SOME ASPECTS OF CHANNEL MORPHOLOGY OF THE UPPER CATCHMENT OF NARMADA

Dissertation submitted to Jawaharlal Nehru University
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MASTER OF PHILOSOPHY

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CERTIFICATE

Certified that this dissertation entitled "SOME ASPECTS OF CHANNEL MORPHOLOGY OF THE UPPER CATCHMENT OF NARMADA" submitted by Mr. Durgesh Yadav, in partial fulfilment of the requirements of the award of Master of Philosophy (M.Phil.) degree of this University, is a bonafide work to the best of our knowledge and may be placed before the examiners for evaluation.

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I remain solely responsible for any error.

J.N.U., New Delhi
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PREFACE

This research attempts to study the channel morphology of the upper Narmada catchment by taking into account some morphological and hydrological attributes of the channel behaviour. These studies are important from regional development point of view, as it has bearing on the canals and dams for irrigation and power generation.

The main focus is to study the channel behaviour of Narmada in the upper catchment at Manot, Jamtara and Barmanghat gauging and discharge sites. The core of the river centres around the channel pattern and its regime, whose characteristics are being taken as the function of erosional and depositional processes along with discharge. It also studies the nature of the river regime in terms of cross-sectional changes in the channel, variations in discharge and sediment load, during (1972-82) and 1972-77) respectively.

The introductory chapter deals with general introduction, statement of the problem, selection and delimitation of the study area, objectives and methodology etc. The second chapter provides general characteristics of the area under study with reference to the Narmada basin. The chapter third deals with morphological and hydrological aspects of channel cross-section long profiles and channel patterns. The fourth chapter deals with the behaviour of discharge and sediment load in the channel; and the summary and conclusion being the last.

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3rd January 1988.

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Chapter I

INTRODUCTION

1.1 Rivers are important agents of landscape sculpturing particularly in a humid region. Therefore, stream behaviour is an indispensible tool in understanding the nature of flow and sediment in the river, spatially and temporally. Channel behaviour study is essential, prior to the framework of a multidirectional development planning of the catchment basin.

Drainage basin is a natural basic unit, an open system. It receives input in the form of precipitation and solar isolation and releases output in the form of runoff, terrestrial radiation and sediment load or simply erosion; and hence it becomes a complete unit to study environment, eco-system and human activities.

The gradual progress of river study went into very minute and critical study of fluvial landforms and its other aspects. Today river channel change is supposed to be the micro study of fluvial landforms and its evolution. The behaviour of channel in a region is a visible expression of multifunctional activities of various causative factors viz. climate, topography vegetal canopy and underlying lithological structure of the terrain.[1]

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1. Kumar, Prahlad (1986), "Geomorphometry of drainage lines: A study of a greater Himalayan basin (The Dhauliganga)", National Geographical Journal of India, vol. 32(3), pp. 235-45.

The channel behaviour of a particular region gives an idea about hydrological and climatological conditions of the basin, the morphological characteristics of stream and its course in a region. The fluctuations in runoff are essential to understand the proper harnessing of water resources and to overcome climatic hazards.

The organization of the drainage network is important because it reflects efficiency of the main lines of energy and material flow through the fluvial system.[1] The plan characteristics of the channel also influences the movement of sediment and water to a considerable extent. In the words of Boudin and Wallis[2] the concept of stream ordering is the touch stone by which drainage characteristics could be related to each other and to hydrologic and erosional processes. Rhodes et. al.[3] stated that channel is a direct consequence of the structure, and surface configuration of the land as altered by flow through erosion and deposition over space and time.

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1. Chorley, R.J. (1969) (ed.), Water, Earth and Man, Methuen, London, p.588.

2. Boudin, K.L. and Wallis, J.R. (1964), "Effects of stream ordering technique on Harton's laws of drainage composition", Bull. Geol. Soci. Amer., vol.75, pp.764-74.

3. Rhodes et. al. (eds.) (1982), Adjustment of fluvial system, George, Allen and Unwin, London.

The river plan form and the equilibrium between channel erosion and deposition constitute the river regime. The river regime is expressed by the channel geometry as denoted by water surface, slope, local channel depth, width, cross-sectional area, flow velocity, discharge and sediment load transport and by the channel pattern in plan as measured by sinuosity. In words of Schumm[1], the river channel in any particular location is an integration of upstream controls of geology, climate and landuse. The fluvial system can be understood by the quantity and type of sediment, the manner in which water is supplied from the source area and the climatic and geologic controls on that sediment and water supply. Hence the behaviour of river largely depends upon the interaction among the geological, geomorphological and hydrological attributes in and along the river reaches.

1.2 STATEMENT OF THE PROBLEM:

The present study of the upper catchment of Narmada deals with the behaviour of the river channel. Narmada flows between Vindhyas and Satpura ranges of the Central India and is considered as a rift channel. A series of multipurpose dams are to be constructed in near future.

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1. Schumm, S.A. (1977), The Fluvial System, John Wiley and Sons, New York, p.2.

Dam construction needs water potentials assessment for which channel behaviour study is invariable.

1.3 LITERATURE SURVEY:

There have been a number of studies on drainage characteristics referring to one aspect or the other, both at national and international level. But here only a few recent studies on channel changes are presented. Most of these involve direct observation of the changes indicating their causative character.

River behaviour studies were first started by Leopold and Maddock[1], Blench[2] and Leopold and Wolman[3], Schumm[4] to understand the changes by direct observation upon rivers, of discharge sediment, morphological characteristics of channel cross-section and the mechanism behind them. Sundborg[5]

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1. Leopold, L.B. and Maddock, J. (1953), "The hydraulic geometry of stream channels and physiographic implications", U.S. Geol. Prof. Paper, 252, pp.1-57.

2. Blench, J. (1957), Regime behaviour of canals and rivers, Butterworth, London, pp.

3. Leopold, L.B. and Wolman, M.G. (1957), "River channel patterns, braided, Meandering and straight", U.S. Geol. Surv. Prof. Paper, 282-B, pp.39-85.

4. Schumm, S.A. (1968), "River adjustment to altered hydrologic regimen, Murrumbidgee river and paleochannels", Australia U.S. Geol. Surv. Prof. Paper, 598.

5. Sundborg, A. (1956), "The river Klaralven: a study of fluvial process", Geografiska Annaler, 38, pp.127-316.

studied fluvial morphology of Kalaralven river, perhaps it was the first major work in river studies.

Dury[1] studied channel geometry and channel changes during 1950s. His work on misfit channel can be mentioned in this context. Schumm[2] (1960, 68, 69) evaluated the response of channels to changes in a wider variety of controls both spatially and temporally. He also studied sediment and bank properties in relation to changing channel form.

Beckinsale[3] divided river regimes into three broad categories: megathermal, mesothermal and microthermal on the basis of temperature, precipitation and discharge patterns.

Another group of studies in channel changes emphasized on the transfer response of the river system as reflected on the channel rather than on its steady state behaviour.

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1. Dury, G.H. (1965), "Theoretical implications of underfit stream", U.S. Geol. Surv. Prof. Paper, 452-G.

2. Schumm, S.A. (1960), "The shape of alluvial channels in relation to sediment type", U.S. Geol. Surv. Prof. Paper, 352-B; Idem (1968), "River adjustment to altered regimen", op. cit., paper 598; Idem (1969), "River Metamorphosis", Journal Hydraulic Division American Society Civil Engineers, 95, pp.255-73.

3. Beckinsale, R.P. (1969), "River regimes" in Chroley, R.J. (ed.), Water,Earth and Man, Methuen, London, pp.452-72.

Ferguson[1] studied channel form and channel changes together. Tinkler[2] analysed channel bedform and identified riffles and pools distribution in the channel. Bridge and Jarvis[3] have studied the dynamics of river bends and related the flow, water, sediment load to the reaches of the channels.

The studies on channel changes in terms of hydraulic geometry have been using direct observation or laboratory flume experimentation. There have been few of the studies related to investigating channel bedform. The difficulty in matching the field knowledge of overall channel changes to the behaviour of a single or even aggregate seems inseparable.

Hey[4] has discussed that there are five degrees of freedom, namely, channel flow, depth, shape, area and width. These are the basic variables which demonstrate

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1. Ferguson, R.I. (1977), "Meander migration: equilibrium and change" in Gregory, K.J. (ed.), River channel changes, Chichester, Willey, pp.235-48.

2. Tinkler, K.J. (1970), "Pools, riffles and meanders", Bull. Geol. Soci. Amer., vol.81, pp.547-52.

3. Bridge, J.S. and Jarvis, J. (1977), "Velocity profiles and bed shear over various bed configurations in river bend", Earth Surface Processes, vol.2, pp.281-94.

4. Hey, R.D. (1978), "Determinate hydraulic geometry of river channels", Journal of the Hydraulic division, American Society of Civil Engineers, 104, pp.869-85.

the channel changes. Coleman[1] has dealt with the channel processes and sedimentation of Brahmaputra river in Bangladesh. Hooke[2] described the distribution and nature of channel changes in river patterns by taking the example of Devon river. Schumm[3] has dealt with the variations in sinuosity of North Plate river, caused by the regulation of channel discharge due to dam construction.

Daniel[4] has attempted to see the channel movement of meandering in Indiana rivers. Koc[5] has attempted to show the changes in Vistula river channel between Ptock and Torun of 19th and 20th centuries and has shown the changes in bank erosion and flood plain aggradation. Burkham[6]

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1. Coleman, J.M. (1969), "Brahmaputra river: channel processes and sedimentation", Sedimentary Geology, vol.3, pp.129-39.

2. Hooke, J.M. (1977), "The distribution and nature of change in river channel patterns: the example of Devon" in Gregory, K.J. (ed.), River Channel Changes, Chichester, Wiley, pp.265-80.

3. Schumm, S.A. (1969), op. cit., vol.95, pp.255-73.

4. Daniel, J.F. (1971), "Channel movement of meandering Indiana streams: physiographic and hydraulic studies of rivers", U.S. Geol. Surv. Prof. Paper, 732-A.

5. Koc, L. (1972), "Nineteenth and Twentieth Centuries changes in Vistula channel between Ptock and Tarun" (Abst.), Przeglad Geograficzny, vol.44, pp.703-19.

6. Burkhman, D.E. (1972), "Channel changes of the Gila river in Stafford valley, Arizona, 1846-70", U.S. Geol. Surv. Prof. Paper, 655 G, pp.1-24.

has paid attention towards channel changes of Gila river in Stafford valley of Arizona in the reference of flood plain, i.e., aggradation and degradation. Samoyogi[1] has tried to show the change in the channel and flood plain development in the Sarkoz section of river Danube from 1782 to 1950. Edgar and Melhorn[2] have discussed the response of drainage basin which is documented in historical and theoretical consideration in the change of channel pattern and channel geometry.

On channel changes caused by human interferences, Leopold[3] has given attention to the increase and decrease of capacity and size of the channel taking an example of Maryland. Graf[4] has made an attempt to study the impact of suburbanization on fluvial geomorphology and also given a direction towards channel incision and flood

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1. Samoyogi, S. (1974), "Channel and flood plain development in the Sarkoz section of the Danube as shown by mapping between 1782 to 1950 (Abst.), Foldrajzi Ertestio, vol.23, pp.27-36.

2. Edgar, D.E. and Melhorn, W.N. (1974), "Drainage basin response: documented historical change and theoreticals considerations", Purdue Uni. Water Resources research Centre Technical Report No.3, Studies in fluvial geomorphology.

3. Leopold, L.B. (1973), "River channel change with time: an example", Geol. Soc. Amer. Bull, vol.84, pp.1845-60.

4. Graf, W.L. (1975), "The impact of suburbanization on fluvial geomorphology," Water Resources Research, vol.II, pp.690-92.

plain aggradation. Lewin and Hughes[1] have revealed the assessment of channel changes in Welsh river. Park[2] was concerned with the changes in river channel capacity due to human encroachment by reservoir construction and discharge regulation. Howard, Dolan and Gallenson[3] have similarly discussed the human impact on the Colorado river showing the increasing rate of erosion downstream of the dam.

Gregory and Park[4] have made an attempt to study the decreasing capacity of Tone river in Somerset below the reservoir. Gregory[5] dealt with the channel and network metamorphosis in Northern Southwales. Ferguson[6] analysed the channel geometry of British rivers in a general

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1. Lewin, J. and Hughes, D. (1976), "Assessing channel change on Welsh river", Cambria, vol.3, pp.1-10.

2. Park, C.C. (1977), "Man induced changes in stream channel capacity" in Gregory, K.J. (ed.), River Channel changes, pp.121-44.

3. Dolan, R., Howard, A. and Gallenson, A. (1974), "Man's impact on the Colorado river in the grand Canyon", American Scientist, vol.62, pp.392-401.

4. Gregory, K.J. and Park, C.C. (1974), "Adjustment of river channel capacity downstream from a reservoir", Water Resource Research, vol.10 (4), pp.870-73.

5. Gregory, K.J. (1977), "Channel and network metamorphosis in northern new Southwales" in Gregory, K.J. (ed.), River Channel changes, Chichester, John Wiley, pp.389-410.

6. Ferguson (1977), "Meander Sinuosity and direction variance", Bull. Geol. Soc. Amer., vol.88, pp.212-14.

perspective. He studied the equilibrium and change in meander migration of English and Scottish rivers. Laczay[1] dealt with the changing pattern of Hungarian rivers. Leopold, Emett and Myrick[2] have studied the change in river bed aggradation of Arroyo de Frijales, New Mexico.

Kinghton[3] studied hydraulic geometry with reference to short term changes in channel configuration of river Dean. Harvey[4] dealt with the frequency of sediment supply on a small upland stream in an active slope erosion. Hickin and Nanson[5] studied channel migration of the Beaton river of northern British Columbia through botanical dating techniques. Andrews[6] has made an attempt to study the

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1. Laczay, I.A. (1973), "Channel pattern changes of Hungarian rivers: an example of the Hernad river" in Gregory, K.J. (ed.), River Channel changes, John Wiley and Sons, New York, pp.185-92.

2. Leopold, L.B., Emett, W.W. and Myrick, R.M. (1966), "Channel and Hill slope processes in a semi-arid area, New Mexico", U.S. Geol. Surv. Prof. Papers, 352 G, pp.193-253.

3. Knighton, A.D. (1973), "River bank erosion in relation to streamflow conditions, River Bollin-Dean, Cheshire", East Midland Geographers, vol.5(8), No.40, pp.416-26.

4. Harvey, A.M. (1974), "Gully erosion and Sediment yield in Howgill fells, West-moreland" in Gregory, K.J. and Walling, D.E. (eds.), I.B.G., Special Publication, vol.6, pp.45-58, Fluvial processes in instrumental watersheds.

5. Hickin, E.J. and Nanson, G.C. (1975), "The character of channel migration on the Beaton river northeast British Columbia, Canada", Geol. Soc. Amer. Bull., vol.86, pp.487-94.

6. Andrews, E.D. (1979), "Hydraulic adjustment of the East fork river, Wyoming, to the supply of sediment" in Rhodes, D.D. and Williams, G.P. (eds.), Adjustments of the fluvial system, Dubuque, Iowa, Kendall, Hunt, pp.69-94.

hydraulic characteristics of the east fork river and concluded that the river has adjusted mutually to transport the sediment contributed by its tributaries.

Harvey, Hitchcock and Hughes[1] in their study on event frequency and morphological adjustment of fluvial systems in upland Britain have attempted to identify process thresholds within fluvial systems and to consider the role of their frequencies in adjustments within dynamic equilibrium. Thornes[2] dealt with the changes in channel and its hydraulic geometry and emphasized the difficulty arose in the way regarding the availabiltiy of data and analysis of the problems.

Lootens and Kishimbi[3] examined water discharge and suspended sediment trasnport in the upstream section of the Kafubu catchment. They concluded that due to the excessive deforestation the mean annual runoff in the catchment is higher than in the undisturbed adjacent basins. Sarma and

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1. Harvey, A.M., Hitchcock, D.H. and Hughes, D.J. (1979), "Event frequency and morphological adjustment of fluvial systems"in Rhodes, D.D. and William, G.P. (eds.), Adjustments of the fluvial system, Dubuque, Iowa, Kendall Hunt, pp.139-67.
2. Thornes, J.B. (1970), "The hydraulic geometry of stream channels in the Xingua Araguaia headwaters", Geographical Journal, vol.136(3), pp.376-82.
3. Lootens, M. and Kishimbi, Y. (1986), "Some aspects of Water and Sediment in the upstream section of the Kafubu river (Shaba-Zaire)", Geografiska Annaler, vol.68A(4), pp.383-91.

Basumallick[1] analysed the form and process of the Burhi Dihing river channel with emphasis on hydraulic geometry and form process response. Ashwarth and Ferguson[2] evaluated spatial and temporal variations in channel morphology, velocity and shear stress, bed-load transport rate, and bed material size distribution in a proglacial braided river.

A few studies have also been done on river behaviour in India. Kayastha[3] discussed problems regarding availability of hydrological data. His emphasis was on the systematic understanding of the flow regime and river behaviour, and stated that they can be used in increasing the efficiency of irrigation and regulation of flood control. Gairola[4] studied flood problems in the Ganga basin by realizing the importance of valley contours in flood routing. He further emphasized that flood stage is significant from flood damage point of view rather than flood volume. He suggested that knowledge of stage discharge

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1. Sarma, M., Jogindra, N. and Basumallick, Sudhir(1986), "Channel form and process of the Burhi Dihing river, India", Geografiska Annaler, vol.68A(4), pp.373-81.
2. Ashwarth, P.T. and Ferguson, R.I. (1986), "Interrelationships of channel processes, changes and sediments in a proglacial braided river", Geografiska Annaler, vol.68(A)(4), pp.361-72.
3. Kayastha, S.L. (1955), "The Himalayan Beas basin - A Hydrographical study", National Geographical Journal of India, vol.1, pp.11-25.
4. Gairola, S.S. (1955), "Flood problems in the Ganga drainage Basin", National Geographical Journal of India, vol.1, pp.26-34.

rating curves for various stations is necessary to estimate inundated area and damage by floods.

Pal and Bagchi[1] made an attempt to compare the geomorphological background of the flood occurrence in the Brahmaputra and Kosi basin. They concluded that in plains recurrence interval of floods has a conspicuous influence on river regime. Huge amount of silt load constantly changing the hydrogfaphy of their flood plain and seismic activity near foothills make the river unstable in character. Sharma[2] analysed mean monthly and instantaneous peak discharge from 1934 to 1973 to study the impact of Damodar Valley Corporation on the flow regime of the Damodar river. He concluded that the adequate flood protection have been helpful in reducing the magnitude of the mean annual floods from 8000 m^3s^{-1} to 3800 m^3s^{-1}, Mean monthly discharges from 1959-73 showed high variability during regulation than before 1934 to 1958, in natural regime conditions.

Das[3] analysed the causes of rapid change in the course of Kosi river and concluded that the river is still in a

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1. Pal, S.K. and Bagchi, K. (1975), "Recurrence of floods in Brahmaputra and Kosi basins: A study in climatic geomorphology", Geographical Review of India, vol.37, pp.242-48.

2. Sharma, V.K. (1976), "Some hydrologic characteristics of the Damodar river", Geog. Rev. of India., vol.38(4), pp.331-43.

3. Das, K.N. (1968), "Westward shift in the courses of the Kosi", National Geog. Jour. of India, vol.14, pp.23-31.

formative phase of development and the westward tendency is yet observed during peak discharges. It is therefore apt to call the Kosi most unpredictable river. Chakraborty and Ghosh[1] made an attempt to identify the methodology for the river basins by a standard technique for establishing the history of major epeirogenic movements and described the resultant changes in the longitudinal profile of the rivers. Taher[2] explained the frequent river changes in relation to its course and through innumerable meanders creating lakes and marshes.

Joshi and Rawat[3] studied the relationship between topographical characteristics and water discharge indices of ten drainage basins in the Kumaun Himalaya. They suggested that discharge is a function of stream length which accounts for 74 % variation in the stream discharge. Kale et. al.[4] analysed channel morphology and hydraulic characteristics of Vashishthi river by taking into account

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1. Chakraborty, S.C. and Ghosh, A.R. (1974), "Longitudinal profile in fluvial process - An analytical study", Geog. Rev. of India, vol.36 (1), pp.31-37.

2. Taher, M. (1974), "Fluvial processes and geomorphology of the Brahmaputra plain", Geog. Rev. of India, vol.36 (1), pp.39-44.

3. Joshi, S.C. and Rawat, J.S. (1982), "Channel morphometry indices and stream discharge in the Kumaon Himalaya", Geog. Rev. of India, vol.47 (2), pp.71-78.

4. Kale, V.S., Karelekar, S.M. and Deodhar, L.A. (1986), "Channel morphology and hydraulic characteristics of Vashishthi river, Maharashtra", Trans. Inst. Indian Geogrs., vol.8 (2), pp.113-26.

depth, width, channel capacity, velocity etc. and channel sediments. Probable causes of the present braided pattern have been explained. It is concluded that there is a definite downstream trend in hydraulic geometry, but the hydraulic factors vary from one segment to another. It can be attributed to the nature of bed and bank material, channel slope, and the planform.

1.4 SELECTION OF THE STUDY AREA AND DELIMITATION OF THE REGION:

Narmada drains an area of about 98796 sq. kms. flowing from Amarkantak to Bharoch, a distance of 1382 kms. Its basin is one of the biggest basins of India and has large catchment which pours its water in the Arabian sea on the west coast of the country.

To utilize the water of river Narmada, large number of multipurpose projects are being constructed across the river. These may be hazardous to the area and the reservoirs are facing the problem of heavy siltation which will cut-short the life of the projects. Heavy siltation in the reservoirs generally is a result of high rates of erosion due to alternation in the landuse practices and also human interferences in different ways. Taking into consideration above factors, upper catchment of the Narmada river as delimited by Water Commission has been selected to study the river behaviour.

The upper catchment of Narmada as delimited has an extent from 21°20' to 23°45' north latitudes and 79°00' to 81°45' east longitudes. It covers an area of 26453 sq. kms. To study the river behaviour, three gauging and discharge sites of Central Water Commission, namely, Manot, Jamtara and Barmanghat, from upstream to downstream have been selected for the present study on river behaviour.

1.5 OBJECTIVES OF THE STUDY:

The study aims at an assessment of the water potential at different sites and the flow of water and movement of sediments which influence the life of the reservoirs. The objectives specifically are as follows:

(a) To understand the channel cross-section and longitudinal profile of the river;

(b) To understand the bed and bank conditions and hydrological characteristics;

(c) To understand the relationship between sediment and discharge;

(d) To understand the river regime.

1.6 DATA BASE AND METHODOLOGY:

Much information for the present study has been obtained from topographical sheets of scale 1:250,000. The numbers are 55 M, N, 64, A, B, C, E, F & G. Geological information was collected from National Remote

Sensing Institute, Dehra Dun. Hydrological data on gauge, discharge and sedimentation was made available by Central Water Commission, New Delhi. Field work in the region has helped in collecting the information of the cross-section of the channel at different sites.

The study is statistical and graphical, accompanied with photograph. The photographs taken at various sites helped in identifying bed and bank conditions of the channel. The locations have been mapped by cartographic techniques.

Sinuosity indices have been calculated to study the channel patterns. Mean, standard deviation and co-efficient of variation in discharge for different years at different sites has been calculated. Probability analysis by Gumble method has been calculated to understand the magnitude of flood.

I.7 LIMITATION OF THE STUDY:

The hydrological data on discharge was obtained for 10 years (1972-1982) for three sites but discharge data at Manot was available from 1977 to 1982 only, while sediment data was not available. The sediment data for the two sites Barmanghat and Jamtara was available for monsoon season only from 1972 to 1977. Some important parameters such as width, depth, velocity, relationship of discharge to cross-section could not be studied because of non-availability of gauge data. The cross-section data was available only for two years for Manot and Barmanghat and for Jamtara it was not available.

Rainfall runoff relationship could not be studied due to the non-availability of rainfall data in the upper catchment.

NARMADA RIVER BASIN

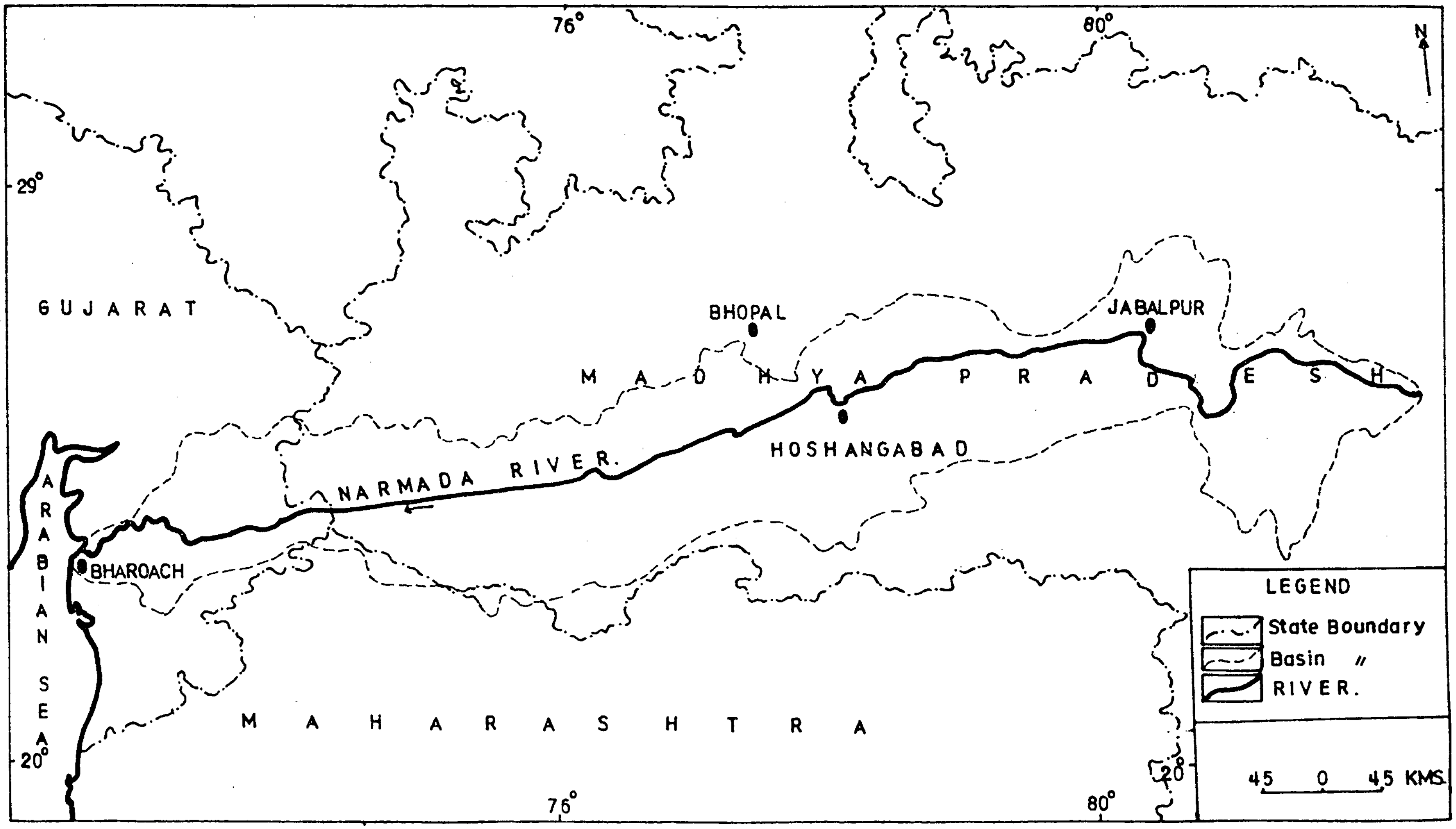

fig. 2·1

Chapter II

INTRODUCTION TO THE STUDY AREA

2.1 GEO-IDENTITY OF THE NARMADA BASIN:

The Narmada basin running east to west, occupies a central position in Indian subcontinent. Narmada is the largest west flowing river of peninsular India. It originates in the Maikala range in the Shahdol district of Madhya Pradesh, at an elevation of 1057 metres above sea level in Amarkantak plateau. The basin lies between 72°32' to 81°45' east longitudes and 21°20' and 23°45' north latitudes and extends over an area of about 98796 sq. kms. in the states of Madhya Pradesh, Gujarat and Maharashtra. (Fig.2.1) The statewise distribution of area being, Madhya Pradesh 85859 sq. kms., Gujarat 11399 sq. kms. and Maharashtra 1338 sq. kms.

