GEOMORPHOLOGICAL, HYDROLOGICAL AND PEDOLOGICAL ASPECTS OF SANKH AND SOUTH KOEL RIVER BASIN FOR

WATERSHED MANAGEMENT

Dissertation submitted to the Jawaharlal Nehru University
in partial fulfilment of the requirements for
the award of the Degree of
MASTER OF PHILOSOPHY

SANTANU KUMAR PATNAIK

CENTRE FOR STUDY OF REGIONAL DEVELOPMENT
SCHOOL OF SOCIAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI—110067.

1988

जवाहरलाल नेहरु विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067

CERTIFICATE

Certified that the dissertation entitled "GEOMORPHOLOGICAL, HYDROLOGICAL AND PEDOLOGICAL ASPECTS OF SANKH AND SOUTH KOEL RIVER BASIN FOR WATERSHED MANAGEMENT" submitted by Santanu Kumar Patnaik for the degree of Master of Philosophy is a bonafide work to the best of our knowledge and may be placed before the examiners for their consideration.

Dr. S.K.Chandra
Supervisor

Prof.A.K.Mathur
Chairman

Gram : JAYENU Tel. : 667676, 667557 Telex : 031-4967 JNU IN

TO MY PARENTS

ACKNOWLEDGEMENTS

- With grateful thanks to Dr. S.K. Chandra, my supervisor for his continuous help and guidance.
- Director, Statistics, Central Water Commission, New Delhi for allowing me to use the Discharge and Sediment Load data.
- Director, All India Soils and Landuse Survey, New Delhi, for allowing me to consult Soil Survey Reports.
- Director, Geological Survey of India, New Delhi, for permitting me to consult the relevant materials.
- Deputy Director, Library, Central Water Commission for allowing me to use library facilities.
- Chinmay Nath for map reductions.
- My friends, Durgesh, Shujat, Archana, Meera for moral support.
- Archana Mathur for invaluable help.

Dated : 21.7.'88

S Patnaik

Santanu Kumar Patnaik

CONTENTS

LIST OF FIGURES

<u>LIST OF TABLES</u>

CHAPTER - 1

INTRODUCTION

Watershed management is a systematic approach to realise an equilibrium between elements of the natural ecosystem of vegetation, land and water on the one hand and man's activities in utilizing the elements in the other. Because , watersheds are natural hydrologic units, planning processes, in a developing agrarian country like India, where 47.36% of total working population are either cultivators or agricultural labourers,[1] should be undertaken with the river basin as a planning unit.

Watershed with its intrinsic control on i) runoff volume , ii) water yield and iii) rate of sediment load, has a dominant role in directly regulating floods, soil moisture condition, critical areas of erosion hazard and indirectly in irrigation pattern, cropping system, industrial and infrastructural set-ups and overall economic progress of the region. The basic cause of watershed problems of land misuse especially , at head water valleys are pressure of population, sometimes surpassing 'carrying capacity'. Watershed degradation on a massive scale at the upper catchment by inappropriate resource exploitation especially deforestation and faulty landuse not only

---

1. Research and Information Division, Ministry of Information and Broadcasting, (1987): India 1986. p.529.

threatens the very existence of its natives rather seriously but injures activities and life of the larger downstream communities too. The other malignant group that accelerates the watershed degradation is the accompanying livestocks. India, which is rich in livestock population , has a total of 31 crores heads of cattle, buffalo and sheeps on a reporting geographical area of 305 million hectares. This high livestock population cause irrepairable damage in watersheds through overgrazing and damaging soils on slopes. All these combinedly make the downstream area susceptible to recurrence of floods , siltation of reservoir and large scale soil erosion in most of humid-tropical watersheds.

Roots and Evolution of Watershed Management

From the very inception of irrigation system in agricultural practices, man realisedthe importance and scarcity of water resources available for various purposes including cultivation. Secondly , realization of the consequences of misuse of head water catchment which resulted in siltation of arable land on flood plains coupled with frequent floods and land degradation. These appear to have given shape to land and water development. The restoration of Alps which started in the last quarter of the nineteenth century and the conservation movement in the USA with the establishment of Soil Erosion Service in 1935(later Soil Conservation Service), are two parallel and independent historic processes that have paternity rights to the birth of watershed management.

Food and Agricultural Organisation (U.N.) even though came into existence in 1945, acting as a catalyst in universalizing the two approaches , i) blending the land restoration, and ii) torrent control techniques developed in Europe with the vegetation manipulation and soil and water conservation techniques developed in USA respectively, together with the conceptual and technical approaches from other sources as well.[2]

SANKH AND SOUTH KOEL RIVER BASIN LOCATION:

Location:

The Sankh and S.Koel river basin which covers nearly 19345 km^2 lies in the western part of the Ranchi Plateau and extends from 21° 50' N' latitude to 23° 37' N latitude and from 83° 52' E longitude to 85° 45' E longitude. The areal extension of the basin covers six districts; Ranchi and Singhbhum of Bihar

2. Botero, L.S.(1986): F.A.O.'s Role in Fostering Watershed Management; Introductory Statement. In Strtegies Approaches and Systems in Integrated Watershed Management. Conservation Guide No.14, pp. 4...

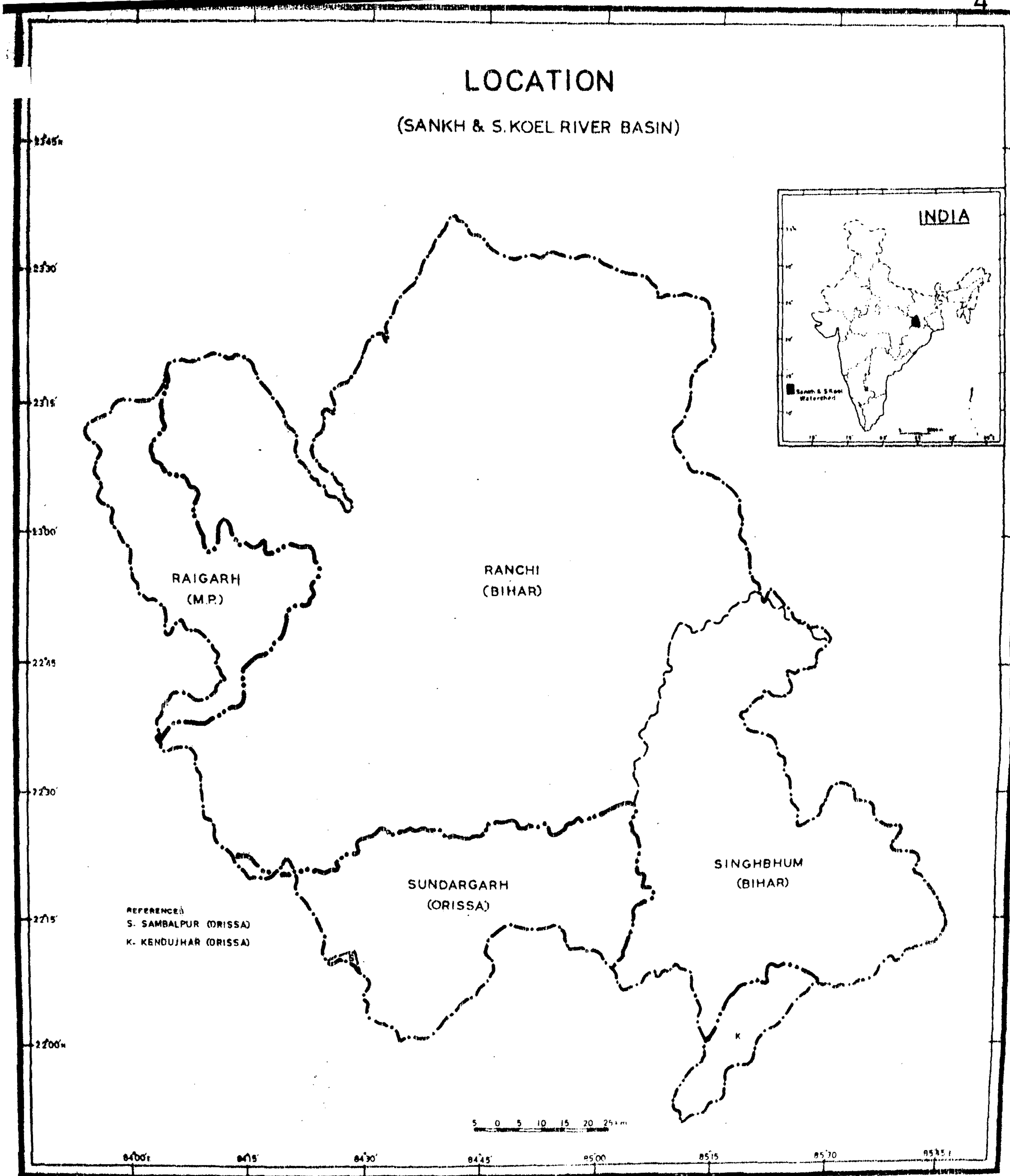
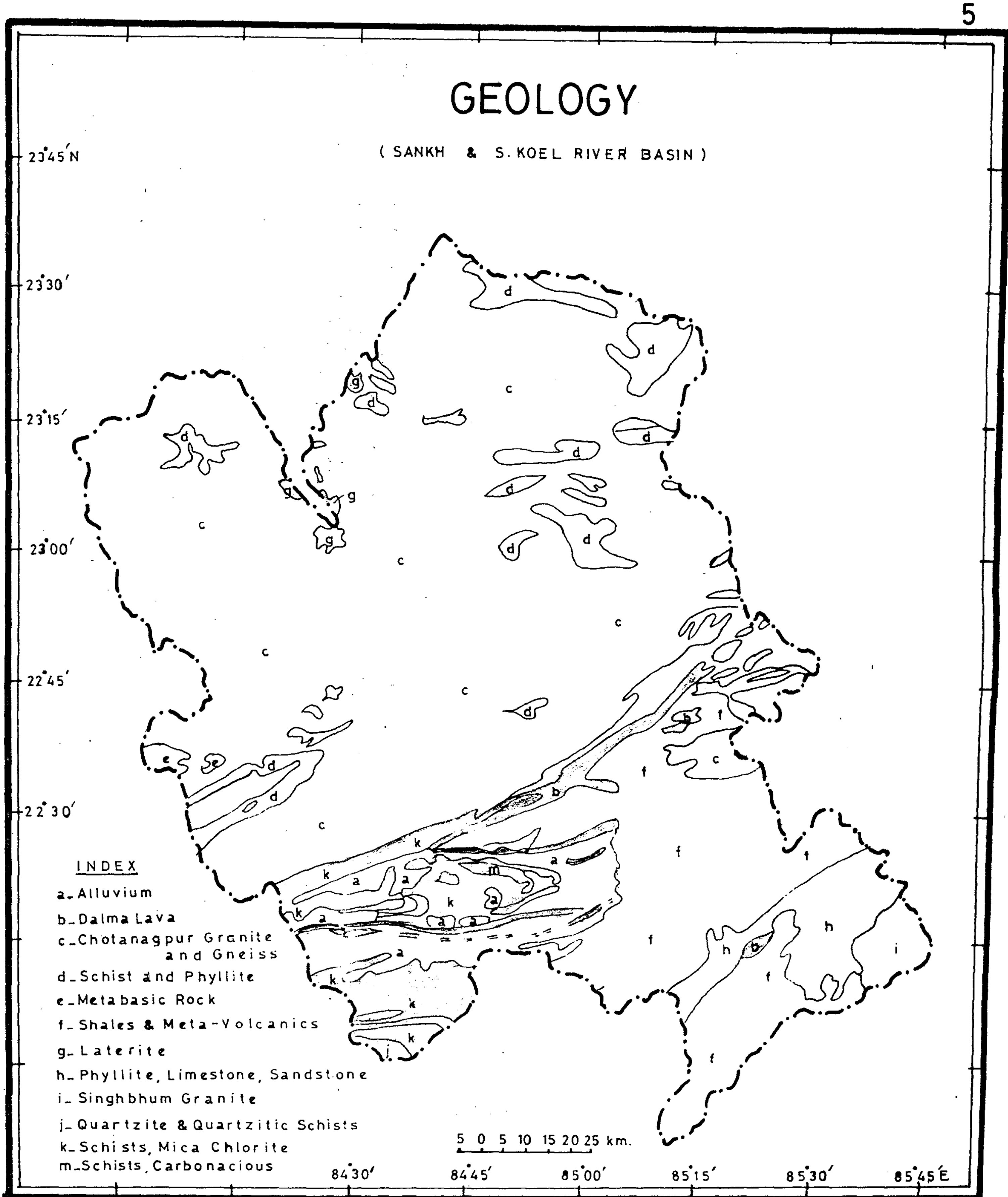

LOCATION
(SANKH & S. KOEL RIVER BASIN)
INDIA
RAIGARH
(M.P.)
RANCHI
(BIHAR)
SUNDARGARH
(ORISSA)
SINGHBHUM
(BIHAR)
K
REFERENCE:
S. SAMBALPUR (ORISSA)
K. KENDUJHAR (ORISSA)

FIG.1.1



Source: G.S.I.

FIG. 1.2

Source: G:S.I.

Raigarh of MP and Kendujhar, Sambalpur and Sundargarh of Orissa with 11687 , 3648 , 1359 ,378,15 and 2258 km^2 respectively,[3] (Fig. 1.1).

Geology:

Rock types contemporary of Precambrian era constitutes a major portion of Sankh and S.Koel basin. Chota Nagpur Granite and Gneiss with minor occurence of Phyllite, Limestone, Sandstone, Schist ; Laterite; Dalma , Dhanjori and Basic Lava; Shales and Meta -volcanics Quartzite, Conglomerate (Fig. 1.2).

After traversing the Ranchi Plateau Sankh river enters the Gangpur anticlinorium. The oldest rocks, which occur in the centre of Gangpur anticlinorium are phyllites and mica-schists containing thin beds and lenses of Gondite rocks. This anti-clinorium forms the northern contiguous part of lower reaches of both Sankh and S.Koel river and extends west ward of former and covers approximatelyan area of 700 km^2.

Gangpur series crops out in a sinuous belt in the southern part of Sankh river and constitutes a part of the peninsular Archeans of Eastern-India . The chronology of this series remains controversial;

---

3. Calculated from Toposheets no. 73A,B,E,F and 64 N of 1:25,000 and 64 M and 73.G of Quarter Inch scale.

one opinion states it is older than the surrounding rocks to the east and south and retains imprints of Eastern Ghat and Satpura orogenies[4] and the other expresses that Gangpur series is a part of the Iron -ore stage perhaps even a stage between the Iron-ore and Chaibasa stages[5] i.e. much younger.

Physical Layout:

The basin of Sankh and S.Koel has diverse topographical features. The stepwise decline of general slope along with escarpments forms the most of the basin area. Small and mostly circular plateaus with constricted river valleys in northern part of basin have remarkable difference with the topographical configuration of down stream valley where wide flat flood plains with intervening residual hills are common features. The general slope of the whole basin is from north to south with highest point at north-west ($23^{o}15'$N, 84^{o} 16'E) with 1071 meter and 190 meter at the outlet near Rourkela . The south and south east of South Koel is highly dissected with hill slopes and intervening river valleys and altitude varies from 883 meter to as low as

---

4. Krishnan, M.S.(1937): The Geology of Gangpur state, Eastern states. Memoirs , Geological Survey of India", V.71, p.181.

5. Dunn, J.A. and Day A.K.

Vegetation

The whole basin receives an average annual rainfall of more than 1500 mm. of rainfall and is occupied by forests and wood lands ranging from rainfed slopes to valleys and plains. Forests have great support in the region by its high moisture content and thick soils. As rainfall along with other climatic conditions , topography, soil and moisture distribution natural vegetation is uniformly distributed besides the areas with rural and urban setups. Even though moist deciduous forest dominate the basin, evergreen species like sal pre-dominates in the moisture and low lying areas of thick soil.

Important species found in the basin are mahua (Bassia Latifolia) , Kusum(Schleichera trijuga) , Kharin (Acacia catechu), Anjan (Harwickia), Karanj (Ponamia Glabera), Bamboo (Dendrocalamus strictus), Pipal, Khajur(Phoenix sylvestris) Mango (Mangifera indica), Jamun(Eugenia jambolana) Jackfruit(Artocarpus integrifolia) etc. Besides a number of species of grasses are found with most common Sabai grass.

Total forest arealcover of the basin is 6339 km^2 with 2684 $km.^2$ of reserved or protected forest.(FIG.1.4). They

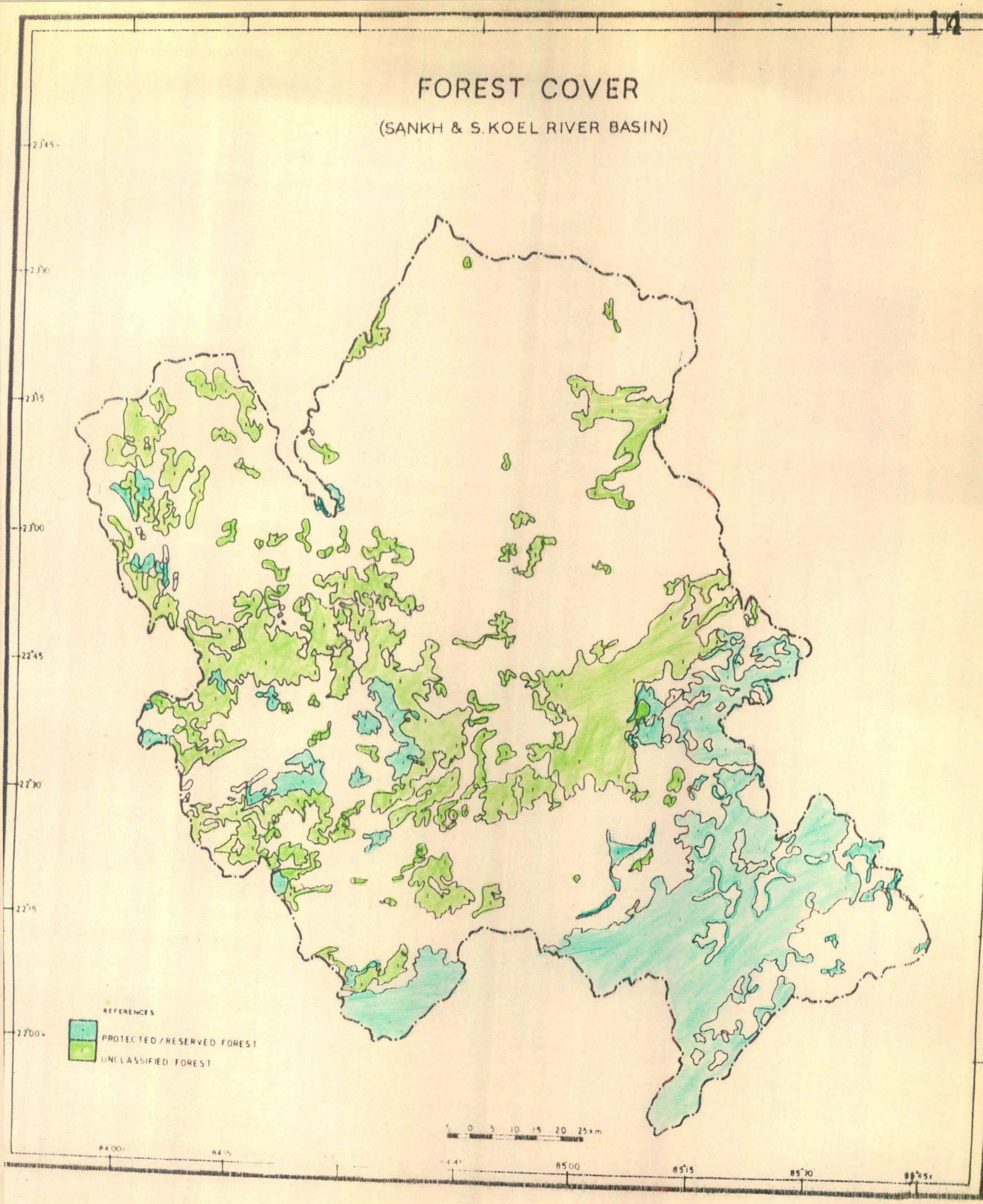

FOREST COVER
(SANKH & S.KOEL RIVER BASIN)
REFERENCES
PROTECTED / RESERVED FOREST
UNCLASSIFIED FOREST
5 0 5 10 15 20 25 km

Fig. 1.4

mostly covers the hill slopes with Sal or mixed species. Sankh basin has a greater forest coverage than S.Koel basin , as much of the plainlands and settlements are found there.

