removing away other vegetation from the area where they grow. Chir is the staple building timber in the hilly tract and a large quantity of it is exported to the plains in the form of sleepers. Resin is also extracted from these trees and their seeds are eaten.

The species of coniferous forests are dominating between the altitudes of 3220 m and 4000 m. The chief specie of the confirous forest in the area is Ragha (Himalayan silver fur) which mainly occurs between the heights of 3250 m to 3550 m.

Above the height of 4000 m some short bushes green grasses and alpine vegetation may be observed. Lichan small grasses and beautiful flowers are the common phenomenon in the spring season, which comes here late.

After providing the general characteristics of the region the present study is aimed at testing the hypothesis postulated below:-

HYPOTHESIS:

(i) The development and distribution of slope is controlled by the morphometric attributes viz. relative relief, dissection index, ruggedness of the configuration, drainage density and drainage frequency which are inter-dependent.

(ii) Drainage density is a multi-functional result of absolute relief, dissection index, average slope, ruggedness number and drainage frequency while some of themviz average slope and ruggedness number are governed by drainage density itself.

(iii) Morphometric parameters are inter-correlated and their inter-relationship reflect the different aspects of fluvially eroded landscape viz age, stages of basin development and intensity of the erosion over the underlying lithological structure and nature of configuration in various ways.

(iv) Area of the drainage basin is determined by the multi-functionality of various morphometric variables viz stream frequency, drainage density, dissection index, ruggedness number, constant of channel maintenance, length of overland flow, relative relief, mean bifurcation ratio, mean channel length, total channel length and number of stream segments.

(v) Dissection index is a determinant of erosional intensity as it has a strong control over the erosion enhancing agencies.

METHODOLOGY:

In the present study, modern geomorphic techniques as well as statistical and cartographic methods have been applied to measure the different aspects of fluvially eroded landscape to test and examine the above mentioned hypotheses. Different aspects related to the nature of configuration viz Relative relief, dissection index, ruggedness number, drainage density , stream frequency and average slope have been represented cartographically. For the preparation of the maps of the aforesaid indicators. Entire basin has been divided into 1992 gride of 1 square kilometre, and the value of the each grid for each variable have been calculated and the areas of different intensities have been demarcated by isoplething.

For the present work, in order to study the spatial distribution of different variables, all statistical measures have been used viz mean, mode median, range, inter quartile range, quartile deviation, standard deviation, coefficient of variation and variation etc. (Appendix V). The nature of spatial distribution of important geomorphic parameters have been analysed on the basis of skewness* and Kurtosis.**

To analyse the impact of different geomorphic parameters on the distribution and development of average slope and drainage, density, correlation matrix and regression equations are prepared. Multiple regression+ and correlation models ++ have been used widely in geographic research.

---

* Skewness = SK $= \frac{\mu_3^2}{\mu_2^2} = \frac{(\mu'_3 - 3\mu'_1\mu'_2 + 2\mu'^3_1)^2}{(\mu'_2 - \mu'^2_1)^2}$

** Kurtosis =

$$= \frac{\mu_4}{\mu_2^2} = \frac{\mu'_4 - 4\mu'_1\mu'_3 + 6\mu'_2\mu'^2_1 - 3\mu'^4_1}{(\mu'_2 - \mu'^2_1)^2}$$

Where, u = moment

\+ In a written expression, it takes the form as:

$Y_1 = a + b_1 X_1 i + b_2 X_2 i + b_3 X_3 i \ldots bn\ Xni, i=1, 2..n$

Where , Y = dependent variables

a = intercept

x_1 to x_n = Independent variables

Stepwise regression is a powerful variation of multiple regression which provides a means of choosing independent variables and provides the best prediction possible with the fewest independent variables. Therefore, this technique has been used for determining the significance of impact of some geomorphic parameters on slope development, drainage density evolution and drainage basin area extension. The significance of relationships has been tested by 't'[+++] test.

The results of the analysis are represented with appropriate cartographic techniques using log log and semi-log graph papers. A model to demarcate the zones of erosion intensity has been developed. The entire basin has been divided into four geomorphic regions with the help of super imposition of different maps of average slope, relative relief, dissection index ruggedness number, drainage density and

---

[++] The correlation coefficient is calculated on the following formula

$$r = \frac{\Sigma dx . dy - \frac{(\Sigma dx) \times (\Sigma dY)}{N}}{\sqrt{\Sigma dX^2 - \frac{(\Sigma dx)^2}{N}} \sqrt{\Sigma dy^2 \frac{(\Sigma dy)^2}{N}}}$$

Where
dx = deviation of X series from an assumed mean.
Similarly, dy = deviation of y series from an assumed mean.
d x dy = sum of the product of the deviations of X and y.
d X^2 = sum of the squares of the deviation of X series.
dy^2 = sum of the squares of the deviation of y series
N = number of observations

[+++] Test of significance is made on the following formula:

$$t = \frac{r}{\sqrt{1 - r^2}} \sqrt{N-2}$$

Where, r = Coefficient of correlation
N = Number of observations.

stream frequency.

DATA AND MAPS BASE:

The present study is totally based on secondary data, which has been collected from Survey of India toposheets. These toposheets include 53 N/10, N/11, N/14, N/15, B/2 and B/3 on a scale of 1 : 50000. Maps used in the study are also based on the said toposheets.

LIMITATION OF THE STUDY:

The boundary of the north water divide of the basin has been drawn tentatively because of non-availability of pertaining toposheet.

Data for climatic variables in the basin are not available as no meteorological observatory has been established in the basin. However, the draft on climatic conditions has been prepared on the basis of records available in the neighbourhood of the basin.

CHAPTER II

PART - A

RELIEF ANALYSIS

Relief, as the identity of terrain is a continuous function of processes working under the different micro-climatic conditions over the varying lithology of a region. Landforms which have their individual distinguishing features depend upon the geomorphic processes for their development. It is recognized that different geomorphic processes produce different landforms in different stages of land form evolution. Thus, the present day relief features of land configuration should to a certain degree reflect the climatic conditions under which the topography developed.

It is experienced that under the same climatic conditions different relief features are developed, this being the reflection of geological characteristics in them. Different rock types and formations play an important role in the development of landforms.

Different aspects of the relief of the present study areahave been discussed in detail below.

ABSOLUTE RELIEF:

Absolute relief is the maximum height from mean sea level per a square unit area. It can be measured on a topographic map with the help of contour of maximum value or spot height. The absolute relief of a region gives an idea about the climatic and vegetal conditions of the area. High absolute relief is an indicator of cold climate with sparse vegetation.

The map of altitudinal zones (Fig - 2.1) of the basin portrays that height of the basin increases constantly from mouth to source ward. Dhauli-ganga river upto Malari flows in a valley with an average height ranging from 3000 to 4000 meters. The area of maximum height lies in the south and south-east portion of the basin, which is almost all glaciated area, with 5000 to 7000 meters of absolute relief. The highest mountain peak of the country Nandadevi (7817 m) lies in this portion of the basin. The zone of highest altitudes (6000 to 7000 meters and above) spread over the water divide of the basin on the south-east boundary of the basin.

The absolute relief in the entire basin varies from 1960 meters lowest to 7817 meters highest. This range of 5857 meters has been divided into 9 categories with an interval of 500 meters. The frequencies of each category have been exhibited by the Table 2.1.

The said table implies that 944 square kilometers area of the basin exists above the snow-line (snow-line in Himalaya recorded around 5000 meters), which is 47.39% of the entire basin. Maximum area of the basin (1409 km^2) lies in between the absolute height of 4000 to 6000 meters.

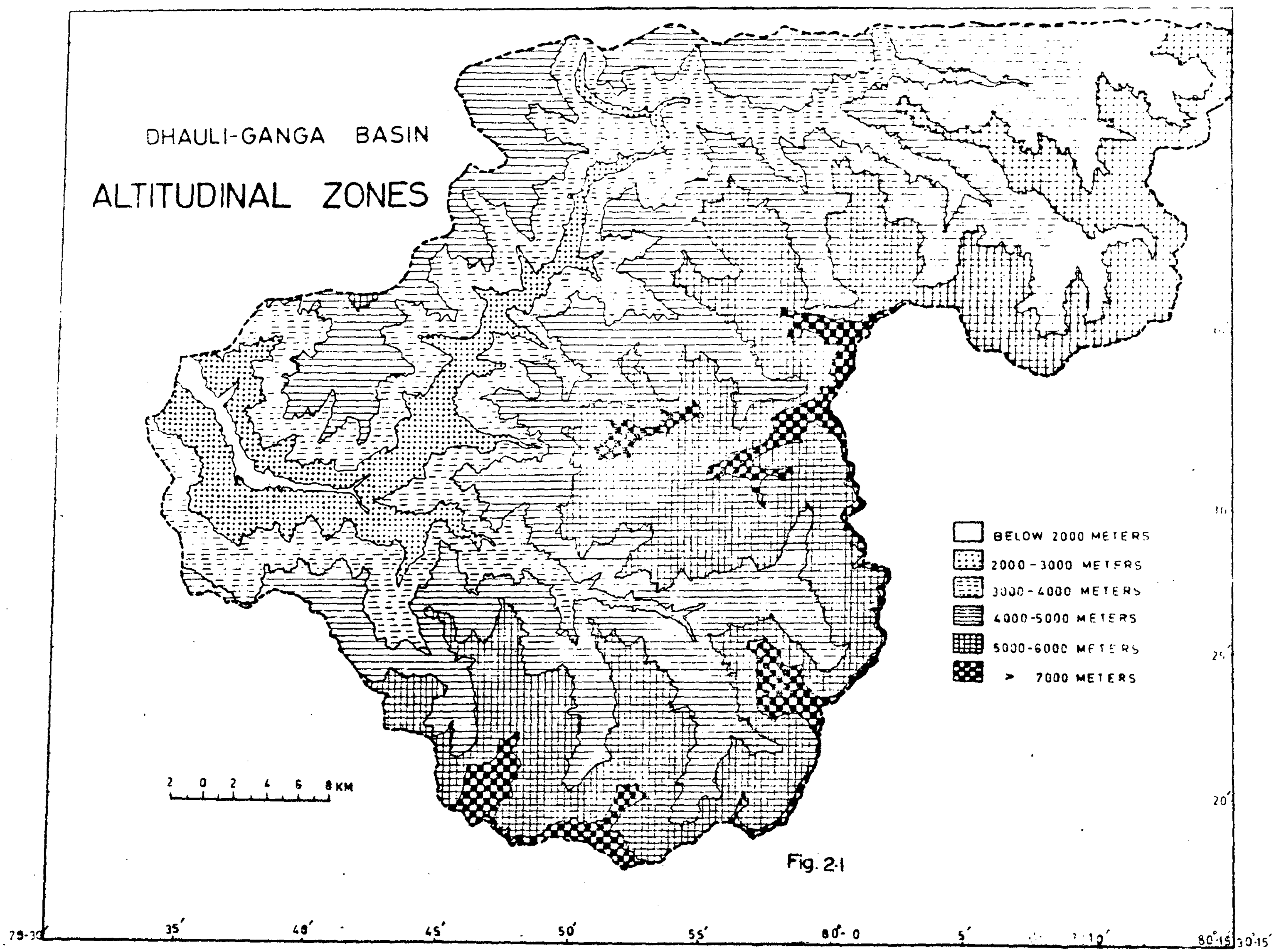

DHAULI-GANGA BASIN
ALTITUDINAL ZONES
BELOW 2000 METERS
2000 - 3000 METERS
3000 - 4000 METERS
4000 - 5000 METERS
5000 - 6000 METERS
> 7000 METERS
2 0 2 4 6 8 KM
79°30'
35'
40'
45'
50'
55'
80°0
5'
10'
80°15'
30°15'
30'
25'
20'

Fig. 2·1

Table 2.1

Distribution of Absolute Relief (Meters)

S.No.	Category	Frequen -cy	Cummulative frequency	%	Cum ulative %
1.	Below 3000	80	80	4.82	4.82
2.	3000-3500	113	193	5.67	9.69
3.	3500-4000	192	385	9.64	19.33
4.	4000-4500	267	652	13.40	32.73
5.	4500-5000	396	1048	19.88	52.61
6.	5000-5500	405	1453	20.33	72.94
7.	5500-6000	341	1794	17.12	90.06
8.	6000-6500	130	1924	6.53	96.55
9.	Above 6500	68	1992	3.41	100.00
	Total	1992		100.00	

NATURE OF ABSOLUTE RELIEF DISTRIBUTION:

A close study of the discussed Table 2.1 reveals the fact that about 19.88% of the total is represented by medium absolute relief categories, wherein the mean value of the absolute relief frequencies standing at 4873.229 meters is located, which clearly indicates that the basin is in the first stage of land form evolution, as the absolute relief is high in the initial stage of the cycle of erosion. The positively skewed frequency percentage polygon (Fig. 2.2-A) represents the fact that the chunk of the area lies within the high altitudes.

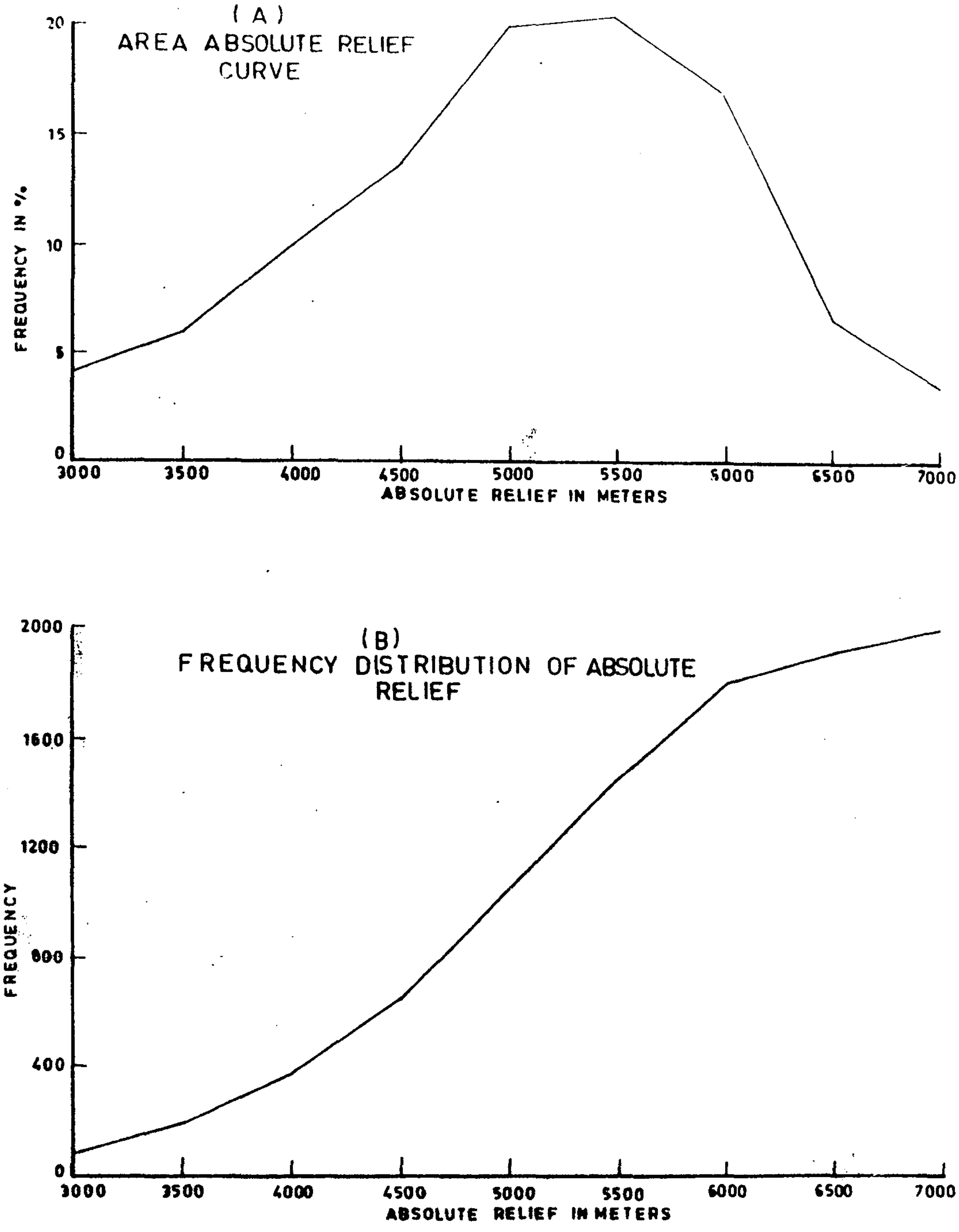

(A)
AREA ABSOLUTE RELIEF CURVE
FREQUENCY IN %
20
15
10
5
0
3000
3500
4000
4500
5000
5500
5000
6500
7000
ABSOLUTE RELIEF IN METERS
(B)
FREQUENCY DISTRIBUTION OF ABSOLUTE RELIEF
FREQUENCY
2000
1600
1200
800
400
0
3000
3500
4000
4500
5000
5500
6000
6500
7000
ABSOLUTE RELIEF IN METERS

FIG.-2.2

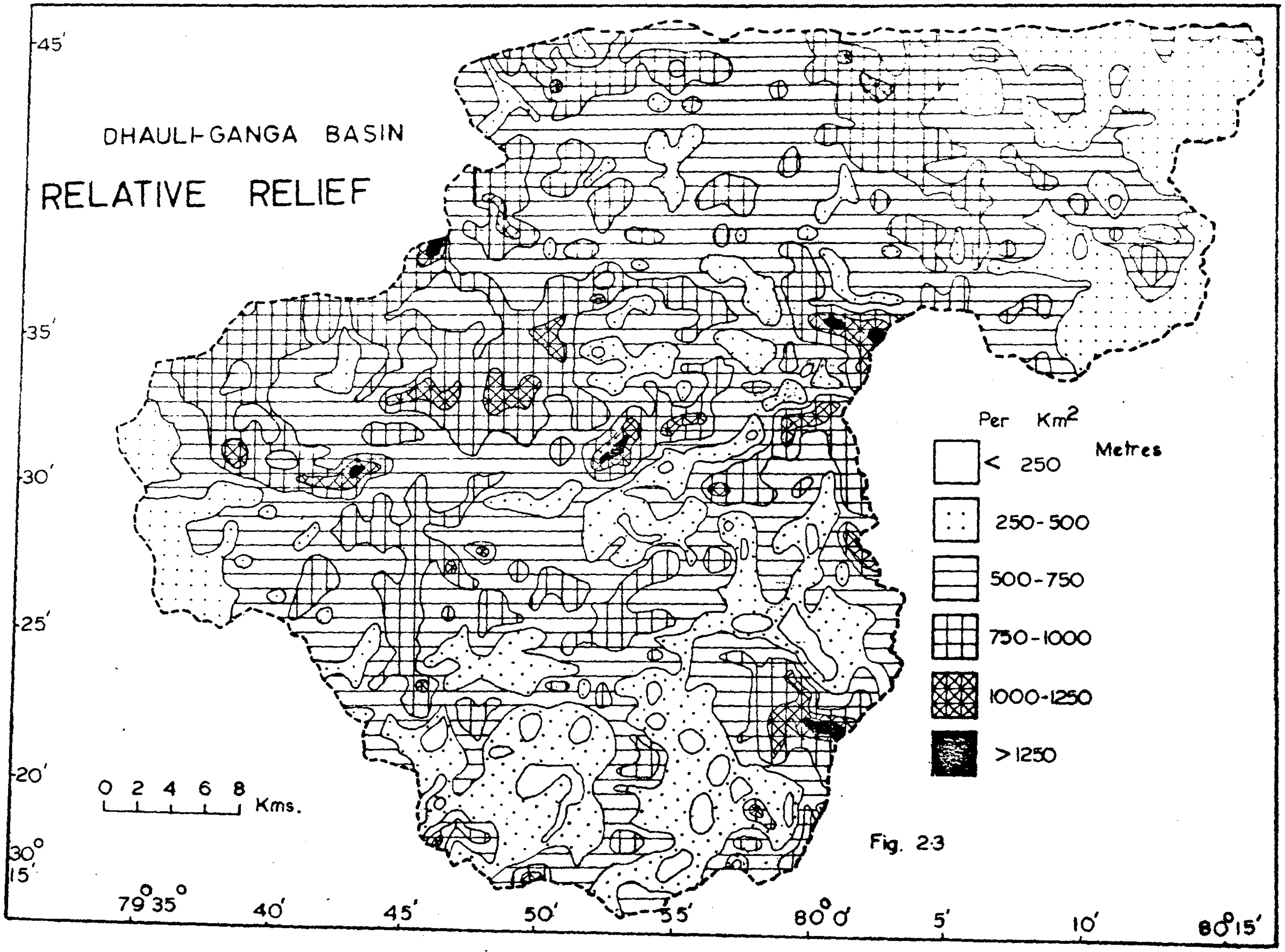
The mean value (4873.229) of absolute relief of Dhauliganga basin indicates concentration of maximum frequencies around the snow line. Which again is an indicator of youthful stage of the present basin development. The cumulative frequency graph (Fig 2.2-B) presents the clear picture of the absolute relief distribution in the basin. Maximum frequencies lie in the high altitudes in the categories of higher absolute relief.

Standard deviation being the best measure of dispersion, is used in the present study to measure the exact degree of variation from the normal distribution. The calculated standard deviation of absolute relief values standing at 967.683 shows a bit smaller degree of variation. Coefficient of variation being 19.8% clearly reveals that the standard deviation is 19.8% of the mean, which supports the low degree of variation.

RELATIVE RELIEF:

Relative relief is relative elevation between highest and lowest heights of a unit, area. Thus, it can be calculated by substracting the lowest height from the maximum height of the unit area. Relative relief gives an idea about the inclination of terrain, which reflects the nature of configuration.

Map (Fig 2.3) exhibits that the area of high relative relief is in the river valleys, while the area of low relative relief is prevailing over the glaciated terrain. Which can help to give a vague idea that glaciated terrain is more flattish in comparison to river valleys and bare



DHAULI-GANGA BASIN

RELATIVE RELIEF

Fig. 2·3

rock land scape.

Relative relief of the area has a great degree of variation due to the varying nature of configuration. It varies from 80 meters to 1640 meters per square kilometer. This great range of 1560 meters has been divided into 6 categories with an interval of 250 meters. The frequencies of each category have been arranged in a Table (2.2).

Table 2.2 implies that maximum area of the basin (815 km^2) lies in the middle category ranging from 500 to 750 meters, it covers 40.92% area of the entire basin. Both adjoining categories of it, comprises of 498 km^2 and 472 km^2 area of the basin, respectively. These three categories of relative relief cover an area of 1785 km^2 in total and thus, 89.61% area of the entire basin varies in its relative relief from 250 meters to 1000 meters per square kilometer. A small area of the basin (4.72% and 5.62%) respectively lies below 250 meters relative relief and above 1000 meters of relative relief.

NATURE OF DISTRIBUTION

Table 2.2 implies that about 40.92% frequencies are represented by the third category ranging from 500-750 meters, wherein the mean value of the relative relief standing at 633.154 is located, which reflects the characteristics of youth stage of landform development. The frequency percentage polygon (Fig 2.4-A) portrays a negative skewed nature of frequency distribution. This represents the fact that majority of the area lies within the steep relative relief category.

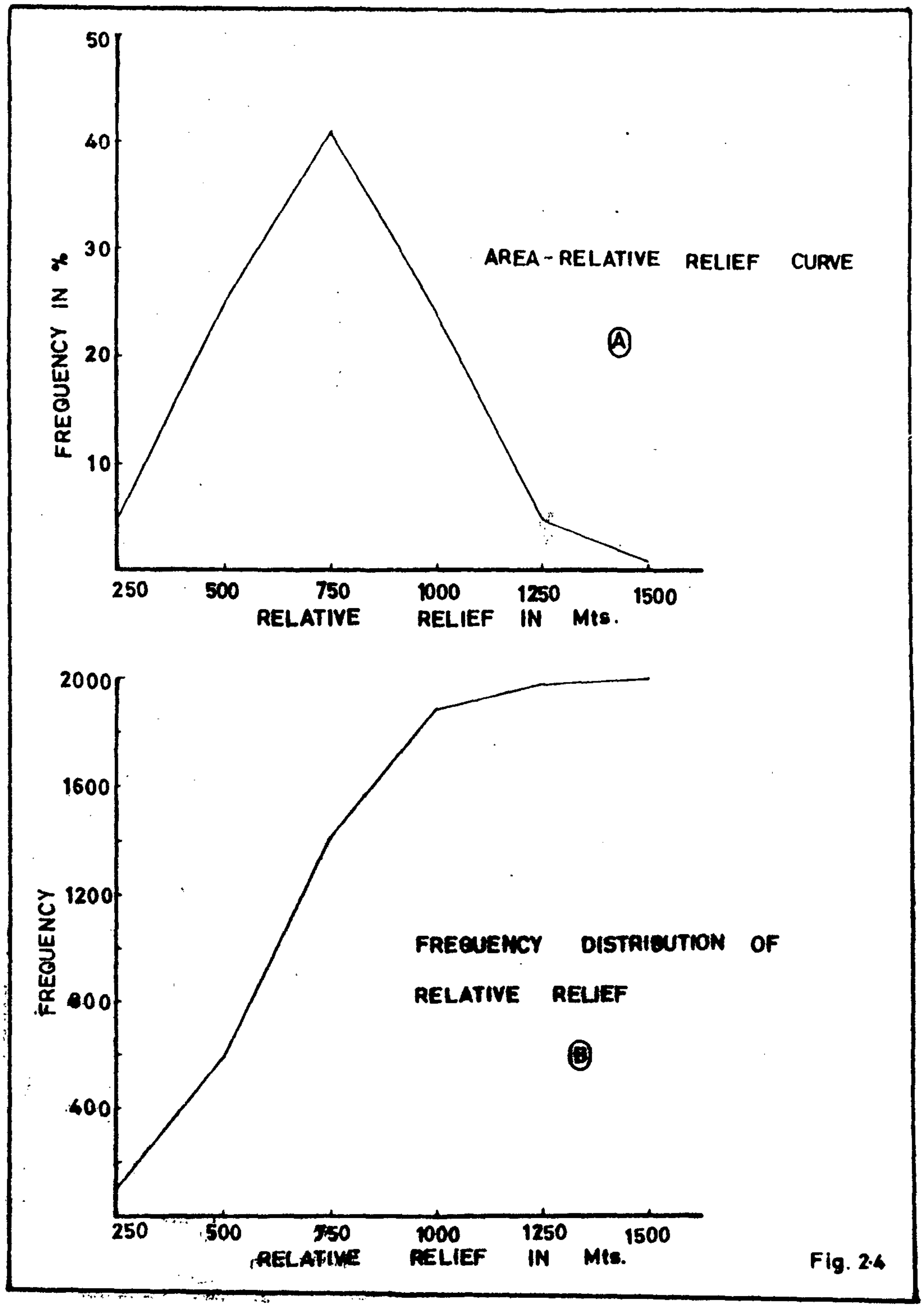

50
40
30
20
10
FREQUENCY IN %
AREA - RELATIVE RELIEF CURVE
Ⓐ
250
500
750
1000
1250
1500
RELATIVE RELIEF IN Mts.
2000
1600
1200
800
400
FREQUENCY
FREQUENCY DISTRIBUTION OF
RELATIVE RELIEF
Ⓑ
250
500
750
1000
1250
1500
RELATIVE RELIEF IN Mts.

Fig. 2·4

Table 2.2

Distribution of Relative Relief (m)

S.No.	Category	Frequency	Cummulative frequency	%	Cum ulative
1.	Below - 250	94	94	4.72	4.72
2.	250 - 500	498	592	25.00	29.72
3.	500 - 750	815	1407	40.92	70.64
4.	750 - 1000	472	1879	23.69	94.33
5.	1000 - 1250	96	1975	4.82	99.15
6.	Above - 1250	17	1992	0.85	100.00
	Total	1992	-	100.00	-

The mean value of relative relief indicates concentration of maximum relative relief frequencies in steep category of 500-750 meters and hence complete uneven distribution of relative relief frequencies, which is well exhibited by the cum ulative frequency graph (Fig 2.4-B).

Variation in the relative relief values from the normal distribution has been measured by the best measure of deviation i.e, standard deviation. The value of standard deviation in the present case standing at 251.196, shows a bit higher degree of variation. Coefficient of variation being 39.60% clearly indicates that the standard deviation is 39.60% of the mean, which further support the higher degree of variation.

DISSECTION INDEX

Dissection index is the measurement of dissected topography in mathematical terms. By dissected topography, we mean topography characterized by a definite pattern of incised hills or mountains separated by low lying area i.e cut by erosion into a network of valleys and interfluves. It has been found to be most convenient to describe the dissection of the landscape, the pattern of ridges and valleys in terms of drainage pattern.

Map (Fig 2.5) exhibits that the area of high dissection index exists in the river valleys, while the area of low dissection index prevails over the glaciated terrain, similar to the relative relief, which trace the fact that the area along the river valleys has developed steep escarpments and gorges due to the deep downward cutting by antecedent drainage. The area under glaciers is more flattish due to the protection offered by the permanent ice sheet and snow has filled up the low areas.

The dissection index of the area has a wide range of 0.40, due to the difficult and extremely undulating nature of configuration. It varies from 0.0 to 0.40. This great range has been divided into five categories with an interval of 0.08. The frequencies of each category have been arranged in Table 2.3.

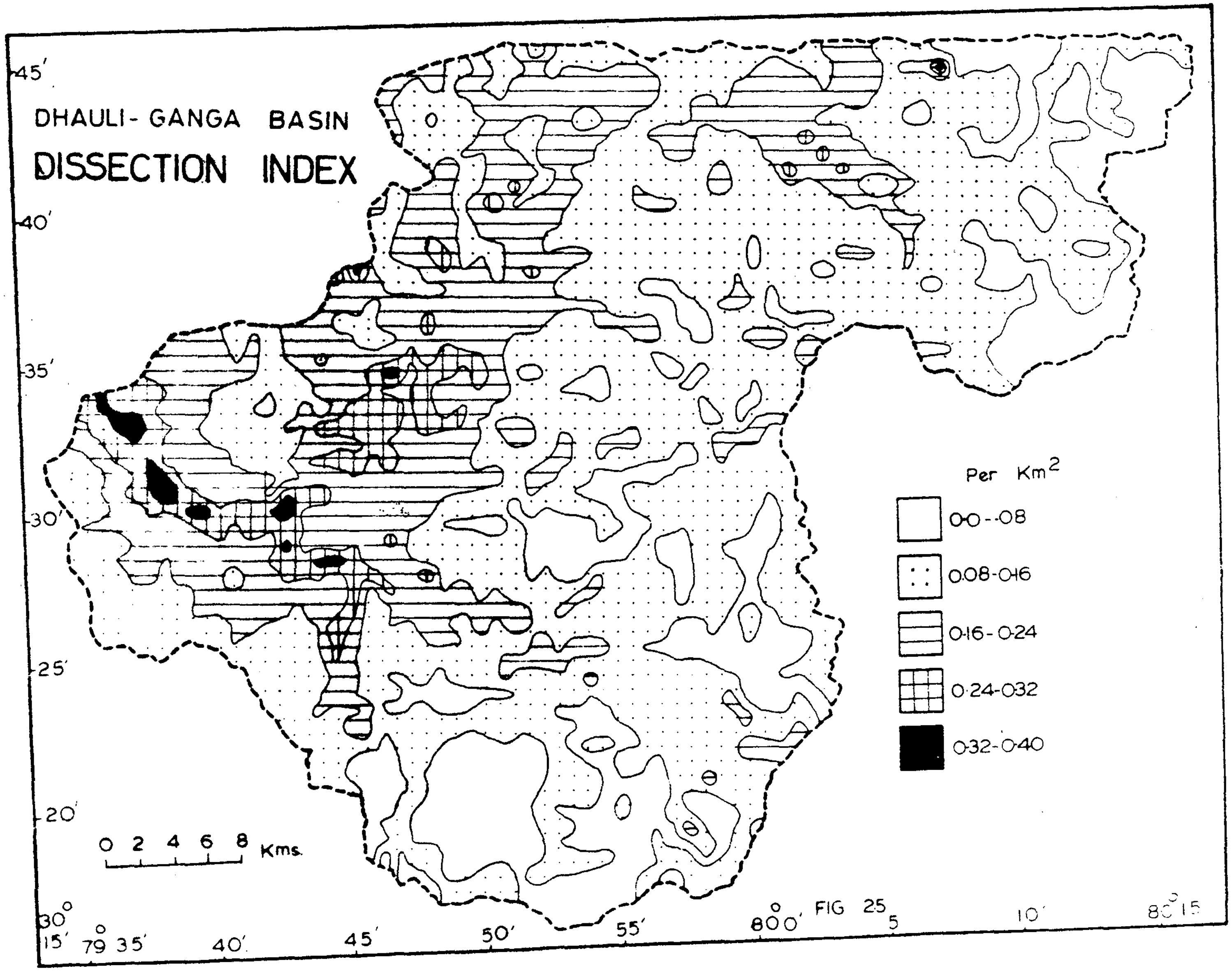

DHAULI- GANGA BASIN
DISSECTION INDEX
45′
40′
35′
30′
25′
20′
30° 15′
79° 35′
40′
45′
50′
55′
80° 0′
5
10′
80° 15′
0 2 4 6 8 Kms.
Per Km²
0·0-·08
0·08-0·16
0·16-0·24
0·24-0·32
0·32-0·40

FIG 25

Table 2.3

Distribution of Dissection Index

S.No	Category	Frequency	Cumulative frequency	%	Cumulative %
1.	0.0-0.08	439	439	22.08	22.08
2.	0.08-0.16	1011	1450	50.75	72.83
3.	0.16-0.24	434	1884	21.77	94.60
4.	0.24-0.32	92	1976	4.60	99.20
5.	0.32-0.40	16	1992	0.80	100.00
	Total	1992	-	100.00	-

The said Table (2.3) exhibits that maximum area (1011 km^2) lies under second category ranging from 0.08 to 0.16 per square kilometer. Which covers 50.75% area of the entire basin. The small area, with cliffs and escarpments in the river valleys covers only 108 km^2 area.

NATURE OF DISTRIBUTION:

A close observation of the Table 2.3 reveals the fact that about 50.75% of the total frequencies is represented by second category, wherein the mean value of dissection index standing at 8.13 is located, which indicates the nature of terrain and youthful stage of ladscape development. The frequency percentage polygon (Fig 2.6-A) presents a negative skewed nature of distribution. This represents the fact that majority of the area lies within the mean value category.

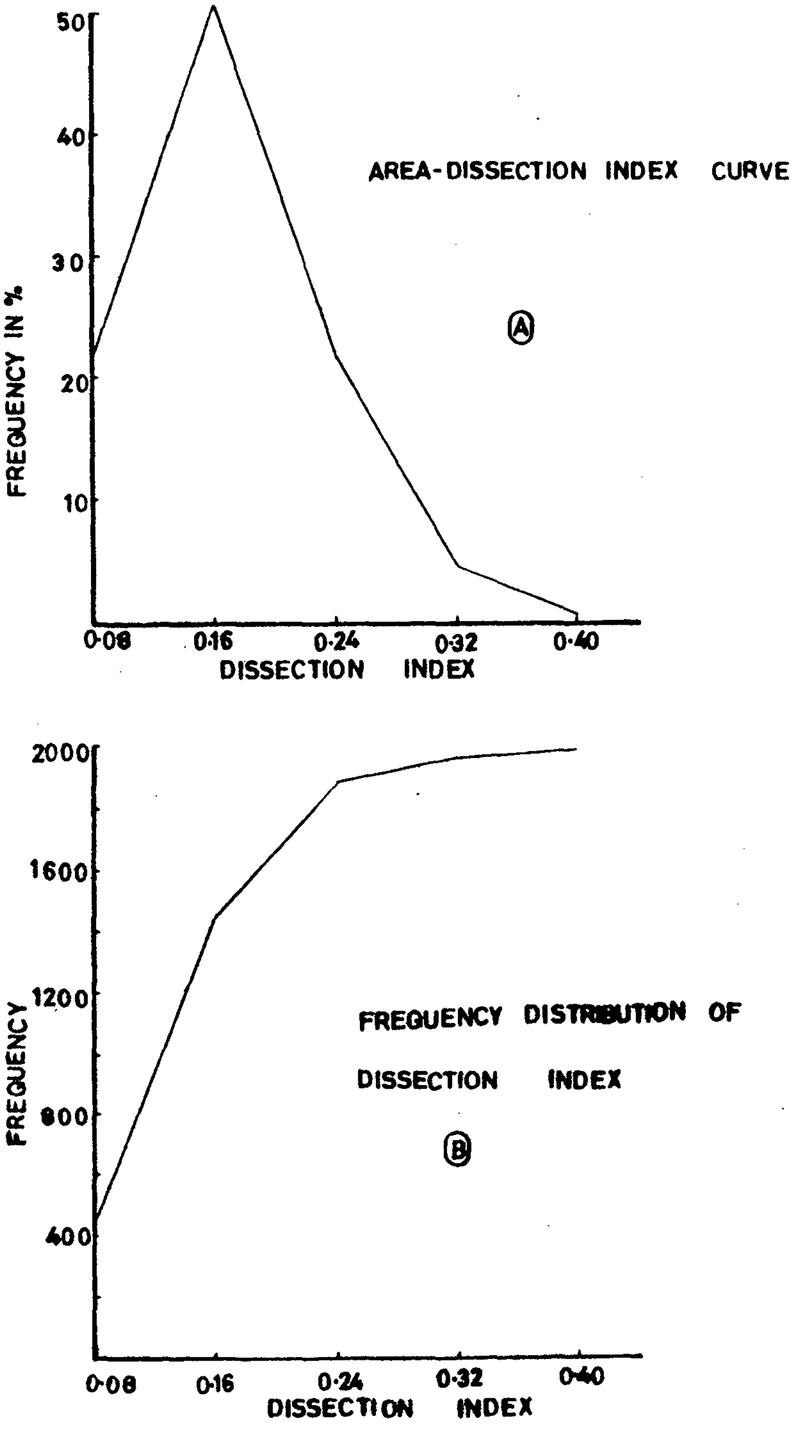
AREA-DISSECTION INDEX CURVE
Ⓐ
FREQUENCY IN %
50
40
30
20
10
0·08
0·16
0·24
0·32
0·40
DISSECTION INDEX
FREQUENCY DISTRIBUTION OF
DISSECTION INDEX
Ⓑ
FREQUENCY
2000
1600
1200
800
400
0·08
0·16
0·24
0·32
0·40
DISSECTION INDEX

Fig. 2·6

The mean value of the distribution indicates concentration of maximum dissection index frequencies in second category 0.08-8.16 and hence complete uneven distribution of dissection index. Frequency of different dissection index categories as shown by comulative frequency graph (Fig 2.6-B) presents the real condition of dissection index development in the basin.

Standard deviation of calculated dissection index values of different categories standing at 0.061 indicates greater degree of variation. Coefficient of variation being 46.38% clearly indicates that the standard deviation is 46.38 of the mean, which further support the greater degree of variation.

RUGGEDNESS NUMBER:

Ruggedness number is the unitless measurement of the degree of roughness of land surface. Topographical maps provide specific informations about height in the form of contour lines and spot heights, and the low lands by drainage lines. These informations fail to bring out the degree of roughness of land surface at a glance, significantly. Thus, the necessity of a quantitative method to measure the nature of land configuration was felt by various geomorphologists.

Horton,[1] Schumm[2], Melton[3] and Strahler whose names are

---

[1] R.E. Horton (1945), op.cit. pp. 275-370.

[2] S.A. Schumm (1956), op.cit. pp. 597-646

[3] M.A. Melton (1957), "An Analysis of the Relations Among Elements of Climate, Surface Properties and Geomorphology" "Project NR 382-041, Tech Rept, Columbia University, Department of Geology, ONR, Geography Branch, New York

[4] A.N. Strahler (1958) "Dimensioned Analysis Applied to Fluvially Eroded Landforms", Bull.Geo. Soc. Amer, Vol. 69, pp. 279-300.

worth mentioning in this connection developed quantitative methods to measure land configurations by computing the ruggedness number from the relative (H), drainage density (D) and a dimmensionless constant denominator. These variables helped them to introduce the dimensionless property of slope into the ruggedness number. Mathematically it can be expressed as below:

$$\text{Ruggedness Number} = \frac{D \times H}{1000}$$

Where , D = drainage density

H = relative relief

1000 = a constant

The ruggedness number in the basin has a range of 6.82 numbers. This total range has been divided into 6 categories with an interval of 1 number. The frequencies of each category have been arranged in Table 2.4.

The said Table (2.4) exhibits that maximum area (1151 km^2) lies under the first category, ranging from 0 to 1.0 number per square kilometer, which covers 57.78% of the total frequencies. The map (Fig. 2.7) clearly portrays that the area of low ruggedness number lies in the glaciated terrain due to the low relative relief and sparse drainage density.

NATURE OF DISTRIBUTION:

It is evident from Table 2.4 that about 57.78% of the total frequency is represented by the first category of 0-1.0, where in the mean value of ruggedness number standing at 1.042 is located, which clearly explains the high rugged

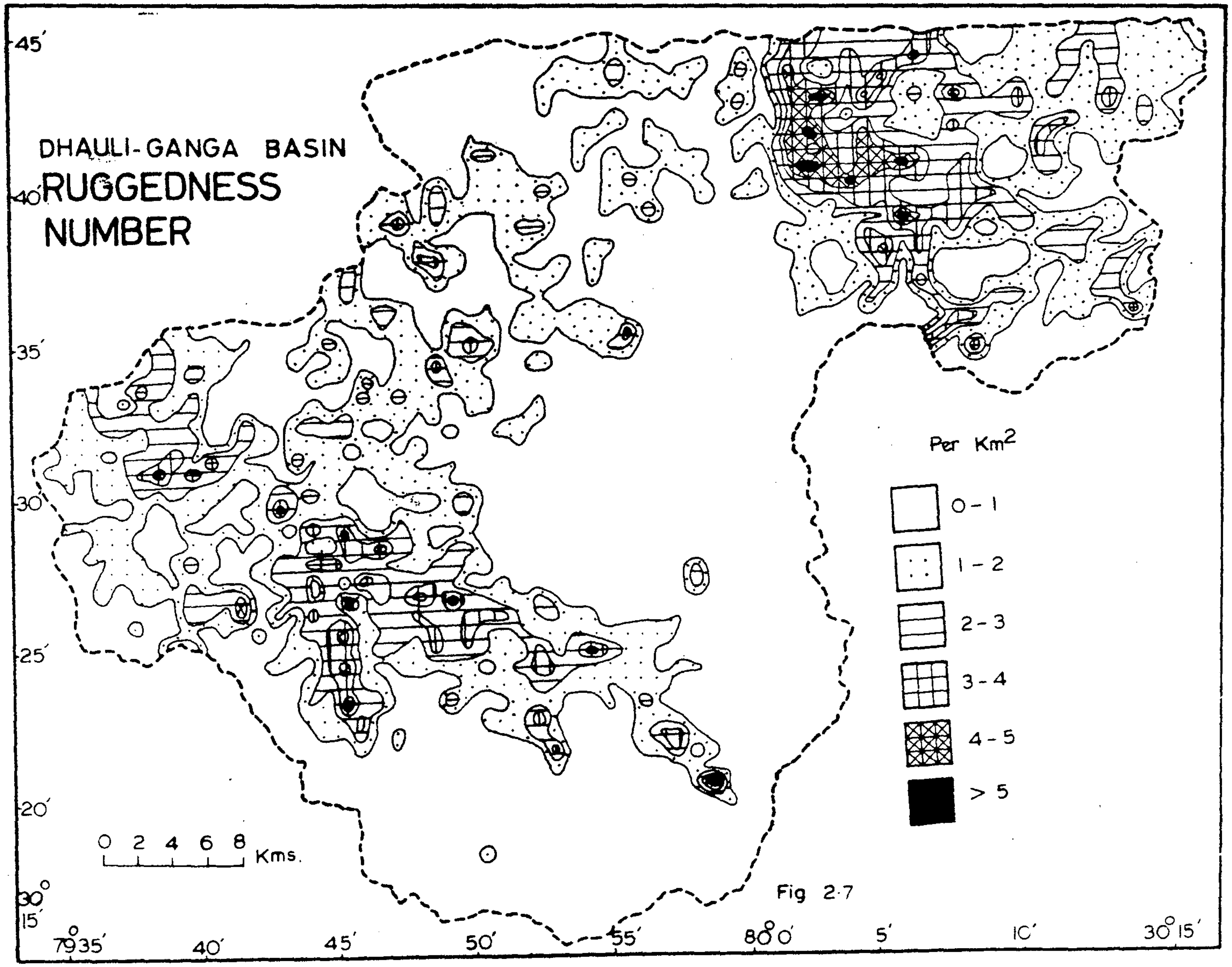

DHAULI-GANGA BASIN
RUGGEDNESS
NUMBER
Per Km²
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5
0 2 4 6 8 Kms.
45′
40′
35′
30′
25′
20′
30° 15′
79°35′
40′
45′
50′
55′
80°0′
5′
10′
30°15′

Fig 2.7

Table 2.4

Distribution of Ruggedness Number

	Category	Frequency	Cumulative frequency	%	Cumulative %
1.	0.0 - 1.0	1151	1151	57.78	57.78
2.	1.0 - 2.0	481	1632	24.15	81.93
3.	2.0 - 3.0	215	1847	10.79	92.72
4.	3.0 - 4.0	103	1950	5.17	97.89
5.	4.0 - 5.0	27	1977	1.36	99.25
6.	Above 5.0	15	1992	0.75	100.00
	Total	1992	-	100.00	-

nature of the land configuration. This is an indication of young stage of landform evolution, because more stream frequency has been experienced in the first stage of basin development and ruggedness number has a strong correlation with drainage frequency (0.773). Further the negative skewed nature of frequency percentage polygon (Fig 2.8 - A) shows that a chunk of frequencies lie in the first category.

The mean value of ruggedness number of the basin indicates concentration of maximum ruggedness number frequencies in first category. This is well supported by the cumulative frequency graph (Fig 2.8-B).

To measure the degree of dispersion from the normal distribution, the standard deviation has been calculated.

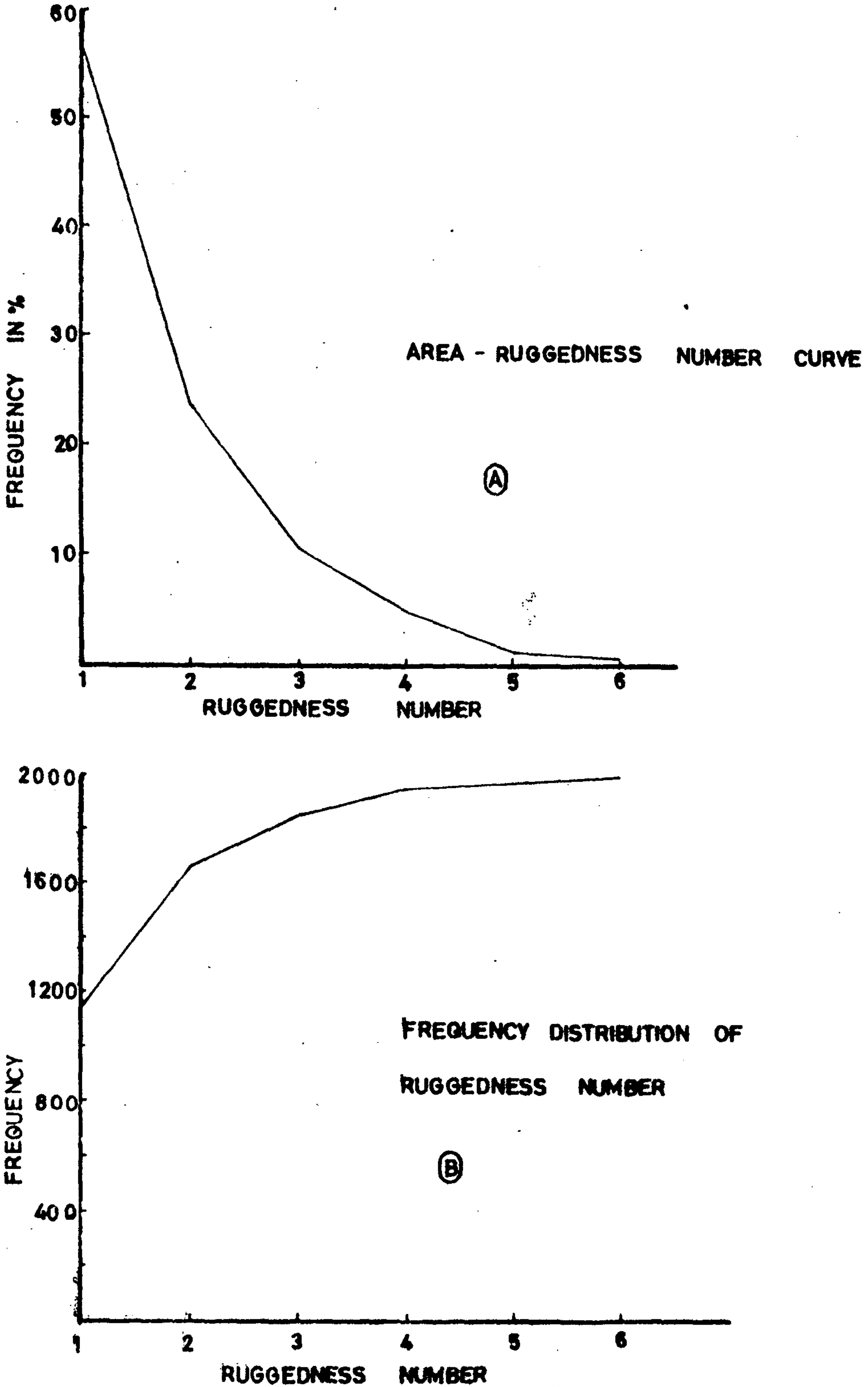

60
50
40
30
20
10
FREQUENCY IN %
AREA - RUGGEDNESS NUMBER CURVE
Ⓐ
1
2
3
4
5
6
RUGGEDNESS NUMBER
2000
1600
1200
800
400
FREQUENCY
FREQUENCY DISTRIBUTION OF
RUGGEDNESS NUMBER
Ⓑ
1
2
3
4
5
6
RUGGEDNESS NUMBER

Fig. 28

The calculated standard deviation standing at 1.168 is near the mean value and shows a greater degree of variation. The coefficient of variation being 111.21% in the present case clearly shows that the standard deviation is 111.21% of the mean, which further supports a greater degree of variation.

AVERAGE SLOPE:

Slopes, defined as an angular inclination of terrain between the hill tops and valley bottoms, result from the combinations of many causative factors, such as absolute relief, relative relief, dissection index, drainage texture and stream frequency, climate, geology and tectonics operating in the area and vegetal cover etc.

There are various scholars who have developed various methods of representing a slope categories. The computation of average slope from the topographic maps having frequent contours, involves the contributions made by Wentworth[1] Raisz and Henry[2], Calef and Newcomp[3] and Miller et al[4] (1960) which are worth mentioning. The scheme developed

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[1] C.K. Wentworth, (1930), "A Simplified Method of Determining The Average Slope of Land Surfaces", American Journal of Science, Series 5, 20, pp. 184-94.

[2] E. Raisz, and H J Henry, (1937), "An Average Slope Map of Southern New England", 27, pp. 467-72.