Lying in the northern extremity of Deccan plateau, the basin is bounded on the north by the Vindhyan ranges, on the east by Maikal ranges, to the south by the Satpura ranges and to the west by the Arabian sea. The basin has elongated shape with a maximum length of 983 kms. from east to west and a maximum width of 234 kms. form north to south.

2.2 PHYSIOGRAPHY:

Most of the basin is at an elevation of less than 800 mts. above sea level. A small area around Panchmarhi is at an elevation of more than 1000 mts. above sea level. The basin on the basis of river course over different lithological setting can be divided into five physiographic units, namely upper hilly area, upper plains, middle plains, lower hilly areas and plains of Gujarat.

In its head reaches, the Narmada has an average slope of 2.5 cms. per thousand metres of distance upto Bargi. From Bargi to Hoshangabad it is 2.5 cms. in 3700 metres. Farm Hoshangabad to Omkareshwar, the river slope is 2.5 cms. for 1700 metres. It then flattens to 2.5 cms. for 2300 metres upto Harinpal. Below Gujarat border, the general slope is about 2.5 cms. for 1600 metres. In Gujarat the river has relatively flat slope of 2.5 cms. for 10,000 metres.

2.3 NARMADA RIVER SYSTEM:

The Narmada river system from the source to mouth constitutes one of the most interesting and important drainage basins of central and western India. Its place of origin on the Amarkantak plateau is an important watershed in India, from where the river Johilla (a tributary of Son) and Narmada drains diametrically in opposite direction, the former distinctively draining into the Bay of Bengal and latter into the Arabian sea.

Soon after leaving the place of origin it falls in a cascade over the edge of the Amarkantak plateau, amidst most picturesque surroundings with a descent of nearly

16 metres.[I] The river has a number of falls in its head reaches. At 8 km. from its source, the river drops 21 to 24 metres at Kapildhara falls. It then flows through a narrow rocky channel with particularly vertical bank. From here a river flows northwestward for same distance than in a general westerly direction until it turns south towards Mandla. Forming a loop round Mandla, the river turns north and southwest of Jabalpur. In Mandla district, the river flows over rocky basaltic terrain. The narrow channel of the river with straight bank continues upto 15 kms. southwest of Jabalpur. Flowing generally southwesterly direction in a narrow and deep valley the river takes pin head turns at places close to Jabalpur. At this point, the river has cut a deep channel through a mass of white marble exposing shear vertical face of 45 metre. The river profile is as narrow as 30 metres at places and it reaches in depth to 40 metres. At Dhuandhar, the river has a vertical fall of nearly 50 metres creating a twisting foaming mass of water. The river here is youth incarnate.[2] It pursues a generally westerly course from here onwards and flows through an

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1. Design flood estimation for Narmada Sagar and Sardar Sarovar Projects, Final Report, vol.I, National Institute of Hydrology, Roorkee, 1984.

2. Design flood estimation for Narmada-Sagar and Sardar Sarovar Projects, Final Report, vol.II, National Institute of Hydrology, Roorkee, 1984.

alluvial tract i.e. upper plain upto Bermanghat till this gauging and discharge site, Central Water Commission, considers the upper catchment of Narmada. Since, the upper catchment of Narmada is being dealt in this study, further discussion will be related to that only.

The river has 41 tributaries of which 22 are on the left bank and 19 on the right. Here, only important tributaries of the upper Narmada catchment which contribute significantly to its discharge have been discussed.

Burnher:

It rises in the Maikal range, south-east of Gwara village in Mandla district of Madhya Pradesh at an elevation of about 900 metres at 22°32' north latitude and 81°72' east longitude and flows in a generally westerly direction for a total length of 176 kms. to join the Narmada near Manot. The Burnher drains a total area of 4070 sq. kms.

Table 2.1: Tributaries of Narmada in the Upper Catchment

	Tributary	Right or Left Side	Distance of confluence from source of Narmada	Catchment area in sq. kms.	Length in kms.
1.	Kharmer	L	122	577	67.5
2.	Silgi	R	201	531	87
3.	Burnher	L	248	4132	177
4.	Banjar	L	286	3629	183
5.	Balai	R	322	531	46.7
6.	Temur	L	381	892	61
7.	Gaur	R	394	1107	71
8.	Sonet	L	434	581	51.5
9.	Hiran	R	463	4795	188
10.	Sher	L	497	2903	129

Source: CWC New Delhi.

Banjar:

It rises in the Satpura range in the Durg district of Madhya Pradesh near Rampur village at an elevation of 600 metres at 21°42' north latitude and 80°50' east longitude and flows in a generally northwesterly direction for a total length of 182 kms. to join the Narmada from the left near Mandla after 287 kms. The Banjar drains a total area of 3584 sq. kms.

Gaur:

This river rises near Niwas in Mandla district and from Sukori in the southeast of Jabalpur, near the village Bilaura, it runs north for a little distance and taking a southwesterly course, joins Narmada on its right bank. The total length of the river is 49 miles.

Sher:

The Sher rises in the Satpura range near Patan in the Seoni district of Madhya Pradesh, at an elevation of 600 metres, at 22°31' north latitude and 79°25' east longitude. It flows in a generally northwesterly direction for a total length of 129 kms. to its confluence with the Narmada from the left near Brahmand. The Sher drains a total area of 2901 sq. kms.

Hiran:

The Hiran rises in the Bhanrer range at an elevation of 600 metres, at 23°12' north latitude and 80°27' east longitude and flows in a generally south-westerly direction for a total length of 187 kms. It joins the Narmada on the right bank near Sankal village. Hiran - the biggest right bank tributary of the Narmada - drains a total area of 4480 sq. kms. It takes a northerly course for about 30 miles through trap country. It turns to the west and runs to the Katangi through a zig-zag course nearly for two miles from Katangi, the Hiran runs in south-westerly direction close to the Bhanrer scarp until it joins the Narmada.

2.4 RIVER HYDROLOGY:

The average annual flow of the Narmada is about 41 billion cubic metres, 92% of which occurs during the monsoon season, and out of the rest of 8%, 5% in the winter and 3% in hot weather season. The year to year variability is also considerable. The 30 years records of annual flows (1949-79) measured at Garudeshwar in Gujarat shows a range of variations from 10.152 to 63.486 million acre feet.[1]

Currently, 32 major projects and a number of medium and minor projects are either existing or envisaged for the development of the Narmada basin in Madhya Pradesh and Gujarat. The river thus has large water resource potentials

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1. Narmada Control Authority, Hydrometeorological network for real time stream flow and forecasting in Narmada basin, C.E. Bhopal, 1984.

UPPER NARMADA CATCHMENT

fig.2.2

within the states for the development of intensive irrigation programmes. Soils of the basin within the state are with excellent drainage possibilities and are suitable much more for such plans, than many other parts of the country. There also exists a large hydropower potential due to drop of 975 metres in river level entirely Madhya Pradesh.

2.5 THE UPPER NARMADA CATCHMENT:

The upper catchment of Narmada as delimited for the present study has an extent from 21°20' to 23°45' north latitudes and 79°00' to 81°45' east longitudes. (Fig.2.2) It covers an area of 26453 sq. kms. It includes areas of Shahdol, Kward-ha, Murwara, Mandla, Balaghat, Jabalpur and Narsingpur districts of Madhya Pradesh. Broadly speaking the catchment is surrounded by the Satpura in the north, Maikal in the east and Vindhyan in the north. These two mountain ranges comprise of thick mass of hills and valleys mixed with extensive plateaus and flatlands. The altitude within the upper catchment varies from 300 metres to 1100 metres above sea level. The slopes are flat to very steep. The important tributaries of Narmada are Burnher, Banjar, Silgi, Halan, Gaur, Sher, Machrewa and Hiran.

2.6 CLIMATE:

Climate is an important factor in shaping and modifying the physical landscape of a region. The intensity of different exogenetic forces over a landscape are governed by climatic conditions of the region. The main sculpturing processes of topography are weathering and running water. The upper catchment of Narmada enjoys the extremes of heat, cold and rainfall. The elevation of the region controls the various aspects of climate. The tropic of cancer crosses the Narmada basin in the upper catchment and a major part of the basin lies below this. The climate is generally humid tropical ranging from sub-humid in the east to semi-arid in the west with pockets of humid climate around higher hilly reaches. In the cold season, the mean temperature varies from 17.3°C to 20°C, whereas, in the hot season the temperature varies from 30°C to 32.5°C and in the post monsoon season from 26°C to 27.5°C.

The average annual rainfall in the upper hilly region is generally more than 1400 mm. (55 inches) and in some parts, it goes upto 1650 mm. (65 inches). The normal annual rainfall for the basin works out to be 1178 mm. The south-west monsoon accounts for nearly 90% of annual rainfall.

Broadly, the year can be divided into four climatic seasons, monsoon season from June to September, post-monsoon from October to December, winter from January to March and the pre-monsoon from April to May. From May to September there is not much variation in the temperature conditions in different parts of the basin, but in the rest of the year, the temperature generally increases from east to the west and winters are relatively mild. The humidity surcharge is very low in dry weather which is 17% and the maximum is in the monsoon season, which is about 87.5%. The general trend of rainfall in the upper basin is gradually reducing along the catchment from 150 cms. at the source of the river to about 125 cms. upto Bargi near Jamtara.

2.7 NATURAL VEGETATION:

Forests occur on the hill slopes and all over the rugged terrain in the southern, eastern and south eastern part of the upper Narmada catchment . The lowlands, the intermountain valleys and a flat tops of plateaus where the soil cover is thick have long been cleared rather indiscriminately of forest cover. The vegetation of the catchment may be divided into:[1]

1. Northern tropical dry decidous forests;
2. Southern tropical dry decidous forests.

In the first group, Sal is an important species, whereas in the second, it is teak. Bamboo mainly occupies areas where top canopy is light.[2] A large area comprises of dry decidous forests with moist teak in heavy rainfall areas

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1. Report on Forest Resources of Shahdol, Balaghat, Mandla, and Seoni districts of M.P., Forest Survey of India, Dehradun, 1985.

2. Report on Forest Resources of Jabalpur, Narsingpur and Chindwara districts of M.P., Forest Survey of India, Dehradun, 1985.

to dry decidous scrubs in low rainfall. Poor occurrances of sal is characteristic of vegetation in the catchment especially in Mandla, Balaghat and Jabalpur.

The vegetation of the catchment may be classified as follows:

1. Slightly moist teak: This type generally occurs in scattered patches often along rivers and big waters courses. These are found in Jamunia nala Kiranpur, Lalburra, Katangi and Langi of south Balaghat district.

2. Southern tropical moist deciduous forests: This type of forests is chiefly confined to non-teak forests of Jagmandal reserves in north Mandla. In this the teak is either totally absent or occurs only sporadically indicating secondary succession of teak.

3. Moist peninsular sal forests: This type is confined to Raigarh plateau of North Balagh at forests and upper slopes of Motinala, Dindori, the Bajag, Sarastal and Karanjia ranges of south Mandla.

4. Moist peninsular low level sal: This type is confined to Baiher plateau of Balaghat and Motinala and Banjar ranges of south Mandla. Sal usually occupies the lower hill slopes.

5. Frost Valley sal: It occurs on severely frost affected areas along the valley portions of the Halan river in Supkhar range of North Balaghat and Seoni nadi and other

GEOLOGICAL MAP OF MADHYA PRADESH AND ADJOINING AREAS.

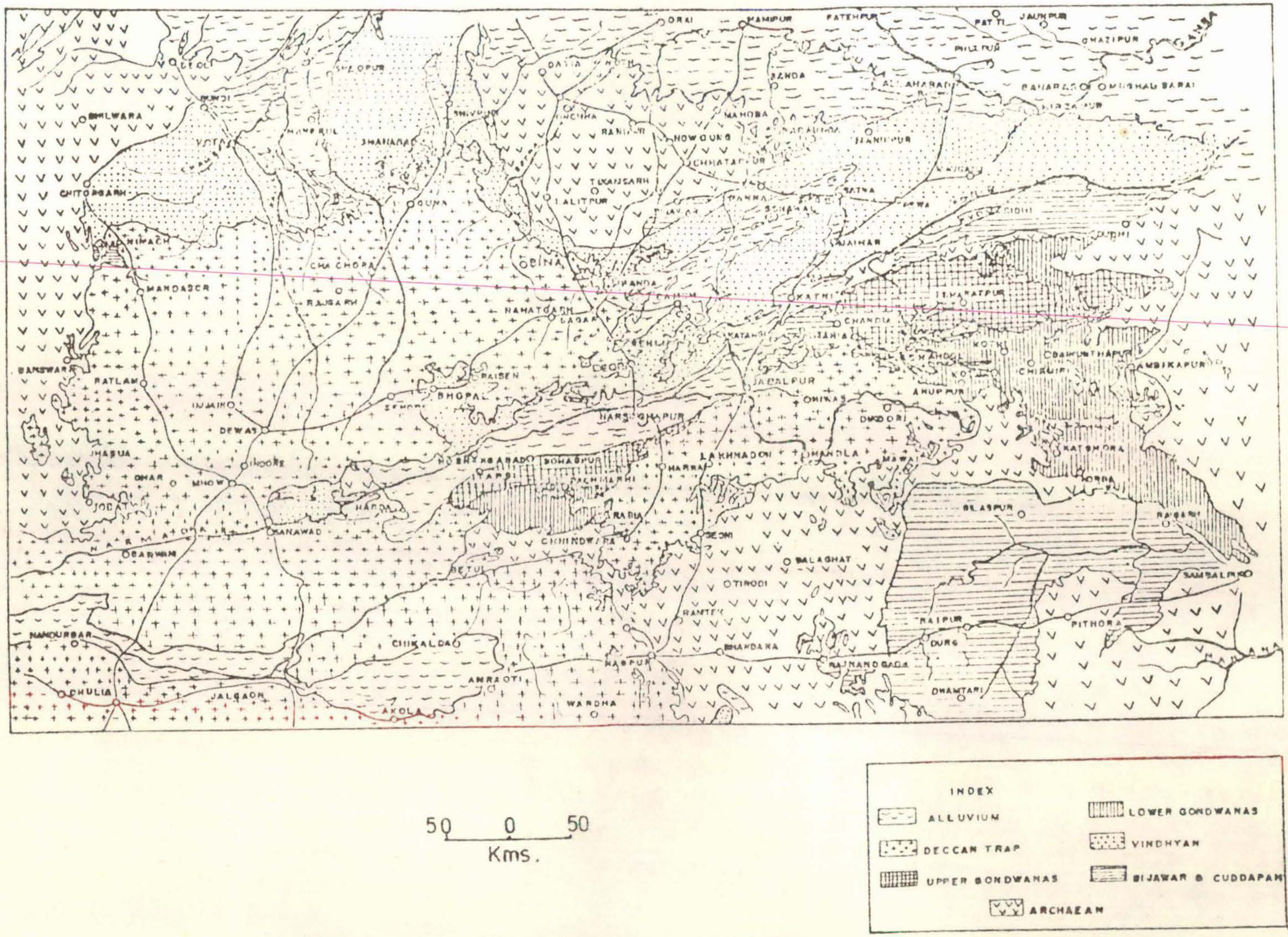

fig. 2·3

large streams of South Mandla. Chir is also found here.

6. Dry Teak forest: This type is represented in the north and Seoni forest and in north Mandla. Teak occurs on a variety of geological formations. These occur in extensive areas of Seoni except the southern and southwestern part and almost entire northern portion of North Mandla district.

7. Southern tropical mixed dry deciduous: It occurs within or around the teak and sal bearing areas of Seoni, Mandla, and Balaghat. In the eastern part of Mohegaon range of north Mandla, it occurs as tension belt between Sal and Teak forests. Generally the upper slopes and plateaus carry mixed forest.

2.8 GEOLOGY:

The geological background of the upper catchment of Narmada is associated with geological sequences of central or peninsular India, dating from Archean to quaternary. (Fig.2.3) The stratigraphic and lithological set-up of the upper Narmada basin is as follows:

Stratigraphy	Lithology
Quaternary	Alluvium
Tertiary	laterite
Upper cretaceous Deccan Trap	Trap flows
Middle cretaceous lameta	Cherty lime-stone calcareous limestone

Unconformity

Vindhyan Supergroup

Upper Bhandar Sandstone Bhandar Sirbu shale	Hardbrick and sandstone siltstone and shale, green and brown shale
Lower Bhandar Sandstone Nagod limestone	Sandstone and silt stone limestone, Dolomite shale with sandstone
Ganurgarh shale	Sandstone and lenses of limestone.

Unconformity

Rewa

Upper Rewa sandstone	Hardstone and thin bands of shale
Jhiri shale?	Green shale and limestone
Lower Rewa sandstone	Hard quartzite sandstone.

Unconformity

Bijawars	Basic intrusives phyllite and quartrite chert, breccia and conglomerate, dolomite

Unconformity

Archean	Schist and magnetite quartzite Marble Granite gneiss

Source: N.R.S.I., Dehradun.

The geological succession of this region comprises of following groups:

Alluvium	Recent
Deccan Trap	Eocene
Lameta and Baghbeds	Uppermost cretaceous
Gondwana system	Upper carboniferous to middle Jurassic
Vindhyan system	Pre-cambrian
Bijawar system	Archean.

The distribution of some rocks in the upper catchment is as follows:[1]

(1) Granite gneisses: The granites which show a faint gneissic structure are found in isolated patches from North east to south west in the upper catchment linear to Lamheta-ghat on the Narmada river through Jabalpur for some distance to the North east. The granite is considered to be younger than Bijawars and some are older than the Bijawars.

(2) Bijawars Series: At the head of the Narmada valley in the northern part of the basin, there is a continuous exposure of rocks belonging to the Bijawar series which consist of crystalline limestones, quartzites and schist. The Bijawars series are in the stage of metamorphism. The limestone is generally crystalline. The marble rocks of the Narmada gorge form almost vertical cliffs rising upto height of 35 mts. on the both sides of the bank.

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1. Miscellaneous Publication, G.S.I., vol.30, Geology and Mineral Resources of M.P., 1970.

(3) Lower Vindhyan: This formation forms a strip in the north eastern portion of the Jabalpur and little to the southwest of Katni. They disappear owing to fault that has brought the younger Rewa formation into contact with the older formations.

(4) Upper Vindhyan: The whole northwestern part of the catchment is occupied by these rocks, the general strike of which is northeast to southwest with dip to the north-west. The upper Rewa formations form a thin fringe of the rocks to the south east of the Bhandars from which they seem to be separated by a strike slip fault through a large portion of their course in Jabalpur region.

(5) Lower Bhandar, Gondwana and Lameta: The lower Bhandar has 300 metres thick alyer comprising of shale, limestone and sandstone. Gondwana consists of sandstone with a thickness of 300 metres as Jabalpur series. The lameta series consist of limestone, sandstone and clay deposits in freshwater. They are found over Deccan trap, their thickness is 45 metres.

(6) Deccan Trap and Pliestocene: Deccan trap is horizontally bedded basaltic lavas that is found principally along the southeast border of Jabalpur. Pliestocene comprises of Kankar in the south west corner of the upper basin as de-limited for this study i.e. Barmanghat.

2.9 SOILS AND GENERAL LANDUSE:

The upper catchment of Narmada consists mainly of black soil. In addition, mixed red and black soil, and skeletal soils are observed in pockets. Of these deep black soil covers the major portion of the basin.

About 35% of the area is underforest and about 60% arable land, and the remaining under grasslands and wasteland etc.

LOCATION OF DISCHARGE AND GAUGING SITE UNDER STUDY.

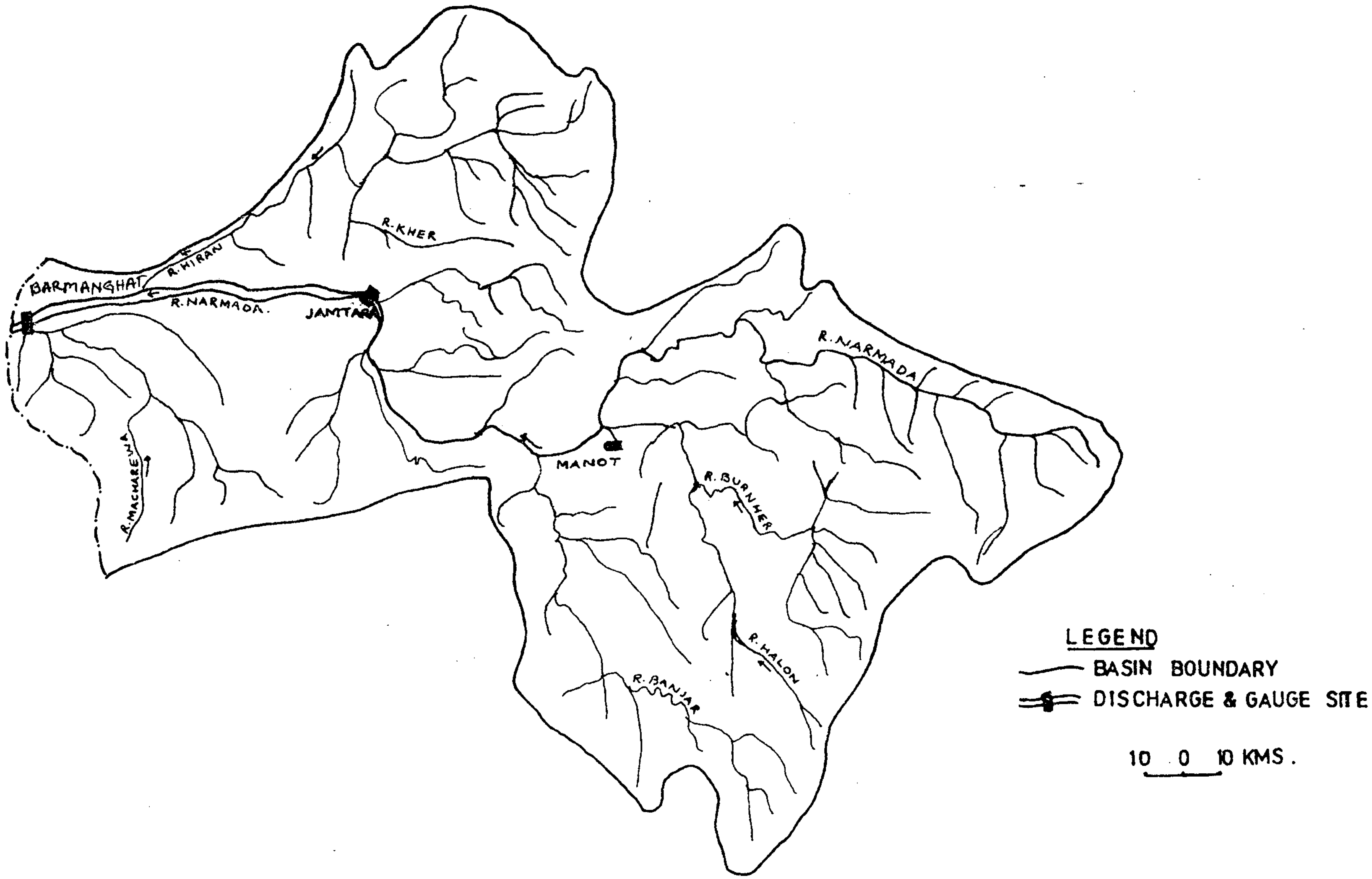

fig. 3.1

Chapter III

CHANNEL MORPHOLOGY

A channel morphological and hydrological characteristics is an outcome of the interaction of geological, geomorphological and hydrological attributes also known as hydraulic variables. The present chapter not only aims at an understanding of hydraulic characteristics but also deals with other fundamental characters, important in the understanding of channel behaviour.

Schumm[1] opines that the river morphology and its behaviour can be understood through alterations of gradient , shape, and patterns of discharge and sediments.

3.1 LOCATION OF SELECTED GAUGING AND DISCHARGE SITES UNDER STUDY:

(1) Manot:

This silt, gauging and discharge site is situated near village Manot in district Mandla (M.P.) on the right bank of Narmada. It is located at 80°31' East longitude and 22°44' North latitude and has catchment area of 4300 sq. kms. The banks are of clay and gravel, having an average height of 16 metres apart from each other. The width and depth of the river at the site is 230 mts. and

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1. Schumm, S.A. (1977), The Fluvial System, John Wiley and Sons, London, p.97.

19 mts. respectively and the length of the river from source upto site is 218 kms.

(2) Jamtara:

This silt, gauging and discharge site is on right bank on main river Narmada near Jamtara village in Jabalpur district. It is located at 79°57'06" East longitude and 23°05'12" North latitude and has a catchment area of 17157 sq. kms. The banks are of sand mixed clay soil and are steep having the height of 30 metres on left bank and 15 metres on right bank. The width and depth of river at the site is 270 metres and 25 metres respectively and the length of river upto site is 399 kms. There is a dam known as Bargi approximately 12 kms. upstream of this site. The water level of this site is of much importance for flood forecasting purpose. The maximum observed water level at this site was 381.815 m. and discharge, 19141 m^3s^{-1} on 30.8.78. Its highest flood level is 381.815 m.

(3) Barmanghat:

This silt, gauging and discharge site is situated at Barman on the right bank of Narmada. It is located at 79°00'54" East longitude and 23°01'36" North latitude and has catchment area of 26453 sq. kms. The banks are steep having an average height of approximately 21 metres.