Relevancy of Watershed Management in Sankh and S.Koel River Basin

Sankh and S.Koel river basin is located in monsoon climatic regime where rainfall is highly seasonal and concentrated from June to October with its highest average intensity of 22.5 mm. day^{-1} for 19.44 rainy days in the month of July. Total monsoonal rainfall accounts for 87% of annual total. The main type of agricultural crops are rice, ragi, maize and gram with fruits and vegetables. Land use pattern of the region reveals that net shown area for Ranchi, Singhbhum , Sundargarh are 34.7, 19.4 and 37.49 per cent of the total areas respectively. This is too concentrated in plain lands of the basin. Pasture lands of these districts are 4.2, 0.7 and 1.1 per cent of the total areas respectively. But the downstream districts of Sankh and S.Koel confluence(i.e. of Brahmani) are highly fertile lands and agriculture is the dominant economy of the region. The problem of downstream area is mainly associated with the floods, siltation, during rain excess season and destroy their economic base; and shortage of water during rest of the year and makes agricultural practices difficult, even impossible where tank and tubewell irrigation facilities are lacking.

So considering these perennial problems a study has been done on geomorphic hydrologic and pedological characteristics of the Sankh and S.Koel river basin, which in a sequential manner affect the latter and have complex relationship among each other.

According to the very concept of watershed management, besides the socio-economic aspect of the region other three parameters have been presented in succeeding chapters.

Geomorphological aspects, discussed in Chapter 2, includes discriptive and quantitative geomorphology. The latter has been studied in detail as 'Drainage basin and hydrology' in which linear, areal and relief properties of the basin has been discussed and related to surface hydrology of the area.

Hydrological aspects, described in Chapter 3, is an attempt to analyse the hydrological characteristics of the basin. Analysis has been done for periods of 10 years and 7 years for two and one hydrological stations respectively. Data has been analysed on annual seasonal and monthly subheads showing range, mean, coefficient variation, and correlation among sites. The second part of this chapter is 'Sediment Budget' in which monthly log values of river discharge and sediment yield has been analysed with correlation and regression analysis. River capacity and competence are responsible for rate of sediment load transported and act as an indicator of soil erosion.

Pedological characteristics, relatively dependent on geomorphic and hydrologic characteristics has been studied as a succeeding chapter to above two chapters. Areas of soils of the Sankh and S.Koel basin surveyed comprise only 1469.76 km^2 out of 19345 km^2. Soils has been classified as per U.S.D.A. Soil Taxonomy and other soil characteristics as per U.S.D.A Soil Survey Manual. Soil structure, texture, depth; soils and landform; Soil and slope; Description of few major soil series; Soil erosion and its types and class; form the sub section of this chapter.

CHAPTER - 2

GEOMORPHOLOGICAL ASPECTS

"Physical environment unlike either the socio-economic or biological environment, is often considered as static or stable, where as infact, this environment is highly dynamic".[1] Any system to be dynamic needs variations in energy through input and corresponding work. Geomorphology, a component of physical environment, is dynamic at micro-level, where active geomorphic processes are caused by two types of causes; firstly, irregular, intermittent events and secondly, regular or periodic in intensity events that trigger geomorphic processes more frequently having a cycle of a day or so.[2] River basin, a unit of geomorphic landscape, is the sub-aerial portion of the earth's surface and can be regarded as an 'open system'.[3] Water flowing down stream to the sea or preferably, to base level, over the face of the land is a dominant agent of landscape alteration, where, precipitation and gravity are 'energy inputs'; erosion and transportation are work done by it; and landscape sculpturing through aggradation and degradation are the outputs of the system.

---

1. Mathewson, C.C. and William, F.C. (1982): Geomorphic Processes and Landuse Planning, Southern Texas Barrier Islands. In Applied Geomorphology, edt. by Craig, R.G. and J.L. Craft, p.132.

2. Ibid., p.136.

3. Chorley, R.J. (1962): Geomorphology and general system theory. "U.S. Geological Survey Professional Paper, 500-B" 10 pp.

For watershed management, descriptive as well as quantitative geomorphology deserve a special status for its evaluation. Regional and local configuration of landforms form an important part in terrain analysis. The lineaments, altitude of hill blocks, or extension of plains and plateaux are of utmost importance in carving out a plan for the management practices for a particular watershed.

Each watershed has a separate entity, bounded by crest-line at the periphery and is drained by a single main channel with numerous tributaries joining along its course. Sankh and South Koel river basin is bounded by Ib, North Koel, Damodar and Subarnrekha river basins at west, north, north east and eastern corridors respectively. More than half of the watershed forms the southern part of the Chota Nagpur Plateau.

"South Koel basin is a region of great inequalities and presents a rich panorama of topographical features".[4] The region is studded with small hillocks, knolls, escarpments, etc. Alluvial plain along the river channel are very wide as the river course crosses areas of very low

---

4. Desai, M. (1970) : A Brief Geomorphological Account of the South Koel Basin. "Geographical Review of India", V-38, n.4, p.375.

slopes of less than 3° for nearly 60 per cent of its total length. Upto the confluence of North Karo and South Koel the topography is typically a terraced slope with gentle gradient. The southern half of the basin with its tributary S.Karo in the region extends upto northern part of Kendujhar district of Orissa,(Fig-1.1). The area is very highly dissected with numerous tributaries of Koina , South Karo and Deo rivers and appears as a rugged hill country with typical mountain scenery of turbulent streams, steep hill side, and cliffs and narrow valleys.[5] In contrast to northern half this highly dissected terrain has highest average slope of 18° in the graticule of 22°-15'-20'N and 85° 10'-15' E. The basin is characterised with resistant residual hills throughout, which stand as a proof of prolonged denudation processes, is at the old stage of the geomorphic cycle. Total area covered by this basin accounts for 12475 km^2.

Sankh river basin is contiguous to and lies West of South Koel river basin. Area covered by the basin is 6870 km^2,which is 55 per cent of S.Koel river basin. It shows a higher diversity in topographic characteristics. The relative relief of the basin is 884 metre where as that of South Koel basin is

---

5. Dunn, J.A. (1929): The Geology of North Singhbhum including parts of Ranchi and Manbhum Districts. "Memoir, Geological Survey of India," V.54, pp. 1-166.

907 metre. Complex topography is seen on the part (one third of the basin) and gently rolling slopes on the rest of the basin. This creates a reverse situation to that of South Koel basin where southern part has complex topography. The lowest slope category is 3-5^{0} in northern half(Fig. 2.4). The drainage pattern is contorted at its upper reach, where Lawa and Basa tributaries originate from the centre, radiate towards the periphery and merge with the main channel, Sankh.

'Quantitiative Geomorphology' is based on geomorphometry and fluvial morphometry. These two parameters depend on geology of the region as well as on each other. Where rocks are resistant to erosion topography controls the drainage network and hydraulic geometry; and where, rocks are non resistant and susceptible to erosion hydraulic parameters control the topographic configuraion. Both combinedly affect and control the lithology and hydrology of the basin.

DRAINAGE BASIN AND HYDROLOGY:

The many tributaries of streams define a network of channels that drain a discernible, finite area recognised as the drainage basin or watershed of the trunk river. "Each basin is separated from its neighbour by a 'divide' and so basins serve as excellent fundamental unit of geomorphic system".[6] This geomorphic unit also serves as a finite unit for surface hydrology as the amount of water entering the basin as precipitation and volume of water leaving the basin as river discharge can be measured and analysed. 'Slope hydrological cycle' deals with stream flow, a result of precipitation, and what route and time a particular drop of water follows to reach a channel. Empirical universal fact is that, there is a time lag between the time of intense rainfall and peak discharge. This time lag is a function of basin morphometry and is accomplished by vegetative cover and lithological characteristics.

Basin Morphometry:

River basins form complicated shapes on the earth's surface. Basin characteristics and channel properties provide the basis to compare and differentiate one from another. The properties of linear (one dimension), areal(two dimensions) and relief (three dimensions) of the drainage basin behave in a orderly frame work and emphasise their own importance on catchment hydrological and geomorphic cycle.

i. Linear morphometric properties

Stream channels form the linear parts of a river basin. Water falling within the boundaries of river

6. Ritter, D.F. (1986): Process Geomorphology, p.154

basin eventually enter the stream channel and the stream transport the materials that slope processes bring to the bottom of the valley. Magnitude of the water borne and sediments transported varies proportionally with the magnitude of stream order. Hence, main streams order and bifurcation ratio are important parameters in judging the capacity of the river.

Sankh watershed is a fifth order stream basin with 724, 178, 39 and 7, first, second, third and fourth order channels respectively.[7] South Koel catchment is a sixth order stream basin with 1242, 276, 63, 13 and 3, first , second, third, fourth and fifth order channels respectively. The trunk river for former basin is Sankh with Lawa, Girma, Palamara, Chhinda and Lurgi river on its main tributaries. For the latter basin crunk river is S.Koel and its main tributaries are Bambhani, N.Karo, S.Karo and Koira rivers. All the first order and second order streams of both the catchment carry water during monsoon season and for remaining parts of the year remain dry. Most of the

---

7. Strahler's method has been used to designate a river/ rivulet with a particular order, where each finger-tip channel is designated as a segment of first order; at junction of any two same order stream produces next higher order stream.

third order rivers behave in a similar way. Sankh river being a fifth order stream should have been perennial, but surprisingly in some years during non-monsoon period it remained dry.[8] South Koel is a sixth order river and carries water throughout the year.

Much of the linear morphometry is a function of bifurcation ratio, Rb[9]. "The primary use of the bifurcation ratio is to allow rapid estimates of the number of streams of any given order and the total number of streams within the basin".[10] The ratio even though gives useful information about individual network, is ineffective in distinguishing differences in network structures due to lithologic control and degree of maturity.[11] Higher bifurcation ratio is derived

---

8. Sankh river at Tilga site(Fig. 3.) remained dry for most of the days of May 80,84,86 and April(85,86).

9. Strahler, A.N. (1976), Physical Geography, p.456.

$$R_b = \frac{N_u}{N_u+1}$$

where N_u = No. of streams of u order.

N_{u+1} = No. of streams of next higher order.

10. Ritter, D.F. , op.cit., p.166.

11. Smart, J.S. (1972) : Quantitative analysis of watershed geometry. "Transaction of American Geophysical Union", V.38, pp. 913-20.

when a catchment is drained by higher number of lower order streams. This explains a close network fabric and then, helps rain water to accumulate more rapidly than a stream having low bifurcation ratio. Mean bifurcation ratio, R_b, calculated for Sankh river is high with 5.3 due to structural control on drainage network. Mean bifurcation ratio for South Koel river is 4.21, which is lower than that of Sankh as much of its basin are plain areas with a average slope of less than 3^o (Fig.2.4).

ii) Areal morphometric properties

Physical characteristics of a watershed play a dominant role in determing the magnitude of the peak flood discharge, time lag and modality of flow. Lag time and peak discharge are positively related to basin size and modality of discharge is related to basin shape. Hence, a complete and careful study is required to assess the surface hydrology and planning flood control methods suitably. Even though "the interdependence of morphometry and hydrology is statistically real but does not necessarily indicate a cause-and-effect relationship".[12] But the high correlation between basin size and flood magnitude exists as they vary harmoniously with the inherent geologic and climatic controls. Sankh and South Koel at Tilga and Jaraikela site, and combinedly

12. Ritter, D.F., op.cit., p.190.

at Bolani site (Fig. 1.3a) have multiple correlation coefficients for $r_{B,J.T}$, $r_{J,T.B}$, $r_{T,B.J}$. of 0.9985, 0.9979 and 0.9609 respectively for monsoon river discharge even though they have different catchment sizes. This supports the concept of relationship between basin size and streamflow, provided they fall in same climatic regime.

Drainage density is the average length of channel per unit area of drainage basin.[13] It has a conspicuous effect on peak discharge and is controlled by terrain transmissibility. Permeable soils with high transmissibility will produce a poor drainage fabric and in contrast impermeable soil with low transmissibility will generate a close network . Hence, the rate of baseflow is inversely related to drainage density. Sankh and South Koel river basin has drainage density of .728 $km.km^{-2}$ [14], which

---

13. Drainage density , $D = \frac{L}{A}$

    where L = length of rivers
    A = Area of basins

14. Length of stream and area have been calculated from 1:25000 toposheets.

indicates a long time lag between intense rainfall and peak discharge. This is also a reflection of high permeable soils having high infiltration rate.[15]

Basin shape regulates the time lag and modality of river discharge. Very long basins take longer time to achieve an output of water from a rainstorm and have a low peak discharge as the channel transit time constantly increases for those tributaries lie farther from the confluence or gage stations. On the other hand in circular basins each tributary has relatively uniform transit time and generate a high peak discharge, and thus are called "efficient streams".[16] Basin shape is analysed with two non-parametric ratios; i) Elongation ratio, ii) Circularity ratio.

Elongation ratio[17] for Sankh river basin is

---

15. Soil permeability and basic infiltration rate has been described in "Soil Series Description", Chapter-IV.

16. Clowes A. and P.Comfort, (1987): Process and Landforms, p.93.

17. Miller, V.C. (1953): Relation of quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain Area, Virginia and Tennesse, "Technical Report-3, Department of Geology".

$$\text{Elongation ratio, } E_r = \frac{D_L}{2\left(\frac{\sum A}{\pi}\right)}$$

1.668. This shows that the maximum length of the basin is 1.668 times greater than the diameter of a circular basin having same area. Likewise, South Koel have an elongation ratio of 1.650 and that for both basins combinedly is 1.408. This shows there exists a considerable basin lag in all the three cases.

Circularity ratio[18] calculated from the basin perimeter and area. Sankh, South Koel and both combinedly have ratios of 0.403, 0.317 and0.281 respectively. These values indicate lower degree of compactness of the basins.

The basins individually or combinedly show high elongation and low circularity ratios. Runoff generated from the upstream of the basin will take time to reach the outlet. Hence, unit flood hydrograph will be dome shaped instead of conical. As a result the magnitude and

---

18. Schumn, S.A. (1956): Evolution of drainage system and slopes in badlands at Perth Amboy, N.Jersey. "Bull, Geological Society of America", V.67, pp.597-646.

$$\text{Circularity ratio } C_r = \frac{\Sigma A(4\pi)}{P^2}$$

Where A = Area of the basin

P = Perimeter of the basin

severety of flood hazard.

"The length of overland flow, considered as a dominant hydrologic and morphometric factor",[19] is the mean horizontal length of flow path from the divide to a first order stream and is a measure of stream spacing and degree of dissection. It is approximately one half the reciprocal of the drainage density.[20] For initiation of a stream, the resistance offered by the surface must be surpassed by the erosive force of the overland flow. As overland flow begins to traverse the slope, the force it exerts on a soil particle depends on the slope angle, the depth of the water, and the

---

19. Singh, S. and D.P. Upadhyaya(1982): "Topographical and Geometric study of Drainage Network, S.E. Chota Nagpur Region (India). In "Perspectives in Geomorphology", V.-II, p.218.

20. Chorley, R.J. (1969): Drainage basin as fundamental geomorphic unit. In Water, Earth and Man, edt. by R.J. Chorley, pp. 77-99.

specific weight of the water.[21] Erosion starts not from the divide as the resistance offered is greater than force of overland flow. The length of this segment or belt of no erosion is called "critical length".[22] This critical length is not fixed, it shortens with intense precipitation and high runoff generation and widens with low precipitation and runoff generation.

In Sankh and S.Koel river basin the length of overland flow is high owing to the long spacing between first order streams especially in central region where drainage density is very low. For the whole basin average length of overland flow is .874 km, hence, headward extension of streams are possible and will result in soil erosion.

---

21. Horton, R.E. (1945): Erosional development of streams and their drainage basin: Hydrological approach to quantitative morphology. "Geological Society of America, Bull". V.56, pp. 275-370.

Erosive Force , $F = \gamma \frac{d}{12} \sin \theta$

where γ is the specific weight

d is the depth of water

θ is the angle of slope.

22. Ritter, D.F.(1986):op.cit, p.162.

Soil moisture condition prior to rainfall is an important determinant for quantity and time of runoff generation. In dry soils runoff is generated when the rainfall intensity is high and is more than infiltration capacity, but saturated soils low amount of rainfall will generate stream flow. Though Sankh and S.Koel river basin fall in monsoon regime has periodic monsoon and non-monsoon seasons. So any(low)amount of rainfall will generate runoff during monsoon period but not during non-monsoon period.

iii. Relief properties

Relief properties include third dimension, height. River basin being a geomorphic unit, can be analysed with i) hypsometric curve, ii) hypsometric integral curve, iii) long profile, iv) slope etc. These analysis provide most useful information about basins evolution, present stage of evolution, river capacity and its stage of development.

i. Hypsometric analysis[23] relates elevation with area. This analysis is used to measure absolute and percentage of area above or below a given altitude and vice-versa. Cumulative area is plotted on abscissa

---

23. Strahler, A.N. (1952): Hypsometric(area -altitude) analysis of erosional topography. "Geological Society of America, Bull". V.63, pp.1117-42.

HYPSOMETRIC CURVE

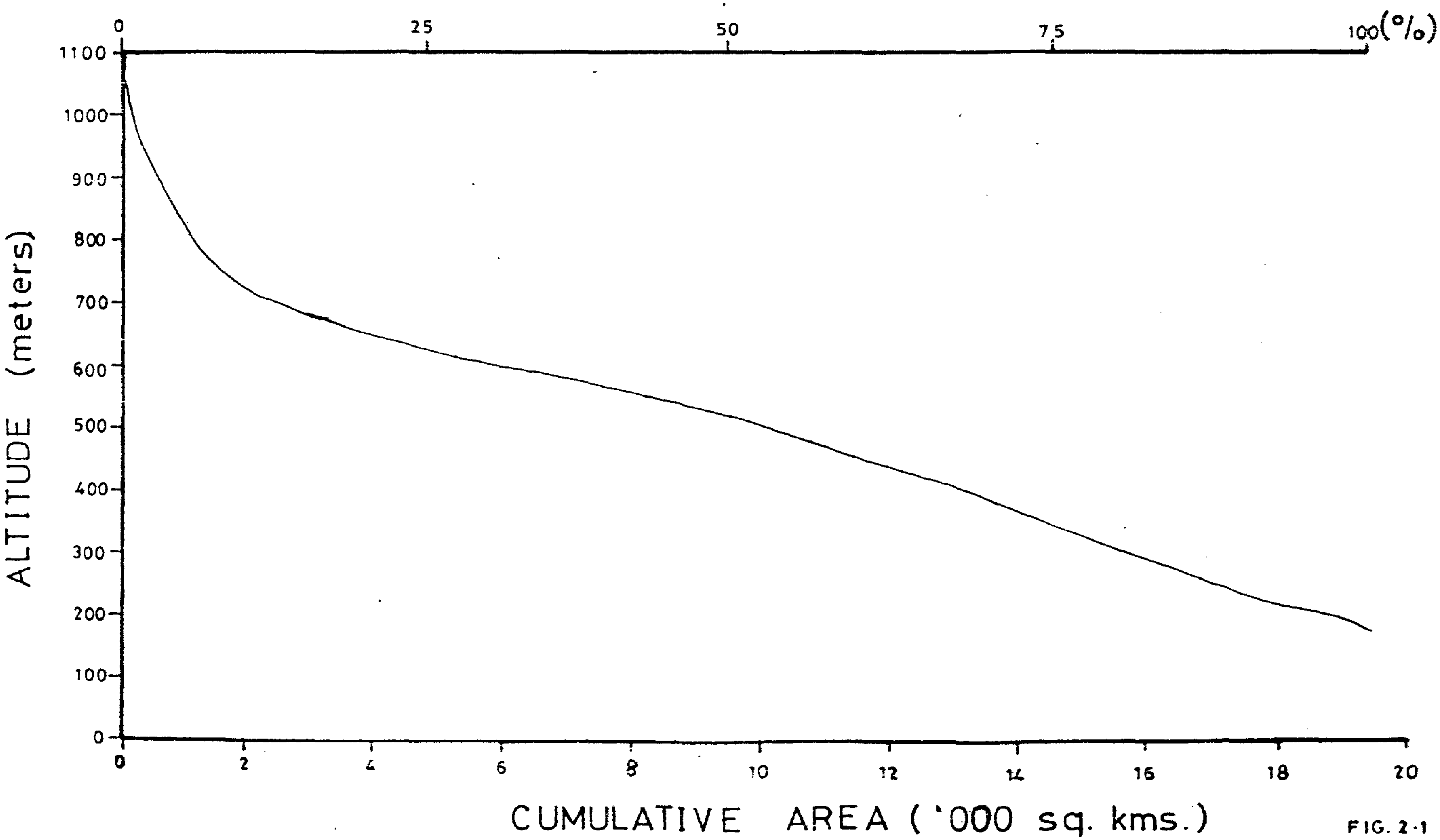


FIG. 2·1

and altitude on ordinate to represent area elevation relationship.

Fig.(2.1) shows the relationship between two stated parameters for Sankh and S.Koel basin. Area above 1000 metre is only 118 km^2 and constitute only 0.6% and area below 200 metre is only 236 km^2 or 1.2% of the whole basin. 40% of the total watershed have altitude between 500 and 700 meters. In 30% of the total area altitude is less than 400 meter. Such a distribution is due to sharp rising peripheral mountains and large inter contour distances(contours of 200 to 800 meters).

ii. Hypsometric integral[24] analysis of a geomorphic unit is an appropriate method in determining the stage of evolution of the landscape or erosional landform. This is a non-parametric analysis where abscissa is represented by quotient of successive cumulative area divided by total area, and ordinate by the quotient of successive elevation divided by highest altitude.