[3] W. Calef, and R. New Comb, (1953) "An Average Slope Map of Illinois" Ann. Ass. Amer Geor, 43, pp. 305-16

[4] O.M. Miller, and H.Charles Summerson, (1960), "Slope-zone Maps", The Geographical Review, Vol. 50, January, No.1, pp. 194-202.

by Wentworth has been used by Indian geographers frequenty, but in the present study a new technique suggested by Dhurandher[1] with a slight modification in Wentworth's formula has been used. This scheme gives a more rational picture of the slope categories because in this technique all contours of different values in a grid have been taken into account on the basis of the following formula:-

$$\text{Tan} = \frac{N \times CI}{3361}$$

Where , N = Number of contours of different values in a grid of 1 sq km

CI= Contour interval

3361= Constant.

SLOPE CATEGORIES:

The entire Dhauli-ganga basin has been divided into 1992 grids of 1 sq km and the ten values of all grids have been calculated on the basis of above formula and are converted into slope degrees. Thus, the slope degree in the area range between a maximum of 27.5° to a minimum of 0.7° with a range of 26.8°. The slope values of all grids in the entire basin have been classified into the following six categories, which have been exibited in the Table 2.5 .

---

[1] K.P. Dhurandher, (1980) "A More Rational Approach to the Determination of Slopes of Land Surfaces" <u>The Indian Geographical Journal</u>, Vol.55, No.2, pp.37-43.

Table 2.5

Frequency Distribution of Slope Values

S. No.	Slope categories	Frequency	Cumulative frequency	%	Cumulative %	Remarks*
1.	0 - 5°	128	128	6.42	6.42	Gentle S_g
2.	5 - 10°	700	828	35.17	41.59	Moderate Sm
3.	10 - 15°	898	1726	45.06	86.65	Moderately steep Sms
4.	15 - 20°	241	1967	12.09	98.74	
5.	20 - 25°	17	1984	8.85	99.59	
6.	25- 30°	8	1992	0.40	100.00	Steep Ss
	Total	1992	-	100.00	-	-

* Classification based on R.L. Singh[1]

FREQUENCY DISTRIBUTION

The above Table 2.5 and map (Fig 2.9) clearly portray the distribution of different slope categories. It is apparent from the Table 2.5 that about 66% of the total frequency is represented by moderately steep slope category. The mean value of the average slope in the study area stand at 10.85°, which indicates the early stage of cycle of erosion in the study area. The gentle and moderate slope categories share about 6.42% and 35.17% respectively of the total frequencies

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[1] R.L. Singh, (1967), "Morphometric Analysis of Terrain" Presidential address, 54th Indian Science Congress, Part II, Geology and Geography Section, Hyderabad, pp. 1-19.

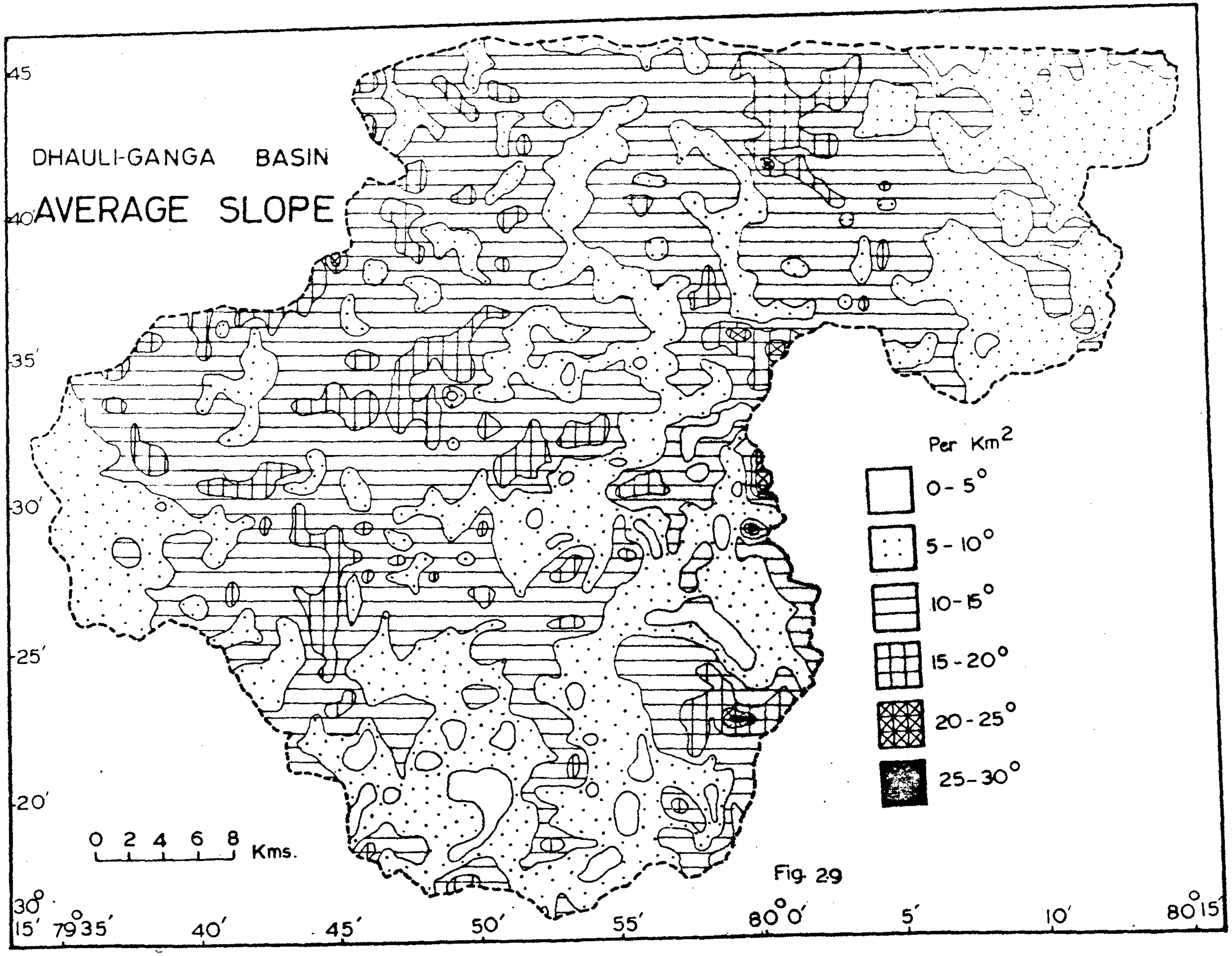
DHAULI-GANGA BASIN
AVERAGE SLOPE
Per Km^2
0-5°
5-10°
10-15°
15-20°
20-25°
25-30°
0 2 4 6 8 Kms.
45
40
35′
30′
25′
20′
30° 15′
79°35′
40′
45′
50′
55′
80°0′
5′
10′
80°15′

Fig. 29

While the steep category having only 0.40% of the total category is located only over the hill tops of high absolute relief in small patches.

DISTRIBUTION OF SLOPE VALUES:

The mean, median and mode are the important statistical tools which are used frequently to know the concentration of slope values. Following Table 2.6 reveals the different statistical measures of the slope values in the study area.

Table 2.6

Different Statistical Measures of the Slope Values

1.	Mean	10.85	8.	Q.D	3.03
2.	Median	10.94	9.	CO. Q.D	0.28
3.	Mode	11.16	10.	Variance	13.19
4.	Q_1	7.65	11.	S.D.	3.63
5.	Q_3	13.71	12.	Co Variation	33.46%
6.	Range	26.80	13.	Skewness	-0.31
7.	I.Q.Range	6.06	14.	Kurtosis	1.868

The above Table (2.6) reveals that the mean, median and mode values of average slopes of the Dhauli-ganga basin standing at 10.85°, 10.94° and 11.16° respectively indicate concentration of maximum slope frequencies (58%) in the category of moderate steep slope. Thus the present study recorded maximum concentration in the category of moderate steep slope ranging 10° - 25°. Thus the uneven distribution of slope frequencies of different slope categories placing the mode and median values (more than mean) to the right of mean value in the comulative frequency graph (Fig 2.10-B) indicate the initial stage of slope development in the study area.

Dispersion of variation dealing with the variability in the number of observations in general range also gives a precise measure of the variation. Statistical measures of dispersion include, range, inter-quartile range, semi-quartile range or quartile deviation, average deviation or mean deviation and standard deviation, average deviation or mean deviation and standard deviation etc. The first and third quartile (Q_1, Q_3) values standing at 7.65 and 13.71 again indicate towards the concentration of slope values in moderately steep slope category and thus prove the results drawn by mean, mode and median. The most frequently used measure of dispersion is standard deviation which gives an exact degree of variation from the normal distribution. For the present study, calculated standard deviation of the slope values of different categories standing at 3.63 indicate wide degree of variation. This fact is supported by the value of coefficient of variation which is 33.46% of the mean, hence support the wider degree of variation from the normal values of slope concentration. The values of quartile deviation (3.03) and coefficient of quartile deviation (28.30%) also follow the same pattern of distribution within the quartiles of slope values.

NATURE OF SLOPE DISTRIBUTION

The above discussed different measures of central tenden-

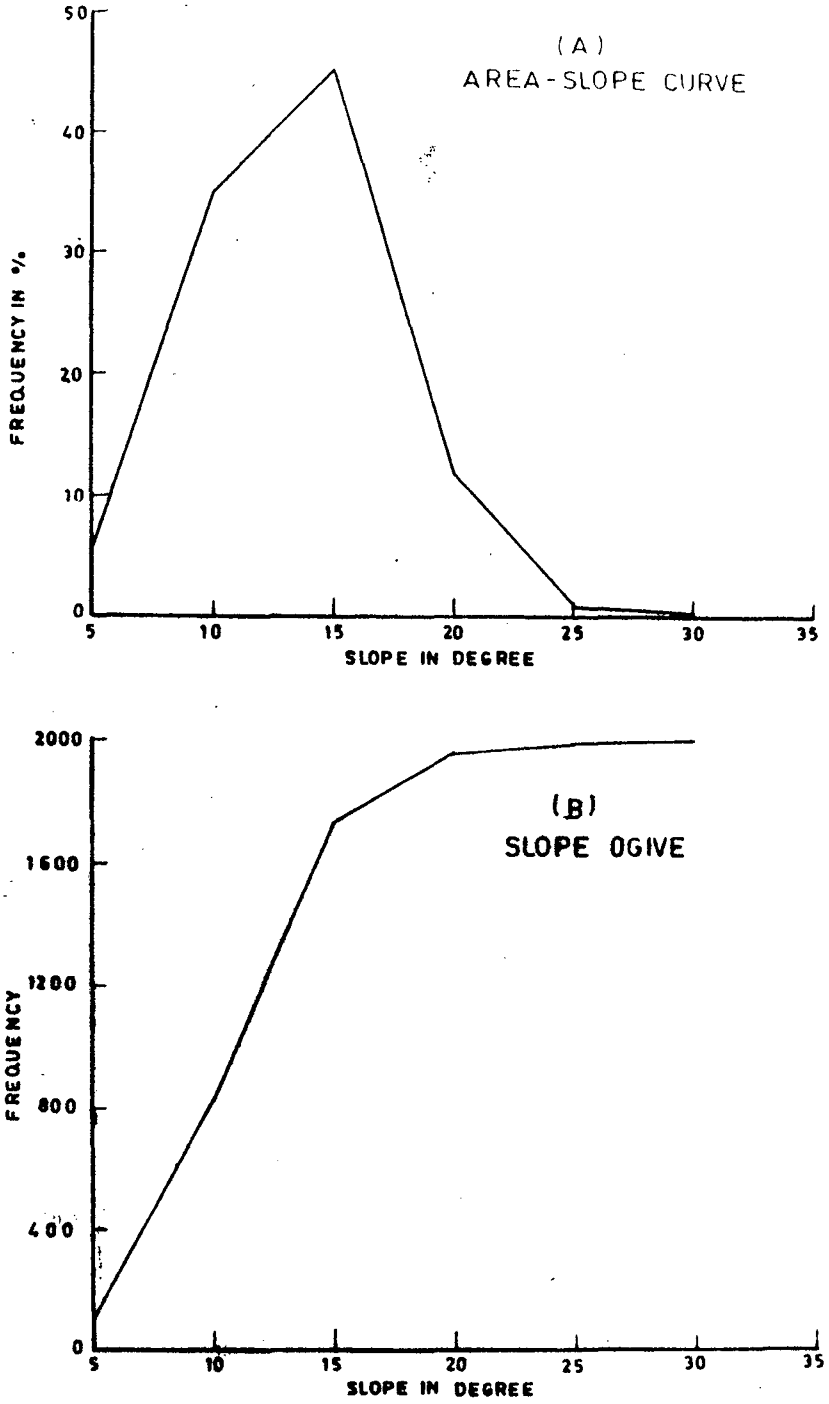
(A)
AREA-SLOPE CURVE
FREQUENCY IN %
50
40
30
20
10
0
5
10
15
20
25
30
35
SLOPE IN DEGREE
(B)
SLOPE OGIVE
FREQUENCY
2000
1600
1200
800
400
0
5
10
15
20
25
30
35
SLOPE IN DEGREE

FIG.-2.10

cies and dispersions indicate the central values and concentration of values around the central value and the degree of variation on dispersion from the central value respectively but these measures are silent on the question of symmetery or asymmetry of the distribution on either side of the mean value. Skewness is a statistical measure which clearly explains the nature of distribution - whether symmetrical or asymmetrical. The coefficient of skewness is o for a symmetrical distribution and it becomes a complete number in the case of asymmetrical distribution. When the curve is skewed to the right the mean value would be more than mode and median and it is called positive skewness but in the case of negative skeweness as in the present study the value of mean would be less than the mode and median values. The percentage frequency polygon (Fig 2.10-A) indicates a negative skewness for which coefficient of skewness stands at - 0.31. This is an indication that majority of the slope frequencies lie in the moderately steep slope category which is a characterstic of early stage of slope development. In the same way Kurtoris indicates whether a distribution is more flat topped or more peaked than the normal distribution. The value of Kurtoris of slope values of the Dhauli-ganga basin standing at 1.868 indicates leptokurtic (peaked) distribution.

IMPACT OF SOME MORPHOMETRIC PARAMETERS ON THE SLOPE DEVELOPMENT:

As it is already mentioned that slope is a resultant of combination of many factors, such factors which have their direct impact on slope development have been discussed below.

CHOICE OF VARIABLES:

The main objective of the present chapter is to examine the contribution of various hydrological, topographical and geological factors in explaining the variations in slope development in the study basin. The study will be incomplete if it does not explain the causes of variations in it. Hence the variables which are chosen for this study are the following:-

Dependent variable:-

X_5 Average slope

Independent variables:

X_1 Drainage density

X_2 Drainage frequency

X_3 Relative relief

X_4 Absolute relief

X_6 Ruggedness number

X_7 Dissection index

CORRELATION MATRIX:

A correlation matrix of the above mentioned variables has been prepared to pick up the best explanatory variables of slope development. It shows that average slope (X_5) is significantly and positively related with drainage density (X_1), drainage frequency (X_2) relative relief (X_3), ruggedness number (X_6) and dissection index (X_7) (Appendix I.) The correlation matrix also shows the inter-correlation among the explanatory variables. Dissection index which is a dominant parameter of topography and affects the development of slope upto a large extent, as it is clear from the high correlation coefficient 0.772, which is significant at 0.001 level, has a positive and significant correlation with X_1, X_2, X_3, X_4 X_5 and X_6. Similar to the dissection index, ruggedness number also shows a significant and positive correlation with all other variables under present study. It is apparent from the correlation of coefficient of ruggedness number with X_1(0.882), X_2 (0.773) X_3 (0.324), X_4 (0.337) and X_7 (0.482) that all are significant at 1 per cent probable level of significance. In the same fashion other variables also show their positive and significant relationship with maximum number of variables.

The above results which have been worked out from the correlation matrix reveal that the development of average slope is directly related with all above mentioned variables except absolute relief (X_4). It is also clear from the above discussion that variables selected for the present study are quite important and well defined.

On the basis of the above results bivariate regression equations have been obtained to find out the exponential function and relationship of average slope with other aforesaid explanatory variables:-

DRAINAGE DENSITY AND AVERAGE SLOPE:

Drainage density has a significant control over the development of slope, as it is apparent from the coefficient of correlation, which standing at 0.087 seems to be low but quite significant at 0.001 level of significance due to the high degree of freedom. The reason behind this positive relationship is the erosional activities of the flowing water. High drainage density will drain the maximum area and thus lower the land surface by scratching, which differ from place to place according to the under-lying rock formation and vegetal cover. Leopold, Wolman and Miller[1] have pointed out how the character of the channel is reflected in the slope of the water surface. This slope is steepwer at bends where the channel is confined by rocks or vegetation and is least in the smooth, straight reaches of the river. The presence of riffles or bards in the river bed also causes slight increase of gradient and this is intensified where the channel divides round an island. Such factors can be demonstrated by detailed field survey, which is not possible for the present study due to the time bond and secondary data based nature of the study.

In the present study, only quantitative evidences based on secondary data, collected from toposheets are being put forward. The validity of linear relationship between drainage density and average slope can be assessed properly by the bivariate regression equation. By running the programme between aforesaid variables, following regression equation

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1. L.B. Leopold, M.G. Wolman and J.P. Miller (1964), '<u>Fluvial Processes in Geomorphology</u>' Eurasia Pub. New Delhi.

has been obtained:

$$X_5 = 10.392 + 0.214\, X_1 \qquad \bar{R}^2 = 0.0074$$

$$(3.891)^*$$

The above equation reveals that the linear relationship between two variables is significant as regression coefficient is quite significant, though, the value of R bar square is not considerable to explain the variations in average slope.

DRAINAGE FREQUENCY AND AVERAGE SLOPE:

Similar to the drainage density, stream frequency also shows the same trend of relationship with the average slope. It is apparent from the coefficient of correlation standing at 0.079. albit not so high in looking but significant at 0.001 level of significance due to high degree of freedom. High stream frequency drains more area and thus erode more earth surface and change the inclination of land surface and ultimately change the land slope. The change in land slope in presence of higher stream frequency is also affected by the nature of rock formation. Soft rocks are easily erodable and change the shape of the surface while hard rocks remain unaffected in the form of residuals which change the nature of configuration and ultimately slope of the terrain. This is what the positive relationship between drainage frequency and average slope reveals.

---

* Significant at 0.001 level.

This shows that relative relief has a strong control over the development of slope. The high value of computed 't' reveals the fact that coefficient of regression is quite significant to prove the validity of positive linear relationship.

RUGGEDNESS NUMBER AND AVERAGE SLOPE:

The ruggedness of the terrain shows to be an important geomprphic variable to govern the development of slope. It is exhibited by the high coefficient of correlation standing at 0.347, which is significant at 1 per cent probable level of significance. This positive relationship reveals the fact that the high degree of ruggedness is an indicator of high degree of slope. The more rugged nature of the terrain provides more ups and downs in the configuration sometimes with steep inclinations. Thus, it is obvious that maximum number of ups and downs with steep inclination will provide a higher account of average slope. The ruggedness number has a positive and significant correlation (1 per cent probable level). With all other slope determining factors viz drainage density (0.882), drainage frequency (0.773) and relative relief (0.324). This indicates that similar to the aforesaid variables ruggedness also plays a vital role in determining the slope of the terrain. The said relationship is well supported by the obtained regression equation, as given below:-

$$X_5 = 9.509 + \underset{(16.508)^*}{1.179\ X_6} \qquad \bar{R}^2 = 0.12$$

---

* Significant at 0.001 level.

The above equation reveals that 12 per cent variations in slope are explained by ruggedness number. The regression coefficient is high enough to prove the validity of linear positive relationship.

DISSECTION INDEX AND AVERAGE SLOPE:

Dissection index has a positive relationship with average slope. It is apparent from the high coefficient of correlation which standing at 0.772 is quite significant at 1 per cent probable level of significance. This relationship indicates that high dissected landscape possesses high degree of slope. The fact behind this postulation is that the steeper inclination of the terrain in highly dissected landscape gives an account of high degree of average slope.

The said relationship is well supported by the obtained regression equation which is as follows:-

$$X_5 = 4.121 + \underset{(54.147)^*}{0.495}\ X_7 \qquad \bar{R}^2 = 0.59$$

The above equation implies that dissection index alone explains 59 per cent variations in the slope development. It indicates that dissection index is an important determinant of average slope. The linear relationship is well proved by the high value of regression coefficient, which is enough high to be significant, as it is clear from the high computed 't' value.

---

* Significant at 0.001 level.

On the basis of the above discussions following equation of the explanatory variables of average slope, has been obtained:

$$X_5 = f (X_1 , X_2, X_3 , X_6 X_7)$$

All these factors have a combined impact to determine the average slope. Stepwise regression analysis has been further used to obtain the best set of explanatory variables.

STEPWISE REGRESSION ANALYSIS:

A stepwise linear regression[1] analysis is attempted here to identify the contribution of various factors in slope development in Dhauli-ganga basin. It will be useful to find out the factors which explain maximum variations in slope development. Stepwise regression analysis helps to choose the best possible set of explanatory variables which explain maximum vairations.

In the initial step, the explanatory variable which has the highest correlation with the dependent variable is considered the most important variable and is entered into the regression equation generating a bivariate relationship. Then first order partial correlations between dependent variable and the remaining independent variables are computed. Among

---

[1] Only a linear farm of regression was tried because in the scatter diagrams plotted to study the relationship between average slope and each explanatory variable, mostly a linear trend was noticed.

these remaining explanatory variables, the one which has the highest correlation with the dependent variable will then enter the regression equation. At this stage, two explanatory variables simultaneously operate in the regression equation. This procedure is continued in the above sequence till the entire set of explanatory variables have entered the regression equation.

The coefficient of determination (R^2) and the adjusted coefficient of determination ($\bar{R}^2$) are obtained at each step of the regression analysis. This exercise also provides standard error of estimated regression coefficients for each step.

By applying the above technique and tests of significance viz 't' and 'f' following equation of the best explanatory variables of average slope has been obtained:

$$X_5 = 5.58 + \underset{(26.235)^*}{0.008\,X_3} + \underset{(24.55)^*}{0.345\,X_7} + \underset{(22.662)^*}{0.001\,X_4} + \underset{(7.477)^*}{0.144\,X_1} \qquad \bar{R}^2 = 0.897$$

The above equation reveals that in the first step, relative relief (X_5) entered as explanatory variable has the highest correlation with explained variable. It alone explains 86.5 per cent of variations in average slope and the coefficient of regression is quite significant (Table 2.7)

In the second step dissection index (X_7) entered as the second best explanatory variable has the second highest correlation with explained variable X_5. These two explanatory

---

* Significant at 0.001 level.

Table 2.7

FACTORS AFFECTING THE AVERAGE SLOPE-A STEPWISE REGRESSION ANALYSIS RESULTS

INTECEPTS	Steps	Regression Coefficients of							
		X_3	X_7	X_4	X_1	R	R^2	$\bar{R}$	$\bar{R}^2$
1.429	I	0.015 (113.022)*				0.930	0.865	0.930	0.865
1.328	II	0.013 (65.319)	0.080 (9.781)*			0.933	0.870	0.933	0.870
4.789	III	0.008 (26.834)*	(0.337) (23.683)	0.001 (21.140)*		0.946	0.895	0.946	0.895
5.580	IV	0.008 (26.235)*	0.345 (24.550)	0.001 (22.662)*	0.144 (7.477)*	0.948	0.899	0.947	0.897

* Significant at 0.001 level.

variables together explain 87 per cent of variations in average slope and again both the coefficients of regression are significant.

In the third step absolute relief (X_4) is entered as the third explanatory variable. Here it is worth mentioning that absolute relief (X_4) does not show any relationship (significant at any level of significance) with average slope, individually, while in the presence of other geomorphic factors it plays an important role to determine the average slope. All these three variables simulataneously, explain 89.5 per cent of variations in average slope. All regression coefficients are quite significant.

In the final step drainage density (X_1) entered as the other explanatory variable of significance and in presence of three already mentioned variables, regression equation explain 89.7 per cent of variations in average slope. All regression coefficients are quite significant.

After fourth step R bar value decreases and coefficients of regression are also insignificant. Thus, above equation of fourth step has been retained as the best set of explananatory variables.

On the whole, the study of the various aspects of the relief in the basin conclude the following results:

The area east of Dhar-Martali fault is rugged in comparison to rest of the region. With high values of absolute and relative relief associated with high rugged number but with low dissection index. The development of average slope in the basin is a resultant of combination of hydralogical, topographical and geological factors such as, drainage density, drainage frequency, relative relief, absolute relief, ruggedness number, dissection index and underlying lithology. The obtained results of the correlation matrix reveal the facts that the development and distribution of slope is positively related with the aforesaid variables, except absolute relief. Absolute relief does not show any direct relationship with the slope, but in presence of relative relief, dissection index and drainage density, it plays a significant role in slope development. The results of stepwise regression analysis prove that relative relief, dissection index absolute relief and drainage density are dominant geomorphic parameters to play a vital role in the development of slope. These factors are inter-dependant.

Thus the study proves the validity of the hypothesis that the development and distribution of slope is controlled by the morphometric attributes viz, relative relief, dissection index, ruggedness of the terrain, drainage density and frequency which are inter-dependant.

CHAPTER II

PART B

DRAINAGE ANALYSIS

Drainage is the reflection of topographic, geologic and hydrologic characteristics of a region. Drainage lines are significant geomorphic tools of nature to sculpture the topography of land configuration, particularly in a humid terrain. Therefore, the study of drainage of a region is quite essential for the terrain evaluation. In the present chapter some aspects of drainage characteristics of Dhauli-ganga basin have been assessed.

Dhauli-ganga river originats from the glacier Kamet, situated in district Chamoli of U.P. The main stream of the river which comes from Dhaulagiri glacier is called Ganesh-ganga in its infant stage. In its early stage it flows in north-east direction and then takes a turn southward upto Bampa (3352 m), after this again it takes a sharp turn in east direction upto Kurkuti (Kailashpur), where Girthi-ganga flowing in east to west direction makes its confluence with Dhauli-ganga. It flows southward till Kurkit to Malari and again takes a sharp turn towards west. Kosa Gad meets Dhauli-ganga on the west bank near village Kosa (3012 m). Here it flows in south direction among the dense reserved forest. Jelam (2985 m) is an another important village on the west bank of the river. Below

Jelam, on the east bank Dunagiri Gad (originating from Dunagiri glacier) makes its confluence near Shyama (2579) and 7 km below Shyama, Jumagad meets Dhauliganga near village Juma. Juma to Tamak, where Wauntigadhera meets the main river, Dhauli-ganga flows in east-west direction on the central crystallines of Garhwal Himalayas. The main rocks of the vicinity of the course are gneisses and schists. One and half kilometre below Tamak, Gankhwi Gadhera (source in Gankhawi glacier) makes its confluence with Dhauliganga on the east bank near village Saigari. Gadigadhera on west bank and Phagtigadhera on east bank make their confluence with Dhauliganga near village Gadikharak. Five and half kilometres below the confluence of Gadigadhera, Rishiganga a big contributory of Dhauliganga joins near village Rini, which is an example of arrow pattern of settlement developed between the fork angle of Dhauliganga and Rishiganga. One and half kilometre from the confluence of Dhauliganga and Rishiganga, there is a water fall of 15 metres high, where Juwagwar gad meets Dhauli-ganga with a steep fall of 60 metres height. Rini to Bilagarh, Dhauli-ganga flows eastward in a straight line and near Bilagarh it takes a sharp turn towards north 3.5 km. ahead from Bilagarh again there is a water fall (8 metres) in course of the river. Homgadhera meets Dhauliganga on north bank near Khancha (1650 m). Here Dhauli-ganga flows in east-north direction and makes its confluence with

Alknanda at Vishnuprayag, where Alaknanda comes from north and takes a sharp turn about 90° towards east.

MAIN TRIBUTRIES OF DHAULI-GANGA:

Dhauli-ganga has following main tributaries which contribute significantly to its discharge.(Fig.2.11).

1. RISHIGANGA:

Rishiganga, the main tributory of Dhauliganga originates from Rishi glacier and it takes water from Uttar Nandadevi glacier and Dakshin Nandadevi glacier and Uttar Rishiglacier too. The total length of Rishiganga is about 32 km. River flows almost all in a straight line west ward and makes its confluence with Dhauli-ganga near Rini village. The main streams which join Rishiganga are, Rishikotgad which meets the trunk stream by a fall of 30 metres on north bank. Bangnigadhera, orginating from Rammi glacier meets near Rammi village (3470 m). One and half km ahead Rammi, Trishuli Nandi (originate from Trishul glacier, trishul peak 7045 m) meets Rishiganga in open mixed jungle. Rishiganga has a water fall (25 metres high) in its course. 2 km before the confluence with Dudhganga, Dubrugethagad (originate from Hanuman glacier) meets Rishiganga by forming itself a steep waterfall of 50 metres height in its finger stream. Another stream Raunthigahadhera (source at Raunthi peak, 6063 m) meets Rishiganga, 5 km below the confluence of Dudhganga.

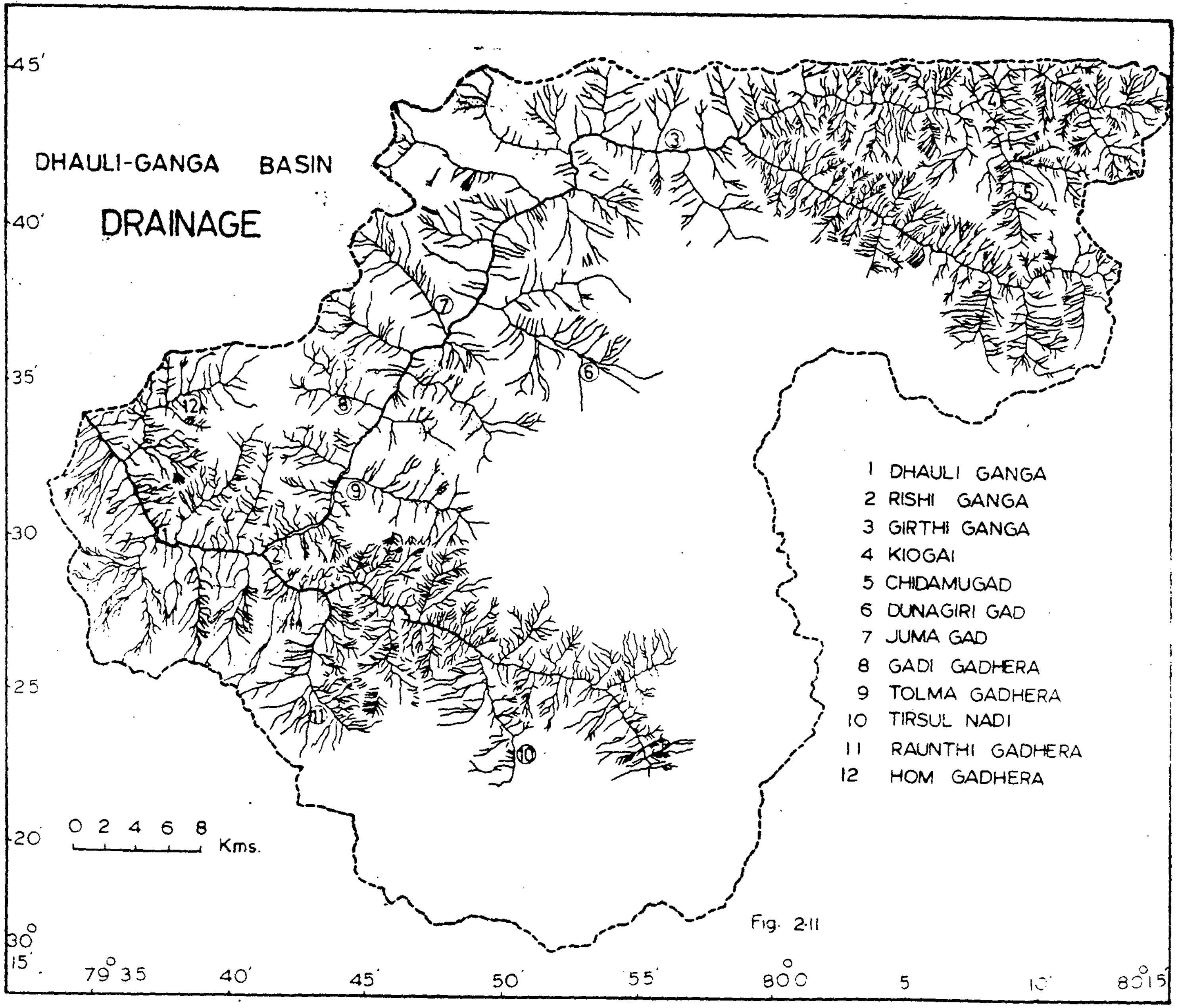
DHAULI-GANGA BASIN
DRAINAGE
1 DHAULI GANGA
2 RISHI GANGA
3 GIRTHI GANGA
4 KIOGAI
5 CHIDAMUGAD
6 DUNAGIRI GAD
7 JUMA GAD
8 GADI GADHERA
9 TOLMA GADHERA
10 TIRSUL NADI
11 RAUNTHI GADHERA
12 HOM GADHERA
0 2 4 6 8 Kms.
45'
40'
35'
30
25
20
30°
15'
79°35
40'
45'
50'
55'
80°0
5
10'
80°15

Fig. 2.11

2. GIRTHIGANGA:

Girthiganga is another important tributary of Dhauliganga, originating from Girthi glacier, which is situated in district Pithoragarh of Kumaon Himalayas. The water to Girthiganga is contributed by Najagaon glacier and Bhilmagar glacier which are situated in south east part of the basin. Several branches of Girthiganga originate from different glaciers. The catchment area of Girthiganga has an elongated shape. The stream coming from both the sides (north and south) are small, less sinuous and numerous. Rockfall is a common phenomenon in the entire Girthiganga basin. The total length of Girthiganga is about 39 kms.

3. KIOGAD:

This stream has an origin in the nearby area of China border. The total length of the river is about 29 km. The main tributaries of Kiogad are Chidamugad and Yonggad. There are two water falls in the course of the trunk stream one 8 metres high and another 6 metres high. The heighest waterfall is in a tributary of Kiogad, which is 2.5 km before the confluence of Kiogad. The finger streams in the area are discontinuous. Rockfall is a common phenomenon of the Kiogad basin with boulders which are generally found in upper parts of the basin. In the basin very small area is covered by scattered trees.

Topography of the area is very rugged and difficult.

DRAINAGE PATTERN:

Drainage patterns are the visible expressions of topographical and lithological characteristics of the landscape and give a broad idea regarding the adjustment of streams with the underlying geological structure. Ere 1950, drainage patterns were usually expressed in qualitative terms. Classifications by several scholars produced different categories of patterns in drainage development (For example, Zernitz[1], Howard[2],). A general look of the drainage map of the basin (Fig. 2.11) gives an idea to be like a dendritic pattern but a close study of various parts of the drainage map portrays - sub parallel pattern too.

STREAM FREQUENCY:

Stream frequency is the number of streams per a square unit which gives the character of underlying lithology, climate and control of vegetal cover in a particular

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[1] E.R. Zernitz, (1932), "Drainage Pattern and Their Significance", Journal of Geology, Vol.40,pp.498-52.

[2] A.D. Howard, (1967) , "Drainage Analysis in Gedogic Interpretation A Summation", Bull.American Association Petroleum Geologist,Vol. 51, pp. 2246-59.

area. Thus, the stream, frequency for the Dhauli-ganga basin, has been calculated by Horton's[1] method taking a unit area of 1 square kilometre. It can be written in a mathematical form as given below:

$$\text{Stream frequency} = \frac{\Sigma N}{A}$$

Where, ΣN = Total number of streams

A = Unit area

The studies of Strahler[2] and Melton[3] reveal that the factors which govern the stream frequency are rainfall intensity, run off, percentage of bare rock area, erosional proportionality, rate of evaporation and infiltration capacity. It seems by study of this basin that the aforesaid factors are significant in determing the stream frequency. The eastern portion of the present study basin has been found to be having the maximum stream frequency because of more bare rock area of high infilterated sedimentary rocks (mainly lime stone) of Tethys zone. Thornbury[4] states "Badland topography refers to one set of conditions which lead to fine drainage texture. Perme-

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1. R.E. Horton, (1945), op.cit. pp. 275-370.
2. A.N.Strahler, (1950, 52) op.cit. pp. 673-696, pp. 341-354.
3. M.A. Melton, (1958), op.cit. pp. 442-460.
4. W.D. Thornbury, (1954), "<u>Principles of Geomorphology</u>" John Wiley and Sons, Inc, New York, pp. 129-30.

able clays and shales, sparse vegetation, prevealence of high rainfall have been responsible for the extremely fine drainage tecture".

Figure (2.12) clearly portrays that high degree of stream frequency has been noticed in the area east of Dar-Martoli fault, which reflects the presence of bouldered topography and sedimentary rocks formation of Tethys zone. The stream frequency in the basin ranges from 0 minimum (particularly in glacial terrain) to 15 streams per square kilometre maximum. The total range of stream frequency has been divided into five categories and frequency in each category is exhibited by Table 2.8 below:-

TABLE 2.8

DISTRIBUTION OF STREAM FREQUENCY

Category	Frequency	Cumulative frequency	%	Cumulative %
0-3	1242	1242	62.35	62.25
3-6	444	1686	22.29	84.64
6-9	222	1908	11.15	95.79
9-12	65	1973	3.26	99.85
12-15	19	1992	0.95	100.00

1992.

The above table reveals the fact that 1242 square kilometres area of the entire basin is being drained by 0 to 3 streams per square kilometres, which is 62.35%

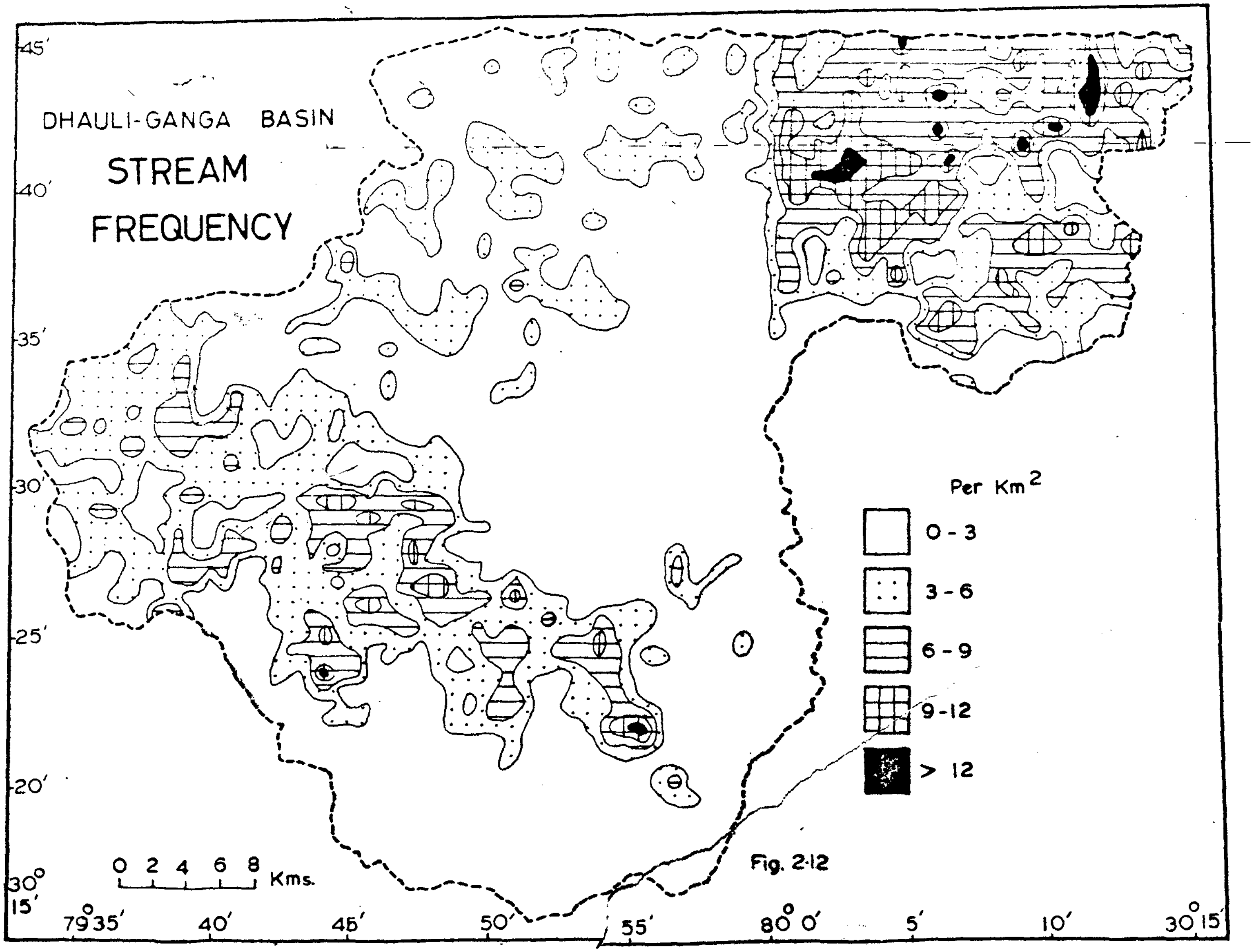

DHAULI-GANGA BASIN
STREAM FREQUENCY
Per Km²
0 - 3
3 - 6
6 - 9
9 - 12
> 12
0 2 4 6 8 Kms.
45'
40'
35'
30'
25'
20'
30° 15'
79°35'
40'
45'
50'
55'
80° 0'
5'
10'
30°15'

Fig. 2·12

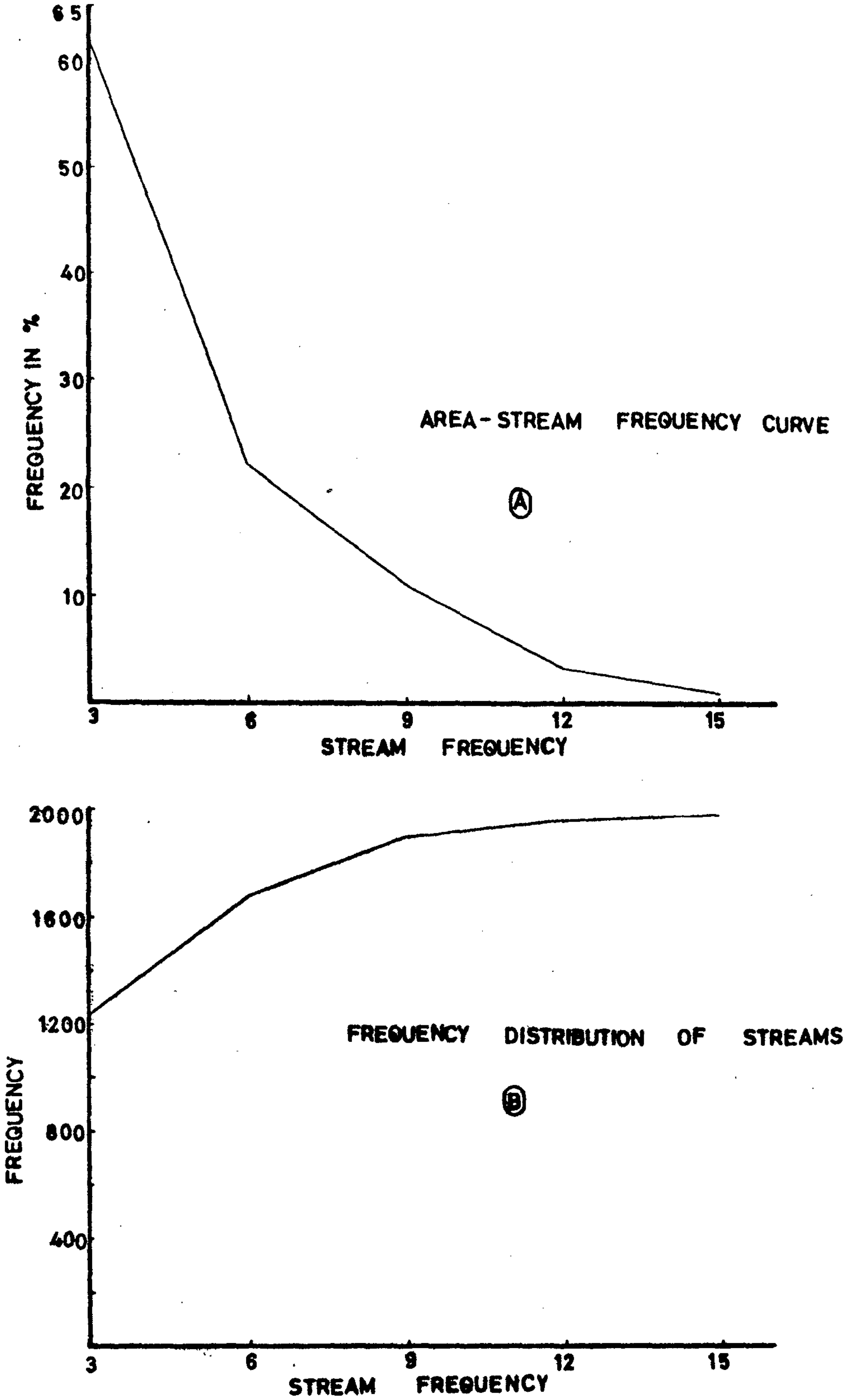
of the total basin area. 33.44% or 666 square kilometers area of the basin is drained by the high stream frequency ranging between 3 to 9 streams per square kilometre. Remaining 4.21% area of the basin is under extremely high stream frequency ranging between 9 to 15 streams a square kilometer of the area.

NATURE OF STREAM FREQUENCY DISTRIBUTION:

A close observation of the Table 2.8 implies the fact that about 62.35% of the total frequency is represented by the average stream frequency categories, wherein the mean value of stream frequency standing at 3.11 is located, which clearly indicates the youthful stage of the cycle of erosion in the study area. Stream frequency is always high in youthful stage. The nature of frequency percentage polygon (Fig 2.12-A) indicates a negative skewness representing the fact that majority of the area lies within the average category.

The mean value of the distribution (3.11) indicates concentration of maximum stream frequencies in first category (0-3) and have complete uneven distribution of stream frequencies of different categories. Cumulative frequency graph (Fig. 2.12-B) portrays this fact clearly.

Standard deviation as important measure of dispersion, standing at 3.39 indicates greater degree of variation. Coefficient of variation being 39.60% in the present case



AREA-STREAM FREQUENCY CURVE

Ⓐ

FREQUENCY DISTRIBUTION OF STREAMS

Ⓑ

Fig. 2.13

clearly indicates that the standard deviation is 39.60% of the mean, which further supports the great range of deviation.

DRAINAGE DENSITY:

Drainage density is the length of the streams per square unit area, which similar to the stream frequency reflects the character of under lying lithology, climate and vegetal cover. The drainage density has been calculated according to the Horton's[1] method which can be obtained by dividing the total length of the streams by the unit area. It can beexpressed o in mathametical form as follows:

$$\text{Drainage density} = \frac{\Sigma L}{A}$$

Where, ΣL = total stream length

A = unit area

Chorley[2] states, that drainage density is directly related to the amount and intensity of precipitation and inversely to the amount of vegetation cover. The less vegetation on hill slopes keeps to maintain the runoff rate. The study of the present basin varifies the control of aforesaid factors on the development of drainage density.

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1. H.R. Horton, (1945), op.cit, pp. 275-370.

2. R.J. Chorley, (1957), "Climate and Morphometry" Journal of Geology, Vol. 65, pp. 628-38.

Area of the basin to the east of Dar-Martoli fault consists of a high degree of drainage density, because of soft rocks formation, which are easily erodable and thus develop short finger tip streams, which give a comparatively higher drainage density. On the other hand area between Dar-Matoli fault and main central thrust, under metamorphic rocks (chiefly dominated by schists and gneiss) formation reflect comparatively low drainage density. The reason is the weak formation of rocks, which enforce the streams to flow along the joints and thus, the lithology is deterimental to high drainage density.

Apart from the significant role played by underlying lithology vegetal canopy also plays its own part in increasing the drainage density. The present study reveals the fact that the area of high drainage density has sparse vegetal cover or almost all bare landscape. Figure(2.14) gives at a glance idea of drainage density distribution in the basin.

DISTRIBUTION OF DRINAGE DENSITY:

The drainage density in the basin ranges between o minimum (for the glaciated landscpae) to 7 km. per square kilometers, maximum. The total range of drainage density has been divided into five categories with an interval of 1.5. The frequencies in each category are tabulated in the form of a table given below:

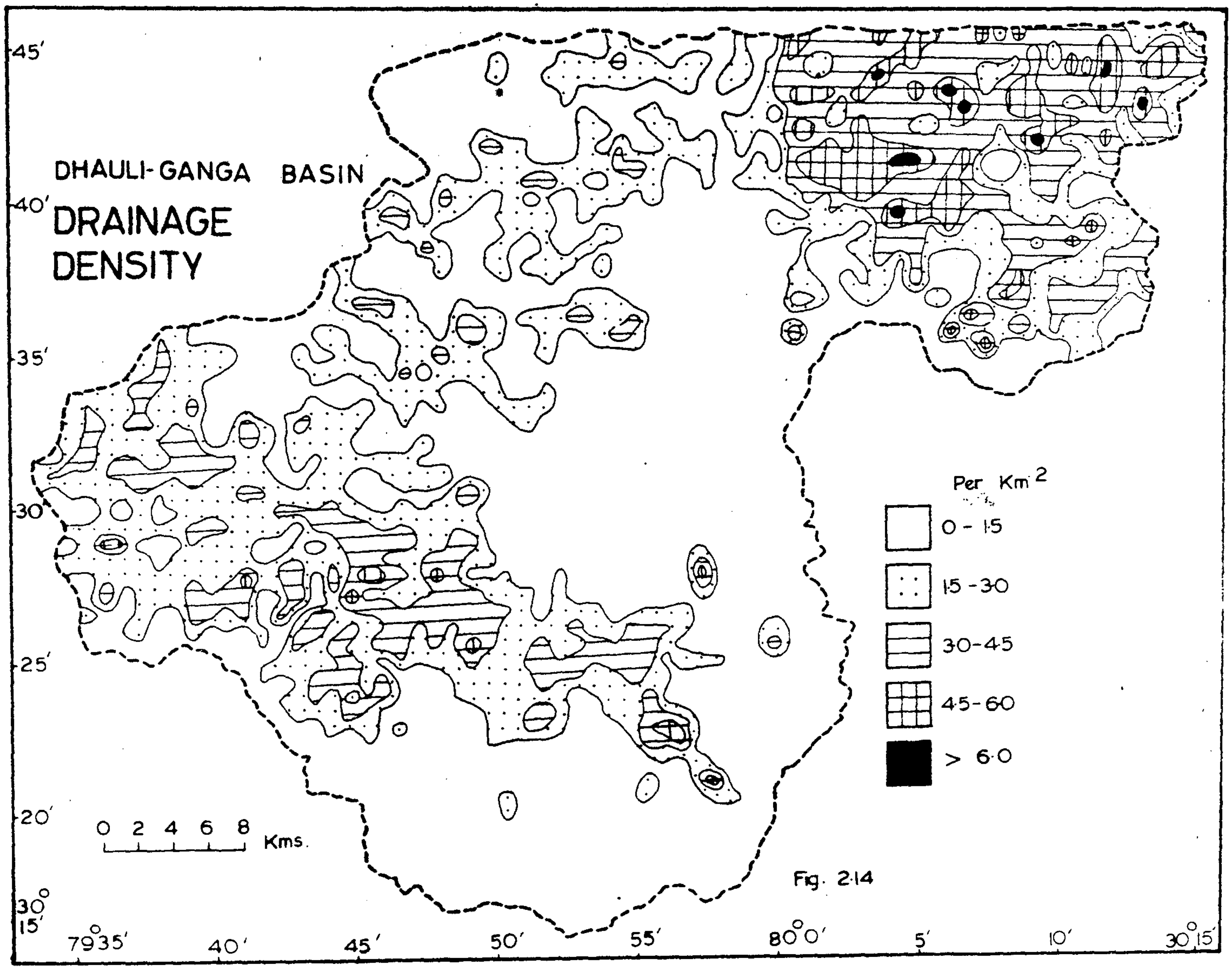
DHAULI-GANGA BASIN
DRAINAGE DENSITY
Per Km 2
0 - 1·5
1·5 - 3·0
3·0-4·5
4·5-6·0
> 6·0
0 2 4 6 8 Kms.
45'
40'
35'
30'
25'
20'
30° 15'
79°35'
40'
45'
50'
55'
80°0'
5'
10'
30°15'

Fig. 2.14

TABLE 2.9

DISTRIBUTION OF DRAINAGE DENSITY

Category	Frequency	Cum ulative frequency	%	Cum ulative	Remarks
0-1.5	1144	1144	57.43	57.43	DDL
1.5-3.0	488	1632	24.50	81.93	DDLm
3.0-4.5	269	1901	13.50	95.43	DD m
4.5-6.0	82	1983	4.12	99.55	DDh
6.0-7.5	9	1992	0.45	100.00	DD Vh
Total	1992	-	100.00	-	-

* Based on S. Singh[1] with slight modification.