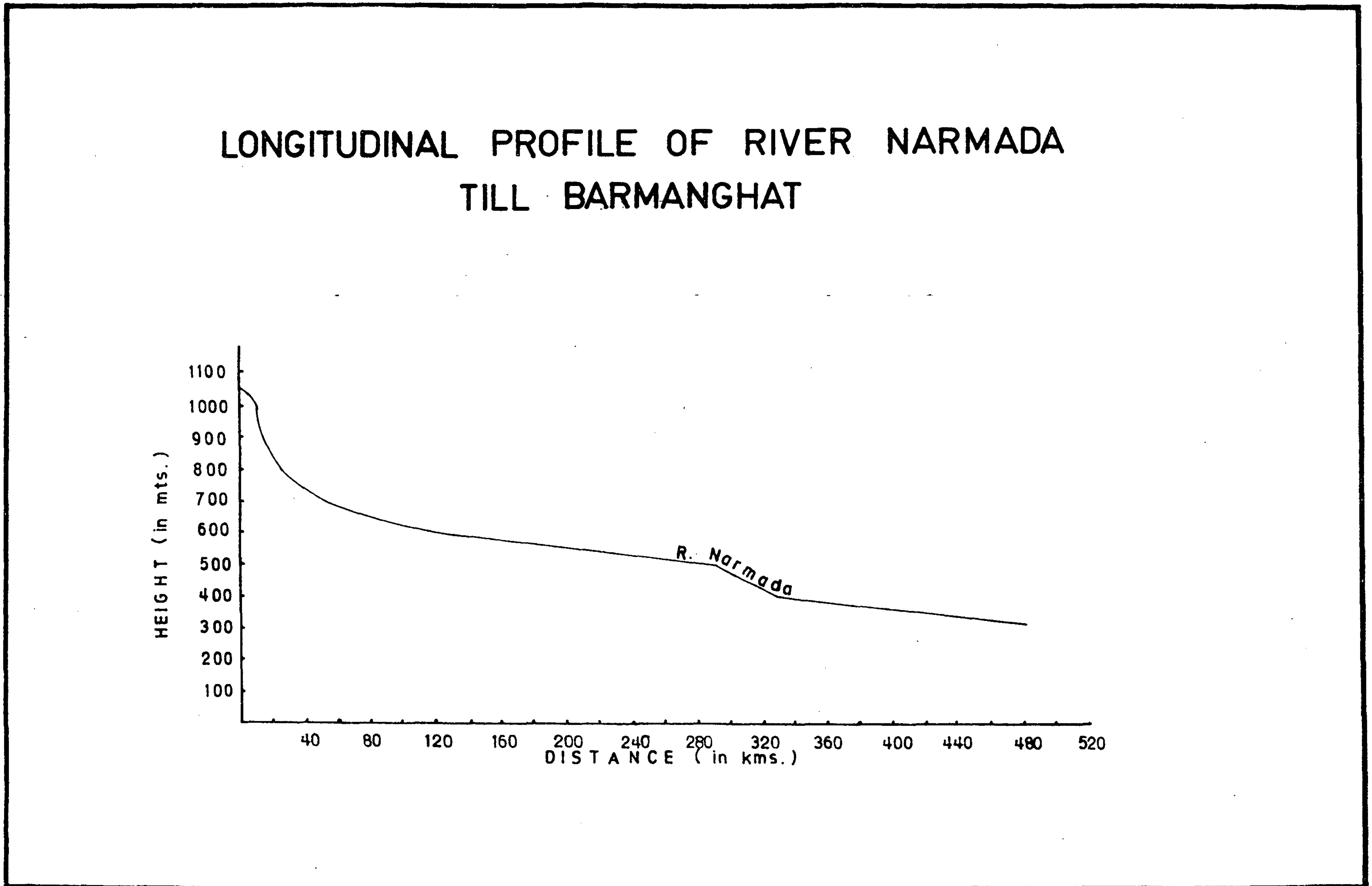
LONGITUDINAL PROFILE OF RIVER NARMADA
TILL BARMANGHAT
HEIGHT (in mts.)
1100
1000
900
800
700
600
500
400
300
200
100
R. Narmada
40
80
120
160
200
240
280
320
360
400
440
480
520
DISTANCE (in kms.)

fig.3.2

LONGITUDINAL PROFILE OF SOME MAJOR TRIBUTARIES OF UPPER NARMADA CATCHMENT.

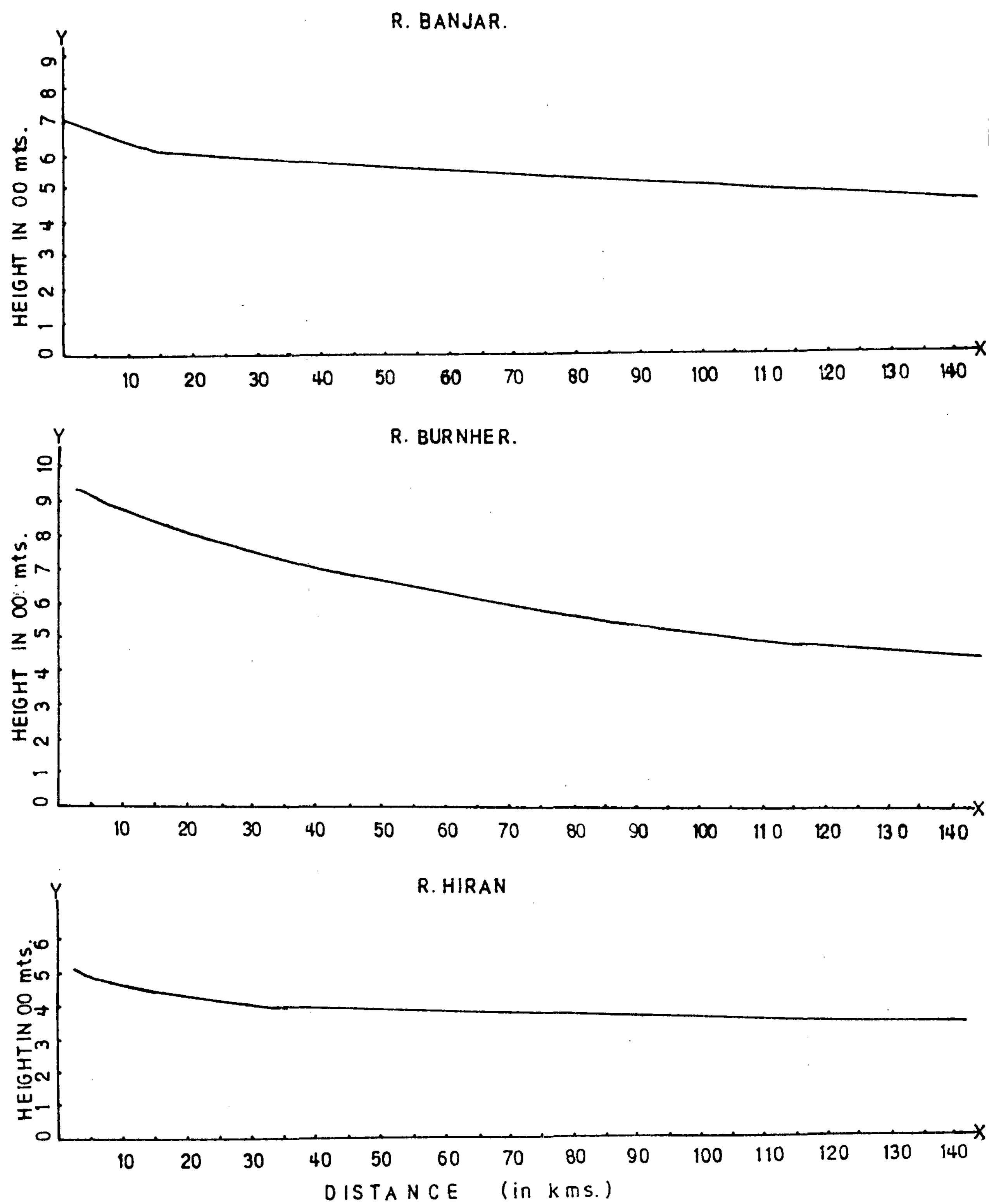

fig. 3.3

LONGITUDINAL PROFILE OF SOME MAJOR TRIBUTARIES OF UPPER NARMADA CATCHMENT

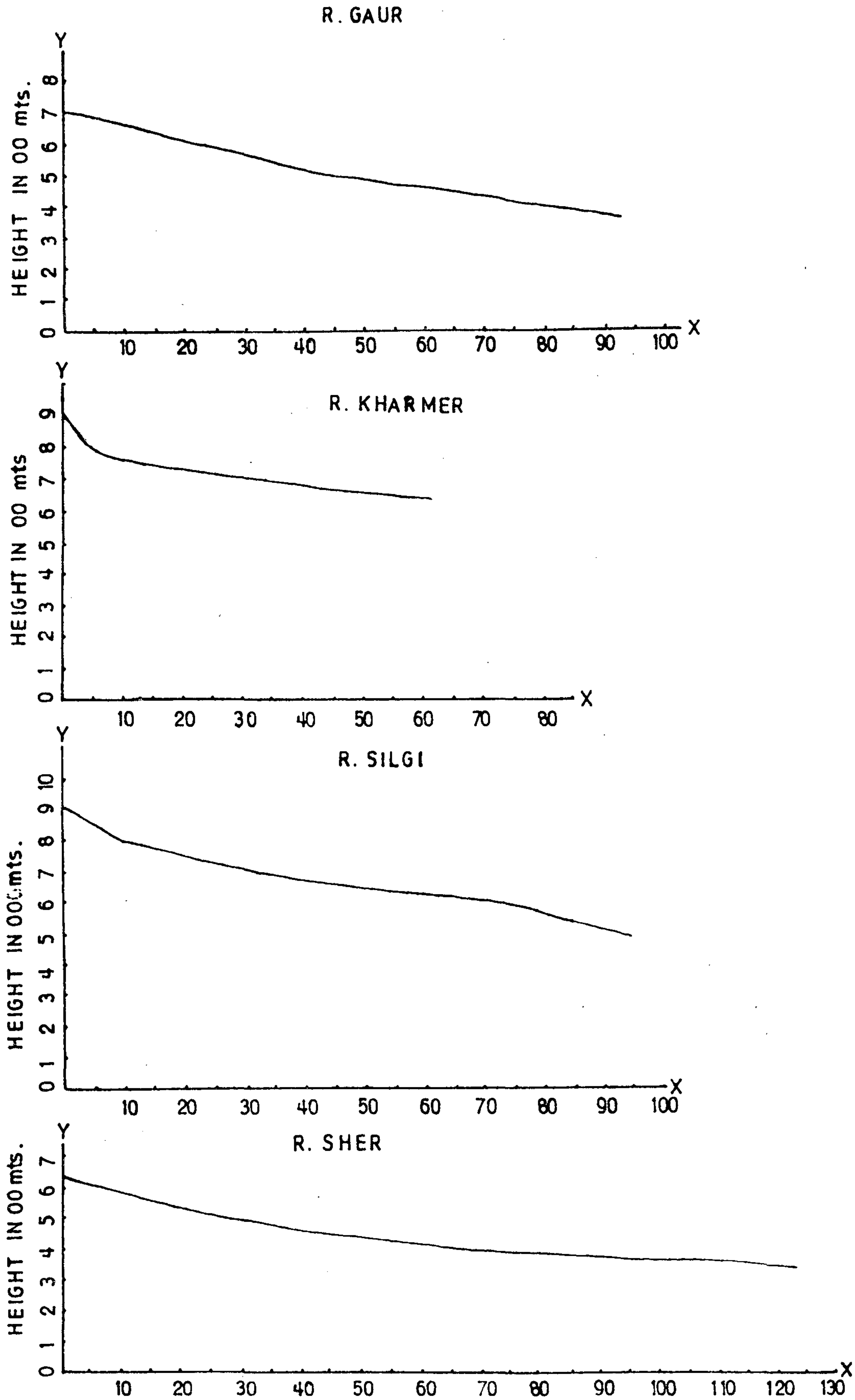

fig. 3.4

The length of river from source upto site is 504 kms. and width and depth is 340 and 28 mts. respectively. The maximum flood recorded in Narmada was in year 1973, when the maximum water level was recorded 330.455 metres and discharge 20908.8 m^3s^{-1} on 30.8.73. The highest flood level of this site was in 1973 is 331.320 metres. (Fig.3.1)

3.2 LONGITUDINAL PROFILE ANALYSIS OF MAIN NARMADA AND ITS TRIBUTARIES:

Longitudinal profile of a river shows the stage of its development and the nature and structure of rocks underlying. In the initial stages of channel development the profile is interrupted with a large number of breaks in the profile. As time passes there comes a time when the river is in equilibrium and the profile becomes smooth. It is generally seen that in areas where the surface is rocky the profile is highly irregular due to the contrasting nature of rocks but in plains the profile generally is smooth.

River Narmada flows through a rift valley between the Vindhyan in the North and Satpuras in the South. Its tributaries have their origin on the highlands of the Deccan. Profiles of its tributaries Banjar, Burnher, Hiran, Kharmer, Silgi and Sher have been drawn in Fig. 3.2, 3.3 and 3.4 and also of river Narmada.

The profile of river Narmada is irregular at three places. The river originates at an height of about 1057 metres and there is a steep fall in the profile for a distance of about 60 kms. and after that the profile becomes smooth. Again at a distance of about 300 kms. from the source there is a fall and then the profile is smooth. In the upper catchment of Narmada till Barmanghat site the profile can be said to be interrupted with smooth stretches in between indicating the flow of the river in hills and plain respectively. In Hills the profile shows break and in plains the profile is smooth.

The long profiles for the tributaries of Narmada also show a similar trend as that of the main river. The subtle breaks could not be recognized on the graphs as the scale of the maps from which these have been derived are 1:250,000 scale maps.

3.3 CHANNEL BOTTOM PROFILE ANALYSIS OF NARMADA RIVER (1985-86):

The study of the channel profile of a river illustrates the shape of the cross-section. The shape (Rs) at any particular location on the river cross-section is the function of the flow, (discharge, D), quantity and character of sediment (S) and grain size (sg.) which not only includes what the river carries but what the river bank is composed of thus written symbolically:

$$Rs \propto D.S.\ sg.$$

Since the flow exerts a deforming stress on the river bed as well as on river bank, any inequality between the shearing stress of the flow and the resisting stress of the river bed and the bank of the channel gives rise to a change not only in the bank of the channel but also in its bed profiles.

Generally, in alluvial regime of the river, it is observed that the channel bed tends to scour during high flood, but when it recedes the shear stress also decreases with decrease in discharge and velocity, causing a filling over the scoured section of the channel. This is due to the settling down of the river sediment, which the river is no longer able to carry with itself either in terms of traction or saltation load, or even in suspension load. Therefore, in the river bed as well as in the river bank. Therefore the channel scour and fill are two processes always succeeded by each other in their job scouring and filling in the river channel respectively.

The behaviour and nature of the channel depends on scouring and filling. They are not independent, as scouring results in wearing away of material, which has to be deposited further lower down in the channel resulting to filling.

Channel bed sounding is an appropriate method to ascertain bank-bed changes at a cross-section occuring during various seasons. Sounding is done only 3 times a year representing 3 seasons namely the pre-monsoon, monsoon and post-monsoon. Efforts are made to make sure that sounding represents normal conditions during respective seasons, though it may not be so in all the cases because a channel is a dynamic phenomena in geomorphology. For this study, cross-sections at Manot and Barmanghat showing channel configuration for 3 seasons during 1985-86 were obtained, but for Jamtara station cross-sections were not available. A study by Sarma and Basumallick[1] clearly shows a direct relation between discharge figures and scouring or siltation processes. As it has been observed in the same study that scouring of the bed takes place during high discharge followed by siltation or filling during low discharge.

3.4 CHANNEL CONFIGURATION ANALYSIS FOR MANOT AND BARMANGHAT (1985-86):

For both the stations we have 6 cross-section each showing channel configuration of 3 seasons for 1985-86.

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1. Sarma, J.N., and Basumallick, Sudhir (1986), "Channel farms and processes of the Burhi Dihing river, India", Geografiska Annaler, vol.68(a) (4), pp.373-81.

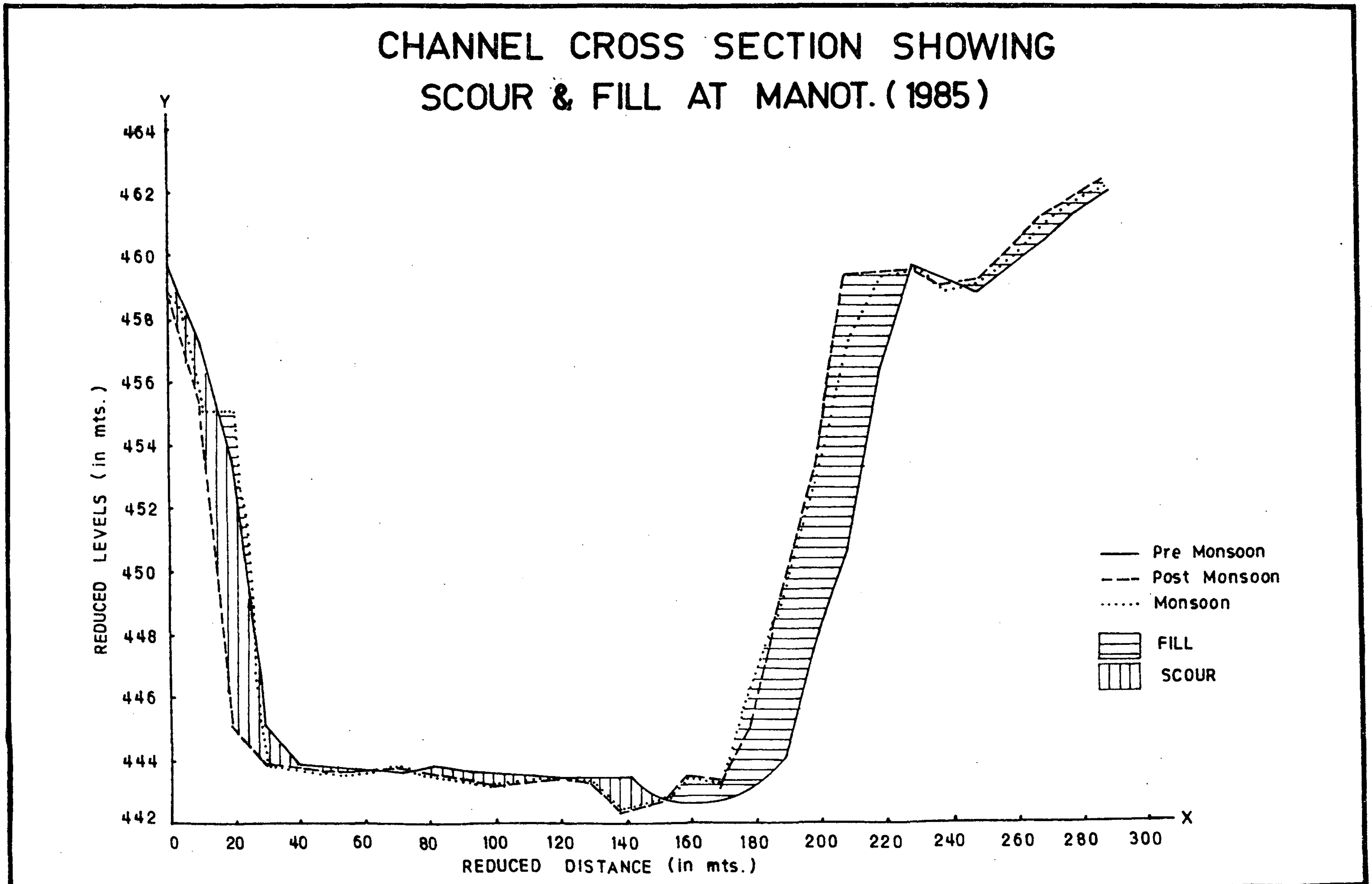

CHANNEL CROSS SECTION SHOWING
SCOUR & FILL AT MANOT. (1985)
Y
464
462
460
458
456
454
452
450
448
446
444
442
REDUCED LEVELS (in mts.)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
X
REDUCED DISTANCE (in mts.)
Pre Monsoon
Post Monsoon
Monsoon
FILL
SCOUR

fig. 3.5

PLATE-1

(a) Coarse deposits on the River bank at Jamtara

(b) Exposed gravel bed at Manot

These will be dealt separately to bring out specific features of scouring and filling, which are evidently very clear. After superimposing the profiles of 3 seasons, the cross-section of pre-monsoon has been considered to represent a base, as the discharge capability of erosion and carrying capacity is minimum during this season.

(1) Manot:

The cross-section at Manot is trough shape and highlights a very important phenomena superimposition of channel profiles show minimum changes in the river bed configuration between 40 to 120 mts. RD'S (Fig.3.5) away from right bank in all the seasons. Another striking feature is filling of the left bank and scouring of the right bank. Though, the amount of scouring is not equal to filling, even though it is significant.

During monsoon the left bank of the river shows considerable amount of filling between 160-220 mts. reduced distances which is 24.33 mts. of cumulative filling. Not much filling occurred during post-monsoon season when the river adds only 1.32 mts. to the previous figure of monsoon season on the left bank. The right bank shows scouring considerable amount in the post-monsoon season, when 11.45 mts. had been scoured away. Monsoon season doesn't show much scouring as only 3.98 mts. had been lost

CHANNEL CROSS SECTION SHOWING SCOUR & FILL AT MANOT.(1986)

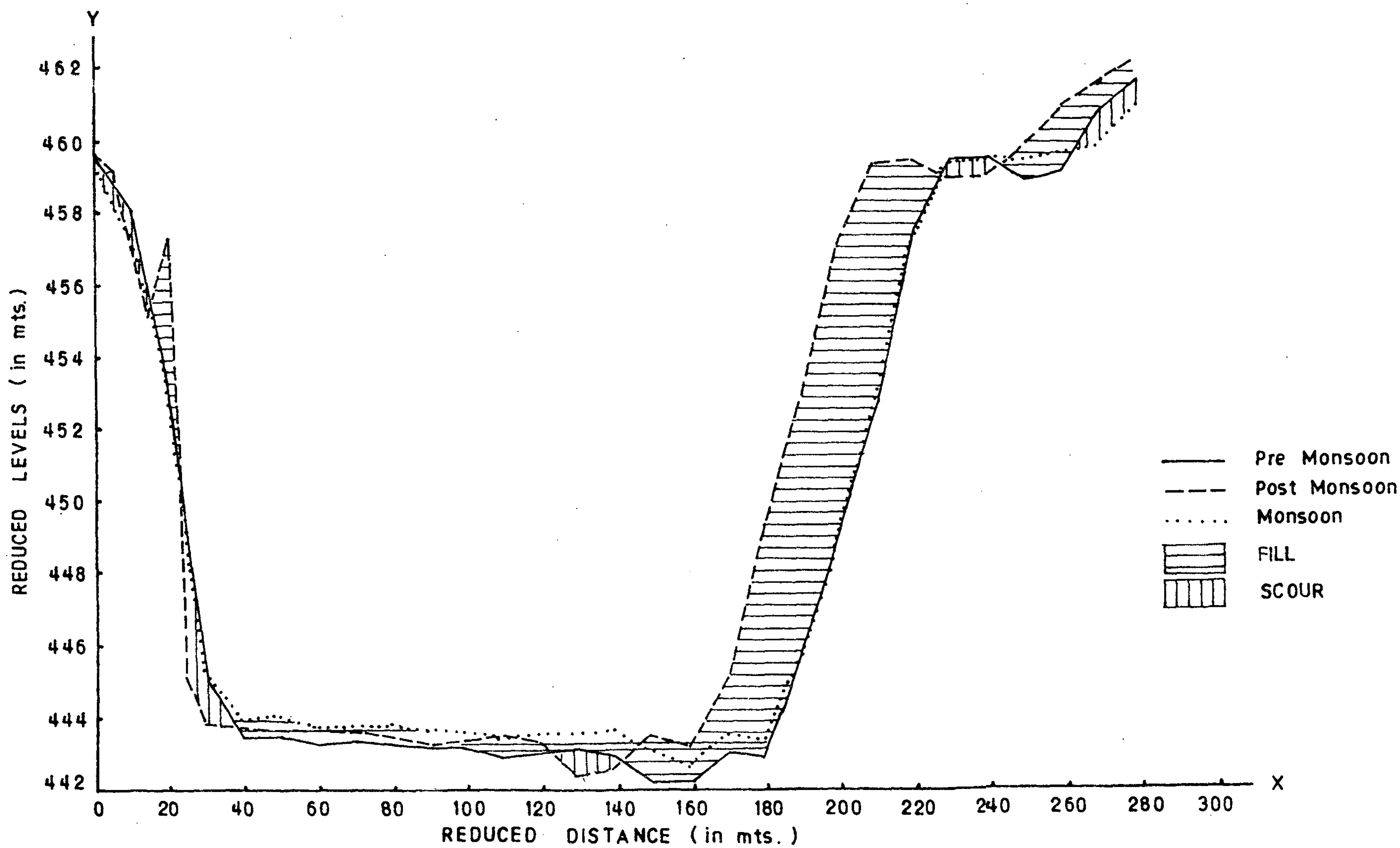


fig.3.6

from the right bank. While 1.78 mts. had been added to the same resulting in only 2.2 mts. of change.

There is hardly any seasonal change in the bed of the channel between 1985 to 1986. During monsoon season 1985 the bed shows scouring of 2.92 mts. while the total filling was 11.91 mts. In post-monsoon, there was net change of 3 mts. indicating neither much scouring nor filling of the bed.

During 1986 (Fig.3.6) filling of the left bank had been mostly in the post-monsoon season, 33.96 mts. was added to the left bank. Of which a considerable amount of 32.30 mts. was added during post-monsoon season and monsoon contributed only 1.66 mts. On the other hand, the right bank shows the development of bar-like feature, while bank close to the bed shows some activity of scouring. There was 9.01 mts. filling, during 1986 monsoon period, while no scouring took place on the river bed. In the post-monsoon period, there was only 2.21 mts. of scouring, while filling was 13.31 mts., which brings the net change in the bed to 11.1 mts.