---

24. Ibid., p.1117-42.

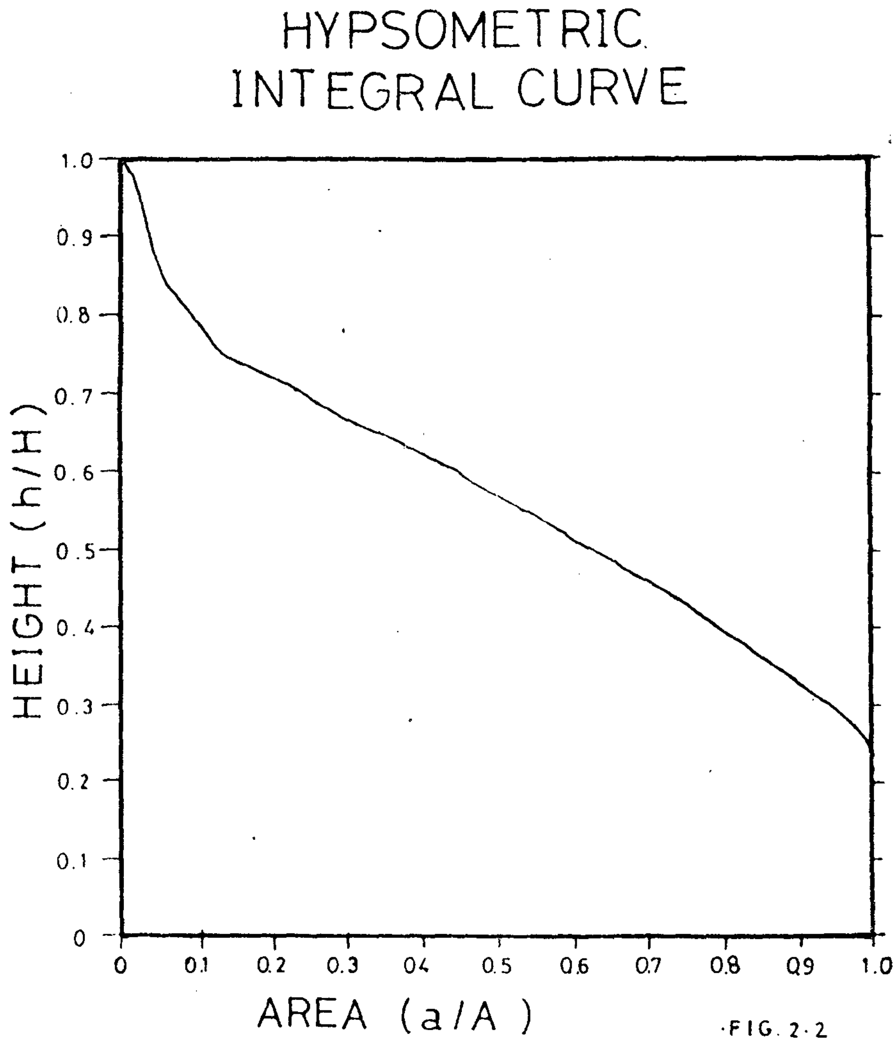

HYPSOMETRIC
INTEGRAL CURVE
HEIGHT (h/H)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
AREA (a/A)

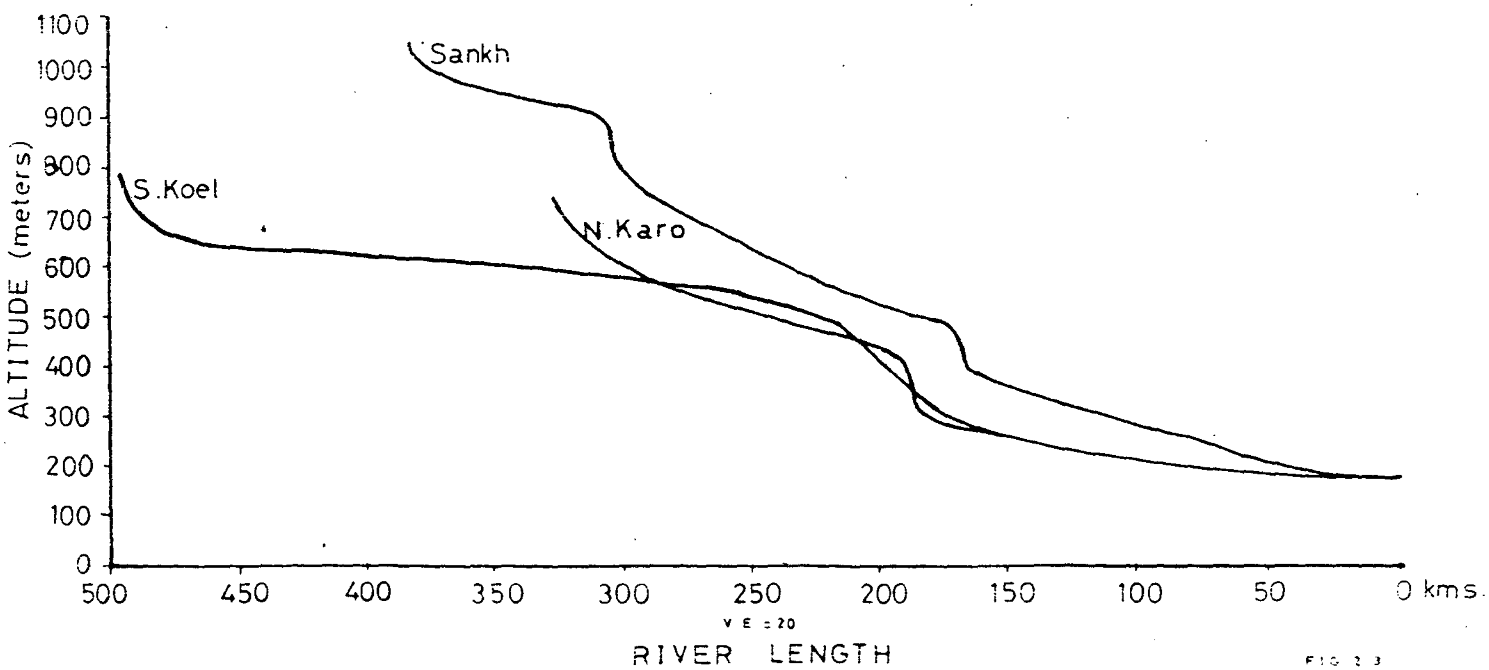
FIG. 2·2

Analysis for Sankh and S.Koel basin reveals that it is mature topography with an integral of .5525, (Fig. 2.2) . But the landform encountered in the region are knolls and residual hills, the marks of old stage. This difference between empirical and quantitiative derivatives owes to the rejunv nation of the region. Hence, it is a landscape of transition, where altitude difference shows sign of maturity with old stage features. This mature stage of landscape will have slow rate of erosion as the main work of the channel is to transport the weathered material of upper reach. Similarly, channel bed erosion will be very low unless there is high runoff as river bed scouring is associated with the velocity and volume of runoff. But channel bank erosion in Sankh and S.Koel must be comparatively higher as it is approaching towards the old stage. This will lead to broad and wide valley and wider flood plain area.

iii. Longitudinal profile of a river relates the river length to altitude. The main aim to present such a graph to show the slope or gradient of the main channel (and its tributaries).

Sankh river originates near Lupung pat at 84° 13' E longitude and 23° 13' N latitude at a

LONGITUDINAL PROFILES



height of 1045 metre and stretches for a length of 335 km. Analysis of the longitudinal profile (Fig. 2.3) of Sankh river reveals that it has two knick points depicting two fold rejuvenation one at 307 km and other at 168km upstream from the confluence with S.Koel river. It is structurally controlled and passes through a fault line for a length of 5 km during its course.

South Koel river originates from Nagri village at 85° 13' E longitude and 23° 21' N latitude and has a length of 495 km. It has flat course in two segments (Fig. 2.3) , one from the confluence to 175 km upstream and second, from 250 to 450 km upstream with gradients of only 0.63 metre km^{-1} (0°2'10") and 0.55 metre km^{-1} (0°1' 54") respectively.

North Karo a major tributary of S.Koel originates also near Nagri village (85° 10' E and 23° 17' N) at an elevation of 740 metre. After running for 194 km it merges with South Koel at an elevation of 250 metre, 134 km upstream of the latter (Fig. ..3a). It has a waterfall (Perugagh Fall) of 20 metre near Lohajimi.[25] 54 km upstream from its confluence

25. Desai, M. (1970) : op.cit., p.377.

Kinetic energy of flowing water in a channel is a function of slope or gradient. It changes with the sine function of slope as the gravitational force acts with its full potential on a 90^{o} slope, with half of its potential at 30^{o} slope and does not act on 0^{o} slope. A sudden fall or steep slope leads to high stream velocity and results in narrowing down the channel width or braiding[26] occurs owing to multiple circulation and upstream erosion etc. Sankh river maintain a steep slope at all its three segments separated by extremely steep gradients at knick points. Hence, the kinetic energy of the flowing water is high which, as a result is capable of transporting high sediment loads and may cause siltation problem for Mandira reservoir(Fig. 1.3a) and own adjoining flood plains. South Koel has typical longitudinal profile with flat courses separated by steep slope at mid portion. This will cause aggradation at the downstream end of these two flat segments and degradation at the upper end of steep segment causing a headward movement of the latter.

---

26. Leopold, L.B. and M.G. Wolman(1957): River Patterns: Braided, Meandering and Straight. " US Geological Survey Paper, 282B"

iv. Valley slopes are the main constituent of earth's land surface. "At a given point on the ground surface it is normally possible to follow the line of maximum slope downwards until a drainage channel is reached; more over a causal relation between the slope and the channel is apparent".[27] Slope system is a product of interaction between processes and form properties. It includes independent variables like rock character, climate and initial slope angle, and independent variables like soil thickness, exposure , reduction, mobility, denudation and renewal of exposure with long-term, medium-term and short-term effects. Slope evolution can take place either by slope decline, slope replacement or parallel retreat and in all these three processes end product is peneplanation of the landscape. Slope processes involves falls, slides, slumps, flow, soil creep and surface wash,[28] and each type of process is dependent on the angle of slope, nature and properties of soil, climate, vegetative cover, intensity of rainfall, rate of infiltration and runoff coefficient of the area. An early, detailed

---

27. Young A.(1978): Slopes, p.1

28. Clowes, A and P. Comfort, (1987): op.cit., p. 52-69.

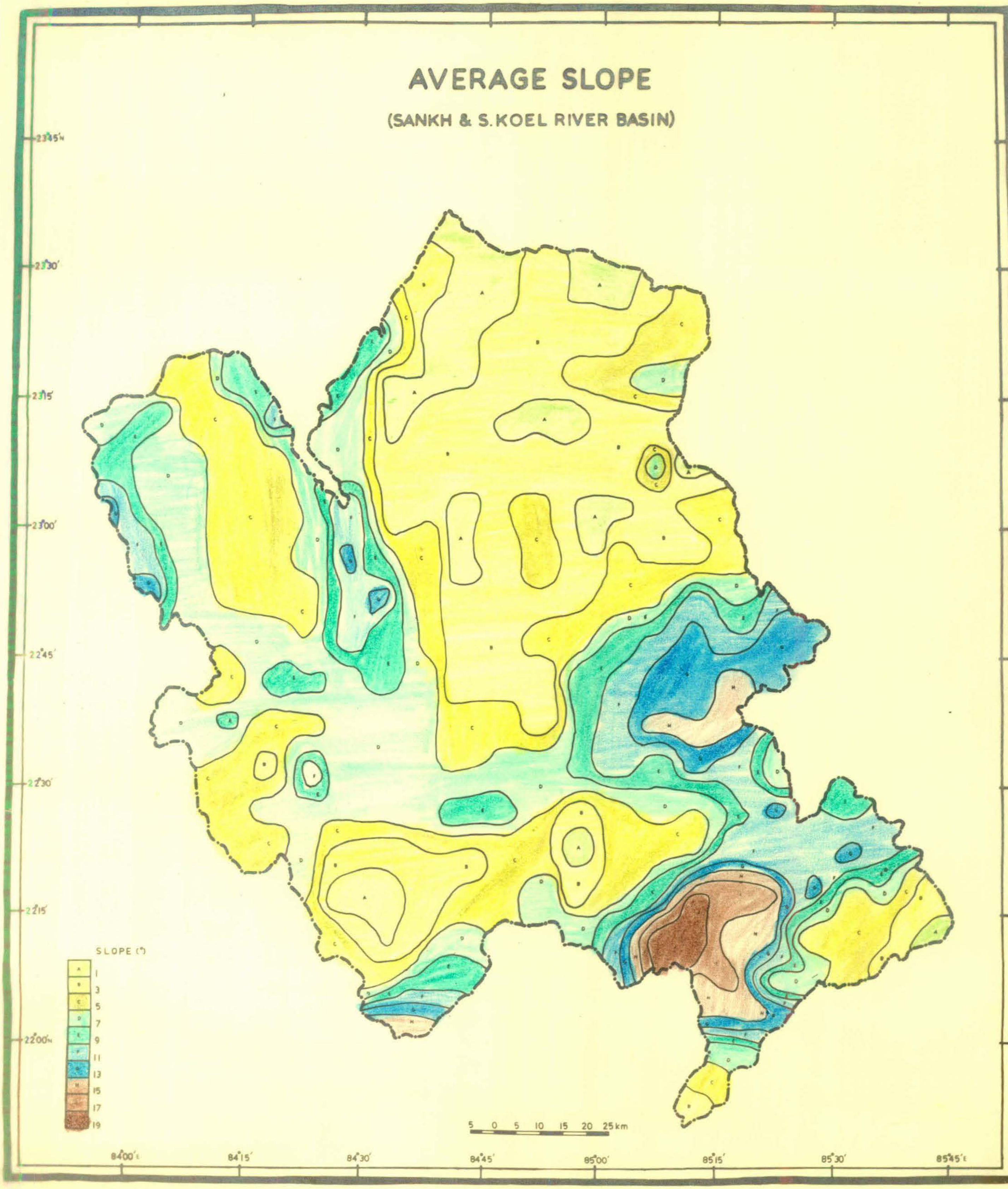

AVERAGE SLOPE
(SANKH & S.KOEL RIVER BASIN)
SLOPE (°)
5 0 5 10 15 20 25 km
84°00'E
84°15'
84°30'
84°45'
85°00'
85°15'
85°30'
85°45'E
23°15'
23°00'
22°45'
22°30'
22°15'
22°00'N

FIG. 2.4

study and survey of slope and other stated parameters is helpful in assessing the type of processes working and makes it possible to predict potential threat of various hazards like mudflow, earth-flow, landslide, rock-fall, soil creep etc.; and chalking out plan for averting them.

Slope has its main application in engineering and agriculture. "Slope angle sets limits upon agricultural landuse, through its effect on the use of farm impliments and on erosion hazard".[29] Hence, this needs a separate, both extensive and intensive study for various purposes.

Sankh and S.Koel river basin has been divided into ten average slope categories by using Wentworth's method[30] of slope analysis, Fig.(2.4). The highest category is 17 to 19° of slope in which highest value is 18°09',

---

29. Young A., (1978) : op.cit., p.250.

30. Wentworth, C.K. (1930): A Simplified Method of Determining the Average Slope of Land Surfaces. "American Journal of Science", V.20 Series-5.

$$\text{Slope angle} = \tan^{-1} \frac{\text{Av. no. of contour crossings per mile x contour interval}}{3361}$$

and lowest category is 0-1° slope with lowest value of 0° for three graticules* and cover 1391 and 145 km^2 or 7 and 08% respectively. Table (2.1)

TABLE- 2.1

Slope Categories (in degrees)	Area (Km²)	Slope Categories (in degrees)	Area (Km²)
1. <1	1391	6. 9-11	1608
2. 1 -3	4240	7. 11 - 13	791
3. 3 - 5	4490	8. 13- 15	571
4. 5 - 7	4024	9. 15 - 17	228
5. 7 - 9	1851	10. 17 - 19	145

Areas having average slope between 0° and 5° cover more than half (52%) of the total area. Third category, 3-5° slope alone covers 23% of the total basin, which accounts for 4490 km^2. As the category increases, the area covered by it decreases. South Koel basin has lowest and highest categories where as Sankh basin has highest category of 13-15° and lowest category of 3-5° of slope. This can be compared with corresponding longitudinal profiles, Fig. (2. 3) where Sankh river has steep gradient than that of S. Koel. The slope has been related to slope processes in this chapter and with soil erosion in Chapter 4 (Fig. 4.2) according to its relevance.

Geomorphometric and fluvial-morphometric parameters of a landscape have maintained their relationship in such a fashion that they mutually adjust to each other and combinedly have an effective control over the basin hydrology and lithology. Starting from channel network fabric to flow volume, hydrological parameters of a watershed are consistently regulated by lithologic characteristics, shape and size of the basin. But they are not the cause of amount of runoff or sediment load of a river. Hence, absolute values of discharge or availability of water at lower reach of a river, their variation at each time-scale are necessary for management of water-resources of a catchment. Therefore, the next chapter has been putforth to present hydrologic characteristics of Sankh and South Koel river basins.

CHAPTER - 3

HYDROLOGICAL ASPECTS

The role of hydrology in water resource management is to provide data regarding the "time and space distribution(of water resource) on land".[1] The most appropriate "geographical unit for water resource planning is usually the river drainage basin"[2], and the objective of water resource planning is to make most effective use of available water resources for varied short and long term needs of both consuming viz- irrigation and non consuming viz-nevivation uses. The concept of river basin as a geographical unit is a successful approach as the ground water basin coincides in most of the cases, if not in all , with it. The stratigraphy and aquifer system are the determining factors for groundwater basin boundary, hence, control the baseflow, as "underground water contribute to river alimentation because it is drained by river channels".[3]

---

1. W.M.O. (1973): Application of Hydrology to Water Resources Management, Operational Hydrology Report No. 4, p.3.

2. Kuiper, E.,(1971): Water Resource Development: Planning Engineering and Economics, p.5.

3. Klimentov,P.P. General Hydrology Translated to English by Gurevich, K.G. ,(1983),p.22.

River discharge is controlled by precipitation(P), evaporation (E) and potential evapotranspiration(PE), change in soil moisture storage (Δ SMS) and change in groundwater storage (Δ GWS)

$$Q = (P) - (E) \ \& /\text{or} \ (PE) \pm (\Delta SMS) \pm (\Delta GWS)$$

Besides these balancing factors moderating factors like forest cover, slope and shape of the drainage basin regulate the flow and time of the peak discharge and volume. The most commonly accepted model of storm runoff is still that proposed by Horton, (1933)[4]. Rainfall intensities in excess of the infiltration capacity of the soil result in overland flow once depression storage has been completed.

FOREST COVER AND RUNOFF

"Hydrologic cycle over a watershed" is affected by forest due to complex interaction"[5]

---

4. Horton, R.E.(1933) : The role of infiltration in the hydrological cycle. "Transactions of A.G.U.", Vol. 14, p.446.

5. Awan, N.M. (1977); Hydrologic Research on Watershed Management. In Seminar on Watershed Management ,(edt) by A. Sevinc Kisalali , p. 154-57.

of components of hydrologic processes viz. precipitation, interception, evaporation, infiltration and surface flow. The first experimental attempt to measure the hydrological effects on changing vegetation over a complete watershed began in U.S.A. in 1911 in the classical "Wagon Wheel Gap" experiment in Colorado. Experiments on different watersheds have proved that "run off is lowest in complete forest cover and that with decreasing cover surface runoff increases";[6] "establishment of forest cover on sparsely vegitated land decreases water yield and response to treatment is highly variable and for the most part unpredictable".[7]

In Sankh and South Koel river basin forest cover occupies 6339 km^2 which is 33% of the total

---

6. Raeder - Roitzsch, J.E. & Masrur, A., Some Hydrologic Relationship of Natural Vegitation on Chirpine Belt of West Pakistan. Cited from Awan, N.M. op.cit., p.157.

7. Hibbert, A.R. (1967): Forest Treatment Effects on Water Yield. International Symposium for Hydrology. Cited from F.A.O.'s Technical Papers, Conservation Guide, No. 4, p.

the area coming in Sankh basin are either under protected or reserved or unclassified forest. This helps in reducing volume of overland flow and sediment yield.

In this chapter, surface hydrological characteristics of Sankh and S.Koel river basins have been studied to provide a clear picture of seasonal and annual distribution of surface runoff for three sites; Bolani, Jaraikela and Tilga. Bolani is located on river Brehmani, 20 km downstream of Sankh and S.Koel junction*. Jaraikela is situated on river S.Koel, 22 km upstream from meeting point of both the rivers. The third one Tilga is located 40 km upstream from the outlet of Mandira resorvoir.**.