Table 2.9 reveals that the maximum frequencies lie in the first category of lower drainage density (DD L), ranging from 0 to 1.5 km per square kilometers, draining an area of 1144 square kilometers, 57.43% of the entire basin. 38% of the entire basin lies in the categories of lower moderate drainage density (DDLm to DDm) ranging between 1.5 to 4.5 km per square kilometers. It comprises of an area of 757 square kilometers. Remaining 4.57%

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1. S. Singh, (1979), op.cit. pp. 213-230.

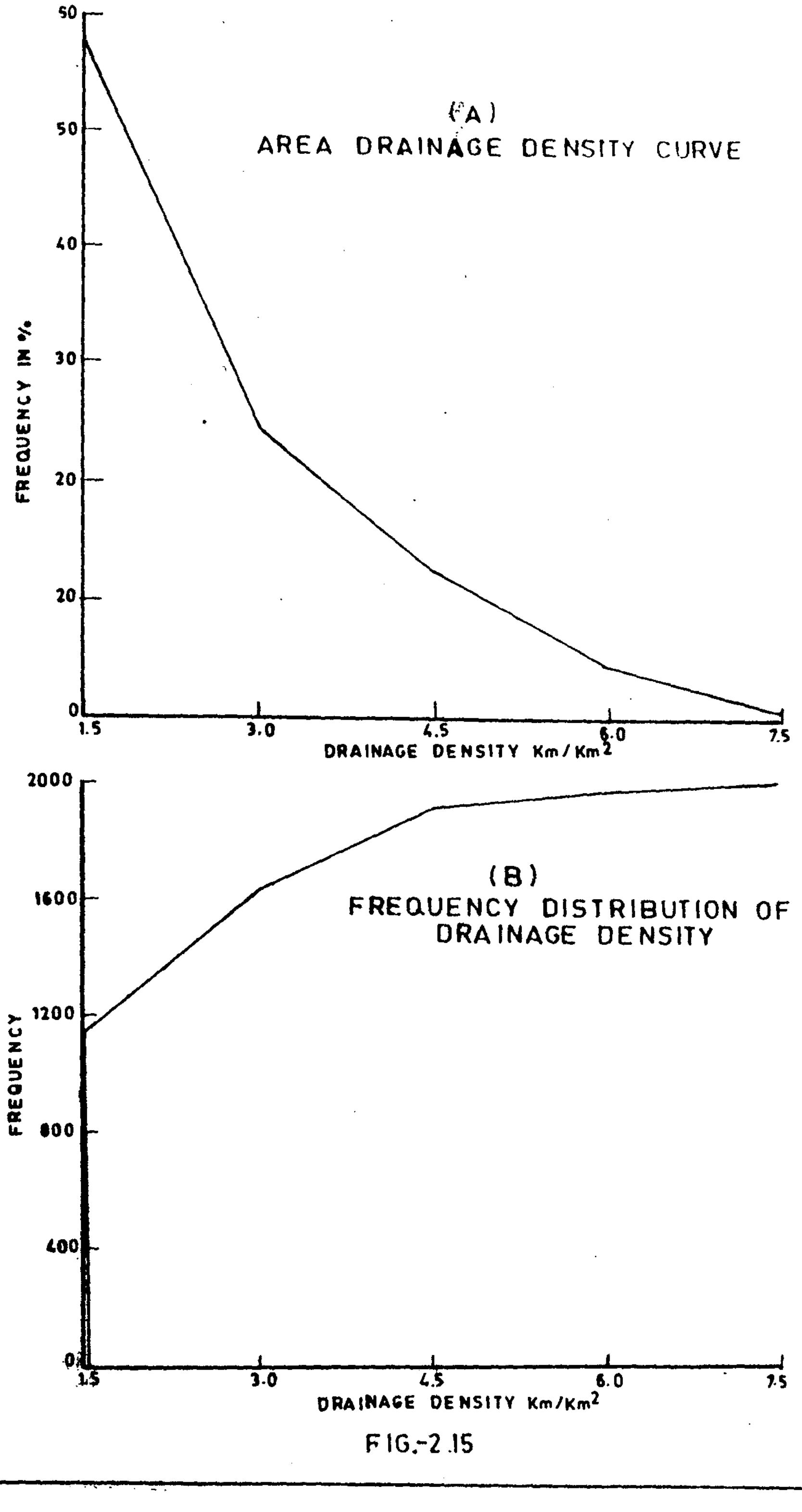
(A)
AREA DRAINAGE DENSITY CURVE
FREQUENCY IN %
50
50
40
30
20
20
0
1.5
3.0
4.5
6.0
7.5
DRAINAGE DENSITY Km/Km2
(B)
FREQUENCY DISTRIBUTION OF DRAINAGE DENSITY
FREQUENCY
2000
1600
1200
800
400
0
1.5
3.0
4.5
6.0
7.5
DRAINAGE DENSITY Km/Km2

FIG.-2.15

falls in the last categories of high to very high drainage density (DDh - DDvh) ranging 4.5 to 7.5 km per square kilometers and, thus it covers 91 square kilometers area of the basin. The frequency percentage polygon (Fig 2.15-A) indicates a negative skewness representing the fact that majority of the area lies within low to low moderate categories of drainage density.

CENTRAL TENDENCIES AND DISPERSIONS OF DRAINAGE DENSITY:

The mean, median and modal values of drainage density of the Dhauli-ganga basin standing at 1.61, 1.95 and 2.06 respectively, indicate concentration of maximum drainage density frequencies in low drainage density to moderately low drainage density categories of 0-3.0. Complete uneven distribution of drainage density frequencies of different density categories placing the modal and median values (more than mean) to the right of mean value in the cumulative frequency graph (Fig 2.15-B) presents the real testemony of early stage of landscape development in the Dhauli-ganga basin.

Dispersion of variation dealing with the variability in the size of items in general also gives a precise measure of variation. Different measures of dispersion include range, inter-quartile-range, quartile deviation and standard deviation etc. Lower and upper quartile (Q_1, Q_3) values standing at 1.486 and 1.92 again produce the same results as derived by mean, median and mode that maximum concentration of density ranges between first two categories. Standard deviation being the best measure of dispersion, is frequently used in analysis of geographical data to measure the exact degree of variation from the normal distribution. The calculated standard deviation just equal to the mean of density values of different categories standing at 1.61 indicate greater degree of variation. Coefficient of variation being 100, in this study area clearly indicates that the standard deviation is 100% of the mean, which further support the great degree of variation.

Following table gives an account of different statistical measures of drainage density distribution in the present basin.

TABLE 2.10

DIFFERENT STATISTICAL MEASURES OF DRAINAGE DENSITY VALUES

1.	Mean	1.61
2.	Median	1.95
3.	Mode	2.06
4.	Q_1	1.486
5.	Q_3	1.92
6.	Range	7.0
7.	I.Q. Range	0.438
8.	Q.D.	0.219
9.	CO QD	0.219
10.	Variance	2.59
11.	S.D.	1.61
12.	Co variation	100.0

NATURE OF DISTRIBUTION:

The aforesaid different measures of central tendencies and dispersions indicate the central values and concentrations of values around the average value and the degree of deviation from the mean value respectively but these measures do not throw light on the nature of distribution to either side of the mean value, whether it is normal or asymmetrical. The frequency percentage polygon (Fig 2.15A) indicates a negative skewness. This is an indication that majority of the drainage density frequencies lie in the 0-3.0 category which is a characteristic of more rugged and dissected terrain.

FACTORS AFFECTING THE DRAINAGE DENSITY:

One of the main objective of the present study is to examine the contributions of various geomorphic factors in explaining the variations and development of drainage density in the basin. The study will be incomplete if it does not explain the causes of variations and evolution of it. Following variables have been taken into account for the study

Dependent variable:

X_1	Drainage density

Explanatory variables:

X_2	Drainage frequency
X_3	Relative relief
X_4	Absolute relief
X_5	Average slope
X_6	Ruggedness number
X_7	Dissection index

CORRELATION MATRIX:

The importance of the above mentioned variables can be interpreted with the help of correlation matrix. It appears from correlation matrix (Appendix I) that X_1 is significantly and positively related with the explanatory variables X_2, X_4, X_5, X_6 and X_7. The relative relief (X_3) does not show any significant relationship with explained variable X_1. Thus it has not been considered for further analysis. The correlation matrix also shows the inter-correlation among the explanatory variables. For instance, ruggedness number (X_6) is highly correlated with the other explanatory variables, drainage density (X_2, $r = 0.773$), relative relief (X_3, $r = 0.324$) absolute relief (X_4, $r = 0.337$) average slope (X_5, $r = 0.347$) and dissection index (X_7, $r = 0.452$), all are significant at 0.001 level of significance. In the same fashion dissection index (X_7) is also significantly and positively correlated with X_1, X_2, X_3, X_4, X_5 and X_6. Similarly, other variables also show the inter correlation with each other. This indicates that variables taken for the present study are quite important and well defined.

The above results, which have been worked out from correlation matrix, reveal that drainage density is directly related with drainage frequency, absolute relief, average slope, ruggedness number and dissection index. These explanatory variables have a combined impact to control the drainage density

On the basis of the above discussions bivariate regression equations have been obtained to find out the exponential function and relationship of drainage density with aforesaid explanatory variables.

ABSOLUTE RELIEF AND DRAINAGE DENSITY:

Absolute relief is a strong geomorphic factor, which shows a significant contribution in the development of drainage density. It is apparent from the coefficient of correlation (Appendix I), which standing at 0.38 is significant at 0.001 level of significance. This positive relationship between these two variables reveals that high absolute relief facilitate the development of high drainage density. The probable reason of this relationship is the situation of water sources i.e glaciers, in higher altitudes, which spread their melted ice into small channels due to the difficult nature of terrain. The extreme uneven nature of configuration in higher altitudes is well proved by higher values of coefficient of correlation of absolute relief with dissection index and ruggedness number, which have 0.337 and 0.509 respectively, both significant at 1 per cent probable level of significance. These results give a clear understanding that area lying in higher altitudes is more rugged and is in very early stage of channel development and topography is more dominant because of low volume of water in streams.

The aforesaid linear relationship between absolute relief and drainage density can be proved with the help of regression analysis. Following regression equation has been obtained:

$$X_1 = 4.690 + \underset{(18.322)^{*}}{0.001} X_4 \qquad \bar{R}^2 = 0.144$$

The above equation implies that 14.4 per cent variations in drainage density are explained by absolute relief alone. The coefficient of regression is quite significant.

AVERAGE SLOPE AND DRAINAGE DENSITY:

Slope is a geomorphic factor which plays a significant role to govern the distribution of drainage density. The coefficient of correlation between average slope and drainage density being 0.087 is significant at 0.01 level of significance. This positive relationship reveals that higher degree of slope is directly associated with the development of higher drainage density. Higher degree of slope enhances the velocity of flowing water, which increases the rate of erosion and thus, ultimately lengthen the streams; The area with high average slope is more rugged and dissected as it is clear from the coefficient

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* Significant at 0.001 level

of correlation of average slope with ruggedness number and dissection index, which are 0.347 and 0.772, respectively and both are significant at 1 per cent probable level of significance. This indicates that the combined effect of these factors enforce the flowing water to flow according to the rugged nature of configuration.

The above discussion gives a clear understanding of higher drainage density in the area of higher degree of average slope. This relationship can be examined with the help of the following regression analysis:

$$X_1 = 1.231 + \underset{(3.891)^{*}}{0.035}\, X_5 \qquad \bar{R}^{2} = 0.0073$$

The above equation reveals that the linear relationship between these two variables is valid as regression coefficient is enough to signify it, but very less variations in drainage density are explained by the average slope, as it is apparent from the low value of R bar square.

RUGGEDNESS NUMBER AND DRAINAGE DENSITY:

Similar to the already mentioned factors, ruggedness of the terrain is also a very strong factor which governs the development of drainage density. It is apparent from the coefficient of correlation, that a value of 0.882 is strongly

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* Significant at 0.001 level.

significant at 1 per cent probable level of significance. This positive relationship reveals the fact that high rugged nature of configuration provides favourable conditions for the development of higher drainage density. Ruggedness number itself has a direct correlation with absolute relief, average slope and dissection index, standing at 0.337, 0.347 and 0.452, respectively and all are significant at 0.001 level of significance. It has already been discussed and proved that higher values of absolute relief and average slope are in favour of higher drainage density. The positive significant relationship of ruggedness number with these variables also prove the same postulation.

The aforesaid relationship of these two variables can be understood well with the help of bivariate regression analysis. Following regression equation has been obtained:

$$X_1 = 0.344 + \underset{(83.33)^{*}}{1.215}\, X_6 \qquad \bar{R}^2 = 0.77$$

The above equation reveals that 77 per cent variations in drainage density are explained by the ruggedness number. The regression coefficient is quite significant.

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* Significant at 0.001 level.

DISSECTION INDEX AND DRAINAGE DENSITY

It is apparent from the coefficient of correlation which standing at 0.227 quite significant at 1 per cent probable level of significance that dissection index is a determinant of drainage density. The positive relationship of these variables indicate that highly dissected landscape favours high drainage density. Dissection index has a direct relationship with the other determinants of drainage density viz absolute relief, average slope and ruggedness number. The coefficients of correlation standing at 0.509, 0.772 and 0.452 respectively are significant at 0.001 level of significance. These variables have already been discussed and it has been proved that they have positive impact on the development of drainage density. So, it may be concluded that dissection index also has a positive control over the development of drainage density. The variations in the drainage density due to the impact of dissection index and the validity of the linear relationship can be proved by the obtained regression equation:

$$X_1 = 0.821 + \underset{(10.399)^{*}}{0.059\ X_7} \qquad \bar{R}^2 = 0.051$$

The above equation implies that only 5.1 per cent variations in the drainage density are explained by the

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* Significant at 0.001 level.

dissection index alone. The coefficient of regression is enough high to be significant.

DRAINAGE FREQUENCY AND DRAINAGE DENSITY:

It is anxiomatic to deduce that higher stream frequncy causes higher drainage density, as coefficient of correlation stands quite high (r = 0.872), which is significant at 0.001 level of significance. It is obvious that more streams frequency will increase the length of streams and ultimately drainage density. The high variations in drainage density due to stream frequency can be measured by the high value of R bar square and validity of linear relationship can also be varified by the obtained regression equation as below:

$$X_1 = 0.319 + \underset{(79.56)}{0.414} X_2 \qquad \bar{R}^2 = 0.76$$

The above equation reveals that stream frequency explains 76 per cent variations in drainage density. The relationship is quite significant as coefficient of regression is quite high

On the basis of the above discussions following equation of the explanatory variables of the drainage density has been obtained:

$$X_1 = f(X_2, X_4, X_5 \ X_6 \text{ and } X_7)$$

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* Significant at 0.001 level.

All these factors have a combined impact to determine the drainage density. Stpwise regression analysis has been used to obtain the best set of explanatory variables on the basis of significance test viz. 't' and 'f' tests and the selected equation is as follows:

$$X_1 = 1.238 + \underset{(31.948)}{0.187\ X_2} + \underset{(18.653)}{0.001\ X_3} + \underset{(7.017)^{*}}{0.00\ X_4} + \underset{(45.497)}{0.839}$$

$$\bar{R}^2 = 0.891$$

The above equation reveals that in the first step ruggedness number (X_6) entered as explanatory variable is having the highest correlation with the explained variable. It alone explains 77.7 per cent of variations in drainage density and regression coefficient is quite significant.

In the second step drainage frequency entered as the second best explanatory variable is having the second highest correlation with explained variable drainage density. These two explanatory variables together explain 86.6 per cent variations in drainage density and both regression coefficients are significant.

In the third step relative relief (X_3) entered as the third explanatory variable, Here it is worth mentioning that relative relief (X_3) does not show any relationship

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* Significant at 0.001 level.

with drainage density, individually. While in presence of other geomorphic factors it plays an important role to determine the drainage density. All these three variables simultaneously explain 88.9 per cent variations in drainage density. Regression coefficients are quite significant.

In the next step absolute relief (X_4) entered as the fourth explanatory variable and in the presence of three already mentioned variables, regression equation explains 89.1 per cent of variations in drainage density. All coefficients of regression are quite significant.

In the next step absolute relief (X_4) entered as the fourth explanatory variable and in the presence of three already mentioned variables, regression equation explains 89.1 per cent of variations in drainage density. All coefficients of regression are quite significant.

Regression equation has been run for a further step and a very interested result has been obtained:

$$\begin{array}{llllll} X_1 = 2.316 + 0.869\ X_6 & +\ 0.177\ X_2 & +\ 0.0\ X_3 & +\ 0.10\ X_4 & +\ 0.06\ X_7 \\ \qquad (47.759)^{*} & (30.56)^{*} & (1.154)^{**} & (12.628) & (10.378) \end{array}$$

$$\bar{R}^2 = 0.897$$

The above equation reveals the fact that when dissection index (X_7) entered as another explanatory variable, the con-

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* Significant at 0.001 level.

** Insignificant at any level

trol of relative relief (X_3) becomes quite negligible, as regression coefficient of X_3 is insignificant (Table 2.11).

Therefore, second equation has been retained as the best set of explanatory variables, excluding relative relief all other four variables are important factors to govern the drainage density.

STREAM NUMBER:

Horton developed a model of stream ordering and suggested that the number of streams of each order of any basin form an inverse geometric series with the order. The Horton's model of stream number can be expressed by the following equation

$$Nu = R_b \quad (S - U)$$

R_b = bifurcation ratio

S = higher order of the basin

This has been termed as first law of drainage composition and has been widely tested in different parts of the world. In the present study basin, the streams were ordered in Strahler's stream ordering fashion, where all the fingertip streams (streams without any tributary) were named as order 1 and in turn 2 first order streams join to make a stream of second order and so on.

The data for the entire Dhauli-ganga basin exhibit the orderly arrangement of the number of streams (N) of different

TABLE - 2.11

FACTORS AFFECTING THE DRAINAGE DENSITY-A STEPWISE REGRESSION ANALYSIS RESULTS

INTERCEPTS	Steps	Regression Coefficients of					R	R^2	$\bar{R}$	$\bar{R}^2$
		X_2	X_3	X_4	X_6	X_7				
0.344	I				1.215 (83.33)*	0	0.882	0.777	0.882	0.772
0.169	II	0.225 (36.80)*			0.710 (40.016)*		0.931	0.866	0.931	0.866
0.792	III	0.187 (31.508)*	0.001 (19.771)*		0.870 (47.983)*		0.943	0.889	0.943	0.889
1.238	IV	0.187 (31.948)*	0.001 (18.653)*	0.000 (7.017)*	0.839 (45.497)*		0.944	0.891	0.944	0.891
2.316	V	0.177 (30.564)*	0.00 (1.154)**	0.00 (12.628)*	0.869 (47.759)*	0.060 (10.378)*	0.947	0.896	0.947	0.896

* Significant at 0.001 level
** Insignificant

orders as follows:

N_1	N_2	N_3	N_4	N_5	N_6	ΣN
2625	581	126	23	4	1	3360

This mentioned data speak itself that the number of stream segments decrease with an increase in order, thereby the exponential function is negative. To have a visible impression of the negative relationship between stream number and order, a scattered diagram has been plotted and a regression line has also been drawn (Fig 2.16).

The equation of the fitted line is given below:-

$\text{Log } Y = \text{Log } 2055.399 - 427.26 X \quad R = 0.77$

The plotted graph portrays the negative exponential function, but a close study of the graph reveals the fact that the stream number of 4th, 5th and 6th orders have a great deviation from the regression line which shows that hierarchy of stream segments does not form an actual geometric series. It has also been discussed in Chapter III.

BIFURCATION RATIO:

Horton[1] considered the bifurcation ratio as an index of relief and dissection. It has been experienced by the number of studies that the bifurcation ratio tend to have

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[1] R.E. Horton (1945), op.cit. pp. 275-370.

values between 2, 5 with an usual value around 3 bifurcation ratio is the ratio of total number of streams of one order to that of the next higher order. Dhauli-ganga basin registered the following bifurcation ratio (Rb) between different orders:

Rb_1	Rb_2	Rb_3	Rb_4	Rb_5	$\bar{Rb}$
4.52	4.61	5.48	5.75	4.00	4.87

This reveals the fact that bifurcation ratio in the basin varies between 4 and 6, it shows more deviation between Rb_4 (5.75) and Rb_5 (4.00) while mean bifurcation of the basin (4.87) follows the results of the earlier studies. Again it has been fully discussed in Chapter III.

STREAM LENGTH:

Horton[1] suggested that the mean length of stream segments of a given order increases exponentially with increasing order or in his own terms "The average lengths of streams of each of the different orders in a drainage basin tend closely to approximate a direct geometric series in which the first term is the average length of stream of first order". In the present study basin total stream length (L) and mean stream length ($\bar{L}$) have been measured as follows

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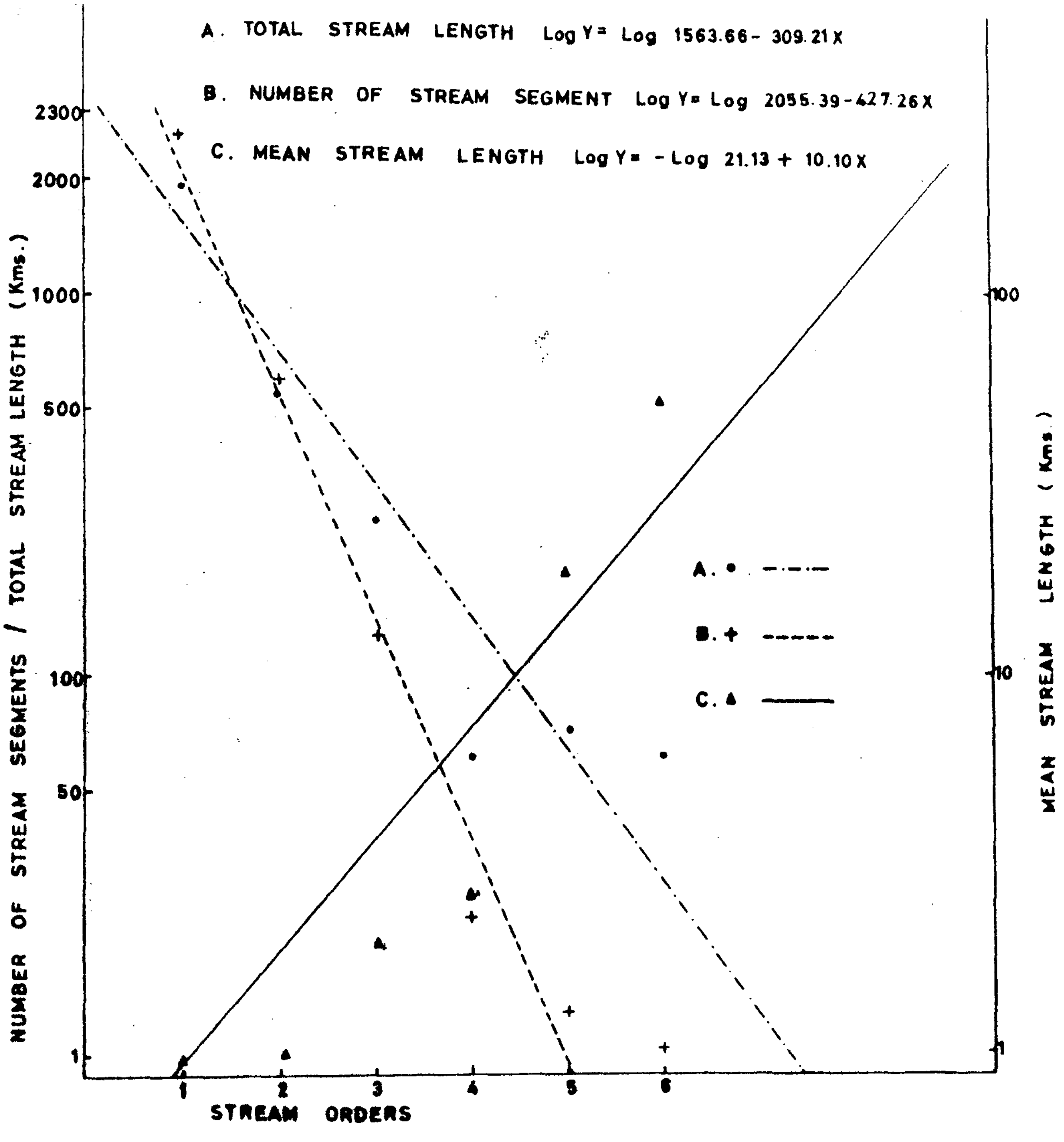
[1] R.E. Horton, (1945), Ibid.

THE REGRESSION LINES



A. TOTAL STREAM LENGTH Log Y = Log 1563.66 − 309.21 X

B. NUMBER OF STREAM SEGMENT Log Y = Log 2055.39 − 427.26 X

C. MEAN STREAM LENGTH Log Y = − Log 21.13 + 10.10 X

Fig. 2.16

Total stream length (Km) :

L_1	L_2	L_3	L_4	L_5	L_6	ΣL
1909.5	535.5	250.5	59.5	72.5	61.0	2888.5

Mean stream length (Km) :

$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$	$\bar{L}_6$	$\bar{L}$
0.727	8.921	1.988	2.586	18.125	61.0	0.859

The said values of total stream length and mean stream length and mean stream length were plotted against order on a semilog graph paper. Both plots give a contradictory behaviour.

The plot of total stream length against order (Fig 2.16) shows a negative exponential function, where the total stream length decreases with an increase in order. The equation of the fitted regression equation is:

$$\text{Log } y = \text{Log } 1563.66 - 309.21 X$$

The plot of mean stream length against order (Fig 2.16) shows a contrast result. It shows a positive exponential function. In this study, the regression line gives an appearance of positive exponential function, though the points fall away from the fitted line and do not prove the perfect geometric series. This relationship is expressed by the following equation:

$$\text{Log } y = -\text{Log } 21.13 + 10.10 X$$

Thus it may be concluded that Horton's law of stream length and stream number are just ideal models. The idea of relationship between these components and order is justified but the concept of geometric series formation is not always valid. It has also been fully discussed in Chapter III.

On the whole, the study of the various aspects of the drainage of Dhauli-ganga basin, leads us to the following conclusions.

Dhauli-ganga basin is 6th order basin, in Strahler's stream ordering system with a dendritic and sub-parallel drainage patterns. The extremely high stream frequency and drainage density of dendritic pattern indicate the youthful stage of the basin development and continuous upliftment of the basin. The detail study of drainage density development in the basin shows that not only underlying lithology but other geomorphic parameters also have their significant control over the drainage density development in the presence of underlying lithology. The correlation matrix indicates that, stream frequency, relative relief, absolute relief, average slope, ruggedness number and dissection index are significant parameters in the development of drainage density. The stepwise regression analysis prove that ruggedness number, stream frequency, absolute relief and dissection index are more dominant factors for drainage density development.

Mean bifurcation ratio of the basin meets the results of earlier studies, but it does not prove the Hortonian concept of geometric series in all orders, neither with stream number nor with stream length.

Thus the study proves the validity of second hypothesis that drainage density is a multifunctional result of absolute relief, dissection index, average slope, ruggedness number and drainage frequency, while some of them viz., average slope and ruggedness number are self governed by drainage density.

GEOMORPHIC REGIONS:

On the basis of the inter-relationship of a few selected geomorphic parameters, it has been tried to trace out the different geomorphic regions of the area under study. Different maps of significant geomorphic parameters of land configuration viz., altitudes, relative relief, dissection index, average slope, ruggedness number, drainage density and stream frequency, have been superimposed and regions of same characteristics have been distinguished and demarcated by interpolation method. Following four geomorphic regions have been identified (Fig 2.17)

GLACIATED TERRAIN:

The area under glaciers has been registered in SSE portion of the basin, Except this, few other patches of glaciers have also been noticed along north water divide

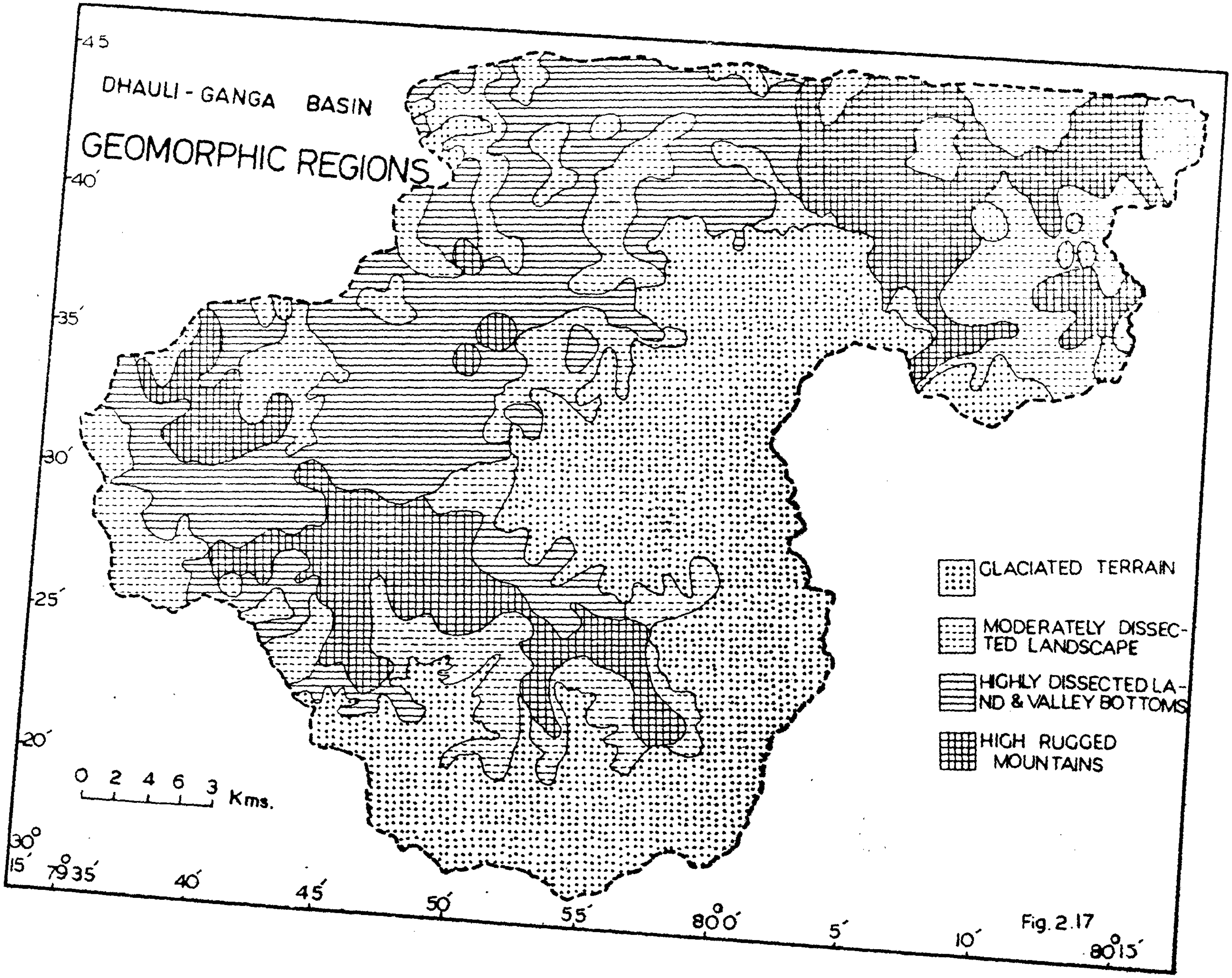

DHAULI - GANGA BASIN
GEOMORPHIC REGIONS
GLACIATED TERRAIN
MODERATELY DISSECTED LANDSCAPE
HIGHLY DISSECTED LAND & VALLEY BOTTOMS
HIGH RUGGED MOUNTAINS
0 2 4 6 3 Kms.
45
40′
35′
30′
25′
20′
30° 15′
79°35′
40′
45′
50′
55′
80°0′
5′
10′
80°15′

Fig. 2.17

and east water divide (Fig 2.17). Important glaciers of the region are Uttar Rishi glacier, Dakshin Rishi glacier, Uttar Nanda Devi glacier, Dakshin Nanda Devi glacier and Trishul glacier etc. The contour line of 5000 meters has been recorded as the snow line in the region, the area of the basin lying above the height of 5000 meters is under permanent ice sheet.

Inspite of high altitudes, this area enjoys lower values of all other geomorphic parameters. For instance, the drainage density and stream frequency in this area are negligible and thus, the ruggedness number is also equally negligible. The relative relief ranges between 250 to 750 meters. A few patches of 1000-1250 meters and above have been noticed along the SSE water divide. Average slope follows the pattern of relative relief and ranges between 0 to 15° with few patches of high average slope. Dissection index is low and varies from 0 to 0.16 only. It may be concluded that the nature of configuration of glaciated terrain is almost flat with a thick cover of ice.

MODERATELY DISSECTED LANDSCAPE:

The area of the basin under this category has been scattered in patches, generally along the area of high dissected landscape and river valleys (Fig 2.17). In eastern part it covers a larger area adjoining the area of highly rugged terrain. In the SSE portion of the basin it forms a belt in between the high rugged terrain and glaciated land scape. The whole dissected landscape lies below the altitude of 5000 meters.

This area is characterized by the medium high values of all geomorphic parameters. The average slope values in the area range between 0 to 15°, while dissection index values are also lower, ranging from 0 to 0.16. Relative relief of this zone has been registered below 750 meters. Ruggedness number varies from 0 to 2 per square kilometer. Drainage density and stream frequency of this zone are moderately higher ranging between 0-3 and 0 to 6, respectively. It may be concluded that this area is rather undulating and dissected in comparison to glaciated terrain.

HIGHLY DISSECTED TERRAIN AND VALLEY BOTTOMS:

This type of area is prevailing along the river valleys from the mouth of Dhauli-ganga to Dhar Martoili fault. This region is characterized by extremely high dissected landscape, due to the deep downward cutting of river valley by drainage lines. Rivers have formed the deep valleys, gorges and escarpments. Maximum area lies in the range of 4000 meters altitude. A very small area lies between the altitudes of 4000 to 5000 meters.

The values of topographic parameters are extremely high in this region. Average slope, dissection index and relative relief are varying between, 15° to 30°, 0.16 to 0.40 and 750 to 1250 meters and above respectively. The values of hydrologic parameters are also higher i.e, drainage density ranges between 1.5 to 4.5 and stream frequency 3 to 6 per square kilometer. Ruggedness number varies from 1 to 3 per square kilometer. On the basis of the above discussed results, it may be concluded that this region is extremely dissected with deep valleys.

HIGHLY RUGGED MOUNTAINS:

The area under extremely rugged nature of configuration is situated in eastern part of Dhar Martali fault in the catchment areas of kio-gad and Girthiganga, in the central part of the basin in the catchment of Rishi-ganga and Trishul Nadi and in the west near the mouth of Dhauli-ganga and subsequently near the catchment of Hom Gadhera, lower Hom Gadhera and Bhangyulgad. Some other patches have also been identified along the Dhauli-ganga (Fig 2.17). This area is situated in all altitudinal zones of below 5000 meters.

This region is characterized by very high values of drainage density, stream frequency and ruggedness number ranging between 3 to 7.5, 6 to 15 and 3 to 6 per square kilometer, respectively. It enjoys a bit lower values of relief parameters in comparison to highly dissected landscape. For example, average slope ranges between 10° to 20° relative relief 750 to 1250 meters and dissection index varies from 0.16 to 0.40 per square kilometer. The area situated in the east of Dhar-Martoli fault is completely bare rock landscape with a general phenomena of rock falling and huge boulders.

CHAPTER III

TOPOLOGICAL AND GEOMETRIC STUDY OF THE DRAINAGE NET WORK

In the preceding chapters, different geomorphic aspects of the entire Dhauli-ganga basin have been discussed. In this chapter for more intensive study of the drainage morphometry, all the third order basins (which sum upto 40) from entire Dhauli-ganga basin have been taken into account, because of the more orderly development on either side of the trunk stream and provide more scope for the choice of the basins with the varying area for more intensive study and different morphometric aspects have been analysed on the basis of 25 variables of drainage morphometry. All relevant modern techniques have been used in this chapter to analyse the various aspects of drainage net work and fluvially developed topography.

The morphometric analysis of a region on different scales, shades, grades, is also a field of integrated approach for allied disciplines. Such type of analysis provides fundamental background for multiple planning of a region (Padmaja,)[1] Morphometry is the measurement and mathematical analysis of the configuration of earth's surface and shape and dimen-

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[1] G. Padmaja, (1976), op.cit. p. 104.

sions of its landforms (Dury)[1]. The pioneer work in this field was headed by Horton[2] and many others which has already been discussed in introductory chapter under the heading 'review of literature'.

The entire Dhauli-ganga basin, lithologically may be divided into two major groups - Metamorphic central crystalline formation of gneiss and schist and sedimentary rocks of Tethys formation. The central crystallines are separated from the Martoli series of Tethys sedimentary zone by a north-north westerly striking fault, the western extension of Dar-Martoli Fault that traverses through Malari village, Out of all the 40 third order basins that compose the basin, Laukagad, Najgaongad, Chidamugad north, Chidamugad South, Girthaigad, Bambanaggad, Girthidhuragad, Devkotgad, Margaongad, Chubaggad, Chubaggad, Lalbasanigad and Siraunchgad fall in the Tethys formation. Lower Malarigad is a basin which lies in the transitional zone. All the remaining basins drain over central crystallines of schist and gneiss. Fig (3.1) clearly exhibits the location of all the third order basins in the Dhauli-ganga basin.

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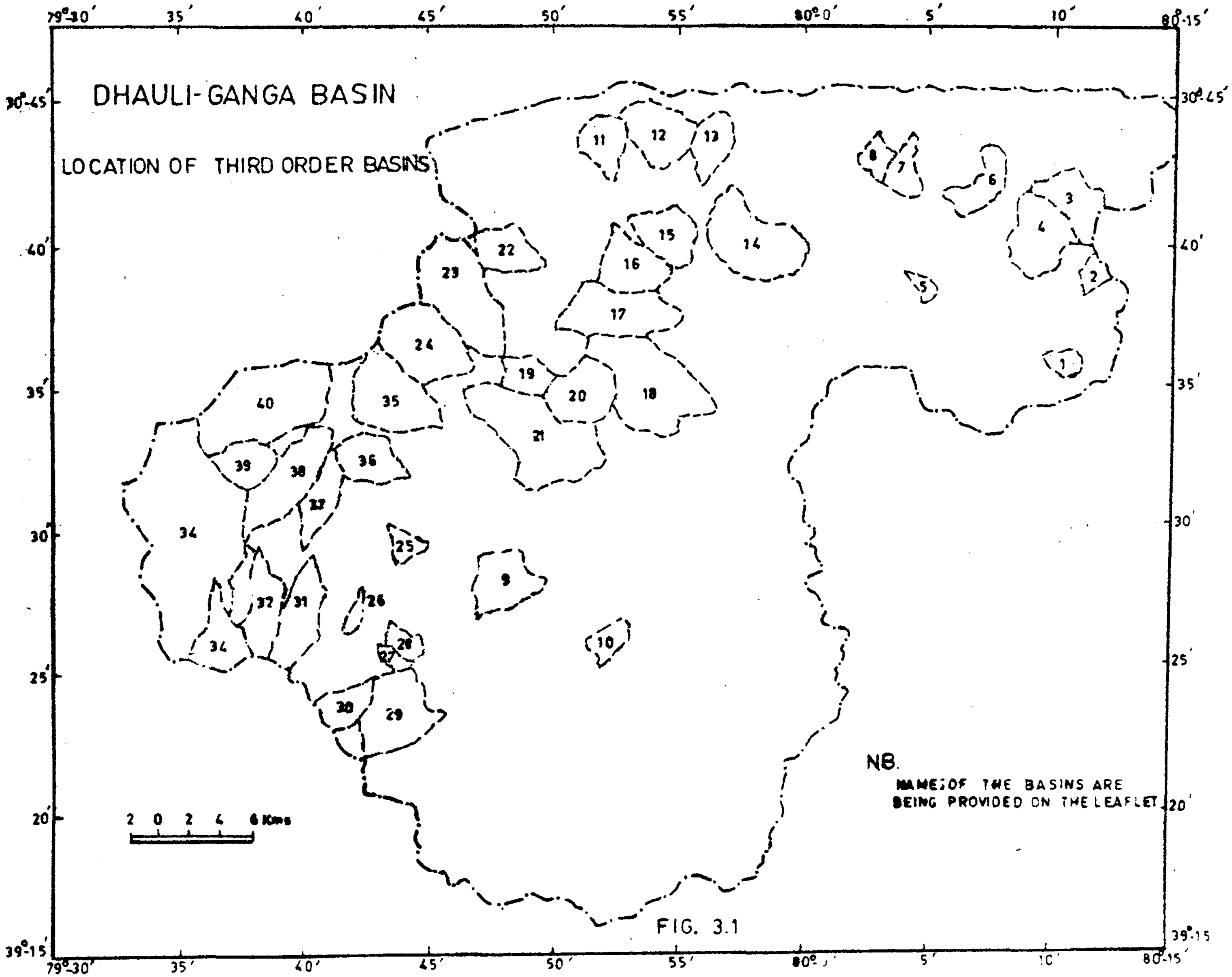
1. G.H. Durry, (1966), "Essays In Geomorphology", American Elsevier Publishing Company, New York.

2. R.E. Horton, (1945), op.cit.



DHAULI-GANGA BASIN

LOCATION OF THIRD ORDER BASINS

NB.
NAME OF THE BASINS ARE BEING PROVIDED ON THE LEAFLET

FIG. 3.1

NAMES OF THE THIRD ORDER BASINS OF
DHAULI-GANGA BASIN

S.No.	Name of the basins	S.No.	Name of the basins
1.	Lauka Gad	21.	Gankhwi Gadhera
2.	Najgaon Gad	22.	Pangti Gadhera
3.	Chidamu Gad North	23.	Juma Gad
4.	Chidamu Gad South	24.	Nauti Gadhera
5.	Girthi Gad	25.	Lata Kharak Gadhera
6.	Bambanag Gad	26.	South Paing Gad
7.	Girthi Dhura Gad	27.	Raunthi Gadhera II
8.	Devkot Gad	28.	Raunthi Gadhera III
9.	Dubrugetha Gad	29.	Chamba Kharak Gad
10.	Rishikot Gad	30.	Raunthi Gadhera I
11.	Margaon Gad	31.	Subhain Gad
12.	Chubag Gad	32.	Ringi Gad
13.	Lalbasani Gad	33.	Tapoban Hot Spring Gad
14.	Siraunch Gad	34.	Regri Gad
15.	Malari Gad	35.	Gadi Gadhera
16.	Lower Malari Gad	36.	West Tolma Gad
17.	Garpak Gadhera	37.	Juwagwar Gad
18.	Dunagiri Gad	38.	Bhangyul Gad
19.	Lower Juma Gad	39.	Lower Hom Gadhera
20.	Nandi Kund Gad	40.	Hom Gadhera

It is quite clear from the map (3.1) that the basins of central crystallines have bigger sizes than the basins of Tethys zone. Basins of Tethys formation though smaller in area but posses more stream numbers and lengths comparatively (Appendix IV). The physiography, shape and size and drainage net work of the basins are exhibited by the maps (Fig 3.2). Mostly basins lie in central part of the basin along the trunk stream and well developed basins may be observed in low altitude area near the confluence of Dhauli-ganga with Alaknanda. Few basins from the central crystallines are covered by forest canopy, among them, the lower Jumagad, Gankhwigadhera, Jumagad, Lata Kharakgad, South Painggad, Subhaingad, Regrigad, Tapobanhot Springgad, Rengigad, Gadigadhera, Lower Homgadhera and Homgadhera are well distinguished.

HIERARCHY OF SEGMENTS AND STREAM NUMBER:

The nested hierarchy of drainage net has been determined by the ordinal scale of stream ordering proposed by Strahler[1] at the source of a river, the order by definition is equal to 1. The order changes by a factor +1 whenever the stream is joined by an other of the same order. The order of a particular stream in this method is always denoted by an integer number. When a stream with lower order u joins another stream

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1. A.N. Strahler, (1952), op.cit.