The analysis of the cross-profile at Manot shows that the banks of the river has a dynamic behaviour than bed. The yearly variations in the bank or bed figures confirm a general state of least change in bed and more

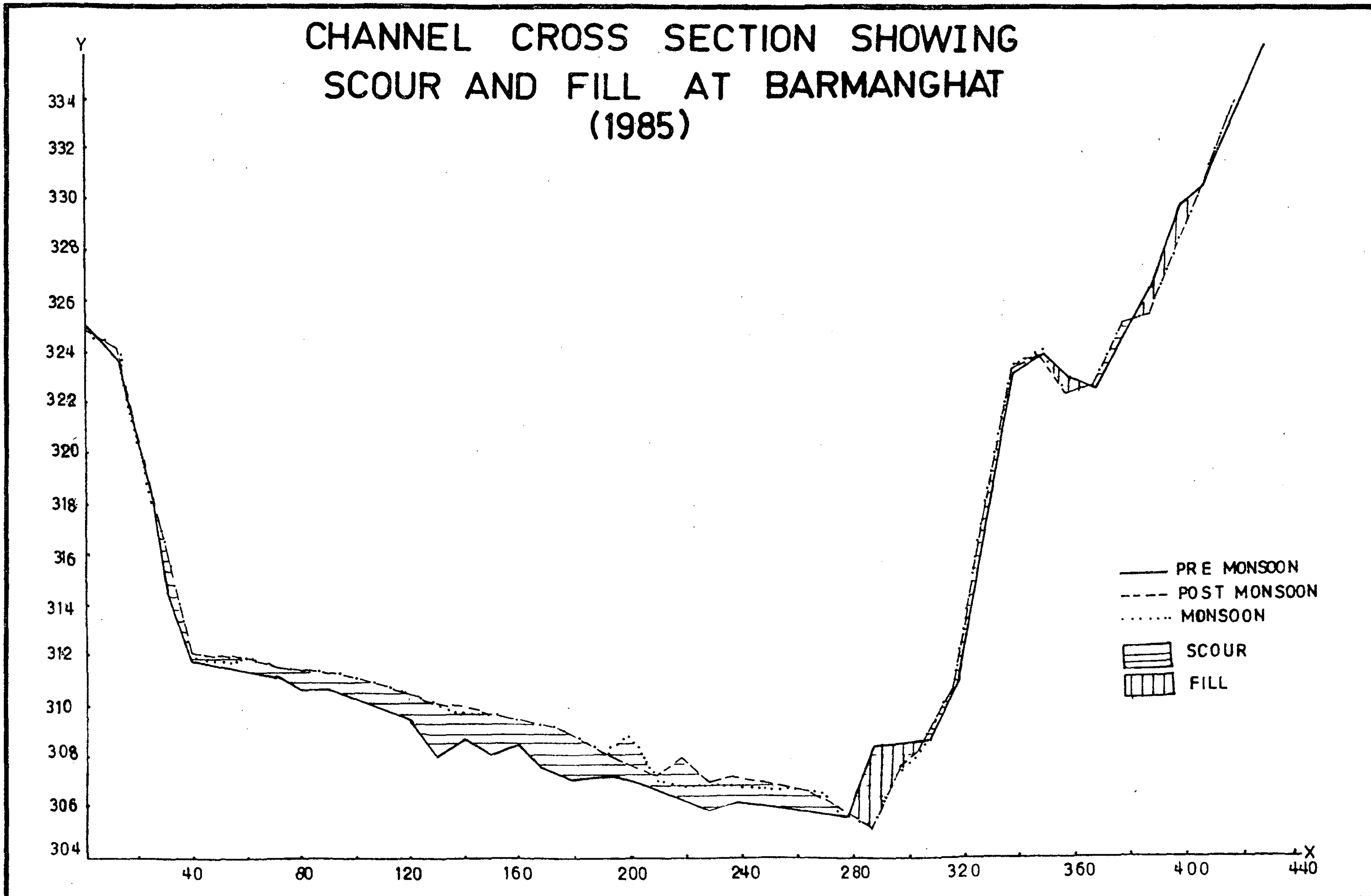

CHANNEL CROSS SECTION SHOWING
SCOUR AND FILL AT BARMANGHAT
(1985)
Y
334
332
330
328
326
324
322
320
318
316
314
312
310
308
306
304
40
80
120
160
200
240
280
320
360
400
440
X
PRE MONSOON
POST MONSOON
MONSOON
SCOUR
FILL

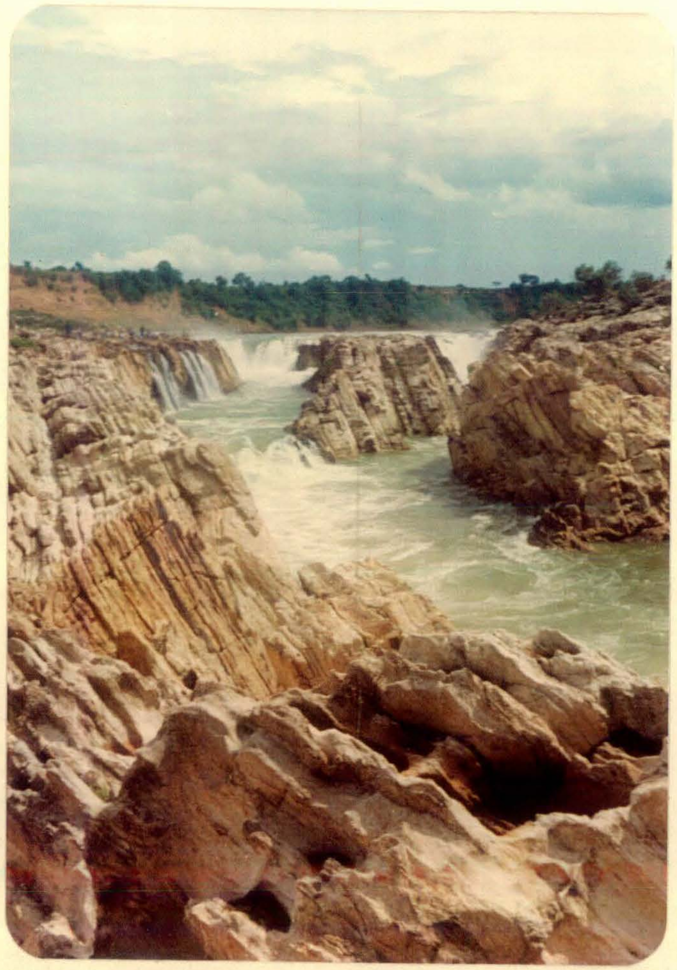
fig. 3.7

PLATE-2

(a) River island dividing the channel upstream of Barmanghat

(b) River cutting across almost horizontal phyllite beds at Barmanghat

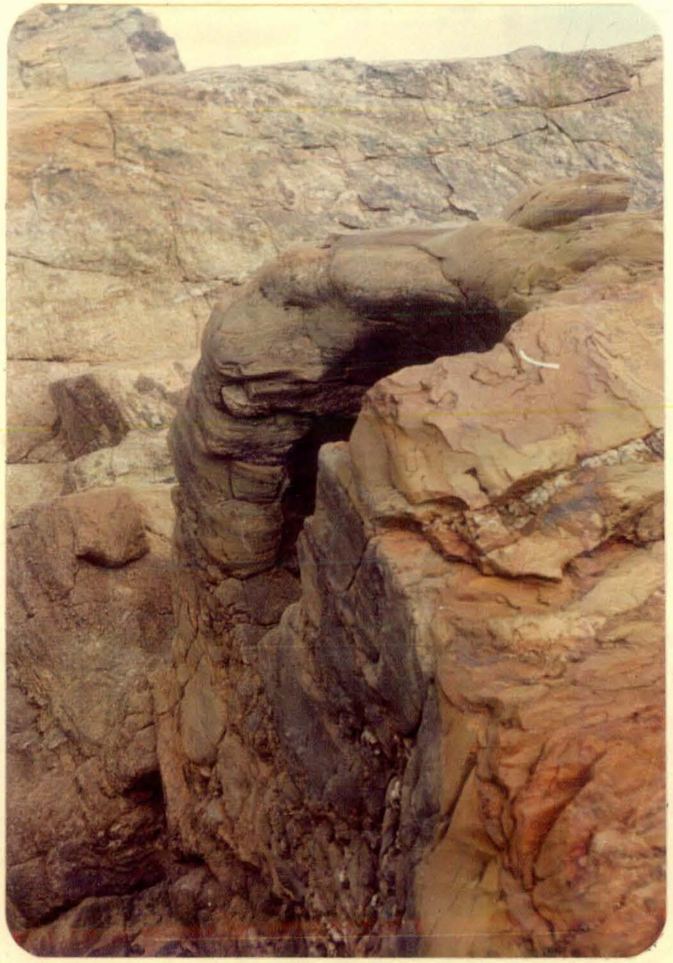
PLATE-3



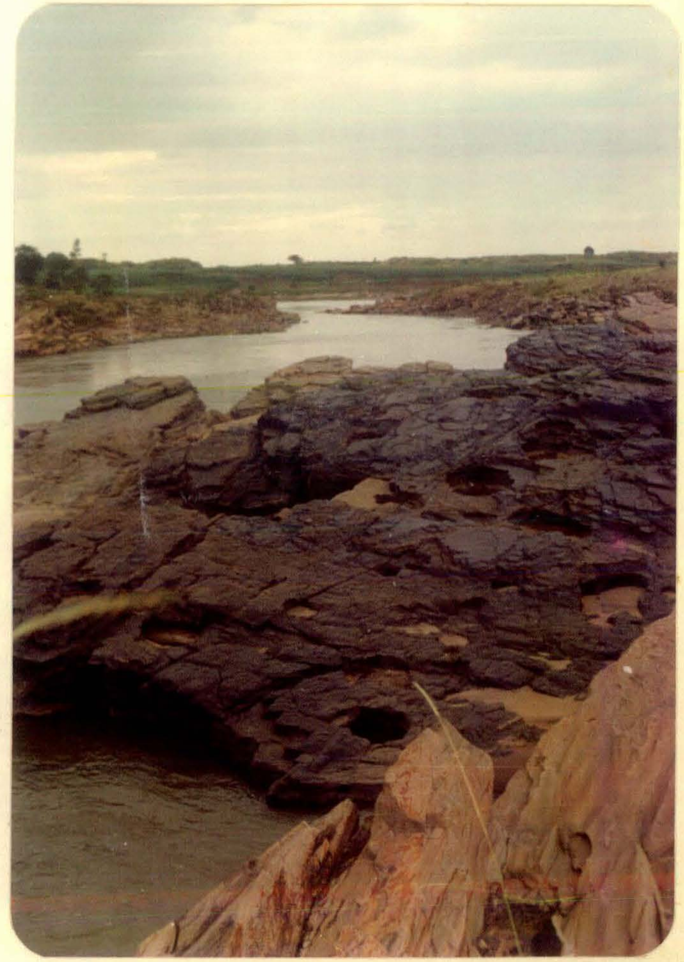
(a) Dhuandhar waterfall

(b) Highly jointed bank of Narmada upstream of Barmanghat

PLATE-4

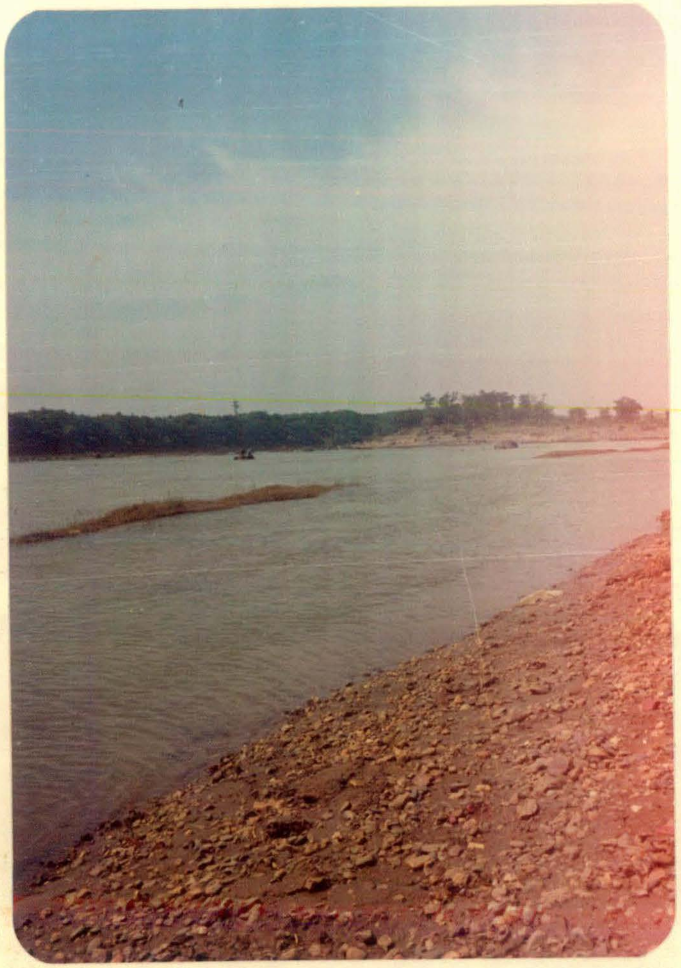


(a) Pothole in highly joined rock face of the bank at Barmanghat

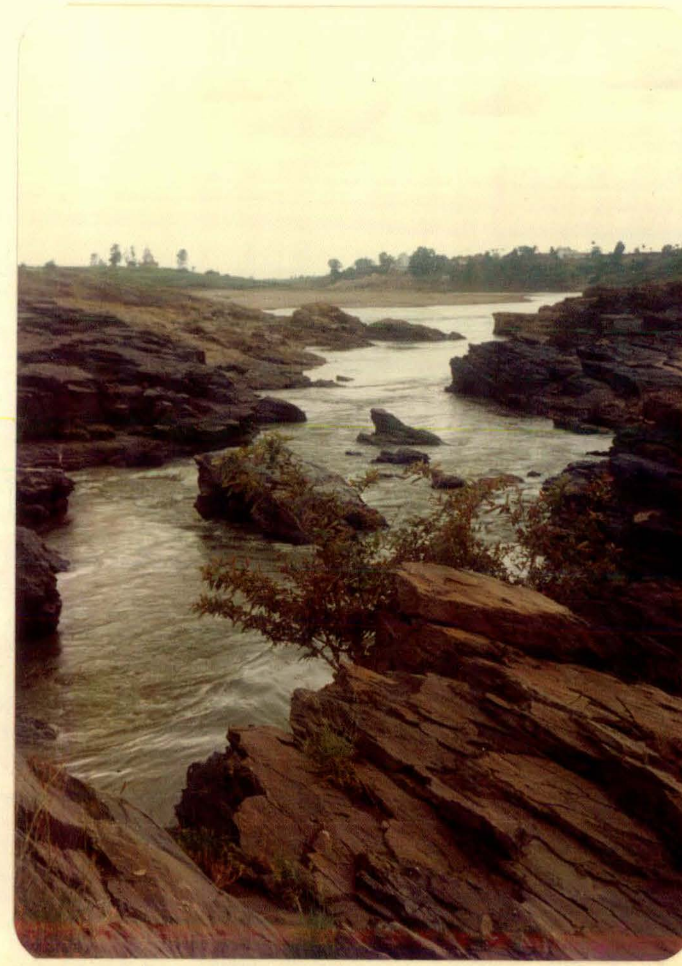


(b) Various Potholes and structural intrusion in the river channel at Barmanghat

PLATE-5



(a) Channel Bar at Barmanghat



(b) River flowing from structural confinements to alluvial tracts at Barmanghat changes of banks. The least changes in bed configuration can probably be attributed to gravel bed of the river at Manot which is shown in at a time when the river had little amount of water in the channel, exposing the gravel bed.

(2) Barmanghat:

The cross-section of Narmada at Barmanghat is Trapezoidal. It has assymmetrical banks with right bank reaching to a greater height than left bank. The banks of the channel doesn't show much of scouring or filling during monsoon or post-monsoon season. During monsoon (1985) period, (Fig.3.7), left bank experienced scouring of 0.29 mt. and filling of 1.28 mts., thus the net change was of only 0.99 mt. of filling. The right bank figures show a greater amount of scouring of 3.2 mts., while filling was only 0.90 mt. The net change was 2.3 mts. During monsoon period, bed configuration shows spectacular amount of filling 20.23 mts., while scouring was only 3.96 mts. Thus, the net change was 16.27 mts. surprisingly, the post-monsoon period hardly shows any change in either the bank or the bed configuration changes found if any are very insignificant as can be observed by the following values. Left bank scouring was of 0.18 mt., filling was of 0.42 mt., and right bank scouring was of only 0.06 mt., while filling was only 0.9 mt. Bed shows the same

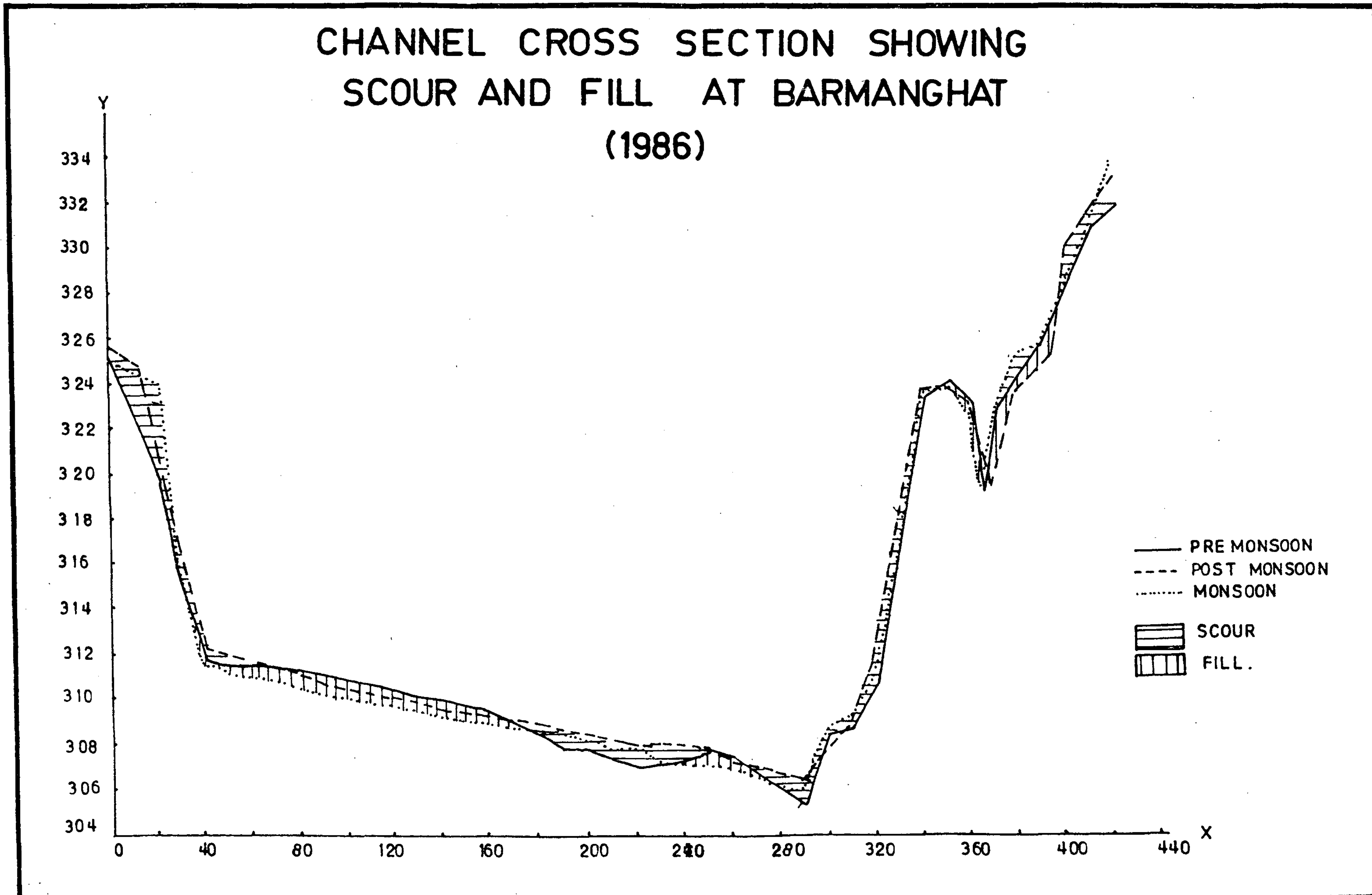

CHANNEL CROSS SECTION SHOWING
SCOUR AND FILL AT BARMANGHAT
(1986)
Y
334
332
330
328
326
324
322
320
318
316
314
312
310
308
306
304
0
40
80
120
160
200
240
280
320
360
400
440
X
PRE MONSOON
POST MONSOON
MONSOON
SCOUR
FILL.

fig. 3.8

tendency, where scouring was 0.35 mt., and filling was 0.23 mt. Not much of scouring or filling took place during post-monsoon season.

The cross-section for 1986 shows, (fig.3.8) a tremendous drop in filling, while scouring at different points (RD'S) shows an overall increase. Comparison with 1985, values show drastic drop in fill at the bed. Though banks might have gained some amount of deposition through filling, left bank shows a total amount of 4.63 mts. as filling during monsoon period while during post-monsoon period, these values have gone in favour of scouring. Bed scouring during monsoon period was 6.68 mts., while filling of bed was only 5.53 mts., thus making net change in favour of scouring with a value of 1.14 mts. During monsoon period, right bank shows 2.48 mts. of scouring and 1.40 mts. of filling, which makes the net change of 1.08 mts. in favour of scouring in the post-monsoon period. During post-monsoon period, the left bank experienced scouring of 2.5 mts. and only 1.01 mts. was filled. While the bed does not show many changes and follow the trend of monsoon period. Only 5.09 mts. was scoured away from the bed and 4.5 mts. was filled. The net change was negligible on the right bank, scouring dominated with a value of 3.9 mts., while only 3.2 mts. was filled showing a low net change.

Table 3.1: Total Seasonal Scour fill and Net Annual Change on the River Narmada

Year/ Site	Monsoon		Post Monsoon		Annual Total		Net annual change	
	Fill	Scour	Fill	Scour	Fill	Scour	Fill	Scour
1. Manot:								
1985	37.74	6.43	32.26	15.95	70.00	22.38	47.62	-
1986	9.26	0.69	31.48	3.93	40.74	4.62	36.12	-
2. Barmanghat:								
1985	20.74	7.41	2.2	0.63	22.97	8.04	14.93	-
1986	10.58	9.24	7.85	1.27	18.43	9.24	9.19	-

The Table 3.1 shows total seasonal scour and fill, and net annual changes at Manot and Barmanghat on river Narmada. A close scrutiny reveals that during monsoon and post-monsoon as well as annually, filling activity dominates the scouring at both the stations.

Both the stations provide certain phenomena which may not be explained by a simple rule of increase in discharge results in increase in scouring. The fillings observed on the left bank of the river at Manot site during monsoon, and post-monsoon period can be attributed to the fact that the site itself is located on or close to the axis of a river bend. In a river bend, the convex bank experiences depositions while the concave bank gets scoured which is clearly evident by the scouring of right bank of the river as shown in the cross-section at Manot.

The site at Barmanghat depicts another characteristic where the bed of the river gets filled during both the seasons. This can be explained by the fact that above the gauging site upstream river is structurally confined to a narrow channel. This leads to an increase in velocity thus increasing carrying capacity, when the river gets near to the gauging site it widens itself thus leading to a drop in carrying capacity giving way to filling of the bed. Finally, it can be concluded that at both sites the channel configuration is rather controlled by structure than the discharge at that site.

3.5 CHANNEL PATTERN ANALYSIS:

Rivers display a continuity of patterns from straight to sinuous and highly sinuous. Sinuosity of rivers is associated with bending, winding, curving and deviating of the same. The nature of river course behaviour varies with the stages of basin development and reflects the age, topography and underlying lithological characteristics. 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 it does not exist in the nature. Thus, the river morphology in terms of geometric structure of channel or drainage network involves the calculation of deviation of observed course from the expected course of a river from source to mouth. The course of a river is governed by various causative factors viz. geologic and hydraulic controls, dip, slopes, absolute relief, relative relief, dissection index, stage of valley development, vegetal cover etc. which forced the drainage or channel lines to deviate from its straight line of expected path. Generally river courses are classified into three categories on the basis of sinuosity index, if (1) SI $<$ 1.05 the channel is straight, an SI between 1.05-1.5 is sinuous, if SI $>$ 1.5, the pattern is meandering. It should be noticed here that any classification of stream sinuosity is arbitrary, and a meandering stream may be of low sinuosity, perhaps as low as 1.2 if the channel displays a repeating pattern of bends (Schumm[1]).

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

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1. Schumm, S.A. (1977), op. cit., p.113.

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

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

where

CL = Channel length

VL = Valley length.

Table 3.2: Sinuosity Indices of Upper Narmada and its major Tributaries

	Rivers	C.I.	V.I.	HSI (in %)	TSI (in %)	SSI
1.	Halon	1.38	1.17	55.2	44.8	1.18
2.	Burnher	1.82	1.32	60.96	38.90	1.38
3.	Banjar	1.42	1.12	70.52	29.47	1.26
4.	Hiran	1.64	1.27	57.25	42.74	1.28
5.	Sher	1.39	1.07	80.01	19.13	1.29
6.	Machrewa	1.69	1.23	66.65	33.34	1.37
7.	Gaur	1.77	1.35	53.84	46.15	1.30
8.	Kharmer	1.41	1.19	52.94	47.05	1.18
9.	Silgi	1.94	1.24	74.17	25.82	1.56
10.	Seoni	1.44	1.21	51.16	48.83	1.18
11.	Sonar	1.44	1.16	62.50	37.50	1.23
12.	Temur	1.52	1.28	45.20	54.79	1.18
13.	Umar	1.55	1.34	38.13	61.86	1.15
14.	Narmada	1.66	1.29	55.38	44.61	1.28

The Table 3.2 clearly reveals that the Narmada and all rivers of upper Narmada catchment have sinuous courses, (except Silgi 1.56) as the values of sinuosity indices range between 1.5 lowest for Umar river and highest 1.38 for Burnher river. It is apparent that only Silgi river has meandering course as the sinuosity index is 1.56. The highest value which is registered by Silgi is due to the underlying sedimentary deposition, where hydraulic activities are dominating over the topographic conditions. Seoni, Kharmer, Temur and Halon register the equal value of Standard Sinuosity Index (SSI).

3.6 HYDRAULIC AND TOPOGRAPHIC SINUOSITY:

Hydraulic and topographic sinuosity indices are important morphometric attributes which enable us 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 the straight line course due to Hydraulic variations within the valley. Whereas topographic sinuosity index (TSI) is the percentage of a streams deviation from a straight line expected due to topographic interference. The values for both indices have been calculated for some drainage basins of the upper Narmada catchment which are important from discharge and catchment area and length of the river by following Mueller's model as below:

$$HSI = \% \text{ equivalent of } \frac{CV-VI}{CV-I}$$

$$TSI = \% \text{ equivalent of } \frac{VI-I}{CV-I}$$

where

$$CI = \frac{CL}{\text{Air length}}$$

$$VI = \frac{VL}{\text{Air length}}$$

where CI = Channel index, VI = Valley index,

CL = Channel length, VL = Valley length,

Air length = Shortest distance between source to mouth.

It is axiomatic to deduce that topographic sinuosity is outstanding in the youthful stage of the basin development, when hydraulic sinuosity is negligible, conversely hydraulic sinuosity is high in senile stage after most of the topographic sinuosity has been removed. It is apparent from Table 3.2 that the value of topographic sinuosity index ranges between 19.13% lowest for Sher and 61.86% highest for Umar (both basins lie over the sedimentary formations). Umar river has highest topographic sinuosity index 61.86% which indicates that about two-fifths of the hydraulic sinuosity has been removed, the lowest hydraulic sinuosity of this river may be attributed to the course of the river over resistent rocky bed. Out of all 14 rivers only 3, viz. Banjar (70.52%), Sher (80.01%) and Silgi (74.17%) present the high domination of hydraulic sinuosity. The value of hydraulic sinuosity index ranges between 38.13% lowest for Umar (for which TSI is highest) and 70.52% highest for Banjar. Only 2 rivers, viz. Umar (TSI=61.86%), Temur (TSI=54.79%) have more than 50% control of topographic sinuosity. On the other hand, 3 rivers show more than 70% Hydraulic sinuosity viz. Banjar (70.52%), Sher (80.01%) and Silgi (74.17%). All rivers except Temur and Umar show domination of topographic sinuosity control on the channel pattern or river behaviour. Other river basins show a mixed effect of both indices, where one may be significant but the control may not be ignored.