Discharge data for monthly total(in cumec days) has been taken for analysis for a period of ten years from 1976-77 to 1985-86 for both Bolani and Jaraikela sites and for a period of seven years from 1979-80 to 1985-86

---

* Bolani site has been selected to represent the both of the catchments' runoff (and sediment load) even though it is outside the basin , as there is no hydrological station at the confluence. Additional area covered by of its downstream location is 480 km^2.

** Mandira Resorvoir is situated 15 km upstream from the confluence of Sankh with S.Koel.

for Tilga site.

ANNUAL RUNOFF:

The overall quantity of surface water that is available in a basin for water resource management is well represented by runoff volumes of individual years or by corresponding mean annual flows. Such data offer a knowledge of yearly availability of water resources which is used in designing resorvoir size, total land can be irrigated, for generating power, etc. Individual annual discharge data show trends in runoff amount and variability whereas mean discharge shows a computed standardized picture for the corresponding period of study.

Mean annual discharge at Bolani from river Brahmani is 98888.61 cumec day which equals to 8.544 x 10^9 m^3 for 10 year period. The highest discharge was 1977-78 with 157178.7 cumec day, which is 158.95% of the mean annual discharge. The lowest discharge was in 1979-80 with 37495.2 cumec day and is only 37% of mean annual discharge. Range of annual discharge is 119683.5 cumec day and coefficient of variability[8] is .3580. Standard error of the coefficient of variation is 27 for gamma distribution

---

8. Coefficient of variation is shown in decimal and can be converted into percentage by multiplying it by 100.
Coefficient of variation , $CV = \frac{\sigma}{\bar{Q}}$

where σ = standard deviation = $\frac{\Sigma (Q-\bar{Q})^2}{n}$

$\bar{Q}$ = mean = $\frac{\Sigma Q}{n}$

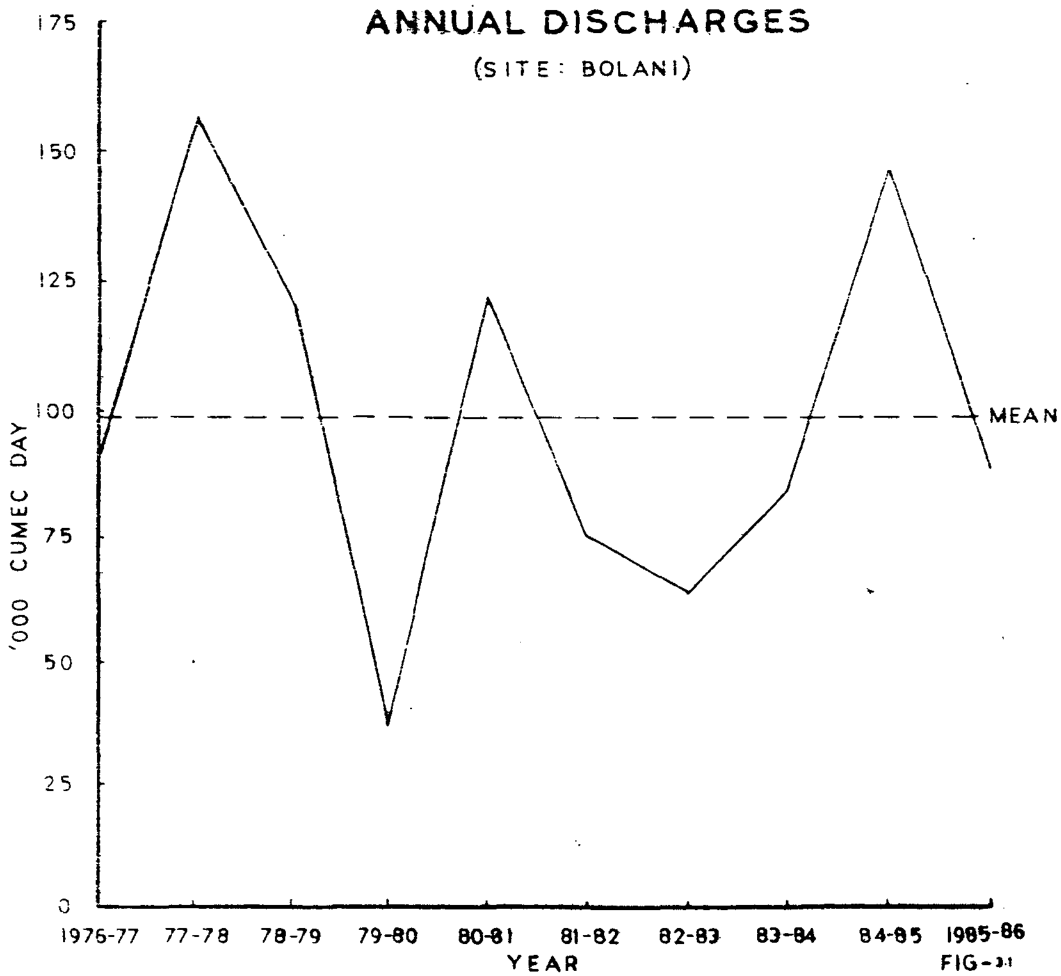

ANNUAL DISCHARGES
(SITE: BOLANI)
175
150
125
100
75
50
25
0
'000 CUMEC DAY
MEAN
1976-77
77-78
78-79
79-80
80-81
81-82
82-83
83-84
84-85
1985-86
YEAR

FIG-3.1

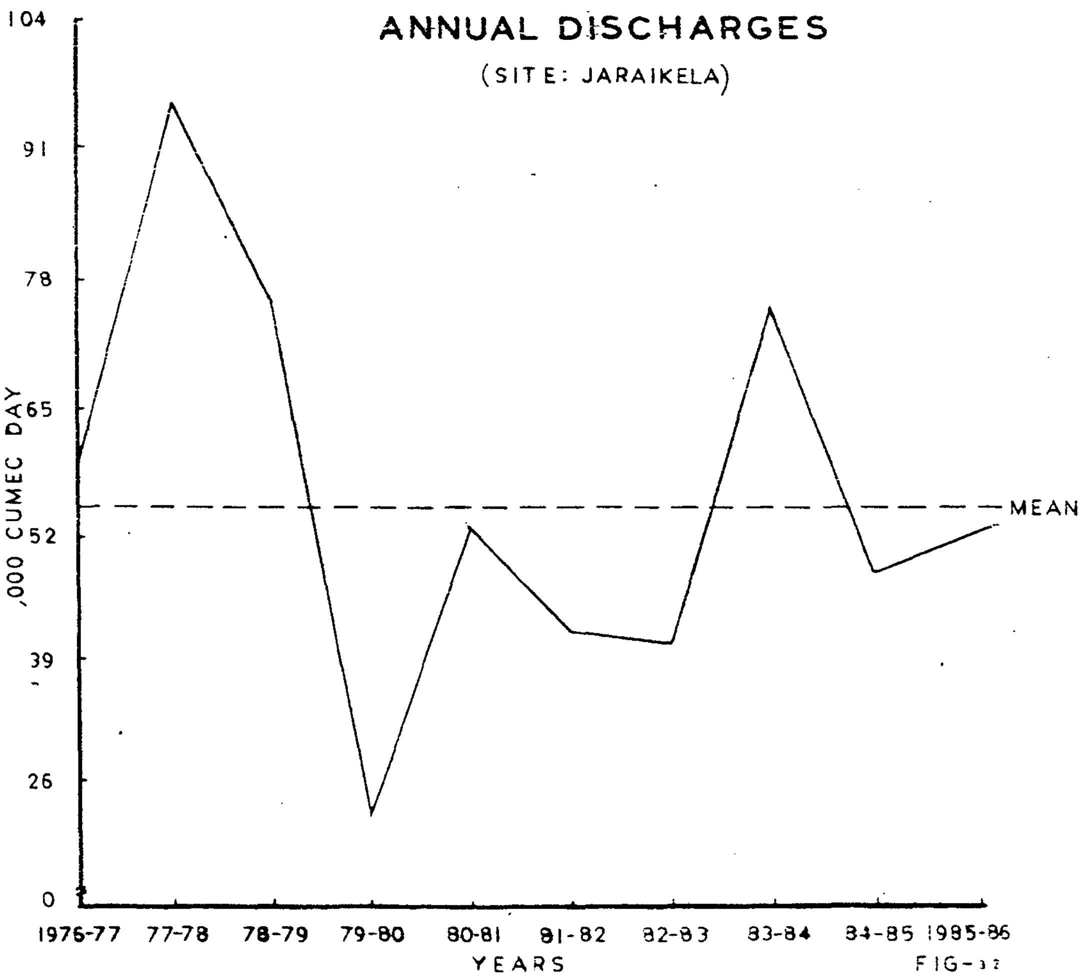

ANNUAL DISCHARGES
(SITE: JARAIKELA)
104
91
78
65
52
39
26
0
,000 CUMEC DAY
MEAN
1976-77
77-78
78-79
79-80
80-81
81-82
82-83
83-84
84-85
1985-86
YEARS

FIG-32

and 24.65 for Gaussian distributionand standard error of the mean annual discharge is 11.38. Skewness[9] of the distribution of 10 years data is .1124. Median value of it is 90705.6 cumec day, and upper quartile for the series is 75523.3 cumec day(Fig. 3.1)

Mean annual discharge at Jaraikela from S.Koel river is 55028.69 cumec day which equals to mean annual discharge of 4.7545×10^9 m^3. Range of annual discharge is 73204.6 cumec day with highest and lowest runoff in 1977-78 and 1979-80 with 95460.5 and 22255.9 cumec day respectively. The median discharge for the period is 50527.6 cumec day and upper quartile is 75112.2 cumec day. Coefficient of variation is .3761 with a standard error of 28.52 for gamma distribution and 25.67 for Gaussian distribution standard error for mean is 11.935 and Skewness of the distribution is .5958 (Fig. 3.2)

At Tilga site mean annual discharge from Sankh river is 19715.41 cumec day as the catchment area is only 3160 km^2.* Range or annual runoff is 24571.1

---

9. Skewness of an n-year series of annual runoff is

$$C_s(Q) = \frac{n}{(n-1)(n-2)} \quad \frac{\Sigma\ (Q-\bar{Q})^3}{\sigma\ n^3}$$

* Area given by Central Water Commission.

ANNUAL DISCHARGES

(SITE: TILGA)

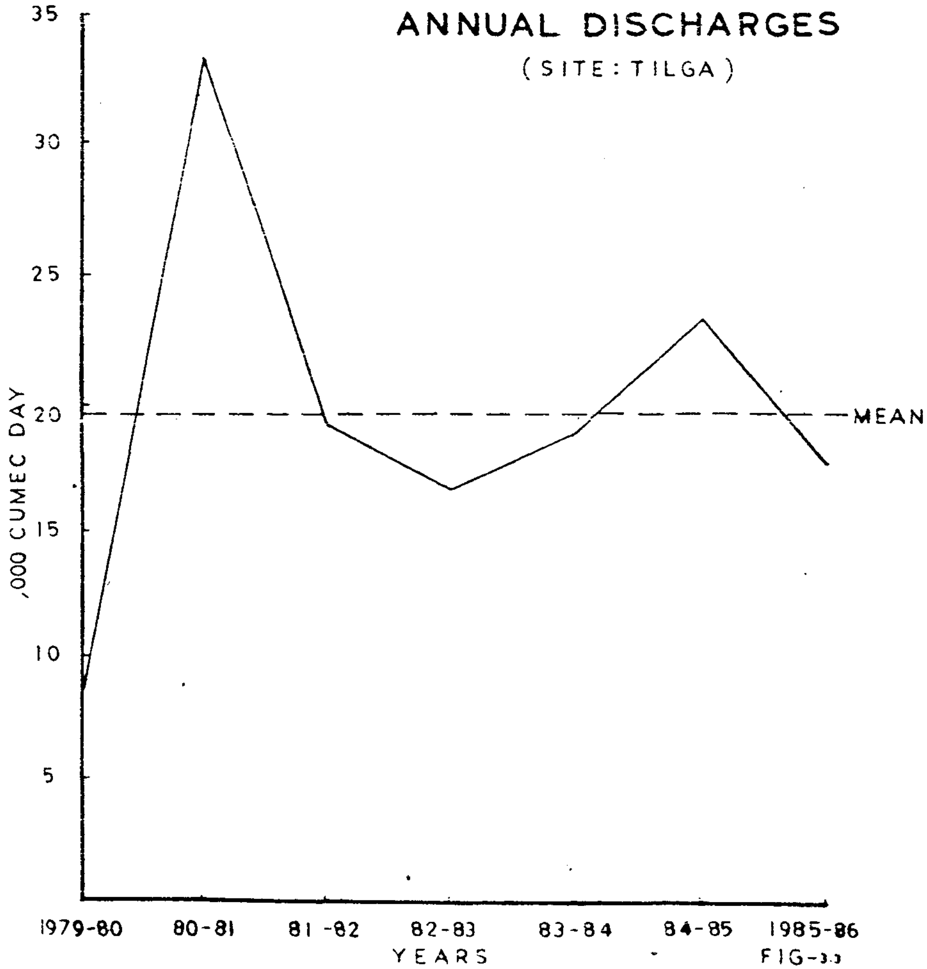


FIG-3.3

cumec day with highest and lowest during 1981-82 and 1979-80 with 33107.6 and 8536.5 cumec day respectively. Coefficient of discharge variation is .3477 for which standard error is 27.95. Median discharge for the seven year period is 18850 cumec day and the same at upper quartile is 20355.35 cumec day. Skewness of the distribution is 0.7431.Fig.(3.3).

SEASONAL RUNOFF

As the drainage basin is located in a monsoon climatic regime, a high proportion of rainfall is received during June to November. This period is considered as monsoon period for hydrological analysis of the basin.

Average runoff at Bolani site for Brahmani river contributed by its two tributaries Sankh and South Koel during monsoon for a period of 10 years from 1976-77 to 1985-86 is 95004.36 cumec day which equals to 8.2084×10^9 m^3 and accounts for 96% of the mean annual discharge. The coefficient of variation is .3661. This high value is due to early or late arrival monsoon, number of rainy days in a month and intensity of rainfall. In the non-monsoon period mean discharge is 3884.25 cumec day and comprises 4% of mean annual runoff. Monthly distribution has a coefficient of variability of .2545 which is comparatively low as the high proportion of flow comes as baseflow.

At Jaraikela from South Koel river mean monsoon discharge of the recorded 10 year period is 52908.73 cumec day or 4.571×10^9 m^3 with a coefficient of variation of .3817. This accounts for 96% or mean annual runoff. The rest 4% is carried during non monsoon period measures 2119.96 cumec day or 1.832×10^8 m^3 with a coefficient of variation of .3122.

At Tilga site like other two sites, monsoon period comprises a major part of mean annual discharge. Mean non-monsoon discharge is 818.68 cumec day and mean monsoon discharge is 18833.586 cumec day. During seven years period from 1979-80 to 1985-86 the monsoon mean discharge shows a coefficient of variation of .3557 and that of non-monsoon period is .3087.

MONTHLY RUNOFF

Mean monthly runoff shows an intra year and intra seasonal variation. For water resource management, as well as for an overall classification of runoff distribution

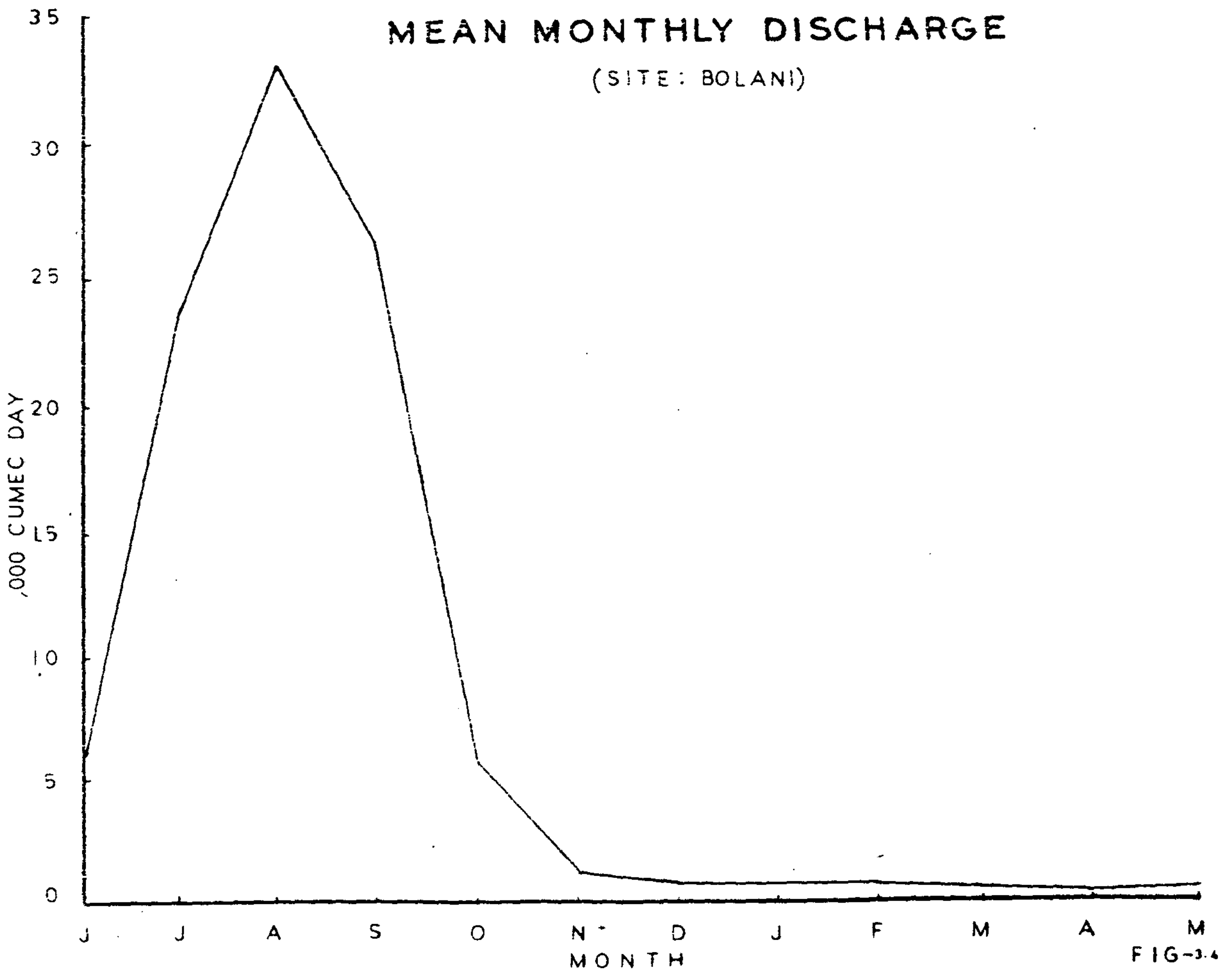

MEAN MONTHLY DISCHARGE
(SITE: BOLANI)
,000 CUMEC DAY
35
30
25
20
15
10
5
0
J J A S O N D J F M A M
MONTH

FIG-3.4

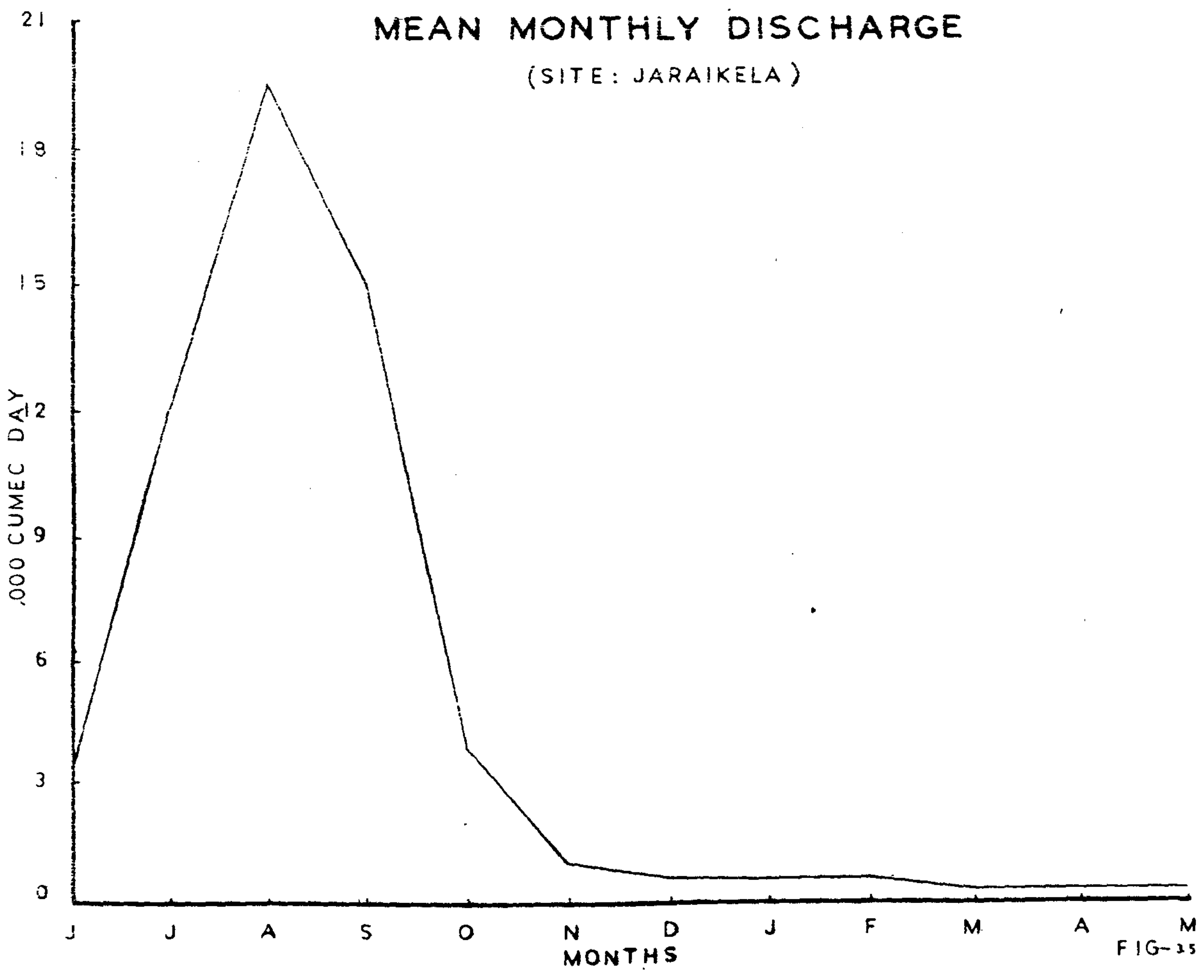

MEAN MONTHLY DISCHARGE
(SITE: JARAIKELA)
,000 CUMEC DAY
21
18
15
12
9
6
3
0
J
J
A
S
O
N
D
J
F
M
A
M
MONTHS

FIG-35

in an annual cycle, a very useful characteristic is found to be monthly distribution of runoff.