PHYSIOGRAPHY-SHAPE AND SIZE

THIRD ORDER BASINS

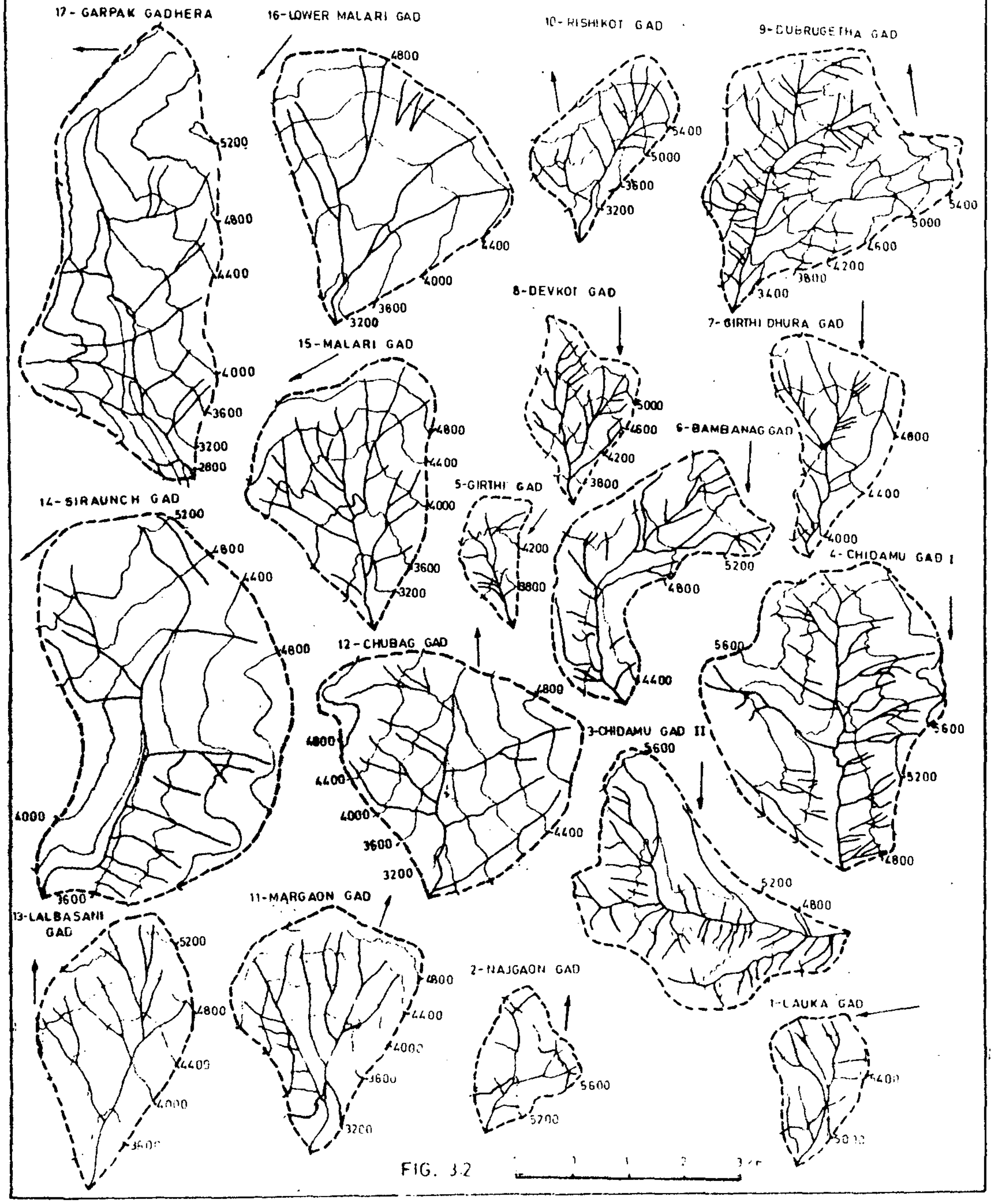
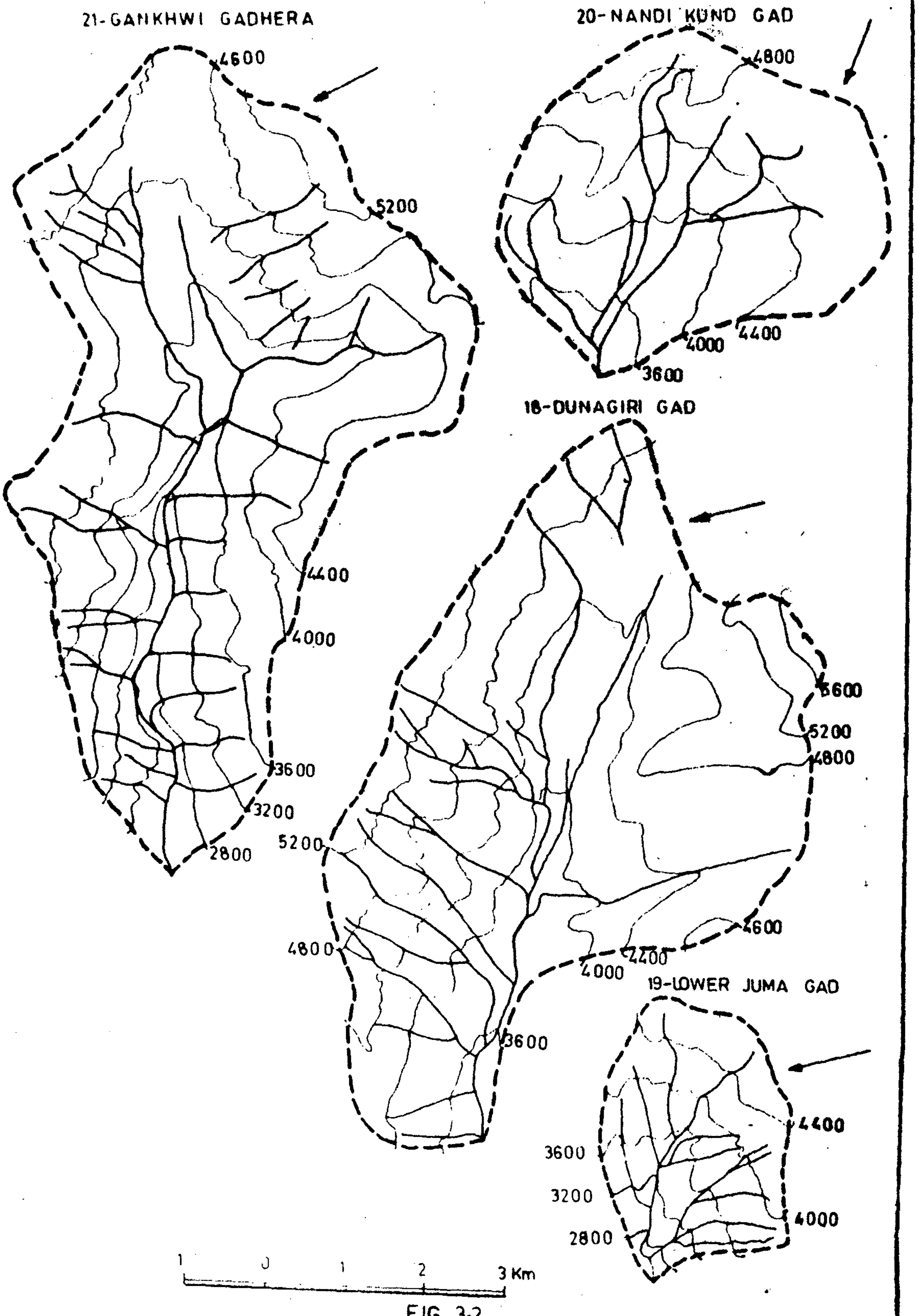


FIG. 3.2



PHYSIOGRAPHY-SHAPE AND SIZE

THIRD ORDER BASINS

FIG. 3·2

PHYSIOGRAPHY—SHAPE AND SIZE

THIRD ORDER BASINS

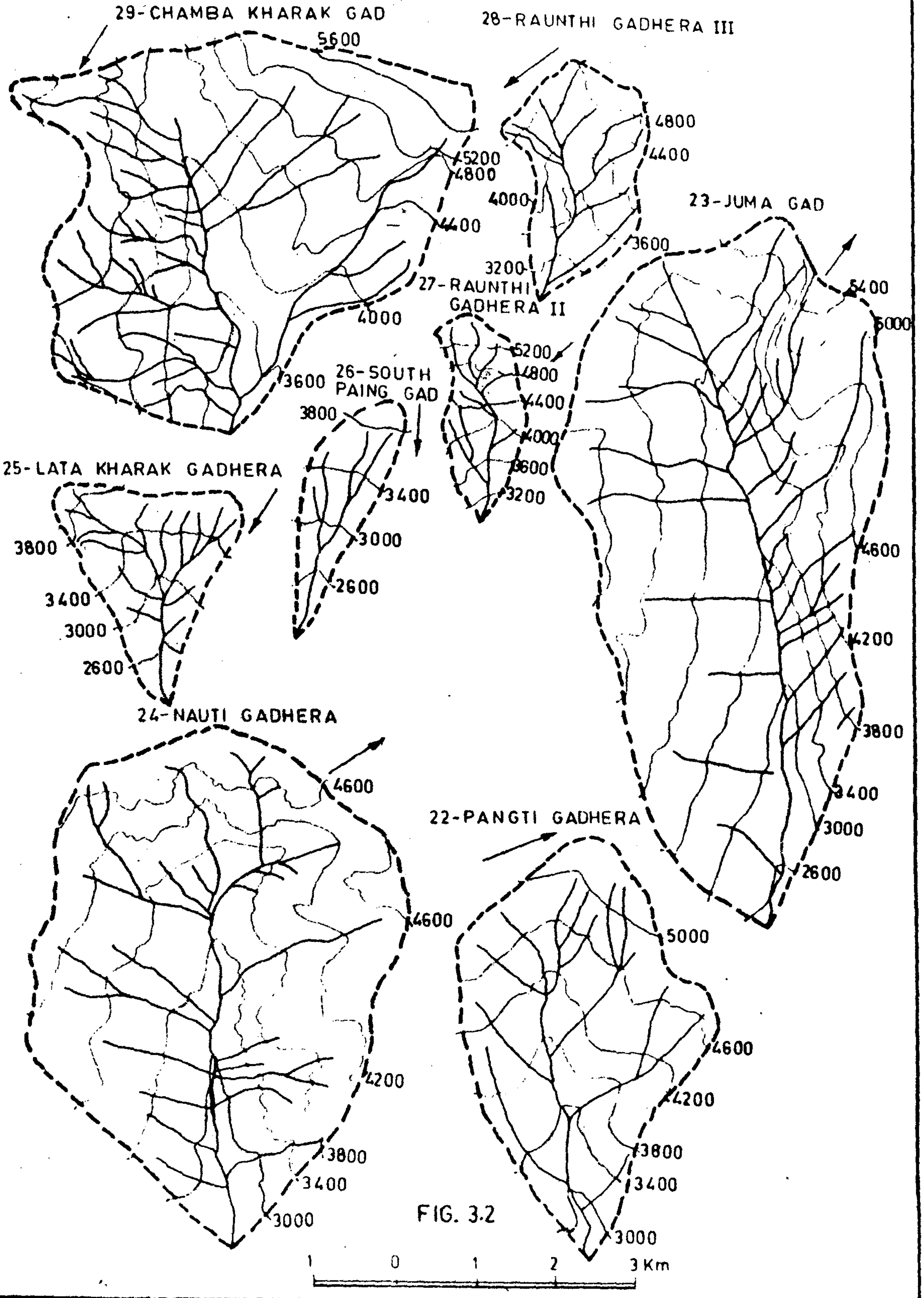


FIG. 3.2

PHYSIOGRAPHY—SHAPE AND SIZE
THIRD ORDER BASINS

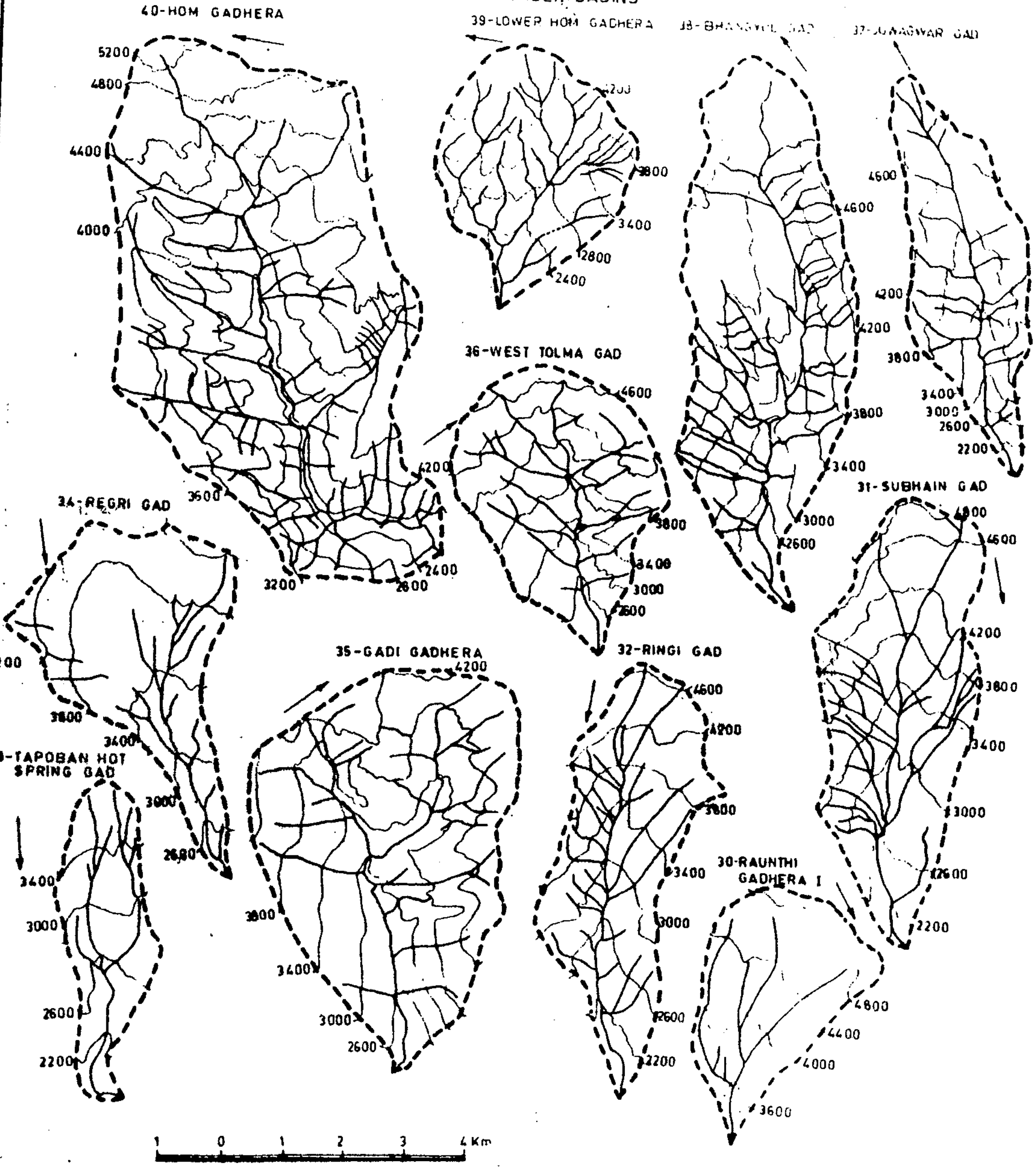


FIG. 3.2

with a higher order u_{+1} produces no change in the order of the resultant stream (Fig. 3.2). It is apparent from the Table 3.1 and Appendix IV that the bigger basins have maximum number of segments and basins of lower area have less number of segments, This may be very well proved by the evidence that all the basins having area above mean area of the basins (11.92 km^2) have stream number above the mean of stream segments of the basins (26.77) viz Chidamugad North (A = 11.12 km^2, N = 52) Chidamugad South (A = 16.11 km^2, N = 64), Dubrugethagad (A= 13.15 km^2, N = 55), Dunagirigad (A = 30.68 km^2, N=30) Gaukherigadhera (A = 32 km^2, N = 38), Jumgad (A = 24.13 km^2, N = 30) Gaukherigadhera (A = 32 km^2, N = 38), Jumgad (A=24.13 km^2, N = 35), Nautigadhera (A = 19.88 km^2, N = 33), Chambakharakgad (A = 18.2 km^2, N = 46), Subhaingad (A = 13.85 km^2, N = 31), Gadigadhera (A = 19.47 km^2, N = 27),Dhangyulgad (A = 18.24 km^2, N = 52) and Homgadhera comprises of biggest area (34.84 km^2) has maximum number of stream segments (82). The value of coefficient of correlation between stream segments and basin area, + 0.628 being significant at 0.01 level of significance, strongly support the above mentioned hypothesis. These results, strongly contradict the results of Singh et al[1]

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1. S. Singh and D.P. Upadhyaya, (1981), op.cit, p. 192.

TABLE - 3.1

NUMBER OF STREAM SEGMENTS (Nu)

S.No.	Basins	N_{u1}	N_{u2}	N_{u3}	ΣN
1.	Lauka Gad	11	3	1	15
2.	Najgaon Gad	9	3	1	13
3.	Chidamu Gad North	46	5	1	52
4.	Chidamu Gad South	51	12	1	64
5.	Girthi Gad	10	2	1	13
6.	Bambanag Gad	27	6	1	34
7.	Girthi Dhura Gad	23	3	1	27
8.	Devkot Gad	20	5	1	26
9.	Dubrugetha Gad	47	7	1	55
10.	Rishikot Gad	13	4	1	18
11.	Margaon Gad	13	3	1	17
12.	Chubag Gad	14	4	1	19
13.	Lalbasani Gad	11	4	1	16
14.	Siraunch Gad	18	4	1	23
15.	Malari Gad	19	5	1	25
16.	Lower Malari Gad	10	2	1	13
17.	Garpak Gadhera	16	4	1	21
18.	Dunagiri Gad	22	7	1	30
19.	Lower Juma Gad	11	3	1	15
20.	Nandi Kund Gad	9	3	1	13
21.	Gankhwi Gadhera	32	5	1	38
22.	Pangti Gadhera	13	3	1	17
23.	Juma Gad	30	4	1	35
24.	Nauti Gadhera	27	6	1	33
25.	Lata Kharak Gadhera	14	2	1	17
26.	South Paing Gad	4	2	1	7
27.	Raunthi Gadhera II	8	2	1	11
28.	Raunthi Gadhera III	10	2	1	13
29.	Chamba Kharak Gad	36	9	1	46
30.	Raunthi Gadhera I	6	2	1	9
31.	Subhain Gad	24	6	1	31
32.	Ringi Gad	25	5	1	31
33.	Tapoban Hot Spring Gad	7	2	1	10
34.	Regri Gad	15	3	1	19
35.	Gadi Gadhera	24	4	1	27
36.	West Tolma Gad	19	5	1	25
37.	Juwagwar Gad	21	4	1	26
38.	Bhangyal Gad	43	8	1	52
39.	Lower Hom Gadhera	26	6	1	33
40.	Hom Gadhera	68	13	1	82

that "stream number is independent of basin area". The reason of this controversy is that in hilly area due to high relief ratio and absolute relief stream frequency is high and the constant of channel maintenance is very low, therefore bigger size of basins require more streams to develop. The development of basin is always due to the headward erosion of streams, if the number of segments are more obviously headward erosion will be more and basins perimeter will retreat further to grow bigger size of the basins. Although it is worth realizing here that lithological characteristics, pedological factors and forest canopy also have their control over the branching of streams. But in hilly areas of high altitudes these are secondary factors while the degree of texture, ruggedness of the terrain and relief ratio are more dominant. High elevation and relief ratio enhance the velocity of streams, which ultimately stimulate the erosional forces of the rivers which enable them to flow freely.

It is apparent from the Appendix IV that the small basins draining over the sedimentary rocks of Tethys formation have developed more stream frequency viz Laukagad (4.67), Najgaongad (4.85), Chidamugad North (3.97), Chidamugad South (7.05), Girthigad (4.09), Bambanaggad (6.30), Girthidhuragad (6.90) Devkotgad (4.18) and Dubrugethagad (4.18). This shows that sedimentary rocks provide easy way for water to flow freely. While metamorphics restrict them to a few available linear and weakness fractures.

It is auximatic to deduce from the Table (3.1) and Appendix IV that the higher texture ratio encourages the development of more stream segments. This is quite clear from the coefficient of correlation value (+0.709), which is strongly and positively correlated to the segments, being significant at 1% probable level of significance. Similar inferences may be drawn from the correlation value of ruggedness of the terrain (+ 0.452) which is again significant at 0.05 level of significance, the nature of configuration is a determinant of stream-segments. Absolute relief (+ 0.403) being significant at 0.10 level of significance reveals that higher elevation gives rise to more number of streams segments.

It may be concluded from the above discussions that stream segments in hilly region, in the basins of same order decrease or increase as the area of the basin increases or decreases. The development of segments are more in the area of soft rocks formation. Some geomorphic factors viz absolute relief, ruggedness and texture ratio have their impact over the branching system of streams.

LAW OF STREAM NUMBER:

Horton propounded a law regarding the net work development of a basin which is called Horton's first law of stream number, i.e the number of stream segments of successively lower orders in a given basin tends to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio involving negative exponential function model.

Exponential function model = $Nu = Rb^{(k-u)}$

Where, Nu = number of stream segments of a given order

Rb = constant bifurcation ratio

K = highest order of the basin

Thus $$\sum Nu = \frac{Rb^{K-1}}{Rb - 1}$$

or $$\sum_{u=1}^{k} Nu = \frac{Rb^{k-1}}{Rb - 1}$$

The Table (3.1) clearly denotes that the number of stream segments decreases with increasing order but this relationship is not significant as it is clear from the coefficients of correlation between stream segments and their respective stream orders (Table 3.2) for all 40 basins. Even a single value is not significant at any level of significance. The values of regression coefficients are also quite insignificant and therefore regression equations are not worth plotting, This proves that stream segments of different orders do not form the geometric series as an exceptional case just because of chance variabilities. It has also been

TABLE - 3.2

NETWORK RELATIONSHIP(TOPOLOGICAL)
(COEFFICIENT OF CORRELATION)

S.No.	Name of Basins	Order(v) Vs cumulative mean length
1.	Lauka Gad	+ 0.964
2.	Najgaon Gad	+ 0,979
3.	Chidamu Gad North	+ 0.931
4.	Chidamu Gad South	+ 0.950
5.	Girthi Gad	+ 0.682
6.	Bambanag Gad	+ 0.860
7.	Girthi Dhura Gad	+ 0.883
8.	Devkot Gad	+ 0.990
9.	Dubrugetha Gad	+ 0.915
10.	Rishikot Gad	+ 0.719
11.	Margaon Gad	+ 0.992
12.	Chubag Gad	+ 0.759
13.	Lalbasani Gad	+ 0.877
14.	Siraunch Gad	+ 0.889
15.	Malari Gad	+ 0.995
16.	Lower Malari Gad	- 0,914
17.	Garpak Gadhera	+ 0.766
18.	Dunagiri Gad	+ 0.808
19.	Lower Juma Gad	+ 0.481*
20.	Nandi Kund Gad	- 0.404*
21.	Gankhwi Gadhera	+ 0.905
22.	Pangti Gadhera	+ 0.943
23.	Juma Gad	+ 0.860
24.	Nauti Gadhera	+ 0.866
25.	Lata Kharak Gadhera	+ 0.866
26.	South Paing Gad	+ 0.327*
27.	Raunthi Gadhera II	- 0.182*
28.	Raunthi Gadhera III	+ 0.500
29.	Chamba Kharak Gad	+ 0.912
30.	Raunthi Gadhera I	- 0.866
31.	Subhain Gad	+ 0.931
32.	Ringi Gad	+ 0.834
33.	Tapoban Hot Spring Gad	+ 0.972
34.	Regri Gad	+ 0.875
35.	Gadi Gadhera	+ 0.920
36.	West Tolma Gad	+ 0.913
37.	Juwagwar Gad	+ 0.942
38.	Bhangyal Gad	+ 0.872
39.	Lower Hom Gadhera	+ 0.924
40.	Hom Gadhera	+ 0.896

All are significant at 1% probable level

* Not significant

proved in Chapter II regarding the entire basin.

LAW OF STREAM LENGTH:

The law of stream length is related to the length of streams of different orders in a basin. The length of first order segments is higher and it decreases as the order of the segments increases because the number of segments of first order is always higher then the number of segments of increasing orders. This fact is very well exhibited by Table 3.3. All 40 drainage basins follow this postulation except some departures in certain orders of a few streams. The deviation from the above postulation has been registered in the length of third order segments only for 12 basins, viz. Girthigad, Bambanaggad, Girthidhuragad, Rishikotgadd Chubaggad, Siraunchgad, Garpakgadhera, Jumagad, South Painggad, Raunthigadhera I, Ringigad. Another important fact which emerges from the close study of the results of the Table 3.3 is that the higher number of stream segments develop in the basins of bigger size. The development of basin area is directly associated with the development of stream lengths. This fact is well supported by the higher positive value of **coefficient** of correlation (+0.863), which is significant at 0.001 level of significance. Generally, the area of the basin develops due to the headward erosion of streams. Thus it, is obvious that an increase

TABLE - 3.3

STREAMS LENGTHS (Kms)

S.No.	Basins	L1	L2	L3	ΣL
1.	Lauka Gad	6.50	2.50	1.50	10.50
2.	Najgaon Gad	2.50	2.00	1.50	6.00
3.	Chidamu Gad North	25.00	5.50	4.00	34.50
4.	Chidamu Gad South	31.25	16.25	4.00	51.50
5.	Girthi Gad	4.00	0.50	0.75	5.25
6.	Bambang Gad	17.00	3.50	4.40	24.90
7.	Girthi Dhura Gad	13.00	2.00	3.00	18.00
8.	Devkot Gad	9.00	4.25	1.50	14.75
9.	Dubrugetha Gad	31.50	7.50	4.00	43.00
10.	Rishikot Gad	9.00	1.00	2.00	12.00
11.	Margaon Gad	11.50	4.00	2.00	17.50
12.	Chubag Gad	16.50	2.00	4.00	22.50
13.	Lalbasani Gad	9.00	3.50	3.00	15.50
14.	Siraunch Gad	19.00	5.00	4.50	28.50
15.	Malari Gad	15.00	6.50	2.00	23.50
16.	Lower Malari Gad	16.00	3.00	0.75	19.75
17.	Garpak Gadhera	20.00	2.50	4.00	26.50
18.	Dunagiri Gad	31.00	7.50	4.00	42.50
19.	Lower Juma Gad	12.00	2.00	1.50	15.50
20.	Nandi Kund Gad	10.00	6.00	0.50	16.50
21.	Gankhwi Gadhera	31.50	7.00	5.50	44.00
22.	Pangti Gadhera	13.00	3.50	2.50	19.00
23.	Juma Gad	32.00	4.00	6.50	42.50
24.	Nauti Gadhera	22.50	5.00	4.50	32.00
25.	Lata Kharak Gadhera	7.50	2.00	1.00	10.50
26.	South Paing Gad	3.00	0.50	1.00	4.50
27.	Raunthi Gadhera II	4.50	0.50	0.50	5.50
28.	Raunthi Gadhera III	7.50	1.00	1.00	9.50
29.	Chamba Kharak Gad	29.00	10.00	3.50	42.50
30.	Raunthi Gadhera I	9.00	1.00	0.50	10.50
31.	Subhain Gad	22.00	8.50	4.00	34.50
32.	Ringi Gad	20.00	2.50	5.00	27.50
33.	Tapoban Hot Spring Gad	5.50	4.00	2.50	12.00
34.	Regri Gad	11.50	2.50	3.50	17.50
35.	Gadi Gadhera	20.00	5.50	5.00	30.50
36.	West Tolma Gad	14.00	5.00	3.00	22.00
37.	Juwagwar Gad	13.50	4.00	2.50	20.00
38.	Bhangyul Gad	31.00	6.50	7.00	44.50
39.	Lower Hom Gadhera	17.50	6.00	3.00	26.50
40.	Hom Gadhera	45.00	15.00	7.50	67.50

in the stream length will increase the area and vice-versa.

Horton was the first person who observed through his studies of stream length hierarchy that the mean length of stream segments of a given order increases exponentially with increasing order, which is called the second law of stream length. This fact is very much clear from the Table 3.4 which exhibits the mean length of stream segments (R1) which is calculated by the following formula:-

Mean length of segments * R1 = $\frac{\bar{L}U}{\bar{L}u\text{-}1}$, while $\bar{L}\ u = \frac{\Sigma L\ \ U}{N\ \ u}$

Where, $\bar{L}$ u = mean length of all segments of u order

NU = number of stream segments of u order

the mean length of all 40 drainage basins varies from 0.40 km (lowest) for Girthigad to 1.52 km (highest) for lower Malarigad. The mean length considerably varies within differnt orders of the basin. For example, shortest mean length for first order segments is registered as 0.28 km for Najgaongad and longest 1.60 km for lower Malarigad. In second order streams 0.25 km is the shortest length occupied by Girthigad. Rishkotgad, South Painggad and Raunthigadhera. Maximum length of 1.50 km is noted for lower Malarigad. In the same way for third order segments shortest length is registered by Nandi-kundgad (0.50 km) Raunthigadhera II (0.50 km) and Raunthigadhera I (0.50 km) and longest third order stream is Homgadhera (7.50 km). This indicates that the lower Malarigad is the basin which

TABLE - 3.4

MEAN LENGTHS ($\bar{L}u$) OF STREAM SEGMENTS (Kms)

S.No.	Basins	$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}$
1.	Lauka Gad	0.59	0.83	1.50	0.70
2.	Najgaon Gad	0.28	0.67	1.50	0.46
3.	Chidamu Gad North	0.54	1.10	4.00	0.66
4.	Chidamu Gad South	0.61	1.35	4.00	0.81
5.	Girthi Gad	0.40	0.25	0.75	0.40
6.	Bambanag Gad	0.63	0.58	4.40	0.73
7.	Girthi Dhura Gad	0.57	0.67	3.00	0.67
8.	Devkot Gad	0.45	0.85	1.50	0.57
9.	Dubrugetha Gad	0.67	1.07	4.00	0.78
10.	Rishikot Gad	0.69	0.25	2.00	0.67
11.	Margaon Gad	0.89	1.33	2.00	1.03
12.	Chubag Gad	1.18	0.50	4.00	1.18
13.	Lalbasani Gad	0.82	0.88	3.00	0.97
14.	Siraunch Gad	1.06	1.25	4.50	1.24
15.	Malari Gad	0.79	1.30	2.00	0.94
16.	Lower Malari Gad	1.60	1.50	0.75	1.52
17.	Garpak Gadhera	1.25	0.63	4.00	1.26
18.	Dunagiri Gad	1.41	1.07	4.00	1.42
19.	Lower Juma Gad	1.10	0.67	1.50	1.03
20.	Nandi Kund Gad	1.11	2.00	0.50	1.27
21.	Gankhwi Gadhera	0.98	1.40	5.50	1.16
22.	Pangati Gadhera	1.00	1.17	2.50	1.12
23.	Juma Gad	1.07	1.00	6.50	1.21
24.	Nauti Gadhera	0.83	0.83	4.50	0.97
25.	Lata Kharak Gadhera	0.54	1.00	1.00	0.62
26.	South Paing Gad	0.75	0.25	1.00	0.64
27.	Raunthi Gadhera II	0.56	0.25	0.50	0.50
28.	Raunthi Gadhera III	0.75	0.50	1.00	0.73
29.	Chamba Kharak Gad	0.81	1.11	3.50	0.92
30.	Raunthi Gadhera I	1.50	0.50	0.50	1.17
31.	Subhain Gad	0.92	1.42	4.00	1.11
32.	Ringi Gad	0.80	0.50	5.00	0.89
33.	Tapoban Hot Spring Gad	0.79	2.00	2.50	1.20
34.	Regri Gad	0.77	0.83	3.50	0.92
35.	Gadi Gadhera	0.83	1.38	5.00	1.13
36.	West Tolma Gad	0.74	1.00	3.00	0.88
37.	Juwagwar Gad	0.64	1.00	2.50	0.77
38.	Bhangyul Gad	0.72	0.81	7.00	0.86
39.	Lower Hom Gadhera	0.67	1.00	3.00	0.80
40.	Hom Gadhera	0.66	1.15	7.50	0.82

has highest mean length for the first and second order segments and subsequently highest meanstream length for all orders among all 40 basins.

The regression lines have been plotted on semi log graph paper to test the law of stream length of positive exponential function model of Horton as below:-

$$\text{Log } Y = \log a + b X$$

Where Y = cummulative mean stream length

X = Stream order

b = regression coefficient

a = constant

Positive exponential function model = $\bar{L}u + \bar{L}_1 \quad Rl^{(u-1)}$

Where $\bar{L}_1$ = mean length of first order segments

Rl = constant length ratio

'The cumulative mean lengths of stream segments increase in geometrical progression with successive increase in stream orders with constant length ratio' (Horton)[1]. All but (Table 3.5) viz Najgaongad, Devkotgad, Margaongad, Malarigad Lower Malarigad, Nandikundgad, Lata Harak Gadhera and Tapoban Hot Springgad basins show the validity of positive exponential function model. These 8 basins show deviation

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1. R.A. Horton, (1945), op.cit.

TABLE - 3.5

MEAN LENGTH RATIOS (R$\bar{L}$)

S.No.	Basins	$\bar{L}_2/\bar{L}_1$	$\bar{L}_3/\bar{L}_2$	$\bar{R}_L$
1.	Lauka Gad	1.41	1.80	1.61
2.	Najgaon Gad	2.40	2.25	2.32
3.	Chidamu Gad North	2.03	3.64	2.83
4.	Chidamu Gad South	2.50	2.95	2.73
5.	Girthi Gad	0.63	3.00	1.81
6.	Bambanag Gad	0.93	7.55	4.24
7.	Girthi Dhura Gad	1.18	4.98	3.08
8.	Devkot Gad	1.89	1.77	1.83
9.	Dubrugetha Gad	1.60	3.74	2.67
10.	Rishikot Gad	0.36	8.00	4.18
11.	Margaon Gad	1.51	1.50	1.50
12.	Chubag Gad	0.42	8.00	4.22
13.	Lalbasani Gad	1.07	3.43	2.25
14.	Siraunch Gad	1.18	3.60	2.39
15.	Malari Gad	1.65	1.54	1.59
16.	Lower Malari Gad	0.94	0.50	0.72
17.	Garpak Gadhera	0.50	6.40	3.45
18.	Dunagiri Gad	0.76	3.74	2.25
19.	Lower Juma Gad	0.61	2.25	1.43
20.	Nandi Kund Gad	1.80	0.25	1.03
21.	Gankhwi Gadhera	1.42	3.93	2.68
22.	Pangti Gadhera	1.17	2.14	1.66
23.	Juma Gad	0.94	6.50	3.72
24.	Nauti Gadhera	1.00	5.40	3.20
25.	Lata Kharak Gadhera	1.87	1.00	1.43
26.	South Paing Gad	0.33	4.00	2.17
27.	Raunthi Gadhera II	0.44	2.00	1.22
28.	Raunthi Gadhera III	0.67	2.00	1.33
29.	Chamba Kharak Gad	1.38	3.15	2.26
30.	Raunthi Gadhera I	0.33	1.00	0.67
31.	Subhain Gad	1.55	2.82	2.18
32.	Ringi Gad	0.63	10.00	5.31
33.	Tapoban Hot Spring Gad	2.55	1.25	1.90
34.	Regri Gad	1.09	4.20	2.64
35.	Gadi Gadhera	1.65	3.64	2.64
36.	West Tolma Gad	1.36	3.00	2.18
37.	Juwagwar Gad	1.56	2.50	2.03
38.	Bhangyul Gad	1.13	8.61	4.87
39.	Lower Hom Gadhera	1.49	3.00	2.24
40.	Hom Gadhera	1.74	6.50	4.12

from the above mentioned hypothesis. The Table 3.4 at a glance proves the fact that the mean length of stream segments increase with increase in stream order. But the regression lines (Fig 3.3) clearly exhibit that the increase in mean length do not form the geometric series as the points extremely deviate from the fitted lines. Thus, it does not prove Horton's postulation that the increasing mean length of segments with the increasing order form a geometric series. It has been proved as in Chapter II by taking the entire drainage net work into account.

On the basis of the above discussion it may be concluded that the length of stream segments is directly associated with the basin area and vice versa. It proves that the mean length of segments increase with increasing order as it is apparent from the correlation Table 3.2 between order and corresponding mean stream length where all values are significant at 0.01 level of significance. But it does not prove Horton's postulation of 'geometric series'.

BIFURCATION RATIO

Bifurcation ratio is the ratio of the total number of streams of one order to that of the next higher order. The bifurcation ratio is obtained by the following equation.

$$\text{Bifurcation ratio} = Rb = \frac{Nu}{Nu + 1}$$

Where, N = number of streams

U = stream order

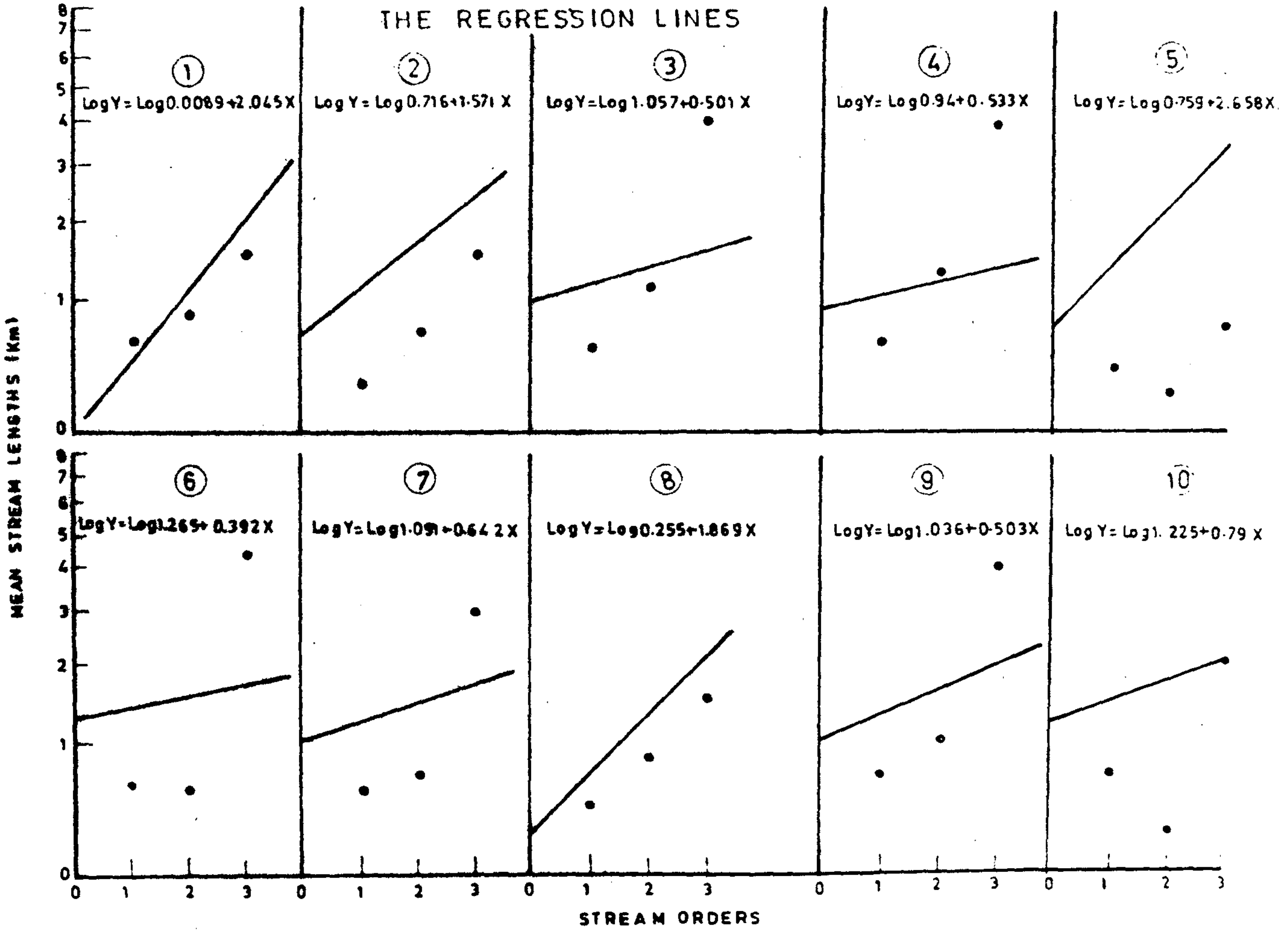
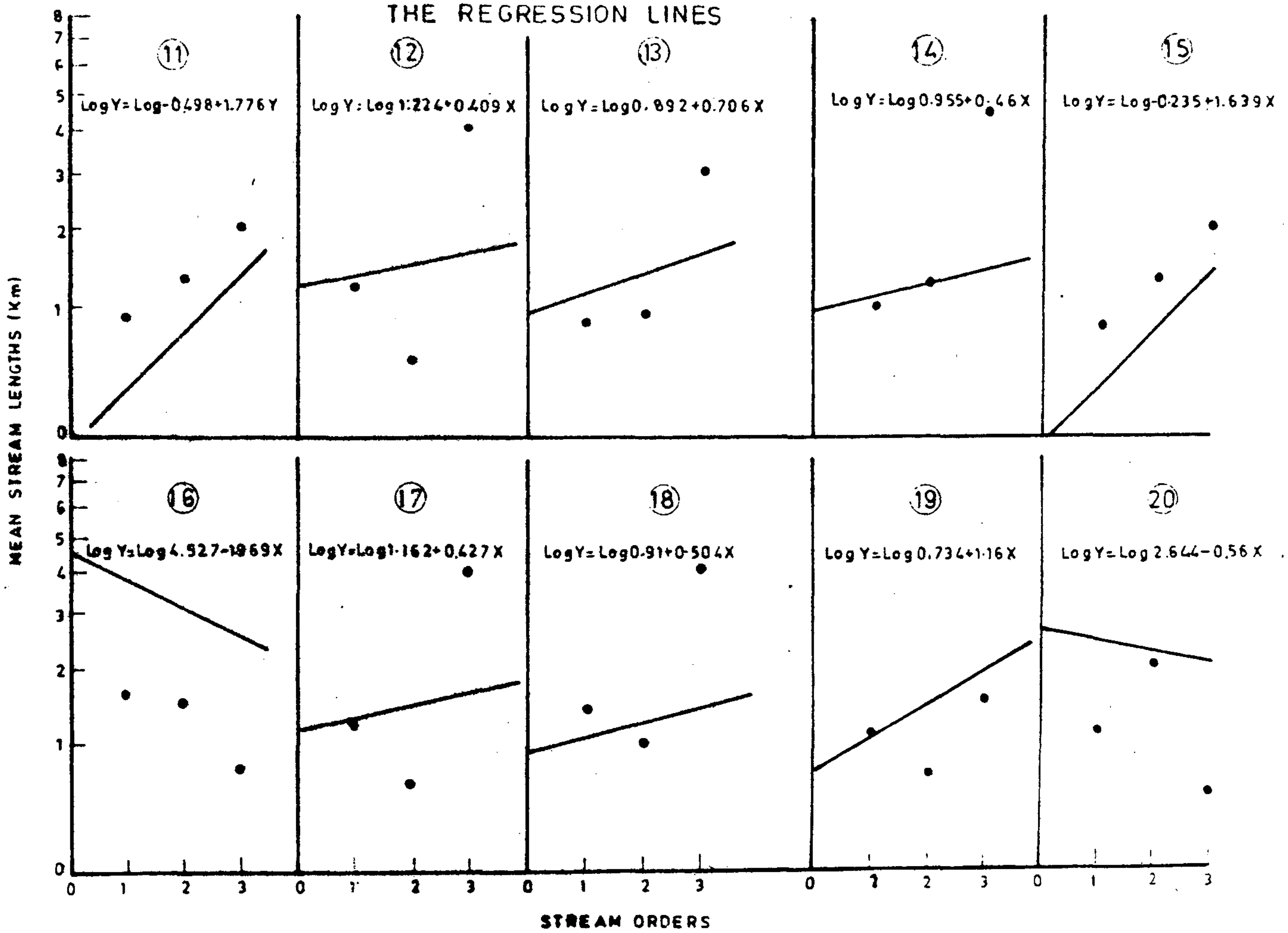

THE REGRESSION LINES
①
LogY = Log0.0089+2.045X
②
Log Y = Log 0.716+1.571 X
③
LogY=Log 1.057+0.501 X
④
LogY= Log 0.94+0.533X
⑤
Log Y= Log 0.759+2.658X
⑥
LogY=Log1.265+ 0.392 X
⑦
Log Y= Log1.091+0.642 X
⑧
Log Y=Log0.255+1.869 X
⑨
LogY= Log1.036+0.503X
10
Log Y= Log1. 225+0.79 X
MEAN STREAM LENGTHS (Km)
8
7
6
5
4
3
2
1
0
STREAM ORDERS
0
1
2
3

FIG.-3.3



THE REGRESSION LINES

FIG.-3.3

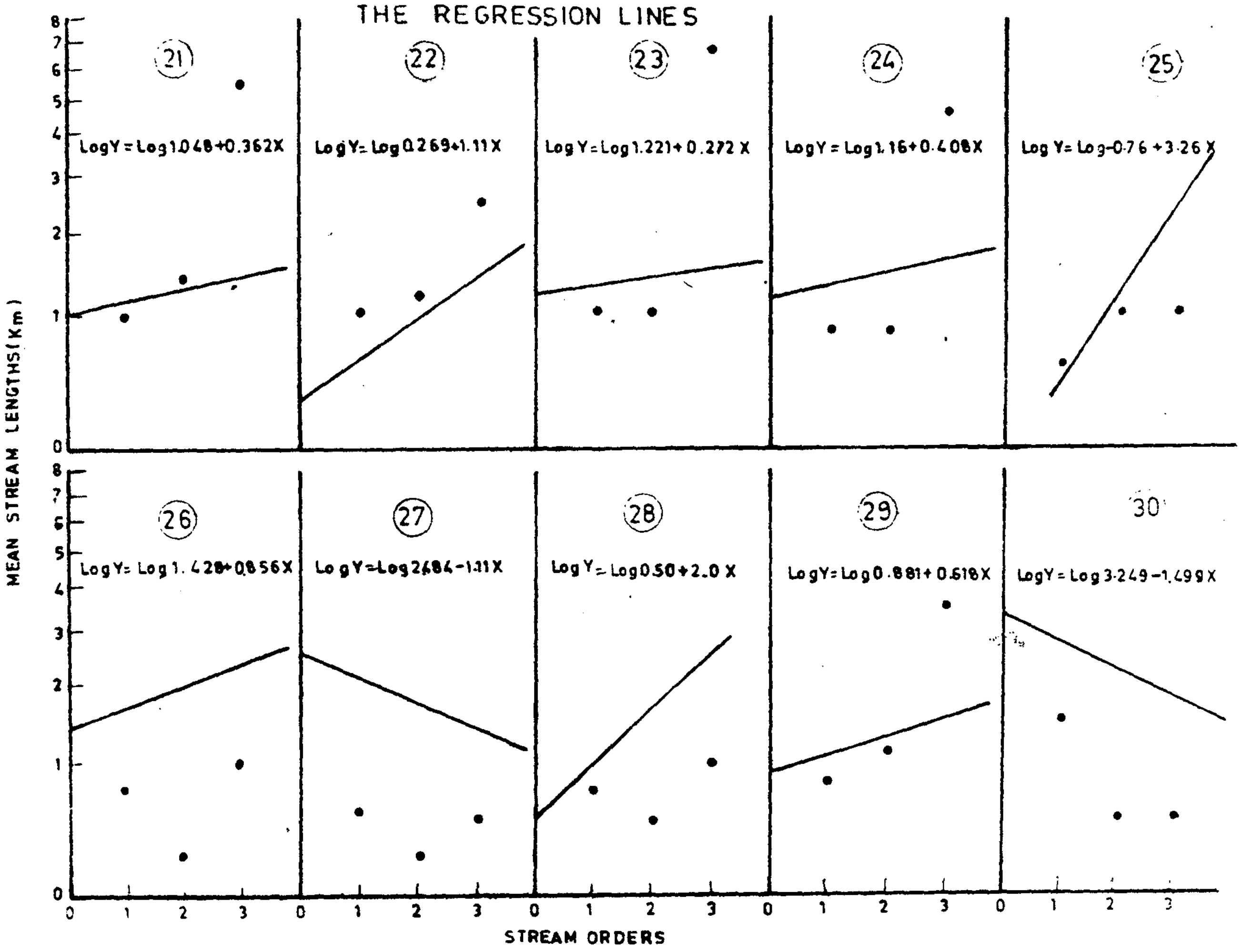

THE REGRESSION LINES
MEAN STREAM LENGTHS (Km)
STREAM ORDERS
0
1
2
3
4
5
6
7
8
21
LogY = Log1.048+0.362X
22
LogY= Log0.269+1.11X
23
LogY = Log1.221+0.272 X
24
LogY = Log1.16+0.408X
25
Log Y= Log-0.76 +3.26 X
26
LogY= Log 1.428+0.856X
27
LogY=Log2.484-1.11X
28
LogY= Log0.50+2.0 X
29
LogY=Log0.881+0.618X
30
LogY = Log 3.249-1.499 X

FIG.-3.3

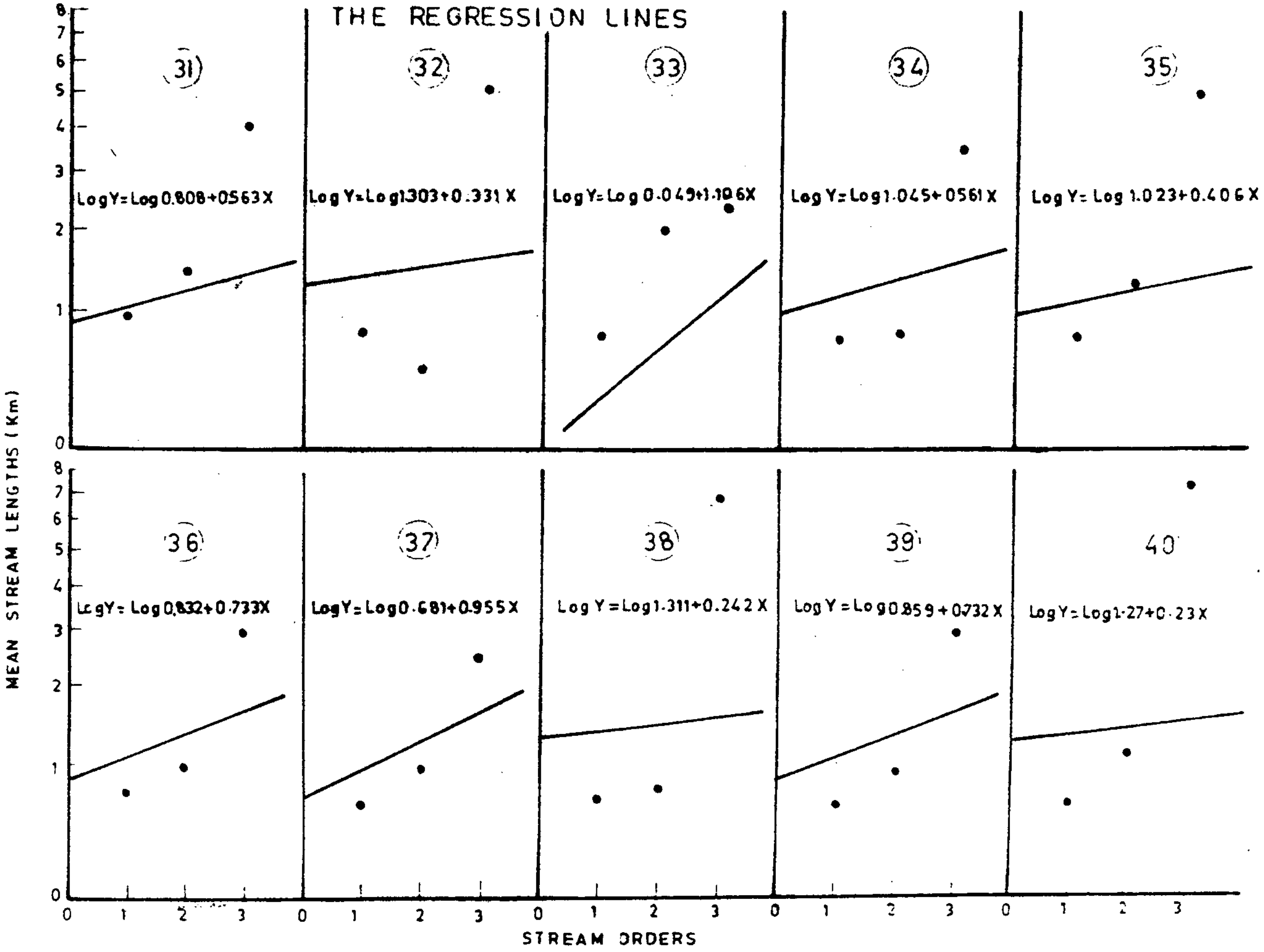

THE REGRESSION LINES
31
LogY=Log0.808+0563X
32
LogY=Log1303+0.331X
33
LogY=Log0.049+1.196X
34
LogY=Log1.045+0561X
35
LogY=Log1.023+0.406X
36
LogY=Log0.832+0.733X
37
LogY=Log0.681+0.955X
38
LogY=Log1.311+0.242X
39
LogY=Log0.859+0.732X
40
LogY=Log1.27+0.23X
MEAN STREAM LENGTHS (Km)
0
1
2
3
4
5
6
7
8
STREAM ORDERS

FIG.-3.3

Several studies so far have pointed out that the bifurcation ratio in different physiographic conditions generally tends to vary between 3 and 5, with an usual value around 4. Schumm[1] has suggested that the bifurcation ratio of different stream orders tends to grow in a geometric series. Coats[2] in his study observed that 'minimum possible ratio of 2.0 is seldom approached in nature, lying between about 3.0 and 5.0 in basins without differential geological controls and only reaching higher values where geological controls favour the development of elongated narrow basins'. This general tendency is confirmed to a large extent by the present study. The Table 3.6 clearly reveals the fact that 22 drainage basins out of all 40 basins, have the average bifurcation ratio (Rb) between 3.0 and 5.0. Remaining 18 basins, which have a deviation from the above mentioned general rule, may be divided into the two categories - 3 basins viz south Painggad (2.0), Raunthi Gadhera I (2.50) and Tapoban Hot Springgad (2.75) have mean bifurcation ratio below 3.0 and the rest of 15 basins viz Chidamugad North (7.10), Chidamugad South (8.13), Bambanaggad (5.25), Girthidhuragad (5.16) Dubrugethagad (6.86), Dunagirigad (5.07),

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1. S.A. Chumm, (1956), op.cit, p. 597-646.