Chapter IV

ANALYSIS OF DISCHARGE AND SEDIMENT IN THE BASIN

The regime of a river can be analysed critically with the help of hydrological data, such as discharge and gauge. The discharge data from 1972 to 1982 for Jamtara and Barmanghat, and 1977-82 for Manot, sedimentation data for 1972-77 (June-September) for Jamtara and Barmanghat have been used to analyse the annual seasonal and monthly variations in flow characteristics in the Narmada river.

The hydrology of the Narmada river basin is controlled by several factors, such as runoff, rainfall, evaporation, evapo-transpiration, infiltration, geology and landuse of the catchment. Thus, the total runoff of the river depends on the factors affecting rainfall and evaporation. These physical and climatological variation provides a varied character to the Narmada basin.

River behaviour studies are multidimensional, of which the nature of discharge and flow of sediments are of much concern. The present chapter basically aims at understanding the nature of discharge and flow of sediments along the course of the river spatially and temporally.

The river regime may be defined as "variations in the discharge during the time period."[1] It may consist of daily, monthly, yearly or decadal variations over a long period of time. In other words, regime refers to the behaviour of river in different seasons, i.e. summer, monsoon and winter. There are several modifying factors which include the two sets of factors human and physical. The physical includes soil, geology, climate and hydraulic geometry of the basin. The hydrological characteristics of the Narmada river can be viewed from different graphical representations, annual, seasonal, monthly and daily discharges respectively. The above stated problem has been dealt with mainly at two sites, viz. Jamtara and Barmanghat. Discharge has been dealt with at three levels, annual, seasonal and monthly. Mean annual discharge for 10 years (1972-82) has been compared with a mean annual discharge being the normal discharge. Mean annual variation in discharge has been found out by subtracting it by the mean annual discharge (i.e. discharge of the normal year) and then dividing it by the mean annual discharge to find out the percentage fluctuation.

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1. Chorley, R.J. (ed.) (1969), Introduction to Physical Hydrology, Methuen, London, pp.176-91.

The river behaviour of Narmada is today manifested by various factors like hydrological pedological, geological, vegetational and the result of human interaction in or along the course of the river. It is also influenced by man-made features viz. dams, canals for irrigation purposes and supply of water for urban centres. Thus, regime of a river is characterized by the river processes and built forms such as Dams, Barrage and Reservoirs etc. as they have important consideration in hydro-power generation and management of water within the channel.

I. DISCHARGE ANALYSIS:

4.1 ANNUAL VARIATIONS IN THE DISCHARGE (1972-82):

During the ten water years, from June 1972 to May 1982, the mean annual runoff varied between 2934.76 m^3s^{-1} to 13033.23 m^3s^{-1} with an average value of 8304.49 m^3s^{-1} for Jamtara, and from 3839.42 m^3s^{-1} to 18068.60 m^3s^{-1} with an average value of 12187.38 m^3s^{-1} for Barmanghat. The above indicated values correspond to an average annual runoff of 261832.75 M.Cum. and 330635.25 M.Cum. for Jamtara and Barmanghat. Manot, another site upstream of Jamtara, for five years (1977-82), the mean annual discharge varied between 905.80 m^3s^{-1} to 4301.48 m^3s^{-1} with an average value of 2742.35 m^3s^{-1}. It corresponds to 86482.75 M.Cum. of average runoff.

The average annual flow in a river at a particular gauging station provides a rough idea of the normal

Table 4.1: Annual Variations in Discharge at Gauge/Discharge Sites (1972-82)

Discharge (in $m^3 s^{-1}$)

Years	Jamtara		Barmanghat		Manot	
	Mean Annual Discharge	Deviation from mean in %	Mean Annual Discharge	Deviation from mean in %	Mean Annual Discharge	Deviation from mean in %
1972-73	7648.51	- 7.89	10860.85	-10.88	-	-
1973-74	12762.57	53.68	18068.60	48.25	-	-
1974-75	5786.49	-30.31	9358.59	-23.21	-	-
1975-76	13033.23	56.94	17285.27	41.82	-	-
1976-77	4913.65	-40.83	7934.00	-39.89	-	-
1977-78	11677.44	40.61	18925.06	55.28	3982.20	45.21
1978-79	7151.24	-13.88	12564.88	3.09	2645.18	- 3.54
1979-80	2934.81	-64.65	3839.42	-68.49	905.80	-66.96
1980-81	12561.48	51.26	16200.63	32.92	4301.47	56.83
1981-82	4575.48	-44.90	6836.52	-43.90	1877.09	-31.55

Jamtara: Mean = 8304.49; Standard deviation=3661.57; Coefficient of variation=44.09%

Barmanghat: Mean=12187.38; Standard deviation= 4983.92; Coefficient of variation = 40.89%

Manot: Mean=2742.34; Standard deviation= 1272.72; Coefficient of variation=46.41

flow of that river at that site. But it is not a scientific proof of the river behaviour, as it varies with seasons, monthly as well as daily. For a more scientific inference, there is a need to look at river behaviour from a temporal point of view to identify the period of negative or positive deviation from the mean, i.e., normal discharge. The spatial dimension of variations is also significant as far as different sites in the upper catchment are concerned.

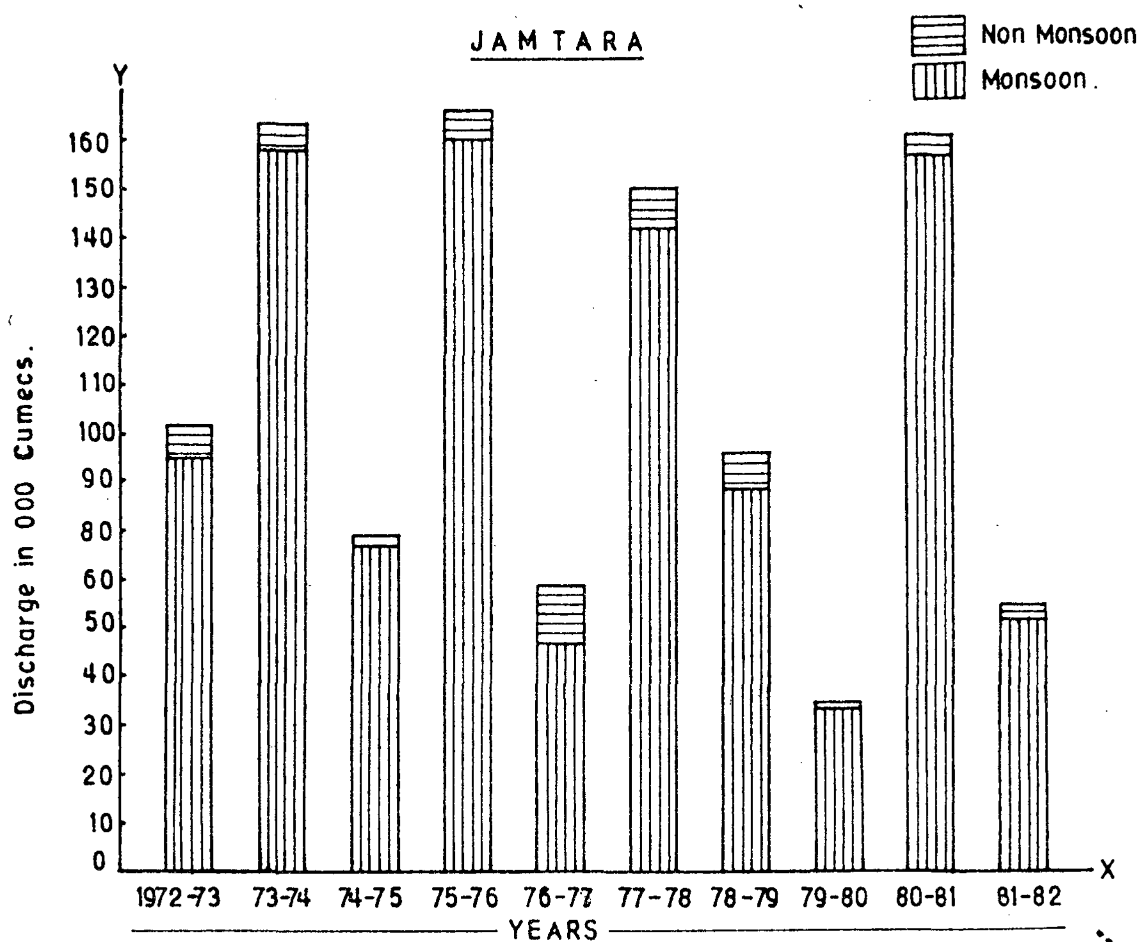
The river flow is depicted both in the objective terms in discharge and also in temporal terms, the mean annual discharge over a decade (1972-82) for Jamtara and Barmanghat, and for Manot (1977-82) (i.e. for five years) discharge. The deviations from this discharge have been considered as positive or negative years of discharge. Considering the averages for Manot, Jamtara and Barmanghat, it can be seen from Table 4.1 that years are either below or above normal discharge values. The highest discharge 13033.23 m^3s^{-1} in 1975-76 and the lowest 2934.81 m^3s^{-1} in 1979-80 for Jamtara and Barmanghat show highest discharge 18925.06 m^3s^{-1} in 1977-78 and lowest 3839.42 m^3s^{-1} in 1979-80. It reveals that both sites show lowest discharges in 1979-80, 2934.81 m^3s^{-1} and 3839.42 m^3s^{-1}, for Jamtara and Barmanghat respectively.

But the highest discharge years of both the sites do not correspond with each other. On the other hand, Manot's highest discharge 4301.47 m^3s^{-1} occurred in 1980-81, while lowest discharge during five years was observed in 1979-80 with 905.80 m^3s^{-1}.

The year 1977-78 was above normal year for all sites, whereas, 1978-79 was below normal year for Manot and Jamtara, but was not for Barmanghat. The years 1972-73 to 1977-78 show similar rythmic pattern of positive and negative deviations from the mean at Jamtara and Barmanghat. Manot and Jamtara from 1977-78 to 1981-82 show the same pattern of below and above normal discharge years. The 1978-79 for Jamtara and Barmanghat, has a reverse variation in the mean annual discharge at both sites, thereby breaks the rythmic pattern in the annual variations of the discharge.

It would appear from Table 4.1 that the percentage deviation in mean annual discharge varies between $\pm$ 3.54 to 66.96, $\pm$ 7.89 to 64.65, and $\pm$ 10.88 to 68.49% for 1972-82 was registered for Manot, Jamtara and Barmanghat respectively. An interesting feature of the annual discharge is that the high discharge during a particular year is followed by a low discharge in the following year, as it is also perceptible in the case of percentage

ANNUAL DISCHARGE
(1972-82)



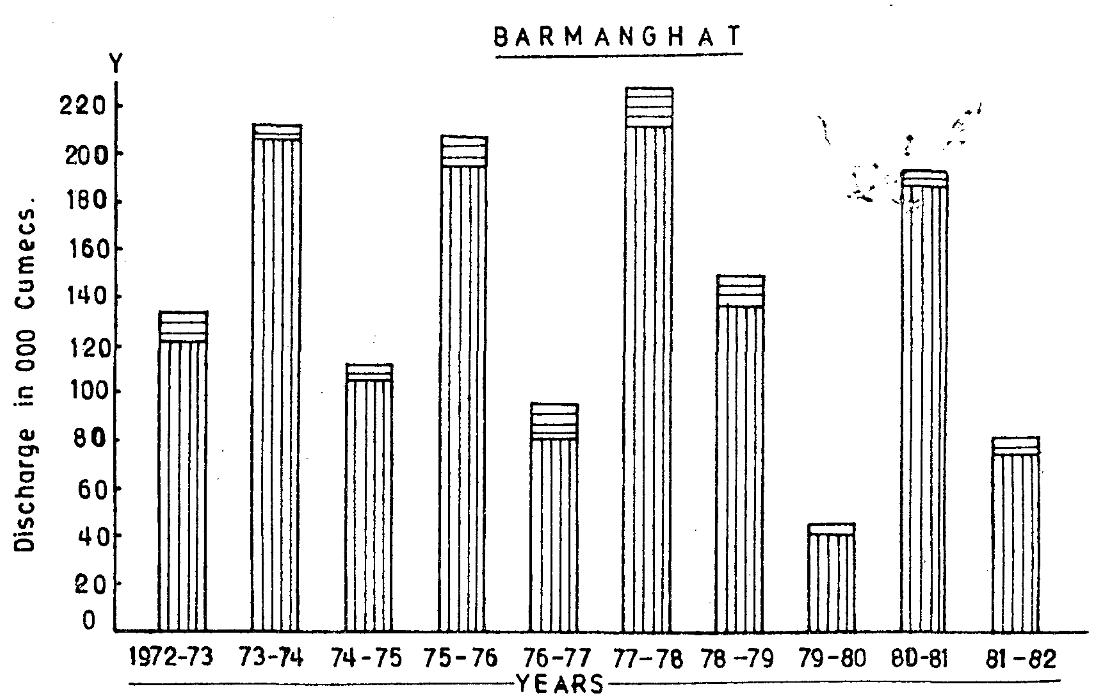


fig.4.1

deviations. Figure 4.1 also indicates that a lion share of annual discharge is contributed by the monsoonal discharge which generally varies between 92-97% of the total annual discharge. The variability of annual discharge calculated was 46.41% at Manot for five years, while 44.09% for Jamtara and 40.89% for Barmanghat was observed for a period of ten years. These values indicate that annual variability decreases to the downstream gauging and discharge sites.

4.2 SEASONAL VARIATIONS IN THE DISCHARGE (1972-82):

Like other rivers of India, the river Narmada also exhibits a seasonal variations in the flow. This, although, influenced by many factors, is largely a reflection of climatic variations and in particular, the balance between rainfall and evaporation. The Narmada, being a tropical river, shows a marked contrast between runoff in the rainy and dry seasons.

Intrinsically, related to the behaviour of discharge in the river Narmada are seasonal variations, which have been studied by dividing the water year between monsoon and non-monsoon period. As mentioned earlier, in the Narmada basin, after looking at the monsoon percentage to the total annual discharge for the water years, from 1972-72 at Jamtara and Barmanghat, and from 1977-82 for

Table 4.2: Seasonal Variations in Monsoon Discharge at Gauge/ Discharge Sites (1972-82)

Discharge (in m^3s^{-1})

Years	Jamtara		Barmanghat		Manot	
	Mean annual monsoon discharge	Deviation from mean in %	Mean annual monsoon discharge	Deviation from mean in %	Mean annual monsoon discharge	Deviation from mean in %
1972-73	17088.52	- 9.30	24274.86	-11.36	-	-
1973-74	29582.72	55.99	41185.54	50.38	-	-
1974-75	13434.43	-28.70	21332.56	-22.10	-	-
1975-76	30091.88	56.69	39157.89	42.98	-	-
1976-77	9369.79	-50.27	16390.5	-40.15	-	-
1977-78	26429.54	40.26	42236.42	54.22	8993.65	43.97
1978-79	15794.67	-16.17	27681.6	1.07	5882.31	- 5.83
1979-80	6852.93	-63.63	8743.36	-68.07	2083.93	-66.63
1980-81	29457.13	56.33	37651.42	37.48	9984.74	59.84
1981-82	10324.79	-45.20	15209.66	-44.46	4288.53	-45.65

	Jamtara	Barmanghat	Manot
Mean	18842.64	27383.81	6246.63
Standard deviation	8716.54	11480.89	2926.24
Coefficient of variation	46.25%	41.92%	46.84%

Table 4.3: Seasonal Variations in Non-Monsoon Discharge at Gauge/Discharge Sites (1972-82)

Discharge (in $m^3 s^{-1}$)

Years	Jamtara		Barmanghat		Manot	
	Mean annual non-monsoon discharge	Deviation from mean in %	Mean annual non-monsoon discharge	Deviation from mean in %	Mean annual non-monsoon discharge	Deviation from mean in %
1972-73	905.64	16.51	1279.41	- 3.87	-	-
1973-74	748.17	3.74	1556.51	16.94	-	-
1974-75	323.68	-58.35	805.75	-39.46	-	-
1975-76	848.48	9.16	1661.97	24.87	-	-
1976-77	1730.7	122.67	1893.65	42.27	-	-
1977-78	1140.23	46.70	2274.08	70.86	402.60	68.24
1978-79	977.37	25.74	1767.22	32.77	332.94	39.13
1979-80	136.16	-82.48	336.61	-74.70	64.28	-73.13
1980-81	493.17	-36.54	878.64	-33.38	242.00	1.13
1981-82	468.82	-39.68	855.71	-35.70	154.64	35.37
	Mean = 777.24 Standard deviation = 435.41 Coefficient of variation = 56.02%		Mean = 1330.95 Standard deviation = 570.48 Coefficient of variation = 42.86%		Mean = 239.29 Standard deviation = 121.03 Coefficient of variation = 50.57%	

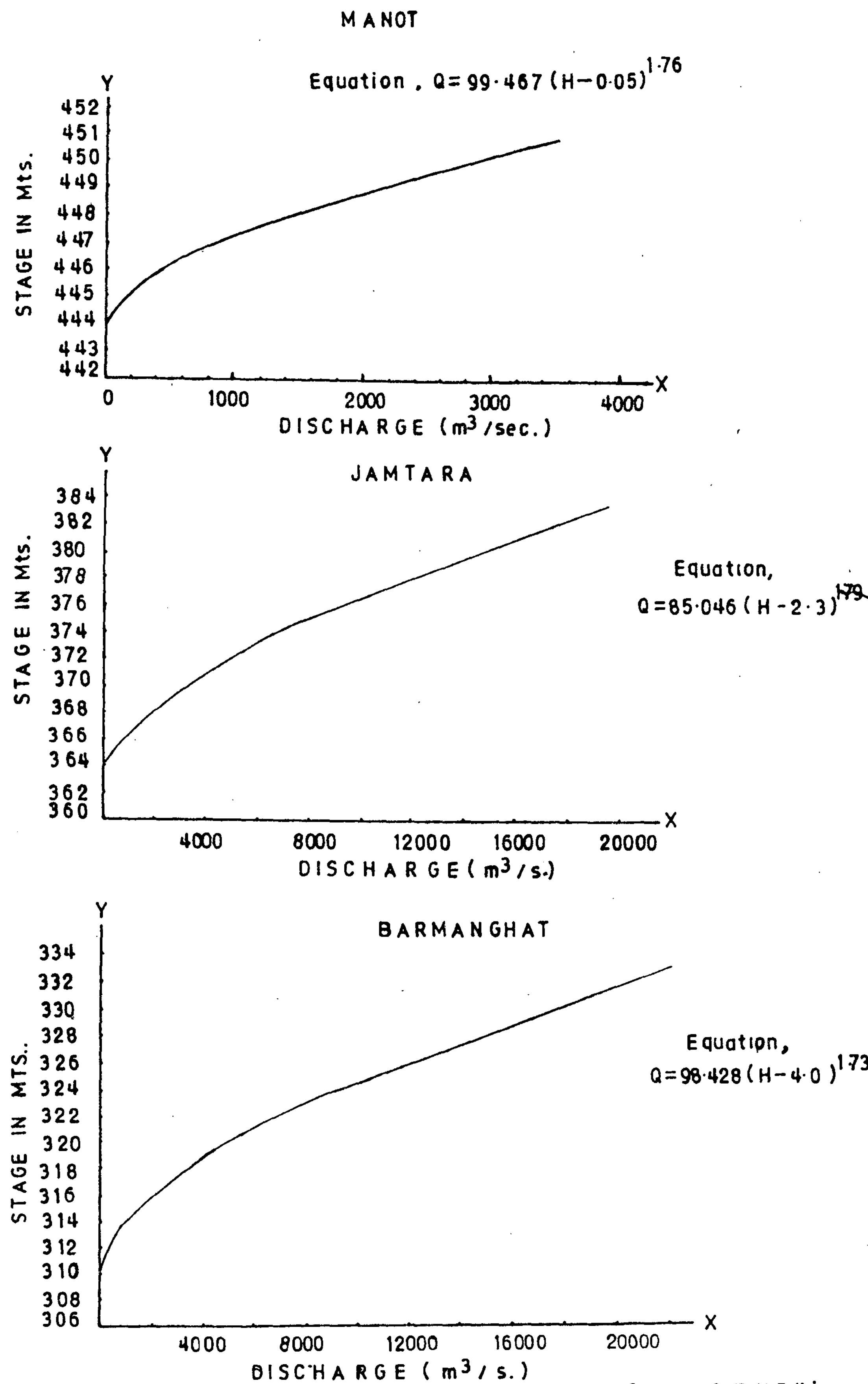
Manot, about 92% is contributed by monsoon rains during the five months from June to October. The rest 8% is contributed in the remaining months through ground water runoff and also by cyclonic rains during January and February. Its contribution was the highest, that is, 97.70% in 1980-81 and 79.4%, the lowest in 1977-78. Conversely, in 1977-78, the highest non-monsoon discharge was 20.60% and 2.30%, the lowest in 1980-81 to the total discharge volume.

To explain the seasonal variations, Mean Monsoon (June-October) and Mean non-Monsoon (November-May) were calculated, and considered as "normal" flow. From this value, i.e., mean of n years has been used to analyse the seasonal variations for Manot, Jamtara and Barmanghat. This value was calculated for each site separately as indicated in the Table 4.2 and 4.3. The year 1979-80 shows the maximum negative deviation of 63.63% from the mean monsoon annual discharge for Jamtara, whereas, for Barmanghat the negative deviation was maximum of 68.07%. Similarly, the positive maximum deviation from mean monsoon discharge for Jamtara and Barmanghat were 56.94% and 56.69% respectively for the year 1975-76. In the case of minimum positive deviations for both the sites, values were 40.26% and 1.07% respectively. A general pattern which emerges from a close scrutiny of the figures suggests that the negative deviation values show a higher variations within itself. While positive deviation values do not give the same picture except in rare cases.

Both Jamtara and Barmanghat show rythmic pattern in the monsoon from 1972-78, but it was disturbed in 1978-79 for Barmanghat with 1.07% and in 1979-80 -63.63% from the mean at Jamtara. The similar pattern in the monsoon is observed of Jamtara at Manot. The non-monsoon discharge shows slight variations in above and below normal years in terms of seasonal water yield of the river, as it largely depends for its discharge on the monsoon season. From 1975-79, there was continuous increase in the discharge but during 1979-82, constant decrease in the discharge of the river is observed both at Jamtara and Barmanghat. The 1972-73 is the year showing reverse pattern in the discharge as above normal for Jamtara and below normal for Barmanghat. These seasonal variations can be attributed to variations in the amount of rainfall. Manot shows 1980-81 as above normal year, which was below normal year for Jamtara and Barmanghat.

The above analysis also shows that seasonal variations in the discharges are complex. In the case of non-monsoon season the clustered pattern for three to four subsequent years in terms of below and above normal discharge is identified. Moreover, high discharge in the

STAGE-DISCHARGE RATING CURVES



Source CWC N.Delhi

fig. 4-2

MEAN MONTHLY DISCHARGE (1972-82)

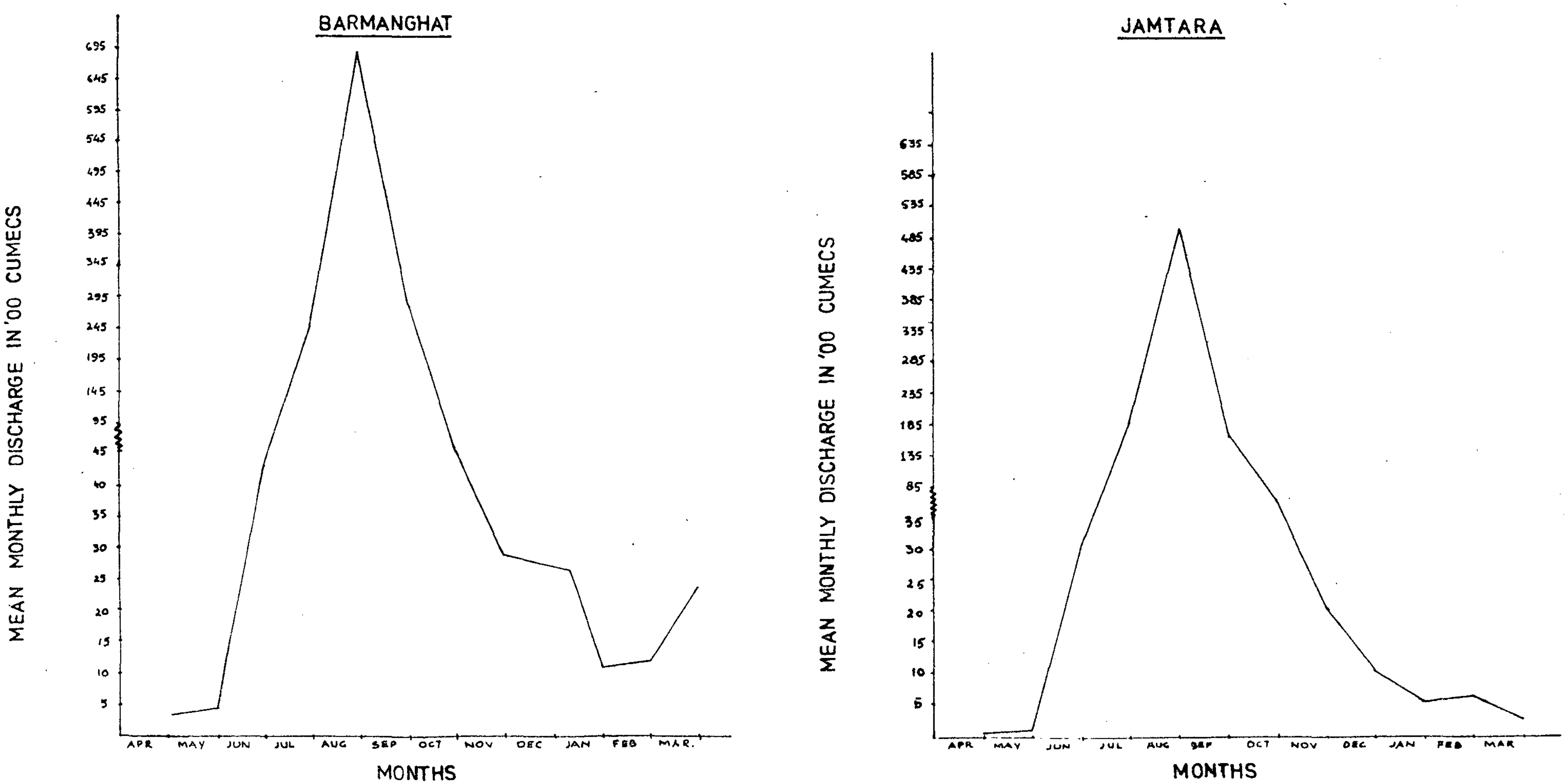


fig.4.3

monsoon season does not lead to high discharge in the non-monsoon, but sometimes, positive feedback in terms of discharge from monsoon to non-monsoon is observed at Manot, Jamtara and Barmanghat.