Fig. 3.4 shows a mean monthly distribution of discharge from Brahmani at Bolani site representing both Sankh and South Koel river. Even the monsoon rainfall, in its normal course, is experienced in second week of June, rainfall intensity and number of rainy days becomes maximum during August, and river discharge from both the catchments becomes highest. Mean monthly discharge during this month is 33068.76 cumec day or 2.857 x10^9 m^3. Highest ever recorded discharge at this site is 10604.1 cumec since 1976-77 was on 6th Aug 1977. During September mean discharge is also quite high with 14728.88 cumec day. Month having lowest mean discharge is April with 413.96 cumec day. Relationship derived through multiple regression analysis with other two sites, Jaraikela and Tilga, have a coefficient ($r_{B.J.T.}$) of 0.9985.

Jaraikela site representing South Koel has a similar trend in mean monthly discharge (Fig. 3.5) with its peak in August with 18143.17 cumec day. And November to May have mean monthly discharges less than 1000 cumec day. The lowest mean monthly discharge at this site

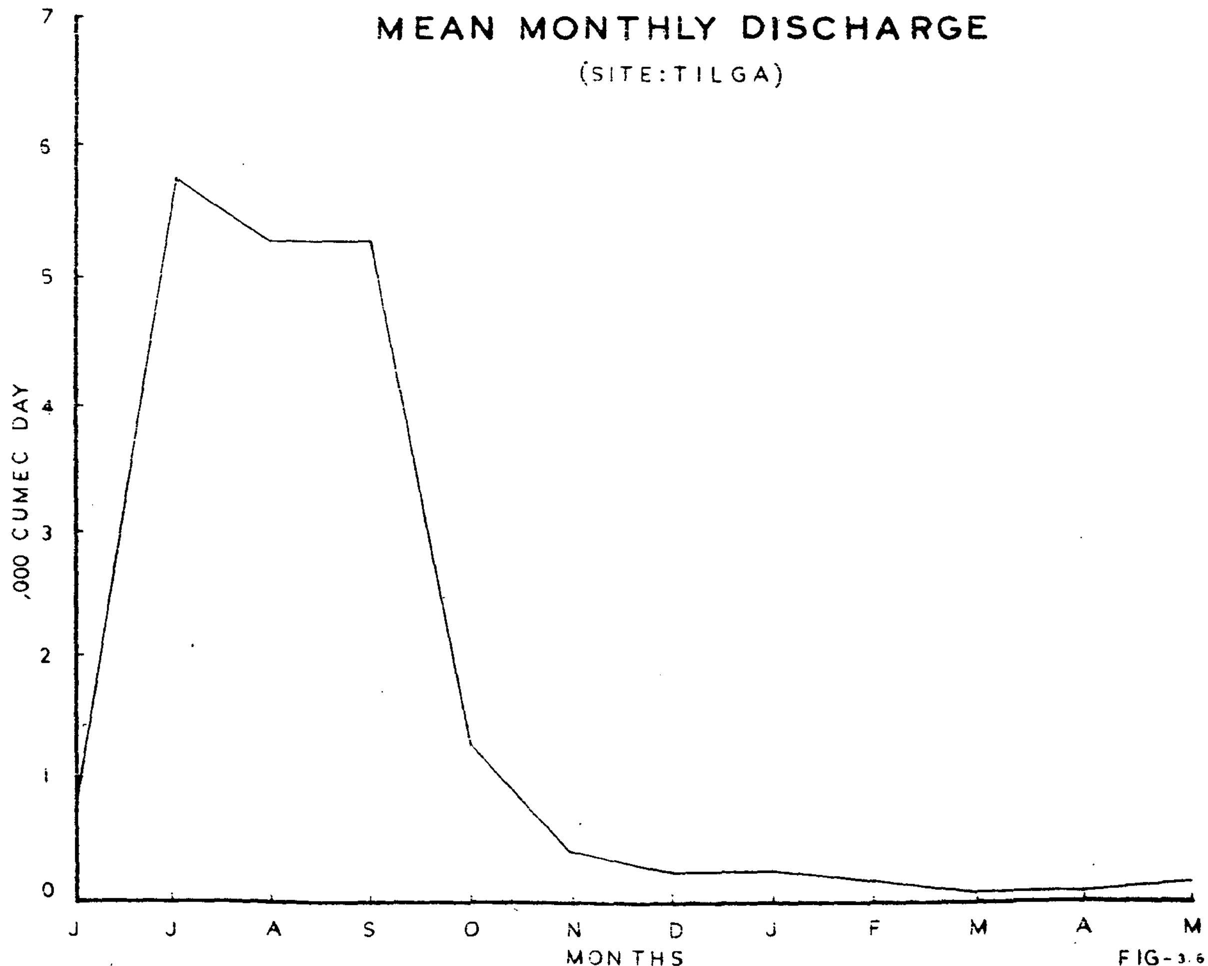

MEAN MONTHLY DISCHARGE
(SITE:TILGA)
,000 CUMEC DAY
0
1
2
3
4
5
6
7
J
J
A
S
O
N
D
J
F
M
A
M
MONTHS

FIG-3.6

also occurs in April with only 167.93 cumec day. Relationship between Jaraikela and Bolani sites and Jaraikela and Tilga sites, when expressed in terms of coefficients shows higher degree correlation with 0.9975 and 0.9673 respectively and multiple correlation coefficient for Jaraikela, Bolani and Tilga($r_{J.B.T.}$) is 0.9979.

Monthly discharges from Sankh at Tilga site (Fig. 3.6) has a little difference with that of other two sites. Peak mean monthly discharge is reached during July and recession limb does not fall suddenly as others. July, August and September have mean monthly discharge of 5716.83, 5282.27 and 5283.93 cumec day respectively and have a difference of only 434.56 cumec day. Correlation coefficient of the distribution with Bolani site is .9762 and with other sites ($r_{T.B.J.}$) is .9609.

SEDIMENT BUDGET

"The quality of river water is a function of its chemistry and of its sediment characteristics"[10]. So sediment load data alongwith other variables are to be studied carefully for a variety of

---

10. Rodda, J.C. (1976): Facets of Hydrology, p.163.

water management tasks. "Sediments originate in erosion of the drainage basin, with major part of it coming from the upland areas where streams are torrential and dissect the land effectively".[11] Amount and type of sediment especially the grain size distribution during transportation are dependent on "river capacity and competence"[12] respectively. Availability of sediment to be transported depend on the geology, type and extension of weathering, rainfall intensity and duration, surface wash, drainage density, and interference of man and animal in the natural system. Forest and vegetative cover, which make a protective shield for soil erosion is the most common field of human intrusion and thus "affect the sediment yield by cutting trees for fuel, hauling of timber and building roads, clearing land for grazing and especially through shifting cultivation"[13]

---

11. Oyebande, L. (1981): Sediment Transport and River Basin Management in Nigeria. In Tropical Agricultural Hydrology. Edited by Lal. R and Russell, E.W., pp. 202-4.

12. Bloom A.L. (1976): Geomorphology, p.213.

13. Kunkle, S.H. and A.J. Dye (1981): The Effects of Forest clearing on Soils and Sedimentation. In Tropical Agricultural Hydrology. Edited by Lal, R and Russell, E.W. , pp. 100-3.

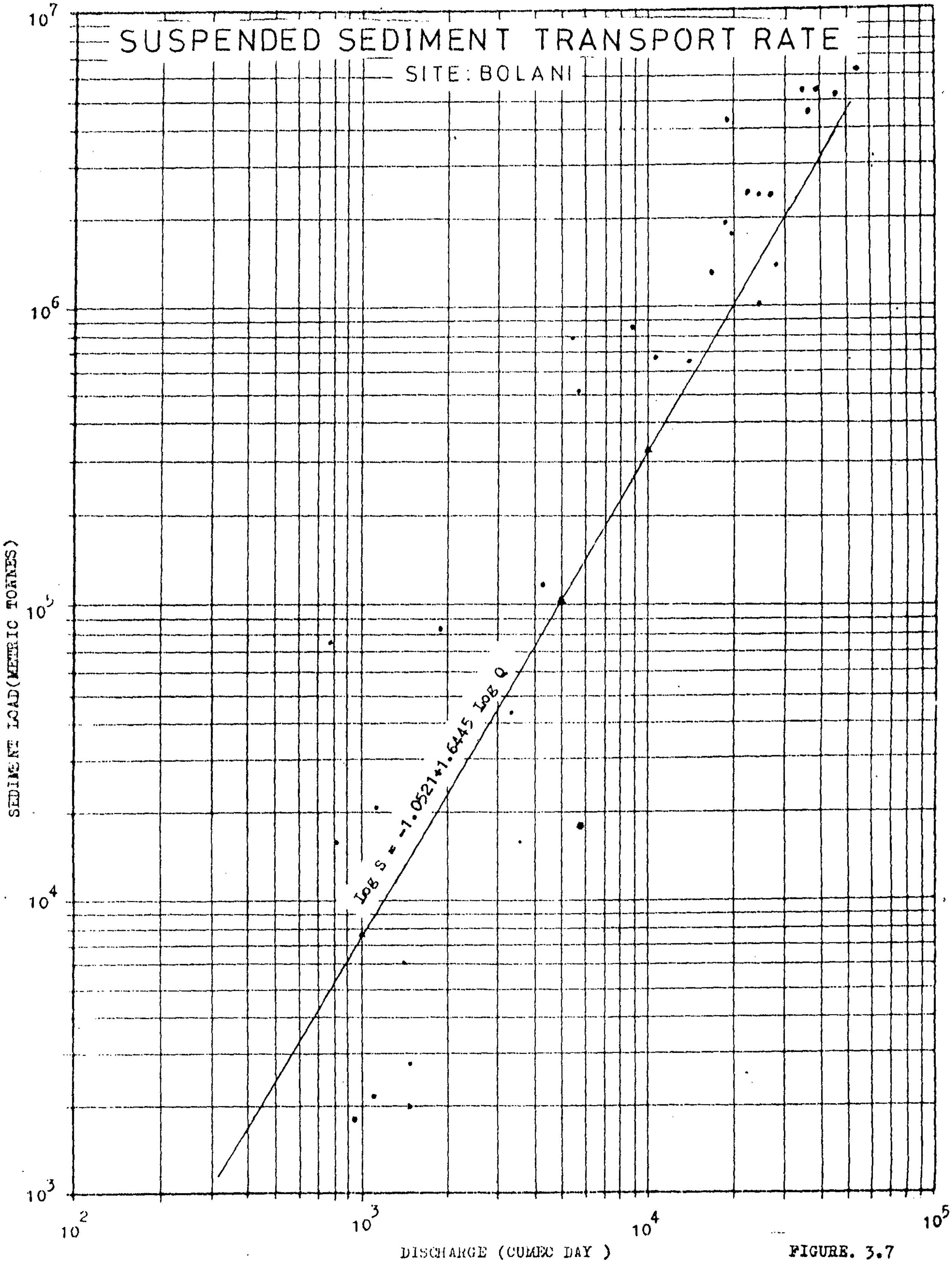
Amount of sediment transport is an index to soil loss as the weathered materials to be/or transported from the pedosphere. Sediment transport is also a function of head difference and slope of the channel, as an increase or decrease of gradient leads to a corresponding degradation or aggradation. As a result of this, the foot hills are marked with alluvial fans or cones and resorvoir or dam face the problem of siltation. In India survey of 21 resorvoirs has indicated that they received sediment at a rate of 8.51 ha.m(100 km^2 $yr)^{-1}$ as against the designed inflow of 3.02 ha.m(100 km^2 $yr)^{-1}$. This represents 182 percent more inflow of sediment than the designed inflow.[14]

Sediment load by their mode of transportation can be designated as "bed-load, wash load and suspended - Load".[15] Here, for the Sankh and South Koel river basins suspended sediment load has been analysed from the

---

14. Gupta, G.P. (1975): Sediment Production Status Report on Data Collection and Utilization, "Soil Conservation Digest", V.3, No. 2., pp. 10-21.

15. Rittter , D.F. (1986) : Process Geomorphology, pp. 211-12.



SUSPENDED SEDIMENT TRANSPORT RATE
SITE: BOLANI
Log S = -1.0521+1.6445 Log Q
SEDIMENT LOAD(METRIC TONNES)
DISCHARGE (CUMEC DAY)

FIGURE. 3.7

same three sites for a period of five years from 1980-81 to 1984-85. Correlation and regression analysis have been done for river discharge and sediment load for the sites Bolani, Jaraikela and Tilga.

Sediment load at Bolani site during the stated period presents an annual mean of 10192512 metric tonnes with a coefficient of variation of .1827. Out of this yearly mean load, 10171863 m.t. or 99.8 % of it are transported during monsoon period and the rest 101290 mt. (0.31%) during non-monsoon period. Relationship between monthly total discharges (in cumec day) and sediment load, after reducing them into log value , for monsoon period has been established. The highest and lowest sediment carried away are 6112105 (August' 84) and 1770 metric tonnes(Nov. 82) respectively. Correlation coefficient of for these two parameters is 0.7276 and slope of regression line is 1.644.(Fig. 3.7).

Jaraikela site located on S.Keel river has a mean annual sediment load of 4917669 metric tonnes out of which 4891521 m.t. (99%) forms average for monsoon period. Highest sediment load during this period was 3467566m.t. in August '84. and lowest was in November'80 with 981 m.t. Mean monthly value for month of August is 1828100.2 metric tonnes and lowest

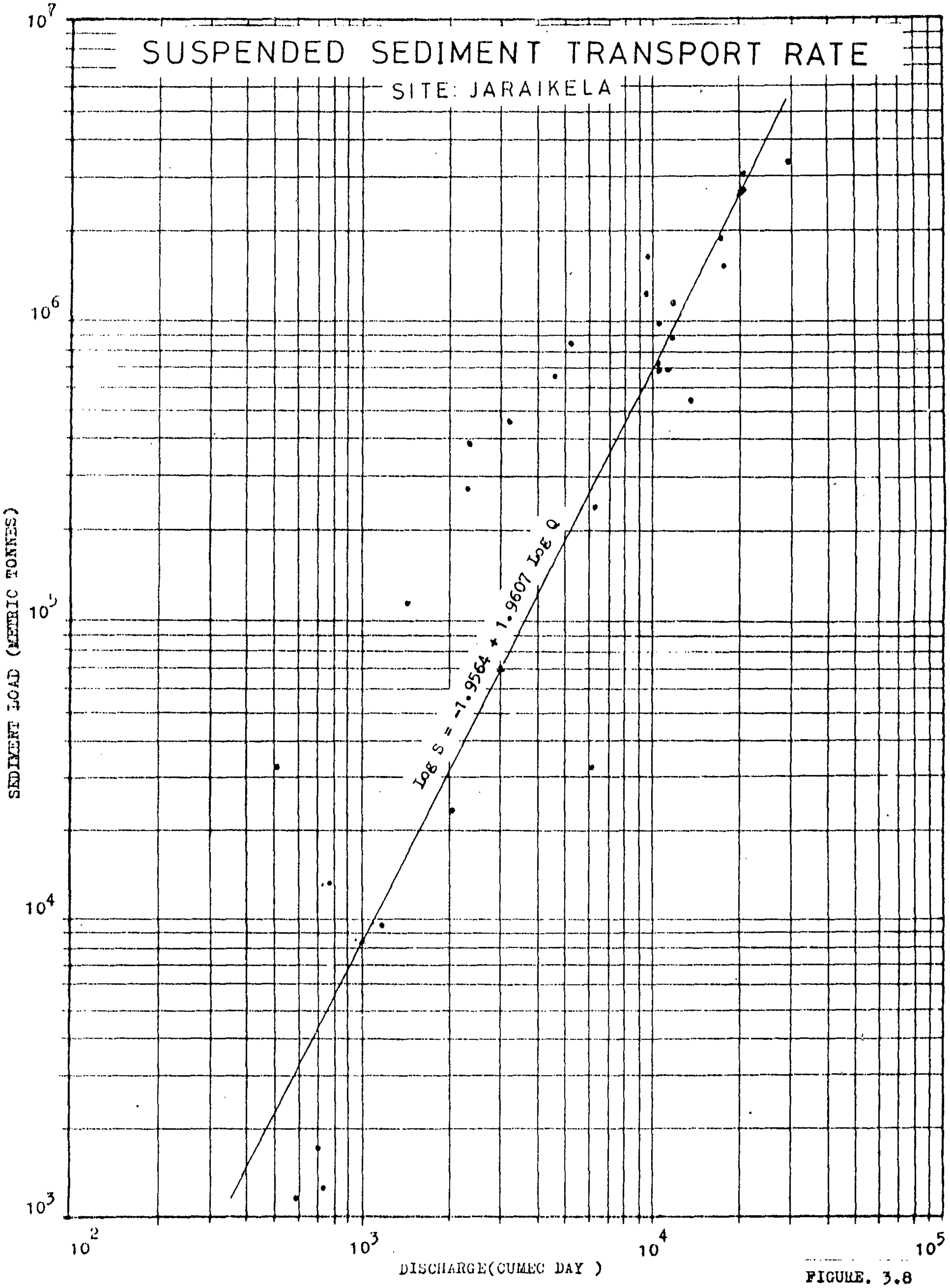

SUSPENDED SEDIMENT TRANSPORT RATE
SITE: JARAIKELA
Log S = -1.9564 + 1.9607 Log Q
SEDIMENT LOAD (METRIC TONNES)
DISCHARGE(CUMEC DAY)
10^7
10^6
10^5
10^4
10^3
10^2
10^3
10^4
10^5

FIGURE. 3.8

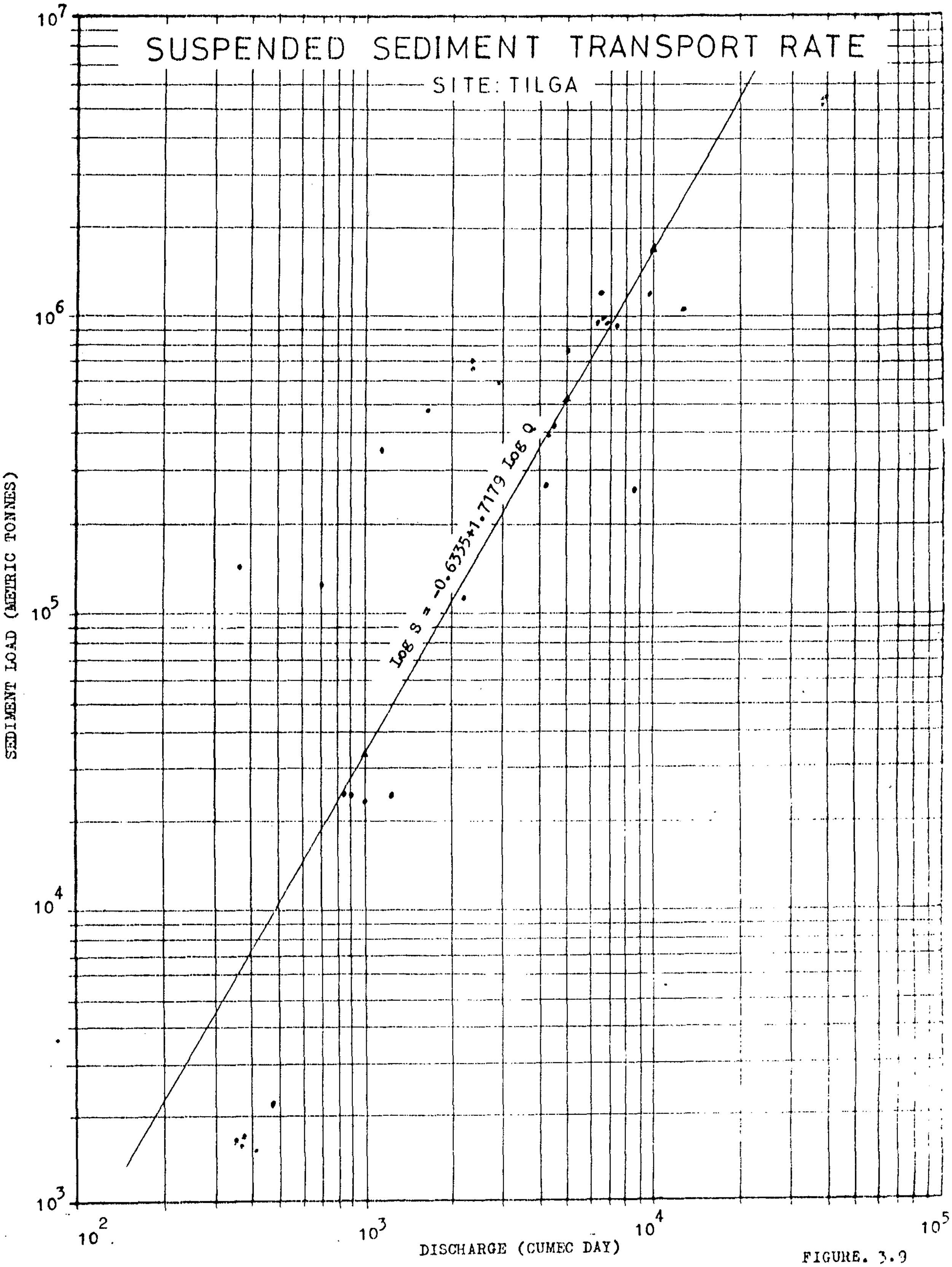

SUSPENDED SEDIMENT TRANSPORT RATE
SITE: TILGA
Log S = -0.6335+1.7179 Log Q
SEDIMENT LOAD (METRIC TONNES)
DISCHARGE (CUMEC DAY)
10^7
10^6
10^5
10^4
10^3
10^2
10^3
10^4
10^5

FIGURE. 3.9

monthly mean is represented by Nov. with 1253.2 m.t. Coefficient of correlation between log values of monthly total discharge and sediment load is .9105 and slope of regression line is 1.9607 on a double log graph Fig. (3.8).