2. D.R. Coats, (1958), op.cit.

TABLE- 3.6

BIFURCATION RATIOS (Rb)

S.No.	Basins	N_1/N_2	N_2/N_3	$\bar{R}$b
1.	Lauka Gad	3.66	3.00	3.33
2.	Najgaon Gad	3.00	3.00	3.00
3.	Chidamu Gad North	9.20	5.00	7.10
4.	Chidamu Gad South	4.25	12.00	8.13
5.	Girthi Gad	5.00	2.00	3.50
6.	Bambanag Gad	4.50	6.00	5.25
7.	Girthi Dhura Gad	7.33	3.00	5.16
8.	Devkot Gad	4.00	5.00	4.50
9.	Dubrugetha Gad	6.71	7.00	6.86
10.	Rishikot Gad	3.25	4.00	3.63
11.	Margaon Gad	4.33	3.00	3.67
12.	Chubag Gad	3.50	4.00	3.75
13.	Lalbasani Gad	2.75	4.00	3.78
14.	Siraunch Gad	4.50	4.00	4.25
15.	Malari Gad	3.80	5.00	4.40
16.	Lower Malari Gad	5.00	2.00	3.50
17.	Garpak Gadhera	4.00	4.00	4.00
18.	Dunagiri Gad	3.14	7.00	5.07
19.	Lower Juma Gad	3.66	3.00	3.33
20.	Nandi Kund Gad	3.00	3.00	3.00
21.	Gankhwi Gadhera	6.40	5.00	5.70
22.	Pangti Gadhera	4.33	3.00	3.67
23.	Juma Gad	7.50	4.00	5.75
24.	Nauti Gadhera	4.50	6.00	5.25
25.	Lata Kharak Gadhera	7.00	2.00	4.50
26.	South Paing Gad	2.00	2.00	2.00
27.	Raunthi Gadhera II	4.00	2.00	3.00
28.	Raunthi Gadhera III	5.00	2.00	3.50
29.	Chamba Kharak Gad	4.00	9.00	6.50
30.	Raunthi Gadhera I	3.00	2.00	2.50
31.	Subhain Gad	4.00	6.00	5.00
32.	Ringi Gad	5.00	5.00	5.00
33.	Tapoban Hot Spring Gad	3.50	2.00	2.75
34.	Regri Gad	5.00	3.00	4.00
35.	Gadi Gadhera	6.00	4.00	5.00
36.	West Tolma Gad	3.80	5.00	6.90
37.	Juwagwar Gad	5.22	4.00	5.11
38.	Bhangyul Gad	5.38	8.00	6.69
39.	Lower Hom Gadhera	4.33	6.00	5.17
40.	Hom Gadhera	5.23	13.00	9.12

Gankhwi Gadhera (5.70), Jumagad (5.75), Nautigadhera (5.25), Chamba Kharakgad (6.50) West Tolmagad (6.90) Juwagwargad (5.11), Bhangyulgad (6.69), lower Homgadhera (5.17) and Homgadhera (9.12) have bifurcation ratios above 5.0. This departure from the general law is due to extremely high relief ratio and absolute relief. High absolute relief provides a few favourable conditions for the development of segments. A poor positive coefficient of correlation (+0.401) between mean bifurcation ratio and absolute relief indicates that high absolute relief with high relief ratio favour the more branching phenomenon of streams to some extent. The values of mean bifurcation ratio for all the basins either lying on sedimentary rocks formation of Tethys or schist and gneiss dominant metamorphic structure, show that geological formation does not have a strong control over the branching system of streams. This follows the results of Padmaja[1] whose study of bifurcation ratio over different lithological groups conclude the same.

It is apparent from the Table 3.6 that the bifurcation ratio is lower in higher order streams in comparison to lower order streams. Albeit it is not safe to establish any relationship on the basis of such few observations, yet this

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[1] G. Padmaja, (1974), op.cit. p. 110-140.

general trend of bifurcation ratios confirm the Givsti and Schneider's hypothesis[1] that bifurcation ratios with in a basin decrease with the increasing order

$Rb1 > Rbk$

Where, k = successive increasing order

The Table (3.6) clearly reveals the above mentioned fact as 24 basins have higher bifurcation ratio between first and second order and lower between second and third order segments. Whereas the rest of the 16 basins (Chidamugad South, Bambanaggad, Devakotgad, Dubrugethagad, Rishikotgad, Chubaggad, Lalbasanigad, Malarigad, Dunagirigad, Nautigadhera, Chambakharagad, Subhaingad, West Tolmagad, Jumagwargad, Bhangyulgad, lower Homgadhera and Homgadhera) show a constant increase in bifurcation ratio with the increase in stream order. The probable reason for this deviation from the aforesaid postulation in basins of Tethys formation may be the sedimentary formation, which facilitate more branching phenomenon in increasing orders.

Albeit average values of 24 drainage basins meet the general trend of natural stream network, yet some enormous

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1. E.V. Giusti and W.J. Schneider, (1965) "The Distribution of Branches in River Networks" U.S. Geological Survey, Professional paper, 442-G.

deviations in the values of bifurcation ratios are also registered. The maximum mean bifurcation ratio is also registered. The maximum mean bifurcation ratio of south Painggad (2.0) is also guided by the smaller basin area (1.85 km^2). The results of the study are directly contradictory to Singh et al's[1] study but strongly confirm Giusti and Schneider's[2] postulation that bearing of equal order but variable areas tend to have the smallest bifurcation ratio in the smallest area; the ratio increases with increasing area upto certain size beyond which the bifurcation ratios tend to become constant. The positive coefficient of correlation between a basin area and mean bifurcation ratio at + 0.596, significant at 0.01 level of significance, provides a strong support to the above mentioned hypothesis. The poor correlation of mean bifurcation ratio with absolute relief (+ 0.36), relief ratio (+ 0.279), average slope (+0.013), drainage density (+ 0.148) and drainage frequency (+0.001) clearly indicate that bifurcation ratio is not governed by these factors. The values of coefficient of correlation of mean bifurcation ratio with number **of** stream (+ 0.95), stream length (+ 0.871), texture ratio (+ 0.683)

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1. S. Singh, D.P. Upadhaya, (1981), op.cit.

2. E.V. Giusti and W.J. Schneiden, (1965), op.cit.

and basin parimeter (+ 0.62) show a strong control over the mean bifurcation ratio. Yet the impact of geological formation, plant cover and climate on mean bifurcation ratio can not be ignored completely,

CONSTANT OF CHANNEL MAINTENANCE:

The constant of channel maintenance (C.C.M.) is inverse of drainage density and it always is expressed in square kilometers. This may be obtained by the following formula:-

$$\text{Constant of channel maintenance} = \frac{1}{D}$$

Where, D = Drainage density

This is a measure of drainage texture similar to the drainage density and expresses the distance for the development and maintenance of stream lines as well as the intensity of surface erosion. The Table 3.7 reveals that the values of constant of channel maintenance range from 0.24 km^2 lowest for Girthidhuragad to 0.82 km^2 highest for Nandikundgad basin. This low range of values of constant of channel maintenance clearly speaks that the basins posses fine textured topography and high drainage density and frequency (Appendix IV). The said Table 3.7 also reveals the fact that the values of constant of channel maintenance are lower in the basins which drain over the sedimentary rocks formation viz Laukagad(0.31), Najgaongad (0.45), Chidamugar North (0.32) Chidamugad South (0.31), Girthigad (0.35), Bambanaggad (0.37) Girthidhuragad (0.24), Darckotgad (0.26), Dubrugethagad (8.31), Rishikot-

TABLE - 3.7

CONSTANTS OF CHANNEL MAINTENANCE(Km^2)

S.No.	Name of the Basin	C.C.M.
1.	Lanka Gad	0.31
2.	Najgaon Gad	0.45
3.	Chidamu Gad North	0.32
4.	Chidamu Gad South	0.31
5.	Girthi Gad	0.35
6.	Bambanag Gad	0.33
7.	Girthi Dhura Gad	0.24
8.	Devkot Gad	0.26
9.	Dubrugetha Gad	0.31
10.	Rishikot Gad	0.36
11.	Margaon Gad	0.49
12.	Chubag Gad	0.58
13.	Lalbasani Gad	0.52
14.	Siraunch Gad	0.81
15.	Malari Gad	0.44
16.	Lower Malari Gad	0.67
17.	Garpak Gadhera	0.72
18.	Dunagiri Gad	0.72
19.	Lower Juma Gad	0.39
20.	Nandi Kund Gad	0.82
21.	Gankhwi Gadhera	0.73
22.	Pangti Gadhera	0.51
23.	Juma Gad	0.57
24.	Nauti Gadhera	0.62
25.	Lata Kharak Gadhera	0.31
26.	South Paing Gad	0.41
27.	Raunthi Gadhera II	0.31
28.	Raunthi Gadhera III	0.38
29.	Chmba Kharak Gad	0.43
30.	Raunthi Gadhera I	0.68
31.	Subhain Gad	0.40
32.	Ringi Gad	0.40
33.	Tapoban Hot Spring Gad	0.44
34.	Regri Gad	0.57
35.	Gadi Gadhera	0.64
36.	West Tolma Gad	0.47
37.	Juwagwar Gad	0.43
38.	Bhangyul Gad	0.41
39.	Lower Hom Gadhera	0.38
40.	Hom Gadhera	0.52

gad (8.36), Margaongad (0.49), Chubaggad (0.98) and Lalbasanigad (0.52), while it is higher in the rest of basins lying over the gneiss and schist rocks of metamorphic formation. The reason for this difference is that the sedimentary rock formation provides enough facilities for the growth and development of stream net work and thus the basins of this formation posses high drainage density and frequency, while gneiss and schist force the streams to flow along the joints and thus it is detrimental in the growth and development of streams. It is auxiomatic to deduce the higher drainage density and frequency are inversely associated with the constant of channel maintenance (Appendix II). The negative values of coefficient of correlation of CCM with drainage density and drainage frequency standing at -0.944 and -0.831, respectively are significant at 1% probable level of significance. It strongly supports the findings of Padmaja[1] that the channels require less space to flow over soft rocks formation than hard rocks.

Albeit it is very much clear from the analysis that CCM is highly controlled by the underlying lithological formations yet some other geomorphic variables also show significant correlation with it. Mean stream length has

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1. G. Padmaja, (1976), op.cit, p. 110-140.

a positive strong correlation standing at + 0.798 is significant at 1% probable level of significance.

It may be concluded by the above discussion that constant of channel maintenance is governed by the underlying lithological formation, geological structure and nature of the configuration.

LENGTH OF OVERLAND FLOW:

Similar to the constant of channel maintenance length of overland flow is also an important hydrologica and marphometric factor. This also provides an account of drainage line spacing. The length of overland flow is 'the mean harizontal length of flow path from the divide to the stream in a first order basin and is a measure of stream spacing and degree of dissection and is approximately one-half the reciprocal of the drainage density (Chorley).[1] The length of overland flow in the present study has been calculated as the 'reciprocal of twice the drainage density as suggested by Horton[2] and it is always expressed in kilometers. It may be calculated by the following **formula**.

$$\text{Length of overland flow} = Lg = \frac{1}{2D}$$

Where, D = drainage density

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1. R.J. Chorley, (1969), op.cit.
2. R.E. Horton, (1945), op.cit.

As the calculation of length of overland flow (Lg) involves the drainage density so it is obvious that it has effective relations with drainage density and constant of channel maintenance. It is apparent from the Table 3.8 that the values of Lg are just half of the constant of channel maintenance.

The said Table 3.8 clearly indicates that the values of Lg range from 0.12 km lowest for Girthidhuragad to 0.41 km, highest for Nandikundgad. The spatial analysis of Lg of 40 drainage basins mark a significant variation in the values of Lg draining over different lithological formations. The values of Lg of basins draining over the sedimentary rocks formation of Tethys zone viz Laukagad (0.15), Najgaongad (0.22), Chidamugad North (0.16), Chidamugad South (0.15), Girthigad (0.17), Bambanaggad (0.16), Girthidhuragad (0.12), Devkotgad (0.13), Dubrugethagad (0.15), Rishikotgad (0.18), Margaongad (0.24), Chubaggad (0.29) and Lalbasanigad (0.26) register the low values while rest of the basins draining over metamorphic formation show higher values of Lg.

It is also of the same behaviour as the constant of channel maintenance. The soft rock formation provides suitable conditions for the headward erosion and thus length the streams. While gneiss and schist force the streams to flow along the joints and keep the drainage density minimum. So, it is auxiomatic to deduce the drainage density which is

TABLE - 3.8

LENGTHS OF OVERLAND FLOW (Kms)

S.No.	Basins	Lg
1.	Lanka Gad	0.15
2.	Najgaon Gad	0.22
3.	Chidamu Gad North	0.16
4.	Chidamu Gad South	0.15
5.	Girthi Gad	0.17
6.	Bambanag Gad	0.16
7.	Girthi Dhura Gad	0.12
8.	Devkot Gad	0.13
9.	Dubrugetha Gad	0.15
10.	Rishikot Gad	0.18
11.	Margaon Gad	0.24
12.	Chubag Gad	0.29
13.	Lalbasani Gad	0.26
14.	Siraunch Gad	0.40
15.	Malari Gad	0.22
16.	Lower Malari Gad	0.33
17.	Garpak Gadhera	0.36
18.	Dunagiri Gad	0.36
19.	Lower Juma Gad	0.19
20.	Nandi Kund Gad	0.41
21.	Gankh'wi Gadhera	0.36
22.	Pangti Gadhera	0.25
23.	Juma Gad	0.28
24.	Nauti Gadhera	0.31
25.	Lata Kharak Gadhera	0.15
26.	South Paing Gad	0.20
27.	Raunthi Gadhera II	0.15
28.	Raunthi Gadhera III	0.19
29.	Chamba Kharak Gad	0.21
30.	Raunthi Gadhera I	0.34
31.	Subhain Gad	0.20
32.	Ringi Gad	0.20
33.	Tapoban Hot Spring Gad	0.22
34.	Regri Gad	0.28
35.	Gadi Gadhera	0.32
36.	West Tolma Gad	0.23
37.	Jumagwar Gad	0.21
38.	Bhangyul Gad	0.20
39.	Lower Hom Gadhera	0.19
40.	Hom Gadhera	0.26

inversely associated with the Lg in relation to underlying lithological conditions.

The spatial analysis of the distribution of Lg reveals the fact that basins of early mature to mature stage of basin development have relatively higher values of Lg (lower Jumagad 0.19), Bangtigadhera 0.25, Jumagad 0.28, Nautigadhera 0.31, Subhaingad. 0.20, Regrigad 0.20, Gadigadhera 8.32 and Juwagwargad 0.21). This is supported by the negative coefficient of correlation value (-0.284) between Lg and hypsometric integral, although not significant. This relationship directly contradicts the postulation of Coates[1] that 'other factors being constant, areas more advanced into maturity appear to contain smaller overland flow than youthful areas'. These results follow the hypothesis of Singh[2] that 'since a drainage basin on an average develops maximum stream segments in its late youth and early mature stages, hence, minimum length of overland flow must be found'.

The length of over land flow has strong positive correlation with mean length of segments (+0.80) and strong negative correlation (-0.83) with drainage frequency which is directly contradictory to the results of Singh et al[3]. Because drainage density and drainage frequency

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1. D.R. Coates, (1958), op.cit.
2. S. Singh, (1978), op.cit.
3. S. Singh, D.P. Upadhyay, (1981), op.cit, 218-20.

are strongly positively correlated (+ 0.893), therefore, both will have negative correlation with Lg shows poor negative correlation with dissection index (-0.252), ruggedness (-0.265), relative relief (-0.259) and a bit higher positive correlation (+ 0.297) with absolute relief.

On the basis of the above discussions it may be concluded that Lg is governed by underlying lithological structure and drainage texture. Yet the impacts of vegetal cover and climate cannot be ignored.

SHAPES OF THE OPEN LINK

Rivers display a continuum of patterns from straight to sinuous and highly sinuous. The meaning of sinuosity of rivers is associated with bending, winding, curving and deviating of the same. The nature of river course exhibits the stages of basin development and reflects the age, topography and underlying lithological background. All streams possess some amount of sinuosity and it may be supposed that the expected path of the river will follow a straight line but practically no where it exists in the nature. Thus, the shapes of the open link in terms of geometric structure of drainage not work involves the calculation of deviation of observed course (Ol) from the expected course (El) of a river from its source to mouth. The course of a river is governed by various causative factors viz. geological and hydraulic controls, dip, slopes, absolute relief, relative relief, dissection index, stage of valley development, vegetal cover etc. which force the drainage lines to deviate from its straight line of expected path. Generally, the river courses are classified into three categories viz (i) straight river course (SS1 = 1.00) (ii) sinuous course (SSI = 1.0 to 1.5) and meandering course (SSI = >1.5) here it should be emphasized that any classification of stream sinuosity is arbitrary, and that a meandering stream may be of low sinuosity, perhaps as low as 1.2 if the channel displays a repeating pattern of bonds (Schumm).[1]

STANDARD SINUOSITY:

Standard sinuosity index as a determinant of the nature of the stream course has been analysed by geomorphologists as it is a ratio which is derived by dividing the channel length by the valley length (Mueller).[2]

$$SSI = \frac{CL}{VL}$$, SSI = Standard Sinuosity Index

Where,

CL = Channel length

VL = Valley length

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1. A. Schumm, (1977), opl cit, p. 113.
2. J.E. Muller, (1968), op.cit, p. 371-85.

The Table 3.9 clearly reveals that all rivers have sinuous courses as the values of sinuosity indices range between 1.02 lowest for Jumagad river and highest 1.13 for Chidamugad South and Nandikundgad rivers. It is apparent that no river of the study area has meandering course as the SSI of all 40 drainage basins does not exceed 1.50. Albeit it has been proved by hypsometric analysis that out of 40 drainage basins 9 basins viz. Lower Jumagad, Pangti Gadhera, Jumagad, Nautigadhera, Raunthi Gadhera II, Subhain Gad, Ringigad, Gadigahdera and Jumagwargad are in early mature stage of the basin development but the underlying crystalline structure of schists and gneisses of these basins is detrimental in the development of more sinuous courses by the small basins because the poor lineaments of the lithology force the running water to flow through the joints. They have developed at least sinuous courses where in Pangti Gadhera and Subhaingad reflect the highest value of SSI (1.10). Besides these 2 basins of early mature stage, 7 other basins viz Lower Jumagad (1.08), Jumagad (1.02), Nautigadhera(1.09), Raunthigadhera (1.04), Ringigad (1.04), Gadi Gadhera (1.07) and Juwagwargad (1.07) have low value of SSI which is an indicator of late youth stage to very early mature stage of the basin development. The highest value which is registered by Girthi Dhuragad (1.13) is due to the underlying sedimentary deposition of Tethys formation where hydraulic activities are dominating over the topographic conditions.

Table - 3.9

SINUOSITY INDICES

S.No.	Basins	CI	VI	HSI(%)	T SI (%)	SSI
1.	Lauka Gad	1.10	1.04	60.00	40.00	1.10
2.	Najgaon Gad	1.10	1.02	80.00	20.00	1.07
3.	Chidamu Gad North II	1.10	1.05	50.00	50.00	1.05
4.	Chidamu Gad South I	1.05	1.02	60.00	40.00	1.13
5.	Girthi Gad	1.13	1.05	61.50	38.46	1.09
6.	Bambang Gad	1.20	1.10	50.00	50.00	1.09
7.	Girthi Dhura Gad	1.17	1.04	76.47	23.53	1.13
8.	Devkot Gad	1.12	1.03	75.00	25.00	1.08
9.	Dubrugetha Gad	1.20	1.10	50.00	50.00	1.09
10.	Rishikot Gad	1.17	1.08	52.94	47.06	1.08
11.	Margaon Gad	1.10	1.04	60.00	40.00	1.06
12.	Chubag Gad	1.57	1.50	12.28	87.72	1.05
13,	Lalbasani Gad	1.06	1.01	83.33	16.67	1.05
14.	Siraunch Gad	1.11	1.07	36.36	63.64	1.03
15.	Malari Gad	1.08	1.04	50.00	50.00	1.04
16.	Lower Malari Gad	1.16	1.05	68.75	31.25	1.10
17.	Garpak Gadhera	1.27	1.13	51.85	48.15	1.12
18.	Dunagiri Gad	1.13	1.03	76.92	23.08	1.09
19.	Lower Juma Gad	1.17	1.08	52.94	47.06	1.08
20.	Nandikund Gad	1.20	1.07	65.00	35.00	1.13
21.	Gankhwi Gadhera	1.20	1.09	55.00	45.00	1.11
22.	Pangti Gadhera	1.17	1.06	64.71	35.29	1.10
23.	Juma Gad	1.08	1.06	25.00	75.00	1.02
24.	Nauti Gadhera	1.18	1.08	55.56	44.44	1.09
25.	Lata Kharak Gadhera	1.14	1.07	50.00	50.00	1.07
26.	South Paing Gad	1.14	1.04	71.43	28.57	1.10
27.	Raunthi Gadhera II	1.06	1.02	66.66	33.33	1.04
28.	Raunthi Gadhera III	1.07	1.03	57.14	42.86	1.03
29.	Chamba Harak Gad	1.25	1.19	24.00	76.00	1.05
30.	Raunthi Gadhera I	1.07	1.03	57.14	42.86	1.04
31.	Subhain Gad	1.16	1.06	62.50	37.50	1.10
32.	Ringi Gad	1.07	1.04	42.86	57.14	1.84
33.	Tapoban Hot Spring Gad	1.20	1.10	50.00	50.00	1.09
34.	Regri Gad	1.14	1.10	38.58	71.43	1.03
35.	Gadi Gadhera	1.23	1.15	53.33	65.22	1.07
36.	West Talma Gad	1.05	1.02	60.00	40.00	1.03
37.	Juwagwar Gad	1.06	1.02	66.66	33.33	1.07
38.	Bhangyul Gad	1.14	1.08	42.86	57.14	1.05
39.	Lower Hom Gadhera	1.18	1.12	33.33	66.66	1.05
40.	Hom Gadhera	1.23	1.12	47.82	52.17	1.09

Nandikundgad (1.13) also registers the equal value of SSI, while it drains over metamorphic structure of schists and gneiss. This high value of SSI is due to the control of vegetal cover and comparatively flattish nature of terrain having 39.62% low relief ratio, low degree of slope (9.07°) and high value of circularity ratio (0.87) which all strem then the hydraulic control. An another important factor which force the low SSI value to remain low is the gradual upliftment of the Himalaya. Therefore, all the rivers of the region are rejuvenated and are being forced to remain in youthful stage.

HYDRAULIC AND TOPOGRAPHIC SINUOSITY:

Hydraulic and topographic sinuosity indices are important marphometric attributes which enable to explore the stages of basin development and to determine the factors which govern the stream sinuosity. The hydraulic sinuosity index (HSI) is the percentage of a stream's departure from a straight-line course due to hydraulic variations within the valley and topographic sinuosity index (TSI) is the percentage of a stream's deviation from a straight-line expected due to topographic interference. The values for both indices have been calculated for all 40 drainage basins following Mueller's model as below:-

$$HSI = \%\ \text{equivalent of}\ \frac{CI - VI}{CI - 1}$$

$$TSI = \%\ \text{equivalent of}\ \frac{VI - 1}{CI - 1}$$

Where, $CI = \frac{CL}{Air\ L}$

$VI = \frac{VL}{Air\ L}$

Where, CI = Channel Index, VI = Valley Index

CL = Channel Length, VL = Valley Length

Air L = Shortest Length Between Source and Mouth

It is auxiomatic to deduce that topographic sinuosity (TSI) is outstanding in the youthful stage of the basin development, when hydraulic sinuosity (HSI) is negligible; conversely hydraulic sinuosity is high in senile stage after the most of topographic sinuosity has been removed. It is apparent from Table 3.9 that the value of TSI ranges between 16.67% lowest for Lalbasanigad and 87.72% highest for Chubaggad. Both basins lie over the sedimentery formation of Tethys zone. Lalbasanigad has low TSI due to the high rugged nature of configuration (Ruggedness 0.93) and a low value of form factor (0.32) which shows the elongated shape of the basin. These factors enhance the control of HSI while it is inverse in case of former basin. Out of all 40 basins only five basins viz. Najgaongad (HSI = 80.00%), Girthi Dhuragad (HSI = 76.47%), Devkotgad (HSI = 75.0%), Lalbasanigad (HSI = 83.33 %) and Dunagirigad (H = 76.92%) present the high domination of hydraulic sinuosity. The value of

HSI ranges between 12.28% lowest for Chubaggad (for which TSI is highest) and 83.33% highest for Lalbasanigad. Both lie on the same formation and causes of difference just have been discussed earlier. Only 3 basins viz Chubaggad (TSI = 87.72%), Jumagad (TSI = 75.0%) and Chambakharagkgad (TSI = 76.0%) have a high control of topographic sinuosity. On the other hand 6 basins exhibit equal control of hydraulic and topographic sinuosity viz Chidamugad II (HSI = TSI), Bambanggad (H SI = TSI), Dubrugethgad (HSI = TSI), Malarigad (HSI = TSI) Latkharkgaher (HSI = TSI) and Tapoban Hot Spring Gad (HSI = TSI) while other basins show a mixed effect of both indices, where one may be significant but the control of other cannot be ignored.

SHAPE OF THE CLOSE LINK :

The shape of the close link in terms of geometric structure of drainage is related to the external shape of the drainage basin. The geometrical structure of the basin shape determine the genetic aspects and reflects the control of lithological structure. In terms of theoretical concepts the drainage basin may possess a straight-line shape to a complete ciruclar shape but practically both extreme conditions are not possible because the shape of the drainage basin is governed by the geological formation, relief, slope aspects and lithological factors. Albeit the ideal shape of the basin is considered to be as pear shape but it is always disturbed by the aforesaid agents. The youthful mature and senile stages of the basin development are reflected in low, medium and high circularity indices, respectively. The geometry of the close link involves the drainage area, basin perimeter and the basin length to determine the shape of the drainage basin. In the present study shapes of all 40 drainage basins have been determined by using the four dimensionless shape indices as discussed below:-

i Form Factor (F)[1] (Horton, 1932)

$$F = \frac{A}{L^2}$$

Where , A = drainage basin area

L = length of the basin

ii Basin circularity (C) (Miller, 1953)[2]

$$Rc = \frac{\text{Area of the basin}}{\text{Area of the circle with same perimeter}}$$

Thus, $$\frac{4\pi A}{P^2}$$

Where, P = Basin Perimeter

iii. Elongation Ratio (E) (Schumm, 1956)[3]

$$E \quad \frac{\text{Diameter of circle with same area as basin}}{\text{Basin length}}$$

$$\text{Thus} = \frac{2\sqrt{A/\pi}}{L} = \frac{2}{\sqrt{\pi}}\sqrt{\frac{A}{L^2}}$$

$$= \frac{2}{\sqrt{\pi}} = \sqrt{F}$$

$$F = \frac{\pi}{4} \qquad R^2)$$

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1. R.E. Horton, (1932), opcit. p. 350-61.

2. V.C. Miller, (1953), op.cit. Report No. 6

3. S.A. Schumm, (1951), op.cit. p. 597-646.

or

iv. Lemniscate (k) (Chorley, Malmand, Pogorzeski, 1957)[3]	Based upon comparison of basin with lemniscat curve Thus $K = \frac{L^2}{4\pi}$

(The values of former three indices vary from 0(highly elongated or straight-line shape) to 1 (circular shape), while higher values of lemniscate (k) indicate elongated shape and lower values show circular shape.).

It is apparent from the Table 3.10 that Juwagwargad Basin has the most elogated shape as it is indicated by low values of form factor (F = 0.17), circularity ratio (C=0.48), Elongation ratio (R-0.47) and highest value of Lemniscate (K= 1.43), whereas Nandikundgad basin has the most circular shape by possessing higher values of Farm factor (F=0.75), Elongation ratio (R= 0.28), circularity ratio (C=0.87) and lowest value of lemniscate (K = 0.33). Taking into account the values of 'F' only 10 basins viz Girthidhuragad (0.27) Garpakgadhera (0.30), South Painggad (0.18), Raunthigadhera II) (0.27), Subhaingad (0.24), Ringigad (0.21), Tapoban Hot Spring Gad (0.19) Regrigad (0.26) (Juwagwargad (0.17) and Bhangyulgad (0.21) have elongated shapes as the values of their shape determinant 'F' are below 30% (0.30) Fourteen basins out of the remaining 30 basins have higher 'F' values i.e above 45% (0.45) viz Chidamugad I (0.58), Dubrugethagad (0.48), Margaongad (0.48), Chubaggad (0.73) Siraunchgad (0.47), Malarigad (0.46), Lower Malarigad (0.59),

TABLE - 3.10

SHAPE INDICES: FORM FACTOR (F.), ELONGATION RATIO(R), CIRCULARITY INDEX(C.) LEMNISCATE(K)

S.No	Basins	F.	R.	C.	K.
1.	Lauka Gad	0.43	0.74	0.83	0.59
2.	Najgaon Gad	0.43	0.54	0.80	0.58
3.	Chidamu Gad North	0.45	0.75	0.62	0.56
4.	Chidamu Gad South	0.58	0.86	0.90	0.43
5.	Girthi Gad	0.36	0.68	0.77	0.69
6.	Bambanag Gad	0.37	0.68	0.53	0.68
7.	Girthi Dhura Gad	0.27	0.58	0.54	0.93
8.	Devkot Gad	0.36	0.67	0.74	0.70
9.	Dubrugetha Gad	0.48	0.78	0.74	0.52
10.	Rishikot Gad	0.36	0.67	0.76	0.70
11.	Margaon Gad	0.48	0.73	0.82	0.52
12.	Chubag Gad	0.73	0.96	0.84	0.34
13.	Lalbasani Gad	0.32	0.64	0.77	0.78
14.	Siraunch Gad	0.47	0.78	0.73	0.53
15.	Malari Gad	0.46	0.76	0.84	0.54
16.	Lower Malari Gad	0.59	0.86	0.79	0.43
17.	Garpak Gadhera	0.30	0.61	0.63	0.84
18.	Dunagiri Gad	0.38	0.69	0.64	0.66
19.	Lower Juma Gad	0.52	0.81	0.84	0.48
20.	Nandi Kund Gad	0.75	0.98	0.87	0.33
21.	Gankhwi Gadhera	0.32	0.64	0.60	0.78
22.	Pangti Gadhera	0.36	0.78	0.73	0.69
23.	Juma Gad	0.32	0.63	0.69	0.79
24.	Nauti Gadhera	0.51	0.80	0.87	0.49
25.	Lata Kharak Gadhera	0.37	0.68	0.74	0.68
26.	South Paing Gad	0.18	0.48	0.55	1.38
27.	Raunthi Gadhera II	0.27	0.59	0.59	0.92
28.	Raunthi Gadhera III	0.40	0.71	0.80	0.63
29.	Chamba Kharak Gad	0.73	0.96	0.71	0.34
30.	Raunthi Gadhera I	0.39	0.71	0.74	0.63
31.	Subhain Gad	0.24	0.56	0.57	1.02
32.	Ringi Gad	0.21	0.51	0.48	1.20
33.	Topoban Hot Spring Gad	0.19	0.49	0.50	1.30
34.	Regri Gad	0.26	0.57	0.49	0.98
35.	Gadi Gadhera	0.46	0.77	0.80	0.54
36.	West Tolma Gad	0.46	0.76	0.77	0.55
37.	Juwagwar Gad	0.17	0.47	0.48	1.43
38.	Bhangyul Gad	0.21	0.52	0.47	1.17
39.	Lower Hom Gadhera	0.56	0.85	0.97	0.45
40.	Hom Gadhera	0.37	0.68	0.70	0.68

Lower Jumagad (0.52), Nandikundgad (0.75) Nautigadhera (0.51) Chambakharak Gad (0.73), Gadigadhera (0.46), West Tolmagad (0.46) and Lower Homgadhera (0.56) indicate more circular shapes of the basin as it is well exhibited by map (Fig -3.4) Rest 14 basins indicate semi-idented shapes having 'F' values between 30% to 45% (0.30 - 0.45).

The values of all four shape indices are proportional to each other except a few exceptions, as it is apparent from the correlation matrix (See Appendix II), but the explanatory range of each index is different. For instances Garpok Gadhera basin falls into the category of elongated shape having low 'F' value (0.30) but for the shape explanation of the same basin 'C' value stands as high as 0.63 and thus puts it into the category of circular shape, which does not look appropriate if we have a look at the physiographic map of the basins (Fig. 3.2). So, it may be considered that circularity ratio below 50% (0.50) indicates the elogated shape and above 70% (0.70) circular shape of the basin. On the basis of circularity ratio 'C& only five basins viz Ringigad (0.48), Tapoban Hot Spring Gad (0.50), Regrigad (0.49), Juwagawargad (0.48) and Bhangyulgad (0.47) fall in the category of elogated shapes as the 'C' values of these basins are below 50% (0.50). Whereas 17 basins viz Lauka Gad (0.83), Najgaongad (0.80, Chidamugad South(0.90), Girthigad (0.77), Rishikotgad (0.76), Margaon Gad (0.82) Chubaggad (0.84) Lalbasanigad (0.77) Malarigad (0.84)

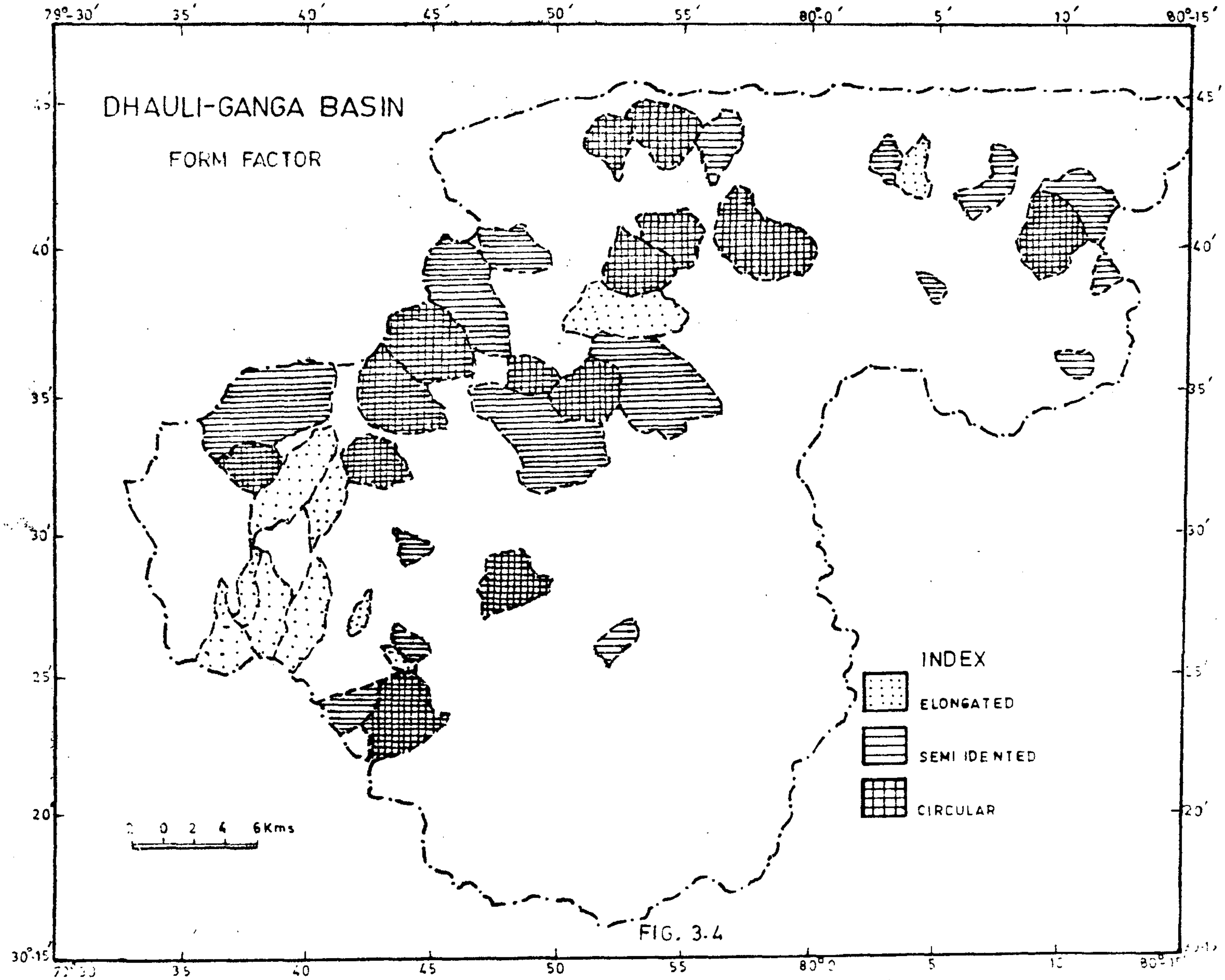
DHAULI-GANGA BASIN
FORM FACTOR
INDEX
ELONGATED
SEMI IDENTED
CIRCULAR
0 2 4 6Kms
79°-30′
35′
40′
45′
50′
55′
80°-0′
5′
10′
80°-15′
45′
40′
35′
30′
25′
20′
30°-15′

FIG. 3.4

Lower Malarigad (0.79) Lower Jumagad (0.84), Nandikundgad (0.87), Nautigadhera (0.87), Raunthigadhera III (0.80) Gadigadhera (0.80), West Tolmagad (0.77) and Lower Homgadhera (C= 0.97) have more circular shapes as the values of circularity ratio is higher than 75% (0.75%). Rest 18 basins fall in the category of unidented shapes passessing 'C' values between 50% to 75% (0.50 - 0.75) (Fig 3.5).

The elogation values (R) of 10 basins viz Najgaongad (R - 0.54), Girthidhura Gad (0.58), South Paing Gad (0.48), Raunthi Gadhera II (0.59), Subhain Gad (0.56) Ringi Gad (0.51), Tapoban Hot Springgad (0.49), Regrigad (0.57), Juwagwar Gad (0.47) and Bhangyul Gad (0.52) place them into the category of elongated shape having 'R' values below 60% (0.60) whereas the circular shape is occupied by 14 basins i.e Chidamugad South (0.86), Dubrugethagad (0.78), Chubaggad (0.96), Siraunchgad (0.78), Malarigad (0.76), Lower Malarigad (0.86), Nandikundgad (0.98), Pangtigadhera (0.78), Nautigadhera (0.80), Chamba Kharak Gad (0.96), Gadigadhera (0.77), West Tolmagad (0.76) and Lower Hom Gadhera (0.85) having 'C' values above 75% (0.75) Rest 16 basins fall in the category mixed shape. Taking into consideration lemniscate 'K' values, the elongated shape is assumed by Girthidhurg Gad (0.93), South Paing Gad (1.38) Raunthi Gadhera II (0.92), Subhain Gad (1.02), Ringi Gad (1.20), Tapoban Hot Spring Gad (1.30), Regri Gad (0.98), Juwagwar Gad (1.43) and Bhangyul Gad (1.17) Having 'K' values

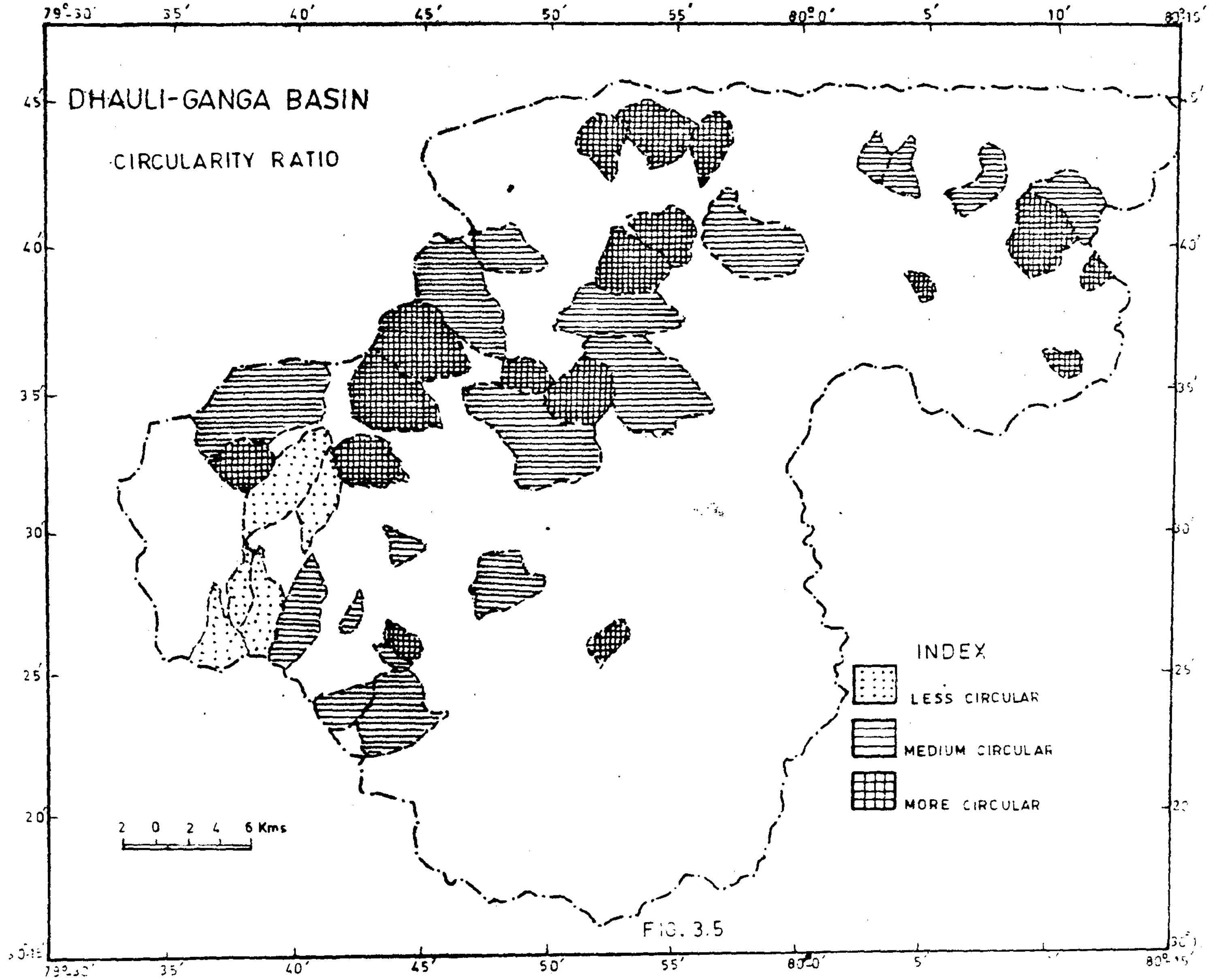
DHAULI-GANGA BASIN
CIRCULARITY RATIO
INDEX
LESS CIRCULAR
MEDIUM CIRCULAR
MORE CIRCULAR
2 0 2 4 6 Kms
79°30′
35′
40′
45′
50′
55′
80°0′
5′
10′
80°15′
45′
40′
35′
30′
25′
20′

FIG. 3.5

above 0.90 (whereas 17 basins Lauka Gad (0.59), Najgaon Gad (0.58) Chidamu Gad North (0.56), Chidamu Gad South (0.43), Dubrugetha Gad (0.52), Margaon Gad (0.52), Chubaggad (0.34), Siraunch Gad (0.53) Malari Gad (0.54), Lower Malari Gad (0.43), Lower Juma Gad (0.48) Nandikund Gad (0.33) Nauti Gadhera (0.49), Chamba Kharak Gad (0.34), Gadi Gadhera (0.54), West Tolamagad (0.55) and Lower Hom Gadhera (0.45) have circular shape having 'K' values below 0.60. Rest 14 basins fall into the category of mixed shape basins having 'K' values between 0.60 - 0.90.

It is clear from the above discussion of four shape indices that only 9 basins (Girthidhura Gad, South Paing Gad, Raunthi Gadhera II, Subhain Gad, Ringi Gad, Tapoban Hot Spring Gad, Regri Gad, Juwagawar Gad and Bhangyul Gad) passess elongated shape and 14 basins out of rest 31 basins have circular shape (i.e Chidamu Gad South, Dubrugetha Gad, Margaon Gad, Chubag, Gad, Siraunch Gad, Malari Gad, Lower Malari Gad, Lower Juma Gad, Nandi Kund Gad, Nautigadhera, Chambakharak Gad, Gadi Gadhera, West Tolma Gad and Lower Hom Gadhera) Rest 17 basins are in the category of mixed shape as exhibited by map (Fig 3.6). It is apparent from correlation matrix (Appendix II) that shape indices do not have any significant correlation with other geomorphic parameters. Thus, it is can be deduced that underlying lithological structure is more dominant in determining the shape of the basin. It is remarkable to note here that out of 9 basins of elogated shape except Girthi Dhura

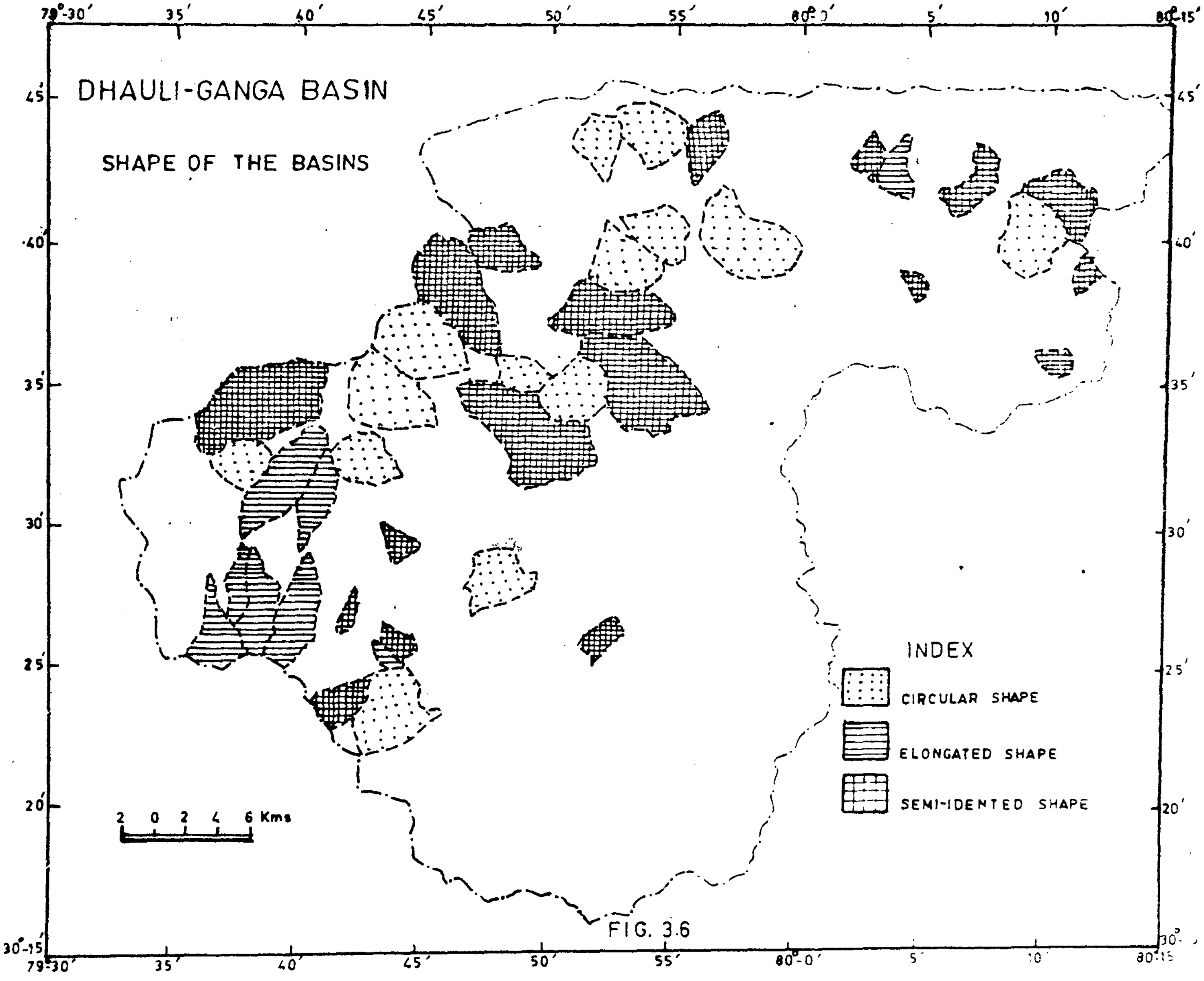
DHAULI-GANGA BASIN
SHAPE OF THE BASINS
INDEX
CIRCULAR SHAPE
ELONGATED SHAPE
SEMI-IDENTED SHAPE
2 0 2 4 6 Kms
79°30′
35′
40′
45′
50′
55′
80°0′
5′
10′
80°15′
45′
40′
35′
30′
25′
20′
30°15′

FIG. 3.6

rest of all the basins drain over the metamorphic structure of schists and gneiss which are an abstacle in the way of development of circular shape. The exceptional case of Girthidhura Gad is due to the very low relief ratio. On the other hand out of 14 basins of circular shape 6 drain over the sedimentary rocks of Tethys formation which have favoured uniform destruction of watershed. Rest 8 basins either favoured by forest canopy of low relief ratio develop circular shape. Vegetal cover and low relief ratio provide the normal conditions to the streams to develop in all directions and thus help to attain a rather circular shape.

ANGULAR PROPERTIES OF THE OPEN LINK:

Horton who pointed out that the angle at which overland flow enters the receiving stream is a function of the ratio of channel gradients to ground slope. Later Lubowe[1] defined the junction angle of two stream segments as 'the angle, projected to the horizontal, between average flow directions, determined by the ends of stream segments extending from the junction point to an upstream point as a distance equal to 0.2 times the average length of the second order streams'. The determination of junction angles in the present

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[1] J.K. Lubowe, (1964), "Streams Junction Angles in the – Drainage Pattern", American Journal of Science, Vol.262, p. 325-39.

study has been done on the same line. The entrance angles of the first order streams have been determined with the help of horizontal inclinations of two first order streams showing average flow direction of the two tributaries of the same order and the same method has been used for the measurement of the entrance angles of second and third orders of all the basins. Mean values of all first, second and third orders have been calculated and tabulated in Table 3.11.

The results of the present study meet the findings of Lubowe, who analysed the stream junction angles of four regions of the Applachian plateau and came to the conclusion that 'the stream junction angles increase as the order of receiving stream increases. The same postulation has been proved by Singh et at[1] by the study of 30 drainage basins of five physiographic regions of South-east Chhota Nagpur region. Satpathy[2] also concluded the same results by the study of Deo river basin, Singhbhum district. It is apparent from the Table 3.11 that the observations of Lubowe, Singh et all and Satpathy are applicable in the present study area. Out of all 40 drainage basins 32 basins (Lauka Gad, Najgaon Gad, Chidamu

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1. S. Singh, D.P. Upadhyay, (1981), op.cit. p. 226-28.
2. Debidutta, P.P.P. Satpathy, (1972-73) op.cit. p.57-66.