The Mean monsoon annual discharge varies for 46.84% at Manot, 46.25% Jamtara and 41.92% Barmanghat. It is clear then that the variation of 4.33% is observed from Jamtara to Barmanghat. The non-monsoon annual variability of discharge was 50.57% for Manot, 56.02% for Jamtara 42.86% for Barmanghat. The upstream station Jamtara shows high variability than the downstream station, Barmanghat.

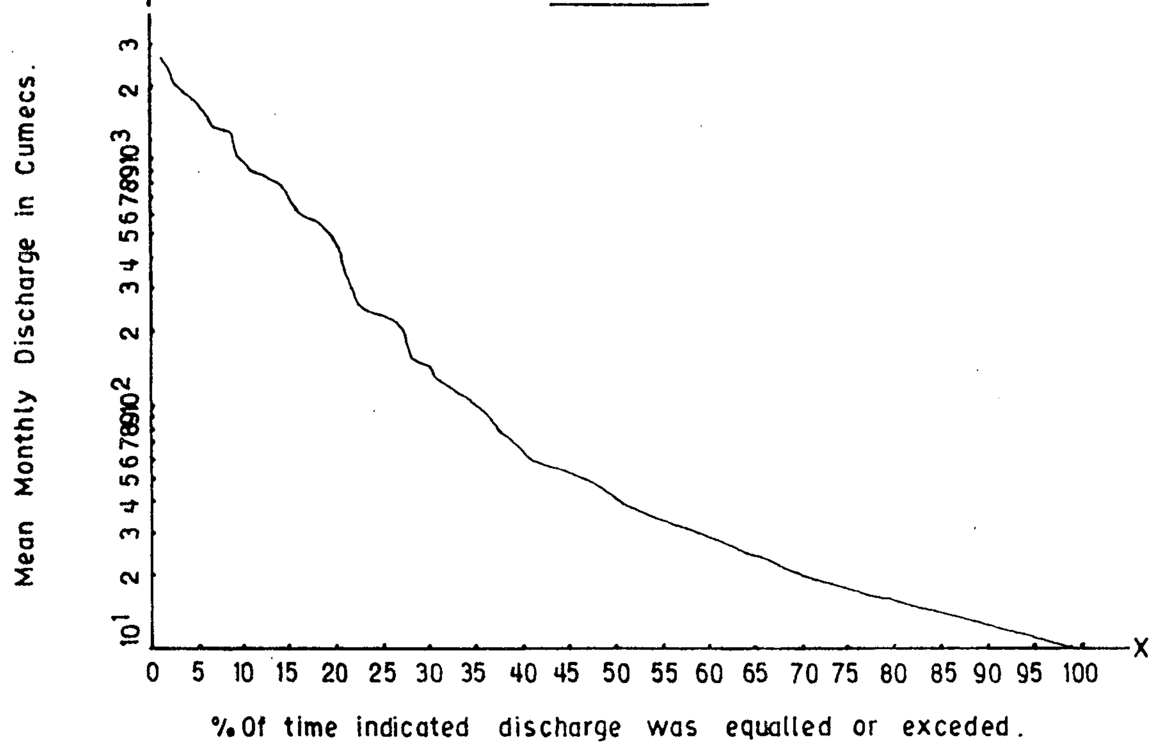
4.3 RATING CURVES:

To utilize a series of individual velocity measurements for a given period, a rating curve is established for a given river cross-section, relating discharge to the stage of the river. The Figure 4.2 shows rating curves at Manot, Jamtara and Barmanghat respectively.

The Figure 4.3 represents the river regime of Narmada, considering mean monthly discharge from 1972-82 at Jamtara and Barmanghat.

FLOW DURATION CURVE OF MEAN MONTHLY FLOWS (1972-82)

JAMTARA



BARMANGHAT

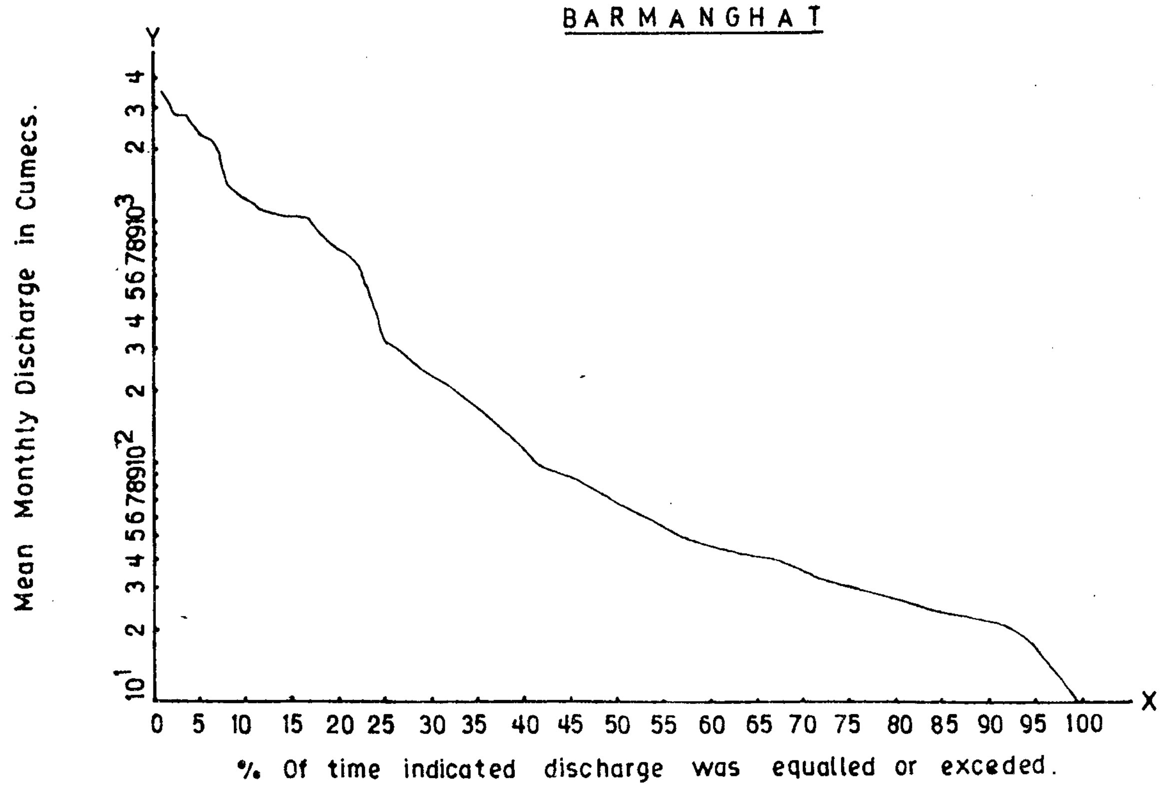


fig.4.4

4.4 FLOW DURATION CURVES:

To study the deviation of flows (Fig.4.4), flow duration curves have also been made to assess the mean flows in relation to per cent time the each flow will occur for Jamtara and Barmanghat. As the mean monthly flow rates are useful in power development plants to form a large storage reservoir. The flow duration curve or discharge frequency curve gives an idea of the long term yield of the river. Both curves have inverse arc shape, it indicates that Narmada has considerable number of frequent floods in a short period during the monsoon period and dry periods with little groundwater contribution.

At Jamtara, 50% of the time, mean monthly discharges varies between 30 to 40 m^3s^{-1} and only 10% of the time it varies between 930 to 2590 m^3s^{-1}. At Barmanghat, the position of mean monthly discharges becomes better due to increase in the discharge downstream with an addition from Sher and Hiran, two of the major tributaries of river Narmada. Here about 10% of time the mean monthly discharges varies between 1180 to 3420 m^3s^{-1} and 50% of time, it varies between 50 to 60 m^3s^{-1}.

4.5 MAXIMUM AND MINIMUM DAILY DISCHARGES AND GAUGES (1972-82):

The maximum flow in a day was recorded, 14574.60 m^3s^{-1} on 22 August 1975 and was lowest 0.10 m^3s^{-1} on

Table 4.4: Showing Daily Maximum and Minimum Discharges (in m^3s^{-1}) (during 1972-82)

	Maximum		Minimum	
	Jamtara	Barmanghat	Jamtara	Barmanghat
1972-73	N.A.	16193.50 (Aug.)	0.20 (May)	7.70 (June)
1973-74	13715.30 (Aug.)	20608.00 (Aug.)	0.20 (May)	9.90 (June)
1974-75	13767.60 (Aug.)	17288.20 (Aug.)	0.20 (June)	5.10 (June)
1975-76	14574.60 (Aug.)	15847.80 (Aug.)	0.80 (June)	10.10 (June/May)
1976-77	2545.30 (July)	3074.30 (Aug.)	0.20 (May)	5.70 (June)
1977-78	9099.4 (Aug.)	18455.20 (Aug.)	4.8 (May)	10.0 (June)
1978-79	4384.50 (Aug.)	4905.00 (Aug.)	0.50 (June)	9.50 (June)
1979-80	7512.90 (Aug.)	8158.10 (Aug.)	0.10 (May/June)	4.50 (June)
1980-81	9065.80 (Aug.)	12375.00 (Aug.)	0.50 (May/June)	7.10 (June)
1981-82	2299.80 (July)	2904.00 (July)	0.20 (May)	N.A.

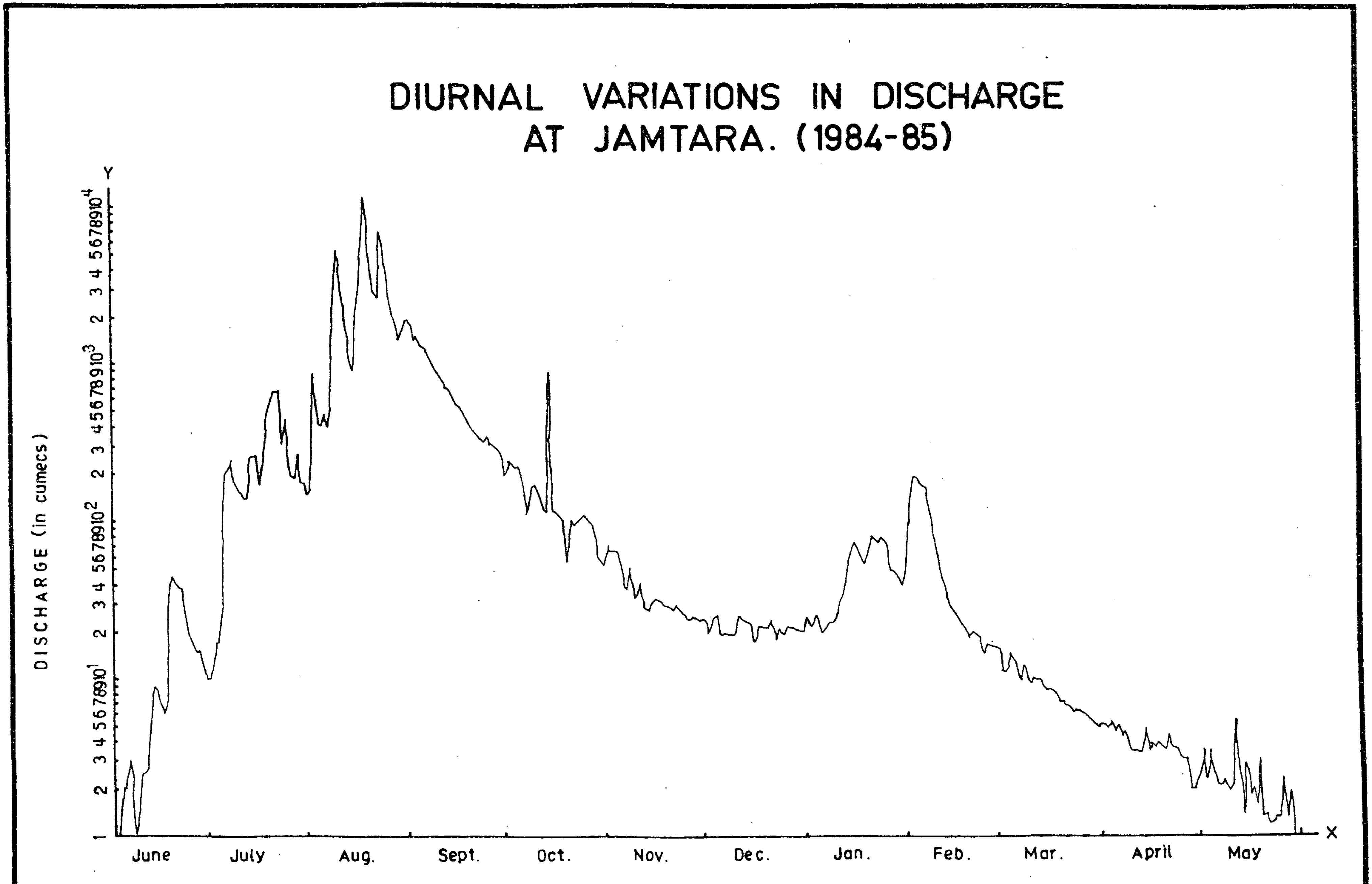
Table 4.5: Showing daily Maximum and Minimum Gauges (in mts.) during 1972-82

	Maximum		Minimum	
	Jamtara	Barmanghat	Jamtara	Barmanghat
1972-73	N.A.	310.10 (Aug.)	362.20 (May/June)	307.60 (April/May/June)
1973-74	380.50 (Aug.)	330.40 (Aug.)	362.32 (May)	307.60 (April/May/June)
1974-75	380.72 (Aug.)	329.30 (Aug.)	362.39 (June)	307.50 (May/June)
1975-76	380.41 (Aug.)	328.21 (Aug.)	362.30 (June)	307.57 (May)
1976-77	369.10 (July)	315.44 (Aug.)	362.20 (April/May)	307.40 (June)
1977-78	375.21 (Aug.)	326.80 (Aug.)	N.A.	N.A.
1978-79	370.55 (Aug.)	318.22 (Aug.)	361.37 (April)	307.50 (June)
1979-80	375.54 (Aug.)	322.18 (Aug.)	361.79 (June)	307.36 (June)
1980-81	376.23 (Aug.)	326.73 (Aug.)	362.18 (April/May)	307.08 (March)
1981-82	368.65 (Aug.)	315.16 (July)	362.18 (June)	N.A.

21 May and 11 June 1980 for Jamtara. But different temporal pattern is observed at Barmanghat, here maximum daily discharge was recorded, 20608 m^3s^{-1} on August 1973 and the minimum 4.50 m^3s^{-1}, which is similar to Jamtara, was recorded on 1 June 1980. The Table 4.4 further indicates that highest flows have occurred usually in August, but it varies between July to September, whereas lowest discharges are recorded in May for Jamtara and in June for Barmanghat.

Although, gauge shows positive relationships with discharge, it varies from zero gauge, as different datum levels are used for different sites. The Table 4.5 shows that highest gauge was recorded 380.72 mts. in August 1974 and the lowest was 361.37 mts. in April 1979 at Jamtara. In case of Barmanghat highest and lowest gauges were recorded 330.40 mts. in 1973 and 307.08 mts. in 1981.

It can be observed from the table that the lowest gauges are usually measured in the months of April, May and June for Jamtara, but at Barmanghat, lowest gauges are registered in the month of June and rarely in May. The highest gauges are always recorded during monsoon season, more in the months of August and sometimes in July at both the sites.



DIURNAL VARIATIONS IN DISCHARGE AT JAMTARA. (1984-85)
DISCHARGE (in cumecs)
Y
X
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
April
May

fig.4.5

DIURNAL VARIATIONS IN DISCHARGE AT BARMANGHAT. (1984-85)

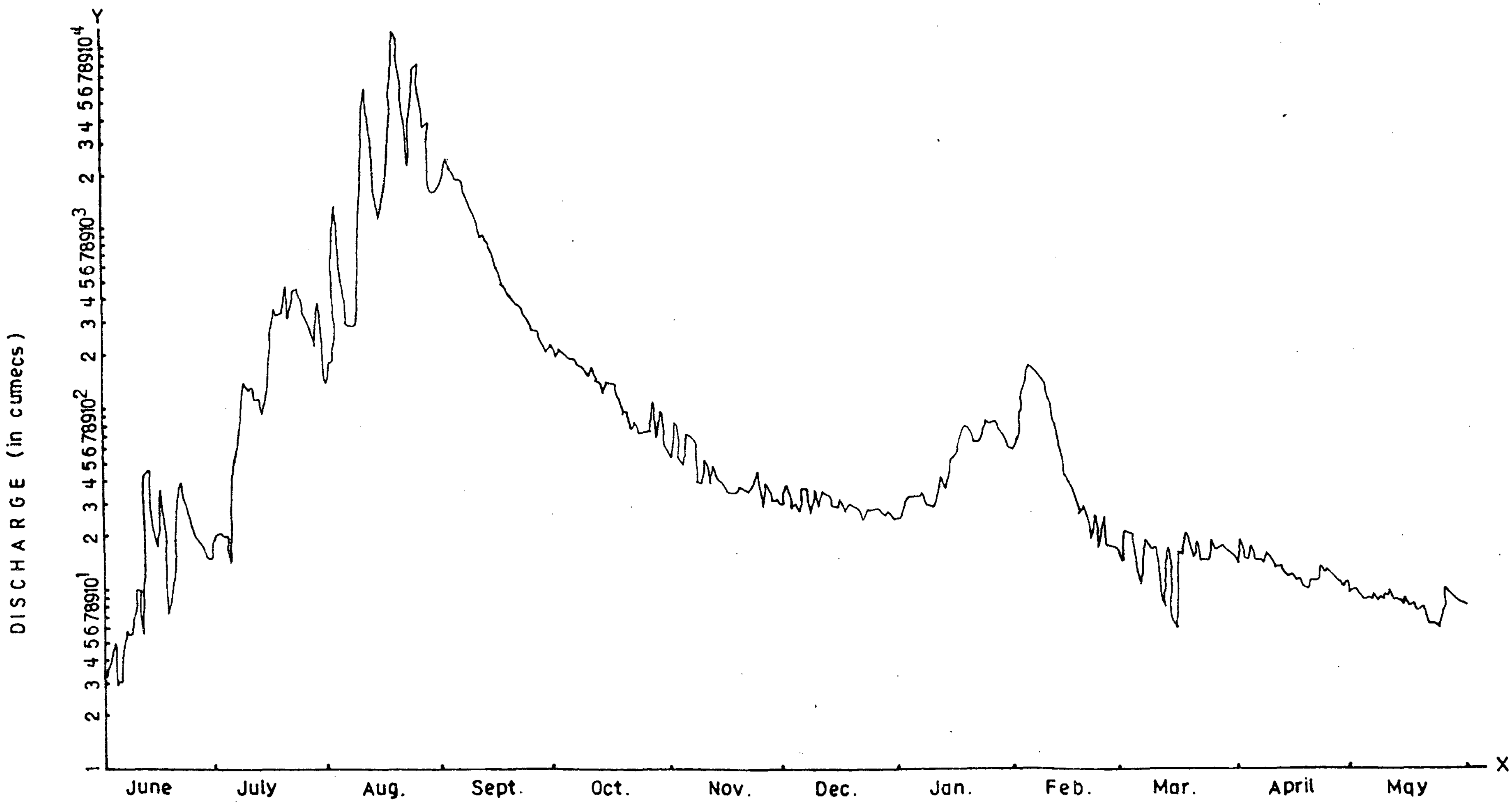


fig.4·6

4.6 DAILY VARIATION IN THE DISCHARGE:

The annual hydrographs (Fig.4.5 & 4.6) for Jamtara and Barmanghat have been plotted to analyse the daily variations in the discharge of the river. For this, discharge data for 1984-85 water year, has been used. Both stations show rythmic pattern of discharge fluctuations during the whole year. Daily variations in the discharge are more prominent during the monsoon season. In the non-monsoon season, variations are of low order in terms of discharge. The figures also show that different hydraulic patterns in the variations of discharge are observed at Jamtara and Barmanghat. For example, a prominent peak is observed at Jamtara on 18 October 1984, but Barmanghat shows gentle variation in the discharge. Again in the month of March prominent ridges and valleys are seen on the hydrograph at Barmanghat, but gentle pattern is seen at Jamtara. Moreover, in the month of April and May, Jamtara shows more fluctuations in the discharges than at Barmanghat. From the above observations, it can be concluded that the annual hydrograph reflects more intensive picture of the Narmada river regime at Jamtara and Barmanghat.

4.7 FLOOD HYDROGRAPH ANALYSIS:

Behaviour of variations in the hydrograph during a flood at Jamtara and Barmanghat can be clearly seen

FLOOD HYDROGRAPH OF RIVER NARMADA AT JAMTARA AND BARMANGHAT.

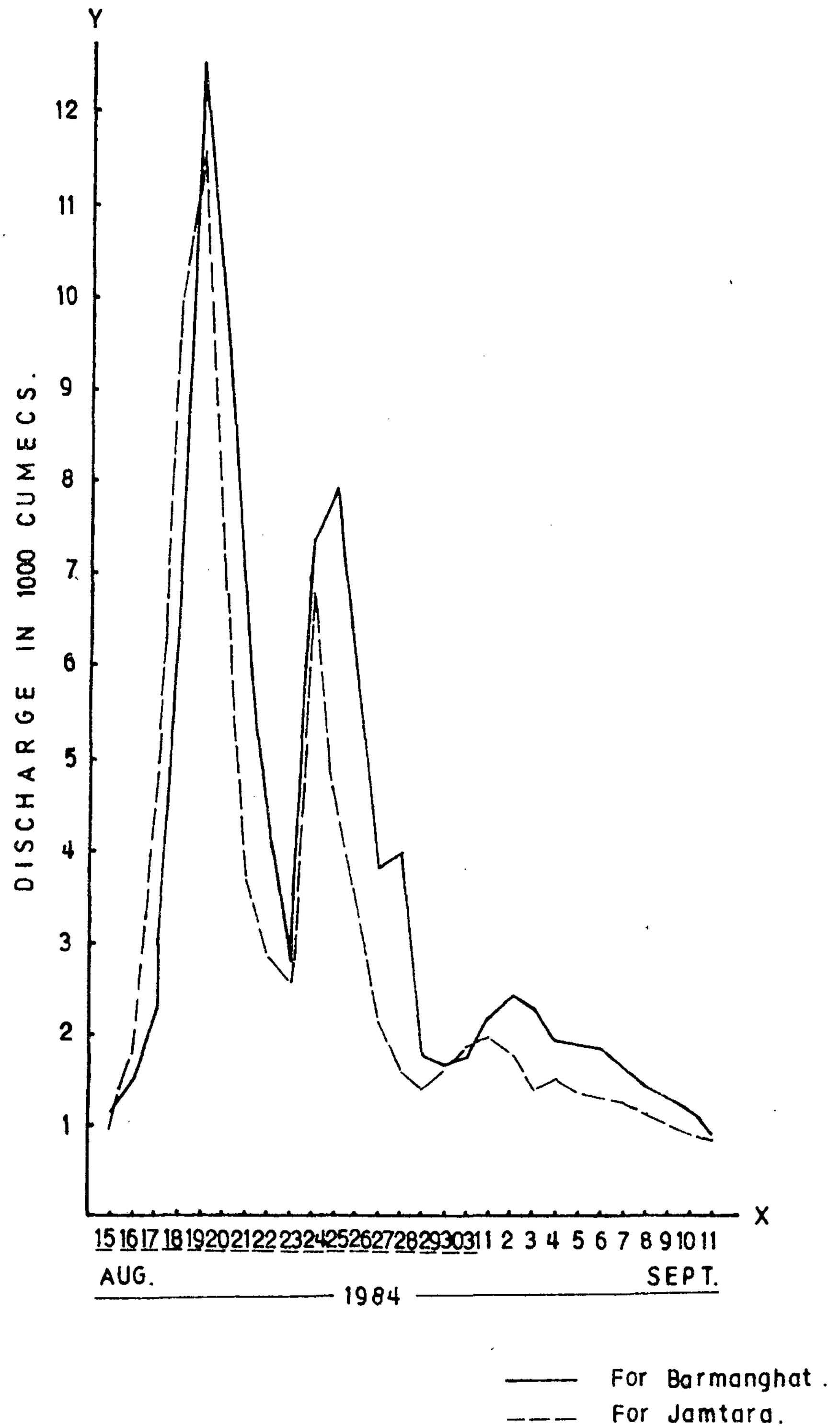


fig.4.7

from the Fig.4.7. During the storm/flood on 15 August 1984 heavy precipitation added to the waterflow in the Narmada river at Jamtara. The daily discharge on 17 August 1984 was about 4566.3 m^3s^{-1} but increased to 9924.4 m^3s^{-1} on 18 August, and reached to its peak on 19 August, with 11526.6 m^3s^{-1} of discharge per day, then it started receding back to the normal till 23 August. Again concentration started, and another succeeding peak was registered of 6820 m^3s^{-1} on 24 August. After this peak, the discharge of the river went back to the normal as before the increase, caused by precipitation.

The same hydraulic pattern and variations in the flood were recorded at Barmanghat, with peak of high discharges, first was of 12483.8 m^3s^{-1} on 19 August and second on 25 August with discharge of 7880. m^3s^{-1}. The variations in peak discharges at Jamtara and Barmanghat may be associated with increase in discharge and velocity downstream in the Narmada river. Furthermore hydrograph shows two ridges and two troughs both at Jamtara and Barmanghat. The rise and fall of hydrograph is comparatively steeper at Barmanghat than on Jamtara, because of downstream movement of flood wave its intensity and duration increases due to increase in the input from tributaries and the main river.

4.8 ANALYSIS ON FLOOD DISCHARGE:

Before starting flood discharge analysis, some idea about its nature of occurrence in the Narmada basin has been given below. The floods in this river are an annual feature and are normally caused by the movement of depression originating in the Bay of Bengal and moving westward across the central parts of the country giving rainfall in the basin. Heavy rainfall in the basin also results due to active monsoon conditions. The upper catchment receives heavy rainfall under the influence of Bay depressions, when they are over Orissa and adjoining eastern M.P. region. In most cases, the Bay depressions which follow westerly track near Narmada basin causes heavy rainfall over the basin.

While there have been many floods which affected the catchment, the flood of August 1973, have probably been the worst in living memory, as far as the catchment upto Barmanghat is concerned. Severe floods have also occurred in the past, in 1925, 1926, 1961 and 1965, affecting an area about 600 miles and 40 miles approximately. The floods of 1926 affected many areas in Mandla, Jabalpur and Narsingpur districts. The losses during the two historical floods of 1970 and 1973 were of the order of 55 mm. to 60 mm. out of total storm rainfall 225 to 240 mm. Since these were very heavy storms resulting in highest recorded floods.