As the recording at Tilga commenced from mid June'80, sediment load are analysed from July'80. In most part of the non-monsoon period there is either negligible flow or bed remains dry. Monsoon period carries bulk of sediment (2473997 metric tonnes) which accounts for 98.8% of the mean annual value of 2503792 metric tonnes. Coefficient of variation of yearly sediment load for monsoon period is 0.1678 and for whole year is 0.1594. Maximum sediment carried away during the five years period is during September 1983 with a total of 1132230 metric tonnes. Lowest amount of sediment was carried away during November 1981 with a total of only 1356 metric tonnes for monsoon period. Correlation coefficient between monthly sediment load and discharge is 0.8539 and slope of the regression line is 1.7179 when both the variables are plotted on log scale. Fig. (3.9).

Catchment hydrology can never be considered or analysed isolatedly as the topography, soils, etc. are the operating factor in deciding how fast and how much water will find its way from the catchment. And in a reciprocal maner they are affected by eroding power of the flow of the water leading to soil erosion. Hence, it is required to have detailed knowledge of soil type, depth, permeability, etc. So the succeeding chapter is devoted to throw light on the pedological aspects of the basin.

CHAPTER - 4

PEDOLOGICAL ASPECTS

Soil, a "dynamic layer"[1] having a "space-time continuum"[2] forming the upper part of the earth's crust "composed of minerals and organic materials"[3] in which "complex chemical, physical and biological activities are going on constantly"[4] acts as "the basis of production of agriculture and forestry"[5] and forms "an important component of human environment"[6].

At any one time and place on the landmass of the earth, there are five factors at work simultaneously making soil from parent material. Hence, soil is a function of (Climate, Biosphere, Relief(topography), Parent material and Time)[7]. Out of them climate,

---

1. Strahler, A.N. (1975): Physical Geography, p.293.
2. FitzPatric, E.A.(1980): Soils, Their formation, classification and distribution, p.7
3. Brady, Nc.(1974): The nature and properties of soils, p.617.
4. Strahler, A.N., op.cit., p.293.
5. Zacher, D (1982): Soil Erosion, p.9.
6. Zacher, D, op.cit., p.9
7. Jenny. H. (1941) : Factors of Soil Formation. Quoted from Soil Conservation and Water Management by Arakeri H.R. & Donahue, R. (1984) : p.21.

and biosphere are active factors; relief and parent material are passive factors; and time is a neutral factor.[8]

Watershed management has a great concern with the pedological characteristics of the concerned region.[9] Soil erosion due to water arises when infiltration rate of soil is low or rainfall does not penetrate the soil and the excess runs off the land transporting the detached soil particles through its course. The detached materials are usually the top soil where plant nutrients are most heavily concentrated. Repeated transportation of soil results in exposure of sub soil, which are being more impermeable in nature often leads to a lower rate of water entry, increased run off and further accelerates the soil loss. Hence a comprehensive study of soil

---

8. Arakeri, H.R. & Donahue, R.(1984): Soil Conservation and Water Management, p.21.

9. Greenland D.J. - (1977): 'Soil Structure and Erosion Hazard'. In Soil Conservation and Management in Humid Tropics, by Greenland D.J. & Lal , R.(edt), p.17.

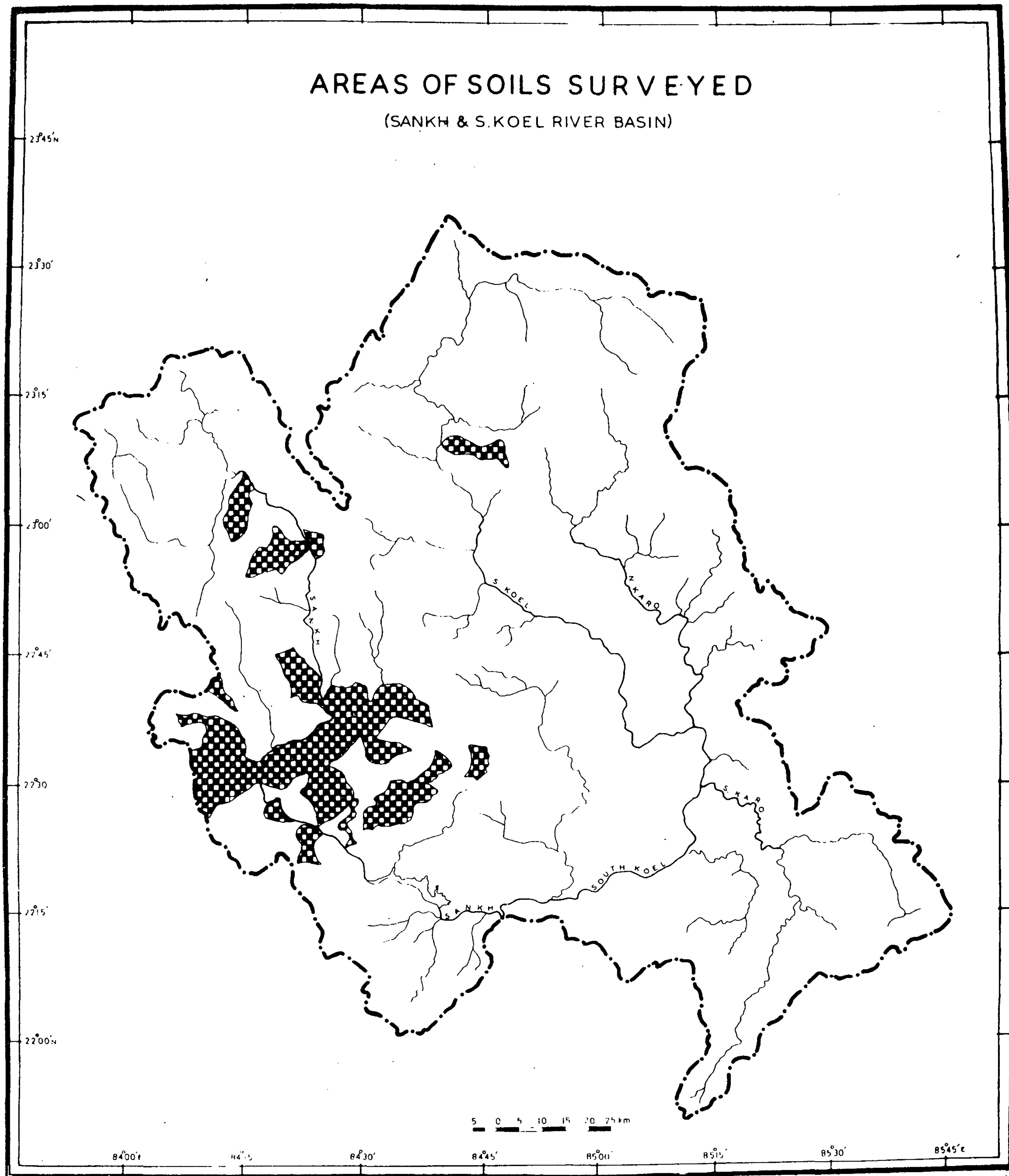

AREAS OF SOILS SURVEYED
(SANKH & S.KOEL RIVER BASIN)
SANKH
S.KOEL
N.KARO
S.KARO
SOUTH KOEL
SANKH
5 0 5 10 15 20 25 km

FIG. 4.1

structure, texture, depth etc. is required for better soil conservation practices. So far, in Sankh and S.Koel basin only 1469.76 km^2 has been surveyed out of 19345 km^2. (Fig. 4.1)

Soil Structure

This refers to the way in which soil grains are grouped together into larger pieces. Pore spaces are corollary to soil structure and is a factor affecting permeability of soil. Soil structure are mainly described in five ways, viz. granular, blocky, prismatic, columnar and platy. Soil series found in the surveyed area of the Sankh and S.Koel river basins are mainly subangular blocky to massive subangular blocky. In former soil structure type Amgaon, Bargaria, Bendukani, Edla, Latu, Parkala, Pashibali, Rengalbeda, Sarabmunda, Sarma, Tileibani, Dhaurgoth, Biru, Balia series etc. are included. In latter Amra, Bathantoli soil series etc. are included.

Soil Texture:

Soil texture is an important characteristics of soil, refers to particle sizes composing the soil.[10] The mechanical constituents of soil are clay, silt and sand. These three constituents are represented by three sides of a triangular graph[11]. Three corners of the triangle represent 100 percent of each of the three grades of particles. Percentile values of the constituents are plotted on the graph to classify the particular soil type to particular soil texture group. Soil texture of each soil of the surveyed region of Sankh and S.Koel river basin are described in "Description of Soil Series."

Soil Depth:

Soil depth is a conspicuous indicator of soil erosion and replenishment. Soil depth is a

---

10. FitzPatric, E.A.(1980): op.cit., p.88. "The texture of soil refers to feel of the moist soil resulting from the mixture of constituent mineral particles and organic matter. Therefore, it is an approximate measure of particle size distribution or mechanical composition which is measured in the laboratory."

11. U.S.D.A. (1969): Soil Survey Manual, p.209.

TABLE No. 4.1

SOIL DEPTH CLASS

(SANKH AND S. KOEL RIVER BASIN) (Area in hectares)

Sl. No.	SOIL SERIES	DEPTH CLASS d_1	DEPTH CLASS d_2	DEPTH CLASS d_3	DEPTH CLASS d_4	DEPTH CLASS d_5	TOTAL
1	AMGAON	-	-	-	-	57	57
2	AMRA	14570	6295.5	-	-	-	20865.5
3	ARRAH	-	-	-	-	280	280
4	BALIA	-	-	-	-	10203.7	10203.7
5	BARGARIA	-	-	-	-	277	277
6	BATHANTOLI	-	-	-	7494	-	7494
7	BENDUKANI	15	1602	-	-	-	1617
8	BIRU	-	-	-	-	831	831
9	CHOI	-	-	-	-	151	151
10	DEOBAHAR	-	-	-	-	18	18
11	DHAURGOTH	-	-	692	-	-	692
12	DIPATOLI	-	-	-	-	104	104
13	DUMKA	3282.8	18005.2	-	-	-	21288
14	EDLA	-	-	-	-	45	45
15	HATHIPATHAR	-	-	-	-	4715.7	4715.7
16	JAMKATHI	-	-	-	-	27	27
17	JARMUNDI	-	-	-	-	1047	1047
18	JETHUBANDH	-	3463	-	-	-	3463
19	KANTI	-	-	-	-	25	25
20	KARAYA	-	-	-	-	9954	9954
21	KAURIYA	-	-	-	-	14	14
22	KHINDA	-	128	-	-	-	128

(Contd.)

Sl No.	SOIL SERIES	DEPTH CLASS d_1	DEPTH CLASS d_2	DEPTH CLASS d_3	DEPTH CLASS d_4	(DEPTH CLASS d_5	TOTAL
23	KONGSERA	-	-	-	177	-	177
24	KURMIA	-	-	-	-	539	539
25	KURNKEL	-	977	-	-	-	977
26	LACHMIPUR	-	-	7175	-	-	7175
27	LATU	-	-	452	-	-	452
28	MAJHAULI	-	-	-	-	1963	1963
29	NAGAR	-	-	-	-	360	360
30	NANDWA	76	256	-	-	-	332
31	NAWADIH	-	-	404	-	-	404
32	NORATOLI	-	-	-	-	752	752
33	PARKALA	-	-	-	2817	-	2817
34	PASHIBALI	-	-	-	763	-	763
35	PUSARO	-	-	-	-	21185.6	21185.6
36	RAMPUR	-	-	-	-	307	307
37	RANGA	-	-	-	85.7	-	85.7
38	RENGALBEDA	-	339	-	-	-	339
39	RENGARI	-	-	106	-	-	106
40	SARABMUNDA	100	1123	-	-	-	1223
41	SARMA	-	-	-	-	538	538
42	SARMA	-	-	-	-	10577	10577
43	SILPHARY	-	-	-	-	82	82
44	TARABOGA	-	-	-	-	162	162
45	TECHATOLI	-	-	-	-	2304	2304
46	TILEIBANI	-	-	-	-	270	270
	TOTAL	18043.8	32188.7	8829	11336.7	66789	137 187.2

function of rate of soil formation minus rate of soil erosion. Table 4.1 shows detailed depth class[12] of each soil series. Depth class

Depth Class d_5 - Amgaon, Arrah, Balia, Bargaria , Biru, Choi, Deobahar, Dipatoli, Edla, Hathipathar, Jamkathi, Jarmundi, Kanti, Karaya, Kauriya, Kurmia, Majhauli, Noratoli, Pusaro, Rampur, Sarma, Sarua, Silphary, Taraboga, Techatoli, and Tileibani soil series come under the depth class of d_5, whose range in upper limit is 127-152 cm. and lower limit is 152 + cm. This depth class in total covers 667.89 km^2 which is 45% of the total surveyed area. This provides an information that a high percentage of area of the watershed has very deep soils.

Depth class d_4 - Soil series like Bathantoli, Kongsera, Parkala, Pashibali, Ranga have soil

---

12. As per soil depth class recommended by Soil Survey Manual U.S.D.A., 1969.

depth of 76-127 cm. in upper range in limits to 152 + cm. in lower range of limits. These five soil series comprise only 113.36 km^2 i.e. 8% of the total surveyed area.

Depth class d_3 - In moderately deep (or moderately shallow) depth class, whose upper range in limit is 51-76 cm. and lower range in limits is 76-127 cm. or 152 + cm.) soil series like Dhaurgoth, Lachmipur, Latu, Nawadih, and Rengari are included. They cover an area of only 88.29 km^2 which is only 6% of the total surveyed area.

Depth class d_2 - Soil series of Jethubandh, Khinda, Rengalbeda and 30% of Amra soil, 99% of Bendukani soil, 85% of Dumka soil, 77% of Nandwa series and 92% of Sarabmunda soil are included in this depth class d_3 whose upper range in limits is 13-25 cm. and lower range in limits is 51-76 cm. Total area covered by these soils is 321.887 km^2 and comprises 22% of the total surveyed area.

Depth class d_1 - The only soil that contributes higher percentage of its total (i.e. 70%) to very shallow soil depth class is Amra soil.

Other soils which contribute to this depth class are Bendukani, Dumka, Nandwa and Sarabmunda. The upper range in limits of this depth class is 0 cm. and lower range in limits is 13-25 cm. Total area covered by this depth class is 180.44 km^2 which is 12% of the total surveyed area.

Soil and Landform :

Landforms are the products of the function of structure, process and time.[13] It is an essential part of soil characteristics "conceived as a three dimensional landscape resulting from the synthetic effect of all materials and processes in its environment".[14] Kinds of soil profiles are the results of kinds of landform which influences former's genesis. Unlike other features of soil landform by itself is not a sufficient basis for differentiating between soil series, rather it is

---

13. Davis, W.(1899): The Geographical Cycle, "Geographical Journal" V. 14, pp. 481-504.

14. U.S.D.A., op.cit., p.155.

usually associated with other differentiating characteristics. As the landform have relationship with stratigraphy, nature of materials etc. cannot be separated from soil differentiating character. Micro relief is in most of the situations are responsible for various special soil features, like terrace materials, typical chemical compositions, concentration of particular materials(placer deposits) etc.

Soil catena is the best representative model for relief drainage and soil type relationships.[15] Plateau regions are poorly drained, upper slope region and lower slope region are freely drained, slope foot are poorly drained and low land are water logged produce a sequence of soil of peat, brown earth, gley and peat respectively.

In Sankh and South Koel river basins escarpments are covered by Amra and Sarabmunda soils; upper convex

---

15. Twidale, C.R., 1975: Analysis of Landforms, p.192.

slope are covered by Kurnkel,Lachmipur and Parkala series; convex depositional upland/slope by Parkala, Lachmipur, Rengari and Kongsera soils; convex erosional slopes by Dumka, Latu, Lachmipur, Nandwa soils; back slopes are covered by Dumka soils; upper piedmont are covered with Balia, Ranga, Silphary, Taraboga, Bathantoli and Pusaro soils; upper valley plan by Pusaro, Kurmia and Arrah; lower valley plain by Techatoli, Rampur, Jamkathi, Jarmundi, Deobahar, Halthipathar and Biru soils; valley bottom or depressions are covered by Sarua, Noratoli, Karaya, Jethubandh and Choi soils; Levees are covered by Karaya soils; and river terraces with Dipatoli and Kanti soils.

Soil and Slope:

Soil slope is used in defining soil classificational units. As soil is a main factor in controlling rate and amount of run off, erodibility of soil and use of agricultural machinery, is given special attention to define a permissible slope range for each soil type which is required for prescribing

TABLE No.4.2

SOIL SLOPE CLASS

(SANKH AND S. KOEL RIVER BASIN) (Area in hectares)

Sl No	SOIL SERIES	A	B	C	D	E	F	G	H	I	TOTAL
1	AMGAON	57	-	-	-	-	-	-	-	-	57
2	AMRA	-	-	-	474.2	11642	1029	6091	1597.3	32	20865.5
3	ARRAH	280	-	-	-	-	-	-	-	-	280
4	BALIA	-	3508.9	6395.8	299	-	-	-	-	-	10203.7
5	BARGARIA	-	-	277	-	-	-	-	-	-	277
6	BATHANTOLI	-	518	6448	528	-	-	-	-	-	7494
7	BENDUKANI	-	-	1582	35	-	-	-	-	-	1617
8	BIRU	-	71	760	-	-	-	-	-	-	831
9	CHOI	-	-	151	-	-	-	-	-	-	151
10	DEOBAHAR	-	18	-	-	-	-	-	-	-	18
11	DHAURGOTH	-	-	692	-	-	-	-	-	-	692
12	DIPATOLI	-	104	-	-	-	-	-	-	-	104
13	DUMKA	-	144.7	5132.3	16011	-	-	-	-	-	21288
14	EDLA	-	-	45	-	-	-	-	-	-	45
15	HATHIPATHAR	1266	887.7	2562	-	-	-	-	-	-	4715.7
16	JAMKATHI	-	27	-	-	-	-	-	-	-	27
17	JARMUNDI	-	30	863	154	-	-	-	-	-	1047
18	JETHUBANDH	244	3	3216	-	-	-	-	-	-	3463
19	KANTI	-	25	-	-	-	-	-	-	-	25
20	KARAYA	-	804	9150	-	-	-	-	-	-	9954
21	KAURIYA	-	6	8	-	-	-	-	-	-	14
22	KHINDA	60	30	38	-	-	-	-	-	-	128
23	KONGSERA	-	15	162	-	-	-	-	-	-	177
24	KURMIA	-	354	185	-	-	-	-	-	-	539
25	KURNKEL	-	39	689	249	-	-	-	-	-	977
26	LACHMIPUR	-	271	6505	399	-	-	-	-	-	7175
27	LATU	-	-	315	137	-	-	-	-	-	452

(Contd.)