TABLE - 3.11

MEAN STREAM JUNCTION ANGLES (DEGREE)

S.No.	Basins	Z_1	Z_2	Z_3	$\bar{Z}$
1.	Lauka Gad	41.66	44	58	47.89
2.	Najgaon Gad	50.33	81	85	72.11
3.	Chidamu Gad North II	56.60	70	67	64.53
4.	Chidamu Gad South I	40.20	53	67	53.40
5.	Girthi Gad	48.50	49	85	60.83
6.	Bambang Gad	46.00	85	86	72.33
7.	Girthi Dhura Gad	39.00	47	91	59.00
8.	Devkot Gad	50.00	56	78	61.33
9.	Dubrugetha Gad	41.70	50	68	53.23
10.	Rishikot Gad	32.00	44	70	48.66
11.	Margaon Gad	40.66	66	97	67.89
12.	Chubag Gad	45.75	58	107	70.25
13.	Lalbasani Gad	41.25	23	75	46.42
14.	Siraunch Gad	46.25	54	76	58.75
15.	Malari Gad	43.00	70	112	75.00
16.	Lower Malari Gad	27.25	36	75	46.08
17.	Garpak Gadhera	45.25	63	94	67.46
18.	Dunagiri Gad	38.83	68	108	71.61
19.	Lower Juma Gad	51.75	53	67	57.25
20.	Nandi Kund Gad	66.66	54	108	76.22
21.	Gankhuri Gadhera	61.40	76	76	71.13
22.	Pangti Gadhera	40.66	55	112	69.22
23.	Juma Gad	33.75	45	79	52.58
24.	Nauti Gadhera	46.40	82	106	78.13
25.	Lata Kharak Gadhera	29.50	45	60	44.83
26.	South Paing Gad	29.00	50	88	55.66
27.	Raunthi Gadhera II	65.50	51	52	56.20
28.	Raunthi Gadhera III	57.00	70	62	63.00
29.	Chamba Kharak Gad	46.00	51	60	52.33
30.	Raunthi Gadhera I	43.00	80	60	61.00
31.	Subhain Gad	43.33	61	70	58.11
32.	Ringi Gad	53.00	84	95	77.33
33.	Tapoban Hot Spring Gad	32.33	52	70	51.44
34.	Regri Gad	47.00	55	49	50.44
35.	Gadi Gadhera	53.00	53	25	43.66
36.	West Tolma Gad	59.50	73	78	70.20
37.	Jumagwar Gad	55.50	72	90	72.50
38.	Bhangyul Gad	53.00	83	86	74.00
39.	Lower Hom Gadhera	49.33	71	75	65.11
40.	Hom Gadhera	53.45	102	75	76.82

Gad South, Girthi Gad, Bambang Gad, Girthidhura Gad, Devkot Gad, Dubrugetha Gad, Rishikot Gad, Margaon Gad, Chubag Gad, Siraunch Gad, Malari Gad, Lower Malari Gad, Garpak Gadhera, Dunagiri Gad, Lower Juma Gad, Gankhwi Gadhera, Pangti Gadhera, Juma Gad, Nauti Gadhera, LataKharak Gad, South Paing Gad, Raunthi Gadhera II, Chamba Kharak Gad, Subhain Gad, Ringi Gad, Tapoban Hot Spring Gad, West Tolma Gad, Juwagwar Gad, Bhangyul Gad and Lower Hom Gadhera) show continuous increase in mean stream junction angles with the increasing order. The remaining 8 basins (Chidamu Gad North, Lalbasani Gad, Nandikund Gad, Raunthi Gadhera III, Raunthi Gadhera I, Regri Gad, Gadi Gadhera and Hom Gadhera) show deviation from the aforesaid postulation of Lubowe. Albeit general trend of junction angles of these basins also explain the same rule at least in their two entrance angles of different orders out of three entrance angles. The factors which are reposnible for the departure from the law are either elongated shape of the basins (Chidamu Gad II, Lalbasani Gad, Nandikund Gad, Raunthi Gadhera III, Raunthi Gadhera I and Gadi Gadhera) or comparatively higher relief ratio (Lalbasanigad, Gadigadhera and Hom Gadhera). Forest cover also plays an important role to break the mentioned rule. When stream enters the vegetal cover surface from the bare surface it deviates from the path and thus deviate from the general law (Nandikund Gad, Raunthi Gadhera I, Topoban Hot Spring Gad, West Tolma Gad and Hom Gadhera).

Schumm[1] found out through his study that 'where the valley side slope is steep in relation to the gradient of the master stream, a tributary tends to join at almost right angles; but where the gradient of master stream and valley side slope are almost the same, the tributory virtually parallels the main channel, joining it at a small angle'. Thus he suggests that the entrance angles may be correlated with the stages of the basin development because 'the entrance angles in mature basins are significantly less than the youthful basins' (Schumm). In the present study out of all 40 basins only 9 basins are in the early mature to mature stages, otherwise all other 32 basins are in youthful stage. Out of 8 basins only Gadi Gadher (43.66) follows Schumm[2]s and Singh[3] et al's observation. The coefficient of correlation between basin stage determinant integral and mean junction angle is very poor (0.057) which is insignificant at any level of significance and thus rejects the Schumm's postulation to be applicable in the present study area. The probable reason of this departure may be that, all the basins lie in the high altitudes with high relief ratio, where gradient is more powerful factor to control the entrance angle of two streams. All the basins whether they lie on

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1. S. A. Schumm, (1956), op.cit.
2. Ibid.
3. S. Singh and D.P. Upadhaya, (1981), op.cit.

schists and gneiss of metarmorphic rock formation or on sedimentary formation of Tethys, show a mixed trend of mean entrance stream angles and this proves Satpathy's[1] view that no clear relationship exists between lithology and the stream junction angle.

LAW OF BASIN AREA, LENGTH AND PERIMETER:

Basin area, basin perimeter and length of the streams are important geomorphic parameters which on one side determine the shape and size of the drainage basin and on the other side speak much about the genetic aspects of the drainage basin development. The strong indicators of drainage basin geometry can be directly correlated to each other to project the genesis of basin development. A strong positive correlation has been observed between basin parimeters and the square roots of the basin areas of all 40 drainage basins which standing at + 0.96 are highly positively correlated, significant at 0.001 level of significance. This indicates that increase or decrease in one parameter is strongly associateed with the increase or decrease in the other variable. The coefficient of correlation between basin perimeter and stream length for all 40 basins at + 0.84 is again significant at 0.01 level of significance. This exposes the fact that increase or decrease in stream length. Similarly, the coefficient of

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[1] Debidutta, P.P.P. Satpathy, (1972-73), op.cit.

correlation has also been computed between channel length and square roots of the area which stands as + 0.87 is significant at 0.01 level of significance. This high positive relationships among the aforesaid geomorphic parameters clearly exhibit the genessis of the basin development. By the headward erosion, first order stream segments increase their length simulatanesoulsy notching down the watersheds and thus help in the growth of basin area as well as basin perimeter. For the smooth functioning of the said process, the geologic structure, climate of the region and forst cover play a significant role. Except these factors, relief aspects of the basin may also disturb the smooth functioning of basin development and register deviations from the above law.

HYPSOMETRIC INTEGRAL:

Hypsometric integral is an important geomorphic parameter which clearly speaks about the stages of basin development. It provides an account of erosional development of a drainage basin through time. The values of hypsometric integrals are determined by the hypsometric analysis as proposed by Strahler[1] that 'hypsometric analysis is the study of the distribution of ground surface area, or horizontal cross-sectional area of a landmass with respect to elevation' The percentage hypsometric curves for all 40 drainage basins have been drawn to determine

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[1] A.N. Strahler, (1952), op.cit. p. 1121.

the values of hypsometric integrals by Strahler's formula as below:

Hypsometric integral $\int_{o}^{100\%}$ xdy, where X = f(y).

$$\frac{V01}{HA} = \int_{o}^{100\%} xdy$$ (Strahler, 1952, p.1121)[1]

Where V = Volume

H = Relative height

A = Relative area of basin.

On the basis of above formula the values of relative heights are plotted on the y axis and relative area in relation to relative height have been plotted on the X axis, both values in percentage. This provides a percentage hypsometric curve which illustrates the degradational history of the basin. The 100% elevation line is the upper undissected surface, and the base of the diagram represents the potential erosion surface on which degradation is working. The right hand edges of the figures (Fig- 3.7) are the focus of points of junction of the channels with some higher order streams. While the left hand edges are the drainage divides. Thus the curves exhibit the distribution of mass to be removed within a drainage basin at a different stages of development, with the position of its mouth controlled by the degrading stream to which

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[1] A.N. Strahler, (1952), op.cit. p. 1121.

PERCENTAGE HYPSOMETRIC CURVES

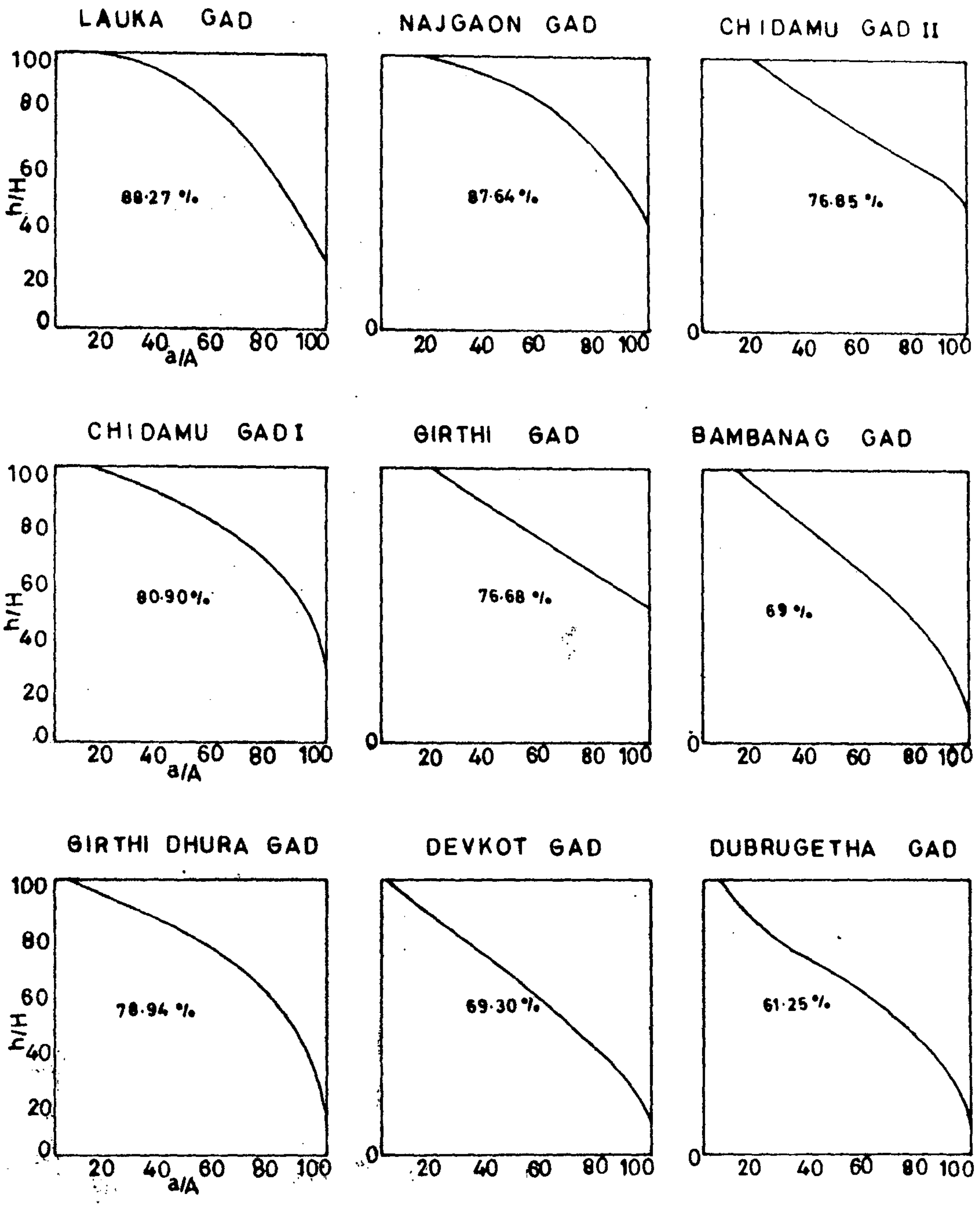


Fig. 3·7

PERCENTAGE HYPSOMETRIC CURVES

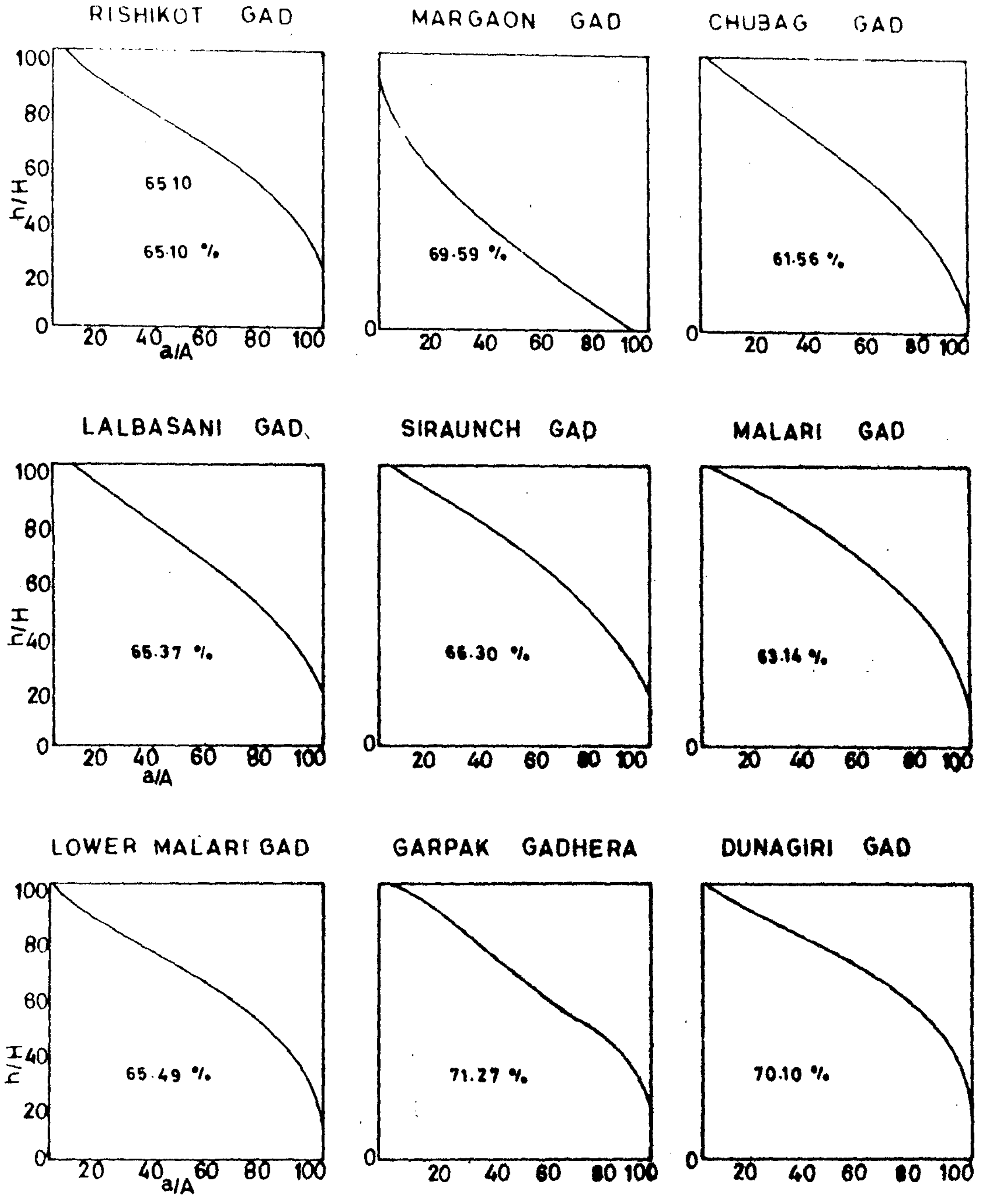


Fig. 3.7

PERCENTAGE HYPSOMETRIC CURVES

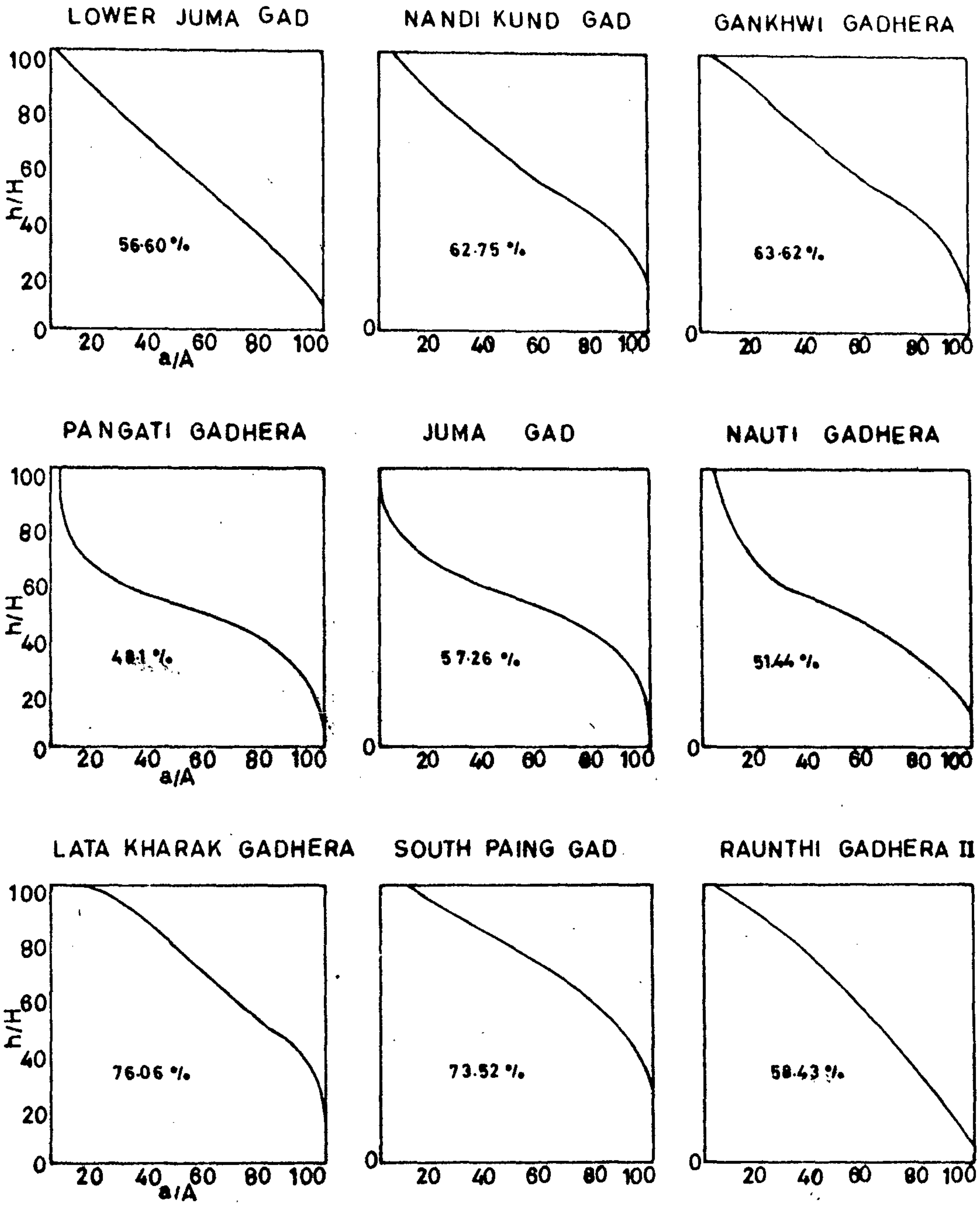


Fig. 3.7

PERCENTAGE HYPSOMETRIC CURVES

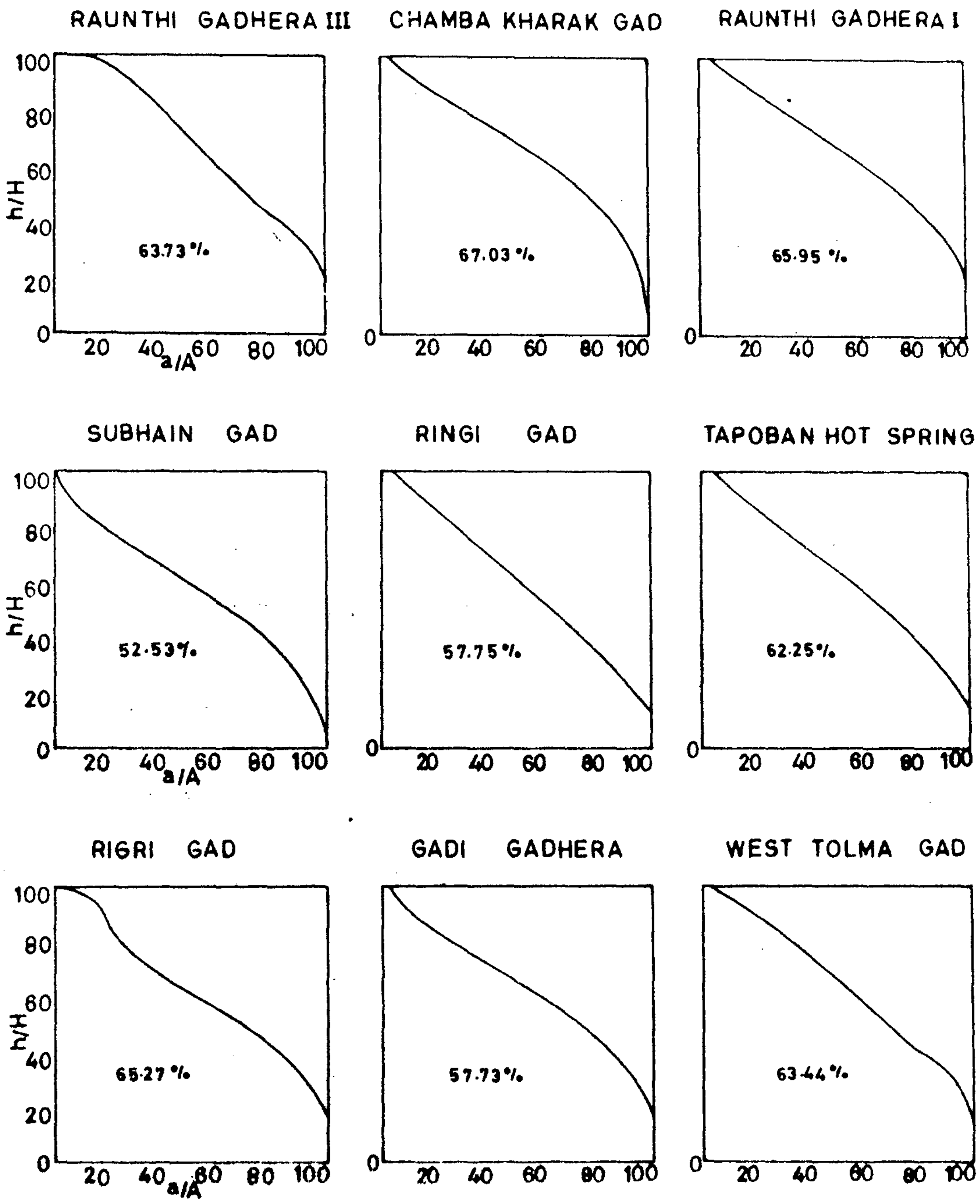
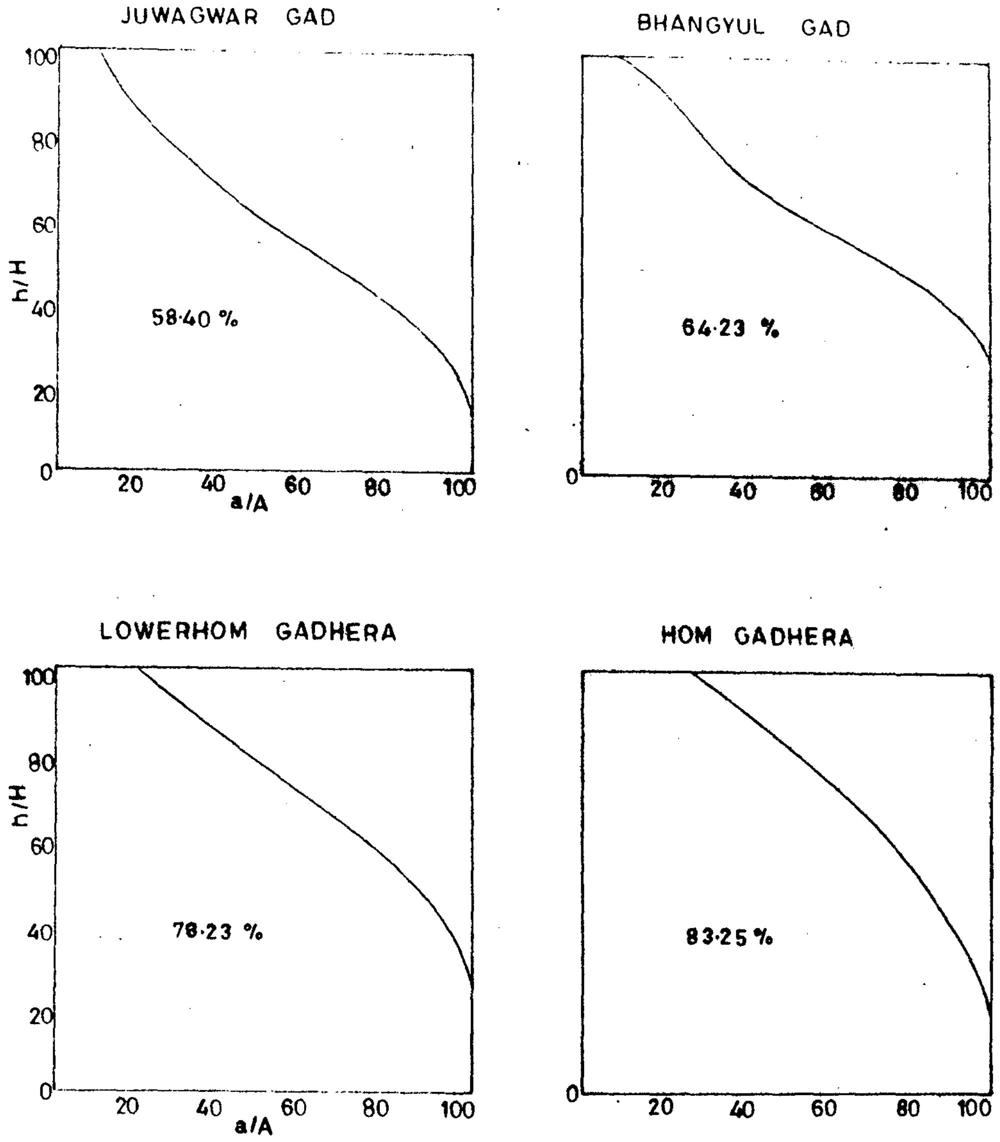


Fig. -3.7



PERCENTAGE HYPSOMETRIC CURVES

Fig. 3.7

it is tributary.

The hypsometric curves of the basins clearly support the postulation of Schumm[1] that 'hypsometric curves show that during erosion of the basin the zone of maximum erosion migrates toward the head of basin' That is the vertical distance between each curve and the lowest point or confluence point, where it joins a higher order stream, is lower (right-hand sides of the illustrations) in youth stage, but it is higher near the basin head (left sides of the curves), while this difference is less in mature stage of the basin development.

Although it is not possible to draw the basins of a series from source to mouth in one square as by Schumm[2] to examine the validity of his results, due to the indifferent nature of curves which will not give a visual impression, yet the values of hyprometric integrals show that the values of hyprometric integrals increase from source to mouth-ward for the same order basins of a sequence on one side of a river. For example, northward draining basins of a sequence on the south bank of **Dh**auli-ganga viz Subhain Gad (52.58%), Ringi Gad, (57.75), Tapoban hot Spring Gad (62.25) and Regri Gad (65.27%) provide increasing order of hypsometric integrals from source to mouthward of Dhauli Ganga. These results are a direct contrast to Schumm, who suggests that the value of integral decrease

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1. S.A. Schumm, (1977), op.cit.
2. Ibid.

from source to mouth for the basins of a sequence. The reason of this controversy is that relief ratio is more stronger to determine the value of hypsometric integral than the location. The relief ratio for the aforesaid basins decrease constantly i.e Subhain Gad (61.57)%, Ringi Gad (59.13%) Tapoban Hot Spring Gad (50.79%) and Regrigad (45.28%).

The spatial analysis of the hypsometric integrals reveal the fact that the integral values vary from 48.10% lowest for Pangti Gadhera to 88.27% highest for Lauka Gad. Mostly basins possess above 60 per cent. Strahler has suggested the following tentative boundaries for determination of different stages of basin development:

i) Above 60% youth stage, inequlibrium.

ii) 35% to 60% Mature stage, Equlibrium.

iii) Below 35% - Senile stage, Monadnock phase.

On the basis of the above classification all basins may be cal classified into three categories as youth stage (above 60%), early mature stage (above 55%) and mature stage 35% to 55%). The Table 3.12 clearly speaks that Pangti Gadhera (48.10%), Nautigadhera (51.44%) and Subhain Gad (52.58%) are in mature stage of their development, while **lower** Juma Gad (56.60%) Juma Gad (57.26%), Raunthi Gadhera II (58.43%), Ringi Gad (57.75%) Gadi Gadhera (57.73%) and Juwagwar Gad (58.40%) are in early mature stage and the remaining basins lie in the youthful stage of the basin development.

TABLE - 3.12

HYPSOMETRIC INTEGRALS & MASS REMOVED (%)

S.No.	Name of the Basins	Hypsometric Integral Hi %	Mass Removed Mr %	Remarks*
1.	Lauka Gad	88.27	11.73	Youth
2.	Najgaon Gad	87.64	12.36	"
3.	Chidamu Gad North	76.85	33.15	"
4.	Chidamu Gad South	80.90	19.10	"
5.	Girthi Gad	76.68	23.32	"
6.	Bambanag Gad	69.00	31.00	"
7.	Girthi Dhura Gad	78.94	21.06	"
8.	Devkot Gad	67.30	32.70	"
9.	Dubrugetha Gad	61.25	38.75	"
10.	Rishikot Gad	65.10	34.90	"
11.	Margaon Gad	69.59	30.41	"
12.	Chubag Gad	61.56	38.44	"
13.	Lalbasani Gad	65.87	34.13	"
14.	Siraunch Gad	66.30	33.70	"
15.	Malari Gad	68.14	31.86	"
16.	Lower Malari Gad	65.49	34.51	"
17.	Garpak Gadhera	71.27	28.73	"
18.	Dunagiri Gad	70.10	29.90	"
19.	Lower Juma Gad	56.60	43.40	Early mature
20.	Nandi Kund Gad	62.75	37.25	Youth
21.	Gankhwi Gadhera	63.62	36.38	"
22.	Pangti Gadhera	48.10	51.90	Mature
23.	Juma Gad	57.26	42.74	Early mature
24.	Nauti Gadhera	51.44	48.56	Mature
25.	Lata Kharak Gadhera	76.06	23.94	Youth
26.	South Paing Gad	73.52	26.48	"
27.	Raunthi Gadhera II	58.43	41.57	Early mature
28.	Raunthi Gadhera III	68.78	31.22	Youth
29.	Chamba Kharak Gad	67.03	32.97	"
30.	Raunthi Gadhera I	65.95	34.05	"
31.	Subhain Gad	52.58	42.42	Mature
32.	Ringi Gad	57.75	42.25	Early mature
33.	Tapoban Hot Spring Gad	62.25	37.75	Youth
34.	Regri Gad	65.27	34.73	"
35.	Gadi Gadhera	57.73	42.27	Early mature
36.	West Tolma Gad	68.44	31.56	Youth
37.	Juwagwar Gad	58.40	41.56	Early youth
38.	Bhangyal Gad	64.23	35.77	Youth
39.	Lower Hom Gadhera	78.28	21.72	"
40.	Hom Gadhera	83.25	16.75	"

* Stages of Basin Development.

This significant morphometric indicator can directly be correlated with other strong variables. The coefficient of correlation of hypsometric integral with dissection index (-0.57) and relief ratio (-0.567) significant at 1% probable level of significance indicate that the nature of the configuration plays an important role to determine the value of hypsometric integral. The more dissected land provides more paths for the streams to erode the surface material and thus lessen the integral. Similarly, high relief ratio also enhances the velocity of running water and estumulate the intensity of erosion and basin grows faster. The same conclusion may be drawn from the correlation value of mean stream length with integral, which standing at -0.454 is significant at 0.05 level of significance. The increase in stream length is always due to headward erosion, and therefore, with the increase in length more erosion will take place and ultimately it will lower the land surface.

From the above discussion it may be concluded that maximum basins are in young stage and a few basins have developed into early mature to mature stage Basin development is a phenomenon of multi-functionality of geomorphic parameters viz mean stream length, dissection index, relief ratio and average slope of the terrain.

Hence the results of this chapter highlight the postulated hypothesis that morphometric parameters are inter-correlated and their inter-relationship reflect the different aspects of fluvially eroded landscape viz-age, stage of basin development and intensity of the erosion over the underlying lithological structure and nature of configuration in various ways.

CHAPTER - IV

PART A

DETERMINANTS OF BASIN AREA

It is auxiomatic to deduce that the basins of the same order possess different shapes, sizes and areas. This indicates that the area of the basin is independent of basin order (Appendix IV) reveals this fact that all 40 basins of third order have different areas) and it depends on the geomorphic, hydrological and underlying lithological conditions. The more important tools, of course are the streams which in presence of different topographic circumstances, shape the basin in various geological formations. Lithological conditions are another significant factors which govern the development of streams and erosional capacities of running water. Rocks of different formations enforce the streams to flow in a particular fashion. Generally, it is observed that more tortuous streams develop rather circular basins of bigger size in presence of soft rocks and suitable geomorphic conditions, while less sinuous streams in hard rock formations and strong topographic circumstances form the smaller basins of elongated shape. Here stage of the basin development is also worth considering. Thus a third factor also emerged here as a strong determinant of basin shape, size and area, i.e obviously, topography of the terrain.

All above mentioned factors are interdependent and enhance the headward erosional capacities of running water (generally basin area increases by the headward erosion of streams) in favourable conditions of each other. Therefore, the factors which estimulate the headward erosion of stream segments may be considered important determinants of the drainage basin area.

CHOICE OF THE INDICATORS:

The selection of indicators for the present study has been made on the basis of correlation matrix. A correlation matrix of 21 variables (which already have been introduced in previous chapters) has been prepared to find out the relationships among the selected hydrologic and topographic parameters. A close study of the correlation matrix (Appendix II) clearly reveals that the area of the basin has a direct correlation, with number of stream segments (Y = 0.628), total stream length (R = 0.863), mean stream length (r= 0.571) and mean bifurcation ratio (r = 0.591), all positively stand significant at 0.001 level of significance. Drainage density and drainage frequency have negative correlation with basin area, -0.574 and -0.612, respectively, both are significant at 1% probable level of significance. This shows that drainage density and frequency are inversely related to the area, while stream length shows a positive relationship with the area. These results bring a controversy which is a bit surprising but interesting. The reasons of this controversy are discussed later.

The other parameters of drainage morphometry which have strong correlation with basin area are, dissection index (r = 0.491), constant of channel maintenance (r = 0.607) and length of overland flow (r = 0.607). All parameters are positively significant at 0.001 level of significance. The absolute relief also has a positive relationship (r = 0.302) with basin area, although not significant. Except these parameters some other variables also show an indirect relationship with basin area, as these variables help those parameters which directly affect the basin area i.e average slope has a positive relationship with dissection index (r = 0.412), relative relief (r = 0.411) and ruggedness number (r= 0.52), which are significant at 0.10, 0.10 and 0.001 level of significance, respectively. Similar results are shown by ruggedness number and texture ratio which have positive but strong relationship with stream segments standing at 0.452 and 0.709 significant at 0.05 and 0.001 level of significance, respectively.

On the basis of the above discussions all factors which determine the drainage basin area may be divided into following three categories:

I. Hydrological Factors:
  i) Total number of stream segments
  ii) Total stream length
  iii) Cumulative mean stream length
  iv) Mean bifurcation ratio
  v) Drainage density
  vi) Drainage frequency

II. Topographical Factors:
  i) Dissection index
  ii) Relative relief
  iii) Constant of channel maintenance
  iv) Length of overland flow

III. Geological Factors:
  i) Metamorphic rock formation
  ii) Sedimentary rock formation

The impact of the above mentioned factors on the development basin area has been discussed below.

TOTAL NUMBER OF STREAM SEGMENTS AND AREA:

The total number of stream segments as determined in Strahler's system have a strong positive correlation with the drainage basin area standing at 0.628, significant at 0.001 level of significance. This result clearly indicates that increase in stream segments produce a direct positive impact on the basin area. This relationship has a direct controversy with the results of Singh et al[1] . Their study on south-east Chhota Nagpur region shows that 'the stream number is independent of basin area'. The development of basin area always is due to the increase in stream length as the streams require more area to drain. The inception of the drainage basin takes place with a fewer number of stream segments. But in due course, the increased erosion by headward extension lenghtens the streams and retreats the basin perimeter. Then this gives rise to more stream segments to drain the newly acquired more area. It may be possible in plain areas that a stream can drain a larger area but it is not possible in hill areas because of very low value of constant of channel maintenance. Thus, it is clear that to drain a larger area more stream segments are required. This relationship is well expressed by figure (4.1 - A). The equation of the fitted line is as follows:

$$\text{Log } X_{18} = \text{Log } 3.190 + \underset{(4.969)}{0.326}\ \underset{*}{\text{Log}}\ X_5 \qquad \bar{R}^2 = 0.394$$

Where X_{18} = basin area.

X_5 = total number of stream segments.

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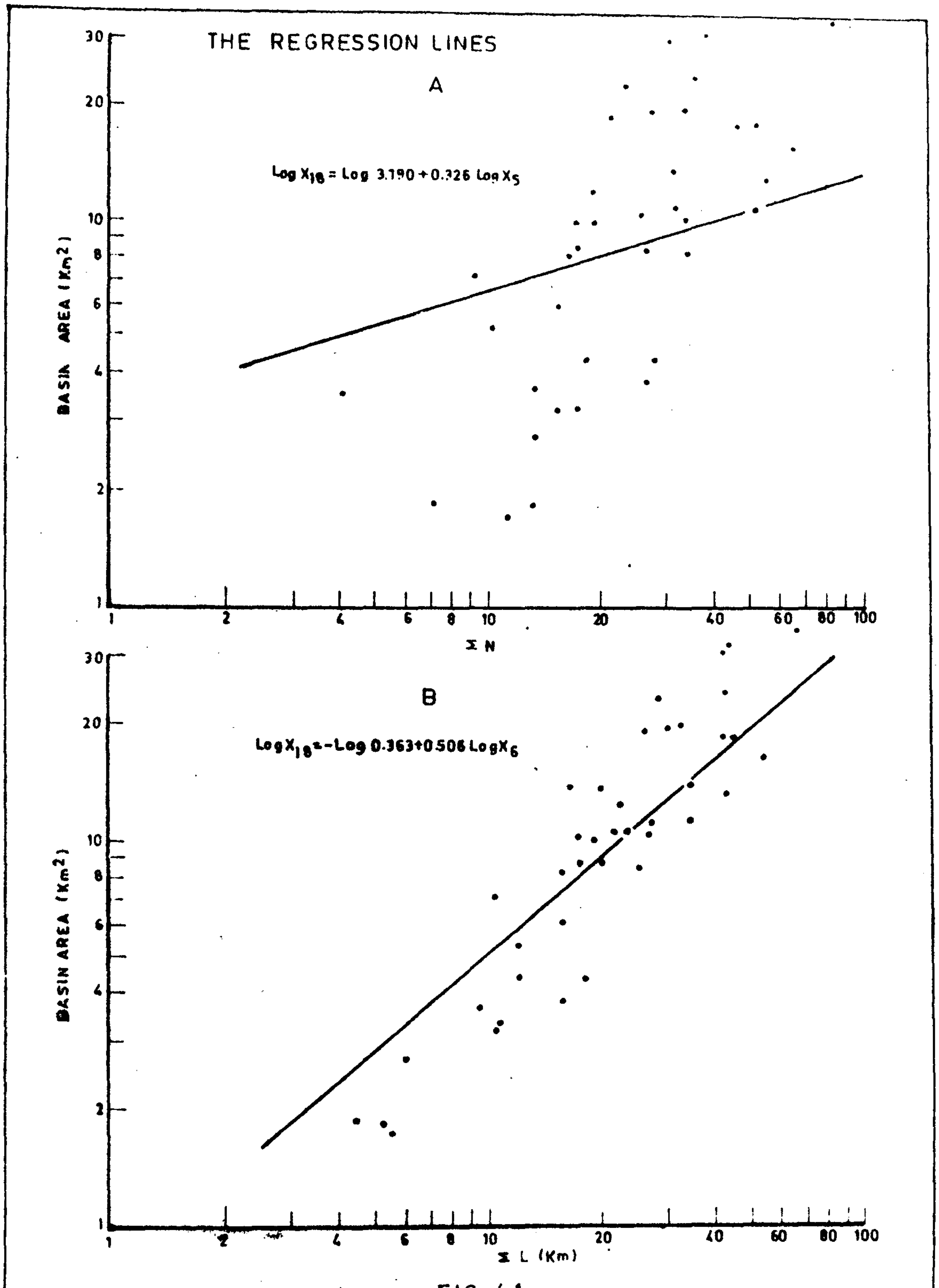
[1] S.Singh and D.P. Upadhayay, (1981), op.cit. p.192.

* Significant at 0.001 level.


THE REGRESSION LINES
A
$\mathrm{Log}\,X_{18} = \mathrm{Log}\ 3.190 + 0.326\ \mathrm{Log}\,X_5$
BASIN AREA (Km^2)
30
20
10
8
6
4
2
1
1
2
4
6
8
10
20
40
60
80
100
ΣN
B
$\mathrm{Log}\,X_{18} = -\mathrm{Log}\ 0.363 + 0.506\ \mathrm{Log}\,X_6$
BASIN AREA (Km^2)
ΣL (Km)

FIG, 4.1

This implies that the total number of stream segments (X_5) has explained 39.4 per cent of variations in basin area. The regression coefficient is quite significant.

TOTAL STREAM LENGTH AND AREA:

Total stream length having a higher value of coefficient of correlation ($r = 0.863$), significant at 1% probable level of significance, shows a strong control over the basin area. It is quite obvious, as it is already been mentioned that the development of basin area is always due to the headward erosion of streams. When streams by headward erosion increase their length, boundary of the basin retreats proportionately which provides more space to streams to drain a over and it ultimately invites more stream segments to develop in finger tips (because the constant of channel maintenance is very low, only 0.475 km^2), which consequently increase the length of streams. This positive relationship is well exhibited by the graph (Fig. 4.1 - B) The points are well distributed along the regression line, which show the trend of distribution. The equation of the fitted line is as below:

$$\text{Log } X_{18} = -\text{Log } 0.363 + \underset{(10.516)^*}{0.506} \text{ Log } X_6 \qquad \bar{R}^2 = 0.745$$

Where, X_6 = total stream length

---

* Significant at 0.001 level

This equation validates aforesaid relationship and implies that the stream length ($\bar{X}_6$) alone explains 74.5 per cent variations of drainage basin area. The regression coefficient of the equation is quite significant.

MEAN LENGTH OF STREAM SEGMENTS AND AREA:

Again a strong and positive correlation has been computed between mean length of stream segments and basin area. The value of coefficient of correlation being 0.571 is quite significant at 0.001 level of significance. This clearly reveals that the basin area is directly proportional to the mean stream length. It is already discussed and proved that the basin area is a function of total stream segments and length. The same logic of headward extension of streams is applicable here too. Thus it is obvious, that the mean length of stream segments will increase as the streams increase their length by headward extension and this process ultimately is related to the extension of drainage basin, area. It may be concluded in the present study area, mean length of streams has a positive impact on the development of basin area. This postulation is well supported by the graph (Fig 4.2-A), which exhibits positive exponential function. The scattered points along the regression line show a good trend of relationship. The equa-

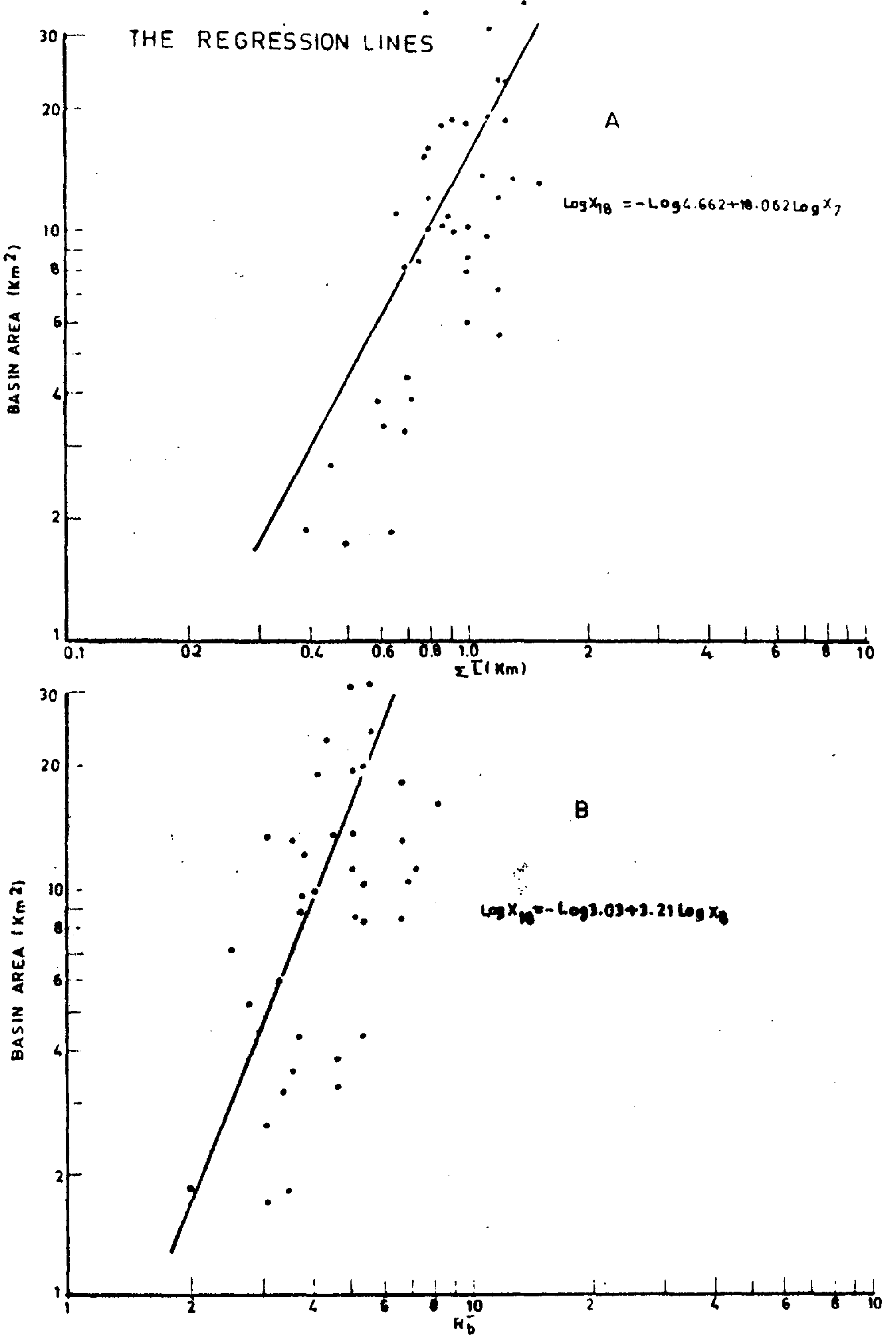

THE REGRESSION LINES
A
$\mathrm{Log}X_{18} = -\mathrm{Log}4.662+18.062\,\mathrm{Log}X_7$
BASIN AREA (Km^2)
30
20
10
8
6
4
2
1
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
$\Sigma\bar{L}$ (Km)
B
$\mathrm{Log}X_{18} = -\mathrm{Log}3.03+3.21\,\mathrm{Log}X_8$
BASIN AREA (Km 2)
30
20
10
8
6
4
2
1
1
2
4
6
8
10
2
4
6
8
10
$\bar{R_b}$

FIG. 4.2

tion of the fitted line is as follows:

$$\mathrm{Log}\ X_{18} = -\mathrm{Log}\ 4.662 + \underset{(4.288)^{*}}{18.062}\ \log X_7 \qquad \bar{R}^2 = 0.33$$

Where X_7 = mean length of stream segments

It is apparent from the $\bar{R}^2$ value of equation that mean stream length explains 33 per cent variations in the area of drainage basin. On the basis of 't' value it is quite clear that regression coefficient is significant.

MEAN BIFURCATION RATIO AND AREA:

Bifurcation ratio is an important parameter which reflects the branching phenomenon of drainage net work. The coefficient of correlation between mean bifurcation ratio and basin area standing at 0.596 significant at 0.001 level of significance, indicates that higher values of mean bifurcation ratio are associated with the bigger areas of the basins and vice versa. The simple logic behind this postulation is that in hilly region, more finger streams are required to develop bigger areas (as it is already proved), which increases the mean bifurcation ratio of streams. The basins of bigger areas have more number of stream segments and higher values of bifurcation ratios

---

* Significant at 0.001 level.

between any two successive orders. This trend of relationship is well portrayed by the scattered diagram (Fig 4.2-B) Maximum points lie along the best fit regression line. The fitted regression line shows a good trend of positive linear functionality of two variables. The fitted equation is as follows:-

$$\text{Log } X_{18} = -\log 3.03 + 3.21 \log X_8 \qquad \bar{R}^2 = 8.36$$

$$(4.576)^*$$

Where, X_8 mean bifurcation ratio

This equation proves the validity of relationship, as the value of regression coefficient is enough high to be significant. This variable explains 36 per cent variations in drainage basin area.

DRAINAGE DENSITY AND AREA:

Drainage density has a strong but negative correlation with the area of the drainage basin. The value of coefficient of correlation being -0.574 is significant at 1% probable level of significance, indicates that the basins of higher drainage density possess smaller areas. The total length of streams is positively correlated with the basin area, but the mean length of segments is strongly but negatively correlated

---

* Significant at 0.001 level.

(-0.903) with drainage density, significant at 0.001 level of significance, while it has a positive correlation with basin area (reasons have been discussed earlier). This shows that basins of higher drainage density have smaller length of stream segments. This indicates that basins are just in their inception stage. More headward erosion is required to increase the length of stream segments which simultaneously retreteat the basin divide and enlargen the basin area. The correlation value between drainage density and the hypsometric integral standing at 0.435 being significant at 0.10 level of significance, indicates that basins of higher drainage density and smaller area are in youthful stage.

Another factor which throws some light on the negative relationship of drainage density and basin area is underlying rock formation. For instance, drainage density generally is higher over soft rocks formation (discussed in Chapter III). Which develops favourable conditions to streams to develop but lesser in poor linements of hard rocks, which enforce the streams to flow along the joints. Streams increase their length by headward erosion along the joints and thus develops the bigger basins of longer stream length. While in soft rocks, development of streams is easier, and they flow in zig zag path, which increase the drainage density in the basins at the inception of their basin development and are of smaller areas.

The basins of bigger areas which develop in the later stage of the Dhauli-ganga near its mouth, are elongated in shape, having longer streams with a bit higher value of constant of channel maintenance.

On the basis of the above discussion it may be concluded that in the present study area, basins of higher drainage density possess smaller areas because they are in their inception of their development. Lesser drainage density has been observed in the well defined basins of bigger areas. This trend of relationship is exhibited by the plotted graph (Fig 4.3-A) and fitted regression line with a gentle negative slope. The regression equation is given below:

$$\text{Log } X_{18} = \text{Log } 27.308 - \underset{(-4.324)^{*}}{6.599} \text{ Log } X_{11} \qquad \bar{R}^2 = 0.33$$

Where, X_{11} = drainage density

This equation explains that 33 per cent variations in the drainage basin area are due to drainage density as the 't' value is enough high to be significant.

DRAINAGE FREQUENCY AND AREA:

Similar to the drainage density, drainage frequency also has a negative relationship with the basin area. This is

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* Significant at 0.001 level.