In the upper reach of Narmada in 1982, Mandla town was flooded. During the present century floods occurred in 1923, 1926, 1961, 1968, 1970 and 1973. The 1926 flood affected numerous villages in Mandla, Jabalpur and Narsingpur. There have been severe storms in the basin, which has affected the catchment, such as (1) the storm of August 1973 for the period 28th to 30th August 1973, which has mainly affected the catchment upto Punasa (N.S.P.) in Khandwa district, during the first three days; (2) The storm of July 1944, for the period 12th to 10th July 1944, which has affected most of the central

Table 4.6: Floods in Upper Narmada Basin

	Site	Date of Occurrence	River/ Tributary
1.	Manot	4-8 Aug. 1978	Narmada
		8-10 Aug. 1979	"
		2-3 Aug. 1980	"
2.	Jamtara	28-30 Aug. 1973	"
		10-12 Aug. 1975	"
		5-9 Aug. 1977	"
		25-27 Aug. 1977	"
		8-12 Aug. 1979	"
3.	Mohegaon	4-8 Aug. 1978	Burnher
		16-18 Aug. 1978	"
4.	Hridynagar	4-7 Aug. 1978	Banjar
		16-17 Aug. 1978	"
		15-17 Aug. 1980	"
5.	Belkheri	4-6 Aug. 1978	Sher
		15-17 Aug. 1978	"
		3-5 Aug. 1979	"

Source: Narmada Sagar Project, Dist. Khandwa, Estimate of Design Floods, vol.II, Part II, Annexure, Aug. 1983.

portion of the catchment and at the same time having significant overall performance in the catchment; (3) The storm of September, 1970 for the period 2nd to 6th September 1970, which has also affected the whole catchment; (4) The storm of 8-10 September 1961 is probably the worst as regards its flood potential in the Tawa catchment. However, the storm of 18-20 August 1974, was also significant.

The east to west movement of storm parallel to the river basin in the direction of flow gives hydrologically an ideal situation for synchronisation of floods from upper to lower catchments. However, no single storm in actual practice has sustained intensity throughout its course to produce rainfall throughout this long and narrow catchment with maximum efficiency.

Flood is often considered as complex hydrogeomorphic phenomena of the river basin. It is usually climatically controlled event of geomorphic significance, but it can also be associated with Hydraulic structures, such as Dams, or reservoirs burst and landslides in the context of river basin. The occurrence of flood is studied as a problem of probability, its knowledge is useful in variety of economic and engineering reasons. The present portion of the chapter deals with the probability of flood discharge and its reccurrence intervals for the river Narmada, which has its bearing on the river behaviour.

Several computational methods are used for flood frequency analysis. The Gumbel method has been used here, as it is simplest and practically applicable. In this method, all annual peak discharges are taken into consideration and ordering is done according to its magnitude over a number of years for a particular gauging and discharge site. For this purpose, discharge data at Barmanghat with respect to the annual peak for the period 1972-84 has been tabulated in the Table 4.7.

Table 4.7: Flood frequency analysis for Upper Catchment of Narmada at Barmanghat

Year	Flow (in cumecs)	Rank (m)	Recurrence interval $\frac{(n+1)}{m}$
1972	16193.50	4	3.5
1973	20658.00	1	14
1974	17288.20	3	4.66
1975	15847.80	5	2.8
1976	3074.30	12	1.16
1977	18455.20	2	7.00
1978	4905.00	11	1.27
1979	8158.10	9	1.55
1980	12375.00	7	2.00
1981	2904.00	13	1.07
1982	5625.20	10	1.4
1983	11475.00	8	1.75
1984	12483.80	6	2.33

As mentioned earlier in the present chapter that the peak annual discharges for most of the years occur in August i.e. in the middle of the monsoon season, but there are some exceptions also, for example, in the year 1981 and 1983, the Narmada river recorded the peak discharge during July (2904 m^3s^{-1}) and 11475 m^3s^{-1} in September respectively.

In the 13 years of annual peak discharge, two highest peak discharges have occurred in the years 1973, 20658 m^3s^{-1} and 17288.20 m^3s^{-1} in 1974. In this data, also, maximum number of flood peaks, 11 have occurred in the months of August, whereas July and September have one occurrence each. The data in Table 4.7 has been used for the flood frequency analysis. This involves the magnitude of discharge, since very high discharge occurs rarely (great magnitude correlates with low frequency) while low flows are common (small magnitude correlates with high frequency). Therefore, Gumbel distribution is used to study flood extremes. For the analysis, the peak discharge data is ranked and after ranking the data are kept in a descending order and the recurrence interval has been calculated by the following formula:

$$R_i = \frac{n+1}{m}$$

FLOOD-FREQUENCY CURVE OF THE NARMADA RIVER, BARMANGHAT

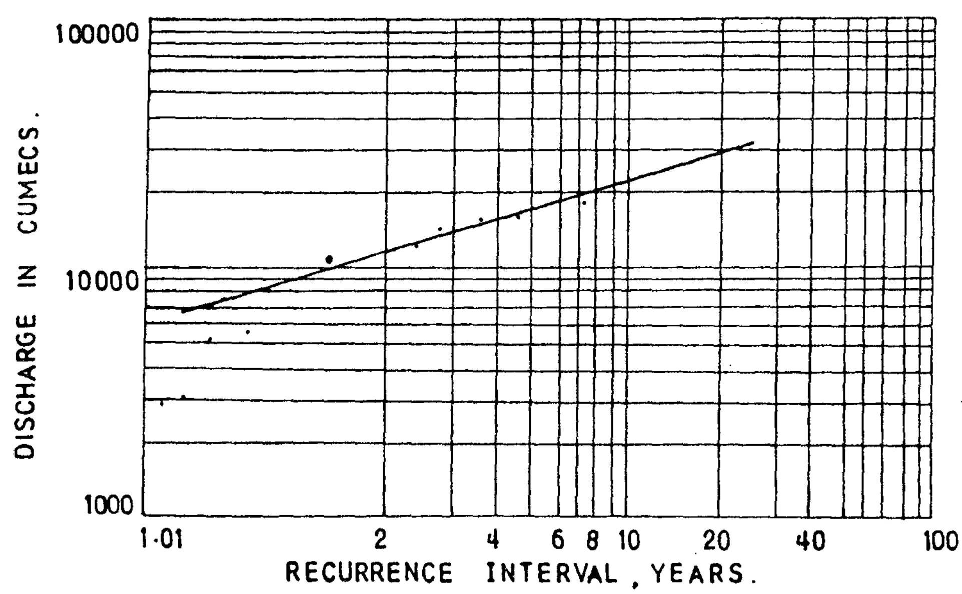


fig. 4·8

where m = ranking order of the data.

n = total number of years.

and R_i = recurrence interval.

The recurrence interval for the ranked data has been plotted against the peak discharge on a Gumbel logrithmic graph (Fig.4.8). The analysis shows that recurrences interval values for the ranked data plotted on a probability paper give rise to a straight line indicating a normal distribution for the data itself. This is an essential condition for the magnitude frequency analysis of discharge here also.

Most of the geomorphologists[1] agreed that a discharge corresponding to 1.5 years recurrence interval can be considered as a bankfull discharge with "zero damage stage" and any discharge above this recurrence interval can be taken as a flood discharge. Accordingly in Fig.4.6 the zero damage stage is marked against 8158 m^3s^{-1}. On examining this figure with respect to this index, it can be seen that in large number of years namely, 1972, 1977, 1980, 1983 and 1984, the peak discharge remains above bankfull discharge to be known as flood discharge, creating floods in the area downstream of Barmanghat probably. But it has to be mentioned that on all sites, Manot, Jamtara and Barmanghat, the river Narmada flows

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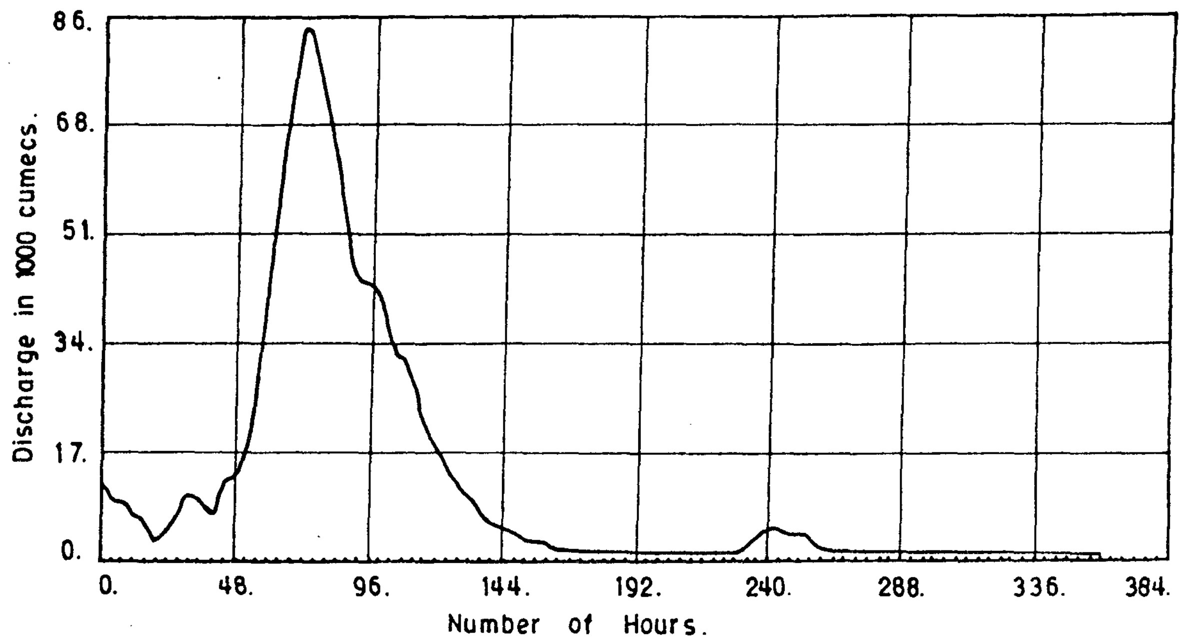
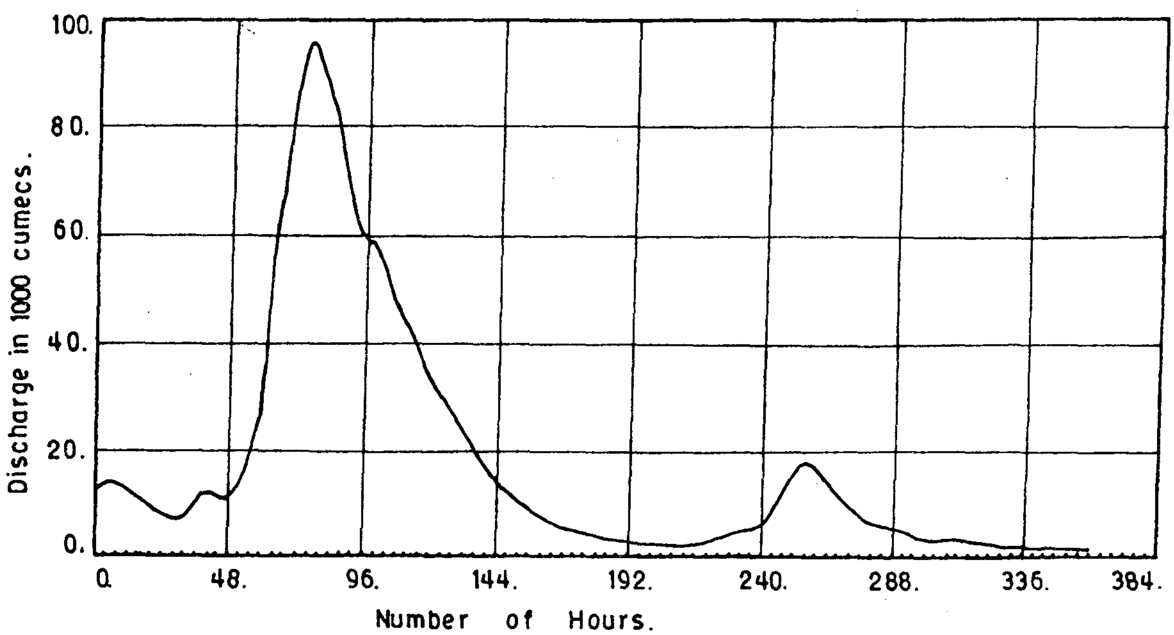
1. Morisowa, M. (1985), Rivers: Forms and Process, Longman, London, p.78.

KINEMATIC WAVE ROUTING OF NARMADA RIVER

JAMTARA



BARMANGHAT



Source CWC, N. Delhi

fig.4·9

in well defined steep banks.

4.9 FLOOD ROUTING:

Routing is generally carried out to determine the length of spill-way required, maximum level to which the water level will rise in the reservoir or in the channel between two reaches. For this, information collected from Central Water Commission has been reproduced. In other words, flood routing is used to stimulate flood wave movement through river reaches and reservoir without causing overbank flows. The Fig.4.9 shows the nature of flow during high discharges in the channel. It is also computed to know the actual channel capacity to carry flood water within the limitation of banks. With the help of figures, changes in the flood wave can be analysed for Jamtara and Barmanghat. By this, relationship between the flow and storage characteristics of a routing reach or reservoir can be identified. The figure shows kinematic routing in which kinematic wave procedure is used for routing the flows in the main stem. Overbank spills wherever they can occur along the main stem of river are also considered. It is based on the assumption that a flood wave moving down a river (is a kinematic wave) travels downstream faster than the water particles themselves.

II. SEDIMENT LOAD ANALYSIS:

Sediments move in stream water by turbulent suspension, by saltation, and by rolling and sliding along the bed. The sediments flow in the river depends upon set of factors viz. topography, lithology, landuse, soil texture, exposed surface and intensity of rain in the catchment. These factors has a particular reference to the quantity of discharge and velocity of current, size of material along with local proturbances such as eddies and other physical obstacles in and along the channel etc.

Here in upper Narmada catchment, the variations in sediment load of the river have been dealt in spatial and temporal context. In this section, an attempt has been made to study interrelationships between the discharge and sediment load, which are intricatingly related in a number of ways. To study the river sedimentation for Narmada river, the sediment data from Jamtara, Barmanghat gauging and discharge sites have been used for the years 1972-77, for monsoon season only, as regular observation throughout the year at these stations regarding sediment flow has started in the beginning of 1980s. To study annual and seasonal variations in the sediment régime, data for the years 1985-86 and 1986-87 for Jamtara site have been used. The discharge sediment relationship has also been established for Jamtara and Barmanghat. Another site Manot because of non-availability of sediment data, does not picture in the analysis.

The sediment analysis is done by gravi-metric method, in which weight and size of grains is taken into account. The grains are categorised on the basis of their diameter, such as coarse (above 0.2 mm. of diameter), Medium (0.2-0.075 mm.) and Fine (below 0.075 mm.).

4.10 ANNUAL VARIATION IN SEDIMENT AND DISCHARGE (1972 JUNE - SEPT. 1977):

During the six years for monsoon season, the mean monsoon annual discharge was 24553.88 m^3s^{-1} and 35121.28 m^3s^{-1}, corresponding to the average sediment load 3115927.3 metric tonnes and 5769779.7 metric tonnes for Jamtara and Barmanghat respectively. The figures for Barmanghat are almost double the sediment load of Jamtara, whereas catchment area of Jamtara is 16576 sq. kms. and 26453 sq. kms. is of Barmanghat. The suspended load was maximum in 1975 and the minimum in 1976, which was 5786217 metric tonnes and 867333.5 metric tonnes, corresponding to the discharge of 33905.60 m^3s^{-1} and 13791.66 m^3s^{-1} at Jamtara. But the same relationship is not evident at Barmanghat, where the high sediment load does not correspond to the discharge. At Barmanghat, minimum and maximum discharges were recorded in the years 1976 and 1977, the minimum

Table 4.8: Mean Monsoon annual Discharge and Suspended Sediment load

Year	JAMTARA Discharge (in $m^3 s^{-1}$)	Suspended Sediment Load (in metric tonnes) Coarse	Medium	Fine	Total Sediment load
1972	19643.80	37944	418160.5	1214170.3	1670274.8
1973	32625.11	96994.5	150442	3065985.3	3313421.8
1974	15998.27	78682.75	243057	4055211.5	4376951.3
1975	33905.60	86151.5	711589.75	4988475.8	5786217
1976	13791.66	18821	53927	794585.5	867333.5
1977	31358.87	69325.25	328701.5	2283338.8	2681365.5
	BARMANGHAT				
1972	28626.72	89957	564510.75	1992325	2646792.8
1973	45991.5	403220	1196397.8	5528753.8	7128371.5
1974	25416.45	44776.5	3038141.8	6793461.8	9876380
1975	43614.51	87654.25	629285	5188411.8	5905351
1976	19614.51	67537.5	182862	2137500.5	2387900
1977	47464.02	72050.5	477856.75	6123975.8	6673883

discharge of 1976 corresponding to the sediment load. But the maximum discharge does not show high concentration of sediment load, whereas highest sediment load was recorded in the year 1974, 9876380 metric tonnes with 25416.45 m^3s^{-1} of discharge.

On the other hand, the high concentration of coarse sediment in the suspended load in the year 1975 does not correspond to the high discharge (Table 4.8). Its concentration was highest in the year 1973, 96994.5 metric tonnes with 32625.11 m^3s^{-1} of total discharge at Jamtara. The rest of the years show positive relationship with discharge and grain size concentration in the suspended load. But in the case of Barmanghat, the relationship of grain sizes in suspended load does not correspond to the high and low discharges of the years.

The coefficient of variation is 52.56% and 45.15% for Jamtara and Barmanghat respectively, which shows more variation is observed at Jamtara than on Barmanghat. It can be related to the intensity of rain, velocity of current in the upstream of Jamtara.

The above normal year (i.e. from Mean monsoon annual sediment load) in terms of suspended sediment load is not always followed by below normal year in terms of sediment flow; i.e. load (Table 4.9). The relationship between

Table 4.9: Annual Variation in Mean Monsoon Suspended Sediment Load (in metric tonnes)

	JAMTARA		BARMANGHAT	
Year	Mean Monsoon Annual Sediment Load	Deviation from Mean in %	Mean Monsoon Annual Sediment Load	Deviation from Mean in %
1972	1670274.8	-46.39	2646792.8	-54.12
1973	3313421.8	6.93	7128371.5	23.54
1974	4376951.3	40.47	9876380	71.17
1975	5786217	85.69	5905351	2.34
1976	867333.5	-72.16	2387900	-58.61
1977	2681365.5	-13.94	6673883	15.66

	JAMTARA	BARMANGHAT
	Mean=3115927.3	Mean=5769779.7
	Standard deviation= 1637811.6	Standard deviation= 2605631
	Coefficient of variation=52.56%	Coefficient of variation=45.15%

Jamtara and Barmanghat from 1972-76 shows the same pattern of above and below normal years of sediment load. But this relationship is not found in the year of 1977, in which below normal sediment load from mean monsoon annual was registered at Jamtara while it was above normal for Barmanghat. The maximum positive deviation in the sediment load was recorded in 1975 (85.69%) at Jamtara and in 1974 (71.17%) at Barmanghat, and maximum negative deviation in suspended load were registered in 1976, 72.16% and 58.61% both at Jamtara and Barmanghat respectively.

DISCHARGE-SUSPENDED SEDIMENT LOAD DURING MONSOON SEASON - 1972-77

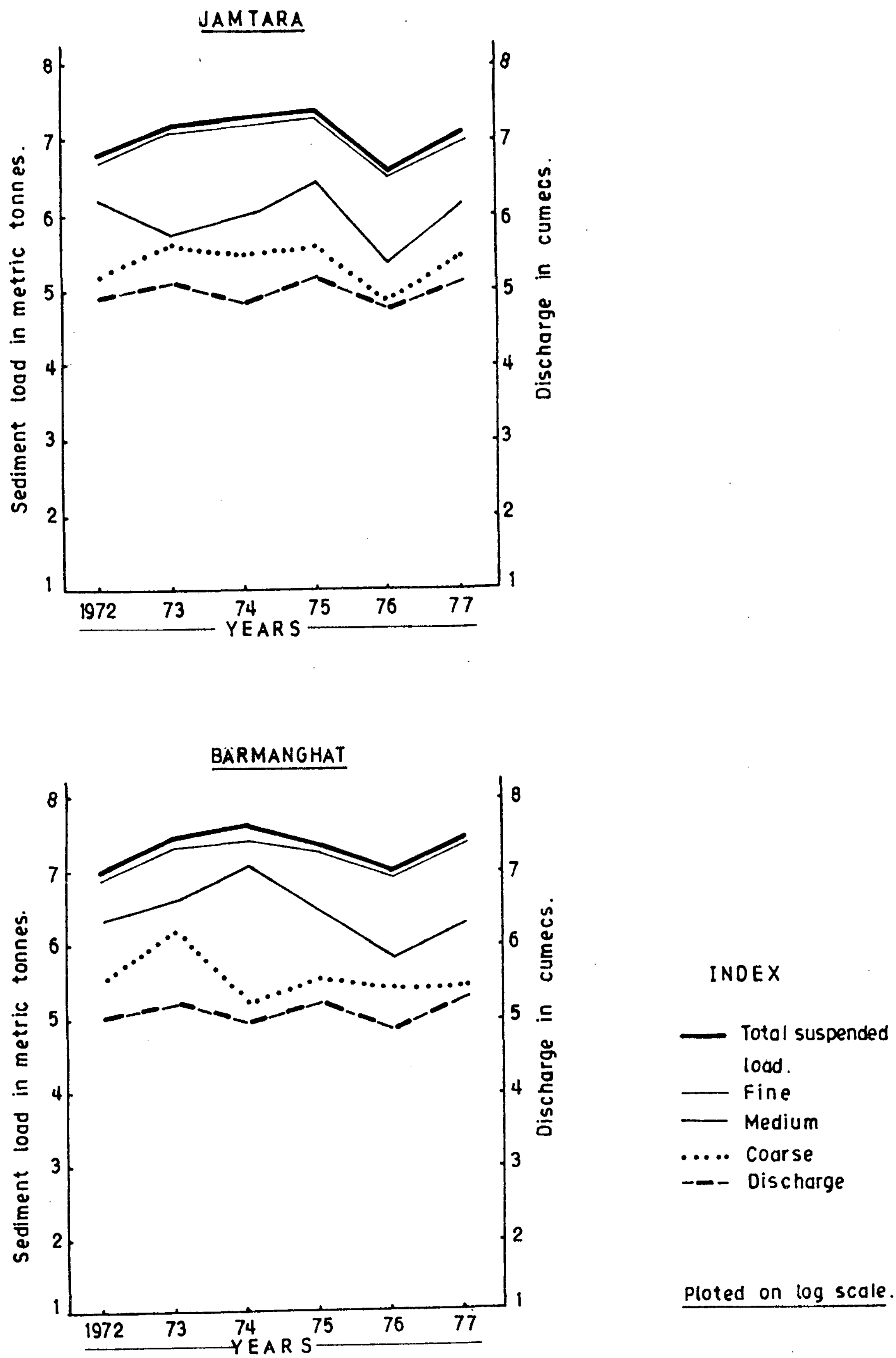


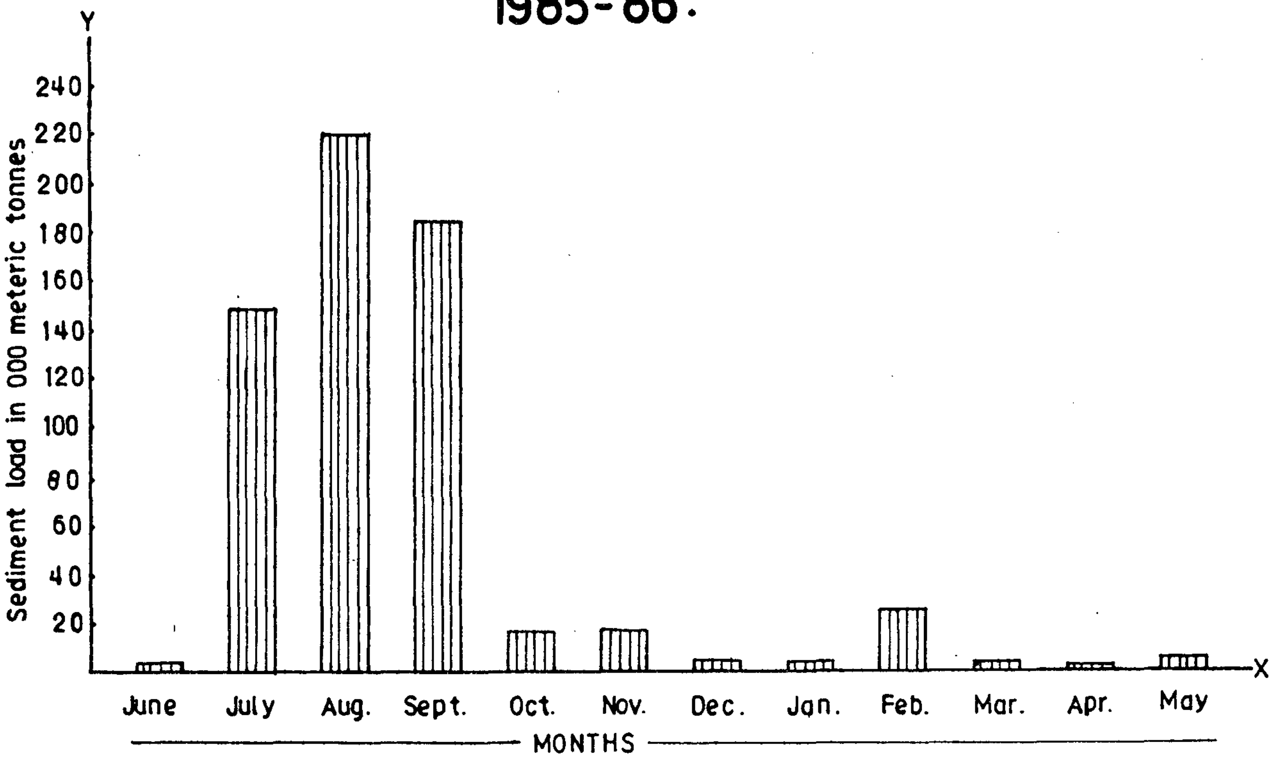
fig.4.10

The downstream variations in suspended sediment load concentration with almost same discharge 19643.80 m^3s^{-1} and 19614.51 m^3s^{-1}, which is slightly less from Jamtara shows considerable variation in the concentration of suspended sediment load, 1670274.8 metric tonnes and 2387900 metric tonnes at Jamtara and Barmanghat respectively.