Sl No.	SOIL SERIES	A	B	C	D	E	F	G	H	I	TOTAL
28	MAJHAULI	-	524	1439	-	-	-	-	-	-	1963
29	NAGAR	-	-	360	-	-	-	-	-	-	360
30	NANDWA	-	-	172	160	-	-	-	-	-	332
31	NAWADIH	-	404	-	-	-	-	-	-	-	404
32	NORATOLI	-	752	-	-	-	-	-	-	-	752
33	PARKALA	-	231	2579	7	-	-	-	-	-	2817
34	PASHIBALI	-	93	670	-	-	-	-	-	-	763
35	PUSARO	-	4456.1	16585.5	144	-	-	-	-	-	21185.6
36	RAMPUR	-	307	-	-	-	-	-	-	-	307
37	RANGA	-	9.2	76.5	-	-	-	-	-	-	85.7
38	RENGALBEDA	-	-	339	-	-	-	-	-	-	339
39	RENGARI	-	-	106	-	-	-	-	-	-	106
40	SARABMUNDA	-	-	-	-	24	66	1055	78	-	1223
41	SARMA	-	-	538	-	-	-	-	-	-	538
42	SARUA	1626	520	8431	-	-	-	-	-	-	10577
43	SILPHARY	-	82	-	-	-	-	-	-	-	82
44	TARABOGA	-	136	26	-	-	-	-	-	-	162
45	TECHATOLI	-	254	1765	285	-	-	-	-	-	2304
46	TILEIBANI	-	123	147	-	-	-	-	-	-	270
	TOTAL	3196	15084.6	78410.1	18882.2	11666	1095	7146	1675.3	32	137187.2

land use pattern and management practices. Significance of slope is related to other characteristics of soil, hence, broad classes of soil slope without reference to other soil characteristics have no consistent , to capabilities of the soil for use.

Soil slope is normally measured with the help of Abney hand level and expressed in terms of percentage. Following soil slope classes from A to I has been taken to describe soil series. Table 4.2 shows detail distribution for each individual soil series.

A Class - This class comprises level or nearly level soil areas on which run off is slow or very slow. Soil slope offers no difficulty in the use of agricultural machinery, nor there is likelihood of significant water erosion except possibly on very slopes of highly erodible soil. The range of slope for this class is 0-1% ($0^{o}00'$ - $0^{o}34'$). In this category no soil series is found contributing a major proportion. Sarua soils contribute 16.26 km^2 i.e. 15% of its total area is the highest.

Hathipathar soils comes next with a total accurence of 12.66 km^2. Jethubandh contribute 2.44 km^2 and Khinda only 60 hectares. Total area under this class is 31.96 km^2 which constitute only 2% of the total surveyed area.

B class - This class consists of very gently slopping or nearly level of 1-3% ($0^{o}34'$ - $1^{o}43'$) of slope. All sorts of agricultural machinery can be used. Erosion of soil is very low and that is confined to highly erodible soils. Soil series like Pusaro, Balia, Hathipathar, Karaya, Noratoli, contribute 44.56 km^2, 35.089 km^2, 8.877 km^2, 8.04 km^2 and 7.52 km^2 respectively. Besides these soils Arrah, Dumka, Bathantoli, Majhauli, Sarua, Kurmia, etc. contribute to this class. The total area covered by this class is 150.846 km^2 which is 10% of the total surveyed area.

C Class - This class consists of gently slopping soils of 3-5% ($1^{o}43'$ - $2^{o}51'$) of slope. These soils are moderately drained and have little higher erodibility factor than earlier categories.

All types of ordinary machinery can be used. In Sankh and South Koel river basin out of 46 soil series found, 34 soils contribute more or less to this class. Highest contributing soil is Pusaro followed by Karaya, Sarua, Lachmipur , Bathantoli, Balia, Dumka, with 165.855 km^2, 91.50 km^2, 84.31 km^2, 65.05 km^2, 64.48 km^2, 63.96 km^2 and 51.32 km^2 respectively. This class accounts for highest percentage i.e. 53.349% of land of the total surveyed area and covers 784.101 km^2.

D class - This class represents moderate slopping soils with a slope of 5-10% ($2^o51'$ - $5^o42'$). In this gently rolling, rolling or moderately slopping soil areas run off is medium to rapid for most soils. Soils with D class slope vary widely in erodibility under cultivation, depending upon other soil characteristics and management practices. Erosion offers no serious problem and can be controlled by relatively simple practices. But on highly eradible soils careful management is needed for controlling soil erosion. Total area under this class is 188.822 km^2 which is 13% of the total surveyed area. Main soil series contributing to this soil class is Dumka with 160.11 km^2. Other soils contributing are Bathantoli, Amra and Techatoli.

E Class - This class is made up of strongly slopping areas of 10-15% ($5^{o}42'$ - $8^{o}31'$) slope on which run off is rapid or very rapid on most soils. Unless the slope is very complex, most farm machinery can be used with difficulty. Out of total 1369.76 km^2 of surveyed area only 116.66 km^2 i.e. only 8% comes under this class. Out of this 116.66 km^2 116.42 km^2(99.79%) is covered by Amra soils and the rest 24 hectare is covered by Sarabmunda soils.

F class - This class consists of moderately steep soils of 15-25% ($8^{o}31'$-$14^{o}2'$) slope where run-off is quite rapid and responsible for water erosion except for the most pervious ones. Mechanized farming is difficult. These soils are suited for intertilled crops and pastures. Total area under this class is negligible in Sankh and S.Koel river basin only 0.7% of total area surveyed area fall in this category. Soil series contributing are Amra with 10.29 km^2 and Sarabmunda with 0.66 km^2.

G Class - In this steeply slopping class run-off is very rapid on most soils. Only lightest type of agricultural machinery can be used. Grass, orchards, or even intertilled crops with proper management can be practised if the soil is highly fertile. The slope varies from 25 to 35% ($14^{o}2'$ - $18^{o}15'$) for this slope class. 5% of the total surveyed area is covered by Amra (60.91 km^2) and Sarabmunda (10.55 km^2) soils.

H Class - Very steep slopes are included in this class where slope ranges from 33-50% ($18^{o}15'$ - $26^{o}33'$). Practically such soils are of very little use and vulnerable to all forms of water erosion. Only very fertile and permeable soils are included in this category otherwise classified as miscellaneous land type. Amra soil contribute 15.973 km^2 i.e. 95.34% of its total occur. The other soil contributing it is Sarabmunda with only 0.78 km^2.

I Class - This is the extremely steep soil slope class whose slope is >50% (> $26^{o}34'$) which is unsuitable to any type of agricultural land use. Runoff is extremely rapid besides those areas falling in fracture zones or unusually high permeable soils. Little rain contribute to surface runoff and thus , causes severe erosion. Only 32 hectare of

Amra soil comes under this class which is only 0.02% of the total surveyed area.

Soil and Geology:

Out of five principal soil forming factors parent material is the basic one. The residuals or transported over-burden of disintegrated rock makes the bulk of the soil. Through the process of weathering parent material is reduced to colloidal size and changed chemically into new compounds. Besides the transported soils like loess and alluvium other depend upon parent material for its differentiating characteristics viz- colour, texture, chemical composition etc. Hence, geology of the region is quite important for the genesis of individual soil series. More than one soil series can be produced from a single type of parent material as other factors do affect greatly for soil genesis. Granitic gneiss, quartzite, quartzite-gneiss, mica-schist with quartzite - schist, recent alluvium and old alluvium are prevalent parent materials found in Sankh and South Koel river basin. Soil series like Dumka, Nawadih, Balia, Arrah, Hathipathar, Karaya, Amra, Bathantoli, Pusaro, Lachmipur, Jarmundi, Techatoli, Khinda, Sarua, Jethubandh, Choi, Majhauli, Biru and Nagar are found on gramtic gneiss. On quartzite and quartzitic schist Jarmundi, Hathipathar, Deobahar, Rengari and Parkala soil series are developed. On colluvium or alluvium Sarua soil series is developed on old and recent alluviums respectively. Latu soils are developed on lateritic parent materials.

DESCRIPTION OF SOIL SERIES:*

Soils found in Sankh and S.Koel river basin are Alfisols, Entisols and Vertisols. Alfisols are characterised with mineral soils; relatively low in organic matter; relatively high in base saturation; an illuvial horizon of sillicate clays; moisture adequate to mature a crop. Entisols are characterized with mineral soils, pedogenic horizoms weakly developed or absent; no deep wide soil cracks in most years. Inceptisols are mineral soils with relatively low in organic matter or base saturation or both; some pedogenic horizons

* As per All India Soil and Land Use Survey, New Delhi.

and some weatherable minerals; no horizon or illuvial clays and water is adequate in most years to mature a crop. Vertisols are mineral soils characterised with very high in clay; deep, wide cracks at sometimes in most of years.

The soil taxonomy used here are of U.S.D.A. Soil Taxonomy.[15] Soil orders has been sub classed further into suborder, great group, sub group, family and series. Soil series are named after the local name where it is found first. Major soils are described which are found in the Sankh and South Koel river basins.

Amra Series - Amra series is a member of loamy skeletal, mixed hyperthermic family of lithic ustrorthents, comprises shallow, dark, brown to dark reddish brown, moderately coarse, skeletal soils, developed over granitic gneiss. The soil occur on hill slopes and escarpments. It is extensively drained and have a rapid permeability with a basic infiltration rate of 7.1 cm. hr^{-1}.

This soil series extends for an area of 208.655 km^2 or 14% of the total area surveyed.

---

15. U.S.D.A(1975):Soil Taxonomy Manual.

Pusaro Series - Pusaro series is a member of clayey, mixed hyperthermic family of Udic paleustalf. It comprises very deep, reddish brown, moderately fine to fine textured soils developed over granitic gneiss on very gentle to gentle foot slopes. Clay cutans are met with within a depth of 50 cm. Oxidation mottles and ferromanganese concentration are present within the soil profile in lower part of 'B' horizon. The soils are moderately drained and have rapid permeability with a infiltration rate of 8.9 cm. hr^{-1}.

This soil series occupies second highest percentage of area i.e. 14% of total surveyed area and accounts for a total of 211.856 km^2,

Dumka Series - Dumka series is a member of the loamy skeletal mixed hyperthermic family of Typic ustorthent. It comprises shallow, yellowish brown to dark brown, medium to fine textured soils developed over granitic gneiss on gently slopping convex uplands. The soils are well .ained and have high permeability with a basic infiltration rate of 8.5 cm.hr^{-1}. These soils can be used for occasional cultivation under adequate soil conservation measures and impro ed agronomic practices.

This is the highest occuring soil of the region. It covers 212.88 km^2 which becomes 14% of the total surveyed area.

Sarua Series - Sarua series is a member of fine loamy mixed hyperthermic family of Aeric Ochraqualf. It comprises very deep, dark, greyish brown, gravelly, fine textured soils developed over granitic gneiss on local depressions. Soils are poorly drained and have slow permeability with a basic infiltration rate of 0.6 cm. hr^{-1}.

Total area under this soil series is 105.77 km^2 which is 7% of the total surveyed area.

Balia Series - Balia series is a member of fine loamy, mixed hyperthermic family of Udic rhodustalf. It comprises very deep, reddish brown to strong brown, medium to moderately fine textured soils developed over granitic gneiss. They are found to occur on gently to moderately slopping convex uplands. Stress cutans are present within one metre depth. Average depth of this soil is 154 cm. and the permeability is rapid with a basic infiltration rate of 8.1 cm. hr^{-1}.

Area covered by this soil series is 102.037 km^2, which is 7% of the total surveyed area.

Karaya Series - Karaya series is a member of fine loamy mixed hyperthermic family of Typic haplaqualf. It comprises silty loam to silty clay type texture with subangular blocky surface structure, developed over granitic gneiss on basin or depressions. This soil has medium permeability with a basic infiltration rate of 1.6 cm. hr^{-1}.

Total area covered by this soil is 99.54 km^2 which is 7% of the total surveyed area of 1469.76 km^2.

Bathantoli Series - Bathantoli series is a member of fine loamy mixed hyperthermic family of Udic haplustalf. It comprises sandy loam to sandy dry loam texture and massive structure developed over gently slopping foot hills. This soil series has a very high permeability with a infiltration rate of 12.6 cm.hr^{-1}.

Total area covered by this soil series is 74.95 km^2 which is 5% of the total surveyed area and stands at 7th place.

Lachmipur Series - Lachmipur series is a member of the coarse loamy, mixed, hyperthermic family of Udic haplustalf. It comprises moderately deep, dark brown to reddish brown, moderately coarse to medium textured soils developed over granitic gneiss on gently slopping convex uplands. Soils are well drained and have high permeability with a basic infiltration rate of 14.1 $cm.hr^{-1}$. The soils are associated with the problems of moderate to severe sheet erosion.

Area covered by Lachmipur soil series is 71.75 km^2 which is 5% of the total surveyed area.

Hathipathar Series - Hathipathar series is a member of fine loamy mixed hyperthermic family of Aeric ochraqualf. This comprises silty clay loam surface texture and sub-angular blocky structure developed on granitic gneiss on the toe slopes. Permeability of soil is low and the basic infiltration rate is 1.3 cm. hr^{-1}.

Area occupied by this soil is 3% of the total surveyed which accounts for 47.157 km^2 and stands at 9th place.

These above nine soil series are most abundantly found in comparison to rest thirty seven soil series. In total they cover an area of 1134.585 km^2 which is 77% of the total surveyed area of 1469.76 km^2 of Sankh and South Koel river basins.

SOIL EROSION:

Erosion is the primary landscape modelling factor. Soil erosion generally means the destruction of soil by action of water and wind but a complete list will contain snow, ice, animals, man etc. in addition. In humid tropics main types of erosion are precipitation or pluvial erosion and water erosion. In former erosion caused by torrential rain is "imbric erosion"[16] and by raindrop is raindrop erosion or "guttation".[17] The second stage of erosion caused by precipitation is that resulting from surface runoff on slopes, and is called slope or "declival erosion".[18] Water erosion refers to flurial erosion or "flurosion"[19] which is part of fluviation and also to stream erosion.

---

16. Zacher, D. (1982): op. cit., p.31.
17. ibid. p.31.
18. ibid. p.32.
19. ibid. p.32.

Factors affecting soil erosion :

Soil erosion is simply not a function of any single factor rather it includes animal, climate, erodibility of soil, geology, landform, relief , slope, rain, forest or vegetative cover, human activity(anthropogenic), etc.

Raindrop effect - In humid tropical region raindrop erosion is more conspicious, since the "concentration of soil in the runoff water increases with the energy of raindrops".[20] Kinetic energy of rainfall is a basic factor in determining the erosivity of rain. Total Kinetic energy available for erosion depend on the velocity of raindrop,[21] which is directly controlled by ceiling of cloud; intensity and the structure.[22]or proportion of raindrops with

---

20. Laws, J.O. (1941): Measurement of fall velocity of water drops and raindrops. "Transactions of the A.G.U.", V.22, p.709.

21. Gunn, R. and Kinzer, G.D. (1949), Terminal velocity of water droplet in stagnant air, "Journal of Metorology", V.6, p.243.

22. Laws, J.O., and Parsons D.(1943): The relation of raindrop size to intensity."Tr. of A.G.U.", V. 22, p.709.

critical and larger than critical kinetic energies, duration and total amount of rain. In Sankh and South Koel river basin, the rainfall is mansoonal in nature (70-80% of total rainfall during mansoon period). Cloud bursts accelerates the soil erosion with its larger droplets and long duration. In general, "the amount, kind, and time of occur of precipitation and related climatic factors"[23] act as erosion hazard.

Popular wisdom insists that planting trees will prevent erosion and that removing trees, per se, results in drastic soil erosion leading to land degradation. Trees and particularly trees in forest stands do indeed reduce the amount of erosion, and conventional wisdom coincide with the proven effects. "Soil erosion under dense natural humid and seasonally humid forest is usually less than one ton per hectare"[24] However, "substantial

---

23. Stevens, M.E. (1976) - Erosion hazard classification and inventory techniques in mountainous areas. In F.A.O. Conservation Guide No. 2.

24. UNESCO/UNEP/FAO(1978) : Tropical Forest Ecosystem, Natural Resource Research, XIV.

surface erosion can occur in undistrubed forest".[25] In Sankh and S. Koel river basin 2684 km^2 of forest is either protected or reserved and 3655 km^2 is unclassified forest. Both combinedly covers 33% of he total area (Fig. 1.4). Forest cover in the region are mainly found on hilly slopes and protect soil from raindrop effect and reduce erosion.

Impact of Slope - As the slope becomes steeper, the runoff coefficient increases, the kinetic energy and carrying capacity of surface flow becomes greater, soil stability and slope stability decrease, splash erosion increases and the possibility of soil displacement in a downhill direction during ploughing is greater. Thus the likelihood of soil erosion increases with the growing steepness of slope". Soil erosion is a function of slope inclination"[26]

---

25. Lal, R.(1983): Soil Conservation in Humid Tropics with Particular Reference to Agricultural Land Development and Soil Management. In Hydrology for Humid Tropical Region, by Keller, R.edt. pp. 221-39.

26. Neal, T.H. (1938): Effect of degree of slope and rainfall characteristics of runoff ar soil erosion," "Agricultural Engineering", V.19 and ingg A.W. (1940), Degree and Length of slope as it af cts the soil, "Agricultural Engineering", V.21.

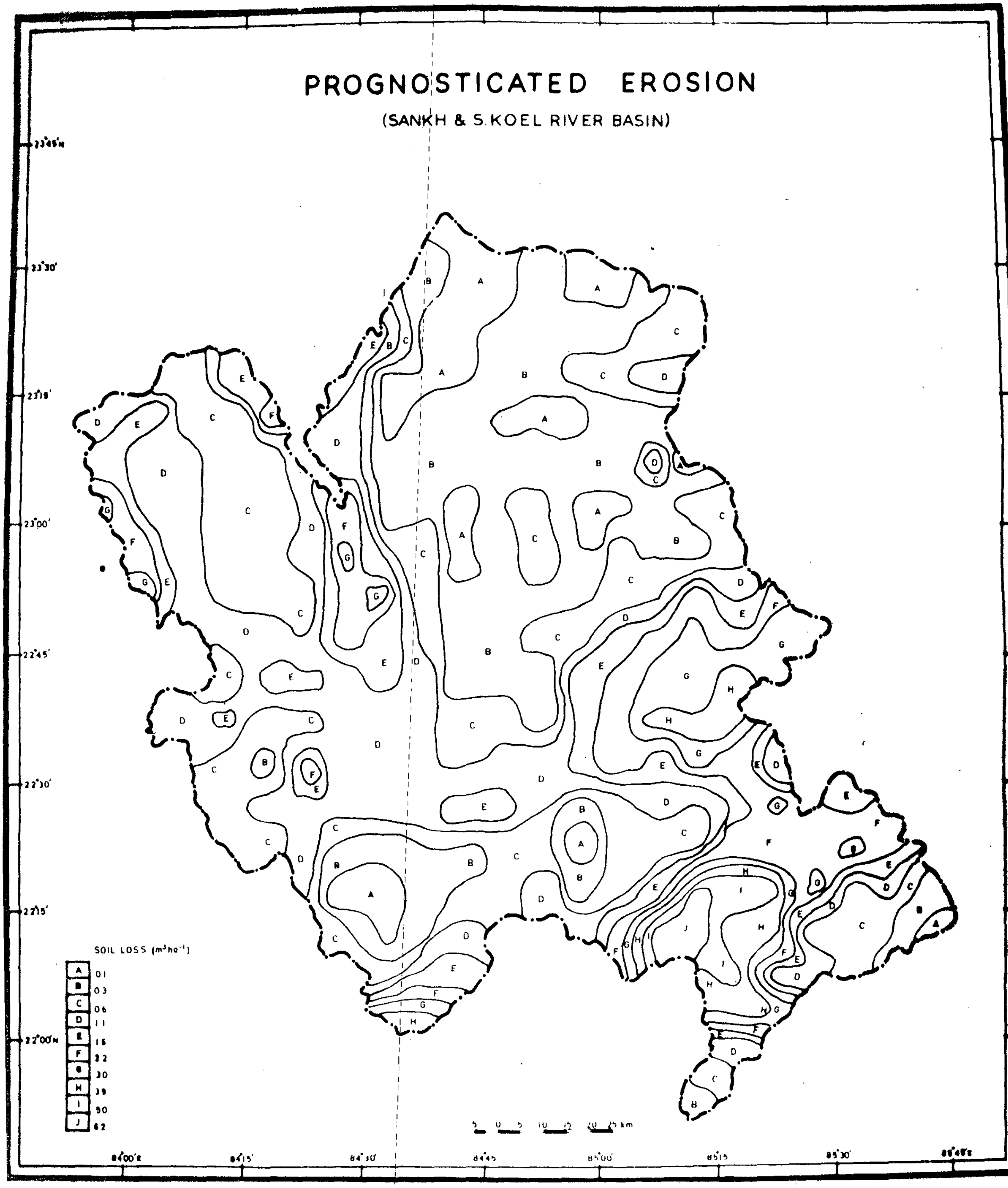

PROGNOSTICATED EROSION
(SANKH & S.KOEL RIVER BASIN)
SOIL LOSS (m³ha⁻¹)
A 01
B 03
C 06
D 11
E 15
F 22
G 30
H 39
I 50
J 62
84°00'E
84°15'
84°30'
84°45'
85°00'
85°15'
85°30'
85°45'E
23°45'N
23°30'
23°15'
23°00'
22°45'
22°30'
22°15'
22°00'N

FIG.4.2

Taking slope as a determinant of soil loss following "satistically generalised equation"[27]

$$e_r = 0.43 + 0.30S + 0.43\ S^2$$

can be applied to predict soil loss from catchment.