THE REGRESSION LINES

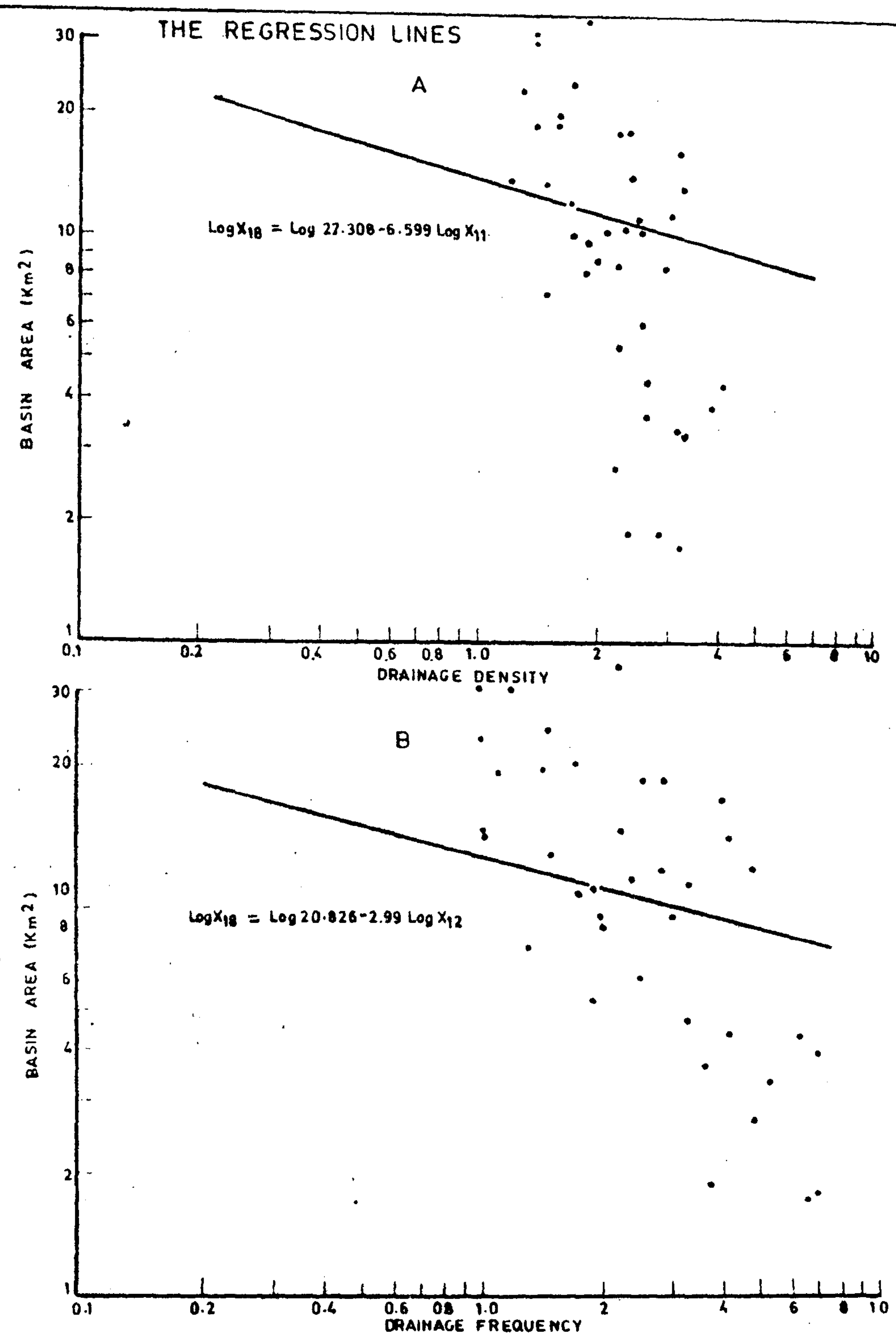

FIG. 4.3

clear by the higher negative correlation value standing at -0.612 being significant at 0.001 level of significance. This also shows that basins of higher frequency and smaller area are in inception of their development. It indicates that drainage frequency does not have significant relationship with number of stream segments as the correlation value is negligible (Appendix III). This is because of the fact that the two variables are indifferent units, one being considered for the whole basin whereas the other variable refers to a part of unit area.

Generally, basins of higher drainage frequency lie over soft rock formation or in lower relief ratio (Appendix IV). Relief ratio has a positive correlation (+0.497) with basin area but a negative correlation (-0.506) with the drainage frequency, both being significant at 0.001 level of significance respectively. This indicates that well defined basins have higher relief ratio and low drainage frequency but basins in their inception have lower relief ratio and higher drainage frequency.

The above discussions prove the validity of negative impact of drainage frequency on the basin area. This is well exhibited by graph (Fig 4.3 - B) and regression line. The equation of the fitted line is

$$\underset{}{\text{Log } X_{18} = \text{Log } 20.826 - 2.99 \underset{(-4.774)^{*}}{\text{Log}} X_{12}} \qquad \bar{R}^2 = 0.374$$

---

* Significant at 0.001 level.

Where X_{12} = drainage frequency

The above equation reveals that drainage frequency explains 37.4 per cent variations in basin area. The regression coneefficient is enough high to be significant.

DISSECTION INDEX AND AREA:

Dissection index is an important geomorphic parameter which has positive relationship with the basin area. The coefficient of correlation between these two parameters being 0.491 is significant at 1% probable level of significance. More dissected landscape provides favourable conditions to the development of more stream segments of longer length. Dissection index has a perfect positive correlation with relief ratio. The higher relief ratio increases the velocity of running water and stimulates the erosional capacity of rivers. Thus a combined effect of gradient and sediment yield brings a change in drainage divide by shifting it headward and hence enlargen the basin area.

This linear positive relationship is well exhibited by the scattered diagram (Fig. 4.4 - A) where points tend to be scattered along the best fitted regression line. The equation of the fitted line is below:

$$\text{Log } X_{18} = -\text{Log } 2.407 + \underset{(3.477)^{*}}{33.134} \text{ Log } X_{13} \qquad \bar{R}^{2} = 0.241$$

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* Significant at 0.01 level.

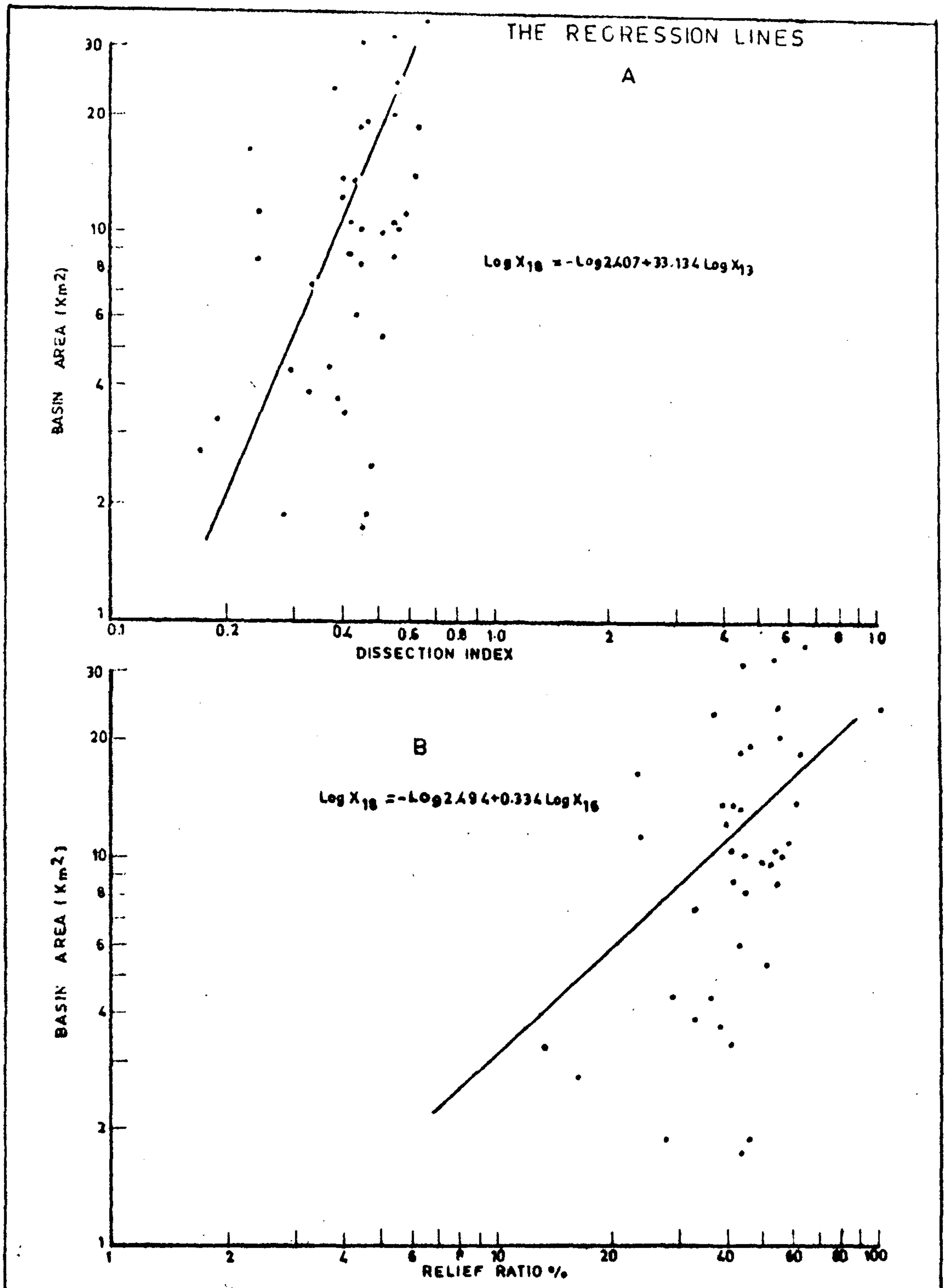
THE REGRESSION LINES
A
Log X18 = -Log2407+33.134 Log X13
BASIN AREA (Km2)
30
20
10
8
6
4
2
1
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
DISSECTION INDEX
B
Log X18 =-Log2494+0.334 Log X16
BASIN AREA (Km2)
30
20
10
8
6
4
2
1
1
2
4
6
8
10
20
40
60
80
100
RELIEF RATIO %

FIG. 4.4

Where X_{13} = dissection index.

Above equation reveals that 24.1 per cent variations in drainage basin area are explained by dissection index. The regression coefficient is positively enough significant to explain the validity of aforesaid relationship and variations.

RELIEF RATIO AND AREA:

Relief ratio also, similar to the dissection index provides the same favourable conditions for the streams to produce the maximum sediment yield by enhancing their velocity to shift the water divide of the basin headward. This increases the stream segment's length which ultimately largen the basin area. Relief ratio has a positive correlation with total stream length and a perfect positive correlation with dissection index. This indicates that basins of bigger size develop due to longer length of stream segments which are affected by higher relief ratio. This positive relationship between relief ratio and basin area is well supported by the coefficient of correlation 0.497 being significant at 1% probable level of significance. Graph (Fig 4.4-B) shows the trend of variations and relationship. The equation of the fitted line is given as below:

$$\text{Log } X_{18} = -\text{Log } 2.494 + \underset{(3.526)^{*}}{0.334} \text{ Log } X_{16} \qquad R = 0.247$$

Where, X_{16} = relief ratio

---

* Significant at 0.01 level.

The equation shows that 24.7 per cent variation in drainage basin area is due to the impact of relief ratio. The value of regression coefficient is enough high to be significant to prove the validity of variations.

CONSTANT OF CHANNEL MAINTENANCE AND AREA:

The constant of channel maintenance has a strong positive correlation with the basin area. The coefficient of correlation (0.607) between two variables is significant at 0.001 level of significance. Basins of smaller areas have lesser values of constant of channel maintenance and higher drainage density. To drain a larger area a higher value of constant of channel maintenance is required. The constant of channel maintenance has a strong and positive correlation with mean length of stream segments. The value of coefficient of correlation being 0.798 is significant at 1% probable level of significance. This indicates that the longer longer length of stream segments is a function of bigger areas of constant of channel maintenance, where, longer length of stream segments play a vital role in retreating the basin divide and ultimately largen the basin area. This positive trend of relationship is clearly portrayed by the scattered diagram (Fig 4.5-A). The points follow the trend of regression line with a small deviation. The equation of the fitted line is as

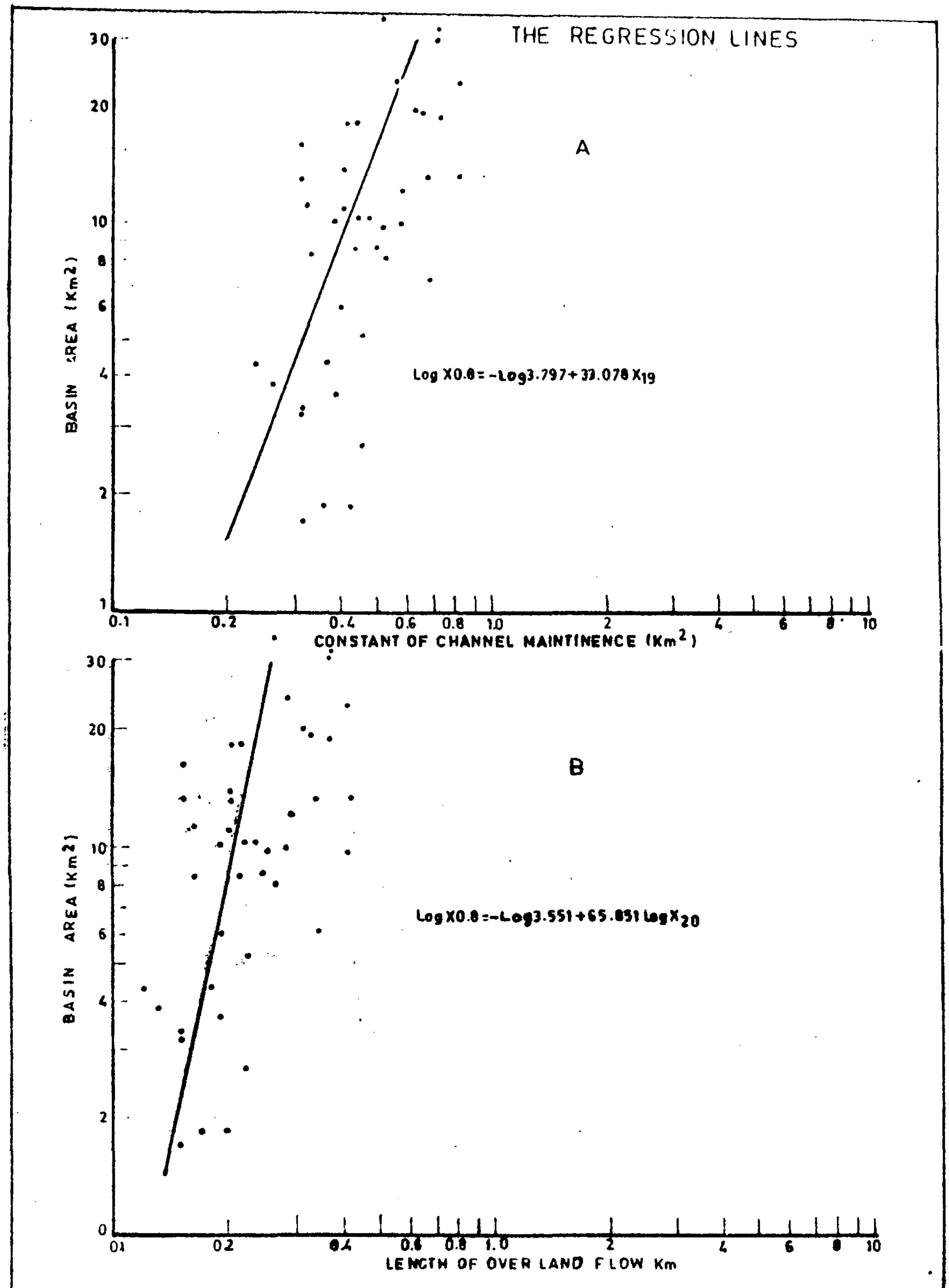
THE REGRESSION LINES
A
BASIN AREA (Km2)
30
20
10
8
6
4
2
1
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
CONSTANT OF CHANNEL MAINTINENCE (Km2)
Log X0.8 = -Log3.797+33.078 X19
B
BASIN AREA (Km2)
30
20
10
8
6
4
2
0
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
LENGTH OF OVER LAND FLOW Km
Log X0.8 = -Log3.551+65.851 LogX20

FIG. 4.5

below:-

$$\text{Log } X_{18} = -\text{Log } 3.797 + 33.078 \underset{(4.710)^{*}}{X_{19}} \qquad \bar{R}^{2} = 0.368$$

Where, X_{19} = constant of channel maintenance

The above equation shows that 36.8 per cent variations in the basin area are explained by the constant of channel maintenance. The value of regression coefficient is enough high to signify the validity of variations.

LENGTH OF OVERLAND FLOW AND AREA:

Similar results as that of constant of channel maintenance have been obtained by the correlation analysis between length of overland flow and drainage basin area. Length of overland flow has a positive correlation with area and thus, indicates that higher length of overland flow developed basins of bigger areas. This postulation is well supported by the higher value of coefficient of correlation (0.607) significant at 0.001 level of significance. Again length of overland flow has a positive and high degree of correlation with mean length of stream segments, which is 0.80, significant at 0.001 level. This shows that higher length of overland flow is a function of longer stream segments, which is the important property of bigger basins. So, it proves the positive functionality of overland flow and basin area.

---

* Significant at 0.001 level.

The above mentioned functionality of two variables is well exhibited by the plotted graph (Fig. 4.5 -B) All points follow the trend of regression line. The equation of the best fit line is given below:

$$\text{Log } X_{18} = -\text{Log } 3.551 + \underset{(4.712)^{*}}{65.851} \text{ Log } X_{20} \qquad \bar{R}^{2} = 0.363$$

Where X_{20} = length of overland flow.

Above equation proves the positive linear functionality of length of overland flow and basin area, as the regression coefficient is enough high to be significant. This shows that 36.3 per cent variations in the basin area are explained by the length of overland flow.

UNDERLYING LITHOLOGY AND AREA:

The results of the present study show that basins of sedimentary rocks formation of Tethys zone have developed higher drainage density but smaller areas (Appendix IV). The basins draining over gneiss and schist metamorphic rocks have lower drainage density but bigger sizes of the basins. The most probable reason of this difference is that basins of smaller areas are in higher altitudes near the source at the inception of youth stage, while bigger basins developed near the mouth are in late youth to mature stages of their development. The drainage basins have lower degree

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* Significant at 0.001 level.

of relief ratio and higher hypsometric integrals in their inception. This is supported by the higher correlation value between relief ratio and hypsometric integral being negative -0.567 but significant at 0.001 level. While relief ratio is positively correlated with the basin area being 0.497 significant at 1% probable level of significance.

The above discussion reveals the fact that the underlying lithological conditions have a significant impact on the development of basin area but it varies according to the basin relief, stage and location.

On the basis of the above discussions following equation of the explanatory variables of the basin area has been obtained:

$$X_{18} = f\ (X_5, X_6, X_7, X_8, X_{11}, X_{12}, X_{13}, X_{16}, X_{19}, X_{20})$$

All these variables have a combined impact on the basin area. Stepwise regression analysis has been used to obtain the best set of explanatory variables on the basis of significance test viz 't' and 'f' tests and the selected equation is as follows:

$$X_{18} = -16.969 + \underset{(9.702)^{*}}{0.788\ X_6} + \underset{(8.969)^{*}}{27.628\ X_{19}} + \underset{(4.312)^{*}}{1.325\ X_{12}} - \underset{(-3.975)^{*}}{0.273\ X_5} \qquad \bar{R}^2 = 0.968$$

---

* Significant at 0.001 level.

The above equation reveals that in the first step, total stream length entered as explanatory variable is having the highest correlation with the explained variable. It explains 74.3 per cent of variations in drainage basin area and regression coefficient is quite significant.

In the second step constant of channel maintenance entered as second explanatory variable is having the second highest correlation with explained variable drainage basin area. These two explanatory variables together explain 95.26 per cent of variations in drainage basin area and both regression coefficients are enough high to be significant.

In the third step drainage frequency entered as third important explanatory variable has a bit lower correlation with explained variable, in comparison to the former two explanatory variables (X_6 and X_{19}). These three variables together explain 95.45 per cent variations in drainage basin area once again, all three regression coefficients are quite significant.

In the final equation four explanatory variables, i.e total stream length (X_6), constant of channel maintenance (X_{19}) drainage frequency (X_{12}) and number of streams segments (X_5) have been chosen as the best set of explanatory variables to explain the maximum variations in drainage basin area. The chosen four variables together explain 96.82 per cent of variations in basin area. The regression coefficient of the equation is quite significant (Table 4.1).

The correlation between these four explanatory variables is very low and insignificant except between X_{19} and X_{12}. The increase in the constant of channel maintenance requires less drainage frequency, that is why the correlation between X_{19} and X_{12} is negative and significant at 1 per cent level. The important fact which comes in light by the step wise regression analysis is that, the total number of stream segments has a negative impact on the area development, while bivariate regression analysis result show a positive relationship between total stream segments and area of the basin. The reason of this controversy is the negative relationship between total stream segments and area of the basin. The reason of this controversy is the negative relationship between total stream segments and drainage frequency. It shows that in presence of X_6 and X_{19}, drainage frequency is stronger than X_5.

On the basis of the above discussion it can be concluded that the area of the drainage basin is dependent on total stream length, constant of channel maintenance, drainage frequency and total number of segments because these four variables explain 96.82 per cent variations in the area. Thus, the study proved the validity of fourth research hypothesis that the area of the drainage basin is deter-

TABLE 4.1

FACTORS AFFECTING THE DRAINAGE BASIN AREA-A STEPWISE REGRESSION ANALYSIS RESULTS

INTERCEPTS	STEPWISE REGRESSION EQUATIONS	REGRESSION COEFFICIENT OF							
		X_6	X_{19}	X_{12}	X_5	R	R^2	$\bar{R}$	$\bar{R}^2$
-0.363	I	0.506 (10.516)*				0.863	0.745	0.863	0.745
-11.123	II	0.455 (20.991)*	25.217 (12.509)*			0.975	0.950	0.975	0.950
-16.961	III	0.473 (21.613)*	31.874 (9.287)*	0.751 (2.332)**		0.979	0.958	0.977	0.954
-16.969	IV	0.788 (9.702)*	27.628 (8.969)	1.325 (4.312)*	-0.273 (-3.975)*	0.985	0.970	0.984	0.968

* Significant at 0.001 level.

** Significant at 0.10 level.

mined by the multi-functionality of various morphometric variables viz., stream frequency, drainage density, dissection index, ruggedness number, constant of channel maintenance, length of overland flow, relative relief mean bifurcation ratio, mean channel length, total channel length and number of stream segments. Moreover the impact of the climate and lithology cannot be ignored.

CHAPTER IV

PART B

DETERMINANTS OF EROSION

Erosion is that phenomenon of nature which plays a vital role in reshaping the ladscape. It is auxiomatic to deduce that the erosion is a function of running water, geological background and geomorphic conditions, particularly in a humid region. In words of Singh[1], erosion is that process in which various erosive agents (running water, glacier etc) obtain and remove rock debries from the earth's crust and transport them for long distance. The more important tools of erosion, of course are the rivers which in presence of different topographic conditions erode the earth's surface by various processes.

Topographic background is another significant factor which provides favourable conditions for the running water to erode the land surface. The velocity of running water which is the significant tool of erosional power of river is governed by the geomorphic conditions of the region.

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1. Savindra Singh, (1976), '<u>Bhoo-Akriti Vigyan</u>' Tara Publication, Kamchchha, Varanasi, p. 318.

Underlying lithological conditions also play an important role to determine the intensity of erosion. Soft rocks are easily erodable while hard rocks form an obstacle in the way of rapid erosion.

The above mentioned factors which are inter dependant determine the intensity of erosion, simultaneously. Therefore the factors which stimulate the velocity of running water may be considered important determinants of erosional intensity.

DETERMINANTS OF EROSION:

The present study is based on the secondary data collected from Survey of India toposheets and the data regarding the water discharge and sediments yield are not available for the rivers of the study area. Erosion itself cannot be measured as a variable like other geomorphic variables because it is a combined function of geomorphic and geological factors. Therefore, it is necessary to decide a geomorphic parameter as a determinant of intensity of eroson. Basically, erosion is a work of running water,so it looks obvious to decide drainage density as a determinant of intensity of erosion. But drainage density itself is controlled by other geomorphic factors (it has been discussed and proved in Chapter II) and a variable which itself is governed by other variables may not be considered as an explanatory variable. Among all variables which have been taken into account for the present study, dissection index looks more appropriate explanatory variable of intensity of erosion because it has a direct relationship with all erosion enhancing agents (Appendix II). On the other hand dissection index is an independant variable which governs the other variables of drainage morphometry. Therefore dissection index is considered an explanatory variable of intensity of erosion.

CHOICE OF OTHER EXPLANATORY VARIABLES:

The selection of indicators for the present study of erosional intensity has been made on the basis of correlation matrix. A correlation matrix of 21 variables (which already have been introduced in Chapter III) has been prepared to find out the relationships among the selected hydrologic and topographic parameters. A close study of the correlaction matrix (Appendix II) clearly reveals that the dissection index has a direct correlation with total stream length ($r = 0.422$) and average slope ($r = 0.412$) both positive, stand significant at 0.10 level of significance. Drainage density, drainage frequency and hypsometric integral have negative correlation with dissection index, -0.414, -0.507 and -0.57 respectively. Former one is significant at 0.10 level while later two are significant at 0.001 level of significance. This shows that these three variables have a negative relationship with dissection index.

The other parameters of drainage morphometry which have strong correlation with dissection index are, basin area ($r = 0.412$) and ruggedness number ($r = 0.502$) both are significant at 0.10 and 0.001 level of significance, respectively. Relief ratio is another geomorphic parameter which has a positive and perfect correlation with dissection index. The mean length of stream segments also has a positive relationship ($r = 0.387$) with dissection index, although not significant. Except these parameters, some other variables also show an indirect relationship with dissection index, as these variables provide easy paths to those parameters which directly affect the erosion enhancing agencies viz. texture ratio has a positive relationship with drainage density ($r = 0.621$) constant of channel maintenance ($r = -0.831$) and length of overland flow ($r = -0.832$) both negatively correlated with drainage density, significant at 0.001 level of significance.

On the basis of the above discussion all those factors which play significant role in determining the intensity of erosion may be classified into following three categogries:

I. <u>HYDROLOGICAL FACTORS</u>:

i. Stream length
ii. Drainage density
iii. Drainage Frequency

II. TOPOGRAPHICAL FACTORS

- i. Hypsometric Integral
- ii. Relief Ratio
- iii. Average Slope
- iv. Ruggedness Number
- v. Basin Area

III. GEOLOGICAL FACTORS

- i. Metamorphic Rock Formation
- ii. Sedimentary Rock Formation

The impact of the above mentioned factors on the intensity of erosion has been discussed as below:-

TOTAL STREAM LENGTH AND EROSION:

As erosion is a function of running water over the earth surface, it is obvious that if the stream length in any region is more, it will drain maximum earth surface and increase the intensity of erosion. In the present study area bigger basins have more stream length (Appendix IV), as it is clear from the correlation coefficient between stream length and basin area, standing at 0.863 being significant at 0.001 level of significance. This relationship reveals the fact that basins near the mouth of Dhauliganga, which are well developed are more erosion prone. Stream length has a positive correlation with determinant of erosion i.e dissection index, which standing at 0.422

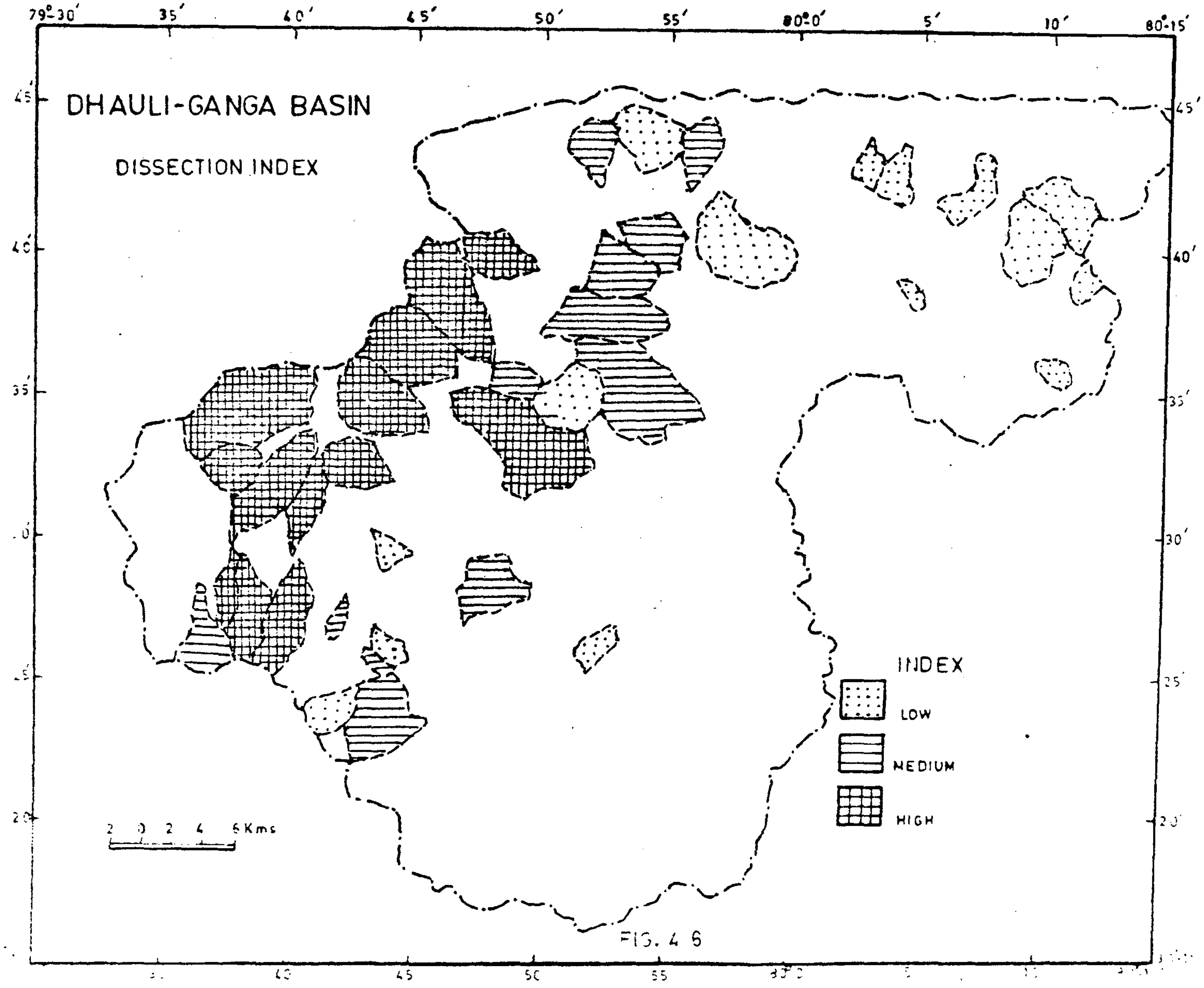DHAULI-GANGA BASIN
DISSECTION INDEX
79°30'
35'
40'
45'
50'
55'
80°0'
5'
10'
80°15'
45'
40'
35'
30'
25'
20'
2 0 2 4 6 Kms
INDEX
LOW
MEDIUM
HIGH

FIG. 4 6

is significant at 0.10 level of significance. This shows that more dissected land scape provides favourable conditions for the streams to increase their length, which ultimately increase the rapidity of erosion. Basins situated near the mouth of Dhauli-ganga have more dissected land as the values of dissection index are higher (Appendix IV) (Fig 4.6). This again indicates towards the fact that bigger basins are more erosion prone. The aforesaid positive relationship between dissection index and stream length is well exhibited by the graph (Fig 4.6-A). The points are well distributed around the regression line. The equation of the fitted line is given below

$$\text{Log } \bar{X}_6 = \text{Log } 3.302 + \underset{(2.869)^*}{48.529} \log X_{13} \qquad \bar{R}^2 = 0.18$$

Where $\bar{X}_6$ = total stream length

X_{13} = dissection index

It implies that the dissection index (X_{13}) explains 18 per cent variations in total stream length which ultimately affect the erosion intensity. The value of regression coefficient is enough high to be significant to prove the aforesaid relationship.

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* Significant at 0.05 level.

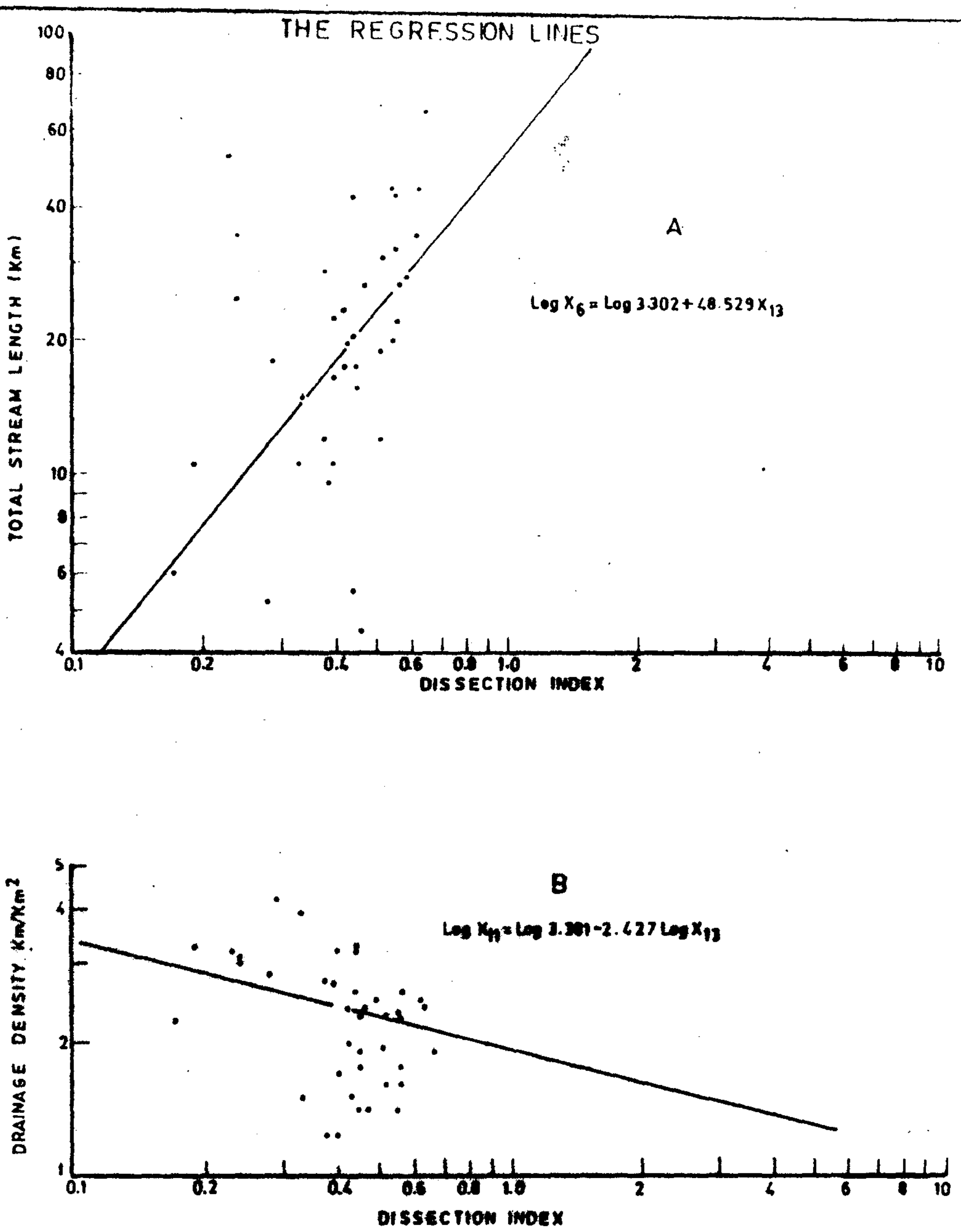
THE REGRESSION LINES
A
TOTAL STREAM LENGTH (Km)
100
80
60
40
20
10
8
6
4
$\text{Log } X_6 = \text{Log } 3.302 + 48.529 X_{13}$
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
DISSECTION INDEX
B
DRAINAGE DENSITY Km/Km^2
5
4
2
1
$\text{Log } X_{11} = \text{Log } 3.381 - 2.427 \text{ Log } X_{13}$
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
DISSECTION INDEX

FIG. 4.6

DRAINAGE DENSITY AND EROSION:

Drainage density can be a strong hydrological parameter which gnaws the earth surface and enhances the erosion intensity. It is apparent from the Appendix IV that drainage basins situated in upper part of Dhauli-ganga basin have higher drainage density (Fig 4.7). This shows that small basins of higher altitudes are more erosion prone. Drainage density has a negative relationship with dissection index, as it is clear by the value of correlation coefficient standing at -0.414 is significant at 0.05 level of significance. This indicates that dissected land scape is detrimental to the drainage density. These results raise a controversy with the previous results. The reason of this controversy is this that the basins having higher drainage density are situated near the source of the Dhauli-ganga and thus are in the initial stage of the basin development. It is apparent from the high values of hypsometric integrals and smaller basin areas (Appendix IV). While bigger basins have removed more land mass and have lower hypsometric integrals. Another important factor which plays a vital role in the development of drainage density is the underlying lithological conditions. Basins of higher drainage density and smaller areas are situated in sedimentary rock formation of Tethys zone and bigger basins in metarmorphic rocks formation of gneiss and schist. Soft rocks provide

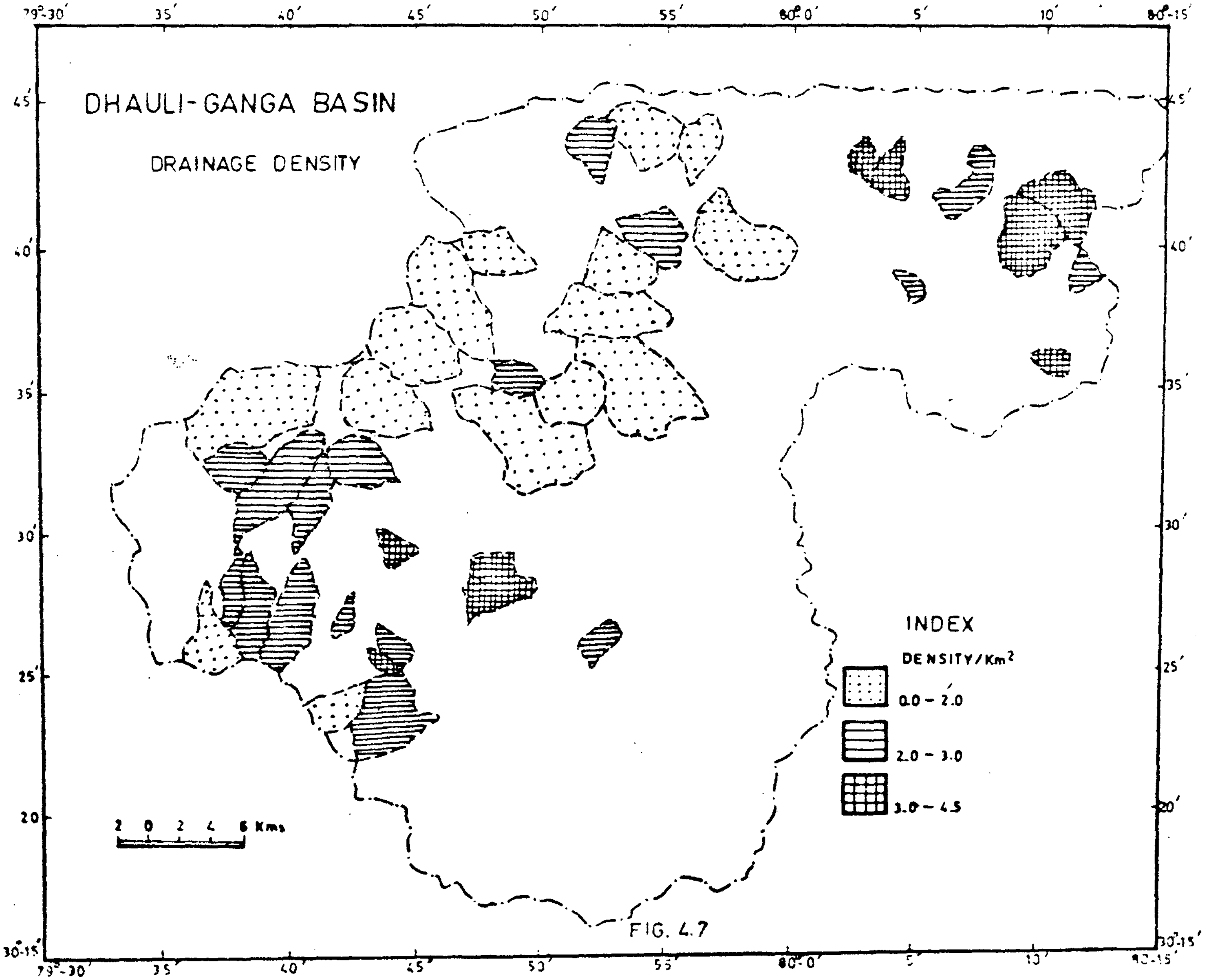
DHAULI-GANGA BASIN
DRAINAGE DENSITY
INDEX
DENSITY/Km²
0.0 – 2.0
2.0 – 3.0
3.0 – 4.5
2 0 2 4 6 Kms
79°-30′
35′
40′
45′
50′
55′
80°-0′
5′
10′
80°-15′
45′
40′
35′
30′
25′
20′
30°-15′

FIG. 4.7

favourable conditions for the stream development due to more erosive nature, while hard rocks enforce the streams to flow in a particular track. Thus the reason of negative relationship of drainage density with dissection index is clear. Graph well exhibits the relationship trend (Fig 4.6-B) with the scattered points around the regression line. The equation of the fitted line is as below:

$$\text{Log } X_{11} = \text{Log } 3.381 - \underset{(-2.80)^{*}}{2.427} \text{ Log } X_{13} \qquad \bar{R}^2 = 0.17$$

Where X_{11} = drainage density.

The above equation reveals that dissection index alone explains 17 per cent variations in drainage density. The regression coefficient is enough high to be significant.

DRAINAGE FREQUENCY AND EROSION:

Similar to the drainage density, drainage frequency also has a negative relationship with the determinant of erosional intensity i.e dissection index. This is clear by the higher negative coefficient of correlation value standing at -0.507 being significant at 0.001 level of significance. (This indicates that the more dissected land scape does not provide favourable conditions for the development of drainage frequency). Smaller basins situated in higher

---

* Significant at 0.05 level.

altitudes have higher stream frequency (Fig 4.7 C) and thus indicates that small basins are more erosion prone. Again this controversy emerges as a result of basin's stage, area and underlying lithology. Smaller basins are in initial stage of basin development as it is apparent from hypsometric integral values (Appendix IV) which have a negative correlation with basin area. Soft rocks provide favourable conditions for the drainage frequency while hard rocks are an obstacle.

On the basis of the above discussion the validity of negative relationship between dissection index and drainage frequency can be proved, which ultimately gives an idea about the intensity of erosion in the study area. Graph shows the negative linear relationship (Fig 4.7-A) between these two variables. Points are well scattered along the regression line. The equation of the fitted line is given as below:

$$\text{Log } X_{12} = \text{Log } 6.003 - \underset{(3{\cdot}621)^{*}}{6.996} \text{ Log } X_{13} \qquad \bar{R}^2 = 0.26$$

Where, X_{12} = drainage frequency.

Above equation reveals that 26 per cent variations in the drainage frequency are due to the impact of dissection index. The regression coefficient is enough high to explain the validity of the aforesaid relationship and variations.

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* Significant at 0.001 level

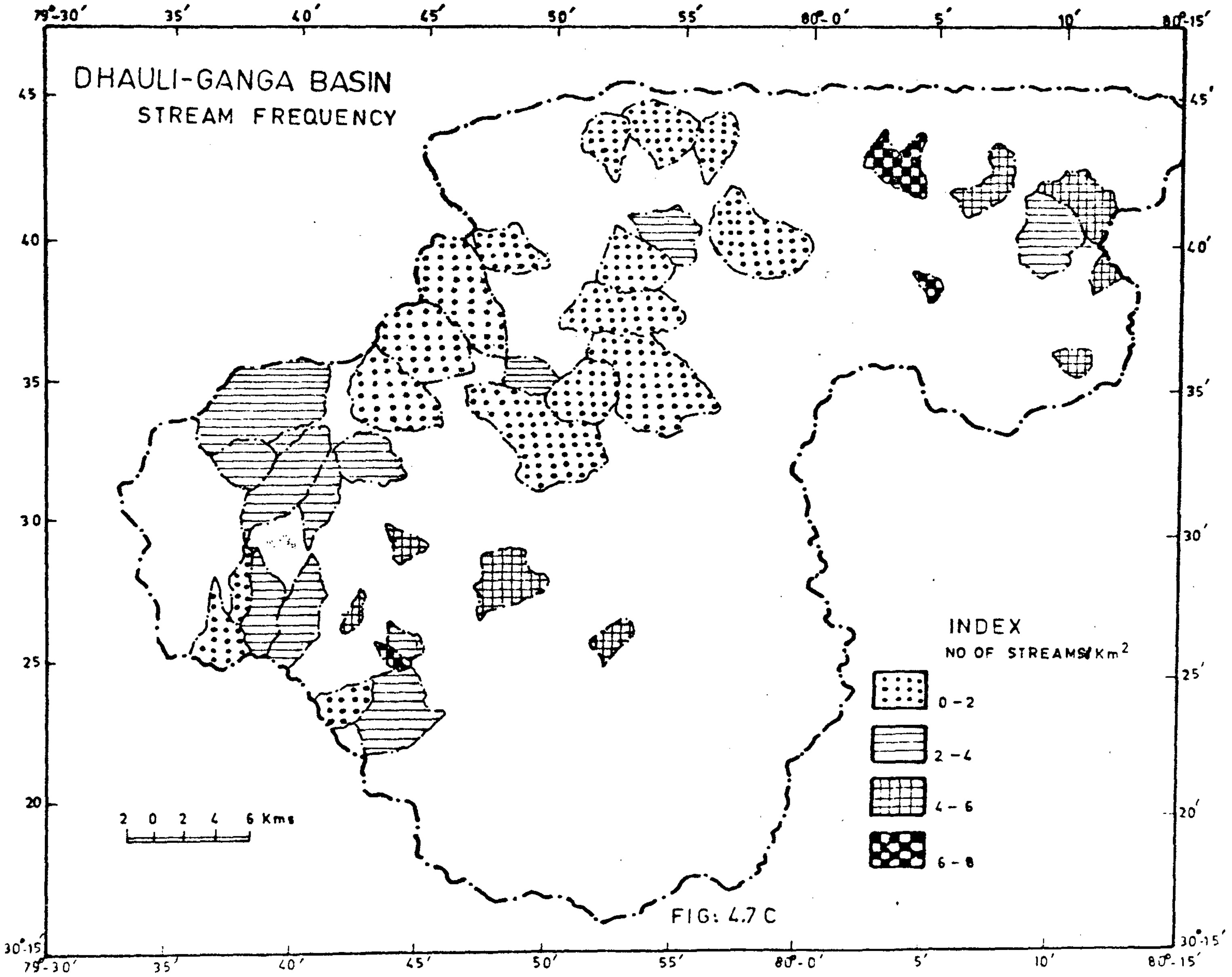
DHAULI-GANGA BASIN
STREAM FREQUENCY
79°-30′
35′
40′
45′
50′
55′
80°-0′
5′
10′
80°-15′
45
40
35
30
25
20
30°-15′
45′
40′
35′
30′
25′
20′
INDEX
NO OF STREAMS/Km²
0 - 2
2 - 4
4 - 6
6 - 8
2 0 2 4 6 Kms

FIG: 4.7 C

HYPSOMETRIC INTEGRALS AND EROSION

Hypsometric integral is an important geomorphic variable which gives a clear idea about the erosional conditions of the region. The higher value of hypsometric integral reveals that the area is under the initial stage of basin development, while higher value of mass removed reveals the opposite fact. Hypsometric integral is affected by the drainage frequency as it has a positive significant relationship with it. Coefficient of correlation standing at 0.435 is significant at 0.05 level of significance. This shows that higher drainage frequency has higher value of hypsometric integral. This statement seems to be contradictory in itself because more frequency of streams over the soft rocks formation erode more sediments (as basins of high stream frequency and higher hypsometric integrals are situated in sedimentary rocks (lime-stone) formation of Tethys zone). Thus, the reason of this superficial controversy is this that basins of higher drainage frequency are smaller and in inception of their development over the soft rocks formation, while bigger basins have low hypsometric integrals and thus lower drainage frequency (basins have lower drainage frequency in their late stage chapter III).

The negative linear relationship between hypsometric integral and dissection index is apparent by the high value

THE REGRESSION LINES

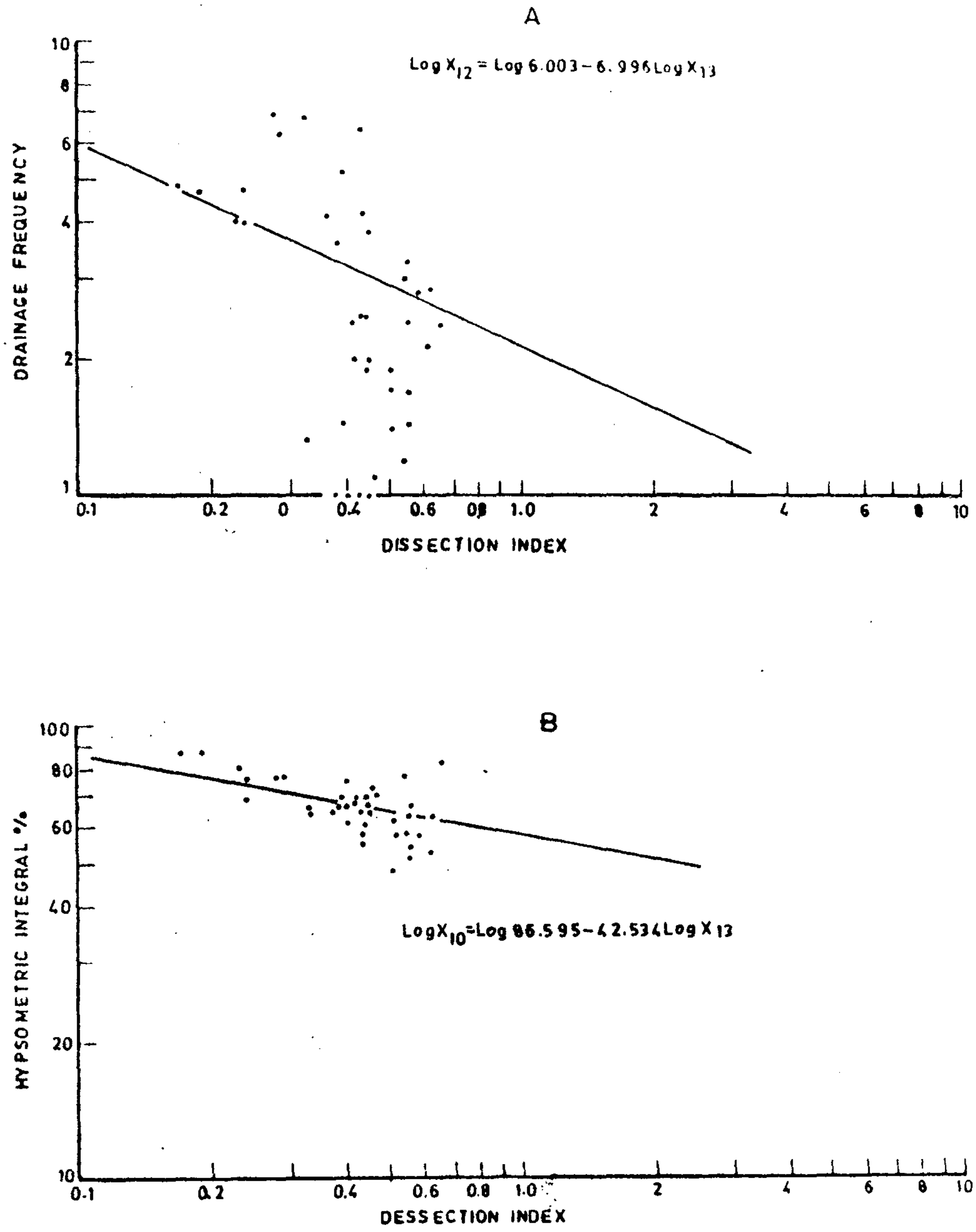

FIG. 4.7

of coefficient of correlation standing at -0.570 being significant at 0.001 level of significance. This indicates that higher dissected land has lower value of hypsometric integral, which ultimately proves that bigger basins are more eroded. Graph (Fig 4.7 - B) shows the compact distribution of points because of higher values and less deviation in value of hypsometric integrals of the basins. The equation of the fitted regression line is as below:

$$\text{Log } X_{10} = \text{Log } 85.596 - \underset{(-4.275)^{*}}{42.534} \text{ Log } X_{13} \qquad \bar{R}^2 = 0.32$$

Where X_{10} = hypsometric integral

The above equation proves the negative linear functionality of hypsometric integrals and dissection index, as the regression coefficient is enough high to be significant. This shows that 32 per cent variations in hypsometric integral are explained by dissection index.