The relationship between the discharge and sediment with coarse, medium and fine grain sizes. (Fig.4.10) It is apparent from the graph that the curves for the total and fine sediment corresponds to that of the discharge, with only exception being in the year 1974, both at Jamtara and Barmanghat. But in the case of coarse and medium sediment, some years such as 1972, 1976 and 1977 shows similar pattern in rise and fall in sediment concentration. Instead of this, the reverse pattern is identified in 1974, and 1975 at Jamtara and Barmanghat. The coarse sediment shows positive relationship with discharge in all years at Jamtara and Barmanghat, but medium sediment does not show positive relationship in the year 1974, and 1975 for Barmanghat and in 1973 at Jamtara. Generally coarse sediment concentration in the channel depending upon high velocities during monsoon season, are found near the bed of the channel and due to local effects such as eddies

MONTHLY SUSPENDED SEDIMENT LOAD AT JAMTARA

1985-86.



1986-87.

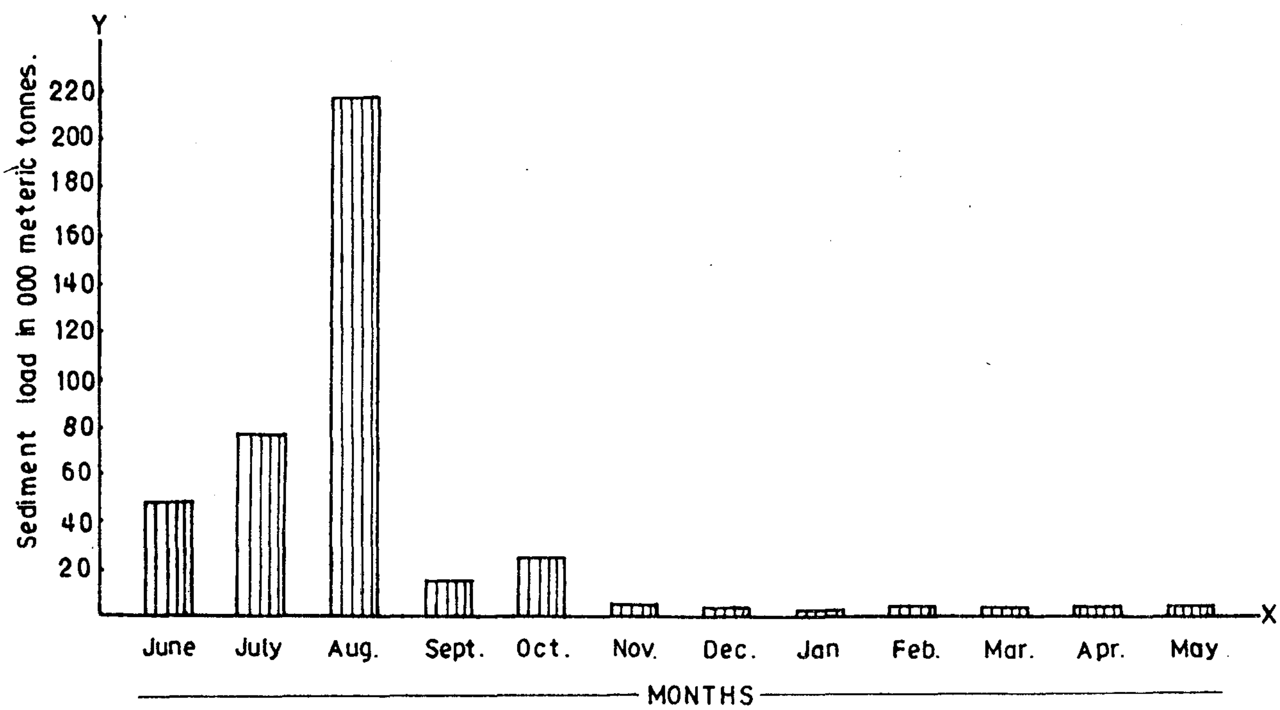


fig.4.11

also occur during high water stages and floods. The velocity plays a significant role in the settling of coarse, medium sediment only. But fine sediments are found to be uniformly distributed in the channel even in low discharges.

4.11 MONTHLY VARIATIONS IN SEDIMENT AND DISCHARGE (1972-77):

During the six years June 1972 to September 1977, the mean monsoon monthly flow varied between 13791.66 m^3s^{-1} to 33905.60, corresponding to 867333.5 metric tonnes and 5786217 metric tonnes for Jamtara. At Barmanghat, this value ranged between 19614.51 m^3s^{-1} to 47464.02 m^3s^{-1} and sediment load varied between 2387900 metric tonnes to 6673883 metric tonnes. Generally, high sediment load takes place both at Jamtara and Barmanghat during the months of high discharges. Only in 1975 at Jamtara during the month of July, highest suspended sediment load was registered, which was 2761624.3 metric tonnes.

The Bargraph at Jamtara for the water year 1985-86 and 1986-87 (Fig.4.1), gives some idea about monthly variations during the years. The figure shows that the sediment load distribution in the channel is high during the peak of monsoon season in the months of August. Its monthly variations depend upon the onset of the monsoon in the Narmada basin. It is also evident from two graphs,

SEDIMENT DISCHARGE RELATIONSHIP AT JAMTARA

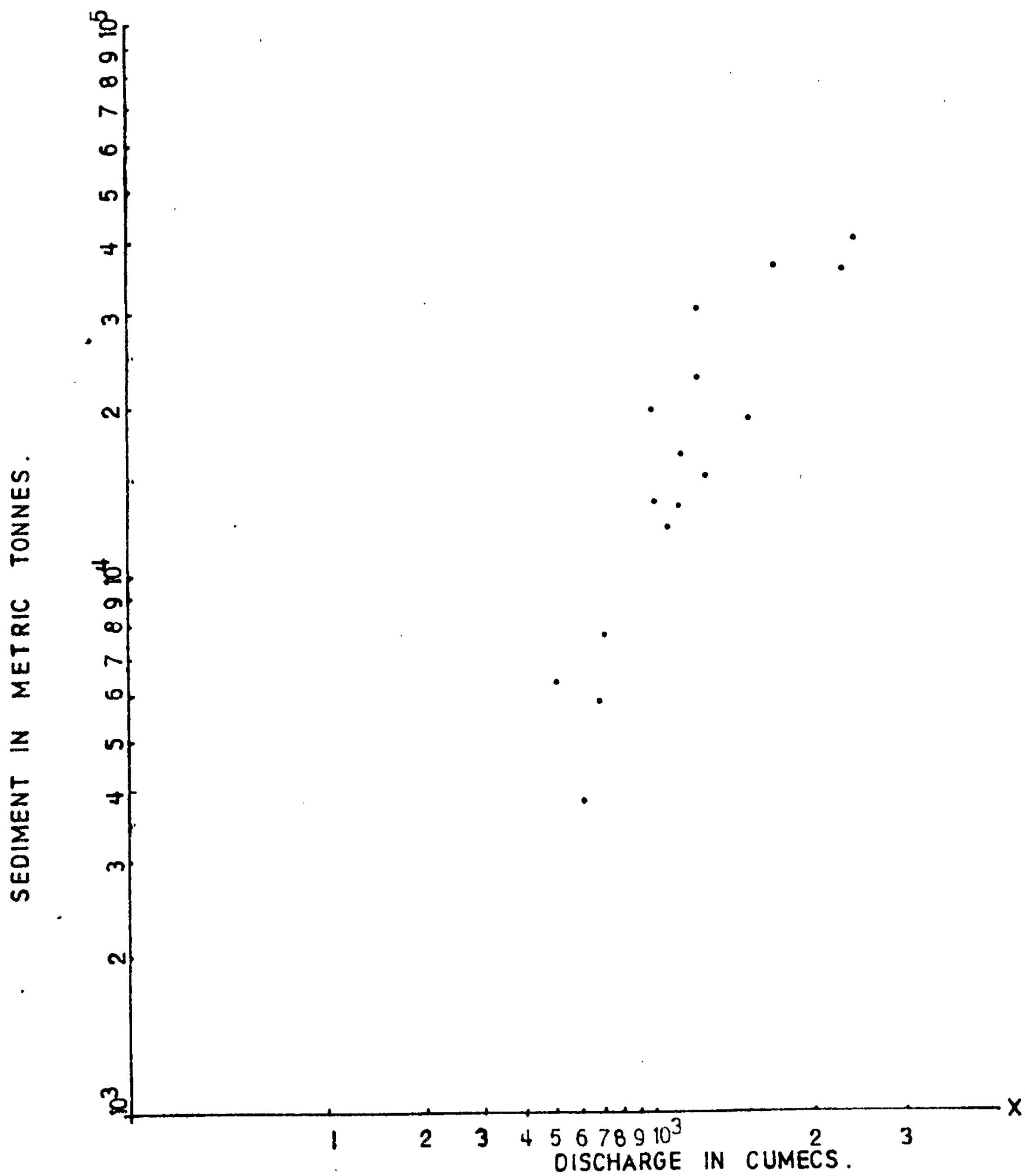


fig.4.12

SEDIMENT DISCHARGE RELATIONSHIP AT BARMANGHAT

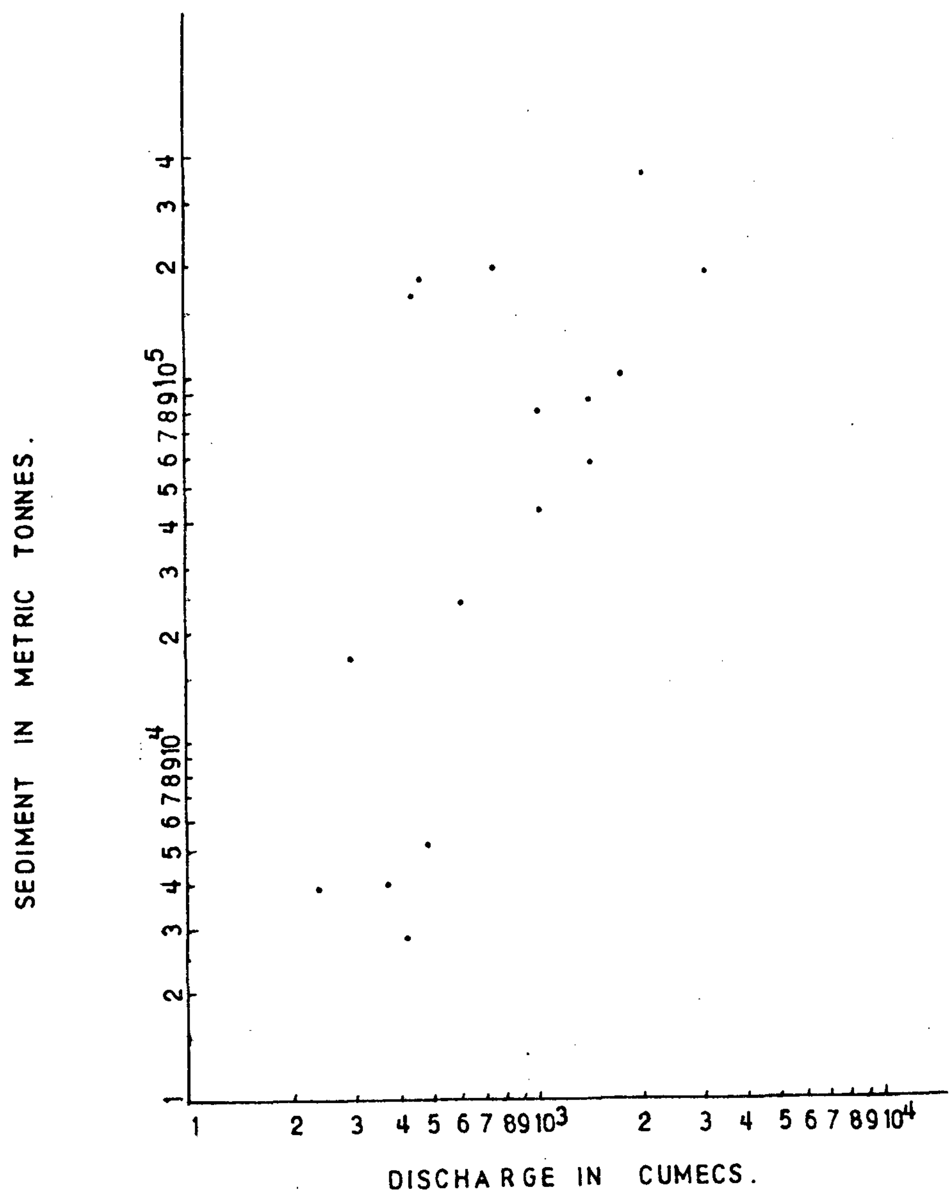


fig.4.13

PROPORTION OF SEDIMENT BY CATEGORIES DURING MONSOON (1972-77)

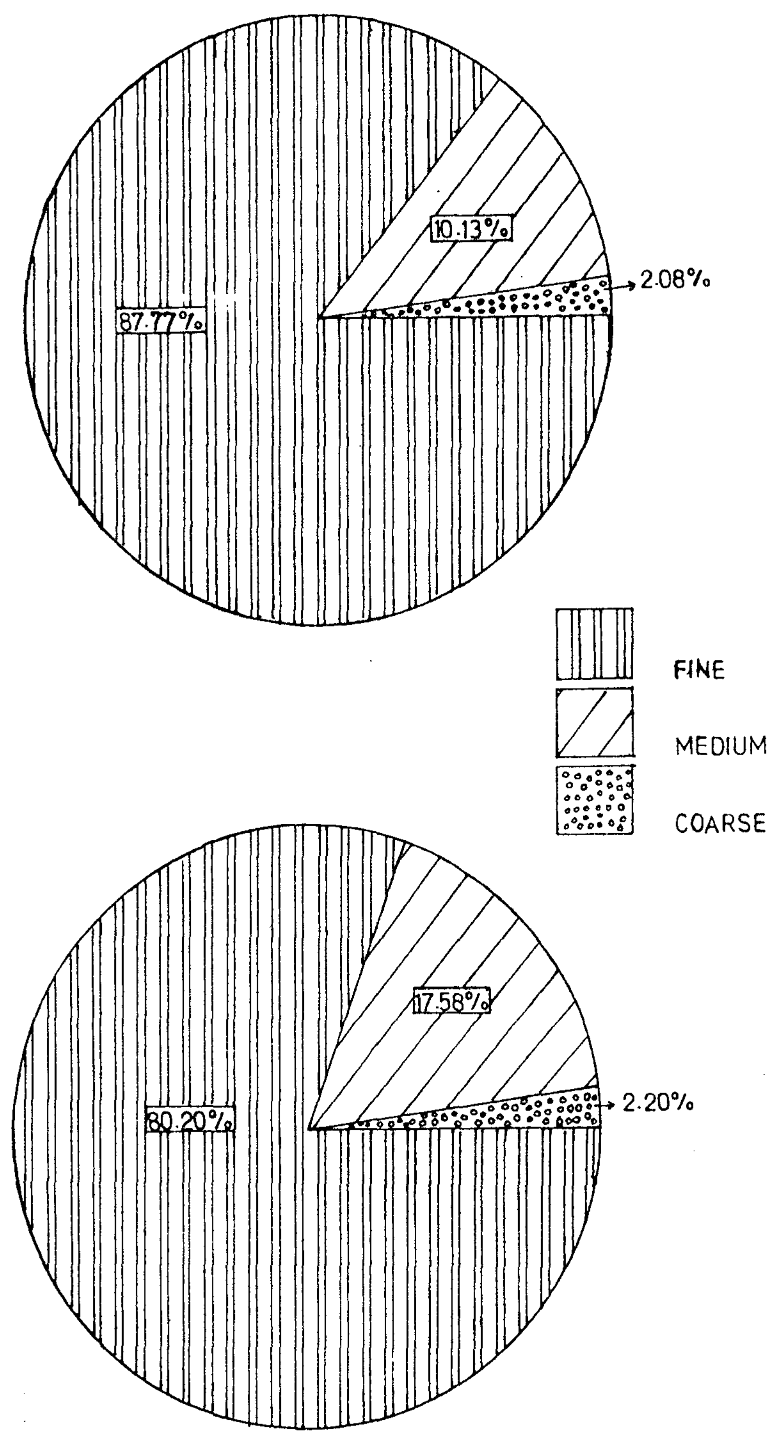


fig. 4.14

that irregular distribution of rainfall apart from monsoon season increases the sediment influx in other non-monsoon months. Such as evident from the February of 1985-86. The sediment load significantly varies in the month of June, July, September and October, but August shows some consistency in the sediment load during the water years 1985-86 and 1986-87 respectively. The lowest sediment load was recorded in the month of April in 1985-86 and in the January of 1986-87 at Jamtara.

The discharge and sediment relationships have also been established, considering daily sediment data for the first fortnight of August 1986 at Jamtara and Barmanghat. (Fig.4.12 and 4.13) The scatter between two variables tentatively shows significant positive correlation on both sites.

The pie-diagram of coarse, medium and fine sediments as a percentage to the total sediments for six monsoon years from June 1972 to September 1977. (Fig.4.14) The contribution of coarse, medium and fine sediments to the total was 2.07%, 10.19% and 87.73% for Jamtara, and 2.47%, 15.72% and 81.78% was for Barmanghat. It further shows that the contribution of fine sediment decreases down-stream from Jamtara to Barmanghat, as it shows 87.73% and 81.78% contribution to the total load. In all the years, the fine sediment, constitutes 68% to 70% of the total suspended sediment load, for Barmanghat and Jamtara respectively. Again the medium sediment is always higher than the coarse sediment at both the sites.

Considering the above sediment and discharge variations, the following conclusions can be drawn:

(1) Coarse sediment quantity always remains less than medium and fine, because of more weight of grain at both sites. The coarse particles contribute significantly during monsoon season only, but medium and fine material always contributes to the river load due to their light weight and can be easily transported by river to the longer distances.

(2) There are exceptions to the general rule at Jamtara and Barmanghat. The year 1974 shows 4376951.3 metric tonnes of sediment load with 15998.27 m^3s^{-1} and reverse conditions are shown by 1973, high discharge of 32625.11 m^3s^{-1} with considerably low load, which was 3313421.8 metric tonnes of sediment load. (Table 4.9) In case of Barmanghat too, during 1974, with 25416.45 m^3s^{-1} of discharge, the sediment load was recorded highest, 9876380 metric tonnes.

(3) There is a relationship between the discharge and the sediment load in terms of total as well as by size of the sediments with some exceptions. For example,

in case of Jamtara, high discharge values in 1975 also give rise to high sediment load by the total and their grain sizes, especially by the fine. But this relationship is not evident in the year 1973 and 1977 during low and high water discharges. In these years the discharges do not correspond to low and high discharges, but they show reverse relationship. In the year of low discharge as 1973 shows high concentration of total sediment load and high discharge year 1977, reflects low concentration of total sediment load in the river. The year 1976 shows low sediment load with low discharge at Jamtara. At Barmanghat, the year 1977 shows highest total discharge with low total sediment load, whereas in 1974 with low discharge, high sediment load was recorded.

Before 1980, sediment data was only available for monsoon season at Jamtara and Barmanghat. Therefore, a suitable percentage as derived from inflow study for Jamtara and Barmanghat sites have been adopted by Central Water Commission to work out inflows and sediment load for non-monsoon period. The percentage of non-monsoon inflow to the monsoon for different reaches is given below:

	Site	% of non-Monsoon to Monsoon flow
1.	Upto Bargi (Jamtara)	7.30%
2.	Bargi to Narmada Sagar Project near Punasa (Khandwa)	15.19%

Then 10% addition was made for the bed load and the total sediment load is worked out to calculate sediment rate per sq. mile of drainage area per year. It is 1.98 and 2.32 Acft/sq. mile/year for Jamtara and Barmanghat respectively. The additions for non-monsoon periods are made on the basis of percentage mentioned to arrive at the total annual inflow. The total sediment load is divided by total inflows to work out average sediment rate in Acft/MAF of inflow at following sites:

Sediment Rate in Acft/MAF of Flow[1]

	Site	Year of Observation	Sediment Rate Acft/ MAF of inflow/year
1.	Jamtara	1972-77	1696.00
2.	Barmanghat	1972-77	1920.0

Thus, sedimentation rate of 1.50 Acft/sq. mile/ year has been adopted for the upper catchment upto Barmanghat.

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1. "Design Flood and Sedimentation Study", Narmada Project, Govt. of M.P., C.E. Lower Narmada Projects, Narmada Valley, July 1985, M.P.

SUMMARY AND CONCLUSION

River basin studies dealing with one aspect or the other of channel morphology and hydrology are widespread. The present study is also aimed at such an analysis of the upper Narmada catchment. Narmada flows through a rift between the Vindhyas in the north and Satpura in the south and falls into the Arabian sea to the west. Its important tributaries are Burnher, Banjar, Gaur, Sher, Hiran and others. Upper Narmada catchment of Narmada river as delimited by Central Water Commission extends from $21^{\circ}20'$ to to $23^{\circ}45'$ north latitude and $79^{\circ}00'$ to $81^{\circ}45'$ east longitudes and covers an area of 26453 sq. kms. The study is based on discharge and sediment data at 3 gauging stations, namely Manot, Jamtara and Barmanghat.

Geology of the region dates from Archean to quaternary and stratigraphy of the region is composed of shale, limestone of Bhandar and Rewa group with unconformities. While Bijawars and Archean system is interspaced with unconformity mainly comprising of basic intrusions like phyllite quartzite, chert, breccia, schist, magnetite and granite gneiss.

Climate ranges between subhumid to semiarid in east and west respectively. Vegetation is of tropical dry deciduous type. Indiscriminate felling of trees in the past have caused much injury to the present natural habitat and environment of the region. About 35% of the area is under thick and dense forest, 60% is under agriculture and miscellaneous, and remaining 5% is under grassland and wastelands.

The analysis of the morphological and hydrological characteristics of the Narmada is based on certain variables, namely longitudinal profiles, channel configuration, and sinuosity. Being a structurally controlled river, flowing over areas of Basaltic nature and varying nature of riverine deposits, the longitudinal profile of the river has many irregularities. The main river profile shows three such points, but rest of the profiles is smooth. The tributaries of the river are much smoother than that of Narmada. This can be attributed to the fact that these tributaries flow through their own eroded valleys not through any rift valley, as it is found in the case of Narmada. The cross-section showing channel configuration is analysed to explain changes in the bank and bed conditions through the two processes of scouring and filling, varying from season to season. Figures for annual, seasonal and net changes show filling exceeds scouring indicating a gradual shrinking of the channel. The upstream site Manot has two distinct phenomena. Firstly, the gravel bed of river Narmada at

Manot, which does not allow much scouring of bed during any of the seasons. Secondly, a bend in the river channel at Manot causes scouring of the concave bank and simultaneously filling of the convex bank. These observations confer to the conceptual behaviour of a river in such conditions. Whereas at Barmanghat located downstream shows considerable amount of filling of the bed during monsoon, when the river experiences highest amount of discharge which otherwise would have caused good amount of scouring in normal conditions. This reversal of channel from normal conditions observed at Barmanghat can be attributed to the fact that sudden broadening of the channel causes a drop in its velocity as well as carrying capacity, which results into filling of the bed. While bank conditions do not change much. The filling of the bed at Barmanghat also makes the channel shallower. This is definitely supporting our earlier statement regarding gradual shrinkage of the channel, decreasing the waterholding capacity of the channel which may prove hazardous in near future by causing floods and reducing the longevity of reservoirs.

Sinuosity index of upper Narmada and its tributaries gives SSI (Standard Sinuosity Index) values between 1.05 to 1.5 indicating their Sinuous pattern. The only exception to this general trend is river Silgi which has SSI value of 1.56, making it a meandering river with the exception of Temur and Umar river, which has higher Topographic Sinuosity Index values. Rest of the rivers including Narmada has higher Hydraulic Sinuosity Index values showing the domination of hydrological control, while Temur and Umar are controlled by topographical factors.

An understanding of spatial and temporal variations of river discharge is important in channel behaviour study. The regime of the Narmada largely depends on monsoon rains for its flow. This is clear from the observation of last 10 years' data that 92-97% discharge is recorded during monsoon season and the rest of 3-8% is contributed through either groundwater runoff or occasional cyclonic rains. Variations are found during monsoon season as month of August represents the peak figures and in months before and after August shows lower amount of runoff. The months of June and July (i.e. beginning of monsoon) show less runoff because the groundwater deficit of the earlier seasons gets recharged through percolation, whereas in the month of August groundwater storage capacity is near saturation, thus, showing maximum runoff. It has been found by the analysis of Annual discharge that for the last decade (1972-82 water years) there exist a rythmic pattern of high and low discharge years from the mean annual successively. Only exception to this pattern is observed in years 1978-79, 1979-80 which shows discharge below normal from the mean annual for Manot and Jamtara. On the other hand, Barmanghat does not follow this pattern because in the year 1978-79 Jamtara was experiencing discharge below normal, the contribution of tributaries between Jamtara and Barmanghat, produced sufficient amount of discharge to change low discharge of Jamtara into above normal discharge, though of very minimal percentage. Another trend observed in annual runoff figures is that variability of annual runoff reduces upstream to downstream. One possible explanation is that in between two sites from up to downstream, there is a gradual increase in the catchment area leading to increase in runoff, thus a decrease in variability of runoff. Generally, it has been found that maximum daily flow occurs somewhere in the last week of August and minimum daily flow occurs in the last week of May or the first week of June. Minimum daily flows for Jamtara and Barmanghat occur in last week of May and first week of June respectively. Observations at Jamtara and Barmanghat confer that higher the discharge figure, lower is the duration of the time at the station.

The regime of Narmada generally shows two annual peaks of seasonal extremes, of high discharge one in monsoon and other is in February. In the last 13 years, maximum number of peaks occurred during the month of August. Many geomorphologists believe that discharge corresponding to 1.5 year recurrence interval can be considered as a bankfull discharge with zero-damage stage and any discharge above this recurrence interval can be taken as flood discharge. At least 5 years out of 13 years can be considered as flood discharge years and remaining years did not experience bank-full discharge.

Suspended sediment load generally increases with increase in discharge exception being coarser material at Jamtara. But the figures at Barmanghat does not conform this pattern. Higher suspended load with high discharge in upstream can be caused by higher surface runoff of fine soil grains because slopes are more rugged, thus even small amount of rainfall causes more erosion. The downstream having gentler slope does not contribute much in the form of suspended load, bringing down the load figures, even though discharge may be high. The year 1974 at Barmanghat shows some extremely irregular conditions, when even with a low discharge figure, medium and fine sediment load is high can be attributed to certain local disturbances in or along the channel. These disturbances may be in any form viz. dumping of material into the channel or collapse of banks etc. Monthly variations of load at Jamtara shows highest figure for the month of August, when the site records maximum discharge, while the lowest load was recorded in the month of January and April for the years 1985-86 and 1986-87 respectively. The proportion of grain size in suspended load decreases from coarse, medium to fine. The coarse is seen only during monsoon. The medium and fine in the post monsoon season and fine during pre-monsoon.

As the sediment load was recorded for 1972-77 for the monsoon months only, and non-availability of data during non-monsoon period, behaviour of sediment in channel could not be analysed fully. Small sample size of sediment load which is only available for two stations Jamtara and Barmanghat and also the irregular nature of data over the years does not give us any conclusive facts which could help in determining its role in the study of channel behaviour.

On the whole, the above study brings into consideration the temporal and spatial variations of discharge and sediment characteristics and their impact on the channel behaviour in the study region.

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