A prognestic erosion map (Fig. 4.2) is prepared for Sankh and South Koel river basin to give an idea of soil loss from the region.

Surface Erosion :

Surface erosion is the down slope transport of regolith materials across the ground surface, through the agency of moving water. Major process involved i: is surface flow and the other is raindrop impact which helps in detaching soil particles. Rainfall which induces runoff is a major component. "Surface erosion under humid primary forest is generally more severe than in humid temperate forest because of more frequent and intense rain".[28]

27. Smith , D.D. and Wischmier W.H. (1962): Rainfall Erosion. "Advance Agronomy", V.14, pp.109-48.

28. Birot, p.1968 : The Cycle of Erosion in Different Climates.

Recognized types of surface erosion are i) Downpour erosion; ii) Sheet erosion; iii) Layer or strip erosion; iv) Rill erosion; v) Wearing erosion.

i. Sheet Erosion

Sheet erosion is characterised by uniform erosion of the soil over the whole surface of the land over a particular part of a slope. Erosion is caused by raindrop and surface runoff. As uniform slope of the surface retards the accumulation of water, sheet erosion becomes more uniform. An accelerated or continuous action of sheet erosion causes the soil mantle to become thiner and finally exposes the underlying rock. Intensity and extension of sheet erosion depends upon the intensity and duration of rain, land use type and prevailing management practices. The foot hill regions of the basin which has a slope more than critical inclination in the Sankh and S.Koel river basin are prone to sheet erosion. Out of total 1469.76 km^2 which has been surveyed 367.72 km^2, (Fig. 4.), 430.59 km^2 and 553.50 km^2 suffer slight to no erosion, moderate erosion and severe erosion respectively depending on intensity. They comprise

91.94% of the total surveyed area. The second and third category comprise 67% which need to be used with careful management practices.

ii) <u>Gully Erosion</u>

Accumulation of larger quantities of water and gradual deepening of rills leads to formation of gullies of various size and form. First instances of gully erosion are its size and form where the depth varies between 30 cm. and 2-3 mtr and typical soil wash prevails with marked headward erosion and vertical (or depth) erosion. In gullied land"soil profiles are destroyed except for small patches between the deep gullies and is not useful for crops and pasture without extensive reclamation"[29] The intensity of gully erosion is strongly influenced by thickness of loose, easily erodible or moderately erodible sediments. "Total removal of soil and bedrock attributable to gully erosion depends on the depth of loose weathered material and the resistance of the bed rock".[30] In highly erodible soils especially with steep slopes "gully erosion grows into polymorphous

29. U.S.D.A,(1969),op.cit., p.295.

30. Zacher, D.(1970): Soil Erosion (in Slovak) cited from Soil Erosion by Zacher D.(1982), p.335.

TABLE No. 4.3

SOIL EROSION CLASS

(SANKH AND S. KOEL RIVER BASIN)

(Area in hectares)

Sl No.	SOIL SERIES	EROSION CLASS e_1	EROSION CLASS e_2	EROSION CLASS e_3	EROSION CLASS e_4	TOTAL
1	AMGAON	57	-	-	-	57
2	AMRA	-	-	20865.5	-	20865.5
3	ARRAH	243	37	-	-	280
4	BALIA	230	7360.5	2226.4	386.8	10203.7
5	BARGARIA	-	-	-	277	277
6	BATHANTOLI	261	5366	1855	12	7494
7	BENDUKANI	-	14	1603	-	1617
8	[illegible]	167	319	328	17	831
9	CHOI	151	-	-	-	151
10	DEOBAHAR		18	-	-	18
11	DHAURGOTH	[illegible]	-	-	-	692
12	DIPATOLI	66	38	-	-	104
13	DUMKA	-	605.1	20682.9	-	21288
14	EDLA	-	45	-	-	45
15	HATHIPATHAR	4706.7	9	-	-	4715.7
16	JAMKATHI	-	27	-	-	27
17	JARMUNDI	-	531	516	-	1047
18	JETHUBANDH	3463	-	-	-	3463
19	KANTI	-	25	-	-	25
20	KARAYA	9954	-	-	-	9954
21	KAURIYA	-	14	-	-	14
22	KHINDA	128	-	-	-	128
23	KONGSERA	-	170	7	-	177
24	KURMIA	-	325	214	-	539
25	KURNKEL	-	50	927	-	977
26	LACHMIPUR	25	4934	2216	-	7175
27	LATU	-	262	190	-	452
28	MAJHAULI	996	877	75	15	1963

(Contd.)

Sl No.	SOIL SERIES	EROSION CLASS e_1	EROSION CLASS e_2	EROSION CLASS e_3	EROSION CLASS e_4	TOTAL
29	NAGAR	360	-	-	-	360
30	NANDWA	-	165	167	-	332
31	NAWADIH	-	301	103	-	404
32	NORATOLI	752	-	-	-	752
33	PARKALA	-	2738	7	72	2817
34	PASHIBALI	-	763	-	-	763
35	PUSHARO	1858	16357.2	1873.3	1097.1	21185.6
36	RAMPUR	307	-	-	-	307
37	RANGA	-	-	43	42.7	85.7
38	RENGALBEDA	-	208	131	-	339
39	RENGARI	-	106	-	-	106
40	SARABMUNDA	-	-	1223	-	1223
41	SARMA	-	457	-	81	538
42	SARUA	10577	-	-	-	10577
43	SILPHARY	-	82	-	-	82
44	TARABOGA	-	137	25	-	162
45	TECHATOLI	1655	571.5	71.7	5.8	2304
46	TILEIBANI	123	147	-	-	270
	TOTAL-	36771.7	43059.3	55349.8	2006.4	137187.2

erosion of badland type by a combination of slipping and sliding of earth and other destructive phenomena"[31]

Sankh and S. Koel river basin does not suffer much of gully erosion. Out of 1469.76 km^2 only 2.53 km^2 area are affected by gully erosion which is only 0.2% of the total area. Though the climatic condition facilitates the basin a monsoon type of seasonal and torrential rainfall, stringent measures to protect further gulling process should be adopted preferably coupled with reclamation of gullied land.

SOIL EROSION CLASS AND SOIL SERIES

Table .3 gives a clear picture of soil erosion where erosion class has been shown taking each soil series as a separate unit. There are four erosion class depicting hierarchical erosion class order.[32]

Erosion Class e_1 - e_1 represents slight or no erosion, where the soil has few rills or places with thin 'A' horizon that give evidence of accelerated erosion, but not to an extent to alter greatly the thickness and character of 'A' horizon. Most of the soils like Amgaon, Arrah, Choi, Dhaurgoth, Dipatoli, Hathipathar,

---

31. Zacher D.(1982): op.cit., p.340.

32. Erosion class has been taken as per the same of U.S.D.A. Soil Survey Manual, 1969.

Jethubandh, Karaya, Khinda, Majhauli, Noratoli, Sarua, Techatoli, contribute to this class totalling to 367.717 km^2 which is 25% of the total surveyed area.

Erosion Class e_2 - The next higher order class is e_2 which represents moderate erosion class where soil has been eroded to the extent that ordinary tillage impliments reach through the remaining.'A' horizon, or well below the depth of original ploughed layer in soil within 'A' horizons. 430.593 km^2 or 29% of the total surveyed area comes under this class. Soils contributing to this class are Balia, Bathantoli, Biru, Deobahar,Dumka, Jarmundi, Kanti, Karaya, Kongsera, Kurmia, Lachimpur, Latu,Nandwa, Nawadih, Parkala, Pashibali, Rengalbeda, Sarma, Siphary, Techatoli, Tileibani, etc.

Erosion class e_3 - Soil erosion class e_3 covers the soils those are severely eroded. Soils of this class are severely eroded where rill erosion are extensive feature. Agricultural landuse without any conservation practice leads to mass soil loss. More than 75% of the original surface soil, or 'A' horizon are commonly part of 'B' horizon or other underlying horizon are lost from most of the area. Extension of this erosion class is vast in Sankh and S.Koel river basin inferred from the surveyed area. Out of this 1469.76 km^2, 553.498 km^2(38%) are severely eroded.

Erosion class e_4 - e_4 erosion class depicts very severe erosion. Gully erosion starts from this point. Soil profiles are destroyed. Such land is not useful for crop cultivation. Reclamation for crop production or improved pastures is difficult, but it may be practicable if the other soil characteristics of the soil are favourable and erosion can be controlled. Extension of very severely eroded soil are limited in Sankh and S.Koel watershed. They cover only 1.5% of the total surveyed area, i.e. 20.064 km^2 out of 1469.76 km^2.

CHAPTER - 5

SUMMARY AND CONCLUSION

'Area Planning' through any approach is best represented by "Watershed" which forms a physical and hydrological unit and has rapport with the agrarian nature of the area. Crops require water for their consumptive use, i.e. for transpiration , evaporation from the adjacent soil and for the building of plant tissues. Adequacy of water at different stages of crop growth is dominant factor in agricultural yield. Only those crops which have water requirement coinciding with monsoon rainfall or rainfed can thrive whereas others cannot be cultivated unless they are suitably irrigated. Soil of the region is also a dominant factor in controlling type of vegetation and crop system. The wilting coefficient, permeability, texture, structure, varies from soil to soil and thus distribution of vegetation over earth and viability to grow a particular crop depends on it.

The drainage system and slope of a region control the soil moisture condition besides rainfall. The problem of water logging related to excess water in the soil especially in the root zone and hampers aeration in it. This leads to spreading out of roots near the surface and this reduces the volume of soil from which the plant may draw nutrients whereas on well drained soils vegetation and crops grow without such restrictions.

Hydrological characteristics of a watershed vary consistently with the pattern of rainfall . The surface hydrological conditions are related to problems of moisture inadequacy in soil and water logging in two extreme cases. Possibility to irrigate lands during no-rain period depends upon the amount of water received during rainy period.

These interrelationship between Geomorphic, hydrological and pedological aspects most effectively determines the nature of agricultural, farm and ranching activities in a agrarian community. As Sankh and S.Koel river basin is inhabitated by agricultural communities need the approach of watershed management for the development of the region, the native community and downstream community by utilizing the available resources.

Sankh and S.Koel river basin is an elongated sixth order streambasin with a drainage density of .728 km. km^2 and average overland flow length of .635 km. This low drainage length is an indicator of high transmisibility of terrain. The average slope of the basin is 3°2″, which is gentle ingradient and makes it possible for several agricultural and other activities possible. The two main channels Sankh and S.Koel and their tributaries originating at peripheral , zones with some exceptions passes through narrow to little broad hilly and dissected terrain, whereas most part of the basin including vast central and northern part are plain lands with slopes of less than 5°. The whole basin experiences monsoon climate with seasonal concentration of rainfall during June to October. The amount of monsoon rainfall accounts for 90 per cent of annual rainfall. River discharge, an effect of rainfall , is also seasonal and runoff for a period of six months from June to November is 96 per cent of annual runoff.

Mean annual runoff at Bolani site is a little over 8.5 km^3 for a period of 10 years. Water yield for the basin is 4.31 m^3 $year^{-1}$. Peak rate of discharge is experienced in the month of August and average monthly flow for the month is 33069 m^3. For other two sites ; Jaraikella and Tilga peak monthly flows occur in the month of August and July with mean discharge of 18413 m^3

and 5717 m^3 respectively. Alongwith variation in discharge , river capacity varies. Thus, sediment transport varies consistently with it. In Sankh and S.Koel river basin discharge and sediment load at three sites show a extremely high relationships. Statistically correlation coefficient is very much closer to +1. Sediment load during monsoon period constitutes 96 percent of the annual load. Sediment yield for the basin is 514 metric tonnes per year and monsoon period contribute 99.8 per cent of mean annual sediment load.

The rae of sediment yield is related to flood plain siltation and soil erosion. Most of the reservoirs do face the problem of siltation especially in Indian context where during monsoon period large quantities of suspended materials and bed load are carried away during monsoon period from the upper catchments and deposited in the reservoir owing to sudden decrease in velocity of flow. This problem is especially caused by the very nature of rain distribution, landuse pattern and soil characteristics.

Even though the soils of Sankh and S.Koel river basin is yet to be studied in detail. The total area surveyed is 1469.76 km^2 eut of which 95.35 km^2 is under miscellaneous types of land use occupying river channel, roads, ponds, settlement units. And 2.53 km^2 are gullied land, the result of severe soil erosion. Though the areas surveyed in total do not reflect the conditions of the soil of the whole basin a conclusive statement is not possible. Still it can be inferred that the basin is not free from gullying and erosion is more than normal erosion in 67 percent area. Secondly, the very structure and texture which is reflected in the permeability of soil is responsible for such soil erosion and land degradation. Permeability of most of the soils is high. This shows their structure is loose and uncohesive, hence, the overland flow, after the soil is saturated , will lead to high rate of erosion.

All these aspects are interwoven in cause and effect manner in both long and short term basis. Hence, they can not be studied in a 'closed end' approach. They not only interact with each other rather determine the ways of human, agricultural activities unless they are practised in a rational and planned manner.

Therefore, this work is an assessment of the geomorphic , hydrologic and pedologic aspects of the river basin for an effective formulation of plan to integrate and foster the economic growth of the community living in the watershed and also of the downstream community.

BIBLIOGRAPHY

Arakeri,H.R.(1984): Soil Conservation and Water Management. Oxford and I.B.H. New Delhi, 254pp.

Awan,N.M.(1973):"Hydrologic Research on Watershed Management," in Seminar on Watershed Management, ed. by A. Sevinc Kisaloli, pp. 154-157.

Bloom,A.L.(1976): Geomorphology. Prentice Hall,India, New Delhi, 510pp.

Botero,L.S.(1986):"F.A.O.'s Role in Fostering Watershed Management: Introductory Statement," in Strategies, Approaches and Systems in Integrated Watershed. F.A.O., Rome, pp 4-9.

Brady,N.C.(1974): Nature and Properties of Soils. Macmillan, New York, 639pp.

Chorley,R.J.(1962): Geomorphology and General System Theory. "U.S. Geological Survey Prof. Paper, 500-B", 10pp.

____________(1969): Drainage Basin as a Fundamental Geomorphic Unit, in Water, Earth and Man, ed. by Chorley,R.J., Methuen, London, 588pp.

Clowes,A. and Comfort,P.(1987): Process and Landform. Oliver and Boyd, Edinburgh, 335pp.

Davis,W.(1899): The Geographical Cycle. "Geographical Journal", pp 481-504.

Desai,M.(1970): A Brief Geomorphological Account of the South Koel Basin. "Geographical Review of India", Vol. 38, n.4, pp 374-81.

Dunn,J.A.(1929): The Geology of North Singhbhum and Parts of Ranchi and Manbhum Districts. "Memoirs, Geological Survey of India", Vol. 54, pp 1-166.

Fitz Patric,E.A.(1980): Soils, Their Formation and Distribution. Longman, London, 353pp.

Greenland,D.J.(1977): Soil Structure and Erosion Hazard, in Soil Conservation and Management in Humid Tropics, ed by Greenland,D.J., John Wiley and Sons Chickster, 283pp.

Gunn,R. and Kinzer,G.D.(1941): Velocity of Water Droplets in Stagnant Air. "Journal of Meteorology", Vol. 6, p 243.

Gupta,G.P.(1975): Sediment Production Satus Report on Data Collection and Utilization. "Soil Conservation Digest" Vol. 3, n. 2, pp 10-21.

Horton, R.E.(1933): "The Role of Infiltration in the Hydrological Cycle. "Trans. American Geophysical Union", Vol. 14, pp 446-60.

__________(1945): Erosional Development of Streams and Their Drainage Basin :Hydrological Approach to Quantative Morphology. "Geological Society of America Bulletin",Vol. 56, pp 275-370.

Klimentov,P.P. (1983): General Hydrogeology. Translated by Gurevich,K.G. , Mir, Moscow, 239 pp.

Krishnan, M.S. (1937): The Geology of Gangpur State, Eastern States. "Memoir,Geological Survey of India", Vol. 71, pt. 2.

Kuiper,E.(1965): Water Resources Development; Planning, Engineering and Economics. Butterworths, London, 483pp.

Kunkle,S.H. and Dye,A.J.(1981): The Effects of Forest Clearing on Soils and Sedimentation, in Tropical Agricultural Hydrology, ed. by Lal,R. and Russell, E.W., John Wiley and Sons, Chichester, pp 221-39.

Lal,R.(1983): Soil Conservation in Humid Tropics with Particular Reference to Agricultural Land Development and Soil Management, in Hydrology for Humid Tropical Region, ed. by Keller,R., pp 221-39.

Laws,J.O.(1941): Measurement of Fall Velocity of Water Drops and Rain Drops. "Trans. American Geophysical Union", Vol. 22, p. 709.

________and Parsons,D.(1943): The Relation of Drop Size to Intensity. "Trans. American Geophysical Union", Vol. 22, p 452.

Leopold,L.B. and Wolman,M.G.(1957): River Patterns; Braided,Meandering and Straight,"U.S. Geological Survey Paper , 282-B".

Mathewson,C.C. and Cole,W.F.(1982): Geomorphic Processes and Land Use Planning, South Texas Barrier Islands, in Applied Geomorphology, ed. by Craig,R.G. and Craft,J.L. , pp 131-147.

Miller, V.C. (1953): Relation of Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennesse, "Tech. Report - 3, Department of Geology".

Neal, T.H. (1938): Effect of Degree of Slope and Rainfall Characteristics of Runoff and Soil Erosion. "Agricultural Engineering", Vol. 19.

Oyabande, L. (1981): Sediment Transport and River Basin M Management in Nigeria, in Tropical Agricultural Hydrology, ed. by Lal, R. and Russell, E.W. pp 201-225.

Research and Reference Division, (1987): India 1986. Publication Division, Govt. of India, New Delhi, 772 pp.

Ritter, D.F. (1986): Process Geomorphology. Wm. C. Brown, Dubuque, 579 pp.

Rodda, J.C. (1976): Facets of Hydrology. John Wiley, London, 368 pp.

Shumm, S.A. (1956): Evolution of Drainage System and Slopes in Badlands, at Perth Amboy, New Jersy. "Geological Society of America Bulletin", Vol. 67, pp 597-646.

Singh, S, and Upadhyaya, D.P. (1982): Topological and Geometric Study of Drainage Network, S.E. Chota Nagpur Region (India), in Perspectives in Geomorphology Vol. II, ed. by Sharma, H.S. pp

Smart, J.S. (1972): Quantitative Analysis of Watershed Geometry. "Trans. of American Geophys. Union", Vol.38, pp. 913-20.

Smith, D.D. Wischmier, W.H. (1962): Rainfall Erosion. "Ad "Advances Agronomy", Vol.14, pp. 109-48.

Stevens, M.E. (1976) : Erosion Hazard Classification in Inventory Techniques in Mountainous Areas. In F.A.O. Conservation Guide No. 2.

Strahler, A.N. (1952): Hypsometric (Area-Altitude) Analysis of Erosional Topography. "Geological Society of America Bulletin," Vol. 63, pp. 117-42.

_______________(1970): Physical Geography. John Willey and Sons, New York, 643 pp.

Twidale, C.R. (1975): Analysis of Landforms. John Willey and Sons, New York., 572 pp.

UNESCO/UNED/FAO, (1978): Tropical Forest Ecosystem. Natural Resource Research XIV.

U.S.D.A. (1969) : Soil Survey Manual. Oxford and I.B.H. New Delhi, 503 pp.

Wentworth, C.K. (1930): A Simplified Method of Determining the Average Slope of Land Surfaces. "American Jr. of Science", Vol. 20, Series-5.

Young, A. (1978) : Slopes, Longman, London, 288 pp.

Zacher, D.(1982): Soil Erosion , Elsevier, Amsterdam, 547 pp.

Zingg, A.W. (1940): Degree of Length of Flow as it Affects the Soil. "Agricultural Engineering", Vol.21.