RELIEF RATIO AND EROSION

Relief ratio is a dominant geomorphic parameter which has a direct control over the erosion enhancing agents. It has a strong but negative correlation with drainage density and drainage frequency, having correlation coefficients -0.414 and -0.506 respectively, both are significant at 0.05 and 0.001 level of significance, respectively. This

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* Significant at 0.001 level.

indicates that the basins of high relief ratio have low drainage density and frequency. High relief ratio increases the velocity of flowing water to erode more sediment yield. In the present study area, basins situated near the mouth of Dhauli-ganga have higher relief ratio and small values of hypsometric integrals and thus prove them to be more eroded. Smaller basins situated towards the source in higher altitudes have lower relief ratio due to their smaller extension. Albeit they have higher drainage density and frequency but higher degree of hypsometric integral too and thus are less eroded because a chunk of land mass has to be removed.

Relief ratio has a perfect and positive correlation with dissection index as it is apparent from the coefficient of correlation (Appendix II), which is significant at 0.001 level of significance. This perfect and positive linear relationship is very well portrayed by the graph (Fig 4.8A) where almost all the points are scattered in a straight line along the regression line. The equation of the fitted line is as below:

$$\text{Log } \bar{X}_{16} = -\text{log } 0.178 + \underset{(234.372)^{*}}{100.239} \text{ Log } X_{13} \quad \bar{R}^{2} \; . \; 0.998$$

Where X_{16} = relief ratio

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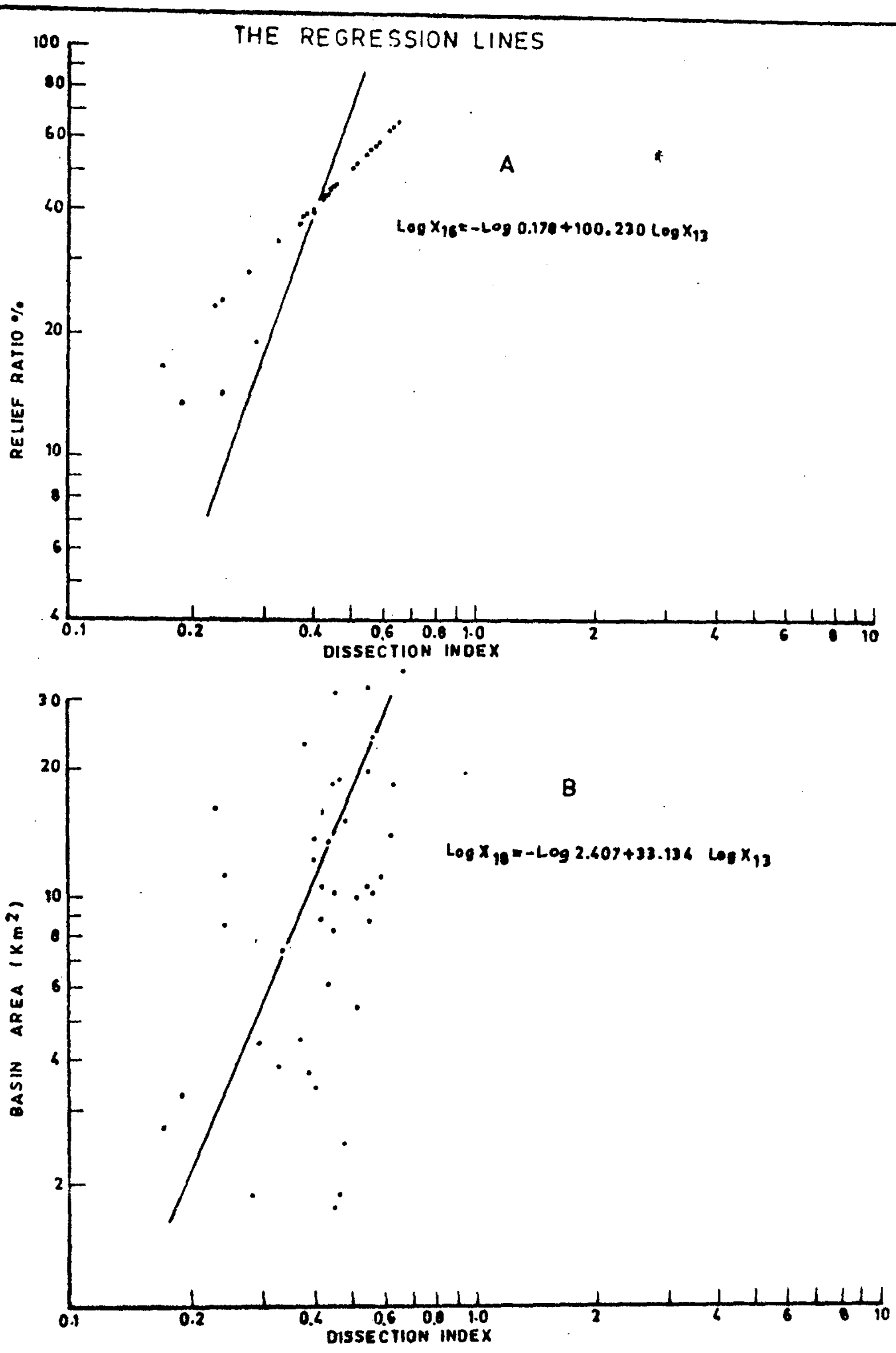
* Significant at 0.001 level.



THE REGRESSION LINES

FIG 4.8

The above equation implies that 99.8 per cent variations in the relief ratio are explained by dissection alone index. The value of regression coefficient is quite significant.

BASIN AREA AND EROSION:

In the first half of this chapter it has been widely discussed and proved that the area of the drainage basin is a function of erosion enhancing agents. Generally, the extension of the drainage basin area is due to the headward erosion of streams. Therefore the area of the basin also speaks about the intensity of erosion. Basins which have developed more stream length and consequently bigger areas are more eroded. This type of basins are situated near the mouth of Dhauli-ganga as has already been discussed. Dissection index has a strong control over the extension of basin area, which is clear from the high positive correlation coefficient standing at 0.491, being significant at 1 per cent probable level of significance. Ultimately, it may be concluded that bigger basins in the present study area are more eroded.

This relationship is well exhibited by the graph (Fig 4.8-B) points scattered along the regression line show the trend of relationship. The validity of relationship can be proved by the fitted regression line. The equation of the fitted line is given as below:-

$$\text{Log } X_{18} = -\text{Log } 2.407 + \underset{(3.477)^{*}}{33.134} \text{ Log } X_{13} \qquad \bar{R}^2 = 0.24$$

Where X_{18} = basin area.

The above equation reveals that 24 per cent variations in the basin area are explained by the dissection index. The value of regression coefficient is enough high to signify the nature of relationship.

AVERAGE SLOPE AND EROSION:

Slope of the terrain is another important factor which provides the suitable conditions for the development of streams and govern the velocity of flowing water, which is the significant force of water for tearing and scractching the earth surface. Average slope has a positive relationship with the ruggedness and relief ratio. This relationship is clear by the coefficient of correlation values 0.52 and 0.411, which are significant at 0.001 and 0.10 level of significance, respectively. These two variables are strong determinants of intensity of erosion and thus it may be deduced that high value of average slope is also an indicator of high eroded ladscape. Basins situated near the mouth of Dhauli-ganga with bigger basin areas have higher degree of relief ratio. This supports the previous results that bigger basins are more eroded.

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* Significant at 0.10 level.

Average slope has a positive relationship with dissection index the value of coefficient of correlation standing at 0.412 is significant at 0.10 level of significance. This relationship shows that just like dissection index high degree of average slope is also an indicator of more eroded land surface. Scattered diagram and regression line well exhibit the aforesaid relationship (Fig 4.9A). The equation of the fitted line is as below:

$$\text{Log } X_{21} = \text{Log } 7.899 + \underset{(2.787)^{*}}{7.935} \text{ Log } X_{13} \quad \bar{R}^2 = 0.17$$

Where X_{21} average slope.

Above equation indicates that 17 per cent variations in the average slope are explained by the dissection index. Reression coefficient is significant to show the validity of relationship and variations.

RUGGEDNESS NUMBER AND EROSION

Ruggedness of the terrain is itself a result of more eroded nature of landscape. Ruggedness has a positive correlation with the drainage density which is clear from the coefficient of correlation value standing at 0.474 being significant at 0.01 level of significance. This indicates that higher degree of ruggedness provides favourable and easy conditions for the development of drainage density and high drainage density obviously will lead to more erosion potential landscape (here area and hypsometric integral of

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*significance at 0.10 level.

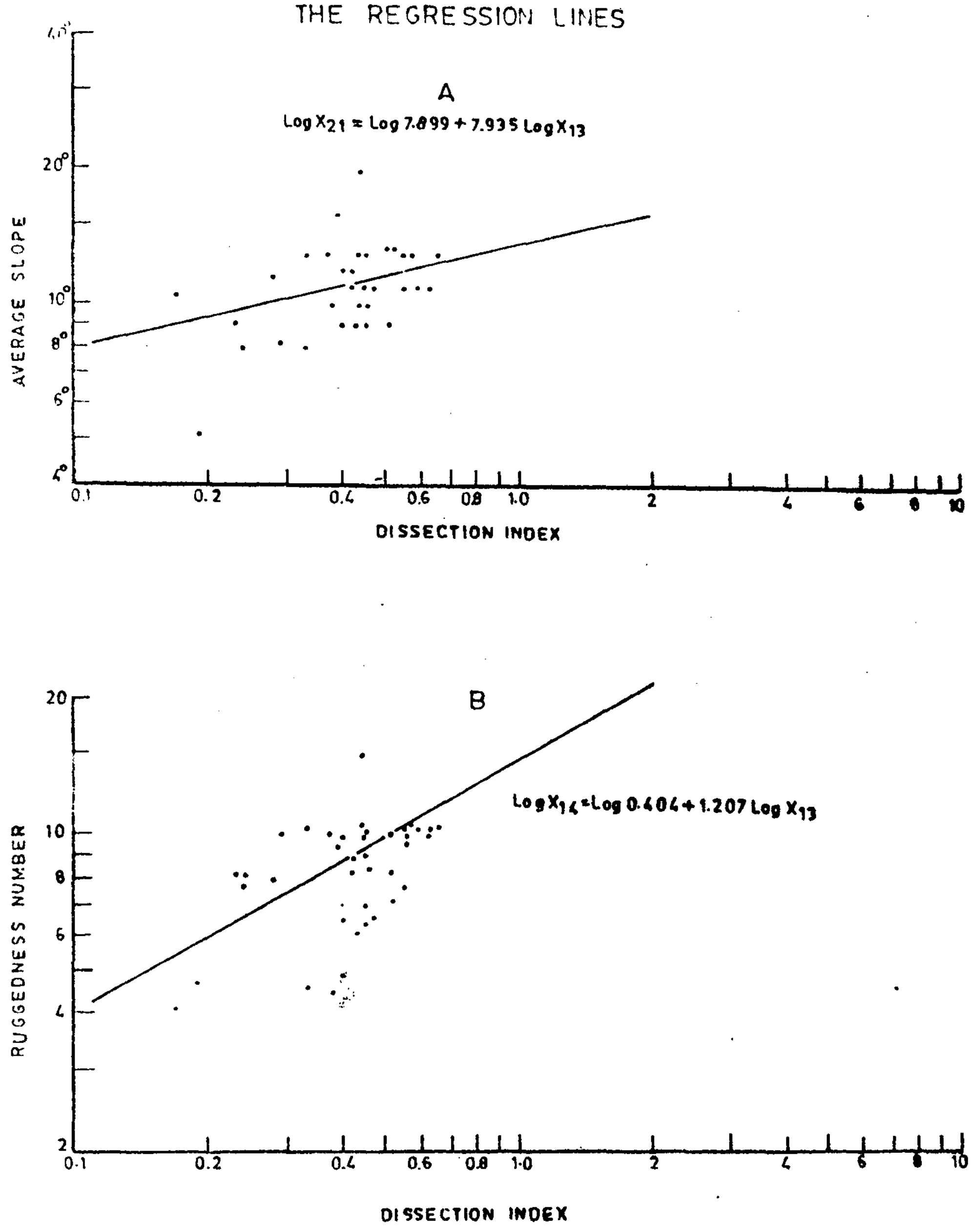
THE REGRESSION LINES
A
$\text{Log}\,X_{21} = \text{Log}\,7.899 + 7.935\,\text{Log}\,X_{13}$
AVERAGE SLOPE
40°
20°
10°
8°
6°
4°
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
DISSECTION INDEX
B
$\text{Log}\,X_{14} = \text{Log}\,0.404 + 1.207\,\text{Log}\,X_{13}$
RUGGEDNESS NUMBER
20
10
8
6
4
2
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
DISSECTION INDEX

FIG. 4.9

the basin are worth considering) (Figure 4.9-C).

The same results have been obtained by correlating the ruggedness number with dissection index, the coefficient of correlation standing at 0.502 is significant at 0.001 level of significance. Thus, it may be concluded that high rugged nature of the terrain is an indicator of more intensity of erosion. The graph (Fig 4.9-B) well expresses this relationship, points are well distributed along the regression line. The equation of the fitted line is as below:

$$\text{Log } X_{14} = \text{Log } 0.404 + \underset{(3.576)^{*}}{1.207} \text{ Log } X_{13} \qquad \bar{R}^2 = 0.25$$

Where X 14 = ruggedness number

The equation expresses that 25 per cent variations in ruggedness number are explained by the dissection index. The value of regression coefficient is quite significant.

UNDERLYING LITHOLOGY AND EROSION:

Lithological background of the region also plays an important role to determine the intensity of erosion. Soft rocks are easily erodable, while hard rocks are an abstacle in the way of production of sediment yield. Basins situated in sedimentary rock formation consists of higher drainage density,which shows that soft rocks easily provide way for water to flow in any fashion, while hard rocks force

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* Significant at 0.001 level

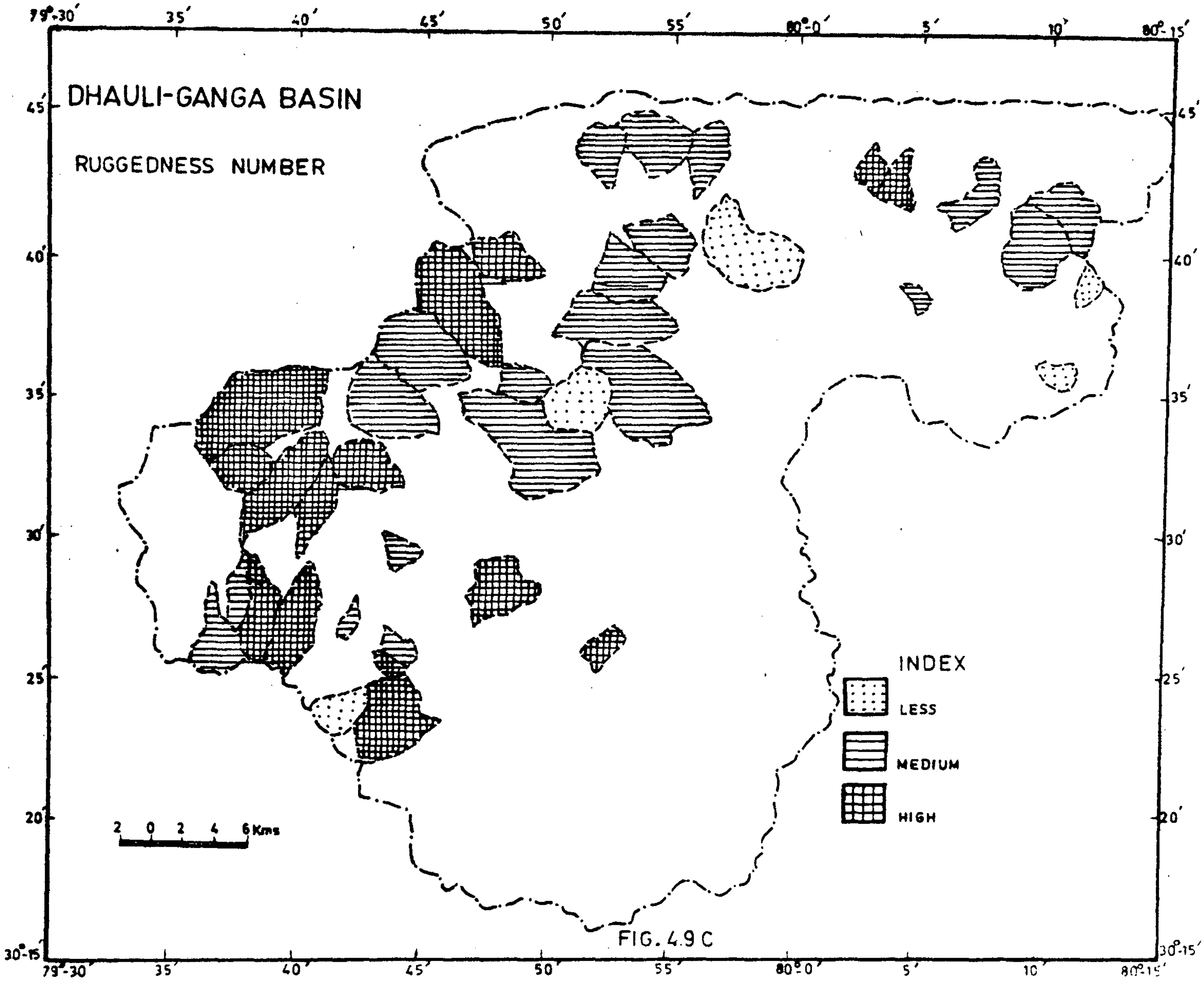
DHAULI-GANGA BASIN
RUGGEDNESS NUMBER
INDEX
LESS
MEDIUM
HIGH
2 0 2 4 6 Kms
79°-30'
35'
40'
45'
50'
55'
80°-0'
5'
10'
80°-15'
45'
40'
35'
30'
25'
20'
30°-15'

FIG. 4.9 C

the water to flow in a particular fashion. This is due to the difference in erodability of rocks. It is worth realizing that hydrological and topographical variables are rather important than rocks formation. For instance, basins situated in soft rocks are less eroded, while basins of hard rock formation are well developed and eroded. This shows the importance of geomorphic variables in determination of erosion intensity.

On the basis of the above discussions following equation of the explanatory variables of erosion has been obtained

$$\text{Erosion} = f\,(X_6, X_{11}, X_{12}, X_{10}, X_{16}, X_{18}, X_{21}, X_{14}, X_{13})$$

On the basis of the above equation it may be concluded that erosion is a combined function of geomorphic, hydrological and geological factors. All the mentioned variables have significant relationship with the dissection index, on the basis of this relationship area has been divided into following three zones of erosion (Fig 4.10).

i. High erosion zone
ii. Medium erosion zone
iii. Low erosion zone

HIGH EROSION ZONE:

According to the above analysis, out of 40 3rd orde drainage basins of the study region 13 basins are recorde in high erosion zone. These basins are, Gankhwi Gadher

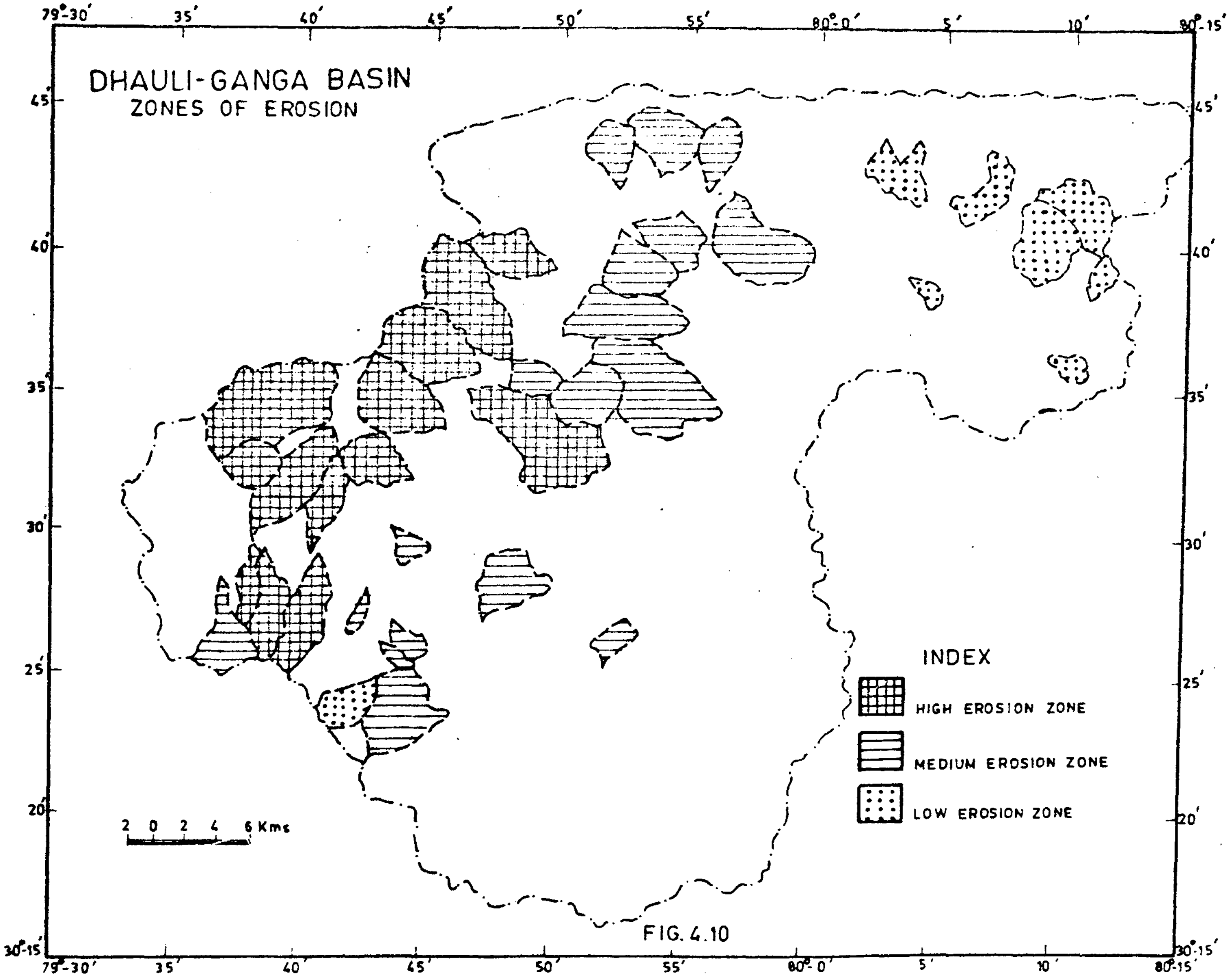
DHAULI-GANGA BASIN
ZONES OF EROSION
79°-30'
35'
40'
45'
50'
55'
80°-0'
5'
10'
80°-15'
45'
40'
35'
30'
25'
20'
30°-15'
INDEX
HIGH EROSION ZONE
MEDIUM EROSION ZONE
LOW EROSION ZONE
2 0 2 4 6 Kms

FIG. 4.10

Pangti Gadhera, Jumagad, Nautigadhera, Subhaigad, Ringigad, Tapoban hot Spring Gad West Tolma Gad, Gadi Gadhera, Juwagwar Gad Bhangyul Gad, Lower Hom Gadhera and Homgadhera. These basins are characterised by high dissection index ranging from 0.50 to 0.66, high relief ratio ranging from 51.30% to 66.43% and lower hypsometric integrals ranging from 48.10% to 83.25% in this zone. Basins of high erosion intensity are located near the mouth of Dhauli-ganga in lower altitudes with bigger areas and higher stream length. These results follow the postulation of Schumm, that the basins of maximum erosion develop near the mouth of basin, possessing bigger areas and migrates towards the head of basin. Figure (4.10) clearly exhibits that basins of high erosion are located in the western lower portion of the basin. Area of these basins ranges from 5.29 km^2 smallest for Tapoban Hot Spring Gad to 34.84 km^2 larger for Hom Gadhera. These basins due to their location possess maximum water discharge and volume, which in favourable relief conditions increase the intensity of erosion.

MEDIUM EROSION ZONE

Out of the remaining 27 third order basins of the

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1. Stanlay A. Schumm, (1977), '<u>The Fluvial System</u>', John Wiley and Sons, New York, p. 68-70.

study region, 18 basins are recorded in second group of medium erosion. These basins are, Dubrugetha Gad, Rishikot Gad, Margaon Gad, Chubag Gad, Lalbasani Gad, Siraunch Gad, Malari Gad, Lower Malari Gad, Garpak Gadhera, Dunagiri Gad, Lower Juma Gad, Nandi Kund Gad, Lata Kharak Gadhera, South Paing Gad, Raunthi Gadhera II, Raunthi Gadhera III, Chamba Kharak Gad and Regri Gad. These basins are characterised by the medium degree of dissection index ranging from 0.33 to 0.50, relief ratio ranging from 33% to 50% and hypsometric integral ranging between 58.40% to 76.06%. Figure (4.10) exhibits that basins of medium erosion intensity are located in the central portion of the study basin, in medium range of altitudes. The basin of medium erosion intensity have smaller areas in comparison of basins of high erosion intensity. Areas of these basins ranges from 1.70 km^2 for Raunthi Gadhera II to 23.18 km^2 for Siraunch Gad. These basins have a bit less favourable geomorphic and hydrologic conditions (already discussed) in comparison to high erosion basins.

LOW EROSION ZONE:

Remaining 9 basins fall in the category of low erosion zone. These basins are, Lauka Gad, Najgaon Gad, Chidamu Gad North, Chidamugad South, Girthi Gad, Bambanag Gad, Girthidhura Gad, Devkot Gad and Raunthi Gadhera I. These basins have lower value of dissection index, ranging from 0.17 to 0.33, relief ratio ranging from 16.58% to 32.80% and higher hypsometric integral ranging from 65.95% to 88.27% in this zone. Figure (4.10) clearly shows that all basins of low erosion are situated in eastern part of the basin in higher altitudes. The area of these basins ranges from 1.85 km^2 minimum for Girthi Gad to 16.11 km^2 maximum for Chidamugad South, Higher values of hypsometric integrals, smaller basin areas, small stream length, location in higher altitudes and higher drainage density and frequency over sedimentary rock formation indicate that these basins are in inception of their development and hence are less eroded.

ZONES OF EROSION AND GEOMORPHIC REGIONS:

The super-imposition of two maps i.e geomorphic regions and zones of erosion, clearly exhibits the fact, that the basins of high erosion are situated in highly dissected landscape, while the zones of medium erosion are situated in highly dissected to low dissected terrain. The basins with low erosion but with a high erosion potential are situated in highly rugged terrain east of Dhar Martoli fault. These results tally with the results of earlier chapters (Chapter II & III)

On the whole the study proved that dissection index is a determinant of erosional intensity as it has a strong control over the erosion enhancing agencies.

SUMMARY AND CONCLUSION

The geomorphometry of Dhauli-ganga basin aims at a detailed analysis of relief and drainage net work to assess the evolution of the basin. This is being carried out with the help of 25 morphometric variables of drainage morphometry. It is being felt that whatever the drainage analysis which has been worked out till now by various Indian authors lacks rationality. It is also being witnessed that the studies are mainly based on a few variables where it comes difficult to associate them with denudational choronology of a region. As the basic aim of geomorphology is to high light the denudational processes, it is felt that the morphometric variables should have a validity in regional multi-planning analysis. With this applied aspect in mind it is aimed in the present study to demarcate the region into erosional zones associated with geomorphic regions on the basis of various chosen variables. These variables have been analysed for the basin as a whole and with a particular reference to all the third order basins for a more detailed and intensive analysis.

Dhauli-ganga river originates from the glacier Kamet, situated in district Chamoli of U.P. The main stream of the river which comes from Dhaulagiri glacier is called Ganesh-ganga in its infant stage. The basin of Dhauli-ganga is a 6th order basin in Strahler's stream ordering fashion, developed on the east bank of Alaknanda river. It forms an unique shaped basin over an area of 1992 square kilometres. This basin is situated near the China border on the transitional area of Garhwal and Kumaon regions of Central Himalayas. Geographically, the Dhauli-ganga basin extends from 79° 30' E to 80° 15' E longitude and 30° 15' N to 30° 45' N latitude. Politically the basin covers an area of Chamoli district of Garhwal region and some part of Pithoragarh district of Kumaon region, in extreme north region of Uttar Pradesh.

A general glance at the basin gives a notion of three physiographic divisions viz., mountains, river valleys and glaciated landscape. The development of valleys is well marked in central part of the basin from Vishnuprayag to Malari. The boundaries of the basin are high mountain ranges and SSE portion of the basin where highest peak of the country Nanda Devi (7817 m) exists is under glaciers. Bare rock landscape may be observed in eastern portion of high altitudes with huge boulders under the phenomenon of rock falling.

The geological background of the basin is directly associated with the geological episodes of the upliftment of the Himalayas. According to the geologists, it has now been well established that the Himalayas did not attain its present height in one single phase. Geological data show that Himalayas has developed during five or more phases of upliftment with intervening periods of quiescene. Therefore, the major and minor geomorphic features of this area are directly related with the sequential upliftments of the Himalayas. The Himalayas are still rising is evident from the presence of deep gorges due to antecedent drainage pattern and the presence of river deposits hundreds of meters above the present river level. The present rate of upliftment is estimated to be 0.5 - 0.8 cm per year.

The underlying lithology of the basin has been divided into two formations by Dhar-Martoli fault. In the West of the fault metamorphic formation, the rocks are mica schists with quartzite layers, alternating with real biotite gneiss which becomes predominant towards Joshimath. While in the east of fault sedimentary rock formation of Tethys zone is prevailing, dominated by lime-stone.

The absolute relief of the basin varies from 1960 meters lowest to 7817 meters highest. This leads that the whole basin lies in high mountainous area. The frequency distribution of the absolute relief in the basin shows that more than half of the basin (57.39%) lies above the height of 5000 meters. The contour line of 5000 meters has been identified as snow line in the basin.

The relative relief of the area has a great degree of variation ranging from 80 meters lowest to 1640 meters heighest. It indicates the development of deep river valleys and escarpments. The same results have been concluded by the dissection index analysis, which ranges from 0 to 0.40 in the basin, that river valleys have developed steep escarpments and gorges due to the deep downward cutting by antecedent drainage pattern.

The analysis of the ruggedness number of the basin provides an account of roughness of the land surface. The distribution ruggedness number indicates that the area east of Dhar-Martoli fault is extremely rugged while area above the height of 5000 meters is rather flat.

The average slope of the basin ranges between a maximum of 27.5° to a minimum of 0.7° with a range of 26.8°. Maximum area of the basin lies in moderately steep slope zone (10°- 25°), which covers 66% of the entire basin, Which indicates the early stage of cycle of erosion. Other statistical measures of the slope values indicate the initial stage of the slope development in the basin. The development of average slope in the basin is a resultant of combination of hydrological, topographical and geological factors such as, drainage density, stream frequency, relative relief, absolute relief, ruggedness number, dissection index and underlying lithology. The obtained results of the correlation matrix reveal the fact that the development and distribution of slope is positively related with the aforesaid variables, except absolute relief. Absolute relief does not show any direct relationship with the slope, but in presence of relative relief, dissection index and drainage density it plays a significant role in slope development, The results of step-wise regression analysis prove that relative relief, dissection index, absolute relief and drainage density are dominant geomorphic parameters to play a vital role in the development of slope and these parameters are inter-dependent too.

Drainage analysis of the basin provide an account of two types of drainage patterns i.e dendritic and sub-parallel drainage patterns. The extremely high stream frequency and drainage density of the basin with high absolute and relative relief indicate the youthful stage of the basin development, whereas deep river valleys shows the continuous upliftment of the basin. The detail study of drainage density development in the basin shows that not only underlying lithology but other geomorphic parameters also have their significant control over the drainage density development in presence of underlying lithology. The correlation matrix indicates that, stream frequency, relative relief, absolute relief, average slope, ruggedness number and dissection index are significant parameters in the development of drainage density. The step-wise regression analysis prove that ruggedness number, stream frequency, absolute relief and dissection index are more dominant factors for drainage density development. Mean bifurcation ratio of the basin meets the results of earlier studies, but it does not prove the Hortonian concept of geometric series in all orders, neither with stream number nor with stream length.

The inter-relationship of a few dominant geomorphic parameters have been used to demarcate the geomorphic regions. The entire basin has been divided into four geomorphic regionS viz., glaciated terrain, moderately dissected landscape, highly dissected terrain and valley bottoms and highly rugged mountains.

Topological and geometric study of the drainage net work reveals the fact that stream segments in hilly region in the basins of same order decrease or increase as the area of the basin increases or decreases. The development of segments are more in the area of soft rocks formation and a few geomorphic parameters viz absolute relief, ruggedness number and texture ratio have their impact over the branching system of streams. The negative exponential function model of Horton, when applied to this basin, proves the validity of stream segments decreasing with increasing order but this relationship is not significant, as it is not supported by the coefficient of correlation between stream segments and their respective stream orders. This proves that stream segments of different orders do not form the geometric series. In the same way the second law of stream length also proves that the length of stream segments is directly associated with the basin area and vice-versa. It again proves that the mean length of segments increase with increasing order, as it is well supported by the coefficient of correlation between order and corresponding mean stream length and prove the validity of positive exponential function model of Horton. But the regression analysis does not prove the Horton's postulation of geometric series.

The mean bifurcation ratios of the maximum basins meet the observations of coats that minimum possible ratio of 2.0 is seldom approached in nature but generally ranges between about 3.0 and 5.0 in basins without differential geological controls and only reaches higher values where geological control favour the development of g elongated narrow basins. The values of mean bifurcation ratio for all basins under the present study, either lying in sedimentary rocks formation of Tethys or schist and gneiss derminant metamorphic structure, show that geological formation does not have strong control over the branching system of streams. The present study confirms the Giusti and Sehneider's hypothesis that 'bifurcation ratios within a basin decrease with the increasing order'. And further study confirms the postulation that 'basins of equal order but variable areas tend to have the smallest bifurcation ratio in the smallest area; the ratio increases with increasing area upto certain size beyond which the bifurcation ratios tends to become constant', yet the impact of geological formation, forest canopy and climate on mean bifurcation ratio cannot be ignored completely.

This study concludes about the constant of channel maintenance that it is governed by the underlying lithological formation, geological structure and nature of configuration and further it reveals that channels require less space to flow over soft rocks formation than hard rocks. The length of overland flow, being just half of the constant of channel maintenance in the present study exhibits the fact that 'since a drainage basin on an average develops maximum stream segments in its late youth and early mature stages, hence minimum length of overland flow must be found',. Length of overland flow is governed by the underlying lithological structure and drainage texture yet the indirect impact of vegetal cover and climate cannot be ignored.

Standard sinuosity index provides the informations regarding the shape characteristics of the open link in the study basin. This indicates that maximum basins have very low values of sinuosity indices which is an indicator of youthful stage of basin development. The sinuosity of streams is directly affected by the underlying geological structure. Except this,topographical conditions and vegetal cover also have their distinct impression on river sinuosity. The low value of standard sinuosity index also reveals the fact that area is under the process of gradual upliftment. The topographical and hydrological sinuosity indices results show that a few basins have a control of hydraulic sinuosity, While maximum basins have a high domination of topographical sinuosity in the development of present drainage net work of the basin.

Similar to the shape of open link, four indices of shapes of the close link concluded that the shape of the drainage basin is governed by the geological formation, relief, slope aspects and lithological factors. Shape of the basin reflects the stage of basin development.

Angular properties of the open link of the present study basin are similar to the earlier findings that 'the stream junction angles increase as the order of receiving streams increases. The present study does not prove that any clear relationship exists between lithology and the stream junction angle. Study does not show any relationship between mean junction angle and basin stage determinant mass integral.

The area of basin shows a strong relationship with basin length and basin perimeter. This positive relationship among the said geomorphic parameters clearly exhibits the genesis of the basin development which is governed by the geologic structure, climate of the region and forest canopy .

The hypsometric analysis of third order basins conclude that maximum basins are in youthful stage and a few basins have developed into early mature to mature stage. This also indicates that the basin development is a phenomenon of multifunctionality of geomorphic parameters viz mean stream length, dissection index, relief ratio and average slope of the terrain.

. The study throws light on the drainage basin area extension. It may be concluded that the area of the drainage basin is a combined function of hydrological, topographical and lithological factors viz., stream frequency, drainage den-sity dissection index, ruggedness number, consistant of channel maintenance, length of overland flow, mean bifurcation ratio, relative relief, mean chann el length, total stream length and number of stream segments. The results of step-wise regression analysis prove that out of all mentioned parameters, total stream length, constant of channel maintenance, drainage frequency and total number of segments are more dominant because these four variables explained 96.82 per cent variations in the area.

Different zones of erosional intensity in the basin have been identified on the bases of inter-relationship of hydrological and topographical parameters. Dissection index proves to be the best indicator of erosion intensity. The relationship between dissection index and other erosion enhancing agents has been established by bivariate regression analysis and basin has been divided into three high, medium and low erosion zones.

On the whole this study upholds the hypotheses which were formulated at the beginning that the topological and drainage characteristics are a multi-functional result of various parameters which are inter correlated. It has also been proved that the area of a drainage basin is a dynamic concept and is once again a resultant of multi functionality of various morphometric variables. The rugged and dissected terrain are two different aspects of topography and this is being highlighted in this basin where dissection index proves a strong determinant of erosional intensity than absolute ruggedness. With these results in mind it is to be seen with a more detailed geological, climatical and bilological informations whether the same hypothesis can be applicable to the said area.

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APPENDIX - I

CORRELATION MATRIX OF GEOMORPHIC VARIABLES OF DHAULI - GANGA BASIN

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1.000						
X_2	.872	1.000					
X_3	0.060	.053	1.000				
X_4	.380	.288	.037	1.000			
X_5	.087	.079	.930	.047	1.000		
X_6	.882	.773	.324	.337	.347	1.000	
X_7	.227	.175	.776	.509	.772	.452	1.00

OTHER STATISTICAL MEASURES

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
1. Mean of variables	1.610	3.116	633.154	4873.229	10.737	1.042	0.13363
2. Standard deviation	1.610	3.391	251.196	967	3.970	1.168	.6188
3. Coefficient of variation	1.000	1.088	0.396	0.198	0.369	1.1121	0.463

APPENDIX - II

STATISTICAL MEASURES AND CORRELATION MATRIX OF GEOMORPHIC VARIABLES OF THIRD ORDER BASINS

```
RECORDS =    40
        MEANS OF VARIABLES
            .401750      .698250      .706250      .712000    26.775000    24.291250      .918250     4.658000
           2.464500    57.199250     2.331500     2.978000      .432500      .927000     1.953750    43.175500
        5189.100000    11.923000      .475250      .235000    11.331250
        STD DEVIATIONS OF VARIABLES
            .145794      .131264      .132891      .280395    16.300838    14.448054      .267830     1.572650
           1.106975     9.374994      .737082     1.734881      .125611      .302207      .817070    12.595566
         591.515082     8.470885      .155481      .078119     2.419435
        COEFF. OF VARIATION
            .362897      .187990      .188164      .393814      .608808      .594784      .291674      .337623
            .449168      .139510      .316141      .582566      .290431      .326006      .418206      .291729
            .113992      .710466      .327156      .332421      .213519
          CORRELATION MATRIX
x1  1.000
x2   .957 1.000
x3   .768  .760 1.000
x4  -.907 -.905 -.833 1.000
x5   .102  .129 -.072 -.121 1.000
x6   .147  .189 -.065 -.151  .914 1.000
x7   .245  .301  .058 -.171 -.070  .298 1.000
x8   .106  .144 -.059 -.143  .950  .871 -.072 1.000
x9  -.212 -.233 -.364  .233  .524  .496 -.077  .483 1.000
x10  .094 -.013  .192 -.173  .161 -.032 -.454  .142 -.035 1.000
x11 -.199 -.189 -.103  .140  .136 -.190 -.770  .148  .028  .336 1.000
x12 -.217 -.245 -.065  .124 -.007 -.347 -.903  .001 -.043  .435  .393 1.000
x13 -.253 -.182 -.256  .345  .247  .422  .387  .275  .259 -.570 -.414 -.507 1.000
x14 -.265 -.192 -.226  .275  .452  .301 -.364  .463  .295 -.272  .474  .344  .502 1.000
x15  .096  .098  .119 -.156  .709  .412 -.630  .683  .279  .439  .709  .621 -.226  .509 1.000
x16 -.259 -.186 -.259  .348  .252  .426  .396  .279  .265 -.567 -.414 -.506 1.000  .501 -.223 1.000
x17  .297  .302  .209 -.426  .403  .380 -.057  .366  .153  .068  .065  .105 -.295  .089  .349 -.293 1.000
x18  .146  .169 -.039 -.170  .628  .863  .571  .595  .362 -.135 -.374 -.612  .491  .007 -.017  .497  .302 1.000
x19  .243  .246  .114 -.206 -.144  .186  .798 -.158 -.077 -.283 -.944 -.831  .291 -.538 -.688  .292  .007  .607
  1.000
x20  .243  .246  .116 -.207 -.143  .187  .800 -.158 -.074 -.284 -.942 -.832  .294 -.535 -.687  .296  .007  .607
   .799 1.000
x21 -.053 -.006  .036 -.012 -.025 -.014 -.180  .013 -.025 -.361  .032  .143  .417  .500  .004  .411  .015  .041
  -.093 -.094 1.000
```

APPENDIX III

AVERAGE QUANTITATIVE GEOMORPHIC CHARACTERISTICS OF THE THIRD ORDER BASINS OF DHAULI-GANGA BASIN

S.NO.	VARIABLES	$\bar{X}$	S.D.	C.V.
1.	Form factor	0.401	0.145	0.362
2.	Elongation ratio	0.698	0.131	0.187
3.	Circularity ratio	0.706	0.132	0.188
4.	Lemniscate	0.712	0.280	0.393
5.	Number of segments	26.775	16.300	0.608
6.	Total stream length	24.291	14.448	0.594
7.	Mean length of segments	0.918	0.267	0.291
8.	Mean bifurcation ratio	4.658	1.572	0.337
9.	Mean length ratio	2.464	1.106	0.449
10.	Hypsometric integral	67.199	9.374	0.139
11.	Drainage density	2.331	0.737	0.316
12.	Drainage frequency	2.978	1.734	0.582
13.	Dissection index	0.432	0.125	0.290
14.	Ruggedness	0.927	0.302	0.326
15.	Texture ratio	1.953	0.817	0.418
16.	Relief ratio	43.175	12.595	0.291
17.	Absolute relief	5189.100	591.515	0.113
18.	Basin area	11.923	8.470	0.710
19.	Constant of channel maintenance	0.475	0.155	0.327
20.	Length of overland flow	0.235	0.078	0.332
21.	Average slope	11.331	2.419	0.213

Abbreviations : $\bar{X}$ = Mean of variables
SD = Standard deviations of variables
C.V= Coefficient of variation

APPENDIX -IV

GEOMORPHOMETRIC CHARACTERISTICS OF THIRD ORDER BASINS OF DHAULI-GANGABASIN

S.No	Name of the basins	Dd. Km/Km^2	Df No/Km^2	Di	Rn
1	2	3	4	5	6
1.	Lauka Gad	3.27	4.67	0.14	0.47
2.	Najgaon Gad	3.24	4.85	0.17	0.41
3.	Chidamu Gad North	3.10	4.68	0.24	0.82
4.	Chidamu Gad South	3.20	3.97	0.23	0.82
5.	Girthi Gad	2.85	7.05	0.28	0.80
6.	Bambanag Gad	3.00	4.09	0.24	0.77
7.	Girthi Dhura Gad	4.20	6.30	0.29	1.08
8.	Devkot Gad	3.91	6.90	0.33	1.33
9.	Dubrugetha Gad	3.27	4.18	0.44	1.62
10.	Rishikot Gad	2.70	4.14	0.37	1.13
11.	Margaon Gad	2.03	1.97	0.42	0.82
12.	Chubag Gad	1.72	1.45	0.40	0.65
13.	Lalbasani Gad	1.92	1.98	0.45	0.93
14.	Siraunch Gad	1.23	0.99	0.38	0.45
15.	Malari Gad	2.37	2.41	0.42	0.89
16.	Lower Malari Gad	1.49	0.98	0.43	0.61
17.	Garpak Gadhera	1.40	1.11	0.47	0.66
18.	Dunagiri Gad	1.39	0.98	0.45	0.70
19.	Lower Juma Gad	2.58	2.50	0.44	0.98
20.	Nandi Kund Gad	1.22	0.96	0.40	0.49
21.	Gankhwi Gadhera	1.38	1.19	0.55	0.77
22.	Pangti Gadhera	1.95	1.74	0.51	1.09
23.	Juma Gad	1.76	1.45	0.56	1.07
24.	Nauti Gadhera	1.61	1.66	0.56	0.99
25.	Lata Kharak Gadhera	3.19	5.16	0.40	0.95
26.	South Paing Gad	2.43	3.78	0.46	0.85
27.	Raunthi Gadhera II	3.25	6.49	0.44	1.48
28.	Raunthi Gadhera III	2.66	3.64	0.39	0.95
29.	Chamba Kharak Gad	2.33	2.52	0.45	1.19
30.	Raunthi Gadhera I	1.48	1.26	0.33	0.46
31.	Subhain Gad	2.50	2.24	0.62	1.05
32.	Ringi Gad	2.51	2.83	0.59	1.30
33.	Tapoban Hot Spring Gad	2.27	1.89	0.51	0.83
34.	Regri Gad	1.75	1.90	0.45	0.64
35.	Gadi Gadhera	1.57	1.39	0.52	0.72
36.	West Tolma Gad	2.14	2.43	0.56	1.11
37.	Juwagwar Gad	2.34	3.04	0.55	1.21
38.	Bhangyul Gad	2.44	2.85	0.63	1.39
39.	Lower Hom Gadhera	2.61	3.25	0.57	1.23
40.	Hom Gadhera	1.94	2.35	0.66	1.37

Abbreviations:

Dd = Drainage density
Df = Drainage frequency
Di = Dissection index
Rn = Ruggedness number

APPENDIX - IV

GEOMORPHOMETRIC CHARACTERISTICS OF THIRD ORDER BASINS OF DHAULI-GANGABASIN

S.No	Name of the basins	Tr	Rr %	Ar (m)	A Km^2	As 0°
1	2	7	8	9	10	11
1.	Lauka Gad	2.14	13.57	5600	3.22	5.75
2.	Najgaon Gad	2.00	16.58	5802	2.68	10.40
3.	Chidamu Gad North	3.47	23.80	5879	11.12	7.96
4.	Chidamu Gad South	4.27	23.29	5840	16.11	9.11
5.	Girthi Gad	2.36	28.03	5280	1.85	11.53
6.	Bambanag Gad	2.43	24.29	5600	8.31	10.19
7,	Girthi Dhura Gad	2.70	29.10	5360	4.29	8.83
8.	Devkot Gad	3.25	33.27	5395	3.77	13.38
9.	Dubrugetha Gad	3.67	43.67	6000	13.15	9.58
10.	Rishikot Gad	2.12	36.74	5880	4.35	12.79
11.	Margaon Gad	1.48	42.06	5040	8.63	11.83
12.	Chubag Gad	1.36	40.00	5000	12.11	11.63
13.	Lalbasani Gad	1.40	45.44	5592	8.10	10.15
14.	Siraunch Gad	1.15	37.50	5120	23.18	10.22
15.	Malari Gad	2.00	41.60	5000	10.36	10.80
16.	Lower Malari Gad	0.90	42.52	5080	13.25	9.30
17.	Garpak Gadhera	1.10	47.31	5280	19.00	10.68
18.	Dunagiri Gad	1.22	45.40	5861	30.68	10.93
19.	Lower Juma Gad	1. 58	43.48	4600	6.01	13.05
20.	Nandi Kund Gad	0.81	39.62	5300	13.52	9.07
21.	Gankhwi Gadhera	1.46	55.32	5372	32.00	12.88
22.	Pangti Gadhera	1.31	51.30	5750	9.77	13.48
23.	Juma Gad	1.67	55.66	5773	24.13	12.74
24.	Nauti Gadhera	1.94	56.40	5780	19.88	12.83
25.	Lata Kharak Gadhera	2.27	40.28	3885	3.29	12.12
26.	South Paing Gad	1.80	46.00	4000	1.85	10.70
27.	Raunthi Gadhera II	1.83	43.64	5500	1.70	20.13
28.	Raunthi Gadhera III	1.73	38.93	4880	3.57	15.66
29.	Chamba Kharak Gad	2.56	44.57	6062	18.27	12.53
30.	Raunthi Gadhera I	0.82	32.80	5000	7.12	8.34
31.	Subhain Gad	1.77	61.57	5100	13.85	11.35
32.	Ringi Gad	1.82	59.13	4600	10.94	10.56
33.	Tapoban Hot Spring Gad	0.87	50.79	3800	5.29	8.93
34.	Regri Gad	1.19	45.28	4240	10.02	8.52
35.	Gadi Gadhera	1.54	52.10	4673	19.47	13.53
36.	West Tolma Gad	1.92	55.47	4940	10.30	12.60
37.	Juwagwar Gad	1.73	55.10	4940	8.55	11.33
38.	Bhangyul Gad	2.36	62.50	4800	18.24	11.32
39.	Lower Hom Gadhera	2.87	56.88	4360	10.15	13.27
40.	Hom Gadhera	3.28	66.43	5600	34.84	13.25

Abbreviations:

Tr = Texture ratio

Rr = Relief ratio

Ar = Absolute relief

A = Area

As = Average slope